

# Aircraft Icing

## “FAR/CS-25, Appendix O and P charts”

Prof. Dr. Serkan ÖZGEN

Dept. Aerospace Engineering, METU

Fall 2015



# Outline

- Appendix O and P - Background
- Existing CS-25 certification specifications for operation in icing conditions
- CS-25 rule change proposal
- Review of accident and incident lessons
- Appendix O – SLD icing conditions
- Appendix P – Mixed phase and ice crystal icing envelope (deep convective clouds)

# Background

- It has been evidenced that the icing environment used for certification of large airplanes and turbine engines needs to be expanded in order to improve the level of safety when operating in icing conditions.
- On 31 October 1994, near Roselawn, Indiana, USA, an accident involving an Avions de Transport Régional ATR 72 occurred in icing conditions believed to include **freezing drizzle drops**.

# Background

- Indeed, the accident investigation led to the conclusion that freezing drizzle conditions created a **ridge of ice** on the wings' upper surface aft of the de-icing boots and forward of the ailerons.
- It was further concluded that the ridge of ice resulted in an **uncommanded roll** of the airplane. The atmospheric condition (freezing drizzle) that may have contributed to the accident is **outside the existing CS-25 Appendix C icing envelope** that is used for certification of large airplanes.



# Background

- Another atmospheric icing condition which airplanes may experience and that is outside of the Appendix C icing envelope is **freezing rain**. These kinds of icing conditions constitute an icing environment known as **Supercooled Large Drops (SLDs)**.

# Background

- Therefore, an **Aviation Rulemaking Advisory Committee (ARAC)** was tasked by the **Federal Aviation Administration (FAA)** in December 1997, through its **Ice Protection Harmonization Working Group (IPHWG)**, to perform the following actions:
  - Define an icing environment that includes SLDs;
  - Consider the need to define a mixed phase icing environment (supercooled liquid and ice crystals);
  - Devise requirements to assess the ability of an airplane to either safely operate without restrictions in these conditions or safely operate until it can exit these conditions;
  - Study the effects icing equipment changes could have on regulations on “Pilot compartment view”, “Airspeed indicating system” and “Static pressure systems” ;
  - Consider the need for a regulation on ice protection for angle of attack probes.



# Background

- Service experience of different engine types installed on CS-25 aircraft has also identified the potential for a **multiple engine failure during take-off, after prolonged ground operation in freezing fog**. A multiple engine failure during take-off would compromise safe flight and landing.
- Moreover, **falling and blowing snow** is a weather condition, which needs to be considered for the powerplants and essential Auxiliary Power Units (APUs) of transport airplanes.
- Although snow conditions can be encountered on the ground or in flight, **there is little evidence that snow can cause adverse effects in flight on turbojet and turbofan engines with traditional Pitot style inlets** where protection against icing conditions is provided.
- However, **service history has shown that in-flight snow (and mixed phase) conditions have caused power interruptions on some turbine engines and APUs**.



# Existing CS-25 certification specifications for operation in icing conditions

- CS-25 provides a set of requirements involving protection systems and airplane operation principles.
- CS 25.1419 (Ice protection) requires the aeroplane to be able to **“safely operate in the continuous maximum and intermittent maximum icing conditions of Appendix C”**.
- Minimum performance and handling qualities, as well as to detect airframe icing and to operate ice protection systems are also required in these icing conditions.



# Existing CS-25 certification specifications for operation in icing conditions

- These specifications can be found in:
  - CS 25.21: Proof of compliance,
  - CS 25.103: Stall speed,
  - CS 25.105: Take-off,
  - CS 25.107: Take-off speeds,
  - CS 25.111: Take-off flight path,
  - CS 25.119: Climb: all engines operating,
  - CS 25.121: Climb: one engine inoperative,
  - CS 25.125: Landing,
  - CS 25.143: Controllability and maneuverability,
  - CS 25.207: Stall warning,
  - CS 25.237: Wind velocity,
  - CS 25.253: High-speed characteristics.



# Existing CS-25 certification specifications for operation in icing conditions

- These specifications can be found in:
  - CS 25.1093(b): Turbine engines air intake system de-icing and anti-icing,
  - CS 25.1093(b)(1): Turbine engine safe operation throughout Appendix C icing conditions,
  - CS 25.1093(b)(2): Defines test conditions in order to demonstrate the safe operation of the powerplant systems in freezing fog conditions at idle on ground.

