

Severe Icing – Aircraft Performance Monitor

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ATR

An Alenia Aeronautica and EADS joint venture

Contents

- Recall
- Engineering review on ice detection
- Aircraft Performance Monitor



Recall – Certification basis

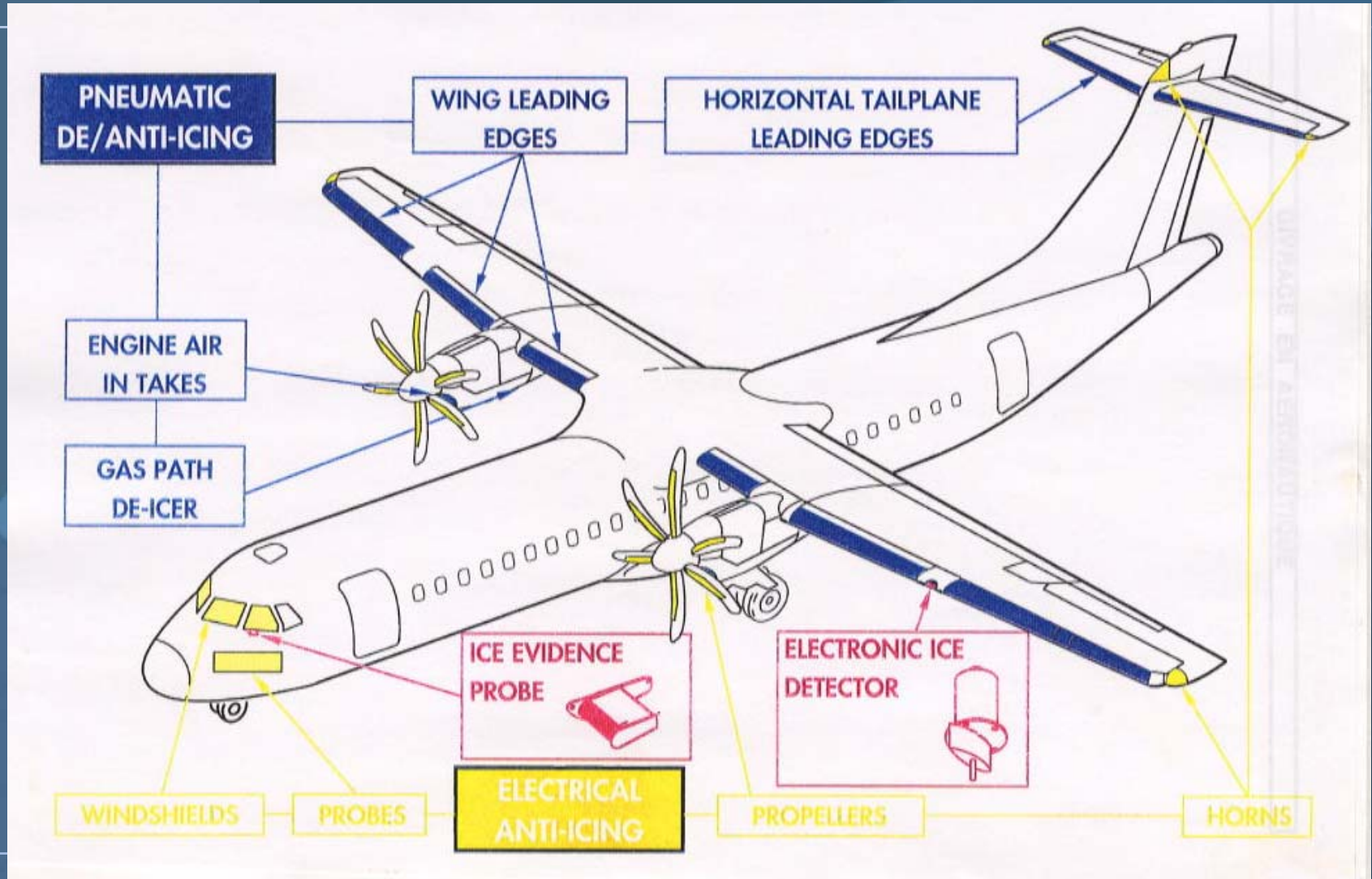
- **ATR aircraft models are certified under JAR 25.**
- **They are fully compliant with Appendix C to JAR 25 covering “Continuous maximum icing” and “Intermittent maximum icing”**
- **Severe Icing addressed after Roselawn Accident**
 - **Recognition means**
 - **Exit Procedure**

Recall – Procedures for flight in icing

Condition	Definition	Action
Icing Condition	Visible Moisture and TAT in range or <i>Icing signal</i> *	Propeller and Horn de-icing Icing AOA
Ice Accretion	First visible sign of ice accretion or <i>Icing Signal</i> *	Engine and airframe de-icing
Severe icing	Visual cues Speed or ROC decrease	Severe Icing procedures
End of icing condition	Clear sky or TAT out of range or <i>Icing Signal</i> *	Ice protection system “Off”
End of ice accretion	No more ice on the IEP (Ice visual cue)	Reset of Icing AOA

