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CHAPTER III

SECTION 1A.0

PNEUMATIC IMPULSE DEICING SYSTEMS

CHAPTER III—ICE PROTECTION METHODS

CONTENTS

				Page
III.1A	PNEUMATIC IMPULSE DEICING SYSTEMS			III 1A-1
	III.1A.1	Operating Concepts and Components		III 1A-1
	III.1A.2	Design Guidance		III 1A-3
		III.1A.2.1	Deicer Embodiments	III 1A-3
		III.1A.2.2	Air Supply and Distribution	III 1A-4
		III.1A.2.3	Impulse Valve Location	III 1A-4
	III.1A.3	Usages and Special Requirements		III 1A-5
		III.1A.3.1	Airfoil and Leading Edges	III 1A-5
		III.1A.3.2	Windshields	III 1A-5
		III.1A.3.3	Engine Inlet Lips and Components	III 1A-5
		III.1A.3.4	Turbofan Components	III 1A-5
		III.1A.3.5	Propellers, Spinners, and Nose Cones	III 1A-5
		III.1A.3.6	Helicopter Rotors and Hubs	III 1A-5
		III.1A.3.7	Flight Sensors	III 1A-5
	III.1A.4	Weight, Power, and Envelope Requirements		III 1A-6
	III.1A.5	Actuation, Regulation, and Control		III 1A-6
	III.1A.6	Operational Use		III 1A-6
	III.1A.7	Maintenance, Inspection, and Reliability		III 1A-7
	III.1A.8	Advantages and Potential Tradeoffs		III 1A-7
	III.1A.9	Concerns		III 1A-8
	III.1A.10	References		III 1A-8
	III.1A.11	Glossary		III 1A-8

LIST OF FIGURES

Figure		Page
III 1A-1	Typical Integrated Composite Leading-Edge Assembly	III 1A-2
III 1A-2	Typical System Schematic	III 1A-3

LIST OF TABLES

Table Page

III 1A-1 System Weight, Power, and Size Estimates III 1A-6

SYMBOLS AND ABBREVIATIONS

Symbol	Description
°C	Degrees Celsius
cm	Centimeter
°F	Degrees Fahrenheit
ft	Feet
gpm	Gallons per minute
Hp	Horsepower
in.	Inch
KPa	Kilopascals
lbf	Pound-force
lbm	Pound-mass
LWC	Liquid Water Content
mm	Millimeter
m	Meter
MPa	Megapascals
OAT	Outside Air Temperature
PEEK	Polyetheretherketone
PIIPTM	Pneumatic Impulse Deicing
psig	Pounds per square inch-gauge
psia	Pounds per square inch-absolute
SCF	Standard Cubic Foot
SCFM	Standard Cubic Feet per Minute
sec	Seconds
Vdc	Volts - Direct Current
w	Watts

III.1A PNEUMATIC IMPULSE DEICING SYSTEMS.

III.1A.1 OPERATING CONCEPTS AND COMPONENTS.

Pneumatic impulse deicing, also called Pneumatic impulse ice protection (PIIP™), is a mechanical ice removal system which fractures, debonds, and expels accreted atmospheric ice from the ice-accumulating surfaces of aircraft. Information on the development of this system can be found in references 1A-1 through 1A-4.

The removal is accomplished by a rapid distortion of the outer surface which occurs upon the introduction of a controlled burst of expanding high-pressure air into a collapsed flexible channel or impulse tube, located underneath the surface (figure III 1A-1). As the expanding air traverses through the tube, the overlying surface is “snapped” outward, inducing bending stresses in the surface and the attached ice, as well as shear stresses at the ice/surface interface. The removal process is augmented by the high outward normal velocity, which is imparted to the surface by the expanding air as well as by the airstream. The expanded air is then vented to ambient through ports located in the backside of the deicer.

