CHAPTER III

SECTION 4A.0

ELECTRO-EXPULSIVE DEICING SYSTEMS

CHAPTER III—ICE PROTECTION METHODS

CONTENTS

LIST OF FIGURES

SYMBOLS AND ABBREVIATIONS

Symbol	Description
ac	Alternating Current
°C	Degrees Celsius
dc	Direct Current
EEDS	Electro-Expulsive Deicing System
EMI	Electromagnetic Interference
°F	Degrees Fahrenheit
FAA	Federal Aviation Administration
SCR	Silicon Controlled Rectifier
V	Volts
Vac	Volts Alternating Current
Vdc	Volts Direct Current

III.4A ELECTRO-EXPULSIVE DEICING SYSTEMS.

III.4A.1 OPERATING CONCEPTS AND COMPONENTS.

Electro-Expulsive Deicing Systems (EEDS) are classed as mechanical ice protection systems because accreted ice is expulsed from blanket-protected structures by a strong and rapid movement of the blanket outer weathering surface, which overlies parallel electroexpulsive conductors and a nonconducting elastomeric matrix (reference 4A-1). This impulse movement results from an electrical current being pulsed in opposite directions through closely-spaced parallel conductors or conducting layers imbedded in a nonconducting elastomeric matrix within the blanket (figure III 4A-1). An electromagnetic force is thus created that acts to move the conductors or conducting layers apart. With the bottom set or segment of conductors stationary, and the top set or segment moveable (figure III 4A-2), this separation force accelerates the top surface of the blanket outward so as to destroy the ice-blanket bond and inertially expel the surface ice into small pieces. Ice removal is accomplished by aerodynamic forces, centrifugal forces, and to a minor extent, gravity. In the most efficient EEDS designs, a minimum amount of momentum is added to the ice as a result of the expulsive force exceeding the strength of the ice-blanket bond. Actual displacement of the blanket surface is a function of ice thickness. Maximum displacement, on the order of 0.025 to 0.050 in., occurs when there is no ice and the elastomeric matrix is warm. The time for a blanket surface to return to a rest position is on the order of 0.001 second.

