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AIRCRAFT ELECTRICAL HAZARDS ON THE FLIGHT LINE

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NORTH ATLANTIC TREATY ORGANIZATION

ALLIED AIRCRAFT ELECTRIC AND ELECTROMAGNETIC CONSIDERATIONS PUBLICATION

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NORTH ATLANTIC TREATY ORGANIZATION (NATO)

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NATO LETTER OF PROMULGATION

3 October 2022

1. The enclosed Allied Aircraft Electric and Electromagnetic Considerations Publication AEP-24, Edition B, version 1, AIRCRAFT ELECTRICAL HAZARDS ON THE FLIGHT LINE, which has been approved by the nations in the Military Committee Air Standardization Board, is promulgated herewith. The agreement of nations to use this publication is recorded in STANAG 7009.

2. AEP-24, Edition B, version 1, is effective upon receipt and supersedes AEP-24, Edition A, which shall be destroyed in accordance with the local procedure for the destruction of documents.

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4. This publication shall be handled in accordance with C-M(2002)60.

Dimitrios SIGOULAKIS
Major General, GRC (A)
Director, NATO Standardization Office

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RECORD OF RESERVATIONS

CHAPTER	RECORD OF RESERVATION BY NATIONS
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RECORD OF SPECIFIC RESERVATIONS

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Chapter 1 Introduction

1.1. GENERAL

1.1.1. Purpose

1. Aircraft and support equipment as well as personnel, ordnance, and fuel are involved in numerous actions and interactions on the flight line in which electrical and electromagnetic hazards may arise either singly or concurrently, and may occur under adverse environmental conditions. This document provides guidance to help prevent personnel injury and minimize property damage, which otherwise could result in loss of life and materiel, increased repair costs, equipment downtime, and reduced operational readiness.

2. This publication considers:

   a. electrical hazards to aircraft, support equipment, personnel, ordnance, and fuels which are encountered on the flight line,

   b. secondary hazards which are associated with electrical hazards,

   c. situations in which electrical hazards and secondary hazards are encountered, and

   d. safety practices for protection from electrical hazards and secondary hazards, particularly electrical safety connections for bonding, earthing, and grounding.

The hazards encountered and the safety practices implemented apply to flight line locations as diverse as airfields with ramp facilities, flight decks on ships, and forward arming and re-fuelling points.

3. Although this allied publication is advisory and addresses problems of a general nature, the information contained in it is based on experience and sound principles. As all local conditions and situations cannot be anticipated, the procedures given may be adjusted as necessary. Similarly, many parameters given are typical values and must be adjusted to comply with national codes or specifications on parts and materiel.

4. Typically more than just electrical or electromagnetic hazards are present during a servicing operation. For instance, during fuel movement there are personnel safety issues arising from fuel toxicity and other properties of the fuel. These safety practices are part of a larger endeavor and must be considered as a component of a cohesive approach to implementing safety on the flight line during all servicing operations. Nations should develop specific instructions for their own particular situations.

1.1.2. Related Documents

1. The Following documents deal with related issues:

   a. STANAG 3109 - Symbol Marking of Aircraft Servicing and Safety/Hazard Points - AASSEP-3

   b. STANAG 3659 - Electrical Bonding Requirements for Metallic Aircraft Systems

   c. STANAG 3632 - Aircraft and Ground Support Equipment Electrical Connections for Static Grounding - AAEP-02

   d. STANAG 3682 - Electrostatic Safety Connection Procedures for Aviation Fuel Handling and Liquid Fuel Loading/Unloading Operations During Ground Transfer and Aircraft Fuelling/Defuelling - AFLP-3682

   e. STANAG 2345 - Military Workplaces - Force Health Protection Regarding Personnel Exposure To Electric, Magnetic, And Electromagnetic Fields, 0 HZ TO 300 GHZ

1.2. REVISIONS

1. Inputs concerning the content, correctness, and completeness of this publication are essential if currency is to be maintained. Recommended changes with supporting justification should be forwarded to the Custodian listed in STANAG 7009.

Chapter 2 Flight Line Electrical Hazards

2.1. TYPES OF ELECTRICAL HAZARDS

1. Electrical hazards encountered on the flight line include:

   a. electric shock to personnel,

   b. biological effects on personnel from radio frequency radiation,

   c. inadvertent release/firing and degradation of ordnance,

   d. ignition of fuel vapor, and

   e. damage and malfunction of electronic systems.

2.2. SECONDARY HAZARDS

1. The normal nervous system reaction to any perceptible electric shock may cause personnel to injure themselves or others. Involuntary reflex movements can result in injury from falling, bumping, or hitting sharp objects. In some instances these secondary hazards are more harmful than the initial shock.

2.3. SITUATIONS SUBJECT TO ELECTRICAL HAZARDS

1. Electrical hazards to aircraft and equipment as well as personnel, ordnance, and fuel can arise during the following situations:

   a. working around parked aircraft,

   b. fuelling operations,

   c. maintenance and servicing operations, and

   d. handling and testing of ordnance.

When these operations are undertaken concurrently, the risks can be magnified and caution must be exercised.

2.4. CAUSES OF ELECTRICAL HAZARDS ON THE FLIGHT LINE

1. For a mishap or accident to occur on the flight line there must be:

   a. a source of energy,

   b. a potential victim,

   c. the proper conditions.

2. The sources of energy are present, and the conditions can exist on the flight line, which will cause electric shock to personnel, produce arcs or sparks sufficient to ignite fuel and ordnance and damage electronic systems. Levels of radiated energy can be sufficient to compromise the health of personnel.

2.5. PREVENTION OF MISHAPS

1. The approaches taken to prevent mishaps or accidents on the flight line are to:

   a. eliminate the hazard,

   b. prevent exposure to the hazard by using barriers or safety devices, and

   c. communicate instructions and warnings to ensure operations are performed safely.

Eliminating the hazard is the preferred approach to personnel safety, with instituting instructions and warnings the least preferable and the least effective.

2. Specific issues and problems will be equipment and platform dependent. A safety engineering analysis should be performed to ensure operational procedures or changes to procedures can be implemented safely.

3. It must also be emphasized that mishaps and accidents can be substantially reduced by proper training, documented work procedures, and effective supervision.

4. Personnel should immediately report any hazardous condition to the supervisor responsible for the operation in progress.

Chapter 3 Flight Line Electrical Hazards

3.1 ENERGY SOURCES

1. The electromagnetic energy sources of concern on the flight line are:

   a. electrical power sources such as AC power mains, AC generators, and DC generators,

   b. electrostatically charged bodies (mainly ground service equipment, aircraft, and the human body), and

   c. radio frequency emitters.

The characteristics of the source mechanism and the source magnitude of released electromagnetic energy are critical in assessing possible occurrences of hazardous situations.

2. Electrical Power Sources. The two basic electrical systems used on aircraft are: 28 VDC and 115 VAC at 400 hertz. The 28 volt system is a two-wire system with the negative side connected to the aircraft structure. The 115 volt system is a four-wire system consisting of phases A, B, C, and neutral (N), with the neutral wire connected to the aircraft structure. Electrically powered equipment is replacing conventional equipment, which depend on pneumatic, mechanic and hydraulic power, under a concept known as the More Electric Aircraft (MEA). To cope with the increased electrical demand, 270 VDC power sources are being incorporated into modern aircraft designs.

3. Ground Power. Since it is often not practical to run the aircraft engines for electrical power while on the flight line, the required AC and DC power is usually supplied by a generator external to the aircraft. This Ground Power Units (GPU) may be fixed and mains-driven or mobile and engine-driven. They can supply power levels as high as 1000 A DC and 90 kVA AC or more. The generators are mounted on either a self-propelled vehicle or a towed trailer, both on rubber tires. The mains driven generator is connected to a 50 hertz or 60 hertz main system and the supply cable includes a safety grounding wire that is connected to the generator chassis.

4. Electrostatically Charged Bodies. Electrostatic energy consists of accumulated electric charges (of opposite polarities) kept apart by an insulator. The isolation of charges can occur because a non-conductive body physically separates the charged conductive bodies or because a body is itself an insulator next to a charged body. The charge can move freely about on an electrically conductive material, but is held captive on an ideal insulator. The charge separation results in an electrostatic potential (voltage) being developed between the charge centers. Although the flow of electric

charge during generation and accumulation is often small, the electrostatic potential between bodies can rise to thousands of volts and the energy levels can be significant

5. If two charged bodies are brought to within a distance shorter than that needed for the breakdown of the air between them, a spark discharge will result. During this type of discharge, electrostatic energy is released and converted to heat energy. In the case of lightning, clouds become highly charged to the point that there is enough voltage built up to cause a discharge, either from cloud to ground, from one cloud to another, or within a cloud.

6. Personnel. Personnel can be an unwanted source of electrostatic energy. Through the normal movement involved in activities on the flight line personnel can generate and accumulate electric charge on their clothing.

a. Physical separation of dissimilar materials is always involved in the generation of electrostatic charge on the body. Under favorable conditions, such as in cold, dry environments, many clothing materials can be involved in the generation of a large electrostatic charge. This can occur when the materials are brought into contact with other materials and then separated, or when they are rubbed on different substances. Walking on various surfaces can cause charge separation between the surface and the soles of the shoes resulting in a charge on the body. Removing a garment can cause charge separation between the garment and the remaining clothing and body and generally results in a high body voltage.

b. The potential developed on the human body due to the electric charge can be high enough to cause a spark discharge. The energy in this discharge while only causing mild discomfort to personnel could be high enough to ignite fuel vapors, affect ordnance, and damage electronics. Even discharges that are not felt by individuals could still cause effects.

7. Aircraft. Electrostatic charge can accumulate on aircraft by the means of several charging mechanisms.

a. Charges can be generated on aircraft when flying through dust or precipitation and remain on the aircraft after landing until dissipated through the tires and runway surface. Electrostatic charging can be caused by the interaction of materials in any type of relative motion, and wind-blown snow or dust particles striking an aircraft on a runway can also result in an accumulated charge on the aircraft. Even distant electrical storms can produce large levels of charge on an aircraft through electrostatic induction. The charge will remain until the charging mechanism ceases and the charge is dissipated through the aircraft resistance to earth.

b. Liquid flowing through a pipe or re-fuelling hoses also provides a mechanism for the generation of electrostatic charge. This mechanism is of particular concern during aircraft fuelling since dangerous potentials can build up on aircraft and servicing equipment if effective precautions are not implemented.

c. Operating aircraft engines, rotor blades, and propeller blades can generate high levels of electrostatic charges and cause high voltages on the aircraft. The charges will be generated and the voltage will remain as long as the engines continue to operate.

d. A helicopter in flight presents a special situation, since it can hover near the earth in the presence of personnel and equipment on the ground. It can generate and store a large amount of electrostatic charge. The stored electrostatic energy increases with helicopter weight, low humidity, and the amount of debris that is blown by the rotor system (dust, sand, or snow). Extremely high electrostatic discharges can emanate from hovering helicopters. When the helicopter lands and touches the earth, this charge is dissipated. However, when the helicopter is in flight or hovering to make a sling load drop, the electrostatic charge remains stored on the aircraft.

8. Radio Frequency Emitters. Radiated energy from the antennas of radio frequency (RF) transmitting devices may be potentially hazardous to personnel, ordnance, or fuel. These RF transmitters may be ground transmitters or may be onboard the aircraft being serviced or other nearby aircraft.

9. The level of the electromagnetic fields from the transmitter and potential effects are greatly affected by:

a. the position of the aircraft relative to an RF transmitter,

b. the modulation present on the transmitted waveform

c. the power output of that transmitter and antenna characteristics,

d. the frequency of the transmitted RF energy, and

e. the number and distance to other RF emitters on the flight line.

10. The radiated fields will cause energy absorption by the human body and will induce currents and voltages in electrical wiring and any other electrically conductive material. The human body absorption can result in hazardous physiological effects, if not controlled. Induced voltages and currents can potentially ignite fuel vapors through arcing or sparking or ignite or dud ordnance. At lower frequencies of operation, particularly in the HF radio range, electrical ground connections can substantially influence induced current flow. Potential arcing is also more likely in this band. There is also a possibility that heating from induced currents in very small metal objects (such as steel wool strands) could ignite flammable material or vapors in the area.

3.2. STRAY CURRENTS

1. The term stray current applies to any electrical current flowing in paths other than those deliberately provided for it. These currents inevitably flow in ground electrode subsystems, and in other paths including the earth, pipelines, and other metallic objects or structures in contact with the earth. A stray current is usually distributed among a number of available parallel paths in proportion to the resistance of the individual path. Stray currents can result from faults in electrical power circuits or they may be inherent to the situation as in the ground-return currents in some types of configurations on the flight line. In some instances they result from the use of cathodic protection systems.

2. Fixed re-fuelling systems are in contact with the earth and stray currents can sometimes flow in the conducting parts of the system [(1)].

3. Stray currents from power systems have no definable limits of voltage or current. It is unusual for the voltage to exceed that required for breaking down an air gap between fixed electrodes; however, contacts which are made and separated can result in momentary and usually incendiary discharges or in cases in which the potential exceeds about 35 volts in sustained arcs [(2)].

4. Therefore precautions should be taken at points where maintenance is performed, ordnance is handled, and where a flammable fuel-air mixture may exist.

5. A single point connection to earth for an aircraft and its ground support equipment is one method to prevent these stray currents from flowing on the aircraft and its subsystems and the support equipment chassis.

3.3. SHOCK TO PERSONNEL

1. There are two possible sources of injury to personnel from an electric shock:

   a. electrical effects which result directly in injury, and

   b. involuntary reflex movements which can result in injury due to secondary effects, such as falling.

2. An electric shock is caused by electric current passing through the body. Effects can vary from mild tingling sensations, burns at the area of contact, severe muscle spasms, internal tissue damage, to heart damage. Current is the controlling factor - the severity of the injury is directly related to the amount of current flow, the duration of the current, the frequency of the current, and the path of the current through the body. Relatively low currents can be lethal if the path includes a vital organ such as the heart or lungs. On the flight line this hazard most commonly occurs when personnel come in contact with energized sources while touching a grounded object or while standing on a conductive surface.

3. Although current is the primary factor in determining the severity of the injury, protection guidelines are often based on the voltage involved to simplify their application. This voltage is related to the current which passes through the body by Ohm's Law, and is dependent upon the impedance of the body and the contact impedance. Guidelines usually specify that personnel be protected from accidental contact with voltages in excess of 30 volts rms or DC (3).

4. Total body impedance varies from individual to individual and is a function of many parameters. To determine guidelines for safety in AC substation grounding, IEEE Standard 802000 uses a value of 1000 ohms to represent the resistance of the human body from hand-to feet, hand-to-hand, or from one foot to the other foot. At voltages greater than 600 V, the skin can be punctured thus lowering body impedance considerably.

5. Serious physiological shock to personnel from an electrostatic discharge is extremely rare. But shocks from an ESD event can be common and although the shock itself is not harmful, the involuntary muscular reaction can cause an accident due to secondary effects. These effects could include bruises, broken bones and even death from collisions or falls.

6. Radio frequency (RF) energy, and in particular in the high frequency (HF) band, can also cause electric shock in the body or burns in tissue. This hazard exists primarily near areas of high RF voltage such as at the output stages of RF amplifiers and at antennas, but can also arise on metallic objects immersed in a sufficiently intense field caused by nearby transmitting antennas.

3.4. RADIATION HAZARDS TO PERSONNEL

1. Exposure to electromagnetic radiation can have deleterious biological effects on the health of personnel. The danger occurs because the human body absorbs electromagnetic radiation. Significant internal heating may occur without the knowledge of the individual since the body does not feel an internal sensation of heat, and tissue damage may occur before the excess heat can be dissipated. These effects will vary with radiation intensity, radiation frequency, duration of exposure, human body size and orientation, and part of the body exposed.

2. The emissions encountered on the flight line may easily exceed most safe levels. Radar and electronic countermeasures systems usually present the greatest potential hazard due to high transmitter output power and antenna characteristics. Personnel assigned to repair, maintenance, and test operations have a high probability for being overexposed because of the variety of tasks, the proximity to radiating elements, and the pressures for rapid maintenance response.

3.5. ORDNANCE VULNERABILITY

1. Ordnance can be inadvertently ignited with the obvious disastrous consequences, or experience degraded performance after being exposed to various forms of electromagnetic energy on the flight line.

2. The main concern with inadvertent ignition of ordnance is the coupling of energy directly to the electrically initiated device that starts the explosive train and accidental initiation of the firing circuit when the ordnance is powered. With regard to the firing circuit, the trend to utilize more sensitive, low-power electronic circuits in the design of ordnance systems raises the potential for problems with inadequate designs and enhances the need to exercise caution in handling.

3. Ordnance subsystems are potentially vulnerable to the electromagnetic environment during a number of operations on the flight line. When the subsystems are transported, they will normally be packaged, containerized, and otherwise prepared for shipping and storage in a manner that provides some level of protection from electromagnetic environments. Some ordnance can be shipped as completely assembled subsystems, while others are shipped as sections or components. Some section or components containing electrically initiated devices may be shipped in non-metal containers. When the containers are loaded and off-loaded they will be handled by personnel and be more exposed to the electromagnetic environment.

