Proposed Special Condition for Qualification in Icing Conditions of External Probes

Applicable to Bombardier CSeries

Introductory note:

The following Special Condition has been classified as an important Special Condition and as such shall be subject to public consultation, in accordance with EASA Management Board decision 12/2007 dated 11 September 2007, Article 3 (2.) of which states:

"*2. Deviations from the applicable airworthiness codes, environmental protection certification specifications and/or acceptable means of compliance with Part 21, as well as important special conditions and equivalent safety findings, shall be submitted to the panel of experts and be subject to a public consultation of at least 3 weeks, except if they have been previously agreed and published in the Official Publication of the Agency. The final decision shall be published in the Official Publication of the Agency.*"

Statement of issue

EASA believes that the related airworthiness code does not contain adequate or appropriate safety standards for Flight Instrument External Probes. Experience from products in service has shown that unsafe conditions may develop and a special condition must therefore be specified.

The intent of this Special Condition is to address malfunctioning of Flight Instrument External Probes, including, but not necessarily limited to Pitot and Pitot-static probes, alpha vanes, side slip vanes and temperature probes certified for flight in icing conditions, due to:

- inadequate failure indications of probe heater failure,
- heavy rain conditions,
- severe icing environment (CS 25 Appendix C super cooled liquid water, mixed phase ice and ice crystals)

Revised environmental conditions are considered in this Special Condition for certification.

Regarding inadequate failure indication of the probe heating resistance, EASA proposes to address failures, such as found in Pitot probes that may not be seen by the low current detection system on aircraft, by modifying CS 25.1326 to explicitly cover abnormal functioning of the heating system. This is considered as a clarification since 25.1419(c) is already very clear by requiring that:

> "*Caution information, such as an amber caution light or equivalent, must be provided to alert the flight crew when the anti-ice or de-ice system is not functioning normally".*

CS 25.1326 is also modified to extend the scope of the requirement to all Flight Instrument External Probes including, but not necessarily limited to Pitot and Pitot-static probes, alpha vanes, side slip vanes and temperature probes.

Regarding the ice crystal and mixed phase icing conditions, this SC takes into account the Aviation Rulemaking Advisory Committee's (ARAC) Ice Protection Harmonization Working Group (IPHWG) recommendations as stated in a report titled "Tasks 5 & 6 Working Group Report," dated October 2006. However, available information from in-service experience show that events may occur at higher altitude and lower temperature than those specified in the IPHWG report or the existing EASA AMC to CS 25.1419.

The ARAC joint Engine and Power Plant Installation Harmonization Working Groups, hereafter referred to as EHWG, also drafted proposed rules addressing FAA 14 CFR Part 25 aircraft turbofan engine installation icing and propeller requirements and Part 33 turbofan engine icing requirements. Included in the EHWG draft rules is a proposed Appendix D to FAA 14 CFR Part 33 defining high ice water content environments in mixed phase and glaciated conditions. The proposed Appendix D to 14 CFR Part 33 has been developed using the history of engine ice crystal in-service events, theoretical models of the atmosphere and atmospheric flight test results (McNaughton FTs). It is intended to be a more representative characterisation of the icing conditions that lead to engine events and, based on the recent evidence, appear to cause Pitot probe icing issues.

EASA understands that there is a need for more extensive and accurate meteorological data to characterise these environments, however it is considered that the proposed Appendix D to Part 33 is the most appropriate and accurate information available at this time.

CS 25.1323(i) is therefore replaced by a new specification to incorporate the mixed phase and ice crystal conditions as specified in the proposed Appendix D to 14 CFR part 33. Moreover, the proposed Special Condition extends the scope of the requirement to all Flight Instrument External Probes including, but not necessarily limited to Pitot and Pitot-static probes, alpha vanes, side slip vanes and temperature probes.

Bombardier CSeries – Special Condition F-14

- Qualification in Icing Conditions of External Probes -

Replace CS 25.1323(i), AMC 25.1323(i) and 25.1326 by SC 1 & 2 and respective AMCs

1. Flight Instrument External Probes Heating Systems

   Each Flight Instrument External Probes Systems must be heated or have an equivalent means of preventing malfunction due to icing conditions specified in CS 25 Appendix C and mixed phase / ice crystal conditions as defined in Appendix 1 of this Special Condition (see AMC in Appendix 2 of this SC)

2. Flight Instrument External Probes heat indication systems

   If a flight instrument external probe heating system is installed, an indication system must be provided to indicate to the flight crew when the flight instrument external probe heating system is not operating normally. The indication system must comply with the following requirements:

   (a) The indication provided must incorporate an amber light that is in clear view of a flight-crew member.

