B1

AVIATION MAINTENANCE TECHNICIAN CERTIFICATION SERIES

MAINTENANCE PRACTICES

7

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003.2	2023.04	Submodule 8 - Added content on *Friction* and *Mechanical lock blind rivet* procedures.
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Potential Safety Hazards When Working With Electrical Systems And Protective Equipment

Submodule

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SUBMODULE KNOWLEDGE DESCRIPTIONS		LEVEL
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7.4	**Potential Safety Hazards When Working With Electrical Systems And Protective Equipment** Electric Shock Hazards and effects of current on the human body. Arc flash/blast and stored energy hazards (capacitors, batteries, power electronics). Battery related hazards: chemical, thermal runaway, fire and explosion. Electrostatic discharge and electromagnetic hazards. Environmental and situational risks (wet conditions, confined spaces, poor accessibility. Protective measures: personal protective equipment, insulated tools, system isolation, verification of absence of voltage.	3

7.4 POTENTIAL SAFETY HAZARDS WHEN WORKING WITH ELECTRICAL SYSTEMS AND PROTECTIVE EQUIPMENT

This submodule is about identifying and understanding electrical hazards such as arc flash and electric shock, establishing appropriate protection zones, the use personal protective equipment (PPE) and an isolation system known as lockout/tagout to warn team members that maintenance is in progress. By combining risk assessment, technology, procedures, and training, you can greatly reduce the risks to personnel and equipment when working with and around electrical systems.

ELECTRIC SHOCK HAZARDS AND EFFECTS OF CURRENT ON THE HUMAN BODY

Electric shock is defined as a sudden discharge of electricity through a part of the body. It occurs when an electric current passes through the body with the body becoming a part of the electric circuit. It can occur from contact with a live electrical source with the severity depending on the path of the current, the amount of current and the duration of the shock. [**Figure 4-1**] Injuries can range from minor pain and burns to severe internal damage, cardiac arrest or death.

Maintainers must be highly safety focused when operating and working on aircraft, aircraft electrical components or avionic components. By following established safety protocols, using appropriate protective equipment and tools, receiving proper training, understanding electrical systems, grounding equipment, maintaining and inspecting systems, and maintaining situational awareness, maintenance personnel can help prevent electrical accidents and ensure the safety of themselves and their fellow maintainers.

STATIC ELECTRIC SHOCK

Electrical shock in aviation often stems from static electricity buildup on the aircraft's surface caused by friction with air particles. This can lead to discharges that can shock technicians or interfere with systems managed by static wicks and grounding. As this can cause a risk for maintenance crews, particularly during fueling, strict protocols, bonding, and specialized personal protective equipment can prevent serious incidents.

ELECTRIC SHOCK AND THE HUMAN BODY

The injury from electrical shock depends on the density of the current, tissue resistance and the duration of contact. Very small currents may be imperceptible or produce only a light tingling sensation. Even still, a shock caused by low and otherwise harmless current could startle an individual and cause injury due to jerking away or falling.

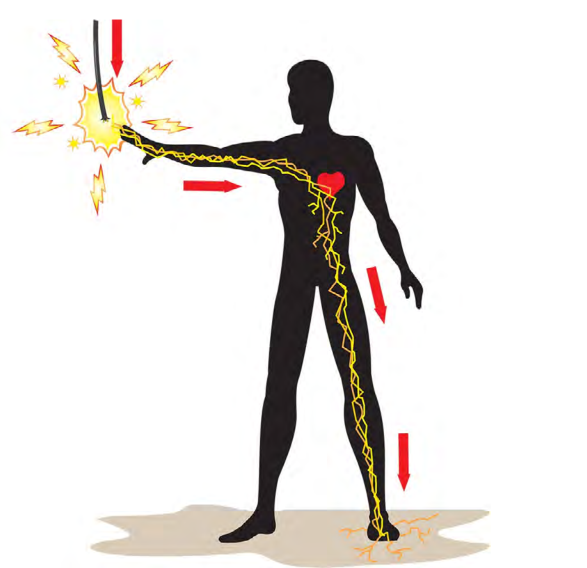

Figure 4-1. Electrical shock occurs when current flows through the body and into a conductive surface.