4. Ordnance subsystems are uploaded and downloaded on the flight line. During these operations personnel will handle the ordnance and physical contact will be made with metal objects and physical structures. Personnel will prepare, examine, perform diagnostic tests, program/reprogram ordnance data, and install or attach the ordnance subsystem to its end-use aircraft. Personnel will also remove, disengage, and re-package the ordnance during downloading if necessary. These procedures may involve making and/or breaking electrical connections, opening and closing access panels, removing/installing safety pins, shorting plugs, clips, and dust covers. The electrically initiated devices and firing circuitry are most susceptible to electrostatic discharge, RF radiation, and stray currents at this phase.

5. There is also a point when the ordnance has been installed on or attached to the aircraft, all uploading procedures have been completed, and the aircraft is parked on the runway. At this time the physical configuration of the system, which includes the ordnance subsystem, the launcher, the aircraft, and all interface cables and wiring, can be a very complex arrangement from a potential coupling standpoint and can still be susceptible to stray electromagnetic energy.

3.6. FUEL IGINITION

1. Hazards to fuel exist during all aircraft fuelling operations. Ignition could occur when transferring fuel to aircraft from hydrant systems, fuel servicing vehicles, or drums. Flammable air-fuel mixtures can be formed by the vapors from the fuel or from

a spray or mist from a pressurized leak. Fuel vapors exist at the opening of filling ports and near fuel vents. Fuel vapors are heavier than air and will spread for some distance along the ground and collect in low lying areas, and at some point could form a flammable mixture with air. If there is an ignition source in the area the mixture could ignite.

2. Spark discharges caused by static charges on personnel or equipment, arc discharges generated when grounding or bonding equipment, and the arcing of electrical equipment can ignite fuel vapors. Arc discharges induced by a strong RF field can contain enough energy to ignite the air-fuel mixture. Overheated wires from a short circuit or ground fault can also ignite a flammable fuel-air mixture.

3. The use (where permissible) of fuels with a high flash point can help alleviate but not eliminate this problem.

3.7. ELECTRONIC SYSTEM DAMAGE

1. Electronic equipment and subsystems can be exposed to levels of energy high enough to cause damage to internal components. Lower levels of energy, when injected onto sensitive components, can cause degradation to overall system performance.

2. Equipment/subsystem function can be upset when extraneous voltages and/or currents exceed the signal levels are introduced in the electronic circuits and when the characteristics of the signal and circuit are such that the circuit incorrectly responds to the signal. These extraneous voltages and currents (or noise) are the result of conducted or radiated emissions which couple into the circuitry through various coupling mechanisms.

3. Intermittent or upset failures occur when equipment and subsystems are operating and are characterized by loss of information or malfunction. Correct operation usually resumes after the energy source is removed or, in the case of digital circuits in some instances after the equipment/subsystem is re-set or re-initialized.

4. While upset failures occur when the equipment is operating, damage or hard failures can occur at any time. Voltages and currents necessary to cause damage are typically one to two orders of magnitude greater than those required to cause upset. Catastrophic failures can be the result of electrical overstress of electronic parts caused by a discharge from a person or object, an electrostatic field, or a high voltage spark discharge. Radiated energy and stray currents can be coupled into the equipment or subsystem and cause hard failures.

5. The exposure to these signals may also cause marginal damage to components and result in latent failures.

6. Electronic equipment is especially vulnerable during maintenance operations when protective covers are removed or electrical connector pins are exposed.

Chapter 4 Summary of Safety Practices

4.1. GENERAL

1. There are numerous activities involving electrical and electromagnetic energy in support of operations on the flight line that can prove to be hazardous and which require awareness and the implementation of safety practices to prevent accidents and mishaps.

4.2 LIGHTNING

1. Even if an aircraft is connected to a static earth point, a severe hazard would exist to servicing personnel if lightning hits the aircraft or strikes within several hundred feet of the aircraft. Servicing personnel should be evacuated from the area when there is danger of a direct or close proximity lightning strike. An electrical storm can be dangerous even if several miles from the servicing area.

2. A direct stroke can severely damage objects in its path as a result of heat energy and associated mechanical forces, as well as by direct ignition of flammable materials. The energy associated with the lightning current can melt metallic components, destroy electronic components, and ignite electrically initiated devices.

3. In addition to the possible damage from the direct stroke, the abrupt change in the electrostatic field caused by a lightning stroke in the vicinity that does not strike the servicing area, can cause secondary sparks at equipment. An electrostatic charge can be induced on an insulated metallic body by the electrostatic field. The metallic body initially becomes charged (by means of induction) at a harmlessly slow rate through its relatively high resistance to ground. When the lightning strikes nearby, this induced charge can be suddenly released in a spark discharge to ground. This discharge can potentially ignite an air-fuel mixture if vapors are present, initiate unprotected ordnance, and damage exposed electronic systems [(2)].

4. There should be a lightning safety procedure for each flight line to minimize exposure to lightning hazards. When lightning is observed or detected within a 10 kilometer (5 nautical mile) radius, personnel should be warned and all servicing operations involving fuel movement, ordnance loading, and maintenance should be terminated. Personnel should be evacuated and seek safe shelter. Personnel inside an aircraft will be in no danger as long as all aircraft doors, hatches, and canopies are closed.

5. All servicing operations should cease even at facilities with lightning protection subsystems. These systems are not perfect and there is still the inherent danger from earth current transients and atmospheric transients.

4.3. EARTHING, GROUNDING, AND BONDING

1. Earthing, grounding, and bonding are methods used to minimize the electric shock hazard to personnel and to control the accumulation of electrostatic charge. The definitions for these terms as used by NATO are given in the glossary at Annex A. Unfortunately, in practice, these terms are employed in different contexts and are sometimes used inter-changeably. In this document the terms are used in the following context.

2. Earthing is the process of establishing an electrical connection between a conducting object and the earth to ensure a common potential with the earth mass. A conductive object can be connected to the earth by a direct conductive path to the earth mass, or by bonding it to another conductive object that is already connected to the earth. Some objects, such as underground metal piping or large metal storage tanks resting on the earth, are inherently connected to the earth mass because of their intimate contact with the soil.

3. Grounding is the process of establishing an electrical connection between a conducting object and a large conducting mass such as an earth electrode subsystem or the hull of a ship to establish a common potential. (Thus grounding an object to the earth electrode subsystem is equivalent to earthing the object). It is also used in the sense of providing a continuous path for fault current to return to the electrical source through the use of a grounding conductor (green wire).

4. Bonding is the process of establishing an electrical connection between two conducting objects with an electrical cable for remote objects or direct mechanical interface for touching objects so that they are at the same potential (but not necessarily at the same potential as the earth mass).

5. Bonding does not dissipate static electricity. It is used to equalize the voltage potential between two conducting objects by allowing charge migration and thus eliminate the possibility of an electrostatic discharge between them.

6. Personnel will bond themselves to a conducting object by touching the object with their bare hands. This is done to equalize the potential between the person and the object and thus prevent an electrostatic discharge.

7. The accumulated charge on the human body will remain until it is deliberately (or inadvertently) removed. Body grounding is the most basic and essential control measure. Grounding is accomplished by making solid contact with a grounded or earthed object with the bare hands.

4.4. PERSONNEL

1. Personnel are an integral part of the servicing operations and can be the victim of an accident or mishap or the cause of an accident or mishap.

2. Personnel can suffer harm from electric shock by coming into contact with a source of electrical or electromagnetic energy. The damage can arise from electrical effects that result in a direct and possibility fatal injury or from the consequence of secondary effects such as falling. In addition, the health of personnel can be jeopardized by exposure to electromagnetic radiated energy from the various emitters present on the flight line. Personnel can also be victims of fire or an explosion when handling fuel or ordnance.

3. Short circuits can be caused by accidentally placing or dropping a metal tool, flashlight case, or other conducting article across an energized line. These short circuits can cause an arc or fire in even relatively low voltage circuits, and may result in extensive damage to equipment and serious injury to personnel. Before beginning work on power or electronic systems, maintenance personnel should ensure that the power is shut down and lockouts are in place.

4. Through the normal movement involved in performing operations on the flight line, personnel can generate and accumulate an electrostatic charge on their clothing, and become an unintentional cause of an electrostatic discharge.

5. Personnel should avoid wearing outer garments made of materials that have high static generating characteristics. Most synthetic fabrics are more active generators than are natural fabrics. Materials of 100 percent polyester, nylon, rayon, silk, or wool are highly static producing. Wool socks, glove inserts, and caps, as well as undergarments of synthetic fabrics or silk are less of a hazard. Nylon field jacket liners should not be worn as an outer garment. Cotton or cotton-synthetic blend materials are preferred.

6. Environmental conditions greatly affect the static electricity characteristics of clothing materials. Low humidity and low temperatures increase the electrostatic hazard. Under low humidity conditions, almost all garments can produce a static charge of sufficient potential to cause a discharge.

7. The use of an anti-static clothing treatment alone is not sufficient to prevent charge accumulation. Clothing treated with anti-static products requires at least moderate humidity to be effective and it is difficult to maintain its anti-static properties. In addition, anti-static finishes are not as effective in low humidity conditions or at low temperatures. Therefore, regardless of the type of clothing worn, personnel can collect a charge of static electricity by being in contact with moving nonconductive substances or coming in contact with a mass that has been previously charged.

8. Personnel should not put on or remove garments while engaged in operations on the flight line in order to reduce the generation of static charges caused by physical separation of materials. If outer garments need to be removed, personnel will step out of the immediate area of operation, remove the garment, ground themselves, and then re-enter. Workers shall not unfasten Velcro fasteners while involved in any operation.

9. Personnel must be particularly careful to discharge their static electrical potential or equalize it to that of the ordnance item, fuel servicing equipment, or electronic equipment that they are handling.

10. Personnel must use earthing (grounding) or bonding techniques to dissipate or equalize electrostatic charges that accumulate during servicing operations on the flight line. Even though electrostatic charge may dissipate through gloves or the soles of shoes, as an added precaution personnel should touch an earth/ bonding point with their bare hand.

11. To avoid the possibility of a shock from an electrostatic discharge during helicopter sling loading operations, flight line personnel should use a static discharge wand to connect the cargo hook to earth. The wand is designed to channel the electrostatic charge from the helicopter directly into the earth while protecting personnel handling it. Once the charge on the helicopter is neutralized, personnel connecting the apex fitting of the sling set to the cargo hook will not be shocked.

a. At a fixed facility the discharge wand can be connected to a static earth point or a mains earth point. If neither is available, then the load should be positioned near the edge of the ramp or runway surface so that an earthing stake can be driven into the earth, and the wand connected to the stake.

b. Personnel handling the discharge wand should wear leather (preferably electrical) gloves to provide protection from static discharge burns.

4.5. ORDNANCE

NOTE

Servicing operations involving all types of ordnance are always inherently dangerous and must be carried out with extreme caution. Since not only electromagnetic hazards are involved, standard practices should be developed for each operation for each system and location. Careful planning and preparation is required.

1. General. Ordnance subsystems that contain electrically initiated devices (EID) can be inadvertently ignited by exposure to the different aspects of the electromagnetic environment found on the flight line. The dangers occur from the accumulation and subsequent discharge of electrostatic charge, lightning discharges, stray currents and voltages, and RF radiation from ground and airborne transmitters. The energy can be imposed upon the EIDs and firing circuitry by various methods. Examples are inductive or capacitive coupling from other cabling; sneak ground circuits; defective components or wiring; and errors in maintenance.

2. ESD. Ordnance is potentially susceptible to inadvertent ignition from electrostatic discharge. The primary concern is discharge through the bridgewire of the EID used to initiate the explosive.

3. Static electricity on insulated conductive objects, such as metal stands with rubber casters, or on a person, can discharge through the air to other objects which are at a sufficiently different potential. Such a discharge or spark, even though too small to be felt, may contain enough energy to cause an electro-explosive device, such as a primer or a detonator, to fire. Static discharges may also be strong enough to break down the insulation within the EID and cause it to fire.

4. All isolated conductive objects should be grounded to remove and prevent the accumulation of electrostatic charge.

5. Personnel should follow proper bonding and earthing practices.

6. RF. EIDs are susceptible to initiation by exposure to the radiated fields of RF emitters. Advances in technology have resulted in the development of extremely powerful communications and radar equipment that radiates high levels of electromagnetic (EM) energy. The degree of susceptibility depends on many variables. These variables are the threshold firing level of the EED; the ability of the leads, circuit, or installation to capture RF energy; the type and characteristics of RF energy; and methods of coupling which can introduce this energy into the EED.

7. RF induced currents will cause bridgewire heating that may inadvertently fire the EID. Interface wiring to the EID generally provides the most efficient path for RF fields to couple energy to the bridgewire. However, RF energy can also fire extremely sensitive devices, such as electric primers, as a result of capacitive coupling from nearby radiated objects. RF energy may also upset energized EID firing circuits, causing erroneous firing commands to be sent to the EID. Non-bridgewire types of EIDs are being increasingly used for many ordnance applications. The electrothermal behavior of these devices differs considerably from bridgewire devices; many have much faster response times and exhibit non-linear response characteristics.

8. Stray Currents. Personnel should check for and eliminate stray currents before undertaking ordnance handling operations. (This may be less important at a remote or forward area location than at a fixed facility or on a ship). Cables should not be connected or disconnected after the operations have commenced. A single point earth or ground should be used where possible.

9. Precautions. All aircraft, both rotary and fixed wing, should be connected to earth when loading (both uploading and downloading) ordnance.

10. Electrical safety connections are to be used to earth or bond explosive ordnance as required by applicable technical publications.

Personnel should connect and disconnect cables, (grounding, bonding, earthing, or other electrical cables), only when established procedures directly dictate the procedure during the handling and testing of ordnance.

11. Personnel should observe the general safety precautions with respect to clothing, and in addition, prior to commencing an uploading or downloading operation, personnel should earth or bond themselves to a suitable earthing or bonding point or to a bare (unpainted) portion of the aircraft.

12. During the uploading of weapons aboard the aircraft, electrostatic protection is considered adequate if immediately prior to removal of the shorting plugs or dust covers and racking, the aircraft, weapon, and personnel are at the same potential. During downloading personnel must replace shorting plugs or dust covers over electrical connectors prior to removal of the weapon.

13. Personnel should avoid touching contacts of electrical connectors associated with ordnance. The primers of electrically-primed munitions, such as rounds for some guns, have been found to be particularly sensitive.

14. Non-essential aircraft electrical systems on the aircraft should not be activated during any ordnance handling operation. Transmitters are not to be energized during the handling and testing of ordnance.

15. The antennas on hand-held and mobile transceivers can generate hazardous situations if they touch the system, ordnance, or support equipment. To avoid this hazard, hand-held and mobile transceivers should not be operated any closer than 3 meters (10 feet) from ordnance subsystems and containers.

16. Radiation hazard surveys should be undertaken on ships to identify the locations where ordnance cannot be placed.

17. EIDs such as squibs, blasting caps, igniters, and similar electrically initiated, sensitive explosive devices are particularly susceptible to initiation when they are directly exposed to RF radiation, without the protection of being in a container or installed within a system. Therefore these devices shall be packaged and kept in completely enclosed metal containers until immediately prior to use. When unprotected EID's are handled, radio and/or radar transmissions should be under emission control procedures.

18. Simultaneously arming and refueling minimizes the time that the aircraft is on the ground and decreases turnaround time, but it is a risky operation. Detailed local operating procedures must be carefully developed and personnel thoroughly trained.

4.6. FUEL

1. General. Fire or explosion hazards are particularly dangerous and always present where fuel is involved. Extreme care must be taken during these operations.

2. Combustion requires fuel vapor, air, and an ignition source. When the proper ratio of fuel vapor and air is present, ignition will result in fire or explosion. The danger is from electrostatic discharge, arcs and sparks due to stray voltages and currents, and radiated RF energy.

3. During fuel servicing, fuel vapors are forced out of the vents by the incoming fuel. An explosive vapor-air mixture normally exists in the vicinity of the aircraft fuel vents and near the fuel orifice during open-port re-fuelling. An aircraft fuel system failure could result in fuel spilling from vent outlets or from other locations. Special care must be taken that no active ignition source is in, or enters into, this area.

4. A Fuel Servicing Area (FSA) should be established for the fuelling operation that encompasses the pressurized fuel carrying servicing components such as a servicing hose, fuel nozzle, single point receptacle, hydrant hose cart, ramp hydrant connection, and the aircraft fuel vent outlets. The FSA is established and maintained during pressurization and movement of fuel. During fuel movement, active ignition sources shall be removed and kept out of the fuel servicing area. No other equipment is to be brought into the FSA during the fuelling operation. The FSA applies to all servicing operations except where specific technical orders prescribe concurrent servicing operations

5. ESD - Personnel. Prior to participating in any fuel servicing operation, personnel should observe the general precautions to reduce static build-up on clothing and earth themselves before entering the fuel servicing area, and periodically as required to remove accumulated charge.

6. If a spark occurs during the initial grounding or bonding procedure, then atmosphere conditions are ideal for additional static charge accumulations; under these conditions, personnel should ground or bond themselves periodically. If no spark occurs during the initial grounding or bonding procedure (or other symptoms do not occur), then additional grounding or bonding is not necessary.

