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ELECTRO-EXPULSIVE DE-ICER FLIGHT TESTS

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Abstract

The basic principles of the electro-expulsive de-icing system are explained. Installation of a test panel and natural icing flight tests in a DeHavilland DHC-6 turbo prop aircraft are discussed. Also covered is the installation of the electro-expulsive de-icer on the engine inlet of a McDonnell-Douglas F/A-18 jet fighter and the subsequent icing tanker tests.

1. Introduction

A primary concern of aircraft component ice protection is to minimize aircraft flight performance degradation. This concern usually leads to the use of anti-ice systems that prevent the accumulation of ice. However, anti-ice systems require high energy that can result in unacceptable aircraft power and weight penalties. As an alternative that substantially reduces operating power, the electro-expulsive de-icer limits the ice accumulated to thin layers that lessen flight performance losses and the effects of ice particles shed from the protected surface.

2. Background

De-ice concepts cyclically remove accumulated ice to limit the amount of ice collected. Designers usually choose thermal de-ice systems over thermal anti-ice systems when the operating power supply is limited, the aerodynamic penalty of ice collected between de-ice cycle is acceptable and there are no aircraft hazards from the ice that is shed.

Mechanical de-ice systems have lower power requirements than the thermal de-ice methods and avoid a potential hazard of thermal de-ice systems which can cause melted ice to refreeze beyond the protected zone and form "runback" ice that adds weight and aerodynamic penalties.

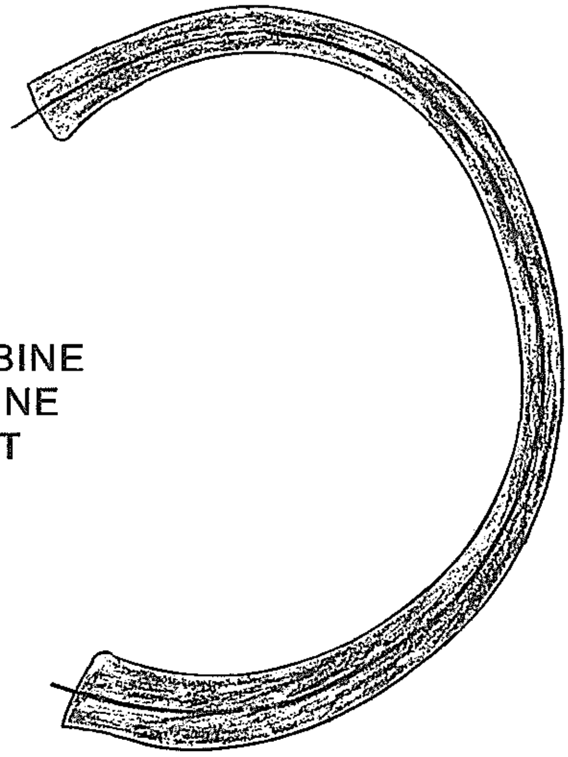
The conventional pneumatic de-icer mechanically removes ice and has very low operating power and associated system weight. The pneumatic de-icer is normally operated to remove minimum thicknesses of ice in the 1/4 to 1/2 inch range.

The need to mechanically de-ice very thin ice led to development of the electro-expulsive de-icer. The systems tested were based on the electro-expulsive de-icer concept described in a NASA patent (Reference 1).

Figure 1 shows comparative average power requirements for representative thermal anti-ice and de-ice systems as well as an electro-expulsive de-icer for a turbine engine inlet.