The system consists of one or more deicers which cover the surface(s) to be protected. Typically, the deicer is built into the leading edge or ice-accreting structure so as to form a smooth, aerodynamically nonintrusive surface. The deicer consists of a thin erosion surface overlying a quasi-flexible polymeric matrix which houses the fabric-reinforced impulse tubes (figure III 1A-1). The tubes are typically oriented in the spanwise (longitudinal) direction. The deicer is designed so that the surface region of action of the impulse tubes matches the region in which atmospheric ice may be expected to accrete for the particular application. This region is determined by analysis or testing of the limits of impingement for the defined icing conditions.

The regulated high-pressure air source may be either a dedicated onboard compressor, stored air reservoir or bottle, or other high-pressure pneumatic system. System operating pressure is typically 600 to 1200 psig.

One or more impulse valves deliver a metered quantity of high-pressure air to the impulse tube(s) in the deicer in a manner which achieves the desired movement, characteristic, or impulse on the surface. Valve activation occurs upon a signal from the controller, typically 28 Vdc, for 0.05 sec. duration. Upon activation, the regulated supply air to the valve is shut off and the impulse air is discharged into the deicer. The quantity of air required per impulse is typically sufficient to deice up to 8 sq. ft. of surface area. Upon deactivation of the valve, regulated supply air is allowed to “recharge” the valve. Recharge time is typically 1 second. The controller provides the timing and switching functions of the 28 Vdc control signals required for operating the impulse valves. The controller also provides the fault detection and annunciation functions for verifying proper operation of the system.