# CS-25 rule change proposal

- It is proposed to **amend CS-25** to better protect large airplanes certified for flight in icing conditions.
- The new icing environment would include Supercooled Large Drops (Appendix O), Mixed Phase and Ice Crystals (Appendix P).
- It is also proposed to update the requirements for turbine engine air intake system protection (updated freezing fog conditions and new falling and blowing snow conditions).
- In connection with this proposal an amendment of CS-E to update turbine engine certification is proposed.



# Accidents in severe icing conditions including SLD

Date	Type of aeroplane	Location	Fatalities	Injuries	Hull loss of the aeroplane
29 April 1993	EMB-120	Pine Bluff, USA	0	13 minor	Yes
31 October 1994	ATR-72	Roselawn, USA	68	0	Yes
30 December 1995	Cessna 560	Eagle River, USA	2	0	Yes
09 January 1997	EMB-120	Monroe, USA	29	0	Yes
19 March 2001	EMB-120	Orlando, USA	0	0	Severe damage
21 December 2002	ATR-72	Pengu island, Taiwan	2	0	Yes

# Review of accidents and incidents lessons

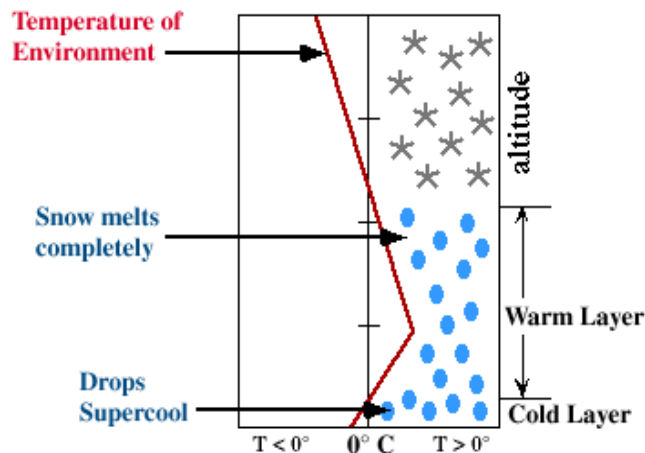
- IPHWG found accidents and incidents that are believed to have occurred in **icing conditions that are not adressed in Appendix C.**
- These icing conditions resulted in **flight crews losing control of the aircraft** and in some cases **engine power loss.**
- The review found **hull losses and fatalities associated with SLD conditions but not for ice crystal and mixed phase conditions.**
- However, there have been a number of **engine power loss events reports during the last two decades, which occurred in presence of ice crystals and mixed phase.** Some of them involved multi-engine power loss.
- Incident history also reveals that temporary loss of or erroneous airspeed indications in severe icing conditions (in deep convection).
  - Static ports are not prone to icing because they are flush mounted,
  - Pitot or pitot-static probes are prone to icing.

# Appendix O – SLD icing conditions

- Supercooled Large Droplets develop as falling snow encounters a layer of warm air deep enough for the snow to completely melt and become rain/drizzle.
- As the drops continue to fall, they pass through a thin layer of cold air just above the surface and cools to a temperature below freezing.
- When the supercooled drops strike the frozen ground (power lines, or tree branches), they instantly freeze, forming a thin film of ice, hence freezing rain.

# Appendix O – SLD icing conditions

- Drop becomes supercooled when crossing the thin layer of cold air close to the ground and freezes upon impact with cold surfaces.
- Freezing rain and freezing drizzle are most commonly found in a narrow band on the cold side of a warm front, where surface temperatures are at or just below freezing.