3. Principles of Operation

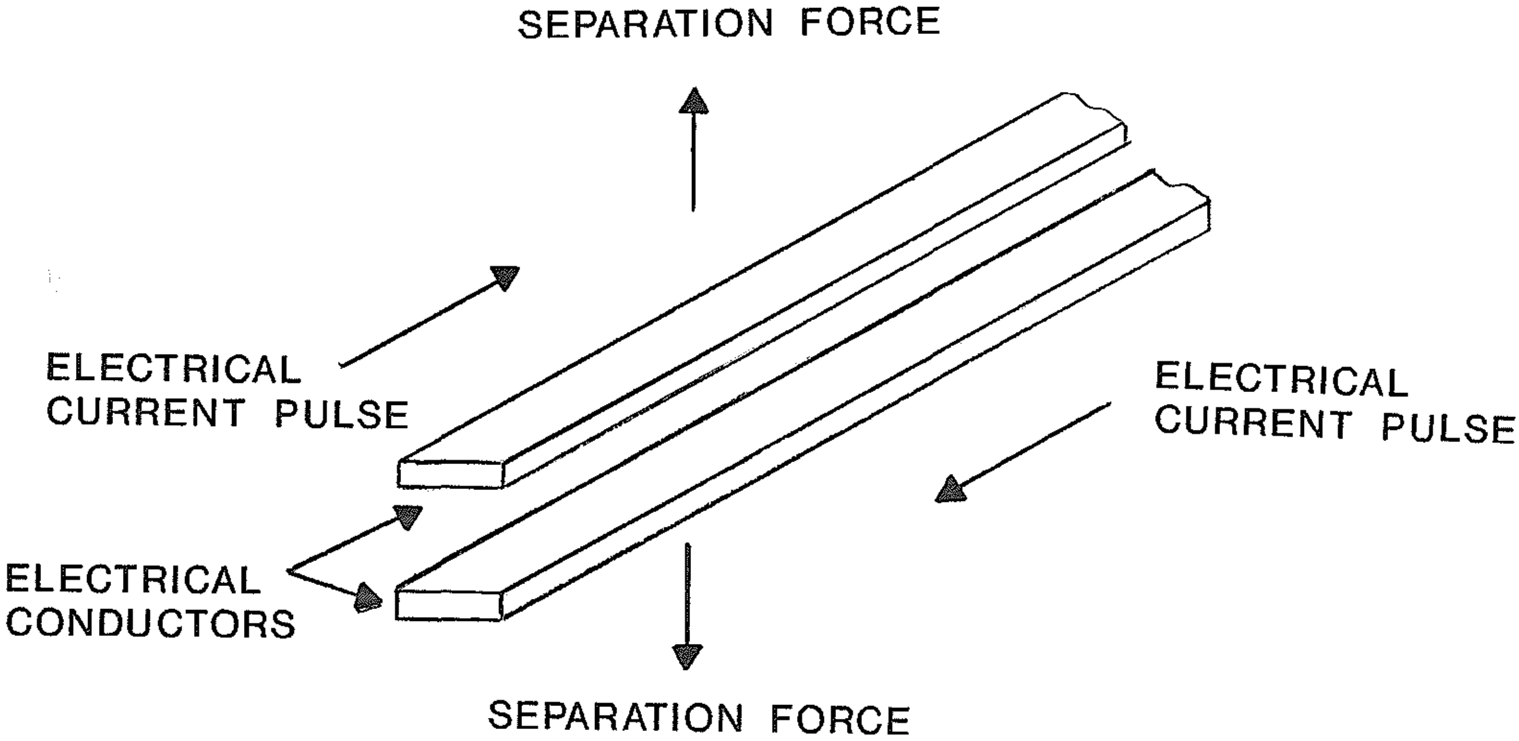
The electro-expulsive de-icer uses the electro-magnetic repulsion principle. When a high amperage electrical current is pulsed in two closely spaced parallel electrical conductors a strong mechanical force is produced. If the electrical current flow in the conductors is in opposite directions, an electro-repulsive force is created that acts to move the two conductors apart. See Figure 2. The forces of multiple sets of parallel conductors in two layers can be directed to an ice covered surface to break the ice.



TYPE OF ICE PROTECTION	POWER REQUIRED WATTS*
THERMAL EVAPORATIVE ANTI-ICE	6,100
THERMAL RUNNING WET ANTI-ICE	39,000
THERMAL DE-ICE	4,800
MECHANICAL DE-ICE ELECTRO-EXPULSIVE	175

* F/A-18

COMPARATIVE POWER REQUIREMENTS
FIGURE 1



ELECTRICAL PULSE CAUSES
SEPARATION FORCE IN
CLOSE PARALLEL CONDUCTORS

FIGURE 2

As applied over an airfoil surface to be ice protected, an electro-expulsive de-icer consists of the following. See Figure 3. A base material layer containing a set of closely spaced flat, parallel electrical conductors is bonded to the airfoil surface. A second layer or outer weathering layer contains a second set of closely spaced flat, parallel electrical conductors that lie opposite to and are electrically isolated from the base layer conductors. The isolation layer also allows the conductor layers to move apart when electrically energized.