A strong electric shock can cause painful muscle spasms, sometimes severe enough to dislocate joints or even break bones. The loss of muscle control is the reason that a person may be unable to release themselves from the electrical source. If this happens at a height, you can be thrown off with injury resulting from that fal. Larger currents can also result in tissue damage and may trigger cardiac arrest. [**Figure 4-2**]

The electrical injury occurs upon contact of a body part with electricity that causes a sufficient current to pass through the person's tissues. Contact with energized wiring or devices is the most common cause. In cases of exposure to high voltages direct contact may not be necessary as the voltage may "jump" the air gap between the device and yourself.

A CASE STUDY

Injuries from electric shock can occur in many situations, including an unexpected contact with exposed terminals during routine maintenance. Awareness of this possibility is always necessary.

Transport Canada - December 2024: Two incidents have been reported in which maintenance personnel received electric shocks while carrying out maintenance on a Bombardier Challenger 605. The maintenance staff were injured when they came in contact with an exposed electrical connection on the baggage compartment heater thermostat. [**Figure 4-3**]

The terminals of the baggage compartment heater thermostat are located on the water tank forward access door, which is normally only accessed by maintenance personnel during maintenance activities.

Transport Canada service bulletin (SB) 605-21-006, was issued which provides instructions to apply adhesive sealant on the end terminals of the thermostat installed on the access panel door.

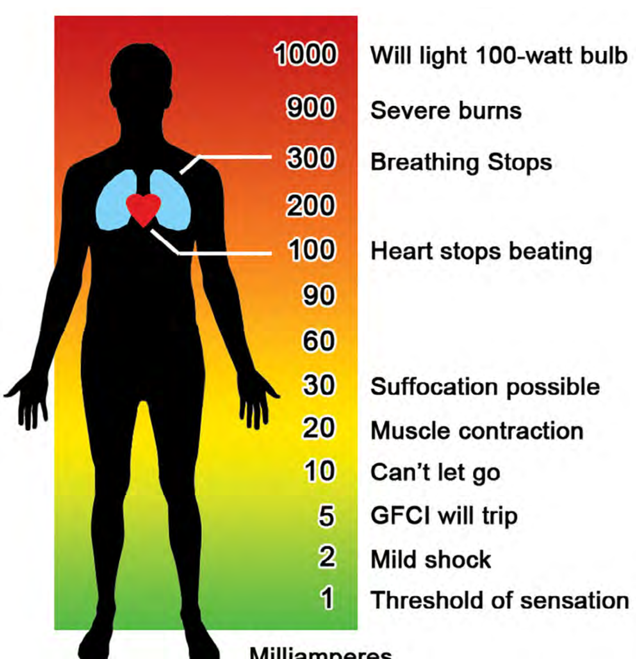

Figure 4-2. The energy of electrical shock is typically expressed in amperes and milliamps. This chart shows the typical effects at various levels.

It is recommended that operators incorporate SB 605-21-006 across their affected fleet and for aircraft maintainers to exercise maximum awareness and caution while servicing Challenger 605 potable water tanks.

ARC FLASH, ARC BLAST, AND STORED ENERGY HAZARDS (CAPACITORS, BATTERIES, POWER ELECTRONICS)

ARC FLASH/ARC BLAST

An arc flash is a type of electrical explosion or discharge that results from a low impedance connection through the air to ground or to another voltage phase in an electrical system. This phenomenon occurs when an electric arc causes a sudden release of electrical energy due to a fault. [**Figure 4-4**]

The significance of an arc flash when maintaining electrical equipment cannot be overstated. It poses a serious risk to workers and equipment in any environment where electrical systems are present. Arc flashes result in a bright flash and intense heat, leading to fires, explosions and severe injury or even death to nearby personnel. An arc flash can generate temperatures over 19 000°C, being several times hotter than the surface of the sun. An accompanying arc blast often occurs with the flash as a result of the sudden release of pressure during the flash event. [**Figure 4-5**]

Common injuries due to arc flash include:

- Severe burns: The intense heat can cause second and third degree burns, even from meters away and can ignite flammable clothing.
- Blast injuries: The pressure wave can cause blunt force trauma, broken bones, concussions, and internal injuries. It can also propel molten metal and other debris at high speeds.
- Other injuries: The bright flash can cause eyesight damage or blindness. The loud noise can lead to permanent hearing loss. Inhaling hot gasses and vaporized metals can cause respiratory issues. Implementing safety measures such as proper personal protective equipment (PPE), and thorough training can help mitigate these risks.