   (b) The indication provided must be designed to alert the flight crew if either of the following conditions exist:

   (1) The flight instrument external probe heating system is switched 'off'.

   (2) The flight instrument external probe heating system is switched 'on' and any flight instrument external probe heating element is not functioning normally

(see AMC in Appendix 2 of this SC)

Appendix 1

Mixed Phase and Ice Crystal Icing Envelope (Deep Convective Clouds)

References

1. THE ANALYSIS OF MEASUREMENTS OF FREE ICE AND ICE/WATER CONCENTRATIONS IN THE ATMOSPHERE OF THE EQUATORIAL ZONE, IAN I. MCNAUGHTON, B.SC., DIP. R.T.C., ROYAL AIRCRAFT ESTABLISHMENT (FARNBOROUGH) TECHNICAL NOTE NO: MECH. ENG. 283

2. SNOW AND ICE PARTICLE SIZES AND MASS CONCENTRATIONS AT ALTITUDES UP TO 9 KM (30,000 FT), R. K. JECK, DOT/FAA/AR-97/66, AUGUST, 1998.

3. CLOUD MICROPHYSICAL MEASUREMENTS IN THUNDERSTORM OUTFLOW REGIONS DURING ALLIED/BAE 1997 FLIGHT TRIALS, STRAPP, J.W., P. CHOW, M. MALTBY, A.D. BEZER, A. KOROLEV, I. STOMBERG, AND J. HALLETT, *37TH AIAA AEROSPACE SCIENCES MEETING AND EXHIBIT*, JAN. 11-14, 1999, RENO, NV. AIAA 99-0498.

4. ARAC EHWG PROPOSED APPENDIX D TO 14 CFR PART 33

Ice crystal conditions associated with convective storm cloud formations exist within the CS 25 Appendix C Intermittent Maximum Icing envelope (including the extension to -40 deg C) and the Mil Standard 310 Hot Day envelope. This ice crystal icing envelope is depicted in the Figure D-1.