7. Personnel should not ground or bond themselves within three feet of aircraft fuel vent outlets or, the fill orifice during open-port re-fuelling.

8. Personnel conducting aircraft fuel vent checks should ground or bond themselves above waist level and at least three feet from fuel vent outlet prior to checking vent.

9. Personnel entering the FSA during concurrent operations should ground or bond themselves before entering the area.

10. Personnel should never put on or remove clothing while in FSA.

11. Conductive aircraft maintenance or work stands, used by personnel to access the aircraft fuel servicing receptacles or support the fuel hose during servicing operations, should be bonded to the aircraft. Other maintenance or work stands, not used for fuel servicing, do not require either bonding or grounding.

12. <u>ESD – Fuel Flow.</u> The fuelling operation itself causes charge separation as the fuel is pumped from the supply tank through the filter-separator and the fuelling hose to the aircraft fuel tanks. This electrostatic charge can accumulate on the aircraft and fuelling system and pose a serious ignition hazard. The use of conductive additives in the fuel will reduce but not eliminate the accumulation of the charge. The fuel servicing equipment must be bonded at all times to the aircraft during the fuelling operation to prevent this accumulation of charge and hence remove this potential source of ignition. Hydrant fuel servicing vehicles and hose carts should also be bonded to the hydrant system in addition to bonding to the aircraft.

13. This connection must be made before the fuelling operation begins, since attaching a cable to a charged aircraft could cause an incendiary spark.

14. Bonding is not required for an all-metal fuel handling assembly with a pantograph-type arm, as long as there is a continuous metal structure from the fuel servicing equipment to the aircraft.

15. If there is no conductive additive, the operator should wait a few minutes after the fuel has stopped flowing before removing the nozzle from the tank to provide more time for the electrostatic charge within the fuel itself to dissipate.

16. A re-fuelling nozzle that discharges into an open tank-fill orifice must have a bonding cable permanently attached to the nozzle. The free end of the cable is to be connected to the airframe in the vicinity of the tank-fill orifice before opening the tank. The cable is not to be removed until the tank has been closed again. This second bonding wire prevents a charged fuel nozzle from creating a spark at the open fuel port when the fuel nozzle first touches the aircraft.

17. Pressure re-fuelling nozzles are bonded to the aircraft when the nozzle is inserted into the aircraft adapter-locking flange; therefore no further bonding is required. The resistance of this bonding path must not exceed 10 ohms. If doubt exists as to a suitable aircraft to nozzle bonding then a separate nozzle to aircraft bonding cable should be used.

18. When re-fuelling from drums is required the following procedures are to be followed:

a. all equipment being used to refuel, i.e., drums, pumps, funnels, etc. must be bonded together with bonding cables and then connected to the aircraft with an another bonding cable prior to opening the fuel tank, and remain connected until after the fuel tank is again closed;

b. the standpipe assembly is to be bonded to the drum prior to removing the drum cap and is to remain bonded until after removal of standpipe from the drum;

19. Specific additional details on ground/bonding requirements for liquid fuels loading/unloading operations, during ground transfer and aircraft re-fuelling/de-fuelling are contained in STANAG 3682 PHE.

20. Electrical Power and Stray Currents. If a ground power unit is powering an aircraft during the fuelling operation, the unit should be outside the fuel servicing area. Since there is a danger of an incendiary arc as cables are connected or disconnected from the aircraft, power cables should not be attached or removed during the fuelling operation.

21. Operating external power units will be parked outside the fuel safety zone area.

22. Non-essential aircraft electrical systems on the aircraft should not be activated during the fuelling operation.

23. Batteries for any type of electronics may not be replaced within the fuel servicing area, due to possible arcs.

24. Do not connect or disconnect grounding and bonding cables during fuelling operations.

25. RF. Since sparks induced by a strong RF field can ignite fuel vapor, transmitters should not be activated during the fuelling operation.

26. Adjacent parked aircraft that intrude into the fuel servicing area should not radiate electromagnetic energy, or be involved in any maintenance requiring energizing or de-energizing external electrical circuits.

27. Laptop computers, cellular phones, or hand-held radios may be operated within the fuel servicing area, but only intrinsically safe radios may be operated within three meters (10 feet) of aircraft fuel vent outlets, open port re-fuelling receptacles, or fuel spills. Antennas must not touch structure.

28. Radars and high frequency (HF) radios (both ground based and onboard other aircraft) should not be operated in the transmit mode within 90 meters (300 feet) of servicing operations (unless otherwise specified in the applicable technical orders, or when other procedures are used to insure a safe distance). Satellite communications radios and ground approach radar may be operated in the transmit mode if the antenna beam is pointed at least ten degrees above the horizon.

4.7. ELECTRONIC SYSTEMS

1. During maintenance and servicing operations of electronic equipment, the aircraft should be connected to earth (either through a static earth point or a power ground point depending on the operation) to remove the hazard that could be caused by the accumulation of electrostatic charge.

2. To protect personnel from the effects of RF radiation, transmitters should not be operated during maintenance and servicing operations. STANAG 2345 and national policies must be observed. When servicing on-board transmitters, dummy loads should be in place.

3. Prior to undertaking any maintenance operation, personnel should observe the general precautions to reduce static build-up on clothing. Maintenance personnel should never put on or remove clothing while handling electronic equipment, assemblies, or components.

4. Before removing, opening, or working on electronic sub-systems or equipment, personnel should electrostatically equalize themselves with the aircraft by making contact with an unpainted part of the airframe with the bare hand. In addition, personnel should not touch connector pins or jacks, and should use connector covers and protectors when assemblies are removed from the aircraft.

5. If undertaking maintenance or other servicing activity during a fuelling or ordnance operation, all electrical equipment must be kept outside the fuel servicing area unless it meets defined safety requirements and is authorized for use within this area.

Chapter 5 Protection Measures

5.1. ELECTRICAL SAFETY CONNECTIONS

1. To protect personnel and equipment from electrical hazards on the flight line, it is generally necessary to provide an electrical safety connection (ESC) between an aircraft and support equipment or to provide an ESC to either a static earth point or to a power ground point for aircraft and/or support equipment.

5.2. EARTH POINTS

1. A clear distinction must be made between earthing for the purposes of dissipating an electrostatic charge and grounding for protection from power system faults. Due to the relatively higher currents involved in a fault condition, power fault protection and power earthing requirements are considered to be in a category separate from static earthing.

2. The electrostatic discharge protection requirement is based on the maximum earth resistance which will maintain a safe voltage level during charge accumulation and allow electrostatic charge to dissipate in a reasonably short time duration.

   a. A static ground or ramp earth point is a point that has an impedance of less than 10,000 ohms referenced to earth.

   b. Temporary static earth points may be installed to meet operational requirements. They consist of metallic stakes driven into the earth to meet the specified earth resistance.

3. Grounding for protection against power system faults requires a low resistance return path between the fault location and the source. This resistance must be low enough to allow sufficient current to flow to activate circuit breakers and other overload protection devices.

   a. At a fixed facility the return path is provided by the fault protection subsystem and the earth electrode subsystem of the facility grounding system.

   b. The design impedance of the earth electrode subsystem referenced to earth is 10 ohms.

4. A mains earth point or power ground is one connected to the earth electrode subsystem and may be used for all earthing requirements. A ramp earth point may not be used as a mains earth point. If there is a need for both a static ground and a power ground, make the ESC to the mains earth point.

5.3. AIRCRAFT FITTINGS

1. Receptacles should be attached to the aircraft to permit ESCs for grounding and/or bonding of the aircraft during fuelling, ordnance loading, and maintenance operations and while parked. These receptacles should be attached to the airframe such that the receptacle-to-airframe resistance does not exceed 1.0 ohm.

a. Fuel Nozzle: A receptacle should be installed within one meter of each fuel inlet for fuel nozzle grounding.

b. Ordnance: Receptacles should be installed at locations convenient for use in ordnance loading operations.

c. Servicing: Receptacles, in addition to those installed for fuelling and ordnance loading, should be installed at locations convenient for servicing and maintenance operations.

d. An earthing bolt, as per Figure 5-1, should be located in a convenient recessed airframe location, to be used to connect the aircraft to either a static earth point or a mains earth point. The bolt-to-airframe resistance should not exceed 1.0 ohm.

5.4. ESC FOR GROUND SUPPORT EQUIPMENT

1. Ground support equipment should have a permanently attached electrical safety cable suitable for connection to a static earth point or a mains earth point. All ground support equipment should have a permanently attached electrical safety cable suitable for bonding the equipment to the aircraft.

5.5. CIRCUIT BREAKERS AND OVERLOAD PROTECTION

1. For effective power fault protection, a conductive path must be provided between the location of the fault and the source supplying the faulted line. The resistance of this path must be low enough to cause ample fault current to flow and rapidly trip breakers or activate other overload protection devices.

2. The necessary low resistance return path is usually the safety ground wire and/or the facility ground network. Ideally, the grounding conductor and the ground network do not carry current unless there is a fault. An inadvertent contact between conductors and any conducting object connected to the grounding conductor will trip breakers or activate the overload protection device.

3. Circuit breakers and other overload protection devices primarily safeguard equipment and not personnel. Personnel coming into contact with an electrical power source would normally cause only limited – although potentially lethal – fault current to

flow. This limited current level would be too low to trip the overload protection devices. They do offer protection to personnel by removing power when faults occur, thus preventing a mishap if someone should come into contact with the equipment or device.

4. Since the airframe is connected to the AC Neutral (DC Negative) lead, the aircraft does not have to be grounded or bonded to the GPU for the overload protection devices to be activated in the event of a power system fault at the aircraft. In addition to being the return conductor, the Neutral (DC Negative) lead in the GPU cable will also provide the needed path between the fault location on the aircraft and the source.

5.6. GROUND FAULT CIRCUIT INTERRUPTERS

1. The Ground Fault Circuit Interrupter (GFCI) is a safety device which trips and breaks an electrical circuit when the current in the hot lead(s) and the neutral lead is imbalanced by more than a few milliamperes. The imbalance is caused by a ground fault (i.e. leakage current to ground). The leakage path may be due to worn insulation, moisture, or deterioration in equipment due to age, or it may be through a person. The current is not high enough to cause a circuit breaker to open, but under some circumstances is high enough to be dangerous to human safety. The GFCI reacts in less than 25 ms – fast enough to prevent injury.

2. The GFCI does not protect against all electric shocks.

a. If personnel touch the hot and neutral leads of a circuit simultaneously without being grounded, the GFCI would not function. All the current from the hot lead would pass through the person and return to the Neutral lead; thus there would be no current imbalance.

b. Therefore a GFCI installed on a GPU connected to an aircraft does not provide protection to personnel interior to the aircraft since the Neutral (or DC Negative lead) is connected to the aircraft frame.

3. The Neutral (or DC Negative) point of the GPU must be connected to the chassis to provide an alternate path for the return current in the event of a fault at the GPU chassis. This means that the airframe is also connected to the chassis.

4. The aircraft and GPU cannot be bonded with an ESC, nor can both the aircraft and GPU be grounded. This would provide another permanent return path for the current, causing an imbalance in the hot and Neutral leads, thus activating the GFCI.

5.7. GROUND FAULT CIRCUITS

1. Some Ground Power Units incorporate a ground fault circuit (GF circuit) to provide protection in the event of a fault occurring between any one of the three

generator phases (or the DC positive output) and the GPU chassis. In this configuration there is no direct connection between the AC Neutral (or DC Negative) lead and the chassis.

2. The ground fault circuit basically monitors the voltage between the AC Neutral (or DC Negative) lead and the chassis. If a low resistance path develops between one of the generator phases (or the DC positive output) and the chassis, the voltage level at the Neutral (or DC Negative) increases, and the ground fault circuit is activated to shut down the GPU. This occurs at approximately 30 VAC and 40 VDC.

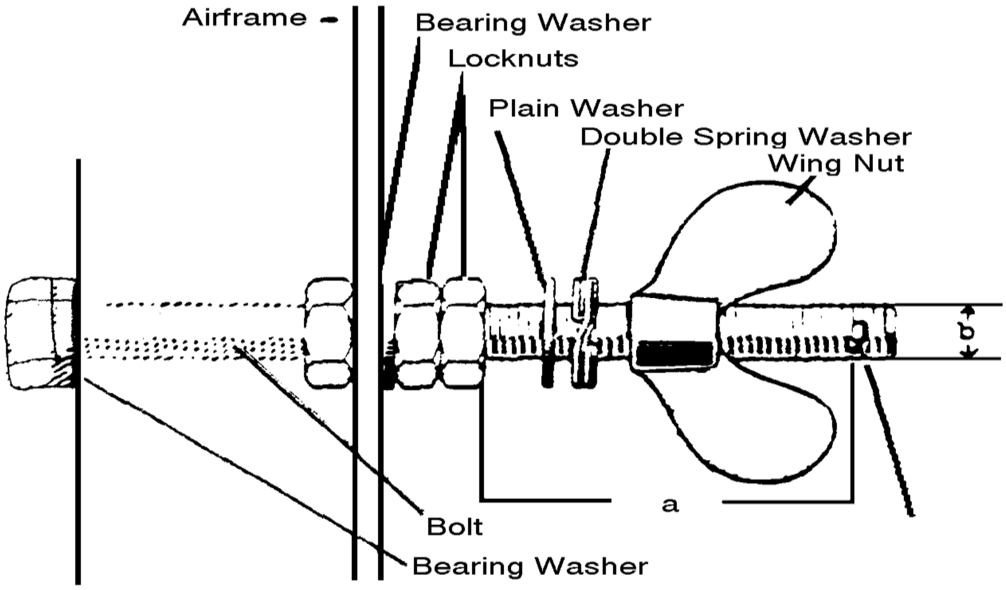
3. If personnel come into contact with both the hot lead and the GPU chassis (or the hot lead and ground if the GPU chassis is grounded), the human body will provide the low resistance path and the ground fault circuit will remove the power. This occurs fast enough and at a voltage low enough to prevent injury.

4. With this configuration, the aircraft cannot be bonded to the chassis of the GPU, since this would connect the Neutral (or DC Negative) lead to the GPU chassis and effectively disable the ground fault circuit. Grounding both the aircraft and the GPU chassis would have the same effect.

5.8. GPU CONFIGURATIONS

1. STANAG 3457 requires that the AC Neutral (DC Negative) of the Ground Power Unit as well as associated control circuitry not be normally connected to the ground power system chassis or framework. Unfortunately practices in this regard appear to be inconsistent. In some instances the GPU AC Neutral (DC Negative) is connected to the chassis, while in other instances it is not.

2. A GPU can be either a mains (motor-generator) driven or a non-mains (engine) unit. The configuration of the GPU in this respect will influence the earthing, grounding, and bonding practices, as well as the usefulness of a GFCI and a GCI. Refer to Annex C1 for more detail.



Dimensions		
	Inches	Millimetres
a	1.5 + 0.063	38.1 + 0.16
b	0.3125 + 0.004	7.9 + 0.01

Figure 5-1 AIRFRAME EARTHING

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Chapter 6 Miscellaneous

6.1. SITING AND TESTING OF EARTH POINTS

1. Siting. An adequate number of earth points are to be provided and located to facilitate aircraft servicing. The following requirements apply:

a. earth points should be approved by the designated technical authority of an operating unit.

b. earth points are to be as near as practical to aircraft parking points and must be situated to allow the use of an electrical safety cable of available length.

c. electrical safety cables should not extend across areas that are traveled by vehicles and equipment.

d. ramp earth points should be marked as per Figure 6-1 and STANAG 3632.

e. Temporary Static Earth points may be installed to meet operational requirements. [They consist of metallic stakes approximately 2.2cm (0.875 inch) in diameter and capable of being driven 1 to 3 meters into the earth to meet the specified earth resistance].

2. Testing. Earth Points require the following:

a. earth point resistance measurements shall be made using the three-terminal fall of potential method [6,27];

b. the inspection completion date or next inspection due date is to be painted within the disc surrounding the earth point (Figure 6-1);

c. when resistance exceeds allowable limits the earth point it is to be removed from service until proper resistance values can be restored;

d. Mains Earth Points are to be tested every 24 months. The resistance is to be as low as possible but not exceed 10 ohms;

e. Ramp Earth Points and Temporary Earth Points are to be tested at regular intervals and must not exceed 10,000 ohms.

6.2. ELECTRICAL SAFETY CABLES

1. Electrical safety cables must meet national code requirements. These cables include the following:

   a. bonding/earthing/grounding cables used to equalize static electricity potentials on the flight line. Maximum resistance of 10 ohms or less;

   b. safety earthing cables that are capable of providing protection from power faults during servicing or maintenance.

2. Electrical safety cables should be tested for continuity and resistance:

   a. on initial fabrication;

   b. at scheduled intervals for cables in use;

   c. when the cable is permanently attached to a structure such as fuel tenders; and

   d. when their condition is suspect.

3. Electrical safety cables are to be connected to the aircraft as detailed in STANAG 3632. When no proper aircraft earthing point is provided, heavy-duty clamps or pincers may be used but they must be connected to a conductive (unpainted) part of the aircraft. Do not attach them to bonding straps used on doors or access panels. The use of alligator clips to provide this requirement is discouraged.