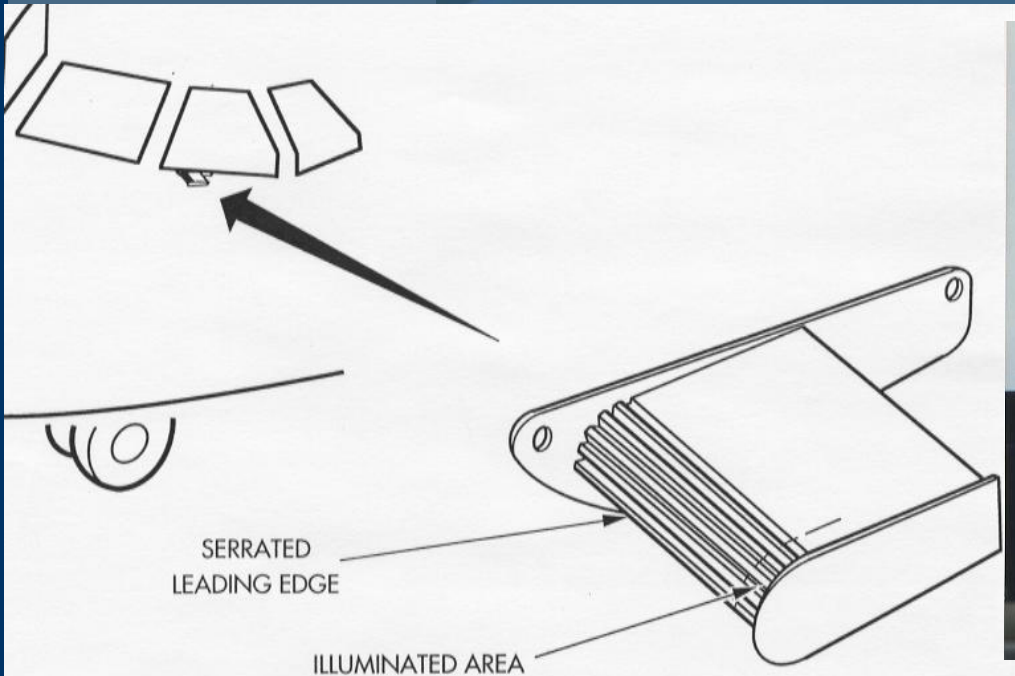
* *Icing signal provided by an advisory ice detector (BFG)*

Recall – Crew awareness



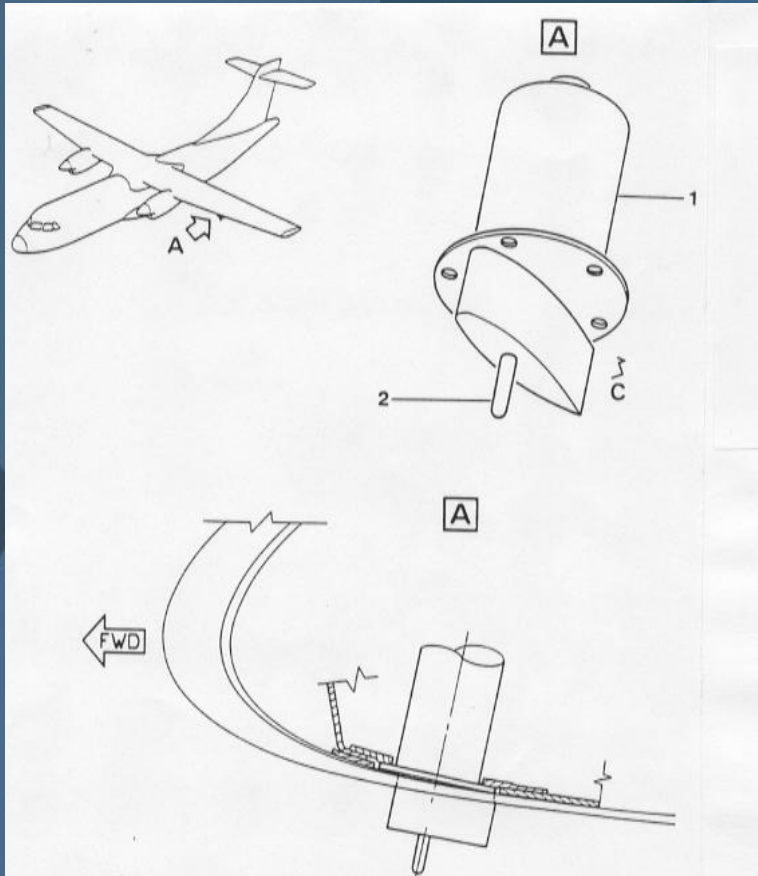
Recall – Crew awareness

**Ice Evidence Probe visible by both pilots \Rightarrow Ice accretion rate
When clean \Rightarrow critical surfaces free of ice**