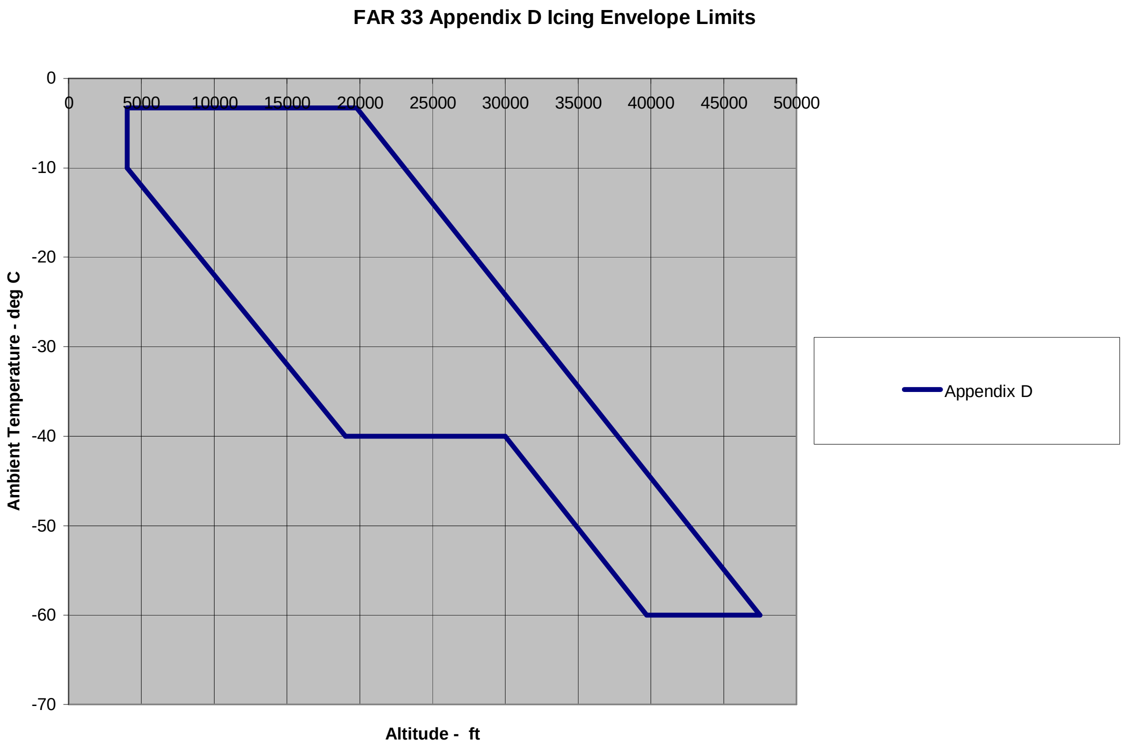


Figure D-1 Convective Cloud Ice Crystal Envelope

Within the envelope, total water content (TWC) in gms/m3 have been assessed based upon the adiabatic lapse defined by the convective rise of 90% relative humidity air from sea level to higher altitudes and scaled by a factor of 0.65 to a standard cloud length of 17.4 nautical miles. TWC is displayed for this distance over a range of ambient temperature within the boundaries of the ice crystal envelope in Figure D-2.

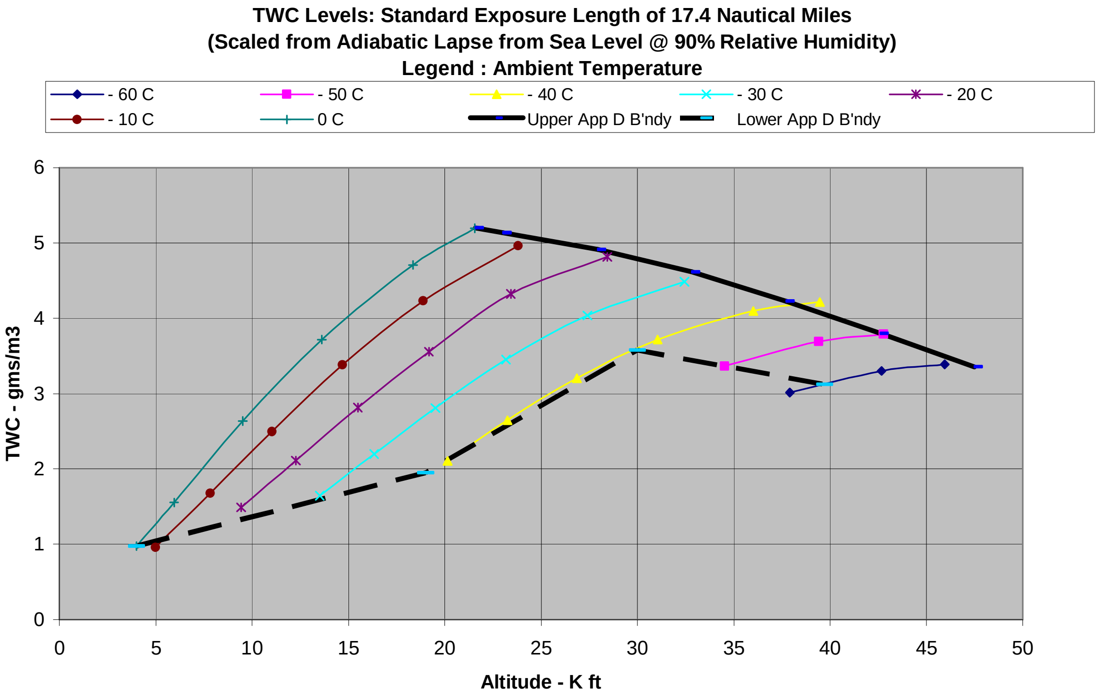


Figure D-2 Total Water Content

Ice crystal size median mass dimension (MMD) range is 50 - 200 microns (equivalent spherical size) based upon measurements near convective storm cores.

The TWC can be treated as completely glaciated except as noted in the Table D-1.

Temperature Range – deg C	Horizontal Cloud Length	LWC – gm/m3
0 to -20	</= 50 miles	</=1.0
0 to -20	Indefinite	</=0.5
< -20		0

Table D-1 Supercooled Liquid Portion of TWC

The TWC levels displayed in Figure D-2 represent TWC values for a standard exposure distance (horizontal cloud length) of 17.4 nautical miles that must be adjusted with length of icing exposure. The assessment from data measurements in References 1 supports the reduction factor with exposure length shown in Figure D-3.