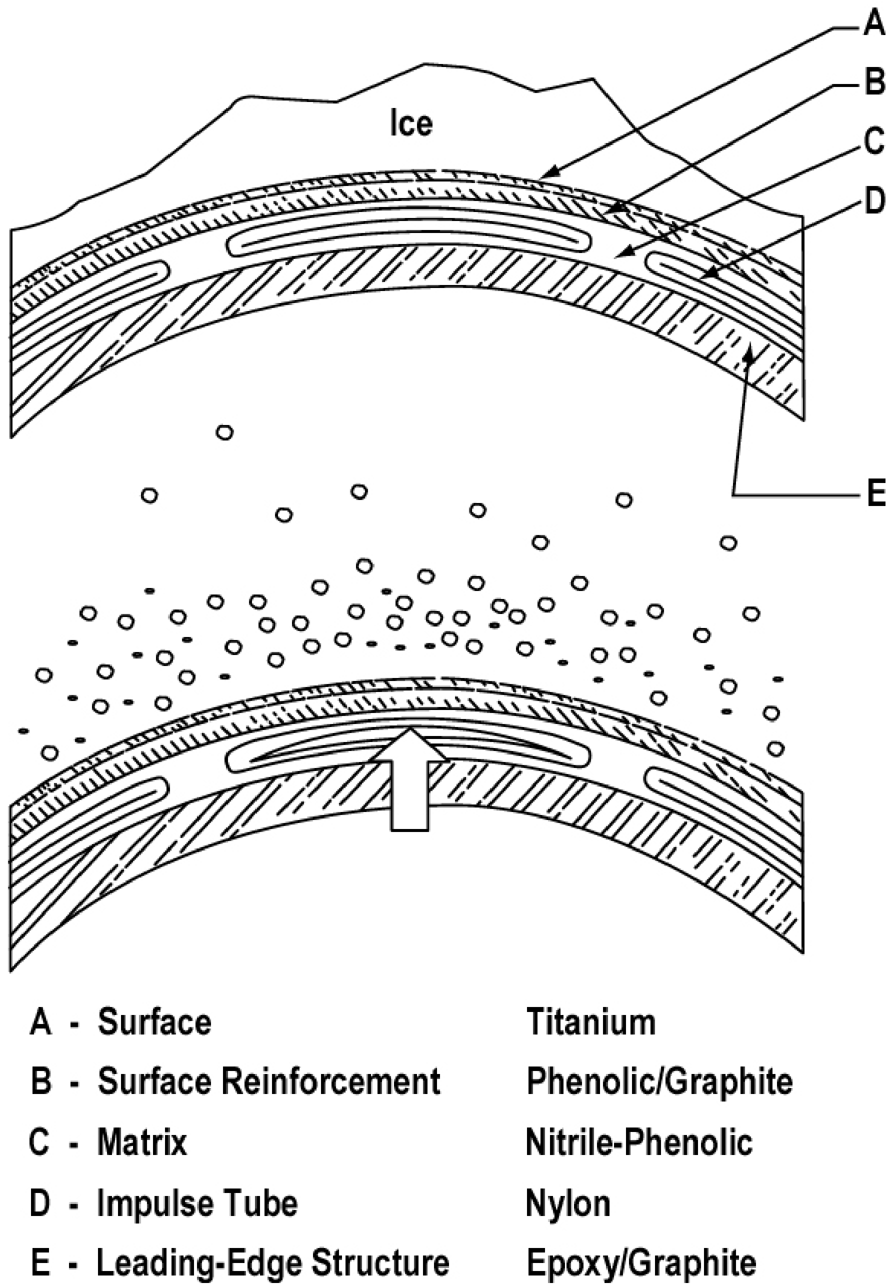

FIGURE III 1A-1. TYPICAL INTEGRATED COMPOSITE LEADING-EDGE ASSEMBLY

Ancillary system operating equipment includes:

- Regulator: Regulates source air to system operating pressure.
- Pressure Switch: Used to indicate delivery of a satisfactory impulse to the controller.
- Shut-off Valve: Used for enabling/disabling compressor hydraulic supply or reservoir supply line when system is turned ON/OFF.

- Air Supply Conduit: Typically size -4 (1/4 in. OD), 3000 psig (20.7 MPa) tubing for distribution of regulated supply air to the impulse valves.

- Wire Harness: Used for interconnecting controller to impulse valves and pressure switches for control and fault detection.

A typical system schematic is shown in figure III 1A-2.