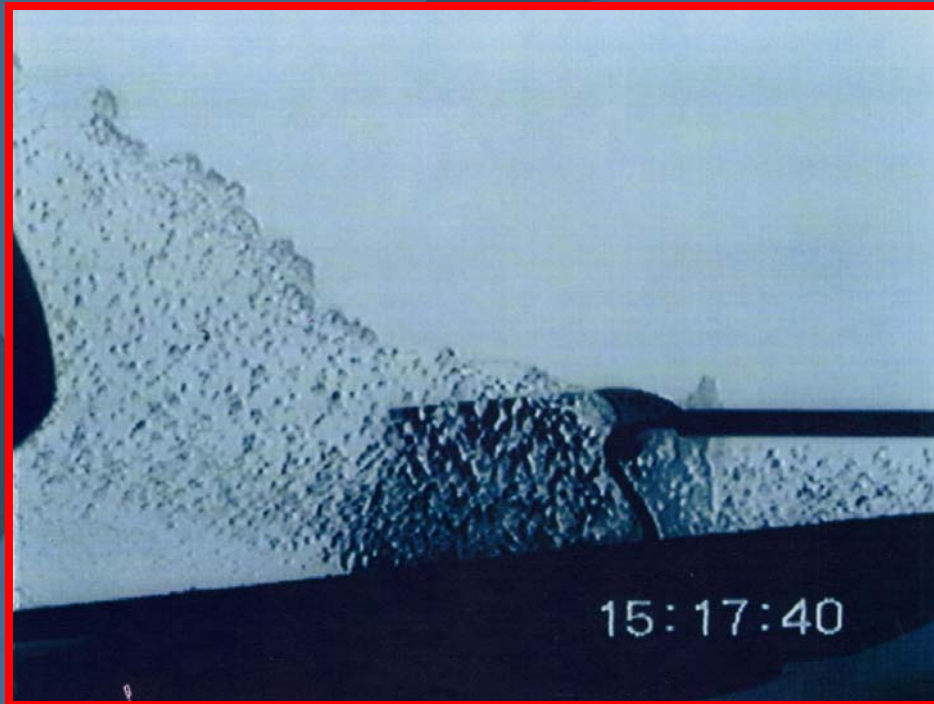
Recall – Crew awareness

Ice detector (BFG) ⇒ Icing signal (amber light + Single Chime)



Recall – Crew awareness

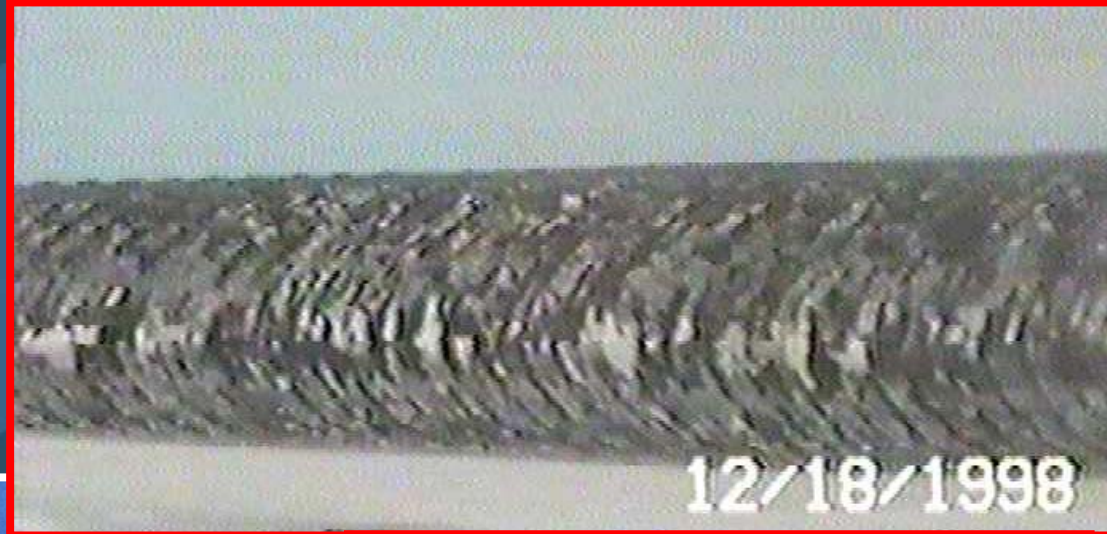
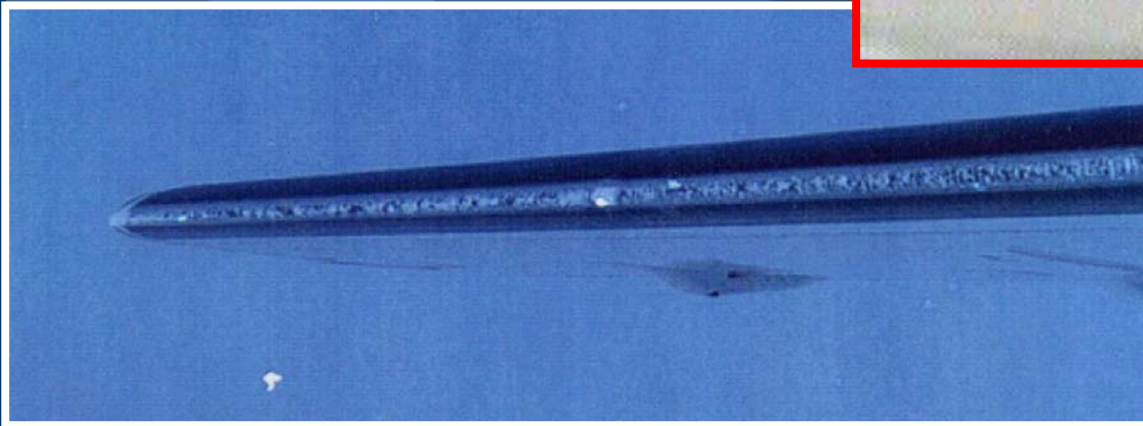
Severe Icing Visual Cues
⇒ Side Window