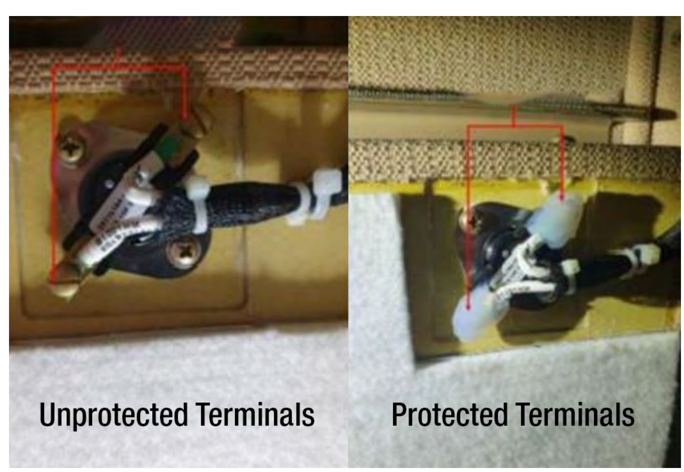

Figure 4-3. Following multiple injuries, exposed terminals (left side) are directed to be protected with an adhesive non-conducting sealant.

CAUSES OF ARC FLASH

Arc flashes are often the result of equipment failure, environmental factors and human error. For example:

- Accidental contact with energized components, often from dropping tools or using improper testing procedures.
- Equipment failure due to aging infrastructure, damaged insulation, or loose connections.
- Environmental factors like conductive dust, moisture, or corrosion creating an alternate path for the current.
- Improper work practices, such as failing to de-energize equipment or not using proper lockout/tagout (LOTO) procedures.

EQUIPMENT FAILURE

Equipment failure can lead to these dangerous arc flash events due to:

- Deterioration over time
- Faulty installation or maintenance
- Component malfunction
- Inadequate ratings
- Contamination

Figure 4-4. The dangers of arc flash can not be understated.

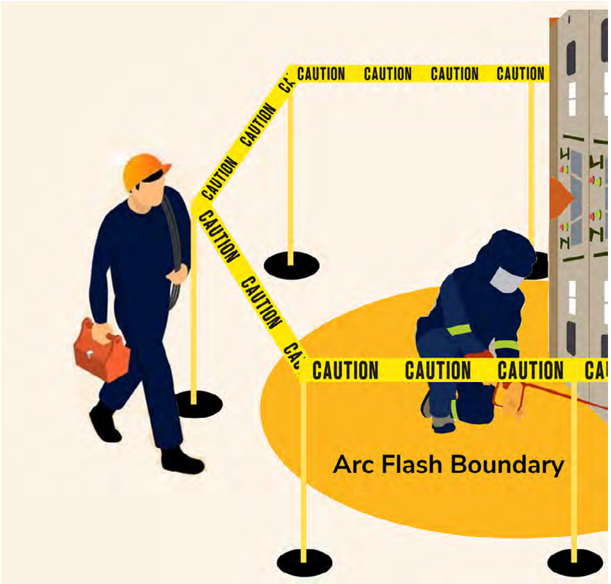

Figure 4-5. Setting up boundary areas when arc flash is possible will help reduce the risks of heat and arc blasts to unprotected personnel.

ENVIRONMENTAL FACTORS

Environmental factors like dust, corrosion, and condensation can significantly increase the risk of arc flashes.

1. Dust: Dust accumulation on electrical equipment can create a conductive path leading to short circuits and arc flashes. Dust can also insulate heat, causing equipment to overheat and fail.
2. Corrosion: Corrosion degrades the integrity of electrical components, compromising insulation and increasing the likelihood of electrical faults. This can result in arc flashes, especially in environments with high humidity or exposure to corrosive substances.
3. Condensation: Moisture from condensation can bridge gaps between conductors, creating unintended electrical paths. This can lead to short circuits and arc flashes, particularly in poorly ventilated or temperature variable environments.

