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Detailed Study of Airfoil and Cowl Ice Protection System

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Abstract: *American Eagle Flight 4184 crashed after flying into unknown icing conditions. Controls were lost and all aboard were killed. Icing has always been considered as a significant aviation hazard. It leads to increased aerodynamic drag and weight along with reduced lift and thrust resulting in higher stall speed and degradation in overall aircraft performance. From 1982 till 2000, 583 icing accidents took place along with more than 800 fatalities during the 19-year period. The project focuses on briefly describing the icing conditions and their effects. System description and the working of various components of two major Ice Protection Systems have been discussed. Ice Protection System comprises of Engine Anti-Ice System (EAI) and the Wing Anti-Ice System (WAI) which are controlled by Airfoil and Cowl Ice Protection System (ACIPS) control cards. An investigation of American Eagle Flight 4184 that crashed after flying into unknown icing conditions has also been included in this project.*

1. INTRODUCTION

Ice protection systems are designed to keep atmospheric ice from accumulating on aircraft flight surfaces while in flight. The effects of ice accretion on an aircraft can cause the shape of airfoils and flight control surfaces to change, which can ultimately lead to a complete loss of control. Ice protection system majorly covers two broad areas which are airframe icing and engine inlet icing.

In airframe icing, ice accumulates on the leading edges of wings, tailplanes, and vertical stabilizers as an aircraft flies through a cloud containing super-cooled water droplets. Super-cooled water is water that is below freezing, but still a liquid. Normally, this water would turn to ice at 32°F (0°C), but there are no "contaminants" (ice nucleus) on which the drops can freeze. When the airplane flies through the super-cooled water droplets, the plane becomes the droplet nucleus, allowing the water to freeze on the surface. This process is known as **accretion**.

In engine inlet icing, Ice accreting on the leading edge of engine inlets causes flow problems and can lead to ice ingestion. In turbofan engines, laminar airflow is required at the face of the fan. Because of this, most engine ice protection systems are anti-ice systems.

The airfoil and cowl ice protection system (ACIPS) consists of two major systems: Engine Anti-Ice System (EAI) and the Wing Anti-Ice System (WAI). Each airplane has two identical EAI systems (left and right) and one WAI system. Each EAI and WAI system uses independent electronic control cards which provide control, status indication and built in test (BIT) functions.

2. ICING CONDITION AND ITS EFFECTS

Icing conditions are those atmospheric conditions that can lead to the formation of water ice on the surfaces of an aircraft, or within the engine**.** Icing conditions exist when the air contains droplets of supercooled liquid water; icing conditions are characterized quantitatively by the average droplet size, the Liquid Water Content and the air temperature. These parameters affect the extent and speed that characterize the formation of ice on an aircraft.

The wing will ordinarily stall at a lower angle of attack, and thus a higher airspeed, when contaminated with ice. Even small amounts of ice will have an effect, and if the ice is rough, it can be a large effect. Thus an increase in approach speed is advisable if ice remains on the wings. How much of an increase depends on both the aircraft type and amount of ice. Stall characteristics of an aircraft with ice contaminated wings will be degraded, and serious roll control problems are not unusual. The ice accretion may be asymmetric between the two wings. Also, the outer part of a wing, which is ordinarily thinner and thus a better collector of ice, may stall first rather than last.

3. AIRFOIL AND COWL ICE PROTECTION SYSTEM (ACIPS)

There are three ACIPS Control Cards-

1) Two cards are located in the right systems cardfile (WAI & right EAI).
2) One in the left systems cardfile (left EAI).

The control card, when combined and interfaced with the valve, motors, detectors, sensors & control switches, will control engine & wing anti-ice systems, perform BIT functions & provide system failure annunciations for crew alerting. The left ACIPS Control Card provides the left EAI function and interfaces directly with the left ice detector. The right ACIPS Control Card provides the right EAI function and interfaces directly to the right ice detector. The center ACIPS Control Card provides the WAI function. Each control card communicates with both left and right ice detectors either by a direct connection or via ARINC 429 communication.

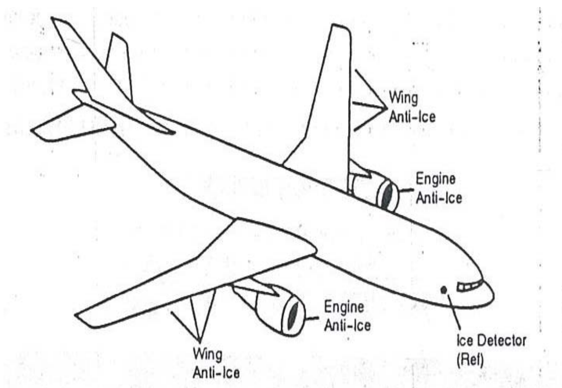

Fig. 1: Anti-Ice System Location

3.1. Engine Anti –Ice System Description

The EAI System provides regulated bleed air from the engine bleed ports to the engine cowl inlet leading edge. Two ACIPS Control Cards independently control the separate left and right EAI systems. The control cards provide closed loop system control of the EAI regulating valves via electrically controlled pneumatic valve actuators and pressure sensors which provide pressure feedback to the ACIPS Control Card. The control cards provide flight deck indication & built in test functions. One EAI valve is used to regulate and shutoff flow. EAI valve controller is used to control servo pressure to position the EAI valve. The control card provides current to the EAI valve controller. This in turn controls the EAI valve.