Partial or total coverage of the unheated part of side Windows

Recall – Crew awareness

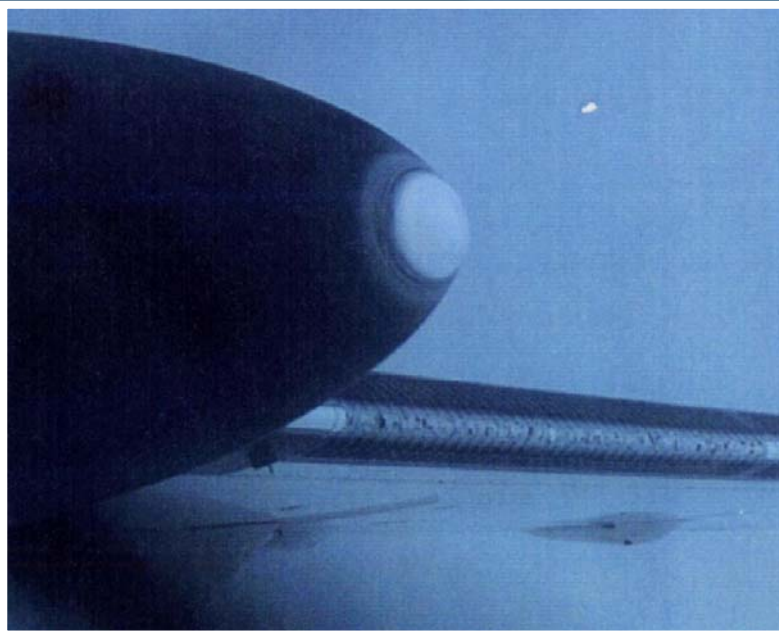
Severe Icing
⇒ on wing leading edge



Residual ice on the whole chordwise extent of the boots

Recall – Crew awareness

Severe Icing visual cues
⇒ on propeller spinner



Appendix C ice accretion on the spinner



Ice accretion on the spinner under SLD's

Lessons learnt

- **Incident/accident review since Roselawn**
 - Pilots usually react pretty well to active warnings
 - At most events the severe icing cues are reported with hindsight but adequate procedures not followed
- **Possible explanation**
 - The side window icing gives conservative warning
 - The aircraft does not exhibit tactile cues that might warn the crew
 - Under AP, speed decay and loss of ROC may be missed by the crew
 - Operational pressure (from ATC, landing slots, ...)
- Based upon the above, ATR engineering department launched in 2003 a design review to determine the feasibility for an active warning in severe icing

Severe Icing Detection – Engineering review

Design review for an active warning

Severe Icing Detection – Engineering review

- Background
 - Definitions
 - Effects of SLD
 - Flight crew awareness
- Ice Detection
 - Review of detection principles
 - Detection of Severe Icing Conditions
 - Detection of Severe Ice Accretions
 - Detection of Severe Icing Effects

Severe Icing Detection – Engineering review

Icing definitions

■ Appendix C icing conditions

- - Droplet range : 5 to 135 microns
 - MVD range : 10 to 50 microns
 - LWC range : 0.05 to 2.8 g/m³

■ Freezing Drizzle

- Droplet range : 5 to 500 microns
- MVD range : 10 to 500 microns
- LWC < 1 g/m³

■ Freezing Rain

- Droplet range : 5 to 2000 microns
- MVD range : 10 to 2000 microns
- LWC < 1 g/m³

Severe Icing Detection – Engineering review Effect of SLD

Larger droplet inertia :

- Increased water catch efficiency
- Faster accretion growth
- Deeper impingement limits
- Deeper ice accretion limits

Resultant ice accretion

- Thicker residual ice with higher roughness
- Leading edge highlight often clear of ice (near freezing)
- Potential ridge of ice at boots edge.

Severe Icing Detection – Engineering review

Effect of SLD

Visual cues

- Deeper ice accretion than normally observed (engine spinner, beyond 5% chord on leading edge, side window icing)
- Water streaming on side windows at near freezing temperature
- Deicing performance often seems to be fair

Effects on aircraft

- Fast drag increase
- Asymmetric wing stall
- Lower CLmax

Severe Icing Detection – Engineering review

Review of detection principles

- ATR had already studied and tested various ice detection principle in the past (up to 1997)
- A new review has been launched to take into account:
 - the better knowledge on the severe icing environment,
 - the up to date development on ice detection systems,
 - the potential of existing principle outside the aviation community,
 - the findings presented at the last FAA icing conference (June 03)

Severe Icing Detection – Engineering review Review of detection principles

- **Detection of Severe Icing Conditions**
 - Measurement of cloud characteristics
- **Detection of Severe Icing Accretion**
 - Detection of ice accretion on side window
 - Detection of ice accretion beyond 5 to 7% chord
- **Detection of Severe Icing Effects**
 - Detection of performance degradation
 - Detection of induced airfoil turbulence

Severe Icing Detection – Engineering review

Review of detection principles

Measurement of clouds characteristics

- **Two conditions to be detected :**
 - $D_{max} > 135$ microns whatever the MVD is, or,
 - $MVD > 50$ microns
- **At least one instrument required to**
 - Measure of droplet spectra from 10 to 2000 micron
 - Compute of the MVD
- **Not available on the market as single instrument**
 - Weather research aircraft are equipped with multiple heavy sensors to accomplish this measurement : FSSP 100, OAP 1C and 2DC