# Appendix O – SLD icing conditions

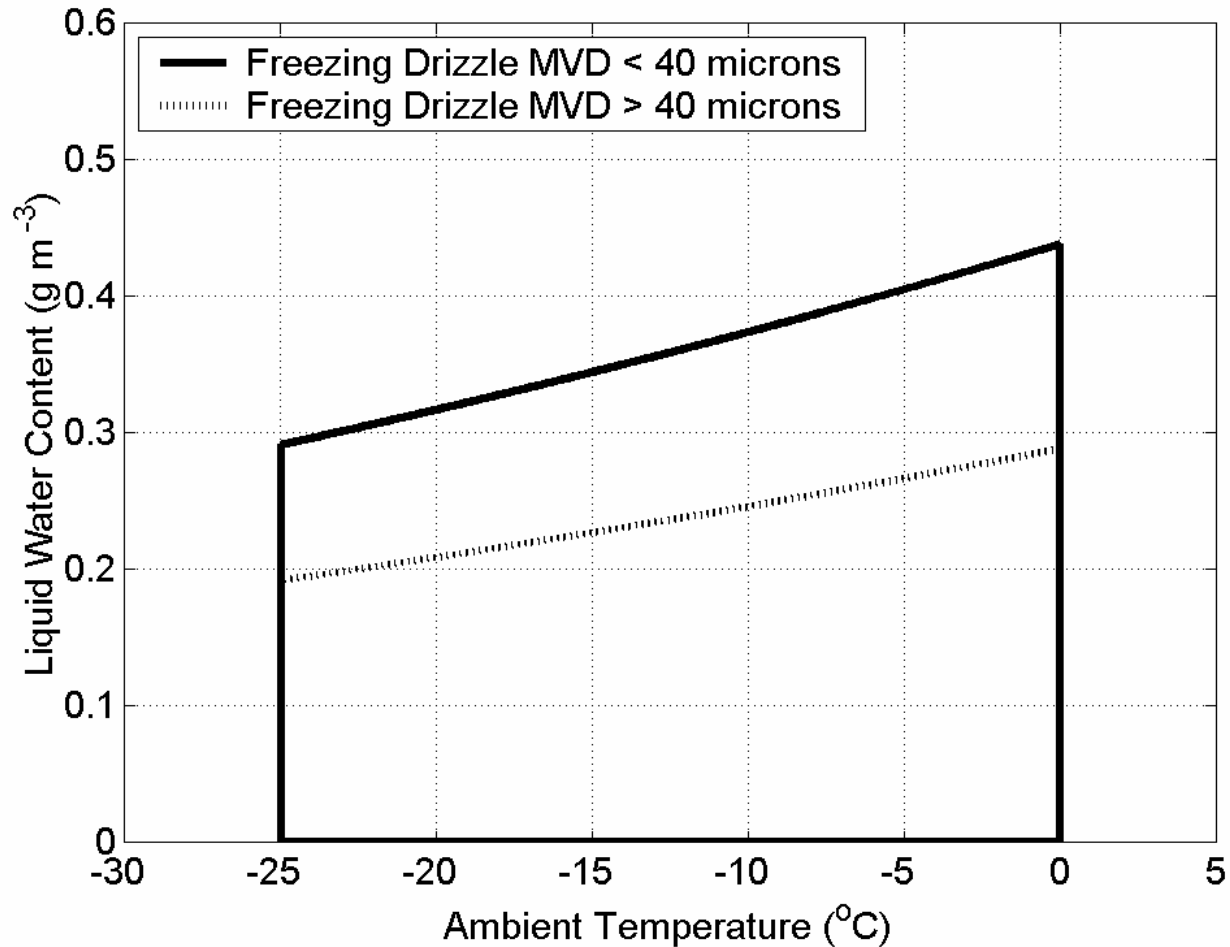
- Description of supercooled large drop (SLD) icing conditions in which the drop median volume diameter (MVD) is less than or greater than  $40\ \mu\text{m}$ , the maximum mean effective drop diameter (MED) of Appendix C continuous maximum (stratiform clouds) icing conditions.
- For Appendix O, SLD icing conditions consist of freezing drizzle and freezing rain occurring in and/or below stratiform clouds.