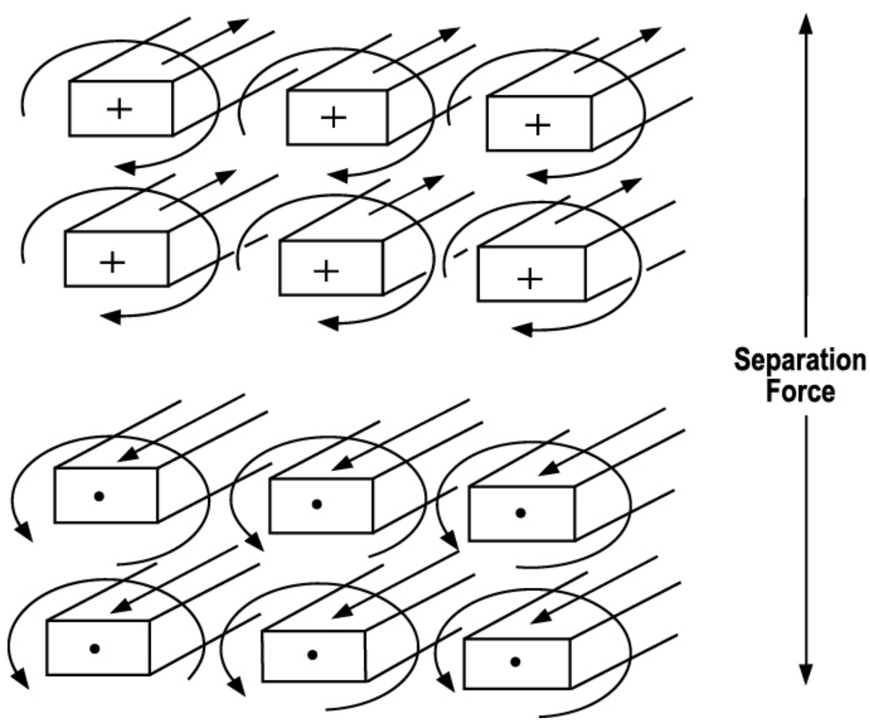

FIGURE III 4A-1. EEDS SEPARATION FORCE CONCEPT

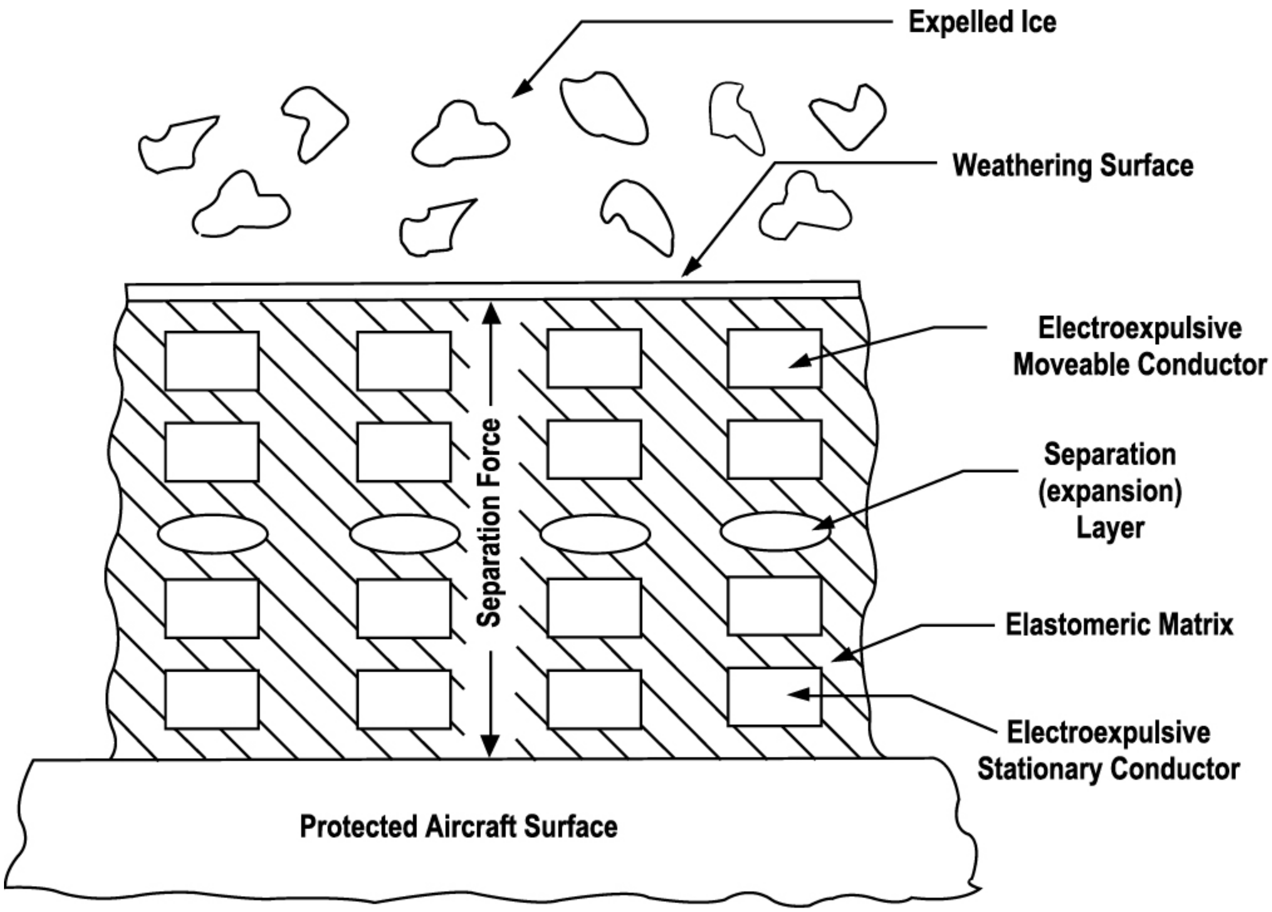

FIGURE III 4A-2. CROSS SECTION OF ENERGIZED BLANKET DEICER SEGMENT

The electroexpulsive deicer conductors are in a self-contained elastomeric medium (blanket) which is bonded onto or integrated into the leading-edge surface and protected by an outer-weathering surface. Other primary components (figure III 4A-3) of an EEDS are some form of controller, energy charging and storage unit(s), energy switching and distribution unit(s), and a cockpit control panel. Miscellaneous components include high-current, low-inductance coaxial cabling, electrical interface wiring, connectors, and the appropriate circuit breakers and/or fuses. All of the EEDS operating equipment can be tailored to operate from either 28 Vdc, 115 Vac single-phase, or 115/200 Vac three-phase configurations.