Regular maintenance and inspections are crucial in preventing arc flashes. Routine checks help identify and address potential issues like dust buildup, corrosion, and moisture before they lead to dangerous situations. Ensuring that all electrical equipment is in good working condition reduces the risk of faults and enhances overall safety.

HUMAN ERROR

Human error is a significant contributing factor to arc flash incidents, often due to a lack of knowledge, inadequate prevention, training or complacency. Human error can lead to dangerous arc flash events do to:

- Inadequate Training
- Ignoring Safety Protocols
- Mistakes in Judgment
- Accidental Contact
- Improper Use of Tools and Equipment
- Failure to De-Energize Equipment
- Complacency

PREVENTION OF ARC FLASH

Preventing equipment failure through regular inspections, proper installation, maintenance and using only components that meet the necessary specifications such as current limiters are critical steps in mitigating the risk of arc flash incidents. Some equipment types that commonly fail and lead to arc flash incidents are:

- Circuit breakers
- Transformers
- Switchgear
- Panel boards and switchboards
- Motor control centers
- Disconnect switches
- Cables and wiring
- Relays

The best way to prevent an arc flash is to de-energize electrical equipment before working on it. When this is not feasible, safety measures must be implemented such as:

- Reducing Fault Current: Use current limiting devices such as fuses and circuit breakers to minimize the amount of current available in the system.

- Limiting Arc Duration: Install arc flash protective relays which use light and current detection to rapidly interrupt a fault. Use zone selective interlocking to enable the breaker closest to a fault to trip faster, which so reduces the total arcing time.
- Compartmentalize and Isolate: Design electrical systems with physical barriers between bus bars, cable connections, and other energized components to prevent the propagation of an arc fault and inadvertent contact.
- Remote Operation: Operate breakers remotely to keep personnel outside the arc flash hazard boundary during high risk operations, such as switching circuit breakers or inserting breakers into a live bus.
- Digital Monitoring: Implement continuous thermal monitoring sensors to monitor equipment health remotely, reducing the need for workers to open panels on energized equipment for inspections.
- Regular Maintenance: Conduct routine inspection programs to identify and address common causes of equipment failure, such as worn insulation, loose connections, dust buildup, or corrosion.

STORED ENERGY HAZARDS

Stored energy hazards refer to the unexpected release of energy from machinery or systems after the main power source is turned off. Examples may include springs, compressed air, hydraulic fluid pressure, or as relevant to this submodule, electrical capacitors, batteries, and powered electronics. The proper lockout/tagout procedures as discussed later in this submodule are key to the prevention of these releases.

CAPACITORS

Capacitors pose hidden hazards because they store large amounts of electrical energy even after equipment is de-energized, leading to potentially fatal electric shocks and arc flash. Key risks include unexpected discharge, thermal failure, and toxic chemical leakages, making safe handling and proper discharging essential. [**Figure 4-6**]

The primary hazards from capacitors include:

- Electric Shock (possibly fatal): A capacitor can retain its electrical charge for long periods, releasing it in microseconds. A capacitor's charge is often measured in Joules. At this scale even a 1 Joule release can cause a painful shock, while a 10 Joule release can trigger cardiac fibrillation, and a 50 Joule charge being often fatal.
- Arc Flash/Blast: A damaged, overcharged, or shorted capacitor can explode, releasing hot gases, flames, and metal debris. In an electrical bank, one capacitor failure can trigger a cascade of explosions.
- "Lurking" Residual Energy: A circuit may seem safe after being powered off, but capacitors downstream can remain charged, often bypassing standard voltage checks. Note that some large capacitors can self-recharge after initially being discharged. This occurs when a capacitor recovers a portion of its original voltage over minutes or hours. Always insure that a capacitor's terminals are kept shorted during storage.
- Thermal Damage & Fire: Overheating from high current, improper soldering or reversed voltage can cause capacitors to catch fire, vent, or fail violently.
- Chemical Hazards: Electrolytic capacitors contain toxic or caustic fluids that can leak, causing skin irritation or environmental damage.

