Aviation Safety Council

Taipei, Taiwan

GE791 Accident Investigation Factual Data Collection Group Report

Systems Group

October 28, 2003

ASC-GRP-03-10-001

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I. Team Organization

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II. History of Activities

Date	Description
2003/01/07	Attended the presentation of ATR72 anti icing / de-icing system maintenance and conducted a surveillance check to ATR72 de-icing boots at TNA
2003/01/15	Attended the 1ST Investigation Progress Meeting and the systems group was added to the investigation team
2003/01/21	Reviewed the CAA 2002 airworthiness inspection records of TNA
2003/01/22	Took photos of ATR72 anti icing / de-icing system, included the cockpit instrument panels and ice detection component at TNA
2003/01/24	Attended the 2nd Investigation Progress Meeting
2003/02/10	Attended the 3rd Investigation Progress Meeting
2003/03/12	Examined the wreckages in Makung
2003/04/22	Collected the ATR72 flight control system data
2003/05/07	Collected the ATR72 lateral control system data
2003/06/16	Studied the information of all turbo-propeller aircrafts accidents provided by BEA. Viewed the flight animation of ATR72 aircraft accident

III. Factual Information

1.6.4 ATR72 Ice Protection Systems

The ATR72 ice protection system consists of the following functions：

- Pneumatic boots deicing system for wing and empennage (figure 1.6-1);
- Pneumatic deicing system for engine air intakes;
- Electrical heating system for anti-icing of the propeller blades, the windshield and the side windows, the pitot tubes, static ports, TAT (total air temperature) probe, and the AOA vanes;
- Electrical heating system for anti-icing of the aileron, elevator and rudder balance horns.

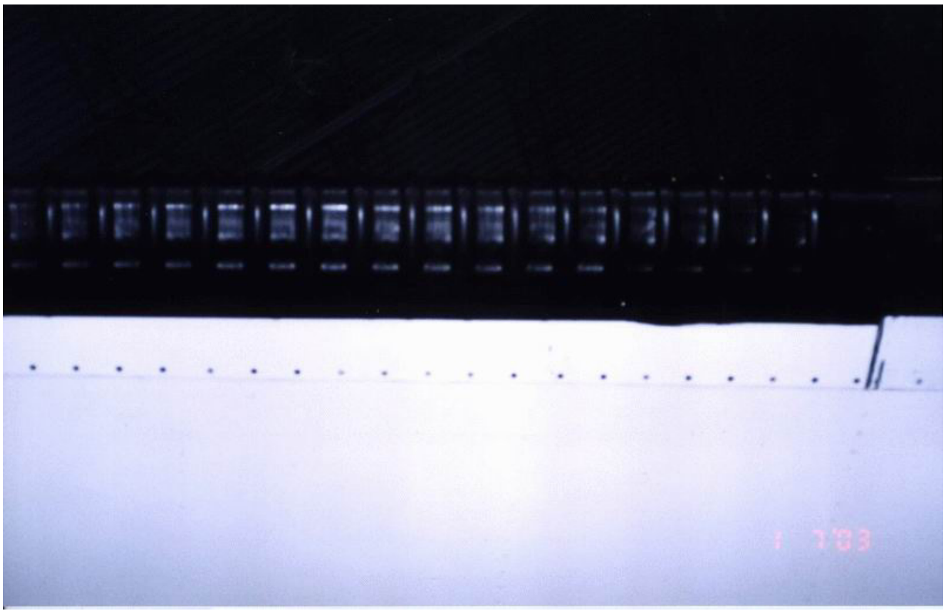

Figure1.6-1 Deicing boot inflates (wing and empennage)