The action of a high electrical current impulse or discharge through the conductor layers causes the outer surface conductor to deflect rapidly and forcefully away from the base layer conductors. This expulsive reaction breaks and expels outer surface ice into small pieces.

The power source for the high electrical current discharge is a capacitor bank that receives its charge from a low voltage power converter.

4. System Description

In addition to the de-icer other system components are the controller, charging/energy storage unit and the distributor. See Figure 4.

The de-icer is divided into de-icing segments to limit the amount of stored energy required and thus the weight of the energy storage unit.

The controller contains all system logic. It receives and interprets all input signals from a pilot's panel and/or an aircraft ice protection control unit or an aircraft ice sensing system. The controller then directs and monitors the use of aircraft electrical power to the charging/energy storage unit. The controller also directs and monitors the discharge of electrical pulses from the energy storage section through controlled distributor switching to individual de-icer de-icing segments.

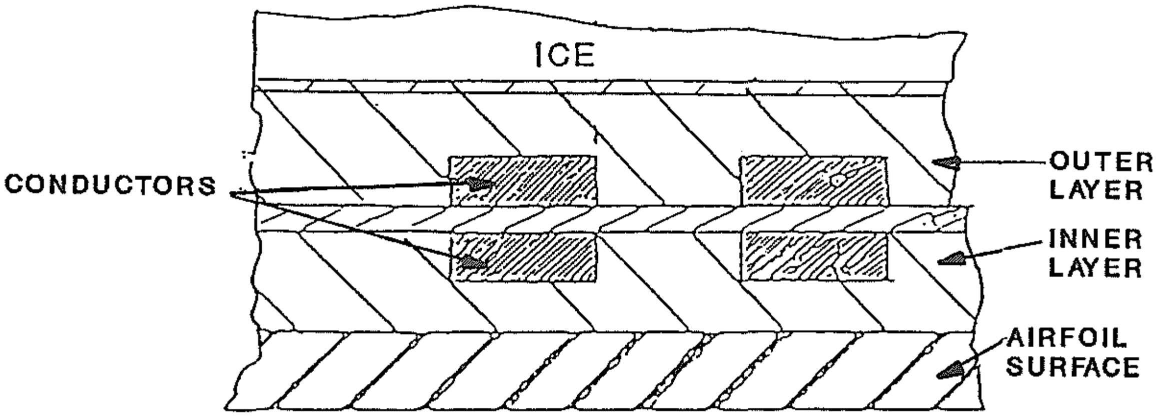
The charging energy section raises aircraft electrical system input voltage to charge the energy storage unit bank of capacitors to the correct high voltage. The capacitor bank charge is then sent to the selected distributor output by controller signal.

The distributor contains a multiple position switching unit that directs the charging energy storage unit discharge pulses to de-icer segments as directed by the controller.

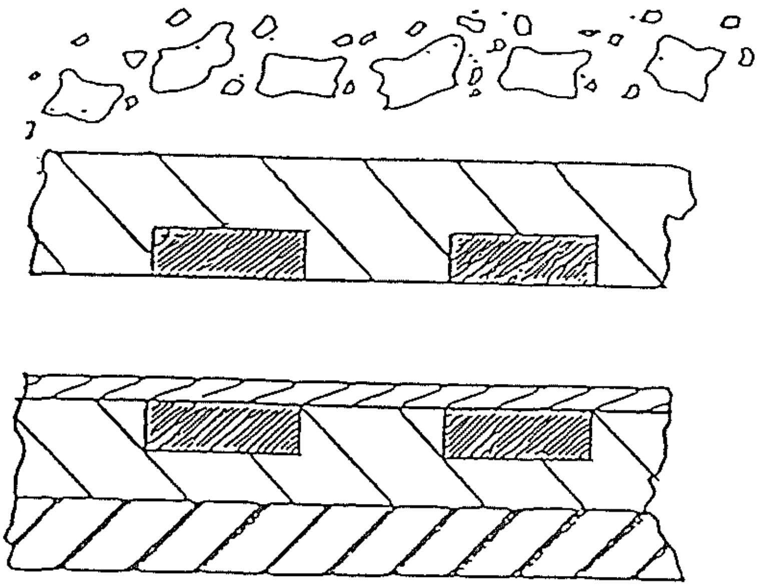
For the proof-of-concept flight tests all system operating components were combined into a single container.