6.3. ELECTRICAL SAFETY CONNECTIONS

1. To prevent shocks to personnel and ignition of combustible mixtures the following connection sequences shall be used:

   a. an aircraft grounding cable shall be connected to an earth point first and **then** connected to the aircraft, and

   b. GSE shall be connected to an earth point **before** electrical safety cables are connected from the GSE to the aircraft.

2. When no proper aircraft earthing point is provided, heavy-duty clamps or pincers may be used but they must be connected to a conductive (unpainted) part of the aircraft. Do not attach them to bonding straps used on doors or access panels. The use of alligator clips to provide this requirement is discouraged.

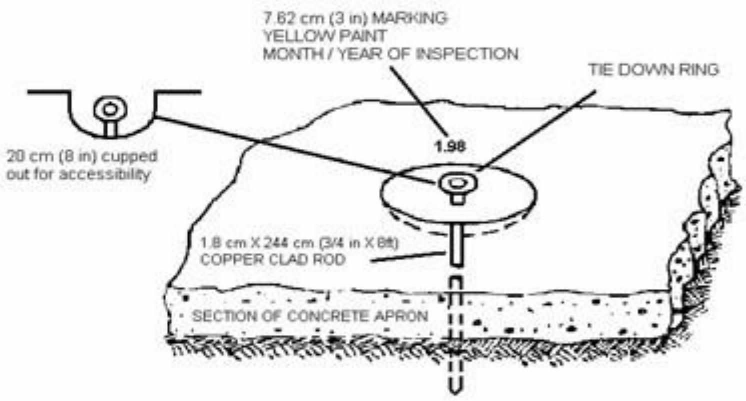

Figure 6-1 IDENTIFICATION OF AN APPROVED STATIC EARTH POINT

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ANNEX B Glossary

B1. GLOSSARY

1. Bonding. The process of mechanically connecting metal parts together so that they make low resistance electrical contact for direct current and lower alternating current frequencies. (AAP-6)

2. Earth. Designates the earth mass. To earth is to make an electrical connection to the potential of the earth mass.

3. Earth Points. These consist of:

    a. Mains Earth Point. An earthing terminal affixed within a structure, floor, tarmac area, etc., suitable for the prevention of lethal conditions in an electrical fault situation. Also called True Earth or National Code Earths.

    b. Ramp Earth Point. A fitting on a fixed structure, floor, tarmac area, etc., suitable for dissipation of static or lightning charges to earth. Also known as ground rods, earth reference points, or static earth points.

4. Earthing. The process of making a satisfactory electrical connection between the structure, including the metal skin, of an object or vehicle, and the mass of the earth, to ensure a common potential with the earth. (AAP-6)

5. Electrical Safety Cables. Otherwise called bonding leads, grounding cables, earthing wires, or equipotential connections, are used for the purpose of accomplishing electrical safety connections between aircraft, ground support equipment (GSE) and earth, so as to maintain the interconnected points at a common potential.

6. Electrical Safety Connection. A connection between two points made with an electrical safety cable to protect personnel, fuel, ordnance, and electronic equipment from electrical hazards.

7. Ground Fault Circuit Interrupter. A device which de-energizes a circuit within a specified time when leakage or fault currents exceed a predetermined value.

8. Grounding. The bonding of an equipment case, frame or chassis, to an object or vehicle structure to ensure a common potential. (AAP-6)

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ANNEX C Acronyms

C1. ACRONYMS

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

ANNEX D Victim Characteristics - Personnel

D1. ELECTRIC SHOCK

1. Electrical hazards represent a serious danger to personnel on the flight line. Most workers know that the principal danger from electricity is that of electrocution, but few really understand just how minute a quantity of electrical energy is required to electrocute a person. In reality, the current drawn by a tiny 7.5 watt, 120 volt lamp, passed from hand-to-hand or hand-to-foot across the chest is sufficient to cause electrocution. According to the National Institute of Occupational Safety and Health statistics, between 1980 and 1992 in the United States, 5,348 workers died from contact with electrical energy. Electrocutions were the fifth leading cause of death, accounting for 7% of all workplace fatalities [(4)].

2. To receive an electric shock, the human body must become part of an energized electric circuit which can deliver a current level high enough to over stimulate the nervous system or cause damage to internal organs. The severity of the shock received is a function of:

a. the level of the current flow,

b. the duration of the current,

c. the frequency of the current, and

d. the path of the current through the body.

3. Current Level. The level at which the current stimulates the nerves is indicated by a slight tingling sensation and is known as the perception current. It is the minimum value of current which will cause any sensation for the person through which it is flowing. The reaction current is slightly greater than the perception current and could produce an involuntary muscular contraction resulting in an accident.

4. Except for the startling effect and involuntary movement that may result in an accident, the smallest electric shock of importance is the current that causes a loss of voluntary control of the hand when grasping an electrified object. When the current is increased there comes a time when the victim cannot let go of the conductor; the victim is said to “freeze” to the circuit. The current stimulates involuntary contractions of both the flexor and extensor muscles. When the stronger flexor muscles dominate, the victim may not be able to release the electrified object as long as the current flows. The maximum current that a person can endure and still release the conductor by using the muscles directly simulated by the current is called the “let-go” current [(5)].

5. Currents at or a little above those at which a person can “let-go” of a circuit, but below currents causing ventricular fibrillation may contract chest muscles and stop breathing during the period of shock [(5)]. Normal breathing may resume when the

current is interrupted. However, with prolonged current, collapse, asphyxia, unconsciousness, and even death may occur in a matter of minutes.

6. Higher currents may produce an effect on the heart known as ventricular fibrillation which is considered to be the main cause of death due to electric shock. The human heart is a pump that, with the coordinated and rhythmical contraction and expansion of its muscular fibers, ensures circulation of blood throughout the body. When an electric current enters these fibers, the heart rate becomes irregular with increasingly uneven contractions which may cause total cardiac arrest. From a practical point of view ventricular fibrillation is the stoppage of heart action and hence blood circulation. The human heart rarely recovers spontaneously from fibrillation.

7. The reaction of the human body to the passage of current varies from person to person. The only meaningful way to provide values for design and accident prevention purposes is to present the data in statistical terms.

8. <u>Duration of Current.</u> The threshold for perception and reaction is independent of the duration of the current. The threshold of let-go and the threshold of ventricular fibrillation are a function of the duration of exposure to the current. These thresholds decrease with an increase in the duration. Because, assuming all other factors are equal, the degree of injury is proportional to the duration of the current flow through the body, low voltages can still be dangerous. Low voltage does not imply low hazard.

9. The human heart becomes increasingly susceptible to ventricular fibrillation when the time of exposure to current approaches the heart beat period. The danger is much smaller if the time of exposure to current is in the region of 60 – 300 milliseconds (for frequencies of 50/60 hertz).

10. Some authors/investigators have identified a relationship between the fibrillation threshold, current duration, and body weight. The IEEE Standard 80-2000 [6] uses the following equations, based on the work of Dalziel and Lee [7], as the basis for determining the minimum body current which can cause ventricular fibrillation of the heart.

I_B = 116 / T-1/2 ma for a 50 kg (110 pound) body weight, and
I_B = 157 / T-1/2 ma for a 70 kg (155 pound) body weight,

where: I_B rms current through the body
T duration of the current exposure in seconds

These equations are valid for range between 30 milliseconds and 3000 milliseconds.

11. Based on the results of Dalziel's studies, it is assumed that the magnitudes of currents determined by the above equations will not cause ventricular fibrillation in 99.5% of all persons whose weights are 50 Kg and 70 kg respectively. Table D-1 shows the current values required to cause ventricular fibrillation for various time durations.

[Note: The IEC Technical Report 479-1 (8) has used time-current zones to summarize the effects of the physiological considerations of the threshold levels. The values in reference (x) are very conservative and the data applies to persons under normal physiological conditions, including children irrespective of age and weight.]

Duration (ms)	Direct Current (ma)		Alternating Current (ma)			
			60/ 50 Hz		400 Hz	
	50 kg	70 kg	50 kg	70 kg	50 kg	70 kg
30	870	1300	670	906	5025	6795
100	-	-	367	496	2753	3720
1000	-	-	116	157	870	1178
3000	370	500	67	91	503	683

TABLE D-1 CURRENT VALUES FOR VENTRICULAR FIBRILLATION

Note: The values at 50/60 hertz were calculated using the above equations.
The values at 400 hertz are based on the frequency factor from IEC 479-2 (9).
The values at DC were taken from Dalziel (10).

12. Frequency. The frequency of the current is an important parameter when considering the possibility of electric shock injuries. The various thresholds are substantially modified by changes in the frequency of the current. Humans are particularly susceptible to frequencies in the 50 Hz to 60 Hz range (6). The internal frequency of the nerve signals controlling the heart is approximately 60 Hz.

13. The thresholds for the perception current, the reaction current, the let-go current, and the ventricular fibrillation current increase considerably as frequency is increased. A greater level of current is required to produce a given effect than is required for a 50/ 60 Hz current.

14. The frequency factor is defined in IEC 479-2 as the ratio of the threshold current for the relevant physiological effects at the designated frequency to the threshold current at 50/60 hertz. The frequency factor differs for perception, let-go, and ventricular fibrillation. The frequency factors for 400 Hz and 1000 Hz are given the following table.

Threshold	Frequency		
	50/60 Hz	400 Hz	1000 Hz
Perception	1.0	1.36	2.1
Let-go	1.0	1.24	1.7
Fibrillation	1.0	7.5	14.0

TABLE D-2 FREQUENCY FACTOR

15. Direct Current. The thresholds for direct current are greater than those for 50/60 hertz. These thresholds are rather different than those defined for alternating currents since, unlike AC only the establishment or interruption of direct current is felt. The let-go current for DC is sometimes referred to as the “release” current since test subjects could let go of the circuit but refused because of the severe shock experienced on release.

16. The ventricular fibrillation threshold, for an exposure to direct current longer than a cardiac cycle, is several times higher than for current at 50/60 Hz. For exposures less than 200 milliseconds, the fibrillation threshold is approximately equivalent.

17. Current Pathway. The critical pathway for current flowing through the body is through the chest cavity where the most serious path is through the heart. Current flowing from one hand to the other or from one hand to the opposite foot (or both feet) will pass through the chest cavity and may paralyze the respiratory or heart muscles, initiate ventricular fibrillation, and burn vital organs.

18. The IEC Technical Report 479-1 has established a heart-current factor. This factor is an approximation of the magnitude of the current passing through the heart for various pathways using the left-hand-to-both-feet pathway as a reference path. It is “a rough estimate of the relative danger of the various paths with regard to ventricular fibrillation”. The factors for some paths are given in the following table (8).

Current Path	Heart Current Factor
chest to left hand	1.5
chest to right hand	1.3
left hand to left foot, right foot, or both feet	1.0
both hands to both feet	1.0
right hand to left foot, right foot, or both feet	0.8
back to left hand	0.7
seat to left hand, right hand, or both hands	0.7
left hand to right hand	0.4
back to right hand	0.3

TABLE D-3 HEART-CURRENT FACTOR

19. Human Body Impedance. At power frequencies the impedance of the body is mainly resistive, but above 1000 Hz it also exhibits reactance due to the body's cellular structure and looks like a capacitance in parallel with a resistance. It is believed that very high frequencies, above 100 to 200 KHz, burns are the main effects produced.

20. The total body impedance is the sum of three components: the internal body impedance and the skin impedances at the two contact points.

21. The internal impedance of the body is mainly resistive and its value depends primarily on the current path. It is usually estimated to be 500 ohms for a hand-to-foot current path.

22. The skin impedance can be modeled as a circuit composed of resistors and capacitors. This impedance varies with voltage, frequency, and conditions of contact (eg. area of contact, temperature, moisture, and type of skin).

23. The total body impedance can vary greatly. Figure D-1 and Figure D-2 indicates the variation in total body impedance with voltage and frequency respectively.

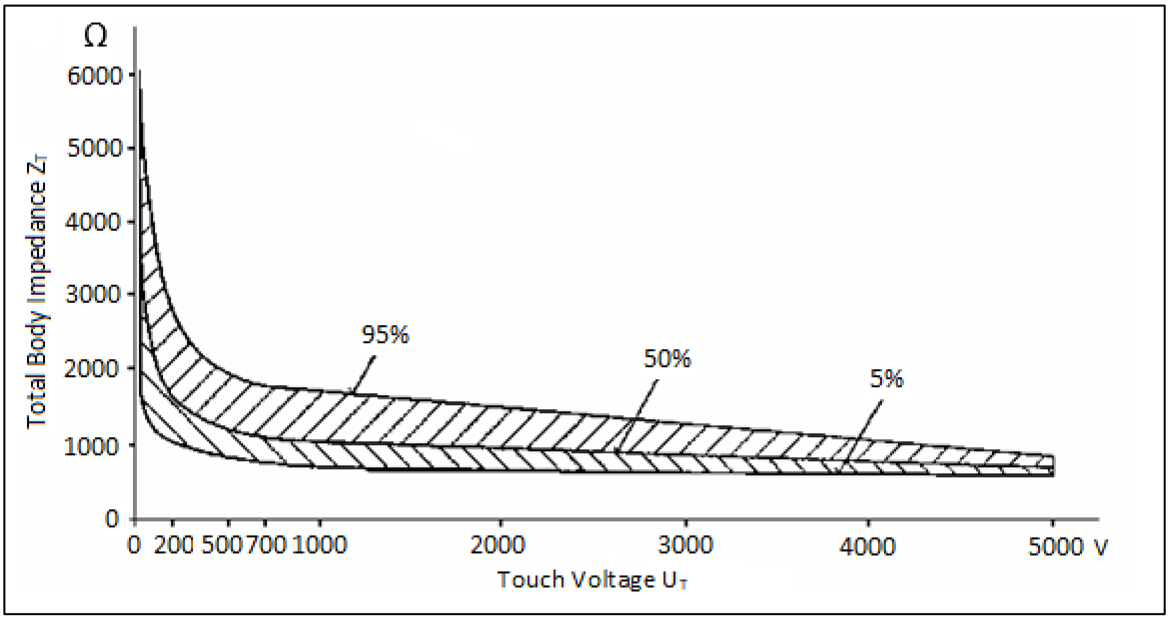

Figure D-1 STATISTICAL VALUES FOR TOTAL BODY IMPEDANCE FOR THE CURRENT PATH HAND-TO-HAND OR HAND-TO-FOOT AT 50/60 Hz [8]

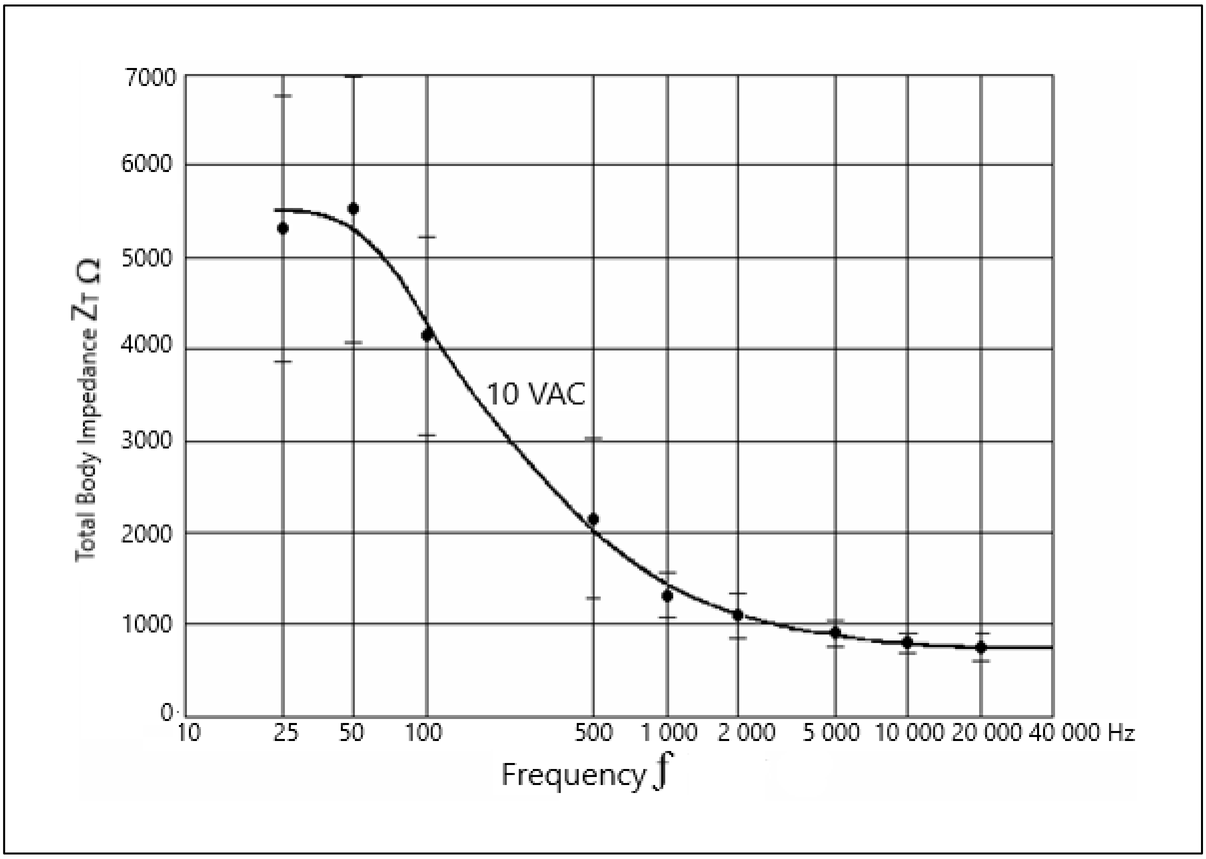

Figure D-2 TOTAL BODY IMPEDANCE VERSUS FREQUENCY FOR THE CURRENT PATH HAND-TO-HAND FOR A TOUCH VOLTAGE OF 10 VAC [8]

Wet and broken skin can cause a considerable decrease in total body impedance. Wet conditions are common during low voltage electrocutions.