Severe Icing Detection – Engineering review

Review of detection principles

Severe Ice Detection on side windows

- During most of recent ATR events, side window icing has been reported.
- Principle: Detect side window icing to trigger an active warning.
- Two detection principle investigated
 - Optical sensors
 - *Intertechnique optical sensor (laser beam echo)*
 - *Light absorption sensors*
 - Electrical sensors
 - *BFG impedance sensor*

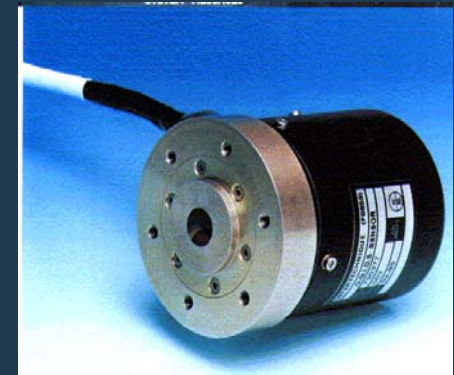
Severe Icing Detection – Engineering review

Review of detection principles

Severe Ice Detection on side windows

■ Intertechnique Optical sensor

- Developed from ground ice detection
- Tested on ATR after Roselawn accident
- Very sensitive for thin ice layer but questionable for ice spots (as exhibited by the side window cues)
- Extensive testing required to refine the detection threshold through the multiple glass layers of the window
- Massive detector
- Difficult to integrate behind the window



Severe Icing Detection – Engineering review

Review of detection principles

Severe Ice Detection on side windows

■ Light Absorption sensors

- Technology developed for rain detection and wiper activation on automotive industry.
- Based upon on light beam absorption. Work for rain droplet or thin film of water.
- Not designed to work with ice spot or layer but it should be possible by tuning the detection thresholds.
- Multi glass layer has also to be addressed.
- Numerous suppliers but no experience on aviation industry.

Severe Icing Detection – Engineering review

Review of detection principles

Severe Ice Detection on side windows

■ BFG Impedance sensors

- Derived from INISS (Ice No Ice System Sensor)
- Measurement of the impedance between two sensors
- Sensors made of thin copper band (1 sq. inch) that can be glued on any surfaces.
- Any presence of ice between the two sensors may be detected (provided ice acts as a bridge - not always true for ice spots)

Severe Icing Detection – Engineering review Review of detection principles

Severe Ice Detection on critical surfaces

- Three detection principles investigated
 - Spot sensors
 - *Intertechnique optical sensor (laser beam echo)*
 - *Vibrometer piezo sensor*
 - Electrical sensors
 - *BFG impedance sensor*
 - Infrared optical detection
 - *BFG Infrared camera*

Severe Icing Detection – Engineering review Review of detection principles

Severe Ice Detection on critical surfaces (cont'd)

■ Spot sensors

- Tested after Roselawn accident
- Flush mounted within the surface to be monitored
- Said non intrusive but do not provide the same thermal coefficient than the aircraft skin
- Bad experience on ATR, did not sense all type of ice (i.e. residual and spot ice)
- Major inconvenient
 - *Extensive flight test required in SLD conditions*
 - *Must be integrated through the current extended de-icer (→ new boots)*

Severe Icing Detection – Engineering review

Review of detection principles

Severe Ice Detection on critical surfaces (cont'd)

■ Electrical sensor

- Manufacturer by BFG
- Measurement of the surface impedance between two sensors.
- Can be glued on the extended boots or at the edge of the inner boots (when installed)
- May be used to detect residual ice beyond 5% chord.
- Major inconvenient
 - *poor detection performance for ice spot*
 - *extensive flight test required in SLD conditions*

Severe Icing Detection – Engineering review Review of detection principles

Severe Ice Detection on critical surfaces (cont'd)

■ Infrared camera

- Manufacturer by BFG (Icehawk)
- Developed for ground icing purpose but not yet certificated. Airborne installation might be possible but no experience available today.
- Major inconvenient
 - *Performance level needs to be documented in natural SLD conditions*
 - *Areas to be monitored need to be determined and accurately positioned.*

Severe Icing Detection – Engineering review

Review of detection principles

CONCLUSION

■ Common findings

- No mature technology available today.
- Very few number of potential manufacturers. Most of them have ceased all activities on ice detection due to the lack of demand.

■ Detection of severe ice accretion

- Low confidence on the detection performance
- Extensive flight test required in SLD

■ Detection through side windows

- extensive development tests required to get proof of concept

Severe Icing Detection – Engineering review Review of detection principles

CONCLUSION (cont'd)

- **ATR decided to focus on the detection of the effect of severe icing exposure**
 - ⇒ **APM = Aircraft Performance Monitor**

Aircraft Performance Monitor

Aircraft Performance Monitoring (APM)
integrated within the MPC

Multi-Purpose Computer

MPC A NEW CONCEPT

- More and more solutions need to be developed to comply with new regulations and/or customer requests (ATC, Maintenance aids, performance monitoring.....)
- ATR has studied an evolving concept capable of fulfilling several purposes including space-saving in the cockpit

Multi-Purpose Computer

Existing system

- SAGEM AFDAU developed for FAR 121/88 parameters
- Regulation applicable in Europe starting from 2007 through the ED-112ion

MPC results from evolution of this existing hardware

Multi-Purpose Computer

- Several needs: customer requests
 - QAR / DAR
 - ACMS (Aircraft Condition Monitoring System)
 - g-meter
 - Maintenance BITE
 - FDEP removal
- Several needs: Airworthiness Regulation
 - FAR 121-344 / 88 parameters
 - Enhanced Surveillance
 - ADS-B
 - Performance Monitoring