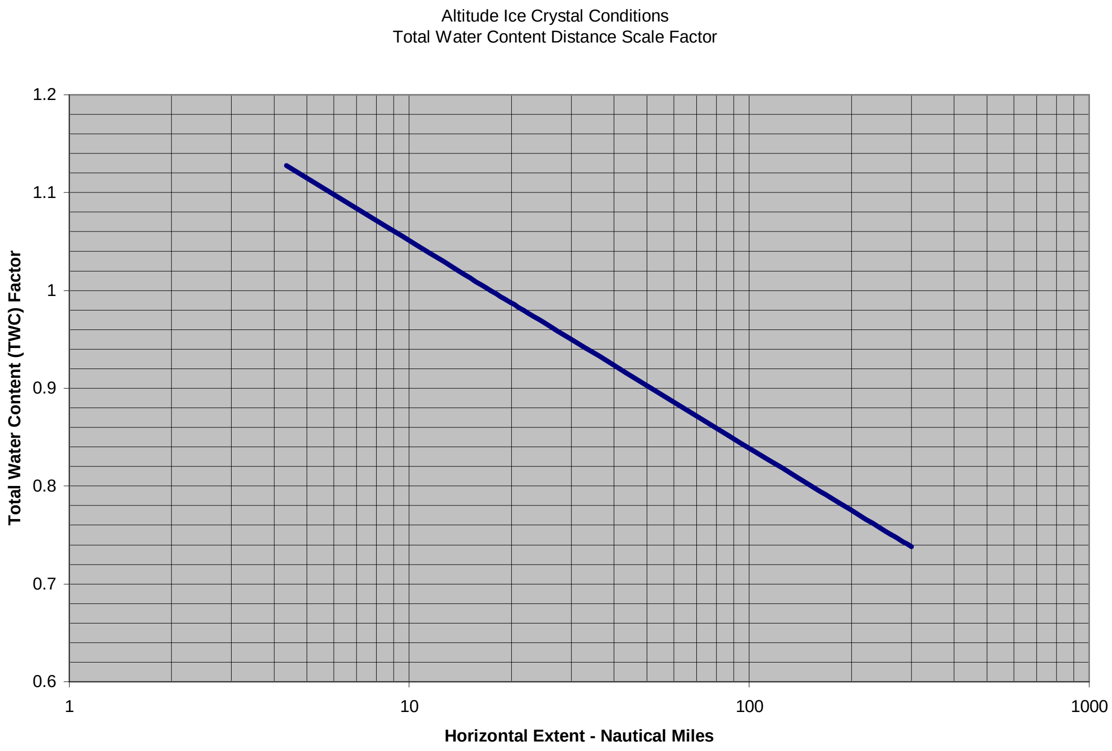


Figure D-3 Exposure Length Influence on TWC

Appendix 2

Flight Instrument External Probes
Acceptable Means of Compliance

1. Nomenclature

SAT	Static Air Temperature
LWC	Liquid Water Content
MVD	Mean Volume Diameter
IWC	Ice Water Content
IMMD	Ice Median Mass Dimension
L(i)	"Liquid" supercooled water conditions
M(i)	Mixed phase icing conditions, contain both supercooled water and ice crystals.
G(i)	Glaciated conditions are icing conditions totally composed of ice crystals.
R(i)	Rain conditions

2. Test setup and Conditions to be tested

2.1. Wind Tunnels

If wind tunnel testing is proposed, all conditions must be appropriately corrected to respect the similarity relationship between actual and wind tunnel conditions (due to pressure and scale differences for example). It is the manufacturer responsibility to determine and justify the various derivations and corrections to be made to the upstream conditions in order to determine actual test conditions (local and scaled). When the tests are conducted in non-altitude conditions, the system power supply and the external aerodynamic and atmospheric conditions should be so modified as to represent the required altitude condition as closely as possible.

Icing Wind tunnel calibration shall be verified, in accordance with SAE ARP 5905, prior to the beginning of icing test campaign, and at the end of the campaign. In particular, the local liquid water concentration at the location of the probe shall comply with values required in the test specification.