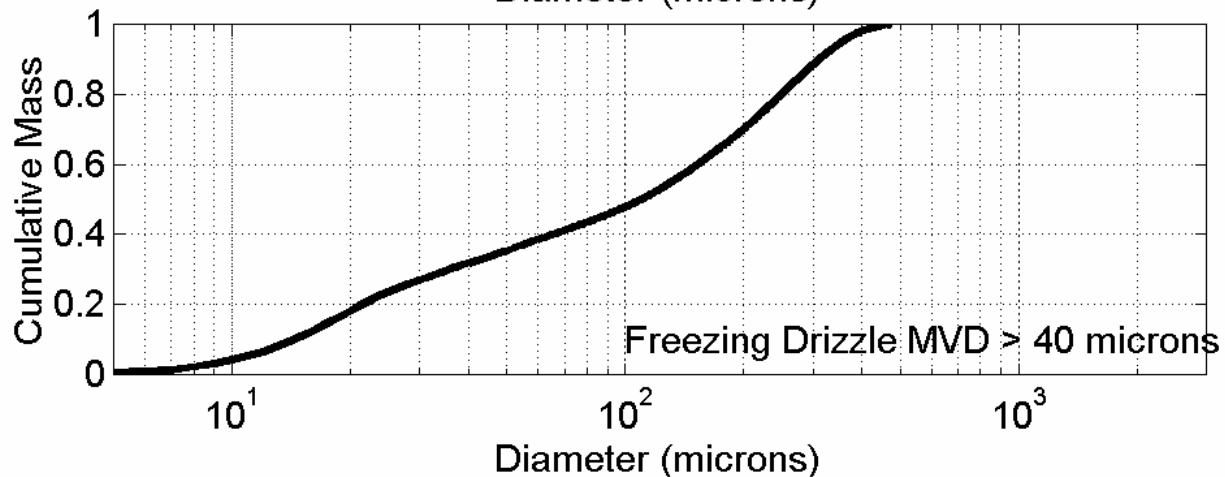
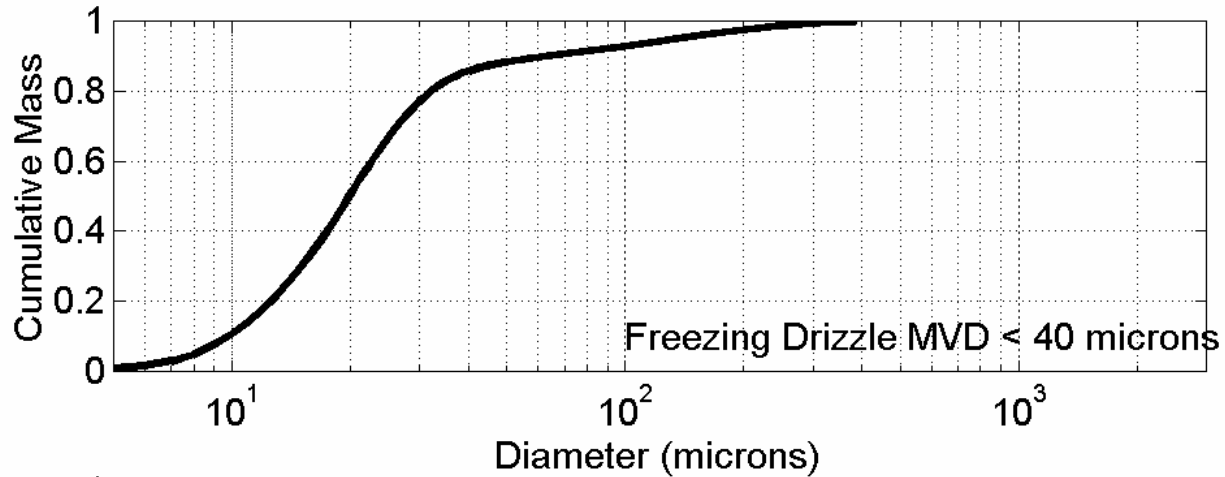
# Appendix O – SLD icing conditions

- Freezing Drizzle (Conditions with maximum drop diameters from 100  $\mu\text{m}$  to 500  $\mu\text{m}$ ):
  - Pressure altitude range: 0 to 6706 m (22000 feet),
  - Maximum vertical extent: 3656 m (12000 feet),
  - Horizontal extent: standard distance of 32.2 km (17.4 nautical miles),
  - Total liquid water content.