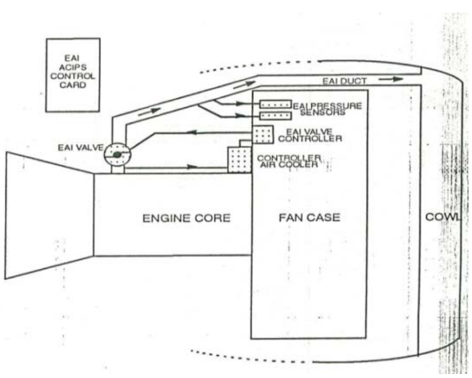

Fig. 2: Engine Anti-Ice System

3.1.1. HARDWARE COMPONENTS

A. Engine Anti-Ice Valve

It controls the flow of hot bleed air to the engine cowl to prevent ice formation. The valve is approximately 2 inches in diameter & mounts by its flanges to the ducts. The valve is an in-line regulating valve. It has a piston that slides on a center guide tube to open or close the valve. The valve also has a manual wrenching & locking device that can be used to close & lock the valve in the closed position.

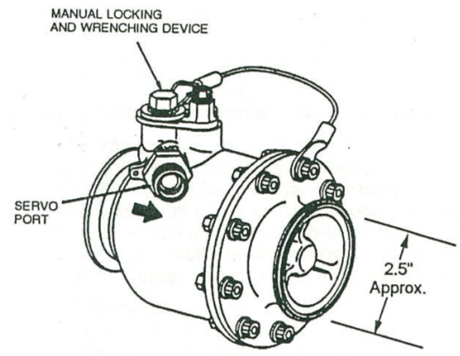

Fig. 3: Engine Anti-Ice Valve

B. Engine Anti-ice Pressure Sensor

The pressure sensor is a solid state, piezoresistive-type sensor. It is used to monitor the cowl pressure (EAI) for the ACIPS Controller Card. The pressure sensor measures the absolute pressure at the pressure port & supplies a differential voltage output increases linearly as the pressure increases.

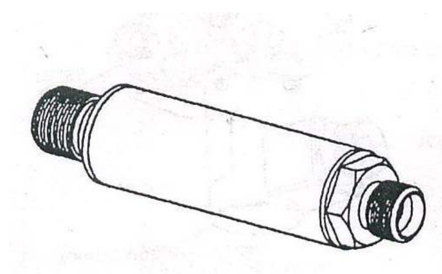

Fig. 4: Engine Anti-ice Pressure Sensor

3.2. Wing Anti –Ice System Description

The WAI system provides wing slat leading edge anti-ice heat via pressure and temperature regulated bleed air flow from the bleed system pre coolers. The WAI system is activated and deactivated by the WAI ACIPS Control Card. The control card provides closed loop system control of the WAI valve using pressure sensors that provide pressure feedback. The ACIPS Controller Card also provides flight deck indication & BIT functions. The WAI system contains two WAI Valves. One is used to control air to the right side and one for the left. The control card will regulate pressure downstream of each WAI valve whenever an adequate supply pressure exists.

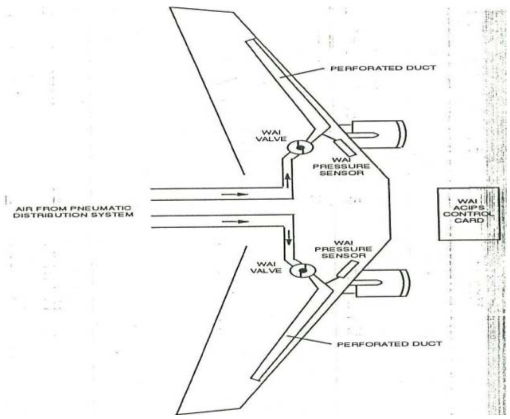

Fig. 5: Wing Anti-Ice System

3.2.1. HARDWARE COMPONENTS

A. Wing Anti-ice Valve

It controls the supply of hot air to sections of the wing leading edge to prevent ice protection. It has two primary parts: an actuator assembly & a butterfly (flow control) valve assembly. The approximate diameter of the valve is 3 inches. The actuator parts operate together to rotate the butterfly disk, inside the valve body, 90 degrees from full closed to full open. Visual valve position is shown by the position of the locking crank relative to the OP (open) & CL (closed) marks that are on the actuator housing. The valve also has a manual wrenching & locking device that can be used to close & lock the valve in the closed position.

B. WAI Pressure Sensor

It is a solid state, piezoresistive-type sensor. It is used to monitor the air pressure (WAI) for the ACIPS Controller Card. It measures the absolute pressure at the pressure port & supplies a differential voltage output to the ACIPS Controller Card. The differential voltage output increases linearly as the pressure increases.