2.2. Test setup

The test setup installation in the wind tunnel must be shown to be equivalent to the installation on aircraft. In particular, the probe must be installed in such a way that the heat sink capacity of the mount is equal to or greater than the aircraft installation.
Surface temperature measurements are typically made, during icing wind tunnel tests to verify thermal analyses and to allow extrapolation to conditions not reachable due to tunnel limitations.

2.3. Local conditions

The Water Content (WC) values provided in this AMC or in the Appendix 1 are upstream values, independent of the aircraft installation. Local WC values (values at the probe location) need to be derived from the upstream values according to the streamline behavior around the aircraft. Overconcentration of the WC at the probe location may occur due to the aerodynamic effects of the fuselage in particular.
Local conditions shall be determined based on many parameters which could be :

- **Aircraft specific**
    - A/C fuselage shape

    - Probe location on A/C fuselage (X, Y, Z coordinates)
    - A/C speed and altitude (Climb, Cruise, Descent …)
- **Environmental Conditions specific**
    - Type (SD, SLD, Crystals, Rain)
    - Size (from 0 to 2000 micron)
    - Density
- **Probe specific:**
    - mast/strut length

Concerning the type and size of the particles, the local WC shall be computed considering the full distribution of the particles sizes that is actually present in the real atmosphere, even if the wind tunnel tests are then performed at a given single size (20 micron for supercooled droplets, 150 micron for ice crystals, 1000 & 2000 micron for rain drops). The local conditions may also be affected by the "bouncing effect" for solid particles or the "splashing effects" for large liquid particles.

2.4. Operational Conditions

The conditions are to be tested at several Mach and Angle of Attack (AoA) values in order to cover the operational flight envelope of the aircraft. It is the manufacturer responsibility to select and justify, for each of the conditions listed in each Cloud Matrix below, the relevant operational conditions to be tested (Mach, AoA and Mode…).
For normal operational conditions all the parameters such as weight and CG position should be considered. Other operational conditions should be considered such as the dispatch in MMEL and major failure conditions having an effect on the Mach number and / or the AoA.

It is expected that several operational conditions will be identified for each matrix condition but exhaustive testing is not intended.

2.5. Power Supply

The heating power supply used during the tests shall be the minimum value expected at the probe location on the aircraft.

2.6. Test article Selection

To be delivered an article has to meet an Acceptance Test Procedure (ATP) established by the equipment supplier. The ATP is a production test performed on each item to show it meets the performance specification. The performance of the ice protection system, in particular the icing tests described hereafter, are expected to be demonstrated with an equipment selected at the lowest value of the ATP with the respect to the acceptability of the heating performance.

2.7. Mode of Operation

The modes of operation of the probe are to be assessed in the two following tests. However, depending of the mode of operation of the heating systems, other intermediate modes may have to be tested (e.g. if heating power is varied as a function of the outside temperature, etc.)
Anti-icing test:
During this test, the icing protection of the probe (typically resistance heating) is assumed to be switched "on" prior to reaching freezing temperatures.
De-icing test:
During this test, the icing protection of the probe (typically resistance heating) must be "off" until 0.5 inch of ice has accumulated on the probe. For ice crystal tests in deicing mode, since no accretion is usually observed, an agreed Off period time duration shall be

agreed before the test; in the past a one minute time duration without heating power has been accepted This mode need not be tested if, in all operational scenarios (including all dispatch cases), the probe heating systems are activated automatically at A/C power ON and cannot be switched to manual operation later during the flight.

2.8. Liquid (L) Conditions

The following proposed test points, are intended to provide the most critical conditions of the complete CS 25 Appendix C icing envelope, however, Critical Point Analysis (CPA) may be used to justify other values.

Stabilized conditions

Test #	SAT (°C)	Altitude Range		LWC(*) (g/m3)	Duration (min)	MVD(*) (µm)
L1	-20	0 to 22000 ft	0 to 6700m	0,22 to 0,3	15	15 to 20
L2	-30	0 to 22000 ft	0 to 6700m	0,14 to 0,2	15	15 to 20
L3	-20	4000 to 31000 ft	1200 to 9450m	1,7 to1,9	5	15 to 20
L4	-30	4000 to 31000 ft	1200 to 9450m	1 to 1,1	5	15 to 20
L5	-40	4000 to 31000 ft	1200 to 9450m	0,2 to 0,25	5	15 to 20

Table 1: Stabilized Liquid icing test conditions

(*) Note:

The upstream LWC values of the table are based on CS 25 Appendix C and correspond to a droplet diameter of 20µm or 15µm. Considering that the local collection efficiency is function of the MVD and the probe location with respect to the boundary layer, and that the upstream LWC value is higher for an MVD of 15 µm as compared to 20 µm, the applicant shall establish the conditions leading to the highest local LWC at probe location and test accordingly.
It is acceptable to run the tests at the highest determined local LWC but using a droplet diameter of 20 µm since most of the wind tunnel are calibrated for that value.

