Safety Hazards and Protective Equipment When Working with Electrical Systems

Submodule 4

SUBMODULE KNOWLEDGE DESCRIPTIONS		LEVEL
		A
7.4	**Safety Hazards and Protective Equipment When Working with Electrical Systems** Risk Scenarios such as Arc Flash and Electric Shock; Lockout/Tagout Procedures	3

7.4 SAFETY HAZARDS AND PROTECTIVE EQUIPMENT WHEN WORKING WITH ELECTRICAL SYSTEMS

RISK SCENARIOS

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 a notification 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 electrical systems.

ARC FLASH

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 4-1**]

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 4-2**]

Figure 4-1. The dangers of arc flash can not be understated.

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.

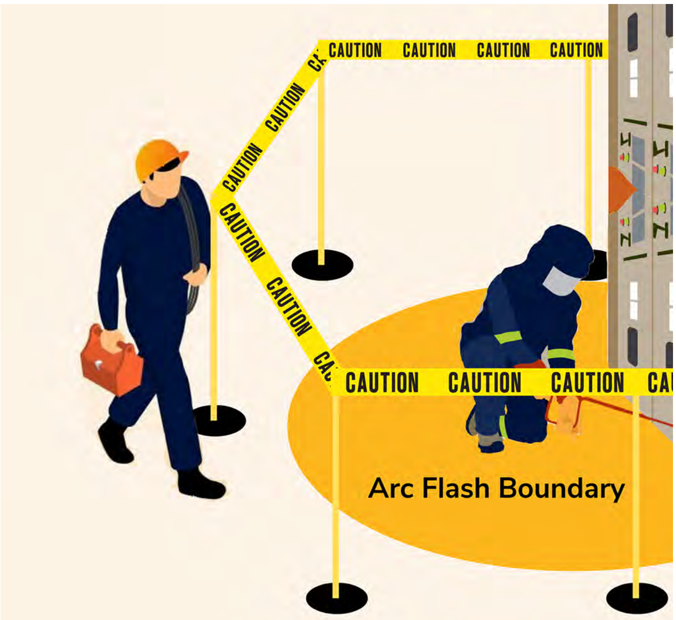

Figure 4-2. Setting up boundary areas when arc flash is possible will help reduce the risks of heat and arc blasts to unprotected personnel.

- 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.

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 using proper lockout/tagout (LOTO) procedures or not wearing appropriate personal protective equipment (PPE).

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

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

When present, these devices should be included in an organization's preventative maintenance plan to prevent such failures and so help prevent arc flash events.

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 current limiting fuses and circuit breakers to minimize the amount of fault 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: Utilize remote racking systems or 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 root causes of equipment failure, such as worn insulation, loose connections, dust buildup, or corrosion.

ARC FLASH PROTECTIVE CLOTHING

IEC/EN 61482 is an international standard developed by the International Electrotechnical Commission (IEC) for protective clothing to shield technicians from the thermal hazards of an electric arc and so limiting or eliminating the possibility of second degree burns during an arc flash event at various energy levels. This standard ensures that clothing materials and garments provide sufficient insulation and do not ignite, melt, or break open when exposed to the heat and energy of an arc flash.

Arc flash intensity, and so the need for protective equipment is described in four categories based on the calories of heat per cm^2 of possible exposure. [**Figure 4-3**]

Category 1 up to 4 cal/cm^2
Requires arc resistant (AR) long sleeve shirt and pants or AR coverall, hard hat, safety glasses, hearing protection, AR face shield or arc flash suit hood, heavy duty leather gloves, and leather footwear.

Category 2 up to 8 cal/cm^2
Requires AR long sleeve shirt and pants or AR coverall, hard hat, safety glasses, hearing protection, AR flash suit hood or AR face shield with AR balaclava, heavy duty leather gloves, and leather footwear.

Category 3 up to 25 cal/cm^2
Requires a full AR flash suit system (jacket and pants or coveralls), AR flash suit hood, AR gloves or rubber insulating gloves with leather protectors, hard hat, safety glasses, hearing protection, and leather footwear.