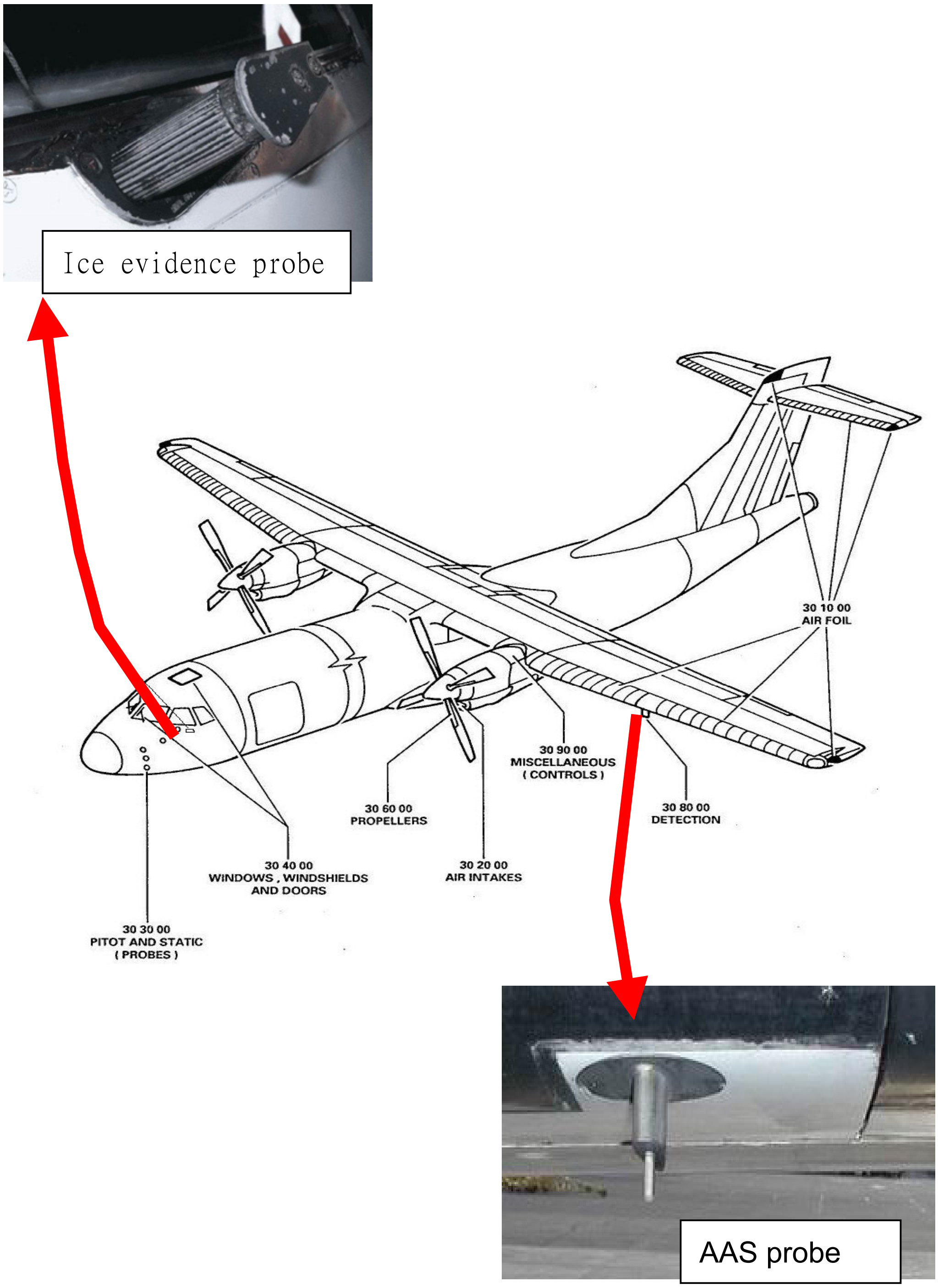

Figure1.6-2 ATR72 anti icing / de-icing system, the Ice evidence probe and the Anti-Icing Advisory System (AAS) probe

The ice evidence probe (IEP) is located outside and below the captain's left side window (Figure 1.6-2). IEP has an integrated light , which is " ON " when the navigation lights are " ON ". The IEP that provides pilots with visual cue of ice formation is visible to both pilots and provides ice accretion condition. The probe was designed to retain ice; itself does not have the ice protection.