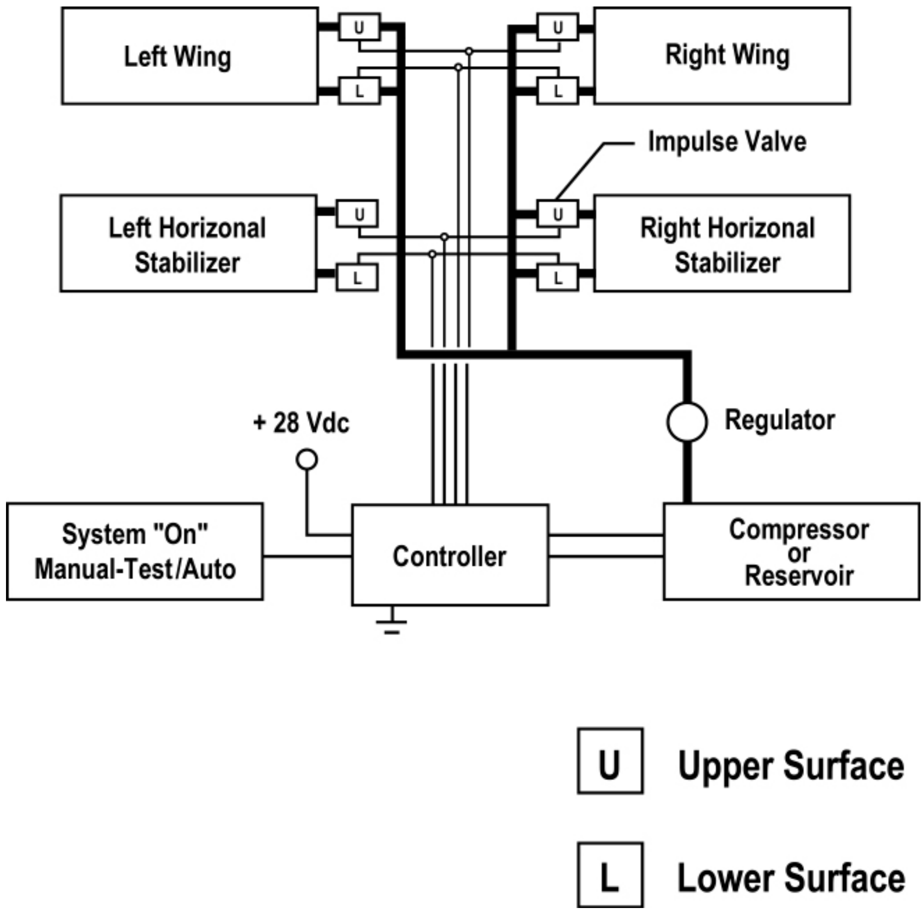

FIGURE III 1A-2. TYPICAL SYSTEM SCHEMATIC

III.1A.2 DESIGN GUIDANCE.

III.1A.2.1 Deicer Embodiments.

The surface material may be titanium alloy, the high performance thermoplastic called polyetheretherketone (PEEK), or a toughened, impact-resistant, fabric-reinforced thermoset resin composite. PEEK or composite surfaces are generally used for applications in which a metal surface is not desirable. All surfaces have been tested extensively for ice removal performance and cycle life.

The deicer may be configured in a number of ways depending on the manner in which it is desired to be installed on the aircraft.

- Skin-Bonded: The deicer is bonded to an existing leading-edge skin, or structure, in a manner similar to conventional pneumatic deicers. This method is most suitable to field installations or retrofit applications, and facilitates removal and replacement; however, it results in an aerodynamically intrusive installation if not recessed.

- Recess-Bonded: The deicer is bonded into a recess in the skin, resulting in a nonintrusive installation.

- Integrated Composite Leading-Edge Assembly: The deicer is manufactured with composite structural backing, designed to meet the structural requirements of the application, resulting in a "stand-alone" composite leading-edge assembly with the deicing function built-in. This is the most desirable embodiment for an aerodynamically smooth and nonintrusive installation.

- Modular Composite Leading-Edge-Assembly (MCLEA): This is similar to the integrated composite leading-edge assembly, except that the surface assembly of the ice protector, consisting of the surface and its composite reinforcement, is mechanically attached, rather than internally bonded, to the underlying portion of the ice protector and leading-edge structure. This allows the surface assembly to be removed and replaced as a separate item should the surface be damaged, without requiring replacement of the entire leading edge.

III.1A.2.2 Air Supply and Distribution.

The system is powered by high-pressure air provided by a dedicated onboard compressor, a stored air reservoir, or another high-pressure aircraft pneumatic system.

The compressor may be either hydraulic or electric motor driven. The hydraulic option is generally more desirable from a weight and size standpoint, provided ample flow capacity from the aircraft hydraulic system is available. The stored air reservoir has the obvious disadvantage of requiring periodic recharging.

Generally, the high-pressure air is regulated to system operating pressure and distributed via a high-pressure line to one or more impulse valves located in the vicinity of the surfaces to be protected. System operating pressure is 600 psig (4140 KPa) nominal for PEEK-surfaced and composite-surfaced deicers and 1200 psig (8280 KPa) nominal for the titanium-surfaced embodiment.

III.1A.2.3 Impulse Valve Location.

It is generally preferable to locate the impulse valves as close to the region to be deiced as possible, in order to minimize attenuation of impulse strength. In practice, the valves are located immediately behind the leading-edge surface wherever possible, and are connected directly to the inlet ports which access the deicing tubes. Where space does not permit this type of installation, it is possible to locate the valves remotely from the deicer, with some reduction in the surface area that may be effectively deiced. The air inlet ports are typically located on the backside of the deicer, but may be provided externally for applications, such as rotor blades, where internal access is not possible.