The following table indicates a range of skin impedance measured at 60 Hertz under various contact conditions. (The voltage at which the measurement was made is unknown).

Total Body Impedance for Various Skin Contact Conditions		
Body Contact Condition	Dry (ohms)	Wet (ohms)
finger touch	40,000 – 1,000,000	4,000 – 15,000
hand holding wire	15,000 – 50,000	3,000 – 5,000
finger-thumb grasp	10,000 – 30,000	2,000 – 5,000
hand holding pliers	5,000 – 10,000	1,000 – 3,000
palm touch	3,000 – 8,000	1,000 – 2,000
hand around 4 cm pipe	1,000 – 3,000	500 – 1,500
hand around drill handle	1,000 – 3,000	500 – 1,500
two hands around 4 cm pipe	500 – 1500	250 – 750
hand immersed	-	200 –500
foot immersed	-	100 - 300

TABLE D - 4 TOTAL BODY IMPEDANCE FOR VARIOUS SKIN CONTACT CONDITIONS

26. Touch Voltage. Although current (its magnitude, duration, and frequency) is the primary factor in determining the severity of injury from electric shock, in most situations this is not sufficient information to determine if there is a potential hazard. In most instances, the magnitude of the touch voltage (defined in IEC as the product of the current through the body and the total body impedance) is the known value with the current passing through the body being determined by Ohm's Law:

$$I = V / Z$$

Where: I = current through the body
V = voltage of the energy source
Z = total impedance of the current path.

[Note: The total impedance of the current path includes the total body impedance and the impedance of any wearing apparel such as shoes or boots and gloves, as well as the ground resistance if the foot is part of the circuit.]

27. This relationship is not linear, as the total body impedance is a function of the touch voltage. Refer to Figure D-1.

28. Burns. In addition to the other effects, burns are also a major hazard connected with electricity. Burns are actually the most frequent injuries caused by electric current (12). There are three types – arc burns caused by the intense radiation of the electric arc, electrothermal burns caused by the flow of current, and thermal contact burns.

29. Arc burns are similar to burns from high temperature sources. The heat from an electric arc can vaporize metals, burn flesh and ignite clothing in close proximity to the arc. The majority are small burns from low voltage arcs. These types of burns can be more extensive if the incident involves a high voltage and will be further aggravated if clothing ignites.

30. Electrothermal burns are a result of heat generated by the flow of current through the body and occur not only at the points of contact but also in tissues, organs, muscles, and bones along the whole current pathway. If currents at the let-go level flow for an appreciable time, they are sufficient to cause electrothermal burns (13). The damage from this type of burn may not be immediately apparent, and typically heals slowly. Internal swelling of tissues and accumulation of fluid in body cavities are also possible.

31. Thermal contact burns occur when the skin comes into contact with the hot surfaces of overheated conductors, conduits, or equipment cases, caused by short circuits or ground faults.

D2. IMPULSE SHOCK

1. The smallest amount of stored energy that a person can feel when an electrostatic discharge occurs to or from the body is approximately one millijoule. As the potential is increased, variations in response are observed. Some people find 10 mJ uncomfortable, whereas others can accept several hundred millijoules before they experience sharp muscular contractions. An individual with a body capacitance of 200 pF charged to 10kV can receive an electrostatic shock with about 10 mJ of energy when touching a grounded object. From a practical standpoint, stored energy on the human body cannot exceed about 156 mJ (worst case model of 25 kV charge level and 500 pF). Generally, it is much less than this value. In incidents where people have been rendered unconscious, the energy of the discharge was estimated to be several joules (14).

2. Mil-Std-464 considers the shock hazard to personnel to begin at about 3000 volts.

3. Dalziel [13] found that shocks from electrostatic discharges with energies less than 250 mJ to be harmless but were very objectionable. Discharges with energies greater than 50 J were likely to cause ventricular fibrillation.

4. Although a shock from an electrostatic discharge may itself not be harmful, the involuntary reaction could cause an accident.

5. IEC 479-2 states that the possibility of ventricular fibrillation depends on the duration and magnitude of the impulse, the heart phase in which the impulse starts, the current path in the human body, and the physiological characteristics of the person. The data in IEC 479-2 indicate that for an impulse duration (3τ) greater than 5 milliseconds and a peak current of approximately 3 amperes, the probability of fibrillation is greater than 50%.

D3. RF RADIATION HAZARD

1. Radio Frequency (RF) radiation refers to the emissions and propagation of electromagnetic waves in the frequency range nominally from 3 kHz to 300 GHz. Such waves are characterized as non-ionizing radiation since the intrinsic electromagnetic energy absorbed by an object at any frequency within this range is much too low to ionize molecules of the object. Although the energy is non-ionizing there are still hazards due to human exposure to RF energy.

2. RF energy which illuminates a body may be reflected, transmitted, or absorbed. The amount of energy absorbed by the body is a function of the dimensions and electrical properties of the body, and the wavelength of the energy. Significant energy absorption will occur only when the height of the body in the plane of polarization approaches a quarter of a wavelength. As the frequency increases, the wavelength decreases, and the body becomes a more effective receiving antenna. The possibility of harmful biological effects becomes greater with increasing frequency. Also, as the frequency increases other parts of the body become significant in terms of the wavelength, thus increasing the amount of energy absorbed.

3. The effects of RF radiation depend on whether the energy penetrates and is absorbed by the body (causing internal overheating) or is reflected from the skin surface causing overheating of one or more layers of the skin. When the body’s circulatory system cannot handle the heat, the result is an elevated temperature, heat stress, or a surface burn similar to sunburn. RF radiation is absorbed unevenly in biological tissue because of the dissimilar dielectric properties of the different tissues. Thus, significant temperature gradients can be established, which may enhance the action of thermal heating from RF energy as compared to that from infrared radiation. RF absorption is high in skin, muscle, and internal organs, and lower in bone and fat tissue.

4. Certain organs of the body are more susceptible than others to the effects of RF radiation. Organs, such as the lungs, eyes, testicles, ovaries, gall bladder and portions of the gastrointestinal tract, are not cooled by an abundant flow of blood through the vascular system. Therefore, these organs are more likely to be damaged by heat resulting from excessive exposure to radiation. This energy can be lethal when the power intensity and exposure time are sufficient to cause a rise in temperature that exceeds an organism’s ability to maintain a state of relative equilibrium. This occurs when the temperature rise exceeds approximately 5 °C (9 °F). There are also non-thermal effects associated with the absorption of RF energy. These effects, which might range from lethargy or work slowdown to delirium (as body temperature becomes highly elevated) are mitigated as soon as the individual is removed from the RF radiated field or the body temperature is lowered.

5. Hazards to the Eyes. The lens of the eye is very susceptible to thermal damage since it does not have an efficient system of blood vessels to circulate blood and remove heat from the area of the lens. If heated excessively, the transparent lens may develop cataracts or opaqueness. Unlike other cells of the body, the cells in the lens are not capable of re-growth, and when damaged cells will slowly lose their transparency and cause impaired vision.

6. Hazards to the Testes. The reaction of the testes to heat caused by exposure to RF radiation will be the same as the reaction to a high fever caused by many illnesses. Temporary sterility which will ultimately correct itself can occur after exposure to low levels of radiation. Permanent injury to the testes can be caused by an extremely high level of exposure to RF radiation or by high levels of exposure over an extended period.

7. Burns. RF voltages can be induced on metallic objects from nearby transmitting antennas. Hazardous RF voltage levels are those levels which are sufficient to cause pain, visible skin damage, or an involuntary reaction. They do not usually include the levels that cause annoyance, a stinging sensation, or mild heating of the skin.

8. These voltages can be high enough to cause a burn injury if physical contact is made with the object. The flow of RF current through the skin impedance produces heat in the area of contact. The effect of this heat can range from noticeable warmth to a painful burn. Mild burns are usually indicated by small white spots on the skin. More severe burns may penetrate deeper into the flesh and produce painful and slower healing injuries.

ANNEX E Victim Characteristics - Fuel

E1. GENERAL

1. The primary hazard when handling fuel is the possibility of a fire or an explosion. Several attributes of fuel affect its flammability and explosive properties.

E2. PROPERTIES

1. Flashpoint. The flash point of a fuel is the lowest temperature at which the fuel vapor will ignite momentarily without propagating when exposed to an ignition source. The lower a flash point, the more dangerous the fuel. The flash points of some fuels used in military aircraft indicate that ignitable vapors are present at temperatures normally found during military operations. JP-4 can ignite even in sub-zero temperatures.

2. Fuels are sometimes further classified by flashpoint. Fuels which have a flashpoint less than 38^{O} C (100^{O} F) are classified as flammable. Those with a flashpoint greater than or equal to 38^{O} C are classified as combustible. Heated liquids are more volatile. Therefore, heated combustible liquids require the same safety precautions as flammable liquids.

3. Explosive Range. Fuel vapor and air can form a range of mixtures that are flammable and possibly explosive. This range is referred to as the flammability limit or explosive range, and is determined by the percentage of fuel vapor in a given volume of fuel vapor and air. For aviation fuels this range is approximately from 1 to 7 percent of fuel vapor by volume. A mixture in this range can ignite in the presence of an ignition source causing an intense fire in an open space and an explosion if the mixture is in an enclosed space. Mixtures above the explosive range will not ignite because there is not enough oxygen present to burn the fuel. Mixtures below the range will not ignite since there is not enough fuel in the air to burn. The lower limit of the explosive range is formed at approximately the flash point of a fuel. Thus ignitable mixtures of JP-4 fuel vapor and air can occur at temperatures as low as $–23^{O}$ C. Ignitable mixtures of aviation fuel vapor and air occur at temperatures normally found in military operations.

4. Volatility. Vapor pressure or volatility is a measure of a fuel’s tendency to form vapors. The fact that some aviation fuels (AVGAS and JP-4) have high vapor pressures is a further indicator that these fuels form explosive vapor/air

mixtures at temperatures in environments encountered by the military. Other fuels such as Jet A, Jet A-1, JP-5, and JP-8, do not have this characteristic.

5. Distillation Range. Since aviation fuels are constituted from different chemical compounds, they vaporize over a relatively broad range of temperatures, known as the distillation range, as compared to pure substances. The distillation range is another relative volatility indicator. Aviation fuels in particular have distillation ranges in the temperature ranges encountered during military operations.

6. Aircraft fuels are classified under four different types related to their distillation ranges: widecut, kerosene, high-flashpoint kerosene, and aviation gasoline (AVGAS). All four types are utilized in turbojet and turboprop engines with certain restrictions. Only aviation gasoline is suitable for use in reciprocating engines.

a. Wide-Cut Type: Wide-cut fuels are mixtures of gasoline and kerosene distillate fractions with an approximate distillation range of 35 degrees centigrade (C) to 315 degrees C (95 degrees F to 600 degrees F). Examples are JP-4 and Jet B.

b. Kerosene Type: Kerosene type fuels are petroleum distillates with an approximate distillation range of 165 degrees C to 290 degrees C (330 degrees F to 550 degrees F). Examples are JP-8, Jet A-1, and Jet A.

c. High-Flashpoint Kerosene: High-flashpoint kerosene fuel has essentially the same characteristics as the kerosene fuels, but with a minimum flashpoint of 60 degrees C (140 degrees F).

d. Aviation Gasoline (AVGAS): Gasoline is a petroleum distillate with an approximate distillation range of 35 degrees C to 165 degrees C (95 degrees F to 330 degrees F). Gasoline-type fuels are not used to any large extent in aircraft turbojet and turboprop engines because of poor lubricating properties as compared to kerosene-type fuels and because of lead additives which have an adverse effect on aircraft turbine engines.

7. Conductivity. Electrostatic susceptibility describes the relative degree to which a fuel will accumulate an electrostatic charge. Aviation peculiar fuels have relatively high electrostatic susceptibilities. This multiplies the danger of these highly volatile and flammable fuels.

8. A conductivity additive is used in both JP-4 and JP-8 fuel to minimize the accumulation of electrostatic charge during fuel flow. The additive is effective in significantly reducing charge relaxation times in a fuel tank, but it does not eliminate the generation of charge in fuel flowing through hoses or pipes. There is some information that additives actually increase charge generation.

9. Fuel conductivity levels are specified and measured in siemens per meter (usually in picosiemens per meter pS/m).

10. Electrostatic charge accumulation can be significant when the conductivity of the fuel is below about 50 pS/m. Above this value charge separation still occurs as a result of fuel flow but the charges recombine as fast as they are separated. Increasing the conductivity of the fuel by treating the fuel with a static dissipative additive can reduce charge relaxation times.

11. Charge accumulation can also be reduced by retaining the fuel in an enclosed pipe or relaxation tank at low turbulence to provide more time for the charge to dissipate

12. <u>Ignition Energy.</u> The ignition susceptibility of a fuel varies with flashpoint, pressure, temperature and specific type of fuel. The minimum energy threshold for ignition of fuel is accepted to be 0.2 millijoule (15).

[Note: Much of the above information is from Army Field Manual FM 10-67-1 Concepts and Equipment of Petroleum Operations, April 1998].

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ANNEX F Victim Characteristics - Ordnance

F1. GENERAL

1. Ordnance is the explosive or pyrotechnic component or subsystem of a land, sea, air, or space system [16]. Explosive subsystems are used for many purposes including store ejection from aircraft, escape systems, rocket motors, and warhead ignition. Ordnance subsystems encompass weapons, rockets, explosives, electrically initiated devices, squibs, flares, igniters, explosive bolts, electric primed cartridges, destructive devices, and jet assisted take-off bottles. Some ordnance subsystems contain an electrically initiated device as either the main or secondary explosive mechanism.

F2. ELECTRICALLY INITIATED DEVICES

1. An electrically initiated device (EID) is a component of an ordnance subsystem which is activated through electrical means and has an explosive, pyrotechnic, or a mechanical output resulting from an explosive or pyrotechnic action, and electrothermal devices having a dynamic mechanical, thermal, or electromagnetic output [16]. (Mil-Std-464) There are many different types of EIDs used in ordnance subsystems, such as hot bridgewire, exploding bridgewire, semiconductor bridge, carbon bridge, conductive composition, exploding foil initiator, fusible link, and laser-initiated devices. EIDs perform a variety of functions within the ordnance subsystem including initiating rocket motors, arming and detonating warheads, and ejecting chaff and flares.

2. EIDs are designed to be initiated by electric current. Most EIDs employ a small resistive element called a bridgewire. When an EID is intentionally fired, a current pulse is passed through the bridgewire, causing heating and resultant initiation of the explosive charge. Non-bridgewire types of EIDs are being increasingly used for many ordnance applications. The electrothermal behavior of these devices differs considerably from bridgewire devices, many of which have much faster response times and exhibit non-linear response characteristics.

F3. ORDNANCE SUBSYSTEMS

1. Firing circuits are another important component of an ordnance subsystem. A firing circuit generally consists of a power source, transmission line or connecting wires, and the switching circuits required to transfer firing energy to the EID.

2. Ordnance subsystems are categorized by whether the firing circuits are energized or nonenergized, and whether or not the EID is in-line with the main explosive train. An energized firing circuit has electrical power applied to its components. Adverse effects can occur whether or not power is applied to the firing

circuit, but energizing a firing circuit can impact the coupling of energy to the EID by altering the electrical path by opening and closing circuits. In addition, RF energy can be coupled easily into circuit components such as relays and micro-switches of energized firing circuits, causing energy to be applied to the EID.

3. An ordnance subsystem with an in-line EID is one in which the EID is always aligned with the main explosive train that it is intended to initiate. Consequently, if the EID should be accidentally initiated by electromagnetic energy, the device in which it is employed will be initiated. In some applications the EID may be initiated automatically upon receipt of signals from timers or sensors that respond to stimuli experienced during the launch cycle of the ordnance system.

4. An out-of-line EID is either not aligned with the main explosive train, or a mechanical shutter interrupts the explosive train. Also, the EID firing circuit may contain EID driven switches or rotors that will interrupt the continuous electrical path to the power source. Typically, this design is used in warhead fuses or rocket motor arm/fire devices. Firing of this device before the EID is put in-line will not cause a catastrophic failure, but will render it incapable of performing its mission.