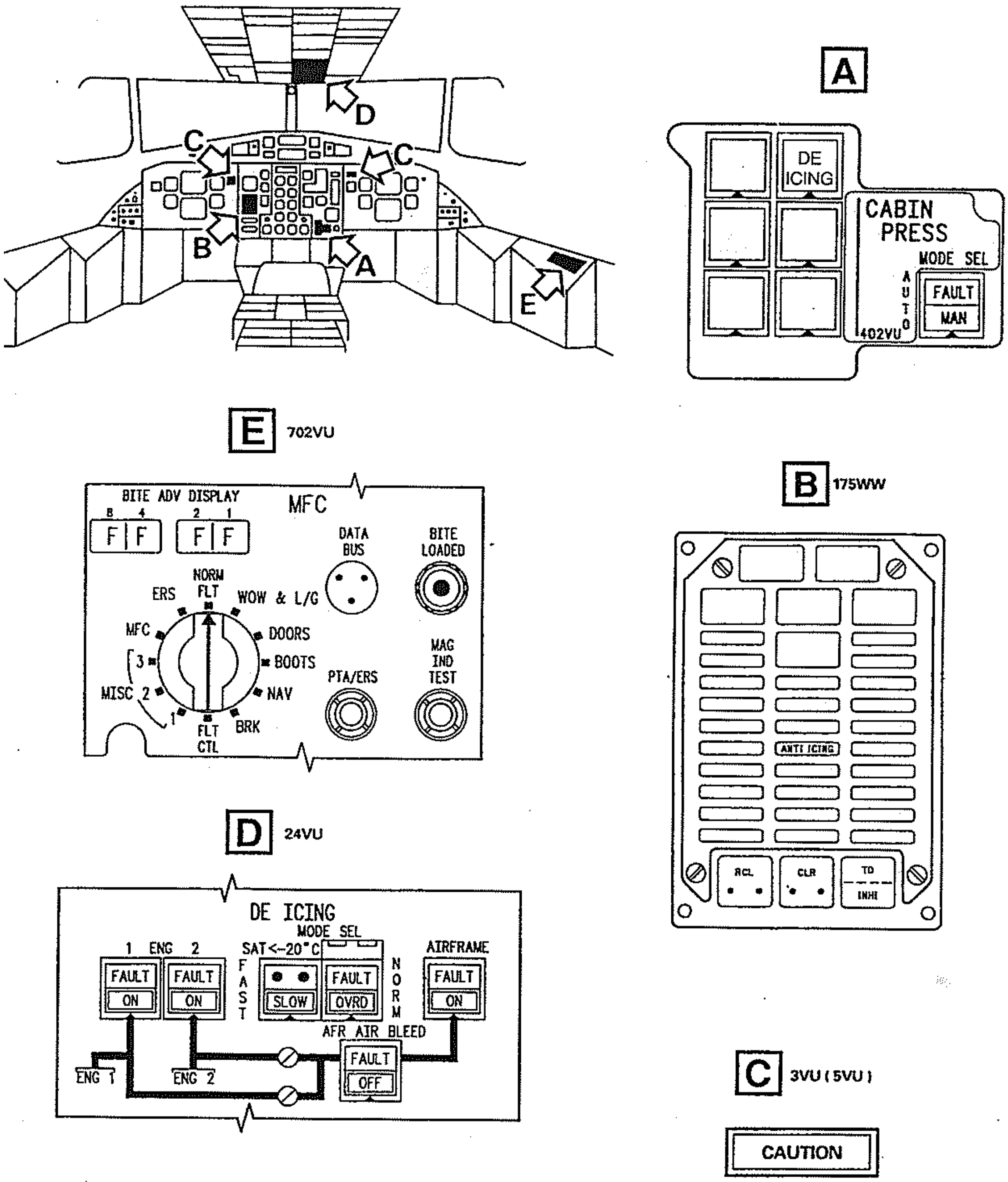

Figure1.6-3 The location of airframe ice protection system instrument panels in the cockpit

Location of airframe ice protection system instrument panels for crew to monitor in the cockpit is shown as Figure1.6-3.

In addition to the IEP, ATR72 also equipped with Anti-Icing Advisory System (AAS) for the supplemental icing detection. The probe is located at the underside of the left wing leading edge and generates the AAS signal. The AAS provides both visual and aural warning to flight crew. The aural alert (chime) is inhibited when boots are activated. Visual alert light stays on as long as ice accretion is detected.

The AAS detects accretion icing condition by using ultrasonic ice detector probe, which senses ice accretions. It is approximately 1/4 inch in diameter and 1 inch long and vibrates along its axis at a given (approx 40 KHz) frequency. The system detects changes in vibration frequency resulting from the increased mass of the accumulated ice. If the frequency drops below 39.867 Hz. It initiates a signal to the Central Crew Alerting System (CCAS) for 60 seconds and provides the amber flashing caution light. That reminds the flight crew that the aircraft is in icing accretion condition.