Category 4 up to 40 cal/cm^2
Requires a full AR flash suit system (jacket and pants or coveralls), AR flash suit hood, AR gloves or rubber insulating gloves with leather protectors, hard hat, safety glasses, hearing protection, and leather footwear.

Figure 4-3. Typical category two and four arc flash protective equipment.

Many aviation maintenance operations frequently encounter situations where Category 1 (4 cal/cm^2 minimum) and Category 2 (8 cal/cm^2 minimum) levels are common during maintenance and troubleshooting tasks on aircraft electrical systems and ground support equipment.

While aircraft systems operate at various voltages, most general aviation aircraft run on 28 volt DC or 115/200 volt 400 Hz AC power which often result in lower incident levels compared to heavy industrial power systems. However the type of equipment being maintained, for example ground power units, avionics bays, battery systems and generators and their specific configurations affect the potential hazard. In addition, working within confined spaces and in the presence of conductive materials increase the risk and so must be accounted for.

Thus, while specific categories depend on the arc flash risk assessment, the typical PPE worn by aviation engineers for electrical work includes:

- Arc-rated long sleeve shirts, pants or coveralls meeting at least a category 1 or 2 rating.
- Safety glasses or goggles.
- Hard hats with an integrated AR face shield
- Hearing protection.
- Heavy duty leather gloves.
- Non-conductive safety-toe footwear.

In aviation maintenance, tasks requiring the higher arc flash PPE categories 3 and 4 are less common but can occur during specific high voltage operations. These tasks typically involve:

- Working on high voltage ground support equipment: Maintenance on large, high powered ground power units can involve significant incident energy levels, especially when troubleshooting energized components.
- Maintenance of specific high voltage aircraft systems: Some larger modern aircraft utilize higher voltage systems in power generation or distribution. Working on these exposed, energized parts can require a higher category of protective equipment.
- Removal of bolted covers on high energy panels: Actions that might disturb components in a high energy panel, such as removing a bolted cover are considered high risk activities that could necessitate Category 3 or 4 protective equipment.
- Working in confined spaces: Performing electrical work in confined spaces, such as an aircraft's electrical or avionics bays can concentrate the energy of an arc flash event, potentially pushing the required protective equipment into a higher category.
- Specific battery maintenance operations: While routine battery checks are low risk, maintenance involving large, high capacity battery systems (e.g., lithium-ion batteries in some modern aircraft) where a fault could lead to a high current discharge may require higher level of protection.
- Testing or troubleshooting that requires exposed energized parts: Any task where a worker must interact with bare, live electrical conductors and circuit parts can escalate the PPE requirements.

ELECTRIC SHOCK

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. 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.

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 4-4**]

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 baggage compartment heater thermostat installed on the water system access panel door. It is recommended that operators incorporate SB 605-21-006 across their affected fleet and for aircraft model maintainers to exercise maximum awareness and caution while servicing the model Challenger 605 potable water tanks.

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.

PREVENTING ELECTRIC SHOCK

Technicians can prevent electric shock by following these safe practices when working with electrical power tools, appliances, light fixtures and machinery.

PERSONAL PROTECTIVE EQUIPMENT

Wear rubber soled shoes and insulated gloves when operating power tools, replacing fuses or working with any device that could give an electric shock. Use rubber floor matting if available. Insulating rubber gloves are often rated and color tagged identifying on the degree of protection they will provide for various voltages. [**Figure 4-5**]

POWER SOURCE CONSIDERATIONS

Inspect Power Cords - Check power cords regularly and replace any that are frayed or have damaged insulation covers. Never tape or splice damaged cords. Occupational safety and health standard requires that extension cords used with portable electric tools and appliances shall be of three wire type and shall be designed for hard or extra hard usage."

Ground All Power Supplies - Systems Ensure that all electrical equipment, electrical circuits, and power supply systems are grounded. Never remove the grounding wire on a three pronged cord. Also, never attach an ungrounded, two prong adapter plug to a three pronged cord or tool.