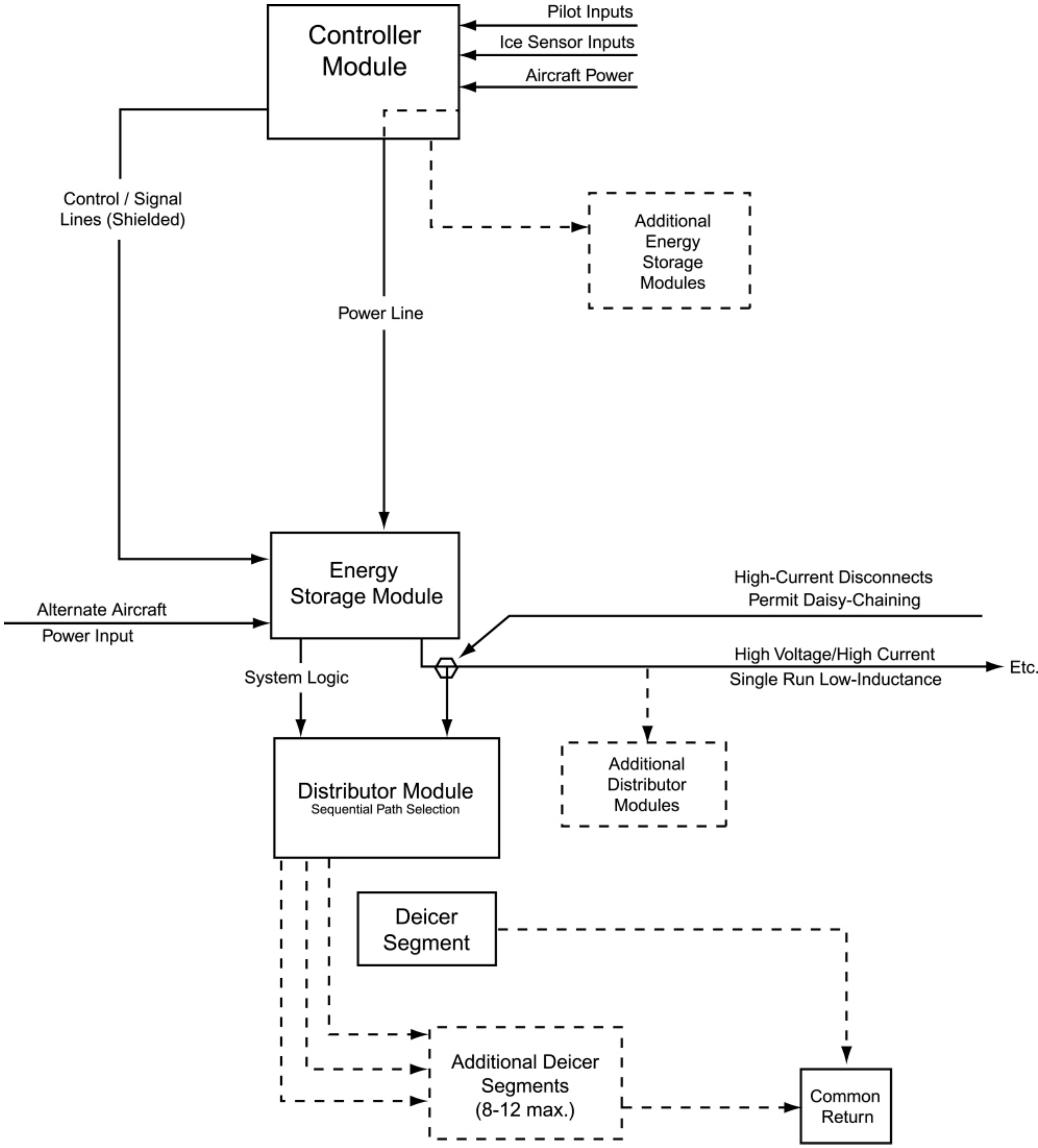

FIGURE III 4A-3. TYPICAL EEDS PRIMARY COMPONENTS

III.4A.2 DESIGN GUIDANCE.

III.4A.2.1 Deicer Blanket.

Deicer blankets differ somewhat between manufacturers but basically consist of an outer weathering surface, an electroexpulsive power circuit (conductors), and a dielectric (nonconducting) elastomeric support matrix. These materials are capable of operating in the temperature range of -67° to 250°F (-55° to 121°C). Blankets are smooth on both sides and nominally from 0.03 (at the leading edge) to 0.08 inch thick. The outer surface of the blanket may be metallic or elastomeric (polyurethane or neoprene), depending upon the application. The metallic surfaced blanket is more difficult to install but has better erosion characteristics and fewer maintenance concerns. The elastomeric surfaced blanket is easier to install and more applicable to retrofit applications.

In addition to providing an aerodynamically smooth surface, the erosion layer also provides a continuous surface to transmit the in-plane horizontal pressure wave of an EEDS blanket. This pressure wave provides ice-shed forces across butted segment joints and also slightly beyond the edge of the outermost conductor.

Blanket materials can be quite simple. This allows material changes for specific reasons with only modest functional test and process verifications. This is advantageous since blanket materials need to be compatible with a number of substrates, adhesive systems, and external environmental conditions. For example, the outer-weathering surface can be changed as material improves. This also permits a potentially simple maintenance philosophy. Should a segment be damaged or fail, the erosion layer is removed, a replacement segment installed, and a new top layer installed to complete the repair.