In accordance with ATR72 Aircraft Maintenance Manual chapter 30-81(attachment 6-1):

> *The purpose of Ice Detection System is to help crew to detect icing accretion conditions.*
>
> *However the primary mode of detection remains visual detection of ice formation by the flight crew.*

As long as ice is detected but the AIRFRAME de-icing has not selected ON, the following caution signals activate (figure 1.6-4):

1. Flashing of ICING amber light
2. Flashing of master CAUTION light
3. Single chime aural signal

Whenever the ice accretion is detected and anti-icing/de-icing have selected ON, the ICING amber light stays on.

When ice is detected but the flight control surfaces and horns anti-icing/de-icing have not been selected ON, the ICING light flashes.

If the AAS probe has not detected ice accretion for more than 5 minutes the AIRFRAME DE-ICING is still " ON ", the DE ICING blue light will flash.

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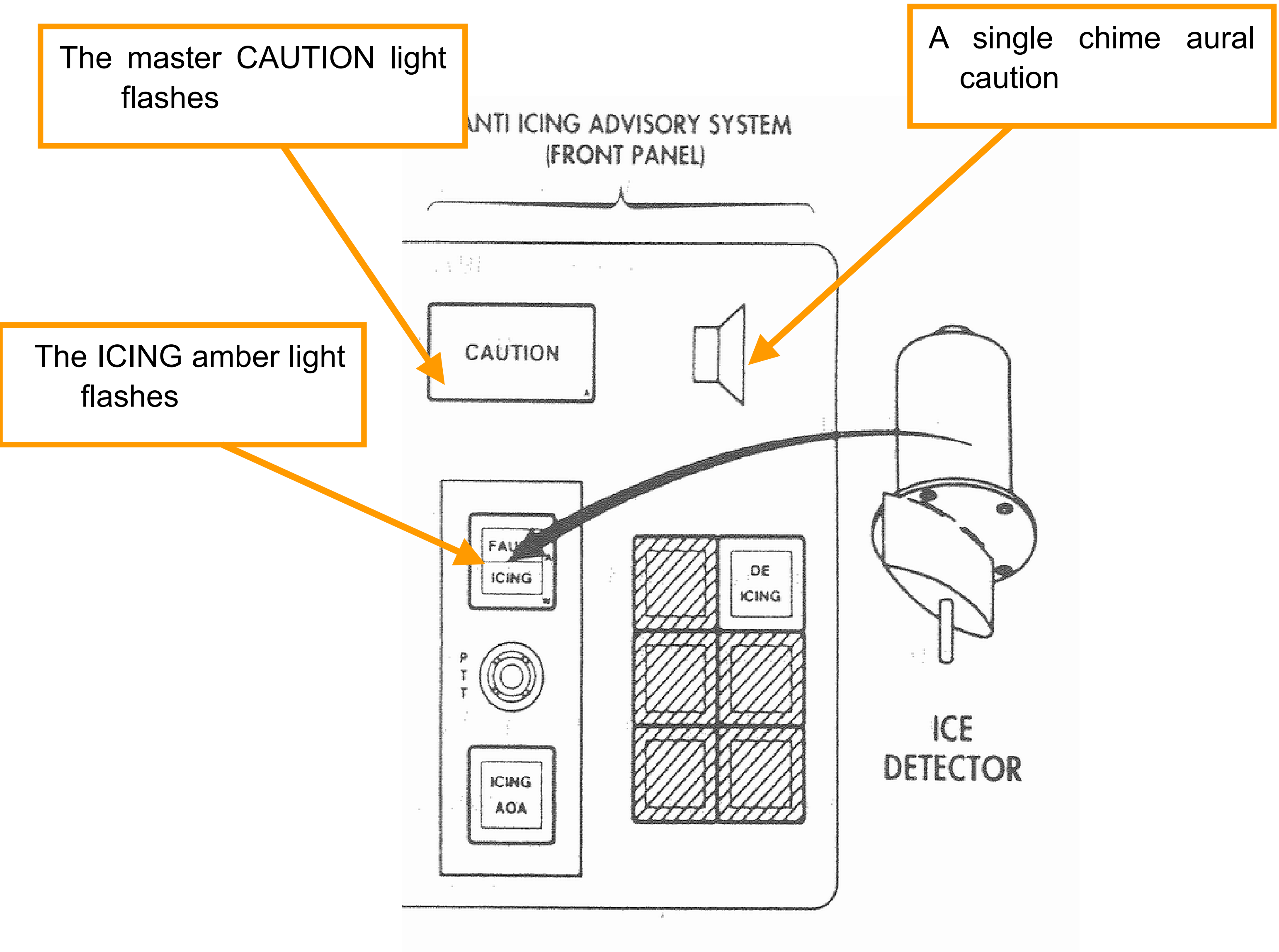