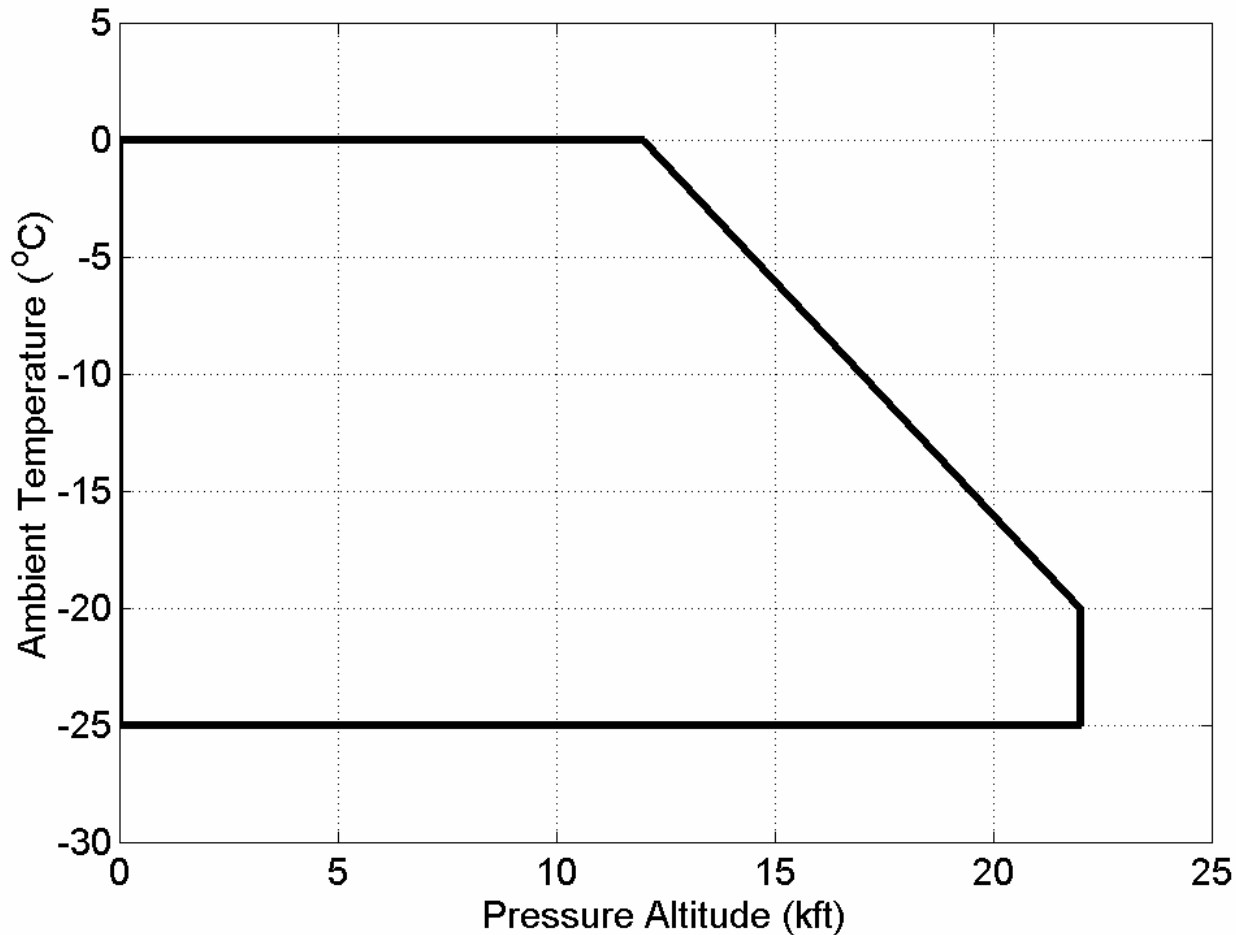
# Appendix O, Freezing Drizzle, LWC



# Appendix O, Freezing Drizzle, droplet diameter distribution