In addition to the type of blanket installation, consideration must be given to the design and layout of the individual deicer zones or segments within the blanket. These may be configured in many shapes, and either chordwise or spanwise, depending upon the particular application. Although a single-segment blanket is appropriate for small areas, a blanket is typically composed of a number of separate electrical/mechanical deicer segments. Each electrical deicer segment is long and narrow, and multiple segments are butted against each other to increase coverage of the area to be protected. By creating alternate electrical segments, each fired by separate, isolated electronics, blanket level redundancy may be achieved. Should a portion of a blanket of this type fail, the adjacent segment will shed ice in the failed section at a reduced efficiency.

Figure III 4A-4 depicts an airfoil with a deicer blanket configured chordwise with three deice zones. Each segment, as well as the combined blanket assembly, is capable of accommodating moderate compound curves, as well as surface twisting and flexing. Blankets are designed to have all electrical connections made at one end of each segment with power leads routed internally within the deicer and each segment connected to a common return. This keeps harness connections to a minimum length and weight and also simplifies harness installation in restricted structures.

The most common installation is the external surface mount where the blanket is bonded to an existing leading-edge surface. With this type of installation, the edges of the blanket are tapered to provide a smooth transition from the deicer blanket to the airfoil surface. The blanket can also be fabricated with a square edge which allows it to be bonded into an existing airfoil recess and results in a nonintrusive installation. Another installation option is the integrated composite leading-edge assembly. In this case, the blanket is manufactured with a composite structural backing which is designed to meet the structural requirements of the particular application. This option results in a "stand-alone" composite leading-edge assembly with the deicing function built-in and is the most desirable for aerodynamic smoothness.

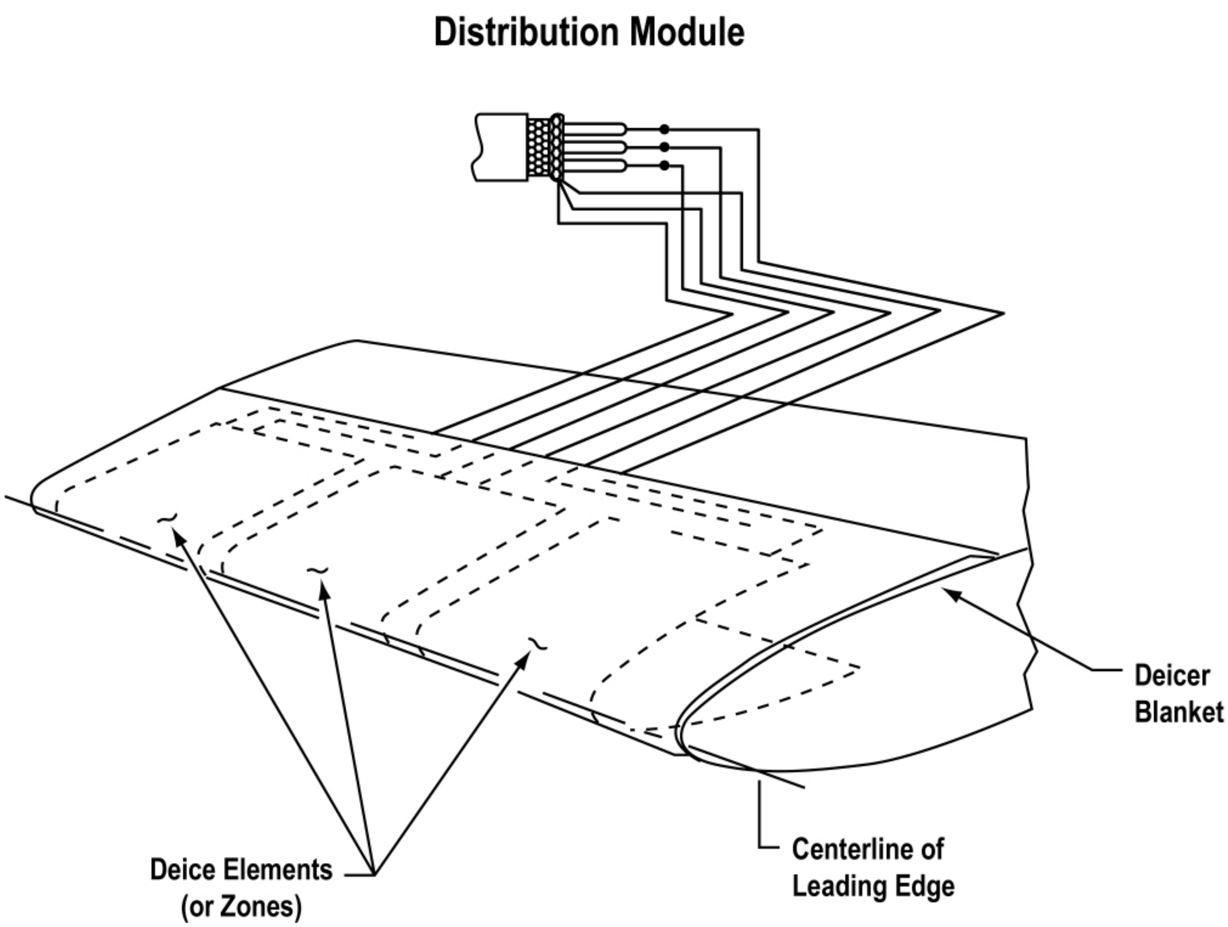

FIGURE III 4A-4. EEDS AIRFOIL BLANKET WITH CHORDWISE DEICER ZONES

III.4A.2.2 Energy Distribution Module.