Cycling conditions

The cycling test conditions detailed in Table 2 below are identical to those established in AMC 25.1093 (b) section 2.4.2, and currently recommended in existing AMC 25.1323(i), 25.1325(b) and 25.1419.

A separate test should be conducted at each temperature condition of Table below, the test being made up of repetitions of either the cycle:

a. 28 km in the conditions of column (a) appropriate to the temperature, followed by 5 km in the conditions of column (b) appropriate to the temperature, for a duration of 30 minutes, or

b. 6 km in the conditions of column (a) appropriate to the temperature, followed by 5 km in the conditions of column (b) appropriate to the temperature, for a duration of 10 minutes.

Test #	SAT (°C)	Altitude Range		LWC (g/m^3)		MVD (µm)
		(ft)	(m)	(a)	(b)	
L6	-10	17 000	5 200	0.6	2.2	20
L7	-20	20 000	6 100	0.3	1.7	
L8	-30	25 000	7 600	0.2	1.0	

Table 2: Cycling Liquid icing test conditions

2.9. Mixed Phase (M) and Glaciated (G) Conditions

The applicant shall propose a set of critical test points to cover adequately the Icing Environment as proposed in Appendix 1 of this CRI. The following considerations shall be taken into consideration.

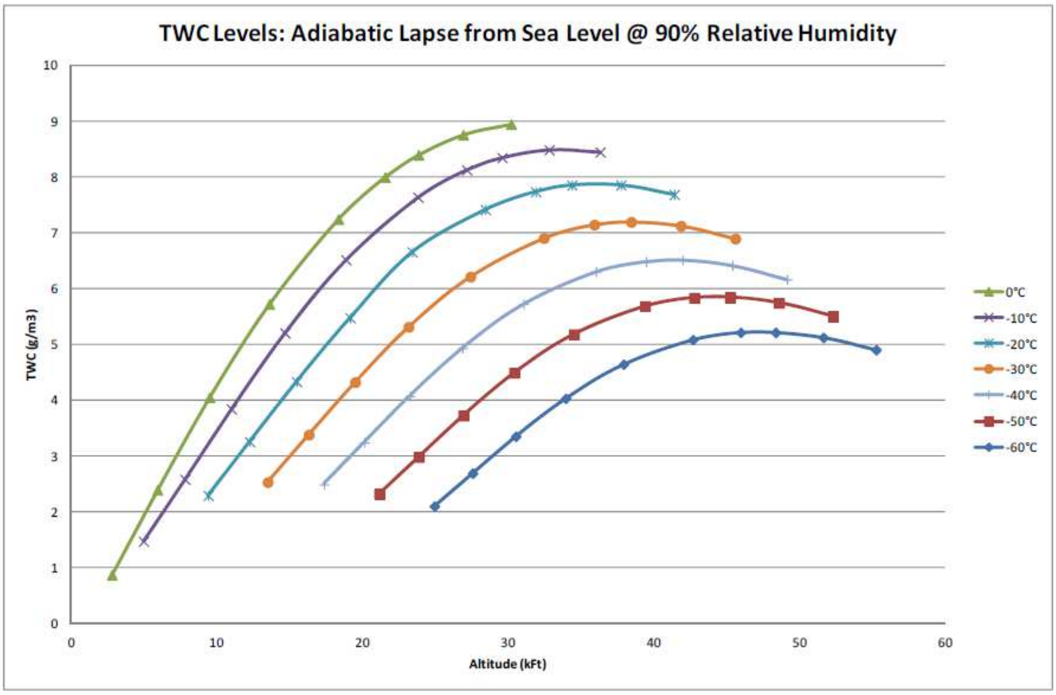
Glaciated Conditions

As indicated in the Appendix 1, the total water content (TWC) in gms/m3 have been assessed based upon the adiabatic lapse defined by the convective rise of 90% relative humidity air from sea level to higher altitudes and scaled by a factor of 0.65 to a standard cloud length of 17.4 nautical miles.