Figure1.6-4　AAS visual and aural alert signals

1.6.5　Malfunction of the Ice Protection

When the crew activates the airframe, engines and propellers ice protection systems, two Multi Function Computers (MFCs) monitor and control the operation. There are 14 independent subsystems monitor the correct operation of the system (attachment 6-2). In the event of any subsystem malfunction, MFCs indicate the failure by the illumination of the FAULT legend on the de icing control panel pushbutton switch and illuminates ANTI ICING alert on CCAS panel. The single chime is activated and the master CAUTION lights flash.　When the MFCs fail the system submit the alert to flight crew, remind them the override de-icing mode has to be used.

The MFCs monitor the following malfunctions:

- Boots air supply fault engine 1-1
- Boots air supply fault engine 1-2
- Air bleed overheat engine 1-1
- Air bleed overheat engine 1-2
- Brush block supply fault propeller 1-1
- Brush block supply fault propeller 1-2
- Boots air supply fault airframe-1
- Boots air supply fault airframe-2
- Boots air supply fault engine 2-1
- Boots air supply fault engine 2-2
- Air bleed overheat engine 2-1
- Air bleed overheat engine 2-2
- Brush block supply fault propeller 2-1
- Brush block supply fault propeller 2-2

Heating of the rudder, elevators and aileron horns are controlled by two horn anti-icing controller. Any subsystem malfunction will trigger the horn anti-icing controller to activate the following alerts:

1. Illumination of ANTI ICING amber light on CCAS panel
2. Flashing of master CAUTION light
3. Single chime aural signal

1.6.6 ATR72 Lateral Control System

The ATR72 lateral control systems composed of movable cable loop driven ailerons and the hydraulically actuated wing spoilers (figure 1.6-5). The ailerons are aerodynamically balanced through the use of an offset hinge line, geared trailing edge balance tabs, and exposed horns (see figure1.6-6 and figure 1.6-7)