5. Safe and arm (S&A) circuits also play an important role in determining the consequence of firing an EID contained in an ordnance subsystem. An S&A device prevents fuse arming until an acceptable set of conditions has been achieved, and subsequently effects arming and allows functioning. S&A devices are designed with safety features that, in most instances, prevent an immediate catastrophic event. Most EIDs used in an S&A device either remove or disable a safety feature, or dud the S&A device if it is fired out of sequence. In some instances, an EID, which is normally used to remove a safety feature in the immediate post-launch environment, will dud the S&A (and the ordnance item) if it is initiated prematurely.

F4. STOCKPILE TO SAFE SEPARATION

1. Ordnance progresses through six stages that begin after the ordnance is manufactured and continue until it is expended or reaches a safe distance from the launch vehicle/platform [17]. (This progression is sometimes referred to as the stockpile-to-safe separation sequence). These stages are:

a. Transportation/storage - The stage in which the ordnance is packaged, containerized, or otherwise prepared for shipping or stored in an authorized magazine area.

b. Assembly/disassembly - The stage where the ordnance is subjected to a build-up and/or breakdown process and requires personnel involvement to perform such procedures.

c. Staged - The stage where the ordnance has been prepared for loading and is prepositioned in a designated staging area.

d. Handling/loading - The stage where physical contact is made between the ordnance item and personnel, metal objects or structures during the process of preparing, checking out, performing built-in tests, programming/reprogramming ordnance data, installing, or attaching the ordnance item to its end-use platform (e.g., aircraft, launcher, launch vehicle, or personnel). These procedures may involve making and/or breaking electrical connections, opening and closing access panels, removing/installing safety pins, shorting plugs, clips, and dust covers. This configuration also includes all operations required for unloading (i.e., removing, disengaging, or repackaging) the ordnance item.

e. Platform-loaded - The stage where the ordnance item has been installed on or attached to the host platform and all loading procedures have been completed.

f. Immediate post-launch - The stage where the ordnance item has been launched from its platform, but has not reached its safe separation distance with regard to the actuation of its explosives, pyrotechnics, or propellants. (The safe separation distance is the minimum distance between the host platform and the ordnance, beyond which the hazard risk to the delivery system and its personnel resulting from the functioning of the ordnance are minimal).

2. There may not always be six distinct stages. For example, assembly/disassembly of the ordnance item may not be required once the item leaves the factory.

F5. INADVERTENT INITIATION

1. Although EIDs are designed to be initiated on command by an electric current, any type of electromagnetic energy which flows in the bridgewire (or other electrothermal element) of an EID will also cause heating of the element. Ordnance subsystems that include EIDs can function accidentally or be affected by the unintentional exposure to stray electromagnetic energy. A large number of these devices are initiated by low levels of electromagnetic energy and are susceptible to unintentional ignition by many forms of direct or induced stray electromagnetic energy, such as from lightning discharges, electrostatic effects, the operation of electrical and electronic subsystems onboard weapon systems, and RF energy due to ground and airborne emitters (transmitters).

2. Mishaps have occurred where induced currents from nearby have initiated EIDs and even distant lightning strikes.

3. Hazards from static electricity to EIDs contained in ordnance items occur mainly in ground operations. Some airborne incidents attributed to static electricity probably

were due to induced effects from lightning strikes or to stray energy from onboard equipment.

4. Stray energy, such as transients and other forms of induced energy, can be imposed on circuits affecting EIDs from other subsystems by various methods. Examples are inductive or capacitive coupling from other cabling; sneak ground circuits; defective components or wiring; errors in design, modification, or maintenance.

5. EIDs may be initiated by exposure to radiated fields of R-F emitters. The degree of susceptibility depends on many variables. These variables are the threshold firing level of the EID; the ability of the leads, circuit, or installation to capture R-F energy; the type and characteristics of R-F energy, and methods of coupling which can introduce this energy into the EID (18).

6. The aircraft, launcher (if required), and interface cables associated with a particular ordnance subsystem can have a pronounced influence on the response of the EIDs. The combined ordnance/aircraft configuration is distinctly different from the isolated ordnance item, due to differences in the size, geometry, and interface of the constituent elements. This unique configuration can produce additional and more efficient coupling paths, especially at the lower frequencies. If there are paths for electromagnetic energy to couple into the EID, the installation on an aircraft can alter the distribution of currents in the vicinity of discontinuities on the ordnance enclosure, thereby altering penetration into the enclosure.

F6. CONSEQUENCES

1. There can be two potentially negative outcomes as a result of ordnance subsystems being exposed to extraneous electromagnetic energy:

a. The EID can be initiated either by energy coupling directly into the device or by an energized firing circuit being triggered and sending an erroneous firing signal the EID. This can have negative consequences on safety or reliability. It can result in premature initiation of explosive trains or render the subsystem incapable of performing its mission since, once initiated, the EID can no longer perform its intended function.

b. The performance of the EID can be degraded by energy being coupled directly into the device. In this case the ignition properties can be altered, without actually firing the EID, by the presence of the electromagnetic energy so that it cannot function when a design stimulus is received.

ANNEX G Victim Characteristics - Electronic Systems

G1. GENERAL

1. Modern electronic systems are very dense and complex assemblies which operate at high speed and function at low voltage levels. They are designed with integrated circuits that contain millions of transistors and millions of metal interconnects. With critical dimensions less than 1 micrometer, these devices are extremely fragile. As the level of integration increases so does their potential vulnerability. If not suitably protected, they are increasingly sensitive to various transient phenomena and may be susceptible to upset and damage by very small levels of electromagnetic energy.

G2. DAMAGE AND UPSET

1. The threshold level for equipment/ subsystem damage is a function of dielectric breakdown (high voltage effect), high temperature damage (high power effect), or a combination of both. Voltages of a few tenths of a volt and an impulse can affect integrated circuits less than one microjoule can cause damage when directly injected onto sensitive circuits. However, since direct injection is unlikely on the flight line, a coupling factor of approximately 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.

2. The approximate range of the threshold for damage of various electronic components is indicated in the following table [(19)].

COMPONENT TYPE	ENERGY LEVEL (Joules)
Relay	10^{-3} to 1
Resistor	10^{-3} to 1
Rectifier Diode	5 x 10^{-4} to 0.5
Medium/High Power Transistors	10^{-4} to 0.1
Low Power Transistors	5.0 x 10^{-6} to 10^{-2}
Integrated Circuits	10^{-7} to 10^{-3}
Microwave Diodes	10^{-7} to 10^{-4}

TABLE G-1 DAMAGE THRESHOLD

3. System damage or upset from RF energy is caused by currents and voltages induced in conductors or coupled to circuits. External conductors, enclosures, and internal conductors act as unintentional receiving antennas and “coupling” paths. They can deliver the resulting RF induced currents and voltages to sensitive components of electronic equipment. Electromagnetic energy such as transients and other forms of induced energy, can be imposed on circuits from other subsystems by various methods including inductive and capacitive coupling, and ground loops. Electrostatic discharge from human contact will cause damage. Since an ESD event is a high frequency phenomenon, there does not have to be a direct discharge to the component. The energy can be coupled to the device by conduction or radiation.

4. Intermittent or upset failures occur when equipment and subsystems are operating and are characterized by loss of information or malfunction. Correct operation usually resumes after the energy source is removed or, in the case of digital circuits, after the equipment/subsystem is re-set or re-initialized.

5. Equipment/subsystem function is upset when extraneous voltages and/or currents exceed the signal levels in the electronic circuits. These extraneous voltages and currents (or noise) are the result of conducted or radiated emissions which couple into the circuitry through various coupling mechanisms.

6. While upset failures occur when the equipment is operating, damage or hard failures can occur at any time. Voltages and currents necessary to cause damage are typically one to two orders of magnitude greater than those required to cause upset.

7. The exposure to these signals may cause marginal damage to components and result in latent failures.

8. Catastrophic failures can be the result of electrical overstress of electronic parts caused by a discharge from a person or object, an electrostatic field, or a high voltage spark discharge. Equipment and subsystems undergoing maintenance on the flight line can be especially vulnerable since enclosures will be opened and assemblies exposed to the environment.

ANNEX H Victim Characteristics – Electrical Power Systems

H1. GENERAL

1. The two basic electrical systems used on aircraft are: 28 volts, direct current (DC) and 115 volts alternating current (AC) at 400 hertz. The 28 volt system is a two-wire system with the negative side connected to the aircraft structure. The 115 volt system is a four-wire system consisting of phases A, B, C, and neutral (N), with the neutral wire connected to the aircraft structure. Electrically powered equipment is replacing conventional equipment, which depend on pneumatic, mechanic and hydraulic power, under a concept known as the More Electric Aircraft (MEA). To cope with the increased electrical demand, 270 VDC power sources are being incorporated into modern aircraft designs.

2. Since it is not practical to run the aircraft engines for electrical power while on the flight line, the required AC and a generator external to the aircraft supplies DC power. These Ground Power Units (GPU) may be fixed and mains-driven or mobile and engine-driven. They can supply 1000 A DC and 90 kVA or more. The generators are mounted on either a self-propelled chassis or a trailer chassis, both on rubber tires. The mains-driven generator is connected to a 50 hertz or 60 hertz main system and the supply cable includes a safety ground wire which is connected to the generator chassis.

H2. POWER SYSTEM GROUNDING

1. Electrical power systems can be described by the nature of the connection of the system to the facility ground system. If the power system neutral or a phase conductor is not connected to ground, the power system is classified as floating or ungrounded. A variation of the ungrounded power system is to make the connection to ground using a high impedance connection. The main advantage to this type of power system is continuity of service. A ground fault will not result in the circuit or system being removed from service, and thus allows critical equipment to function while the fault is located and removed. (A requirement for this type of system is the incorporation of a ground detector for the immediate notification of a ground fault).

2. In contrast, a grounded power system has the neutral lead (usually) or one of the phase conductors connected to the facility ground (and hence the earth mass), and as soon as there is a phase-to-ground fault the circuit breaker or other protective device will function removing the circuit from service.

H3. SHIPBOARD POWER

1. Naval primary shipboard electrical power is provided by a 440 VAC, 50 Hz or 60 Hz, three phase, delta connected, ungrounded power system. Other electrical service requirements are derived from this main system. 120 VAC, 50 Hz or 60 Hz ungrounded service is provided through the means of an auto-transformer or an isolation transformer. Three phase, four wire, wye connected, and grounded 400 Hz power is provided for aircraft and aviation support equipment aboard naval vessels by means of a motor-generator set or a solid-state frequency changer.

2. Shipboard ungrounded power systems have large service distribution sub-systems and hence are not completely isolated from ground. A virtual AC ground exists due to the capacitance of equipment, cables, and EMI filters. Because of this virtual ground, potential hazards exist since lethal currents could flow through a person's body if a live conductor is touched while in contact with the ship's ground. Thus, even with this type of generation and distribution system a grounding wire is required on all metallic, non-current carrying parts of powered equipment. This grounding wire provides protection in a different manner compared to the grounding connection in a "grounded" system. It has a shunting action thus reducing the amount of current that would otherwise flow through the person.

H4. FAULTS

1. A power system fault is either a direct short or an arc (either continuous or intermittent) in a power distribution system. These faults occur when the high voltage side of an external power connection is brought into contact with the airframe. The main reason for this occurrence is an internal misswiring of the connector plug, backward attachment of the connector, or component failure. When the fault occurs, the entire airframe could be at power line potential of 115 volts AC or 28 volts DC.

2. These faults can be hazardous to personnel since:

a. fault currents flowing in the ground system may cause the chassis of grounded equipment to be at a hazardous potential above ground,

b. the energy in a fault arc can be sufficient enough to present a severe burn hazard to personnel,

c. there is a fire hazard associated with any short circuit or arc, and

d. burning insulation can be particularly hazardous because of the extremely toxic vapors and smoke which may be produced.

3. If there is failure or deterioration in component or equipment insulation, leakage currents will flow. In some instances these leakage currents will not be high enough to damage equipment or trip circuit breakers but will be high enough to pose a hazard to personnel.

4. System capacitance is an inherent characteristic of all AC systems. When a voltage is applied to the system, a small current flows to ground through this capacitance. For a balanced, three phase, wye connected system, the magnitude of the current in the three phases is equal and displaced by 120 degrees. Conditions change when a ground fault occurs on an ungrounded system. The fault will short out the capacitance on the phase that is grounded and no charging current will flow in that phase. The voltage to ground on the other two phases increases by a factor of 1.73. The phase angle between the two unfaulted phases decreases to 60 degrees and the vector sum of the resultant system charging current results in three times the original system charging current per phase. If the fault is not detected and cleared, low level line-to-ground fault arcing can continue to charge the system capacitance and the resultant line-to-ground voltage can approach six times the rated voltage. This sustained overvoltage condition can break down cable insulation or exploit existing insulation weaknesses, and result in another phase to ground to phase. This second fault has high levels of ground fault current and voltages which can cause arcing and flash hazards, injury from explosion, shock, flying solid or liquid metal, or fire [(20)].

H5. GPU CONFIGURATIONS

1. STANAG 3457 requires that the AC Neutral (DC Negative) of the Ground Power Unit as well as the associated control circuitry not be normally connected to the ground power system chassis or framework. This is “for the safety of ground power applications and the protection of aircraft ground power equipment”. The STANAG also requires that “provision be made to accommodate electrical safety connections between the aircraft and ground support equipment” and that the Ground Power Unit be equipped with current interruption to prevent current overload” of the generator.

Note: When the AC Neutral (DC Negative) lead of the GPU is connected to the GPU chassis, the chassis of the GPU is also connected to the airframe by means of the AC neutral and/or the DC negative leads. Since there is then return current in the Neutral (DC Negative) lead, the airframe will be at a slightly higher potential than the GPU chassis.

2. The practices in this regard appear to be inconsistent. In some instances the GPU AC Neutral (DC Negative) is connected to the chassis, while in other instances it is not. Power from a facility power distribution system and as such will have its chassis connected to earth through the main electrical (input power) cable as required by the safety code.

3. <u>No connection between Neutral (DC Negative) and chassis</u>. In essence this is an ungrounded or floating power distribution system. When connected to the aircraft there is no hard connection to earth.

4. If a single fault occurs at the aircraft (one phase in contact with the airframe) it will be cleared by the circuit interrupters since the airframe is also connected to GPU Neutral via the Neutral (DC Negative) lead. There would be no danger from

leakage currents (insulation damage) if personnel made contact with the aircraft since there would be no return path to the GPU neutral point. This would be true even if the individual came into contact with both the GPU chassis and the aircraft. This is true even if aircraft were grounded/ connected to earth

5. If a single fault occurs at the chassis of the GPU, it will not be cleared by the current interrupters since there is no path between the chassis and the GPU neutral point.

6. A GFC if installed would shut down the GPU.

7. Since the GPU chassis is grounded, an individual standing on the parking apron and touching the aircraft would receive a shock. (An exception would be the insulated flight deck of a ship, although if personnel would receive a shock if they touch both the aircraft and a metal part of the ship).

8. If the GPU chassis is bonded to the aircraft, the circuit interrupters will operate and shut down the GPU since there now is a return path from the chassis to the GPU neutral point through the bond wire and the AC Neutral (DC Negative). Note: The bond wire is usually intended to equalize electrostatic potential and as such to carry small currents. Power Fault currents could be quite large and cause overheating of this wire. Using this bond wire also connects the aircraft to earth.

9. Connecting the aircraft to ground would also provide a return path between the chassis and the GPU neutral point. Shipboard this would definitely cause the current interrupters to function. At facilities with an earth electrode subsystem the interrupters would also function, but at other facilities it would depend on the resistance of the return path through the earth.

10. <u>Connection between GPU neutral point and chassis.</u> A GFCI could be used with this configuration, but there cannot be a bond from the aircraft to the GPU chassis or a connection from the aircraft to earth (since GPU chassis is already connected to earth).

11. A GFC would not function with this configuration.

12. If there is a fault at either the GPU chassis or the aircraft, it will be cleared by the GPU current interrupters.

13. If there is leakage current not great enough to trip the interrupters, and there is no GFCI, then there could be a shock hazard to personnel.

14. <u>Non-Mains (Engine) Driven GPU.</u> The engine driven GPU does not have its chassis inherently connected to a ground system or earth.

15. <u>No connection between Neutral (DC Negative) and Chassis</u>. In essence this is an ungrounded or floating power distribution system. When connected to the aircraft there is no hard connection to earth.

16. Since the GPU Neutral (DC Negative) point is isolated from the chassis, the GFCI would not function if there were a (soft) fault at the chassis or the airframe.

17. If a single fault occurs at the aircraft (one phase in contact with the airframe) it will be cleared by the circuit interrupters since the airframe is also connected to GPU Neutral via the Neutral (DC Negative) lead. There would be no danger from leakage currents (insulation damage) if personnel made contact with the aircraft since there would be no return path to the GPU neutral point. This would be true even if the individual came into contact with both the GPU chassis and the aircraft. This is true even if either or both the GPU and aircraft were grounded/ connected to earth.

18. Since there is no voltage between the GPU chassis and the Neutral (DC Negative) a GFC, if installed, would not function.

19. If a single fault occurs at the chassis of the GPU, it will not be cleared by the current interrupters since there is no path between the chassis and the GPU neutral point.

20. A GFC if installed would shut down the GPU.

21. Since the GPU chassis is not grounded, an individual standing on the apron and touching the aircraft would not receive a shock.