In service occurrences show that several Pitot icing events in Glaciated Conditions, above 30 000ft, are outside of the Appendix 1 domain in term of Altitude and outside air temperature. In particular, a reported event occurred at a temperature of -70°C. Testing may not be possible at such a low temperature due to simulation tool limitations however, the presence of Ice Crystals has been observed and it is anticipated that an extrapolation of existing test data at higher temperature should allow assessing the predicted performance of the probe heating down to this minimum temperature.

In addition, based on various feedback (Eurocae WG 89 in particular), EASA is of the opinion that the standard cloud of 17.4 NM and the associated average TWC concentration values provided by appendix 1 may not provide the most conservative conditions for Flight Instrument External probes testing.

The “max” or “peak” TWC concentration values should be considered instead of the “17.4 NM” values provided by the Appendix 1. These max or peak values are given in FAA document DOT/FAA/AR-09/13. They correspond to the “17.4 NM” values multiplied by a factor of 1.538 (1/0.65). The “max” concentration values (TWC) are provided below:

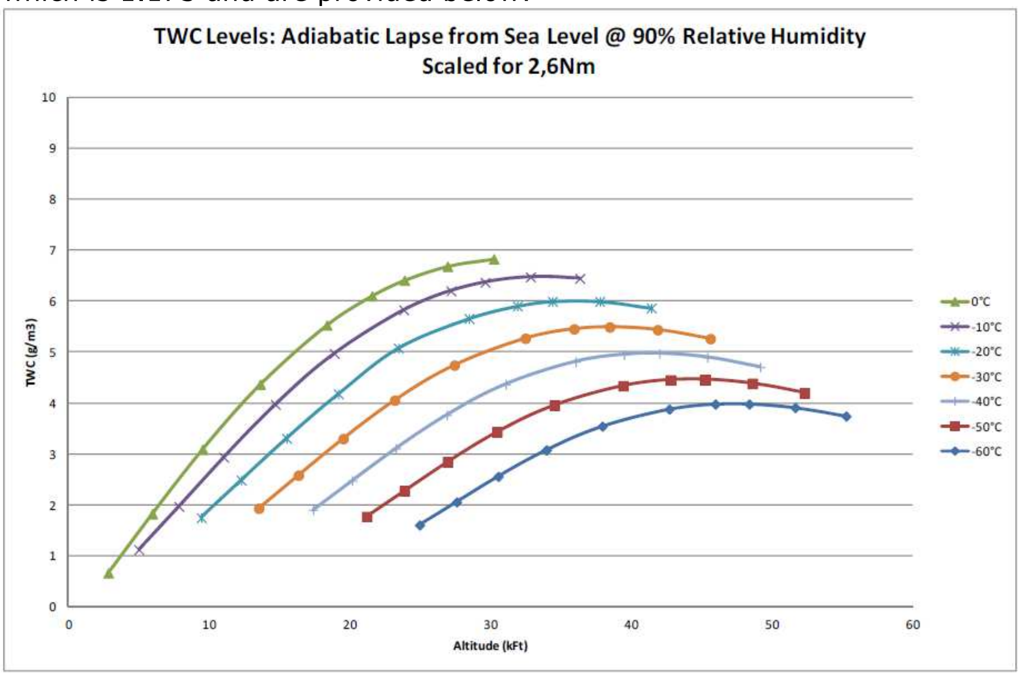


Mixed Phase Conditions

In service occurrences show several Pitot icing events in Mixed phase conditions, between 20 000 & 30 000 ft, outside of the Appendix 1 domain in term of Altitude and outside air Temperature.

Based on various feedback (Eurocae WG 89 in particular), EASA is of the opinion that the "2.6 NM" TWC concentration values should be considered instead of the "17.4 NM" values, as the CS 25 Appendix C Intermittent conditions provide data for a 2.6 NM cloud.