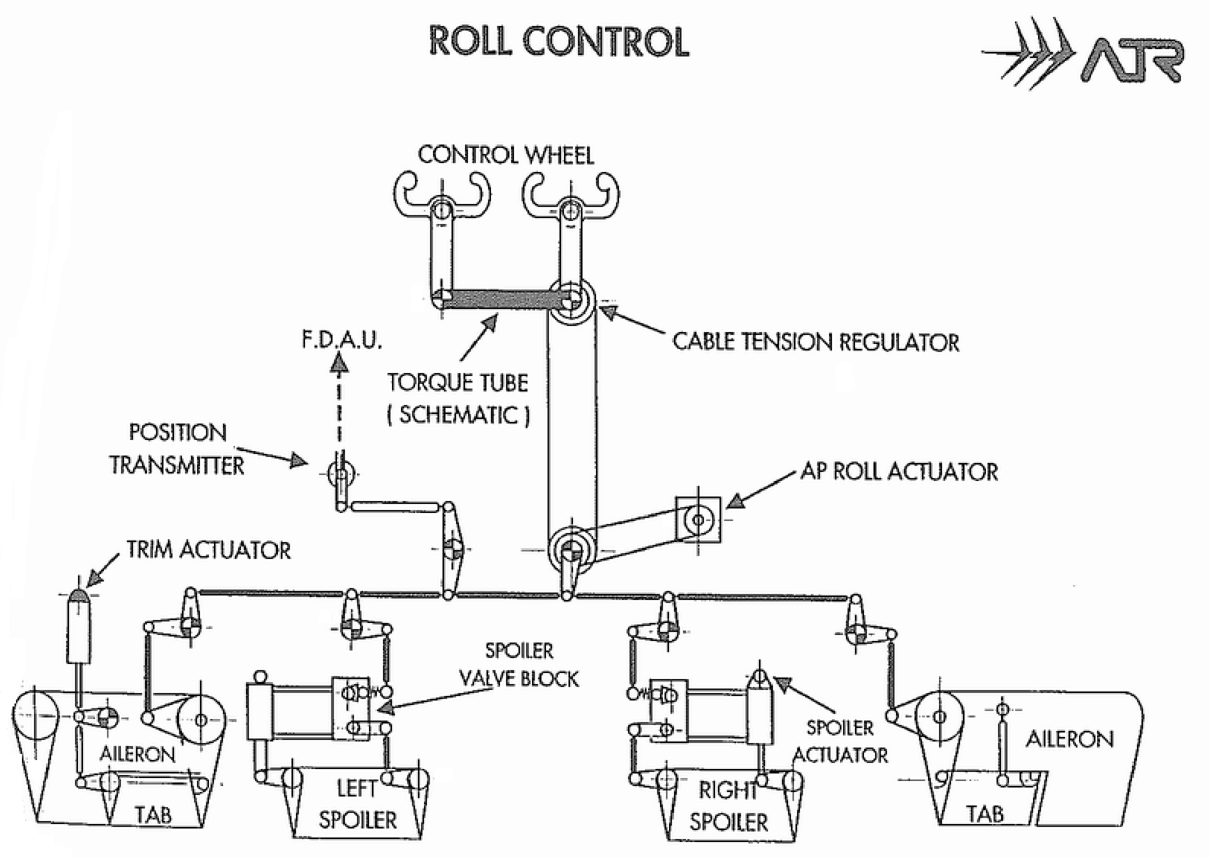

Figure1.6-5 Roll control system diagram

The ailerons are driven by the cockpit control wheels through cables, bellcranks and push pull rods. The cable tension compensator maintains specific cable tension. An electric trim actuator motor is connected to the left aileron balance tab. The ranges of deflection for the ailerons, control wheels and the balance tabs are about +/- 14 degrees, +/- 65 degrees and +/- 4 degrees, respectively. The hydraulic actuated spoiler for each wing enlarges the lateral control system. The aileron control linkages control spoilers' deployment mechanically. The spoiler actuator for each side activates at the aileron deflection of 2.5 degrees trailing edge up, and the spoiler deflection is about to 57 degrees for 14 degrees of aileron deflection. The required input force to control wheel is related to the moment of balance tab hinge and the air pressure cover the tab.

Figure1.6-6　ATR72 aileron and balance tab

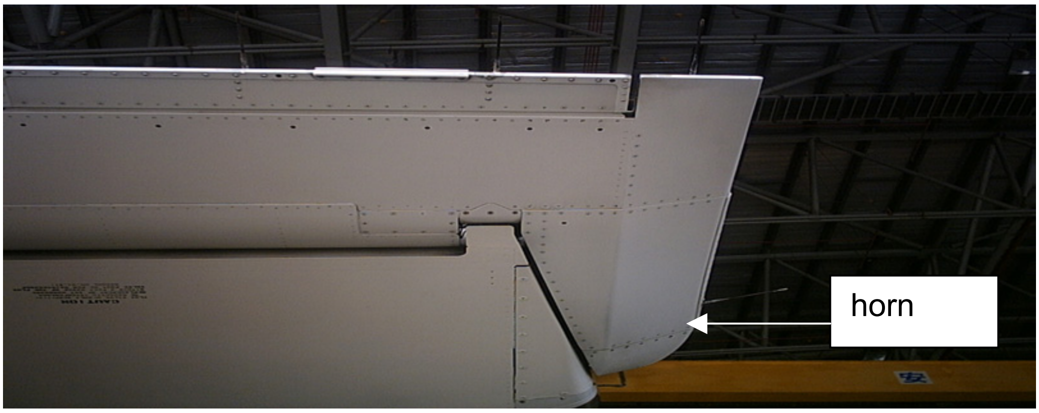

Figure1.6-7　ATR72 horn

1.6.7 ATR72 Stall Protection System

The ATR72 stall protection system (SPS) provides crew different stages warning devices before the aircraft reaching AOAs consistent with “clean” and ice-contaminated flow separation characteristics. The devices are:

- An aural warning and a stick shaker, both activate simultaneously when the angle of attack reaches a predetermined value that affords a margin prior to the onset of adverse aerodynamic characteristics;
- A stick pusher activates and pushes down the aircraft in a strong movement when the AOA reaches a preset higher value nearer to the onset of stall.

Two MFCs control the stall protection system and are operated by the following sources:

- AOA probes;
- Flap position;
- Engine Torque;
- On-ground/in flight indicator;
- Horn anti-ice status;
- Airplane altitude above or below 500 ft; and
- The presence / absence of optional deicer leading edges

The AOA probe information is used to reduce the triggering threshold when the AOA is quickly moving toward positive values. In accordance with the aircraft maintenance manual (AMM), the phase lead of the triggering threshold has a maximum value of plus 3 degree AOA and does not intervene with the anti-icing system in use.