1 computer for
all functions
all a/c models

Aircraft Performance Monitor

APM Background concerns

Aircraft Performance Monitor

Analysis of world fleet incidents/accidents, related to flight into severe ice, shows two main risk area:

- Lack of reconnaissance of severe ice condition
 - **Information background/training not adequate**
 - **crew awareness not adequate**
- Crew committed to continue the flight with unchanged flight profile
 - **external pressure to avoid flight delay**
 - **intentional or passive acceptance of speed decay with consequent reduction of safety margins to face the changed atmospheric condition (IAS change to meet the target FL)**
- Human factor aspects:
 - **Need to keep record of performance degradation encountered during the flight**

Aircraft Performance Monitor

- APM objectives:
 - Give evidence to the crew of severe ice effect on the A/C performance
 - Give indication of the minimum required IAS to keep
- Human factor aspects:
 - Show evidence of external conditions encountered as proof of compliance of timely procedure application.

Aircraft Performance Monitor

APM Principle

Aircraft Performance Monitor

- Compare actual aircraft polar with the expected one
- Computes the minimum icing and severe icing speeds
 - from aircraft weight (computed or entered by the crew)
- Computes the objective cruise speed

- Provides active alerts to the flight crew
 - Cruise speed low
 - Degraded Performance
 - Increase speed

Aircraft Performance Monitor

APM Man/Machine Interface concept

Aircraft Performance Monitor

- “Speed-not-nominal” advisory:

**CRUISE
SPEED LOW**

- It advises the crew that cruise IAS is lower than the expected value by 10kts.
- If illuminated :
 - Monitor the icing conditions and speed

Aircraft Performance Monitor

- Performance loss alert:

**DEGRADED
PERFORMANCE**

CAUTION

+



Single Chime

- During climb, cruise and descent it alerts the crew that :
 - Performance is being degraded (speed or RoC decrease)
 - Probable cause may be an abnormal ice accretion

Aircraft Performance Monitor

DEGRADED PERFORMANCE

Check de-icing ON
Red bug + 10 Kt
Auto Pilot OFF

CAUTION



Single Chime

Severe icing cues or IAS < (red bug +10kts) or abnormal handling

YES

**Severe Icing Procedures
Apply**

NO

**Continue Scheduled flight
Monitor Speed and Icing condition**

Aircraft Performance Monitor

- “SPEED” alert:

**INCREASE
SPEED**

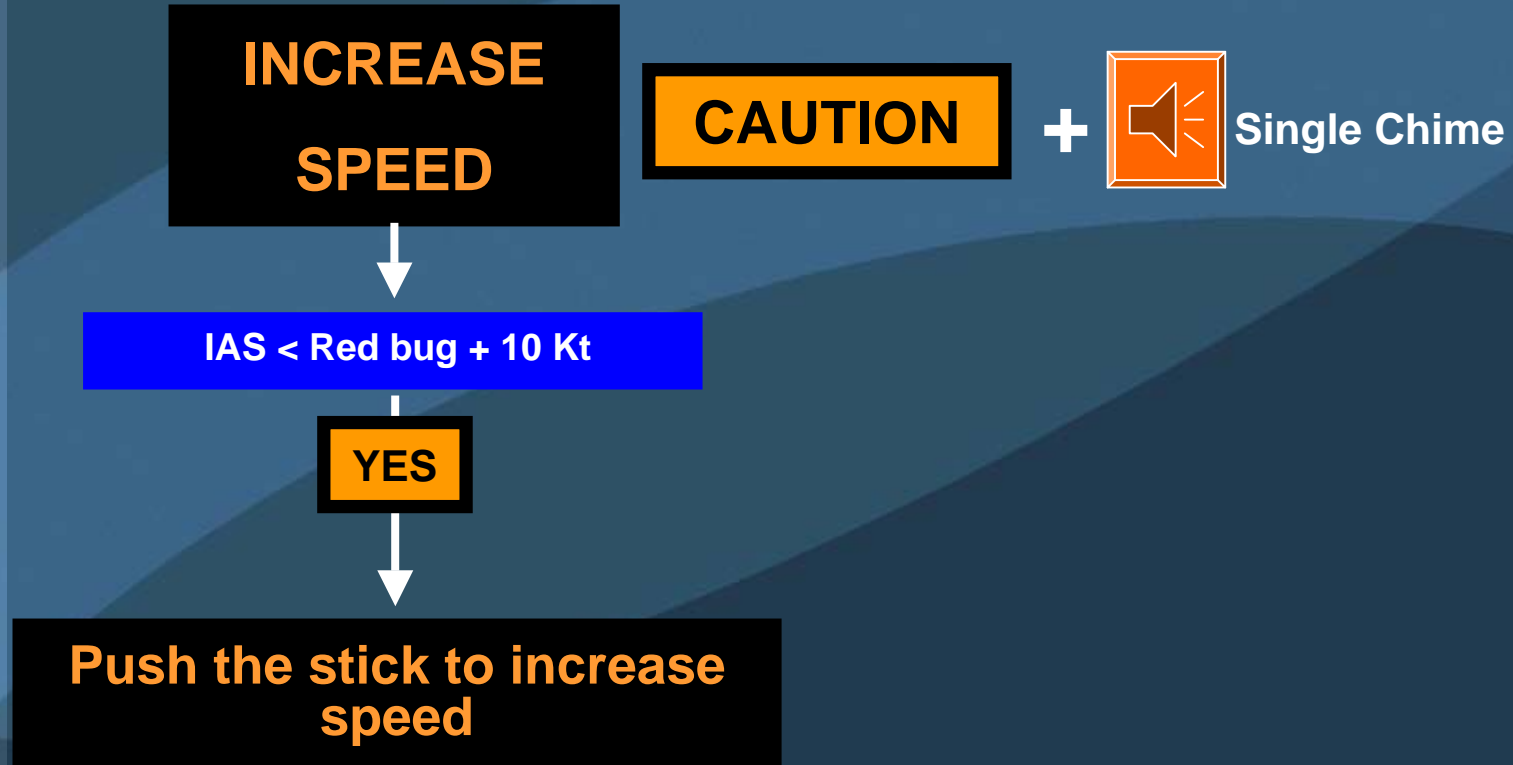
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CAUTION