The "2.6 NM" values are given by the "17.4 NM" values scaled by the F factor for 2.6 NM clouds which is 1.175 and are provided below:



Ice Particles

According to the IPHWG, several methods of generating ice particles are used in testing and produce a wide range of particle sizes. Some methods of generating ice particles results in irregular shapes which are difficult to quantify in terms of mean particle diameter. The heat requirements for mixed phase icing are driven primarily by the quantity of ice collected in the probe rather than the size of the ice particles. Particles in

the range of 50 to 1000 μm tend towards ballistic trajectories with collection efficiencies approaching one on conventional Pitot tubes. As such, the IPHWG determined it is acceptable to specify ice particle sizes based on the available range of ice particle generation techniques and using the IMMD consistent with draft AC 20-147 for engines.
Past experience shows that an ice crystal MMD size of 150 micron is the more practical size to be tested in wind tunnel. For mixed phase conditions, it shall be tested together with supercooled droplet MVD size of 20 micro.

Duration
For each condition a minimum of 2 minutes exposure time shall be tested. This is the minimum time needed to reach a steady state and stabilised condition.

2.10. Rain (R)Conditions

<table>
<tr><td rowspan="2">Test #</td><td>SAT</td><td colspan="2">Altitude Range</td><td>LWC</td><td colspan="2">Horizontal Extent</td><td>Droplet MVD</td></tr>
<tr><td>(°C)</td><td>(ft)</td><td>(m)</td><td>(g/m3)</td><td>(km)</td><td>(nmi)</td><td>(μm)</td></tr>
<tr><td>R1</td><td rowspan="3">-2 to 0</td><td rowspan="3">0 to 10 000</td><td rowspan="3">0 to 3000</td><td>1</td><td>100</td><td>50</td><td rowspan="3">500 to 1000</td></tr>
<tr><td>R2</td><td>6</td><td>5</td><td>3</td></tr>
<tr><td>R3</td><td>15</td><td>1</td><td>0.5</td></tr>
</table>

Table 3: Rain icing test conditions

2.11. Pass/fail criteria

The pass/fail criteria of a given test are as follows:

The output of the probe must quickly stabilize to the correct value (after the start of an Anti-icing test or once the icing protection is restored in a De-icing test), value which has to be agreed before the test between the manufacturer and EASA, and it must stay correct as long as the icing protection is maintained. The measurement is considered to be correct if any observed fluctuation when assessed by the manufacturer has no effect at A/C level.
In addition, for Pitot probes and especially during ice crystal or mixed conditions tests, it shall be observed that the measured pressure is not 'frozen'(pressure signal without any noise, i.e. completely flat), which would indicate an internal blockage resulting in a captured pressure measurement.
At the conclusion of each test, the amount of water trapped in and around the probe (i.e in the line conveying the air to the electronics) shall not interfere with the output correctness, if the probe were suddenly subjected to freezing or re-freezing after melting.
After each tests, any moisture accumulating in the probe connection line shall be removed and measured. A maximum of 1 gram should not be exceeded.

3. Probes heat indication systems

If a flight instrument external probes heating system is installed, an indication system must be provided to indicate to the flight crew when that flight instrument external probes heating system is not operating normally. In other words, failures must be indicated to the crew if such failures have an impact on the performance of the heating system to the extent of having an "effect on operational capability or safety" (see CS 25.1309).

The setting of the warning provided to the flight deck is expected to be not lower than the lowest acceptable value of the heating performance according to its performance specification and/or qualification standards.

All performances of the probe ice protection system, in particular the icing tests described in this AMC are expected to be demonstrated with equipment selected at the level of the flight deck warning indication of the probe.

4. Maintenance Tasks

As part of the overall Ice and Water protection, probes usually feature drain holes to evacuate melted ice or water from the equipment. It is essential that the drain holes and more generally the probe tube are kept free of any contamination. Simple maintenance tasks of checking for probe drain holes cleanliness, with subsequent cleaning and flushing if any particle/dust/etc. is detected, are expected frequently. Inspection interval of the probes could be derived to cope with classification of the failure condition linked to the loss of speed on more than one probe. A 300 to 500 hours maintenance time interval should not be exceeded for such a check on each pitot probe.

5. Further Guidance

Further guidance can be found in the following documents:

- BS 2G135 revised "Specification for Electrically-heated pitot and pitotstatic pressure heads
- AS8006 "Minimum performance standard for pitot and pitot-static tubes"
- MIL-HDBK-310 "Global climatic data for developing Military products"