Even though a single failure of any component in the system does not result in the loss of the stick pusher function, improper activation of the stick pusher, the loss of aural warning alert, or the loss of both stick shakers.

The ATR72 has icing and non-icing AOA triggering thresholds for each flap configuration. When flying in icing conditions defined in 14 CFR Part 25, Appendix C, the SPS activates at lower AOAs when the anti-icing system is on to cope with the aerodynamic changes. The SPS does not cover more adverse icing weather beyond that defined by 14 CFR Part 25, Appendix C, for instance, in a freezing rain condition.

1.6.8 Automatic Flight Control System

A Honeywell SPZ-6000 Digital Automatic Flight Control System (DAFCS) is equipped on the ATR72 including following subsystems :

- Attitude and Heading Reference System (AHRS);
- Air Data System (ADS);
- Electronic Flight Instrument System (EFIS);
- Flight Guidance System (FGS) and
- PRIMUS 800 Color Weather Radar System

The DAFCS is an automatic flight control system that offers fail-passive flight director guidance; autopilot, yaw damper and pitch trim functions. The autopilot computers continuously monitor the system and alert the flight crew to any fault that has been detected. The autopilot system uses two in-flight bank angle selections: “HIGH” bank angle (default 27 degrees) and “LOW” bank angles (default 15 degrees). The flight crew can manually select the limits and the selection applies the maximum amount of bank angle executed by autopilot.

The autopilot will trip automatically if the computer senses any of the following system faults or malfunctions (attachment 6-3):

- One of the engagement conditions of the AP and/ or YD is no longer met, includes the exceeding travel rate of the ailerons (3.6 degrees per second), or
- A disagreement between the two AHRS or between the two ADCs (air data computers), or
- A mismatch between the two pitch trims, or
- Stall warning indicator threshold is reached.

If the aileron rate monitor is tripped, power will be removed from autopilot servo-motor and servo clutch. The crew will receive an aural and visual warning alert.

1.18 Other Information

1.18.8 Certification of Ice Protection System

1.18.8.1 Approval of Modified Deicing Boots

According to the NTSB Accident Report[1] states:

> *Aerospatiale developed a modification that consists of an increase in coverage of the active portion of the upper surface of the outer wing deicing boots form 7 percent chord to 12.5 percent chord for ATR72. The enlarged wing deicing boots were certificated by extensive dry air and icing wind tunnel tests, and by dry air and natural icing flight tests conducted by Aerospatiale and FAA flight test pilots. In addition, an ATR72 fitted with the modified boots was flown behind the icing tanker at Edwards AFB. The results of all these tests revealed that the modified boots perform their intended function within the icing*

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[1] National Transportation Safety Board, Safety Report, NTSB-AAR-96/01, at Roselawn, Indiana on Oct 31, 1994.

requirements contained in Appendix C of Part 25 of the Federal Aviation Regulations. All U.S. – registered Model ATR72 series airplanes were modified with the new boots prior to June 1, 1995.

Aerospatiale developed the deicing boot modification to provide an increased margin of safety in the event of an inadvertent encounter with freezing rain or freezing drizzle (SLD). With the ability to recognize that an inadvertent encounter had occurred, flight crews would be afforded an increased opportunity to safely exit those conditions. However, even with improved boots installed, Model ATR72 airplane along with all other airplanes, are not certificated for flight into known freezing drizzle or freezing rain conditions.

1.18.8.2 Operational Considerations that May Require Changes

The NTSB Accident Report No AAR-96/01 also states that:

Several recommendations regarding operational considerations for the turboprop transport fleet were made. These recommendations include changes to flight crew and dispatcher training, expanded pilot reports, Air Traffic Control and pilot cooperation regarding reporting of adverse weather conditions, flight crew training in unusual attitude recovery techniques, aircraft systems design and human factors, and Master Minimal Equipment List (MMEL) relief.

1.18.8.3 Changes to the Certification Requirements

In addition, the NTSB Accident Report No AAR-96/01 states：.