- It alerts the crew that minimum icing speed is reached Active during climb, cruise and descent.
- This alert should be triggered after a «Degraded Performance» warning
- No specific procedure

Aircraft Performance Monitor



Aircraft Performance Monitor

■ Recap

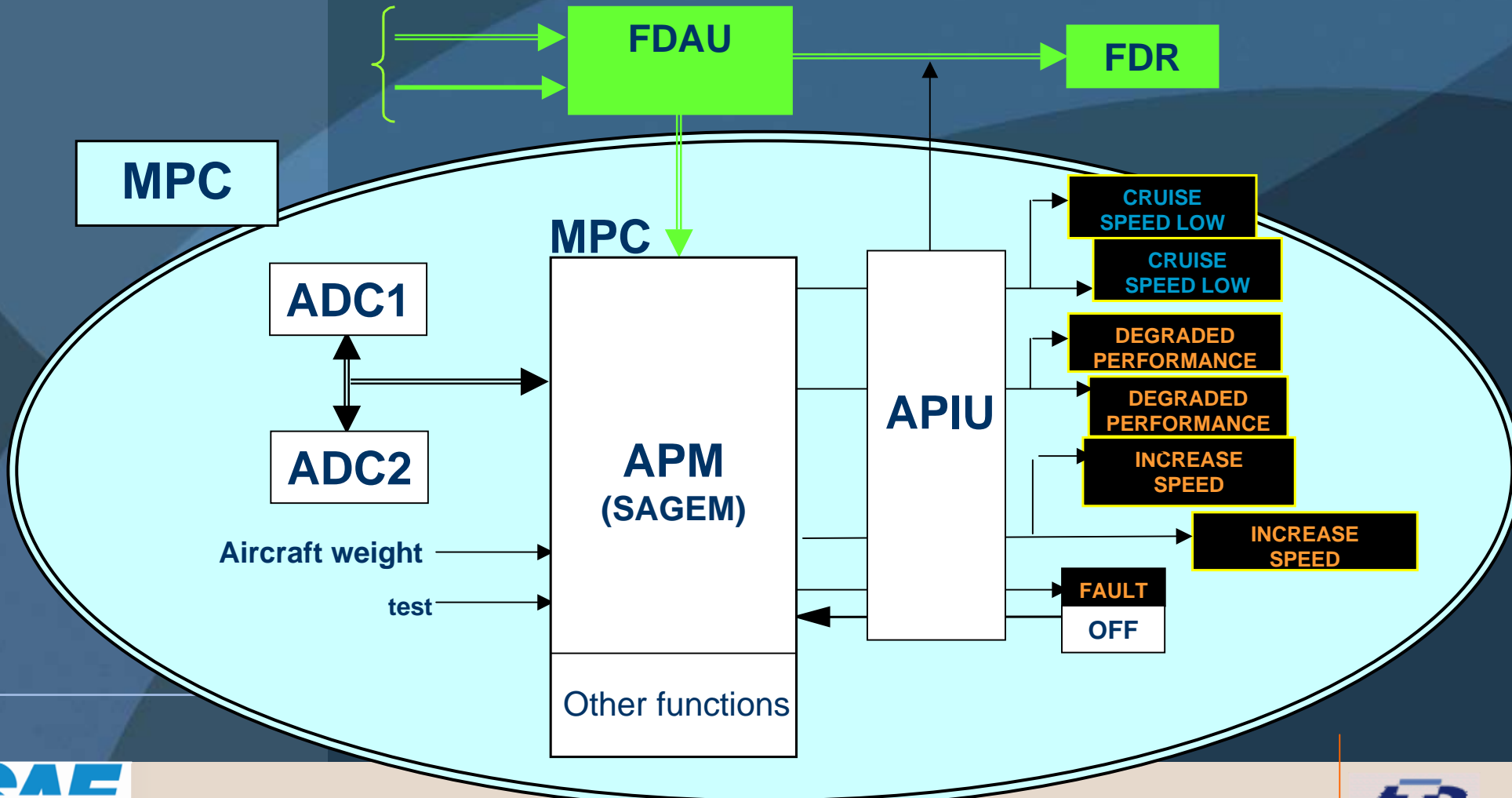
Causes	Crew does not detect problem	Crew do not take into account indications	No justification for pilot
Solutions	Draws pilot 's attention	Indicates minimum speed	Help pilots to justify
Means	<p>CRUISE SPEED LOW</p> <p>DEGRADED PERFORMANCE</p>	<p>INCREASE SPEED</p>	<p>Record all alerts in FDR</p> <p>Adaptation of procedures after a «Degraded performance»</p>