Do Not Overload Circuits - Ensure that all circuit breakers or fuses have the correct rating.

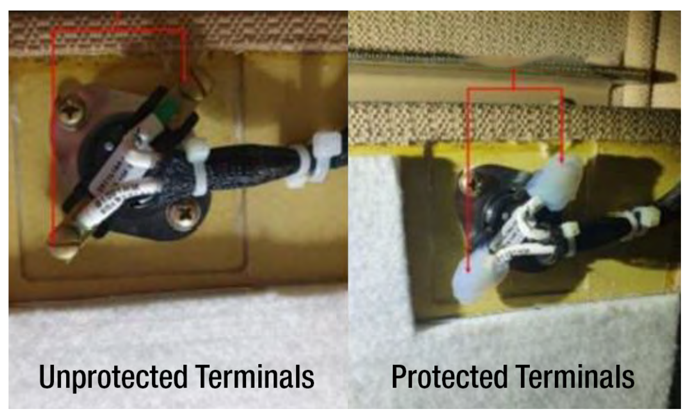

Figure 4-4. Following multiple injuries, exposed terminals (left side) are directed to be protected with an adhesive non-conducting sealant.

Voltage Classifications for Rubber Gloves			
Tag Color	Class	Proof Test Voltage AC/DC	Max. Usage Voltage AC/DC
Beige	00	2,500/10,000	500/750
Red	0	5,000/20,000	1,000/1,500
White	1	10,000/40,000	7,500/11,250
Yellow	2	20,000/50,000	17,000/25,500
Green	3	30,000/60,000	26,500/39,750
Orange	4	40,000/70,000	36,000/54,000

Figure 4-5. Insulating gloves can offer protection from voltages up to 54 000 volts DC.

Always Use Ground Fault Circuit Interrupters (GFCIs) - GFCIs interrupt the flow of electricity within as little as 1/40 of a second. They can prevent electrocution in wet areas such as sinks or outdoors. Always follow the manufacturers' testing procedures to make sure GFCIs are working properly.

Disconnect Electrical Equipment from Its Power Source Before Repairs - Never assume the electrical device has been unplugged. Check to make sure.

TOOLS AND EQUIPMENT

Follow Manufacturer's Instructions - To avoid electrical shock, always use tools and equipment as intended and as outlined in the manufacturer's instructions.

Inspect Tools Before Use - Ensure that all tools are in good working order before use. Remove from service any defective tool with a frayed cord, missing prongs, or a cracked casing. Attach a "Do Not Use" tag to the damaged tool. Set it aside and report it to a supervisor. Allow only a qualified electrician to complete repairs.

Never Use Electric Appliances or Tools Near Water. Avoid all liquids when using electrical devices. Even the water content in the human body can make an efficient conductor of electricity when it seeks a path to the ground.

Use Double Insulated Tools - Tools with non-metallic cases and a manufacturer's label that says “double insulated"means the insulation is inside the tool. This insulation protects the user from shock if water enters the tool's housing. If a double insulated tool is dropped into water, disconnect the power source before reaching for it.

Keep Tools and Equipment Clean - Clean and inspect tools after each use. Liquids, such as grease, oil, and solvents left on tools and equipment can result in electric shock.

FIRST AID FOR ELECTRIC SHOCK

An electric shock is a medical emergency that occurs when the body completes an electrical circuit, leading to symptoms such as burns, muscle spasms, difficulty breathing and potential cardiac arrest. Immediate medical help is crucial.

In all cases, the first action when a coworker is subject to electric shock is to turn off the power source, either by a switch, a circuit breaker or by unplugging the device. If this is not possible use a dry non-conductive item, such as wood or plastic to move the source or the victim away. Never touch the person while they are in contact with electricity. Once this is assured, immediately call for emergency medical help.

While waiting for their arrival, check if the person is breathing or has a pulse. If they are not breathing begin cardiopulmonary resuscitation (CPR) if you are so trained. If burns are evident, cover with sterile non-stick bandages or a clean cloth. Do not use blankets or towels. If breathing is present but faint, lay the victim down with legs elevated and keep them warm.