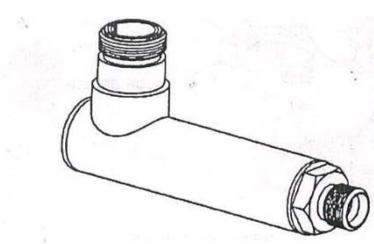

Fig. 6: WAI Pressure Sensor

4. ACIPS SYSTEM OPERATION

4.1. Engine Anti-Ice Control

4.1.1. EAI On/Off Control Logic

The EAI system will be enabled when the flight deck EAI switch is ON or when the switch is in the AUTO position & the primary ice detection system (PIDS) indicates an icing condition. The system will be off if the cockpit switch is in the OFF position or when the switch is in the AUTO position & the PIDS does not indicate an icing condition. The engines will also be off when the engines are being started or if the duct leak overheats detection system (DLODS) indicates a fan case overheats.

4.1.2. EAI Heat Flow Control

When anti-ice flow is enabled, the primary function of the heat flow logic is to determine the torque motor current to be applied to the EAI Valve Controller, which will in turn command servo pressure to move the EAI Valve.

If the system is operating when the conditions are within the FAR25 envelope, the system will control the amount of heat flow delivered to the cowl. If the conditions are not within the FAR25 envelope, the system will control the amount of heat flow delivered to the cowl unless the mass flow limit is exceeded. If the mass flow limit would be exceeded during the operation outside the FAR25 envelope, the system will control the EAI valve to control the appropriate mass flow.

4.2. Wing Anti-Ice Control Logic

4.2.1. WAI On/Off Control Logic

It is enabled when the cockpit switch is in the ON position & is disabled when the switch is in the OFF position.

When the switch is in the AUTO position, the system will provide ice protection if either PIDS indicates possible wing icing. If there is no indication of icing from either PIDS when the switch is in AUTO mode, the system is disabled.

4.2.2. WAI Pressure Control

The WAI reference pressure is the target pressure that the ACIPS Controller card will maintain downstream of the WAI Valve by varying current applied to the servo valve torque motor located inside the WAI Valve Actuator. The reference pressure is calculated based on ambient pressure, altitude & the temperature of the pre-cooled air supplied to each wing system. Since the temperature of the air supplied to the right side can vary from the temperature supplied to the left side, independent reference pressures are calculated for each side.

4.3. Back Up Control

4.3.1. EAI & WAI On/Off Control

Under certain failure conditions, the EAI or WAI system can reconFig. to an On/Off mode. When in this state, the system control logic will determine if anti-ice system is needed. If anti-ice function is needed, the EAI or WAI valve will be commanded to the full open state. The failures can cause loss of EAI or WAI pressure sensors and torque motor open circuit.

5. AMERICAN EAGLE FLIGHT 4184 INVESTIGATION

It was an American Eagle ATR 72 that crashed after flying into unknown icing conditions on October 31, 1994 because the controls were lost and all aboard were killed. The plane encountered freezing rain, a dangerous icing condition where super-cooled droplets cause intense ice buildup. As they were cleared to descend to 8,000, pilots were ordered to make another hold. During this a warning sound indicating an overspeed warning due to the extended flaps was heard in the cockpit. A strange noise was heard on the cockpit voice recorder after the pilot took an action by retracting the flaps, followed by an uncommanded roll excursion which disengaged the autopilot. Flight recorder data revealed that the ATR went through at least one full roll with the crew able to regain control of the descending aircraft. Another roll occurred and within thirty seconds, contact was lost as the plane crashed into a soybean field near Roselawn, Indiana killing all 64 passengers and 4 crew on board.

The National Transportation Safety Board analyzed the probable causes of this accident were the loss of control, attributed to a sudden and unexpected aileron hinge moment reversal that occurred after a ridge of ice accreted beyond the deice boots because ATR failed to disclose adequate information concerning previously known effects of freezing precipitation on the stability and control characteristics, autopilot and related operational processes.

ATRs were moved from Northern American hubs to Southern hubs. The American FAA issued 18 Airworthiness Directives (ADs), in an attempt to prevent further icing accidents in ATR aircraft. They included revisions of pilot operating procedures in icing conditions like higher minimum speeds, non-use of the autopilot, different upset recovery procedures as well as physical changes to the coverage area of the de-icing boots on the airfoils.

ATR 72 aircrafts are compliant with all icing condition requirements imposed by those 18 ADs, the de-icing boots still reach back to 12.5% of the chord. Before accident, they had extended only to 7%. But as per certain tests ice could form as far back on the wing as 23% of the chord and on the tail at 30% of chord. Rather than extending the boots to 12.5%, they should focus more on moving the aircrafts to the operating areas where severe icing is not a problem.

Fig. 7: Eagle 4814 Before Crash

6. CONCLUSION

ATR investigation gave us an insight where a small ridge of ice can cause a severe accident. After this incident, icing became primary concern for all the aircrafts across the globe which brought Anti-Icing System into notice. Critical components of an aircraft such as Engine and Wing were modified with advanced anti-icing systems.

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