This unit distributes high voltage, high current, narrow-width pulses to blanket deicer segments via selection circuits and multiple cables. The selection circuits may be implemented with electromechanical switches or silicon controlled rectifiers (SCRs). Current designs use SCRs. The number of SCRs per unit is dictated by system requirements.

The energy distribution module is a high-voltage/high-current carrying device; thus wire sizing and run distance are quite critical between each energy storage module and its family of energy distribution modules and blankets. The ohmic drop and inductive reactance in the wiring must be small compared to the impedance of each blanket segment. The module is usually located within a few feet of the blanket lead exits to minimize weight.

Multiple cables connect associated blanket segments to their energy distribution module which is connected by high-current disconnects to a single run of low-inductance cable leading to its associated energy storage module. Multiple high-current disconnects along this single run of low-inductance cable can be used to daisy chain energy distribution modules.

III.4A.2.3 Energy Storage Module.

This unit is an electronic driver assembly that stores the blanket firing energy in capacitors and, as directed by the controller sequencing logic, fires the high-voltage pulse that will be directed through sw itching circuits to various blanket deicer segments via the energy distribution modules. Voltage levels vary between types and required coverage, but can be on the order of 200 Vdc for simple minimum systems up to near 2000 Vdc for more extensive complex systems.

III.4A.2.4 Controller Module.

The controller receives pilot and optional ice sensor inputs, and contains the logic circuits for monitoring and self-test functions. On some types, aircraft power is inputted to the controller and converted to capacitor charging current. On other types, this function may be part of the energy storage module. The wiring run distance between the controller module and each energy storage module is not critical, and a single run of shielded cable can contain both heavy-current/low-inductance power lines and control signal lines. Depending upon redundancy requirements, one controller module can monitor and operate all EEDS system hardware. For very simple systems, the controller, energy storage, and energy distribution modules can be combined into a single assembly.

III.4A.3 USAGES AND SPECIAL REQUIREMENTS.

III.4A.3.1 Airfoil and Leading Edges.

The EEDS can be adapted to virtually any airfoil or leading edge. Blankets can be fabricated with single or multiple deicing segments in various widths and lengths and for either chordwise or spanwise installations. Installation is done in much the same manner as that of the standard pneumatic deicer and can be accomplished either as original equipment or as retrofit. In the latter case, consideration must be given to the effect on structural integrity of any cabling penetrations. Wiring, harnesses, and module placement differs between manufacturers.

Tests have demonstrated continuous (cyclic) ice shedding in all icing conditions when the accreted ice thickness is between 0.08 and 0.10 inch. As with most mechanical ice removal systems, the thinner accreted ice does not shed completely. Residual ice left after the first deice cycle is usually removed on the second deicing sequence. The EEDS has also demonstrated its ability to maintain shed-ice particle sizes less than 0.25 inch equivalent spherical diameter (reference 4A-2).

III.4A.3.2 Windshields.

EEDS blankets are not optically clear and so are not appropriate to protect windshields from icing.

III.4A.3.3 Engine Inlet Lips and Components.

Elastomeric surfaced EEDS blankets can be designed and constructed to conform to most engine inlets. Consideration must be given to local radii of curvature when internal conductor patterns are defined. The metallic surfaced blanket with compound curvature has not yet been developed.

The major operational concerns to be addressed are particle size, redundancy level, and potential foreign object damage to the engine from a damaged blanket. In a traditional bleed-air thermal system, the entire inlet duct subject to ice accretion or runback is heated to prevent the formation of ice. The water created then must pass through some portion of the engine. In an EEDS protected engine, particles of ice are generated that must also pass through some portion of the engine.

In a traditional bleed-air thermal system, redundancy is achieved by cross-ducting hot air from one engine to the other after a single failure. For EEDS, reasonable redundancy can also be achieved by using interpolated segments. Since ice removal is somewhat less efficient after the first failure of an interpolated blanket, allowance must be made for the thicker ice shed and larger particles produced by this shedding. The reduced shedding efficiency generally means minimum shed thickness on the order of 0.02 inch in the failed area of blanket.