The FAA recognizes that the icing conditions experienced by the accident airplane, as well as other airplanes involved in earlier accidents and incidents may not be addressed adequately in the certification requirements. Therefore, the FAA has initiated the process to create a rulemaking project under the auspices of the Aviation Rulemaking Advisory Committee (ARAC). The ARAC will form a working group, made up of interested persons from the U.S. aviation industry, industry advocacy groups, and foreign manufacturers and authorities. The ARAC working group will formulate policy and suggested wording for any proposed rulemaking *in the area of icing certification.*

According to the SCR report, the team concluded, based on their review and evaluation of the data, that:

1. *The ATR72 series airplanes were certificated properly in accordance with the FAA and DGAC certification basis, as defined in 14 CFR parts 21 and 25 and JAR 25, including the icing requirements contained in Appendix C of FAR/JAR 25, under the provisions of the BAA between the United States and France.*
2. *The Roselawn accident conditions included SCDD outside the requirements of 14 CFR Part 25 and JAR 25. Investigations prompted by this accident suggest that these conditions may not be as infrequent as commonly believed and that accurate forecasts of SCDD conditions do not have as high a level of certitude as other precipitation. Further, there are limited means for the pilot to determine when the airplane has entered conditions more severe than those specified in the present certification requirements.*

The SCR team also made the following recommendations:

**The current fleet of transport airplanes with unboosted flight control surfaces should be examined to ascertain that inadvertent encounters with SLD will not result in a catastrophic loss of control due to uncommanded control surface movement. The following two options should be considered:*

1. *The airplane must be shown to be free from any hazard due to an encounter of any duration with the SLD environment, or*
2. *The following must be verified for each airplane, and procedures or restrictions must be contained in the AFM:*
    a. *The airplane must be shown to operate safely in the SLD environment long enough to identify and safey exit the condition.*
    b. *The flight crew must have a positive means to identify when the airplane has entered the SLD environment.*
    c. *Safe exit procedures, including any operational restrictions or limitations, must be provided to the flight crew.*

d. Means must be provided to the flight crew to indicate when all icing due to the SLD environment has been shed/melted/sublimated from critical areas of the airplane.

**FAR 25.1419, Appendix C, should be reviewed to determine if weather phenomena which are known to exist where commuter aircraft operate most often should be included…*

**Rulemaking and associated advisory material should be developed for airplanes with unpowered flight control systems to address uncommanded control surface movement characteristics that are potentially catastrophic during inadvertent encounters with the SLD environment. Discussions about these new criteria should consider the criteria already contained in the certification requirements…;*

**Existing criteria used for evaluation of autopilot failures [should] be used to evaluate the acceptability of the dynamic response of the airplane to an uncommanded aileron deflection. Moreover, since both of these events (failure/hardover aileron deflection) can occur without pilots being directly in the loop, the three-second recognition criteria used for cruise conditions also should be adopted;*

· Policy should be developed to assure that on-board computers do not inhibit a flightcrew from using any and all systems deemed necessary to remove an airplane from danger;

· Airplane Flight Manuals (AFM) should be revised to clearly describe applicable icing limitations;

· The FAA/JAA harmonization process for consideration of handling qualities and performance of airplanes while flying in icing conditions should be accelerated…;

· Evaluate state-of-the-art ice detector technology to determine whether the certification regulations should be changed to require these devices on newly developed airplanes;

· Flightcrew and dispatcher training related to operations in adverse

weather should be reevaluated for content and adequacy;

· Flightcrew should be exposed to training related to extreme unusual attitude recognition and recovery;

· Pilots should be encouraged to provide timely, precise, and realistic reports of adverse flight conditions to ATC. The tendency to minimize or understate hazardous conditions should be discouraged;

· An informational article should be placed in the Winter Operations Guidance for Air Carriers, or airline equivalent, which explains the phenomenon of uncommanded control surface movement and the hazard associated with flight into SLD conditions;

· MMEL relief for all aircraft, particularly items in Chapter 30(Ice and Rain Protection),should be reviewed for excessive repair intervals; and

· Methods to accurately forecast SLD conditions and mechanisms to disseminate that information to flightcrews in a timely manner should be improved.

IV. Attachment

6-1 ATR72 Aircraft Maintenance Manual, revised on Oct 02, 2002
6-2 ATR72 Aircraft Wiring Diagram Manual, revised on Oct 01, 2002
6-3 ATR72 Flight Crew Operating Manual, revised in Dec. 96
6-4 Chung Shan Institute of Science and Technology (CSIST)-Aeronautical Research Laboratory-Aero Materials Department, Report 920021, dated Mar 11,2003
6-5 BEA's Study of Weather Conditions and Their Interaction on the management of the flight
6-6 NASA/FAA Tailplane Icing Program Overview, Jan 1999

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