III.1A.3 USAGES AND SPECIAL REQUIREMENTS.

III.1A.3.1 Airfoil and Leading Edges.

As with most mechanical ice removal systems, thicker ice will more readily be shed than thin ice. Thus, the thinness of the ice which can be effectively removed becomes a measure of the ice removal performance of the system. In extensive icing tunnel tests, the deicer has demonstrated maximum ice thicknesses of 0.080″ to 0.100″ in continuous cyclic shedding in all icing conditions, including difficult slush ice, with shed ice particles sizes less than 0.25 in. equivalent spherical diameter.

III.1A.3.2 Windshields.

Pneumatic impulse deicing is not applicable to windshield deicing.

III.1A.3.3 Engine Inlet Lips and Components.

PEEK-surfaced and composite-surfaced pneumatic impulse deicers have been demonstrated in icing wind tunnel tests to provide effective ice removal performance on engine inlet lips. Use of titanium on surfaces with compound curvature has not yet been developed.

III.1A.3.4 Turbofan Components.

The suitability of pneumatic impulse for use on turbofan components has not yet been evaluated.

III.1A.3.5 Propellers, Spinners, and Nose Cones.

The suitability of pneumatic impulse for use on these surfaces has not yet been evaluated.

III.1A.3.6 Helicopter Rotors and Hubs.

PEEK, composite-surfaced, or titanium-surfaced pneumatic impulse embodiments have all been icing-tunnel tested extensively and satisfactorily on rotor-blade airfoil shapes, but in a fixed rather than rotating condition. Special consideration would have to be given to location of the impulse valves and deicing ports, as well as the transmission of the high-pressure source air through a rotating union. These items have not been addressed to date.

III.1A.3.7 Flight Sensors.

Pneumatic impulse deicing is not suitable for the protection of flight sensors.

III.1A.4 WEIGHT, POWER, AND ENVELOPE REQUIREMENTS.

The weight, power and size estimates listed in table III 1A-1 are for guideline purposes only and may vary depending on the application. Also, these values reflect the current state of the system and may change with continued operational experience. Deicer values are specified on a unit area basis, and discrete components are specified on a unit basis. Weight and power required for a specific application may be estimated by multiplying the appropriate values by the surface area which would be required to be deiced.

TABLE III 1A-1. SYSTEM WEIGHT, POWER, AND SIZE ESTIMATES

Item	Unit Weight	Quantity or Application	Power	Envelope Dimensions
Deicer	0.50 lb/sq.ft.*	-	-	0.100″ thick
Impulse Valve	1.0 lb.	1 valve/8 sq. ft.	300W***	5.5″ x 4.2 x 1.5″
Compressor	21.0 lb.	one	1.6 gpm**	11.5″ x 9 x 10.3″
Controller	1.0 lb.	one	3W	4.8x 4.0 x 3.6″
Regulator	0.2 lb.	one	-	2.6″ x 2.0 x 1.0″
Shut-Off Valve	0.8 lb.	One	24W	3.2″ x 2.5 x 2.0″
Pressure Switch	0.2 lb.	One per impulse valve	-	2.5″ x 1.0 x 1.0″

* per sq. ft. of ice accreting surface area.
** nominal flow rate of 2500 psig hydraulic fluid.
*** intermittent power requirement: 0.1% duty cycle.

Notes: Compressor weight and power values based on hydraulic motor-driven unit.

Values for electric motor-driven unit will vary.

Deicer weight does not include composite substructure which must be designed in accordance with aircraft manufacturer's structural requirements.

III.1A.5 ACTUATION, REGULATION, AND CONTROL.

The controller automatically and repetitively operates the impulse valves in a manner which provides symmetric shedding about the aircraft centerline, typically on a fixed-time cycle basis. Generally, the system may also be commanded to perform a single shedding cycle "on demand." System function may also be initiated by a remote signal, such as from an OAT, LWC, or ice detector sensor. Typically, the control and fault detection functions are provided by a dedicated deicing system controller, but these functions may also be assigned to an onboard computer.