III.4A.3.4 Turbofan Components.

EEDS blankets require electrical connections and have minimum radii of curvature and so are not an appropriate method of protecting moving turbofan components. They can be applied to stationary surfaces as long as the ambient temperatures are compatible with the elastomers used in the blankets. Special elastomers can be used in high-temperature locations but they require nonstandard manufacturing and test procedures.

III.4A.3.5 Propellers, Spinners, and Nose Cones.

Electroexpulsive ice protection can be applied to propellers but the blankets must be specially designed to withstand erosion, centrifugal loads, and the blade flexing. Centrifugal force actually assists in ice shedding. It typically reduces blanket coverage to those blade radii where the G force is less than 3000.

Configuration of an EEDS propeller deicer can be similar to that of an electrothermal propeller deicer in thickness, area, and installation. The energy storage module and controller module are located on the nonrotating side of the hub and the energy distribution module on the rotating side. Interface between the nonrotating and rotating sides is a slip ring assembly which is mounted to the spinner hub. The slip ring is similar to those used for electrothermal systems except that it is rated for higher voltages. It is important to locate the energy storage module as close as possible to the distribution module(s) and blanket(s) to minimize line losses.

Spinners require custom blanket designs to conform to their usually unique shapes. The same electronics used to operate a propeller expulsive system can operate a spinner blanket. The operating environment is usually less severe than that of the propeller.

Nose cones that are required to withstand high temperatures are usually not appropriate for expulsive ice protection. If the nose cone must provide radar or optical transparency then expulsive blankets are not appropriate. Excepting these limitations, expulsive blankets applied to nose cones have characteristics similar to spinner blankets.

III.4A.3.6 Helicopter Rotors and Hubs.

Electroexpulsive deicing blankets have been developed and tested for use on helicopter rotors and aircraft propellers. Their compatibility with composite structure and operational life when rotated has been demonstrated. Their erosion life, due to available materials, is too short for application to be considered to date. Careful consideration must be given to this application because of the increased number of deice zones as well as to fatigue due to the higher centrifugal forces. Helicopter blades flex in a complex manner and blankets must be designed to accommodate this motion. When blades are hinged or include blade folding, the harness that carries pulse current to the blades must be very carefully designed in order to provide long reliable life in its installed environment. Rotating electronics are required as the high-pulse currents cannot be transmitted through slip rings. The energy storage module and the energy distribution module can be integrated into a single package but the additional weight must be added to the rotating system. For rotors and propellers, a synchronizing signal can be applied so that ice shedding occurs when particle trajectories will not intersect aircraft structures. Additionally, design can provide for simultaneous symmetrical shedding on corresponding portions of the rotating airfoil.

III.4A.3.7 Flight Sensors.

Electroexpulsive protection for aircraft flight sensors is not suitable. While blankets can be applied to a pitot sensor, a static port requires heat to keep its internal section from filling with water or ice. In general, protecting a small and delicate flight sensor can best be accomplished by thermal means.

III.4A.3.8 Radomes and Antennas.

In general, the conductors embedded in expulsive blankets are opaque at radar and radio frequencies. Thus, expulsive blankets cannot be used to cover those portions of radomes that must be transparent to radar frequencies or to surround those portions of an antenna that must radiate. In fact, to use expulsive blankets in close proximity to radiated fields, a careful analysis must be performed to ensure that side lobes and fringing effects do not harm intended operation of the antenna.

III.4A.3.9 Miscellaneous Intakes and Vents.

Electroexpulsive blankets can be used on intakes and vents with the same guidelines and restrictions previously discussed for engine inlets. Since failure modes are less significant than for an engine inlet, some of the restrictions can usually be relaxed to produce a less expensive solution.

III.4A.3.10 Other.

Electroexpulsive blankets can be installed in areas that must be routinely accessed but are subject to freezing rain or other forms of ground icing. Latches, access doors, and inspection ports are typical examples. The blankets are fired manually when access is required during or after icing conditions.

III.4A.4 WEIGHT AND POWER REQUIREMENTS.

Weight and power requirements will vary depending upon the manufacturer and the application design. The effects of weight and balance should be considered as part of the application selection.

Careful harness design for expulsive systems is a must to avoid significant weight penalties. Larger systems (150 square feet of protected surface) generally incur a smaller proportional weight penalty than medium sized systems (30 to 150 square feet). Harness weight is usually not an issue for small systems (less than 30 square feet).

III.4A.5 ACTUATION, REGULATION, AND CONTROL.

Several methods of actuation and control are possible depending on the level of sophistication desired.

In its simplest form, the pilot would activate the system through a cockpit control switch. The deicing system would in turn sequence through its deicing cycles at a preset rate. With this method, it must be realized that not all aircraft surfaces are visible to the pilot.