5. Icing Flight Tests

Two icing tests were conducted in joint BFGoodrich/NASA programs. In the first test, natural icing evaluations were made on a de-icer applied to an airfoil mounted on a DeHavilland DHC-6 aircraft. In the second test, tanker (artificial) icing evaluations were made to a de-icer installed on McDonnell-Douglas F/A-18 engine inlet. Both tests were initial flight exposures of the electro-expulsive de-icer for proof-of-concept studies.



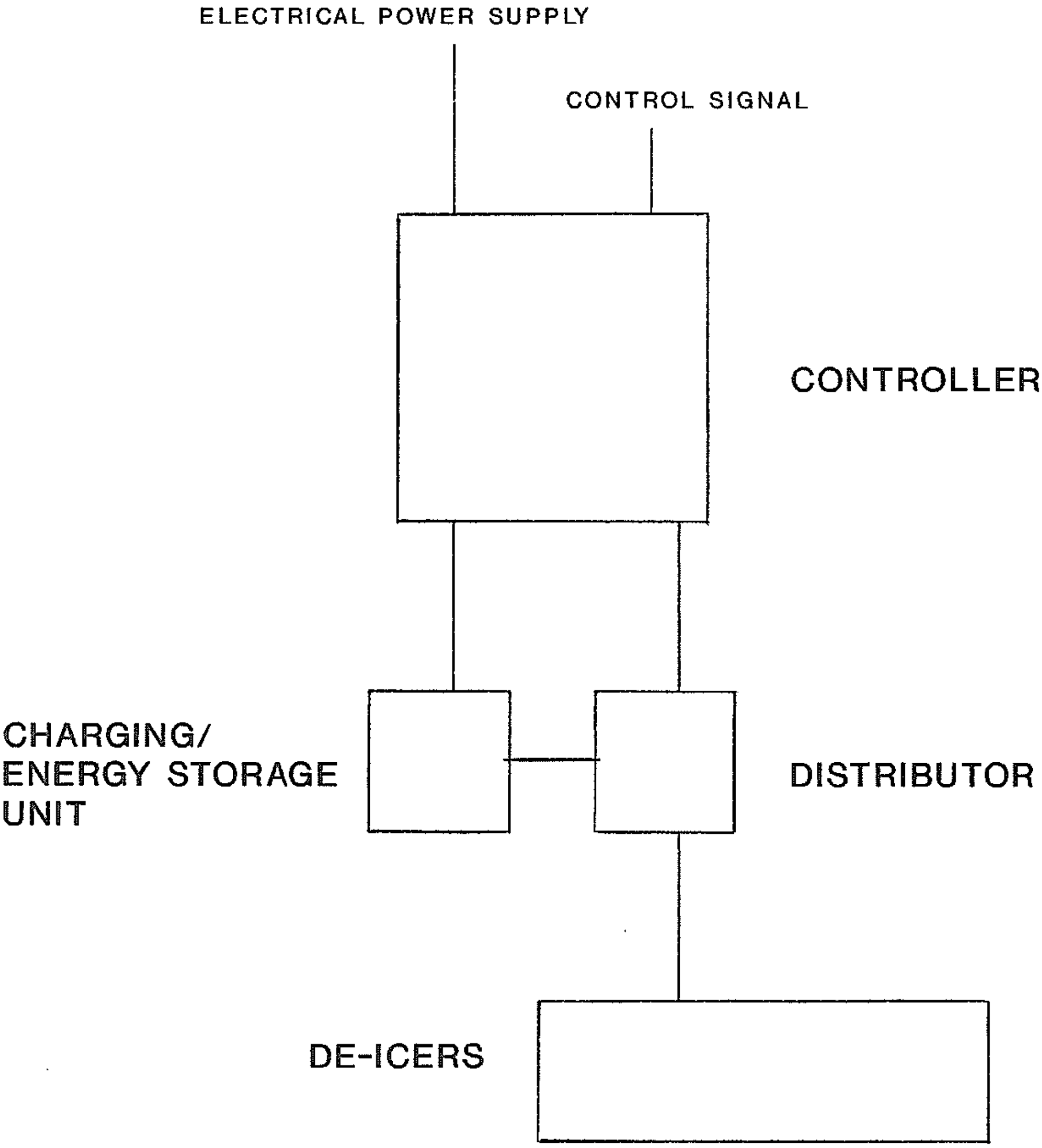
DE-ENERGIZED CONDITION



ENERGIZED CONDITION

ELECTRO-EXPULSIVE DE-ICER

FIGURE 3



BASIC SCHEMATIC
FIGURE 4

6. DHC-6 - Natural Icing Tests (See Figure 5)

The test panel was a non-standard, symmetrical airfoil having a 12 inch chord, a 22% maximum thickness and a 0.5 inch leading edge radius. As installed in the NASA-Lewis DHC-6 aircraft, the airfoil could be extended or retracted vertically in flight through a removable hatch in the ceiling of the DHC-6 fuselage. The leading edge of the upper end of the airfoil was covered by an electro-expulsive de-icer. The de-icer