III.1A.6 OPERATIONAL USE.

Preflight checkout of the deicing system, by use of a self-test mode, is recommended. The system is capable of operating in the temperature range of -67° to +165°F. The system should be activated by selection of the AUTO cycle mode when icing conditions are known or expected.

In this mode the system will cycle continuously on a predetermined, fixed-time basis, typically 1-minute cycles, until the system is switched OFF. A momentary MANUAL command may also be used to operate the system for one cycle of the entire aircraft on demand.

There is no minimum or maximum ice thickness required or recommended for initiation of system operation.

There are presently no reduced ice adhesion (icephobic) or weathering-enhancing coatings required or recommended with either the titanium or PEEK-surfaced deicers.

Composite-surfaced deicers may require a coating to withstand the effects of rain erosion, particularly for high-speed aircraft. The coating may be spray-applied in the field periodically as required to refurbish the surface.

Use of paint on active deicing surfaces is not recommended unless approved by the aircraft manufacturer.

III.1A.7 MAINTENANCE, INSPECTION, AND RELIABILITY.

Lack of operational and service experience precludes accurate estimates of maintenance intervals and reliability.

Periodic visual inspection of the deicing surfaces is recommended for detection of foreign object damage or fatigue cracks. Impulse valves should be accessible for repair or replacement, as should the compressor and controller. Periodic filter replacement and lubricating oil changes, if applicable, may be required on the compressor. No routine maintenance is presently required on the impulse valve, the deicer, or the controller.

III.1A.8 ADVANTAGES AND POTENTIAL TRADEOFFS.

Advantages of the system are:

a. Low power requirements.

b. Aerodynamically nonintrusive in an integrated composite leading-edge-embodiment.

c. Thin ice removal capability: 0.080″ to 0.100″ ice thickness in all icing conditions, and shed ice particle sizes less than 0.25″ equivalent spherical diameter.

d. Low radar capability in PEEK-surfaced and composite-surfaced embodiments.

e. No runback and refreezing.

Potential tradeoffs of the system are:

a. The system is not presently installed or certified on any aircraft. Therefore, field service data on maintenance and reliability is not available.

b. As with all mechanical deicing systems, some residual ice will remain after cycling.

c. Noise associated with pulsing the system has to be considered.

d. Ordinarily the system must be designed into the leading edge and, therefore, is not readily suitable for retrofit applications.

III.1A.9 CONCERNS.

Fatigue of the deicer surface is a concern, particularly in view of the lack of operational experience with the system. Laboratory testing to date has demonstrated over 250,000 impulse cycles prior to the onset of surface fatigue, and efforts are continuing to reduce the stresses which are induced by impulse.

III.1A.10 REFERENCES.

1A-1. Sweet, D., "Development of an Advanced Pneumatic Deicing System," A-87-46-65-J000, American Helicopter Society, 43rd Forum, May 1987.

1A-2. Leffel, K., Putt, J., and Martin, C., "Development of an Advanced Impulse Deicing System," AIAA-89-0492, paper presented at the 27th Aerospace Sciences Meeting, Reno, Nevada, January 1989.

1A-3. Ramamurthy, S., Keith, T., and DeWitt, K., "Numerical Modeling of an Advanced Pneumatic Impulse Ice Protection System (PIIP) for Aircraft," AIAA-91-0555, paper presented at the 29th Aerospace Sciences Meeting, Reno, Nevada, January 1991.

1A-4. Martin, C. A. and Putt, J. C., "Advanced Pneumatic Impulse Ice Protection System (PIIP) for Aircraft," J. Aircraft, Vol. 25, No. 4, July-August 1992, pp. 714-16.

III.1A.11 GLOSSARY.

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

Icephobic — A surface property exhibiting a reduced adhesion to ice, literally, "ice-hating."