22. If the GPU chassis is bonded to the aircraft, the circuit interrupters will operate and shut down the GPU since there now is a return path from the chassis to the GPU neutral point through the bond wire and the AC Neutral (DC Negative) lead. Note: The bond wire is usually intended to equalize electrostatic potential and as such to carry small currents. Power Fault currents could be quite large and cause overheating of this wire.

23. Connecting both the GPU chassis and the aircraft to ground/earth would also provide a return path between the chassis and the GPU neutral point. Shipboard this would definitely cause the current interrupters to function. At facilities with an earth electrode subsystem the interrupters would also function, but at other facilities it would depend on the resistance of the return path through the earth.

24. <u>Connection between GPU neutral point and chassis</u>. A GFCI could be used with this configuration, but cannot bond the aircraft to the GPU chassis or connect the both the GPU chassis and the aircraft to earth.

25. A GFC would not function with this configuration.

26. If there is a fault at either the GPU chassis or the aircraft, it will be cleared by the GPU current interrupters.

27. If there is leakage current not great enough to trip the interrupters, and there is no GFCI, there is no shock hazard to personnel if neither the GPU chassis nor the

aircraft is grounded (unless the individual is in contact with both the chassis and the aircraft).

28. If there is leakage current not great enough to trip the interrupters, and the GPU chassis is grounded/ earthed, there is a possible shock hazard to personnel in contact with the aircraft if the leakage fault is at the aircraft.

ANNEX I ENERGY SOURCES - ELECTROSTATIC

I1. GENERAL

1. Electrostatics involves wide ranging, complex physical phenomena and associated events. There are two events for a body that can result in an electrostatic charge:

a. electrons can move or migrate within a body resulting in polarization (this can occur even when a single body has a net overall charge of zero), and

b. the transfer of electrons from one body to another (conductive charging) resulting in a net positive or negative charge.

2. The movement or transfer of electrons is due to the interaction of charged and/or uncharged bodies. The magnitude of the charge is primarily dependent on the size, shape, composition and electrical properties of the substances which make up the bodies. Some substances readily give up electrons while others tend to accumulate electrons. A body with an excess of electrons is charged negatively; a body with an electron deficit is charged positively. When two substances of any type are contacted or rubbed together, one substance gains electrons and the other loses electrons. This results in each substance becoming charged. When the two materials are subsequently separated, the net positive or negative charge on each substance can be measured. These charges are equal, of opposite polarity, and in the case of non-conductors tend to remain in the localized area of contact. Charges on a conductor are rapidly distributed over its surface and the surfaces of other conductive objects which it contacts [(21)].

I2. ELECTROSTATIC CHARGE.

1. Stored electrostatic energy results from the separation and accumulation of electric charges (of opposite polarity) kept apart by an insulator. Work is performed to separate the charges and the energy is stored in the capacitance of the body on which the charges are placed.

2. The primary mechanism of charge separation is contact electrification (or triboelectric charging) where two materials come together and then separate carrying opposite and equal charges. Contact electrification can occur at the interface of two solids, two liquids, and a solid and a liquid. (Although gases are not charged by this mechanism, a gas can carry an electrostatic charge if suspended particles are charged by contact electrification).

3. This mechanism of material contact, electron transfer, and separation is a complex physical process. The amount of charge that is accumulated on each body involved in the charging process is affected by their relative position in the triboelectric

series, the area of contact, the speed of separation, relative humidity, as well as other factors. Relative motion between two bodies increases the area of contact and generates heat due to frictional effects, which further enhances the charge separation process.

4. Capacitance. The ability of a body to accumulate electrostatic charge is determined by its capacitance. The capacitance is a function of many variables. If a charge has accumulated on a body, it will develop a potential difference with respect to another body. Potential difference, charge, and capacitance are related by the mathematical expression

$$V = Q / C$$

Where: V is the voltage (in volts) developed between the bodies,
Q is the amount of charge (in coulombs), and
C is the relative capacitance of the bodies (in farads).

5. Familiar examples of charge separation and accumulation occur as one walks across a carpet and the shoe contacts and then separates from the carpet surface or as one slides across a vinyl seat when exiting an automobile. Charge accumulates on the human body, and energy is stored in the body capacitance. Shock is felt when a metal object such as a doorknob or automobile is touched and the energy stored in the capacitance is discharged.

6. Induction. An electric field exists around a charged body, and conductive materials placed near a highly charged surface will experience a separation of opposite charges under the influence of the field. The field will attract charges of similar polarity, while the field will repel charges of opposite polarity. This conductive body will develop a voltage potential dependent upon its position in the field and relative to the original charged body. The conductive body because of its potential and the separated charges is capable of an electrostatic discharge(14).

7. If the conductive body, while still in the electric field, is momentarily connected to earth (grounded) the charges, which are repelled by the field, will flow to earth. When the earth connection is removed, a charge imbalance exists, and when the conductive body is removed from the field, a net charge remains on the body. This net charge is referred to as an induced charge.

8. Charge Transfer. When a charged body is connected to or otherwise makes contact with an uncharged body, the charge is shared between them in portion to their relative capacitances. This is a potent source of electrostatic charging when charged sprays, mists, or dusts impinge upon a solid object(14).

I3. MATERIAL CHARACTERISTICS

1. Virtually all materials, including water and dirt particles in the air, can be triboelectrically charged. How much charge is generated, where that charge goes, and how quickly, are functions of the materials' electrical characteristics.

2. Insulators. A material that prevents or limits the flow of electrons across its surface or through its volume is called an insulator. Insulators have an extremely high electrical resistance. A considerable amount of charge can be generated on the surface of an insulator. Because an insulative material does not readily allow the flow of electrons, both positive and negative charges can reside on insulative surface at the same time, although at different locations. The excess electrons at the negatively charged spot might be sufficient to satisfy the absence of electrons at the positively charged spot. However, electrons cannot easily flow across the insulative material's surface, and both charges may remain in place for a very long time.

3. Conductive Materials. A conductive material, because it has low electrical resistance, allows electrons to flow easily across its surface or through its volume. When a conductive material becomes charged, the charge (i.e., the deficiency or excess of electrons) will be uniformly distributed across the surface of the material. If the charged conductive material makes contact with another conductive material, the electrons will transfer between the materials quite easily. If the second conductor is attached to an earth grounding point, the electrons will flow to ground and the excess charge on the conductor will be "neutralized."

4. Electrostatic charge can be created triboelectrically on conductors the same way it is created on insulators. As long as the conductor is isolated from other conductors or ground, the static charge will remain on the conductor. If the conductor is grounded the charge will easily go to ground. Or, if the charged conductor contacts or nears another conductor, the charge will flow between the two conductors.

5. Static Dissipative Materials. Static dissipative materials have electrical resistance between insulative and conductive materials. There can be electron flow across or through the dissipative material, but the surface resistance or volume resistance of the material controls it.

6. As with the other two types of materials, charge can be generated triboelectrically on a static dissipative material. However, like the conductive material, the static dissipative material will allow the transfer of charge to ground or other conductive objects. The transfer of charge from a static dissipative material will generally take longer than from a conductive material of equivalent size. Charge transfers from static dissipative materials are significantly faster than from insulators, and slower than from conductors.

I4. ELECTROSTATIC CHARGE DISSIPATION

1. Electrostatic discharge, which accumulates on conductive bodies, will dissipate, or recombine with charges of opposite polarity, at a rate determined by the resistance of the system. Charge will leak from the system at a rate determined by the time constant $\tau = RC$, known as the charge decay time or the relaxation time. The dissipation process is exponential and is described by the following equation:

$$Qt = Q0\text{-}t/\tau$$

where: Qt = charge at time t (coulombs),
Q0 = charge at time t = 0 (coulombs),
t = elapsed time (seconds),
τ = system time constant (seconds),
R = resistance through which charge relaxation occurs (ohms), and
C = capacitance of the system.

2. If the rate at which the charge accumulates exceeds the rate at which it is dissipated, the conductive body will reach a potential equal to

$$V_{max} = IR$$

Where: I = Q / t = electrostatic charging current.

For a system to maintain a significant accumulated electrostatic charge after the charging mechanism has ceased, the resistance of the system must exceed at least one megohm.

3. An electrostatic charge on a non-conductor will be retained by virtue of the resistance of the material itself.

I5. ELECTRICAL PARAMETERS

1. Aircraft have electrical properties similar to resistors and capacitors. An aircraft on the flight line can be modeled by a capacitance to earth connected in parallel with a resistance.

2. The capacitance of fixed wing aircraft was found to be a fairly consistent parameter. Values up to 0.005 microfarads were measured over a wide range of aircraft types and ground plane materials. The capacitance of a helicopter is usually assumed to be 0.001 microfarad.

3. The resistance of aircraft is determined by a combination of the resistance of its tires, the resistance of the runway surface, and the contact resistance between the runway surface and the tires. Aircraft resistance is a highly variable parameter. As a tire wears, its resistance increases due to the breaking of the carbon black chains. The load on the aircraft and the pressure of the tire affect the resistance of the aircraft by

affecting the tires' contact with ground. The runway material is also a factor in the resistance of the aircraft to the ground.

4. On typical asphalt and concrete runway surfaces, values of aircraft resistance ranging from .001 megohm to 100 megohm have been measured[(22) (23)].

[Note: The Rubber manufacturers Association in its Aircraft Tire Information Service Bulletin Volume 1/ Number 1 dated October 1991, cautions operators concerned about the dissipation of static electricity from aircraft not to rely on tires to dissipate static electricity.]

5. For the purpose of describing the accumulation and dissipation of electrostatic charge, the human body can also be modeled using the electrical parameters of capacitance and resistance. The particular values used depend on the standards authority. Typically the values assigned for capacitance range from 100 picofarads to 500 picofarads and for resistance from 150 ohms to 1500 ohms. The human body model (HBM) used for the purposes of ESD/EOS testing is a capacitor of 500 picofarads discharging through a resistor of 1500 ohms. The selected values for Mil-Std-883 Test Method 3015 is 100 picofarads and 1500 ohms, while Mil-Std-464 prescribes discharging a 500 picofarad capacitor through a 500 ohm resistor for ordnance testing.

6. These electrical parameters are summarized in the following table:

Characteristic	Value
fixed wing aircraft capacitance	0.005 µF
helicopter capacitance	0.001 µF
aircraft resistance	100 MΩ
human body model capacitance	0.0005 µF
human body model resistance	150 Ω to 1500 Ω

TABLE I-1 ELECTRICAL CHARACTERISTICS

I6. ELECTROSTATIC DISCHARGE

1. As electrostatic charge accumulates voltages and electric fields increase. When the electric field strength between two bodies exceeds the insulating properties (dielectric strength) of the atmosphere an electrostatic discharge will occur where there is a sudden recombination of separated charges. There are various types of electrostatic discharges with different characteristics and incendive energies. A release of electrostatic energy can be in the form of a spark discharge, corona discharge, brush

discharge, or propagating brush discharge. (There are other types of electrostatic discharge but they are not of concern to conditions on the flight line).

2. Spark Discharge. A spark discharge occurs between conducting bodies when the field strength between them exceeds a level known as the dielectric breakdown strength. (The breakdown strength depends on gap width and radius. For objects with a large radius separated by greater than 10 mm the breakdown value is approximately 3x103 kV/m, and increases somewhat as the gap decreases). A spark discharge is characterized by a well-defined luminous discharge channel that carries a high density current. The discharge is very rapid and is often accompanied by an audible crack. If the bodies concerned in the discharge are conductors, almost all the charge will be drawn into the spark, in which almost all the available energy will be dissipated.

3. Corona Discharge. The corona discharge occurs from charged conductive surfaces with a small radius of curvature such as sharp edges, points, and wires. It may be directed towards another body or it may be dissipated into the atmosphere. It is characterized by a hissing sound and is sometimes accompanied by a faint luminosity. The energy density is much less than in a spark discharge(14).

4. Brush Discharge. The brush discharge occurs between a charged non-conductor and a conductor. It takes the form of short luminous bursts from discrete areas of the surface of the non-conducting body. The localized energy density in this type of discharge can be high enough to be incendive.

5. Propagating Brush Discharge. The propagating brush discharge occurs from an insulator in sheet form which has high levels of charges with opposite polarities on its two surfaces. Often a conductor backs the sheet. If a conductor approaches the insulative surface the resultant electrostatic field promotes ionization across a large area of the surface. A discharge occurs in which the charge from an extensive area of the non-conductor sheet rapidly flows to the initial discharge point through the ionized gas adjacent to the surface. The result is an intense and high energy density discharge that can be very dangerous.

I7. CHARGE GENERATION MECHANISMS

1. The various charge generation mechanisms interact with the electrical parameters to establish the actual electrostatic potential levels and time duration for the hazardous voltages.

2. Triboelectric Effects. Contact electrification depends upon an excess or imbalance of electrical charge, which may be produced by the transfer of charge when two materials are brought together and then separated or rubbed together. It is well known that as an aircraft in motion encounters dust, rain, snow, and ice crystals that an electrostatic charge is built up on the airframe. However, electrostatic charges and hence relatively high electrostatic voltages, can result from interaction at the contact surfaces of various materials in any type of relative motion; e.g., wind-blown snow or dust particles striking a parked aircraft.

3. TO 1-1-3, paragraph 2-4.1, states that ”some common means of generating static charges are a person removing clothing, dust blowing across a surface or liquid flowing through a pipe". The Glossary of Meteorology, American Meteorological Society, under the definition of electrical storm indicates that “triboelectrification due to blowing dust may charge fences and other metallic objects to such an extent that slight shocks are felt upon touch". P. Guest in the Bureau of Mines (US Department of Commerce) Bulletin #368 describes sand storms in west Texas where severe shocks are sometimes received from radio antennae, fence wires, and automobiles. He also states that if the definition of dust as “fine, dry particles of matter” is accepted, then “it may not be out of place to consider blizzards in this connection”. He has observed support wires in a snowstorm “be so charged as to give sparks”. AFOSH Standard 91-38 states “support equipment can develop charges of static electricity while parked due to the movement of dust particles and air currents or during periods of electrical storm activity in the vicinity”.

4. It is estimated that, for a moderate wind-blown dust situation, an electrical current of 30 microamperes (µA) is possible on parked aircraft. If an aircraft with a resistance of 100 megohm (worse case) is not connected to earth, airframe electrostatic potentials of 3000 volts can appear. These voltages dissipate to earth through the aircraft resistance once the charging source ceases.

5. <u>Friction.</u> Electrostatic charge generation is enhanced by close moving (frictional) contact between two materials. The magnitude of the electrical charge is dependent upon the type of materials involved and the amount of humidity that is present. With synthetic materials, (such as nylon) undergoing friction in a cold, dry climate, the charge effect is even greater.

a. (1) Human Body Model. There is a continuous generation of charges in the clothing of a moving person especially during the action of removing garments. If a person contacts external objects, charges can also be produced on the outside of garments.

(2) 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. The only effect is to create an attraction between the layers of clothing or cause the garment to cling to the skin. However, if the outer garment is removed, a charge of up to 27 kV can be formed on the surface of the newly exposed clothing.

b. (1) Fuel Flow. During the fueling process, the passage of fuel from the supply vehicle through the fueling hose to the aircraft provides a mechanism for the accumulation of electric charge. This is a common occurrence when liquid is being moved through pipes, mixed, poured, pumped, filtered, or otherwise agitated. Other causative processes include the settling of solids or immiscible liquid through a liquid, the ejection of particles or droplets through a nozzle, and the splashing of a liquid against a solid surface.

(2) The friction effect between the moving fuel and fuel filter, hose, and other surfaces results in charge separation and a consequent buildup of electrostatic charges. Since fuel is normally an excellent insulator, the flowing fuel to a distant location easily removes separated charges. As this charged stream enters the fuel tank, charge separation will occur. A charge equal in magnitude to the charge on the fuel, but of opposite sign, will be induced on the inside surface of the tank, and a charge of the same sign as the incoming fuel will be left on the outside surface of the fuel tank and the airframe.

(3) Field strengths of several hundred kilovolts per meter have been observed in the fuel tanks of aircraft(22) and in some instances field strengths in the range of 500 kilovolts per meter have been recorded(24). These field strengths decay essentially to zero within a minute after the flow of fuel is stopped. Fuel conductivity was 2-3 picosiemens/meter for these tests.

(4) During fuel transfer, the separation of charge can result in an electric current of 13 microamperes(22). The current is dependent on the rate of fuel flow. Tests performed by the US Navy(24) showed that the current was 1.4 microamperes at 120 gallons per minute (gpm) and 7.5 microamperes at 400 gpm. Similar results were obtained in the CRC study(5).