Safety precautions when handling capacitors include:

- Discharge Before Touching: Use a properly rated discharge tool or a high resistance resistor to bleed the charge before touching the terminals.
- Verify with a meter: Never assume a capacitor is empty. Always verify zero voltage with a meter. [**Figure 4-7**]
- Proper Storage: For long term storage or maintenance, keep terminals physically shorted with a wire or bar to prevent self-recharging.
- Visual Inspection: Look for bulging cases, leakage, or burn marks before handling.
- Wear PPE: Use insulated gloves, safety glasses and arc rated clothing when working with capacitors or other high voltage systems.

BATTERIES

Storing energy in batteries presents several physical and chemical hazards, primarily stemming from the risk of an uncontrolled energy release. Primary hazards include:

- Thermal Runaway: This is a self-sustaining chain reaction where a battery cell generates heat faster than it can dissipate it. This often leads to intense fires which can burn for days and/or explosions if the expanding gasses are confined in enclosed spaces such as battery boxes.

Figure 4-6. Capacitors are found throughout an aircraft. These depict those of a typical strobe light unit.

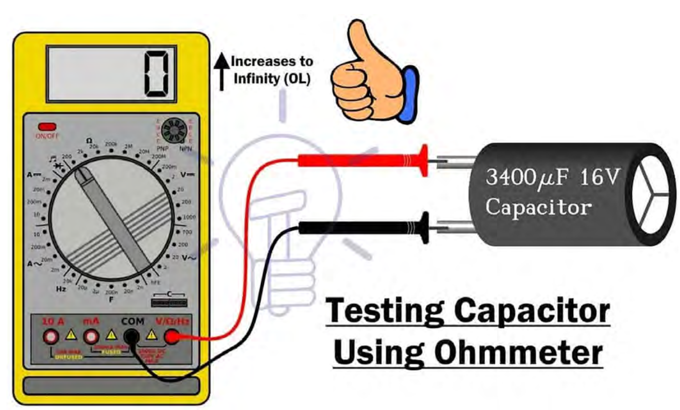

Figure 4-7. An Ohmmeter or multimeter's probes are connected to each capacitor terminal. If the reading is zero, the capacitor is free of any residual charge.

- Toxic Gas Emissions: During a failure or fire, batteries release a cocktail of harmful gases, including hydrogen fluoride, carbon monoxide and hydrogen cyanide.
- Stranded Energy: Even after a fire is seemingly extinguished, damaged batteries can retain a significant electrical charge with no safe way to discharge it.
- Electrical Hazards: Arcing from high voltage systems (typically 50V plus) can cause electrical burns or electrocution.
- Corrosivity: Electrolytes in many batteries are corrosive and can cause chemical burns to skin or eyes upon leakage.
- Several factors can cause battery failures including:
- Mechanical Abuse: Physical damage such as crushing, dropping, or puncturing the battery.
- Electrical Abuse: Overcharging, over-discharging, or external short circuits.
- Thermal Abuse: Exposure to extreme external temperatures, both hot and cold.
- Environmental Factors: Flooding, high humidity, or debris ingress such as dust or salty fog can compromise internal components.
- Manufacturing Defects: Internal short circuits caused by poor quality control or contaminants introduced during production.

Best mitigation and safety practices need to be observed to avoid battery related mishaps. First is the inclusion of an approved battery management system which is capable of monitoring voltage, current and temperature, and is self capable of shutting the system down before failure occurs.

Second regards proper storage. Batteries should be stored at room temperature in well ventilated dry areas and away from flammable materials. For lithium-ion batteries, a charge level somewhat below 50% is often recommended for long term storage.

POWER ELECTRONICS

As powered electronic units often contain capacitors, inductors and batteries, they must be treated in the same way as with the above individual components which can maintain their charges for long after they are disconnected from a power source. Always ensure that any residual charge is fully dissipated prior to disconnection or disassembly. Always handle and store devices in a gentle and acceptable manner. And, always employ proper lockout/tagout procedures during maintenance.