was of elastomer/fabric construction and contained two 8 inch long electro-expulsive spanwise de-icing segments that butted at the leading edge centerline. The de-icer was bonded to the airfoil and had power leads extending along the airfoil, through the airfoil extension mechanism to the operating equipment container located in the cabin. In four natural icing flights, the test temperature limits were +11° to +31°F, the cloud liquid water content was from 0.10 to 0.75 grams per cubic meter and the flight speed range was 123 to 147 miles per hour. The thinnest ice consistently removed was .02 inches thick and the thickest ice accumulated (and removed) was 0.4 inches thick.

7. F/A-18 - Icing Tanker Tests (See Figure 6)

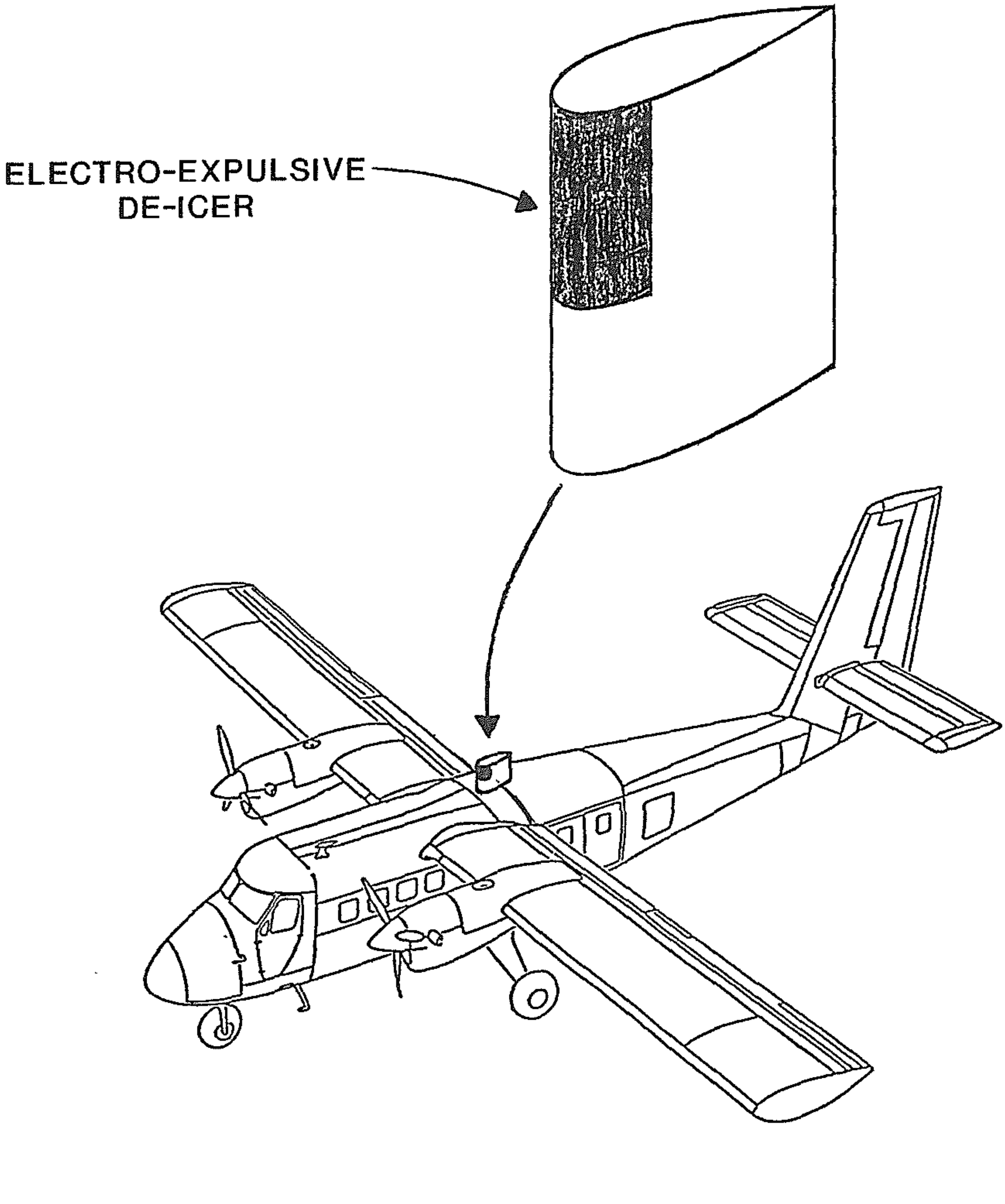
The first experimental flight test of an electro-expulsive de-icer applied to a functional aircraft component was made on a McDonnell-Douglas F/A-18 aircraft operated by the U. S. Navy. The de-icer and its operating components were installed for proof-of-concept evaluation on the left or port engine inlet.