In a more sophisticated state, the controller module would receive input signals from an icing rate detector and automatically select a firing cycle based on the icing condition. With this method, it is necessary for the designer to be certain that ice accretion at the sensor installation site is representative of the most critical areas to be protected. The same signal can be used to notify the pilot when icing conditions begin. A tradeoff must be made to determine the operational requirements with respect to weight, cost, and pilot involvement.

For systems that can tolerate modest accretions of ice, some manufacturers can offer an integral distributed ice detector which uses the blankets and their characteristics to monitor the presence of a significant ice accretion. By monitoring the structural response of blankets with integral sensors, a manufacturer can analyze the natural modes and damping terms of the blanket response when it is fired. When sufficient ice accretes, these change such that an average ice thickness determination can be made. These sensors are also self-deicing. This type of ice detection is largely independent of the airfoil substructure characteristics.

A self-test mode can be included in the controller module which can either be pilot initiated or automatically initiated. The test would cycle through all the deicer segments, checking the distributor positioning and deicer circuit integrity, and verifying the capabilities of the energy storage module. Any deviation from the functional requirements would activate a cockpit warning light.

III.4A.6 OPERATIONAL USE.

A system preflight checkout is recommended. This checkout can be conducted in either of two ways. The first is through the controller self-test mode, which automatically cycles every deice zone and monitors circuit integrity as well as that of the energy storage and distribution modules. This preflight checkout method can also be used as an inflight system check. The second method of preflight checkout is more readily applicable to smaller electroexpulsive systems. This checkout is very simple; one places a hand on the blanket surfaces to ensure that each blanket segment is firing. Also, audible differences are evident for faulty segments.

There is no minimum or maximum ice thickness required or recommended for activation. Operationally, the system should be manually activated in accordance with existing Federal Aviation Administration regulations, which call for turn-on whenever visible moisture is present and the temperature is below 50°F (10°C). Simple systems might merely have a power on/off switch. More complex systems might have an off/auto/manual-on/self-test selector switch plus display of system status and icing rate. In ON and AUTO modes the system will cycle continuously on a predetermined time basis until the system is placed in the OFF mode. In MANUAL-ON mode the system will operate for one complete cycle of all respective deice zones. The predetermined cycle time is a matter of requirement and designed logic circuits. The firing rate of each segment is controlled by the maximum ice particle size that is desired by the systems designer. A leading edge that accretes ice more rapidly and an engine inlet that must expel only small particles of ice will be fired more frequently than other areas that might accrete ice more slowly and do not present a structural impingement problem. Typically, 1- and 3-minute cycle times are used, but an EEDS system has the capability to operate with different cycle times assigned to different deicer segments.

III.4A.7 MAINTENANCE, INSPECTION, AND RELIABILITY.

There is no scheduled maintenance for an electroexpulsive system. Lack of operational and service experience precludes accurate estimates of maintenance intervals and reliability.

Reliability of the system depends on the complexity of the electronics. In general, the electronic reliability is measured in tens of thousands of power-on hours. Blanket operational life is a function of firing frequency and environmental exposure, e.g., erosion and fluid exposure. Blankets can be expected to provide 250,000 cycles. Thus, if every segment is fired once per minute when the system is powered, operational blanket life is 250,000 minutes or 4,166 hours in icing conditions.

Periodic visual inspection of blanket surfaces is recommended for detection of weathering, foreign object damage, or fatigue cracks. Small nicks or cuts can usually be repaired “on aircraft” thus preventing aerodynamic penalties from surface roughness and preventing small flaws from growing. Should a deicer segment be damaged or fail, the erosion layer is removed, a replacement segment installed, and a new top layer installed to complete the repair.

No routine maintenance is presently required for the controller, energy storage, or distribution modules. All modules should be designed as line replaceable units and accessible for repair or replacement. To operate at extremely low temperatures, nonelectrolytic (metallic) capacitors are required to ensure no performance degradation.

III.4A.8 SAFETY.

EEDS blankets are designed so that failure will not create a hazard. The energies required to operate a segment are substantial (short duration high current pulses). When a segment fails it can either open or short internally. The open failure prevents capacitor discharge and the controller module moves on to the next working segment automatically. When there is an internal short, impedance is so low, that the short generates significant conductor heating. The heat vaporizes the conductors in the vicinity of the short and causes an open circuit. As part of the blanket design process, materials and blanket geometry are selected so that the vapors from the vaporized metal and carbonized polymer will be contained within the blanket layers after a failure.

The controller module is designed to isolate high voltage from aircraft ground. Thus, no single failure subjects personnel to hazardous voltages. Most practical EEDS would incorporate ground fault current detection to protect personnel. In order to prevent static charges on blankets from causing internal arcing or creating radio noise, controllers routinely reference the charging circuits to air frame through a large resistance (to maintain personnel safety).