BATTERY RELATED HAZARDS: CHEMICAL, THERMAL RUNAWAY, FIRE AND EXPLOSION RISKS

Battery safety, beyond the precautions discussed above requires the additional understanding of the hazard of thermal runaway. Thermal runaway, as prevalent mostly in regards to lithium-ion batteries is an uncontrollable, self accelerating chain reaction where an increase in temperature changes conditions in a way that causes a further increase in temperature.

This positive feedback loop occurs when a system generates heat at a rate significantly higher than it can dissipate to its surroundings. As internal chemical reactions, get hotter, they release more energy which further releases thus more heat energy, often reaching temperatures above 600°C within minutes. In a battery bank of multiple cells, this intense heat from a single failed cell can then spread to adjacent cells leading to the runaway condition throughout the entire battery pack. [**Figure 4-8**]

A number of conditions can lead to a thermal runaway. Physical damage to the battery such as punctures or crushing can cause internal short circuits. Electrical abuse such as overcharging or deep discharging can lead to an overheat condition, as could a general failure of the battery's cooling system. In addition manufacturing flaws such as impurities or poorly made separators can lead to failures over time.

STAGES OF A THERMAL EVENT

A thermal event generally follows a specific sequence of internal degradation.

1. The solid-electrolyte interphase layer begins to break down. (~70°C–120°C).
2. Anode/Electrolyte reactions begin to occur when exposed lithium reacts with the electrolyte generating gasses and more heat. (~100°C–120°C).
3. Separator Melting: The physical barrier between the anode and cathode melts, causing an internal short circuit. (~130°C–150°C).
4. Cathode Decomposition: The cathode material breaks down, releasing oxygen that fuels intense combustion and possible explosion. (~150°C–200°C+).

Beyond user errors such as physical abuse and poor charging practices, thermal runaway can be controlled through a battery management system (BMS). A BMS is a standard component within a battery pack system which monitors certain conditions and if exceeded will shut the system down before damage can occur. [**Figure 4-9**]

The additional prevention strategies employed by the battery manufacturer include the use of fire resistant barriers such as Aerogel placed between cells to prevent heat spread. In addition, battery chemistries are constantly improving which have a higher tolerance of heat as the onset of runaway. An example is the use of lithium iron phosphate as a replacement for the previous nickel manganese cobalt chemistries.

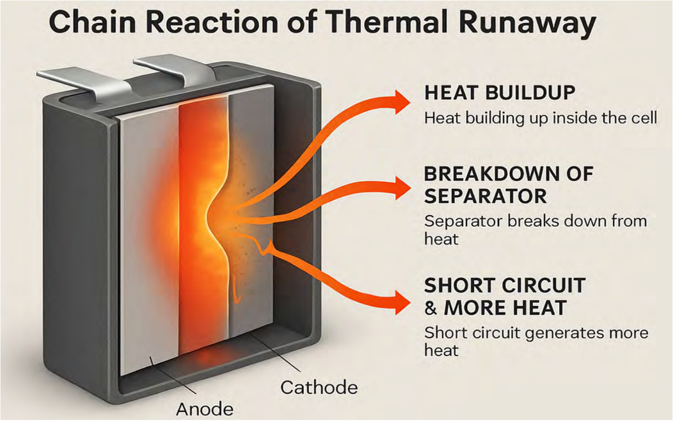

Figure 4-8. Thermal runaway begins with heat buildup between the cathode and electrolyte, breaking down the separator and thus generating more heat.

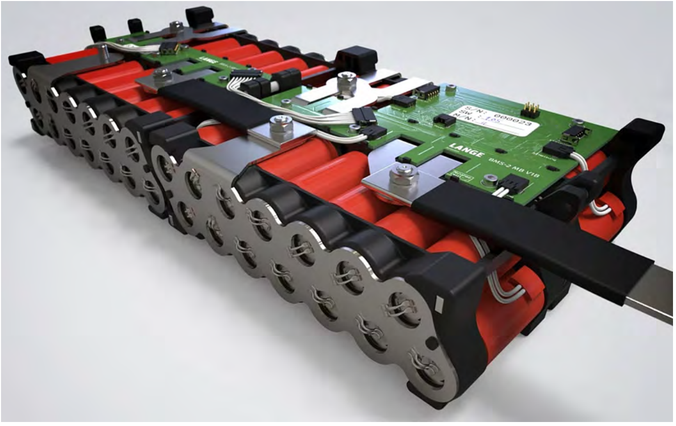

Figure 4-9. A battery pack with management circuitry from Lange Aviation.