Aircraft Performance Monitor

APM General architecture

Aircraft Performance Monitor

APM Architecture



Aircraft Performance Monitor

APM Cockpit integration

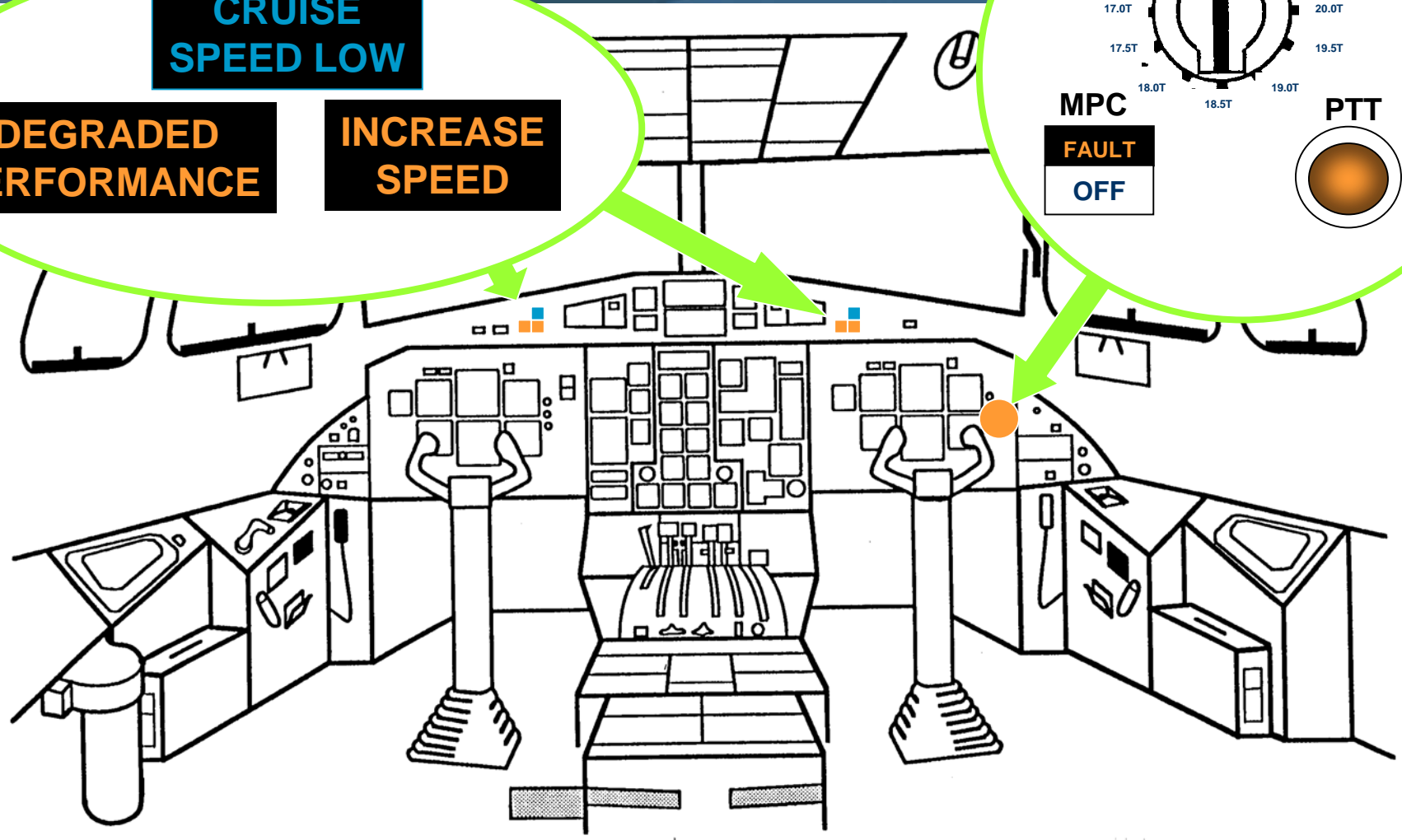
CRUISE SPEED LOW

DEGRADED PERFORMANCE **INCREASE SPEED**

MPC
FAULT
OFF

PTT

21.5T, 21.0T, 20.5T, 20.0T, 19.5T, 19.0T, 18.5T, 18.0T, 17.5T, 17.0T, 16.5T, 16.0T



Aircraft Performance Monitor

MPC overall planning

- End 2004: ATR initial SBs approved for ATR72-212A and available for CSU
- Beginning 2005 during 4 months: CSU and follow-up - in the mean time, development of other parts
- After CSU, APM laws modification
- June 2005: validation on all ATR models –
- July 2005: Modification approval granted by EASA

Aircraft Performance Monitor

MPC Fleet Status

- Installed on production aircraft since March 2006
 - 14 ATR42-500 and 33 ATR72-212A delivered with APM
- Available for retrofit since beginning of 2006
- ATR42-300/-320
 - First retrofit on April 2006 and 9 kits ordered
- ATR42-500
 - First retrofit on March 2007 and 19 kits ordered
- ATR72 all models
 - First retrofit on April 2007 and 31 kits ordered