III.4A.9 ELECTROMAGNETIC INTERFERENCE (EMI) CONSIDERATIONS.

EMI considerations for EEDS blankets, harness, and controllers are significant. Blankets are designed to largely cancel the electric and magnetic fields generated at a relatively small distance from the blankets. Thus, MIL-STD-461 emissions requirements are satisfied. Harnesses between the energy storage module and blankets generate pulsed magnetic fields that can couple to sensitive wire bundles if those bundles are too close to the high currents. Distances exceeding 6 inches usually afford adequate protection.

Controller modules are designed to provide compliant operation. They are neither susceptible nor excessively noisy electrically, except for the high current pulse emanating from the energy storage module-to-blanket harness when a segment is fired.

III.4A.10 PENALTIES.

Expulsive ice protection sheds particles of ice. If these particles are not tolerable then expulsive ice protection cannot be used.

If radar cross-section is to be controlled, then expulsive blankets may not be compatible with radar-signature requirements. The high-copper content in an expulsive blanket makes it radar reflective, therefore, potentially compromising to stealth aircraft.

Particle size is a function of firing frequency and the ice accretion rate. To make smaller particles, the blankets must be fired more frequently, and this will shorten blanket life.

III.4A.11 ADVANTAGES AND LIMITATIONS.

- Advantages of the EEDs system are:

  a. Low-power requirements, so low that it may be operated in all flight regimes including takeoff and landing without compromising engine performance.

  b. Affords ice protection without creating water run-back and refreeze.

  c. Reduces aerodynamic penalty during icing encounters. Reliable thin-ice removal capability with limited residual ice. Ice thickness of 0.08 to 0.10 inch can be consistently shed while maintaining ice shed particle sizes on the order of 0.25 inch sphere-equivalent diameter.

  d. Blankets can be triggered to fire at a precise instant making it possible for ice shed from rotors and propellers not to impact aircraft structures.

  e. External surface mount installation is easily retrofit to existing aircraft surfaces.

  f. Integrated leading-edge composite installation is nonintrusive for aerodynamic smoothness.

- Limitations of the EEDS system are:

  a. System not presently installed or certified on any aircraft.
  b. Field service data on maintenance and reliability not available.
  c. Some residual ice will remain after cycling.
  d. Noise associated with pulsing the system has to be considered.
  e. Composite blanket surfaces not as durable as metal surfaces.
  f. Lack of blanket transparency to electromagnetic wavelengths.
  g. Pulse firing creates some degree of EMI and suppression must be considered.

III.4A.12 CONCERNS.

In view of the lack of operational experience with EEDS systems, fatigue of the deicer surface and conductors is a concern. Laboratory testing has demonstrated over 300,000 impulse cycles without fatigue failure. Fatigue will be a major design consideration for rotating applications requiring ice protection.

Electromagnetic interference may occur when the high-energy pulse (high voltage) is discharged. The rapid discharge of up to 2000 volts creates transient electromagnetic fields and may cause undesirable signals in communication, control, or navigation equipment. EMI testing of flight test hardware has demonstrated that this undesirable effect can be suppressed.

Whenever a high-pulse current harness is installed, care must be exercised to exclude sensitive wiring from the immediate vicinity of the harness. Usually, 6 inches of spacing is sufficient to limit coupling effects to acceptable levels.

III.4A.13 REFERENCES.

4A-1. Goldberg, J. and Lardiere, B, "Developments in Expulsive Separation Ice Protection Blankets," AIAA 89-0774.

4A-2. Bond, T.H., Shin, J., Mesander, G.A., and Yeoman, K.E., "Results of USAF/NASA Low Power Ice Protection Systems Test in the NASA Lewis Icing Research Tunnel," NASA TP 3319, 1993.

III.4A.14 GLOSSARY.

Dielectric — An insulator or nonconducting electrical medium.

Elastomeric — Any substance having the properties of rubber.

Electromagnetic interference — The field of influence produced around a conductor by the current flowing through it which contributes to a degradation in performance of an electronic receiver. Also called electrical noise, radio interference, and radio-frequency interference.

Equivalent spherical diameter — The uniform diameter an ice shard would have after melting into a liquid water droplet.

G-force — A dimensionless descriptor relative to normal of the force acting upon an object due to gravity, where two Gs would infer a weight doubling due to twice the gravitational pull upon the object mass. Also used to describe acceleration or centrifugal reactive forces.

Neoprene — Any of a group of synthetic rubbers. A nonconductor of electricity and superior to rubber in wear resistance.

Polyurethane — A strong plastic resin that resists fire, weather, and corrosion; made in flexible or rigid materials. A nonconductor of electricity.

Silicon controlled rectifier — A semiconductor device that functions as an electrically controlled switch for dc loads. Also known as a "thyristor" which is the solid state equivalent of a thyratron vacuum tube.