(5) If the refueller and the aircraft are not bonded the electrostatic potential developed on the aircraft will be dependent on the grounding conditions. For an aircraft on an asphalt or concrete surface and an aircraft resistance of 100 MΩ the potential developed would be:

$$V = IR = 13\mu A * 100\ M\Omega = 1300 \text{ volts}$$

and the stored electrostatic energy is

$$U = ½\ CV2 = ½ * 0.005\mu F * (1300V)2 = 4.25\ mJ$$

(6) Both the US Navy study(24) and the CRC study(22) simulated a refuelling operation under desert or arctic conditions where there would be little or no charge relaxation through the tires by placing the tires of the aircraft and fueller on acrylic plastic or teflon pads. The resistance to earth was between 100MΩ and 200MΩ. This condition is also similar to fuelling an aircraft on surfaces with an insulating coat such as anti-skid hangar floors and aircraft carrier decks. The electrostatic potential which developed on the aircraft was measured at 2500V. The stored energy in this case would be:

$$U = ½\ CV2 = ½ * 0.005\mu F * (2500V)2 = 15.6\ mJ$$

(7) These voltages build up on the aircraft and represent a serious danger. If these voltages arc over to points of lower potential when the right fuel-air vapor mixture is present, an explosion will occur. These examples illustrate the importance of assuring that the bonding wire is connected between the aircraft and refueling truck/hydrant and is in good condition. The bonding wire equalizes the potential between the items and eliminates any significant voltage build-up with respect to the earth.

c. Helicopters while hovering or in-flight develop very high electrostatic potentials, in the order of 300 kilovolts (16).

6. The energy levels from the electrostatic energy sources are summarized in the following table:

Potential Level of Electrostatic Energy		
Mechanism	Voltage (volts)	Energy (joules)
Triboelectric	1200 V	3.6 mJ
Atmospheric Induced	60 kV	9 J
Helicopter	300 kV	45 J
Friction – HBM	27 kV	182 mJ
Friction – Fuel Flow (100 MΩ)	1300 V	4.2 m J
Friction – Fuel Flow (Isolated)	2500 V	15.6 mJ

TABLE I-2 POTENTIAL ELECTROSTATIC ENERGY LEVELS

I8. ATMOSPHERIC ELECTRICITY

1. Atmospheric electricity refers to the collective electrical phenomena that occur in the earth’s atmosphere. These phenomena include not only such displays as lightning and St. Elmo's fire, but also the more mundane and ever present effects such as atmospheric ionization, the air-earth current, and other quiescent electrical processes. The existence of separated electric charges in the atmosphere is a consequence of many processes such as spray electrification, dust electrification, cosmic-ray ionization, radioactive-particle ionization, and thunderstorm electrification. Although the mechanisms are not completely understood, the process of thunderstorm electrification causes charge separation within a cloud, with the bottom of the cloud having a predominantly negative charge. As a result an enormous electrostatic potential can develop between different parts of the cloud and between the cloud and the earth.

2. Lightning. Lightning is a discharge of electrostatic energy from one cloud to another, within a cloud, or from a cloud to earth. The cloud to earth or ground strike is the type of discharge that produces the direct lightning strike issue for ground servicing operations. Lightning is an extremely variable phenomenon and currents up to 200,000 amperes have been recorded.

3. Induction. Electrical storms involve the relatively slow movement of electrically polarized clouds that set up an intense electrostatic field over a large area of the earth's surface beneath the cloud. This area can extend from 15 to 150 square kilometers, and the field strength has been estimated to be as high as 50 kV/m but is commonly found to reach values of between 10 kV/m and 30 kV/m [19] [25].

4. The presence of an electrostatic field between an active storm cloud system and the earth results in large induced charges on aircraft and ground servicing equipment (GSE). 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 that results in a relatively small current flow that causes no damage to the aircraft. A potential hazard arises if a sudden change in the electric field takes place (e.g., 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 high potentials from airframe to earth. If the aircraft is bonded to GSE, there will be no potential difference between them, only with respect to earth.

5. To determine the charge induced on the aircraft (or on an area of the earth for that matter), the applicable formula for the static boundary condition is:

D=E *e= surface charge density

Where: D = the electric field displacement
E= the electric field
e = epsilon zero.

For a 20,000 volt/meter field, the equation produces a surface density of 1.76 E-7 Coulombs/square meter, regardless of whether it is the earth or the aircraft. For a very large aircraft such as the C-17, the projected surface is on the order of 685 square meters resulting in an induced charge of about 1.21 E-4 Coulombs.

When the cloud suddenly discharges, this charge then appears between the capacitance of the aircraft and the earth.

6. The charge on the aircraft will also be neutralized, but at the instant the cloud is discharged it will be at a potential with respect to the earth defined by the equation:

$$V = Q / C$$

Where: V = the potential of the aircraft with respect to earth due to the accumulated charge Q

Q = the accumulated charge left on the aircraft after the cloud is discharged
C = the capacitance of the aircraft with respect to earth where the capacitance of a very large aircraft is 0.005 uF. .

Since Q and C are the same as before the strike, the initial voltage, V, on the aircraft must be equal to about 24,300 volts. The charge Q will be dissipated through the aircraft tires or a ground wire and the voltage will decrease to zero very quickly. The available energy calculates to 1.37 J, adequate to provide a good shock.
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[Note: There are several references in the literature to the indirect or secondary effects caused by thunderstorm activity. The American Petroleum Institute Recommended Practice 2003: 1998 states:

"In addition to direct-stroke lightning, the abrupt change in the electrical field caused by a lightning stroke can cause secondary sparking at equipment that is relatively remote from the direct stroke. These induced charges or sparks usually occur when an insulated metallic body is present. The metallic body initially becomes charged by means of induction at a harmlessly slow rate through its high resistance to ground. When lightning strikes nearby, this induced charge is suddenly released in a discharge to ground, which can ignite a flammable mixture".

NFPA 780 the 1997 Edition refers to this induced charge in reference to fires that have occurred in open-top floating roof tanks:

"Ignition can be from a direct stroke or from the sudden discharge of an induced (bound) charge on the floating roof, released when the charge on a cloud discharges to ground or to another cloud".]

I9. DISCHARGE TIME

1. Because of the nature of the charging mechanisms, it is not possible to control the generation of electrostatic charge. This generation of charge by itself does not produce discharges. A high electrostatic potential is required and this will only happen when charge that has been generated accumulates.

2. Electrostatic charges continually leak away or dissipate from a charged body. The dissipation begins as soon as a charge is generated and will continue after generation has stopped. Electrostatic charges accumulate when they are generated at a higher rate than they dissipate. The rate of dissipation is determined by the resistance in the path needed for the recombination of the charges.

3. The accumulated electrostatic charge on an aircraft and ground servicing equipment will be present and therefore a hazard as long as the charging mechanism is present. The charge will dissipate quickly through the aircraft tires after the charging mechanism ceases.

4. A capacitor will discharge through a resistor exponentially with time. The time required for an aircraft with an accumulated charge to discharge to a specific voltage is given by:

$$T = RC \ln (V_o / V_s)$$

Where: T = time to reach V_s after charging mechanism ceases
R = aircraft resistance to earth
C = aircraft capacitance to earth
V_o = electrostatic potential on aircraft (caused by charging mechanism)
V_s = specific voltage level

5. The following table shows the possible aircraft voltages and times to dissipate the accumulated electrostatic charge with the various aircraft resistances to the 1 mJ threshold of sensation (632 volts for an aircraft with capacitance of 0.005 uF).

Charging Mechanism	R = 100 MΩ		R = 200 MΩ		R = 10 KΩ	
	V_o	T	V_o	T	V_o	T
Triboelectric	3000 V	1.1 sec	6 kV	2.2 sec	300 mV	-
Induced	25 kV	1.8 sec	25 kV	3.7 sec	25 kV	0.18 msec
Fuel Flow	520 V	-	2500 V	1.4 sec	130 mV	-

TABLE I - 3 ELECTROSTATIC DISCHARGE PARAMETERS

6. Therefore, except in the case of electrostatic charging by induction, it is possible to minimize charge accumulation and limit hazardous potentials by connecting the aircraft to a static earth point. In all cases providing a low impedance path for the dissipation or re-combination of charge drastically reduces the time required to discharge the aircraft to a safe potential. Also, following procedures to clear the flight line of personnel when lightning is in the area is will minimize the possibility of shock hazards or other effects. Electric fields are the most intense when the thunderstorm clouds are directly overhead.

ANNEX J ENERGY SOURCES – RF

J1. GENERAL

1. High power radar and communication transmitters located near the flight line can cause unintentional and disastrous consequences if these transmissions are not considered when operations are planned. In particular, shipboard electromagnetic environments can be extremely hazardous. Also, of concern are aircraft whose onboard systems which when being tested may affect nearby flight line operations. Unfortunately, these radiated emissions can have many unintended and unexpected effects. It is important that the effects of electromagnetic energy be considered when planning for operations on the flight line.

J2. RADIO FREQUENCY ENERGY

1. In the far or radiated field, more than several wavelengths distance from a typical RF source, the field propagates or radiates energy. The wave impedance relates the electric and magnetic fields to each other, and it is only necessary to measure one of these quantities in order to determine the other quantity or the power density.

2. Closer to the source, in the near or reactive field, the physical relationships between the electric and magnetic components of the field are usually complex. In this case, it is necessary to determine both the electric and magnetic field strengths to fully characterize the RF environment. The reactive field stores energy, and this energy can be transferred via inductive or capacitive coupling.

3. RF fields can enter metal enclosures through openings and other shielding compromises, including holes for adjustments, seams, improperly terminated cable shields, and poorly grounded cables. Unless properly treated, each opening is a leak through which the RF field can couple directly into the enclosure. Leakage through an aperture depends on its size, the type of enclosure, and its location. The aperture responds to both total magnetic and electric fields at the site of the leak.

4. Inadvertent antennas are electrically conducting wires and cables that penetrate an enclosure and intercept RF energy and permit its entry into the enclosure. As a rule, the larger the inadvertent antenna, the more efficient energy collector it is, producing current and voltage levels in the enclosure. This energy later reaches the electronic systems inside the enclosure at the other end of the connecting cable.

5. Many factors affect the coupling of EM energy to penetrating conductors. The waveform characteristics, such as magnitude, rate of rise, duration, and frequency, are each important. Because the interaction between fields and conductors is a vector process, the direction of arrival and polarization is also important. Conductor characteristics also affect coupling. These include conductor geometry (length, path,

terminations, and distance from a ground plane or other conducting surface), physical and electrical properties (including diameter and resistivity), and the presence and effectiveness of shielding.

6. At a fixed facility, RF energy can couple to structures such as power and telephone lines, antenna towers, buried conduits, and water pipes and onto the facility grounding system. Electromagnetic fields from HF transmissions can induce current flow in the hull of a ship.

7. RF energy can induce currents onto any metal object. The magnitude of the induced current will depend mainly on the conductor length in relation to the wavelength and the orientation in the radiated field. Many parts of a weapons system, a re-fuelling vehicle, and static grounding conductors can become inadvertent receiving antennas.

J3. CONSEQUENCES

1. High levels of radiated electromagnetic energy can cause:

   a. burnout or breakdown of electronic components,

   b. inadvertent operation of electronic equipment and ordnance,

   c. unintentional detonation and ignition of electroexplosive devices and flammable materials, and

   d. personnel injuries.

J4. RF ARCING

1. RF arcs can occur if cable connections are disconnected and interrupt induced current flow. In high RF fields, arcs also occur at gaps between metal surfaces. RF arcs can occur at any discontinuity in metal objects – a discontinuity being any place where the nature of the metallic object changes such as points where the type of metal or the thickness of metal changes. Metal objects, which are large with respect to the wavelength, tend to reflect energy while objects long in one dimension but not the other provide a more favorable site for arcing.

ANNEX K EARTH GROUND

K1. EARTH POINTS

1. While the generation of electrostatic charge cannot be prevented, its accumulation on a conducting body can be controlled by connecting the body to the earth. The earth mass can accept an unlimited amount of electrostatic charge. Any charge that flows to the earth mass recombines with available charges of opposite polarity and is effectively dissipated.

2. The total resistance in the path between an object connected to earth and the earth mass is the sum of the individual resistances of the connecting wire, the connectors, and the resistance of the earth electrode (i.e., ground rod) to the soil. Most of the resistance in the path exists between the ground electrode and the soil. This earth resistance is quite variable, since it depends on the area of contact with the electrode, the resistivity of the soil, and the amount of moisture present in the soil.

3. The electrostatic discharge protection requirement is based on the maximum earth resistance which will maintain a safe voltage level during charge accumulation and allow electrostatic charge to dissipate in a reasonably short time duration.

4. Typically a resistance to earth of 1 megohm or less is considered adequate to dissipate accumulates charges. Generally the accepted design value for a static earth ground is 10 kilohm.

5. At fixed airfields and on ships there will be permanently installed ramp earth points.

6. Temporary static earth points may be installed to meet operational requirements. To effectively earth equipment, a conductive electrical path into the soil must be provided. This path is formed by connecting a conductive cable from the piece of equipment to a conductive metal rod (or several connected metal rods) driven into the earth to the level of permanent ground moisture. It is difficult to obtain a good connection in rocky or sandy soils because they have low conductivity. Chemicals can be used to condition the soil and raise its conductivity. Frozen soil is a particular problem and makes it difficult to install an adequate earth point. It will usually be necessary to drive in several rods to as great a depth as possible. Another possibility is to locate the rod near a source of heat[26].

K2. POWER SYSTEM GROUND

1. Grounding for protection against power system faults requires a low resistance path between the fault location and the source.

2. It is necessary to connect utility generation and distribution systems to earth for safety. All major components of the system such as generating stations, substations, and distribution systems are connected to earth to provide a path back to the generator for the fault currents in case of transmission line trouble. The path to earth should have as low a resistance as possible. A low resistance minimizes the potential difference between equipment connected to the earth when fault currents flow. Thus personnel who come in contact with two or more pieces of equipment at one time are protected.

3. At a fixed facility the earth electrode subsystem provides the connection to the earth mass for the facility ground system. It is the part of the path through which faults in the components of the utility power system are cleared. It is designed to:

a. provide a path to earth for the discharge of lightning strokes in a manner that protects the structure, its occupants, and the equipment inside, and

b. restrict the step-and-touch potential gradient in areas accessible to persons to a level below the hazardous threshold even under lightning discharge or power fault conditions.

4. Although as low a resistance to earth as possible is desirable, there are practical limits as to the value that can be obtained. The compromise design value for the earth electrode subsystem is a 10 ohm resistance to earth. If 10 ohms cannot be achieved, the following electrode enhancements recommended in MIL-HDBK-419 should be considered:

Step 1: ensure the earth electrode subsystem design incorporates multiple ground electrodes connected by 1/0 AWG copper cable, the electrodes are of suitable size and material, etc.

Step 2: if 10 ohms cannot be achieved on installation, consider the following electrode enhancements:

a. Improve water retention by:

i. Backfilling the electrode emplacement with a mixture of 75% gypsum, 20% bentonite, and 5% sodium sulfate,

ii. Backfilling the electrode emplacement with 100% bentonite. NOTE: Bentonite expands and contracts with moisture content and can pull away from the grounding rod and surrounding soil. It can expand to several times its dry volume and can cause damage to the surface if the grounding rod is paved over.

iii. Managing soil drainage to maintain higher soil moisture around the electrodes including channeling surface drainage to keep the electrodes moist

b. chemical salting of the soil surrounding the electrode with one of the following:

i. Magnesium sulphate ($MgS0_4$) - epsom salts.
ii. Copper sulphate ($CuS0_4$) - blue vitriol.
iii. Calcium chloride ($CaC1_2$).
iv. Sodium chloride (NaCl) - common salt.
v. Potassium nitrate (KNO_3) - saltpeter.

Note: common salt and saltpeter should only be used when absolutely necessary due to the corrosive effects on the grounding rod.

Step 3: If the previous steps are unsuccessful, earth electrode subsystem referenced to earth resistance of up to 25 ohms is acceptable for general living and office areas. Facilities with communications and sensitive electronics equipment requires an earth electrode subsystem referenced to earth resistance of less than 10 ohms.

WARNING

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.

5. Grounding for protection against power system faults requires a low resistance return path between the fault location and the source. At a fixed facility the return path is provided by the fault protection subsystem and the earth electrode subsystem of the facility grounding system. The resistance of this path must be low enough to allow sufficient current to flow to activate circuit breakers and other overload protection devices.

6. On ships the hull performs a function similar to that of an earth electrode subsystem and connects the ship grounding system to the earth mass. Shipboard power is supplied by a three phase delta ungrounded (floating) electrical distribution

system. In this instance a grounding conductor connects the non-conducting metal parts of equipment directly to the ship's hull.

K3. FAULT PROTECTION SUBSYSTEM

1. Equipment grounding is necessary to eliminate the voltage shock hazard to personnel caused by unintentional contact of an energized conductor with its metal frame or enclosure, and also provides a nondestructive current carrying path for fault current until a protective device can interrupt it.

2. The fault protection subsystem consists of the intentional connection of all non-current carrying metal parts within the facility and is a component of the facility ground system. The noncurrent carrying metal parts such as frames, supports, and enclosures of all equipment must be connected to the fault protection subsystem. It provides the electrically continuous path for fault current to return to the source of the system supplying the equipment (building service or separately derived system whichever is applicable).

3. The fault protection subsystem does not depend on the earth electrode subsystem to trip over current devices. Fault currents normally flow through the grounding conductor (green wire) to the source side of the first service disconnect, where the grounding conductor and the neutral are tied together. The fault current then flows through the neutral to the transformer to complete the circuit. This path functions completely independent of the connection to the earth electrode subsystem.

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