LOCKOUT/TAGOUT (LOTO)

Lockout/Tagout (LOTO) is a critical safety protocol ensuring aircraft systems (electrical, hydraulic, pneumatic, etc.) are fully de-energized and secured with locks and tags during maintenance, in order to prevent an accidental startup, system release, or energy surge that could severely injure workers or damage the aircraft.

This procedure is mandatory for all personnel servicing aircraft. It involves identifying energy sources, releasing stored energy, shutting down and/or isolating equipment such as breakers and valves and locking/tagging the devices to prevent a restart.

THE LOCKOUT/TAGOUT PROCESS

The process involves two main actions. First there is lockout. This means physically locking energy isolating devices like switches and circuit breakers in the off position. This ensures they can not be operated while maintenance is ongoing.

Second is tagout. This involves attaching physical warning tags to these devices. These tags indicate that maintenance work is in progress and the equipment should not be energized. [**Figure 4-6**]

Before any maintenance begins, the team identifies the systems and equipment they will work on. They consult job cards and maintenance manuals to insure they know what they are dealing with. The responsible technician or supervisor then isolates the energy sources by locking and tagging the appropriate controls. This step also includes dissipating any stored energy such as residual hydraulic pressure or electrical charge.

If the maintenance work takes longer than a single shift, the lockout/tagout devices and tags must stay in place until the work is completed. This ensures that everyone involved knows that the equipment is still under maintenance. If multiple technicians are working on the same systems, each can apply their own tags. This clear communications is essential for safety. Once the maintenance is finished, the mechanic or supervisor removes the lockout/tagout devices and files the documentation in the control log. They also check that all systems are back to their normal operating condition before the aircraft is released from maintenance.

EIGHT STANDARD STEPS IN AVIATION ELECTRICAL (LOTO)

An aviation LOTO process typically follows these eight steps:

1. Preparation: Identify all energy sources (electrical, hydraulic, etc.) using aircraft maintenance manuals.

Figure 4-6. A circuit breaker panel with the critical system breaker locked and tagged.

2. Notification: Inform all "affected" employees—those working in or around the area—that systems will be locked out.
3. Shutdown: Power down the aircraft systems according to standard procedures.
4. Isolation: Physically separate the equipment from its energy sources (e.g., pulling breakers or closing valves).
5. Application of Devices: Attach authorized locks and tags to each isolation point.
6. Control Stored Energy: Relieve residual pressure in hydraulic lines or discharge electrical capacitors.
7. Verification: Attempt to operate the system to confirm it is truly de-energized (often called the "Tryout").
8. Restoration: After work is complete, only the person who applied the lock may remove it and return the system to service.

To facilitate the lockout/tagout process, a lockout/tagout kit is commonly available within a maintenance facility. This kit contains both locking mechanisms and warning labels for multiple devices and system types. [**Figure 4-7**]

ADDITIONAL ELECTRICAL SAFETY STANDARDS

Additional information regarding electrical safety standards beyond those specific to the aviation environment can be found through these documents:

- EU Directive 2006/42/EC - Machinery Directive
  Covers general requirements for the safety of machinery and electrical equipment. Specifically Annex 1 - 1.5.9 which requires that electrical equipment must be protected against electrical risks during operation, maintenance and transport.
- EN50110 - Operation of Electrical installations
  The established EU standard for safe work on electrical installations. Covers risk assessment, shielding/zoning, LOTO, voltage control, the use of PPE, procedures for dead working.
- IEC/EN 61482 - Arc Flash Protective clothing
  Describes material requirements and certification standards for clothing that protects against arc flash. Used to define the type of PPE required when working in different incident energy levels.
- Swedish ELSAK-FS 2008:1
  Requirements for electrical safety work addresses systematic electrical safety work, risk assessment, routines, competence requirements.
- Swedish ELSAK-FS 2007:1
  Installation rules including which parts require a voltage free environment and steps for safe installation.

Figure 4-7. A typical lockout/tagout kit, contains multiple locking device styles and warning tags.