The de-icer was an elastomer/fabric unit molded to fit the inlet contour. The de-icer contained six electro-expulsive segments arranged peripherally around the inlet leading edge with three segments on the inner wall and three on the outer wall. The de-icer was applied to the inlet with an air cure adhesive. The smooth surface of the de-icer was faired into tapered trailing edges to minimize aerodynamic impact on the engine and aircraft operation. No anomalies were noted in flight test maneuvers up to speeds of 350 knots.

The system operating equipment container was located in an instrumentation pod under the fuselage at a center mounting station. The balance of the system consisted of connecting wiring and a temporary pilot control panel located in the cockpit.

Since the aircraft contained operating components that were electro-magnetically sensitive, the de-icer system was designed and tested before its installation to assure its operation did not create any electro-magnetic interference problems for the aircraft. Aircraft ground and flight checks confirmed the adequacy of the system's electro-magnetic compatibility.

Test icing clouds were provided by a USAF NKC-135 water spray/icing tanker aircraft that produced a simulated icing cloud having a liquid water content of 0.5 grams per cubic meter. Three icing flights were made at an aircraft speed of 250 knots. The test inlet's engine power was maintained at idle setting so as to produce high air "spillage" that would cause shed ice particles to go outboard of the inlet and reduce possible engine damage. A post test review indicated that this condition also reduced icing collection on the inlet.