ELECTROSTATIC DISCHARGE (ESD) AND ELECTROMAGNETIC HAZARDS

ELECTROSTATIC DISCHARGE (ESD)

Electrostatic discharge (ESD) is the sudden release of static electricity when two objects with different electrical potentials make contact or come close to each other. While often perceived as a harmless "zap", ESD presents significant hazards in aviation environments, ranging from invisible electronic damage to catastrophic explosions.

FIRE AND EXPLOSIONS

The risks of fire due to an ESD discharge are particularly high during the transfer of fuels. As fuels are poor conductors, they can accumulate large charges causing sparking and the resultant fire. As a preventative measure, it is critical to always ground both the aircraft and fuel dispensers while fueling or defueling an aircraft. [**Figure 4-10**] More on the fueling/defueling procedure is presented in submodule 17 of this book.

Static electricity, even a single spark, can also ignite airborne dust and flammable gas mixtures during various maintenance operations. For this ignition to occur, a charge must be generated either by friction or a triboelectric effect, allowed to accumulate and then discharged into the atmosphere.

DAMAGE TO ELECTRONICS

Electrostatic discharge is the leading cause of failure for integrated circuits and other sensitive equipment. The most vulnerable components being microchips, MOSFET transistors, capacitors and magnetic storage media as are often found in all avionics equipment and computing devices, some of which can be destroyed by as little 10 volts. [**Figure 4-11**]

Failure types can be either catastrophic due to the immediate breakdown of electronic junctions or can be latent whereby a component is weakened to the point where it will pass an initial test, only to later fail later during operation.

For more on the prevention of ESD damage to electronic equipment, see module 5, submodule 12 of this Aviation Maintenance Certification Series.

Figure 4-10. Grounding an aircraft (of any type) is a critical step during all fueling or defueling procedures.

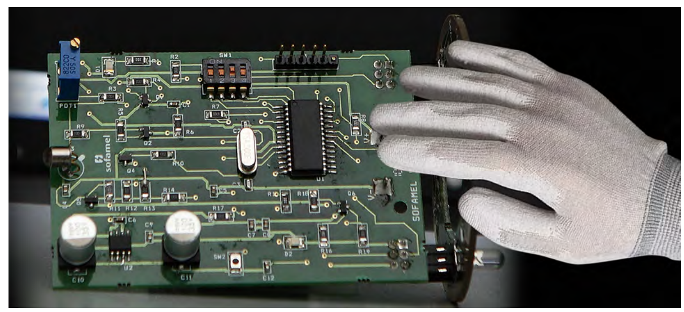

Figure 4-11. Electronic equipment is extremely sensitive to ESD, necessitating careful procedures, even when only in close proximity to the device.

PERSONAL SAFETY

While an ESD shock by itself is rarely life threatening, the involuntary recoil or muscle contraction from the surprise zap can cause a technician to fall or drop sensitive equipment. However, during more extreme cases if batteries or high voltage equipment is involved, an ESD event can lead to electrocution or severe burns. In addition an ESD event can interfere with the function of medical devices such as a pacemaker.

ELECTROMAGNETIC HAZARDS

Hazards in aviation primarily involve electromagnetic interference, which can disrupt critical flight systems, and ionizing radiation, which poses health risks to crew and passengers.

Electromagnetic interference refers to electrical signals that interfere with the performance of avionics and is typically categorized by its source, either external, internal, or natural. External sources, known as high intensity radiated fields (HIRF), can come from radio transmitters, radar and other types of transmitted fields. Internal sources such as cell phones and other personal electronic devices, while lower powered, can interfere with certain systems such as GPS reception and radar altimeters. Natural phenomena such as lightning can cause direct damage and electrical surges. Solar flares leading to increased radiation levels can corrupt data in flight computers sometimes causing navigational errors. HIRF is additionally covered in submodule 19 of this book.