DEHAVILLAND DHC-6

FIGURE 5

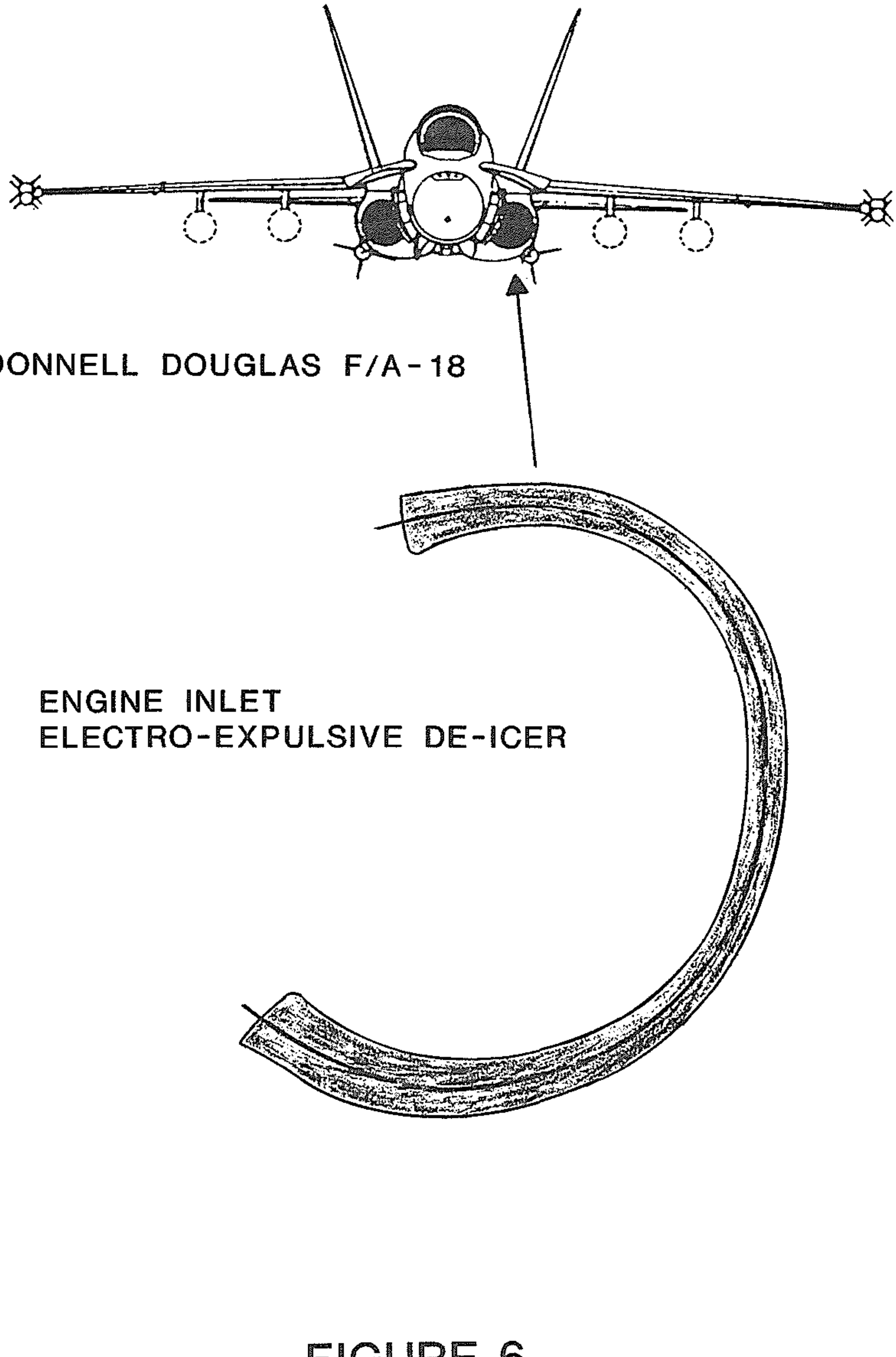

MCDONNELL DOUGLAS F/A-18
ENGINE INLET
ELECTRO-EXPULSIVE DE-ICER

FIGURE 6

Flights were conducted at various altitudes to obtain temperatures to produce glaze (-10°C) and rime (-20°C) icing clouds. The test plan called for an icing exposure to be terminated after 5 minutes or when 1/4 inch was observed on the inlet or surfaces forward of the inlet. No test run was stopped because of the 1/4 inch thickness limit.

For the initial icing sequence, the de-icer system was turned on and set to operate on a repeat cycle basis before the icing cloud was entered. Design of the test operating equipment limited repeat cycle period to a minimum of 30 seconds. Observers in the tanker and a chase aircraft did not observe any shedding of ice but did note a very narrow band of ice along a section of the inlet leading edge. A post-test examination of the de-icer indicated ice removal failure at the leading edge was due to a fabrication error in the spacing of de-ice segments.

In later tests, the de-icer system was to be turned on after a signal from a test icing sensor located aft and outboard of the de-icer. The sensor was designed to trigger after collecting .005 inch of ice. High speed camera records made of the later test show thin ice layers being shed in small pieces. A post-test inspection of the engine revealed no ice-ingestion damage.

8. Test Conclusions

As confirmed by prior icing tunnel tests and evaluations on two aircraft, the electro-expulsive de-icer demonstrated the ability to remove thin layers of ice in small particles.

The system design requires that high electrical energy be discharged periodically to remove ice. The tests showed the system can be designed for use on electronically sensitive aircraft.

The system operating power of less than 200 watts per inlet is substantially less than a thermal ice protection system.

References

1. United States Patent 4,690,353
   Electro-Expulsive Separation System,
   L. A. Haslim - Sep. 1, 1989