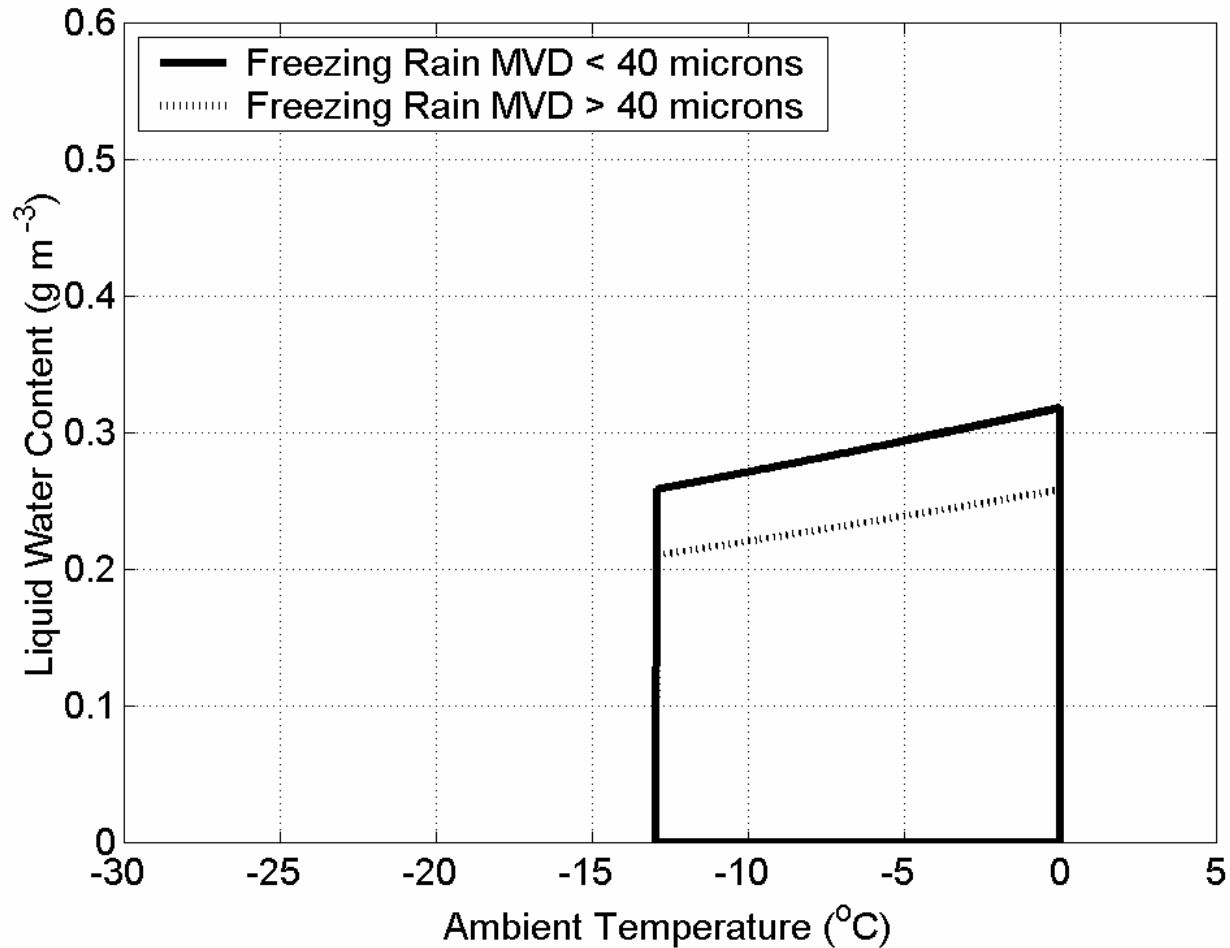
# Appendix O, Freezing Drizzle, altitude and temperature



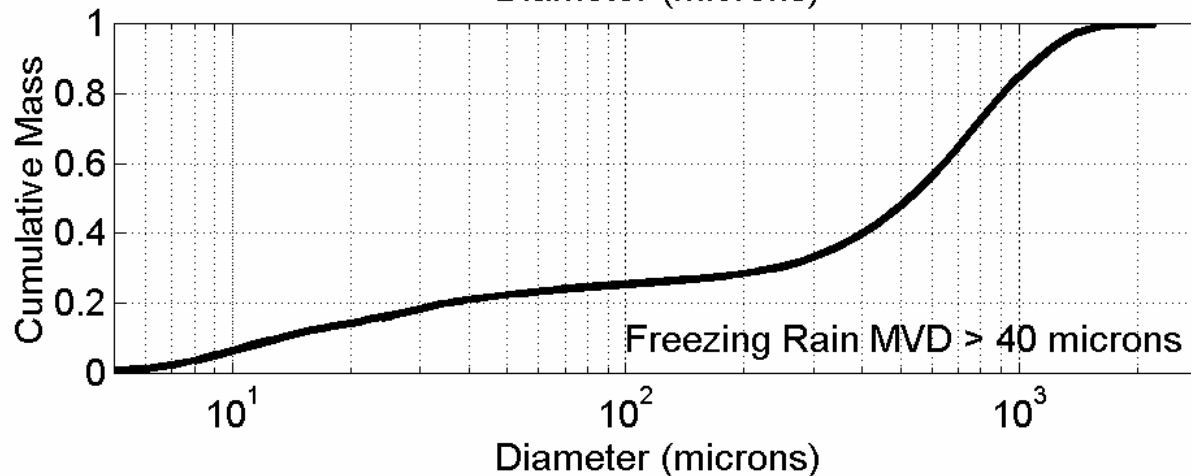
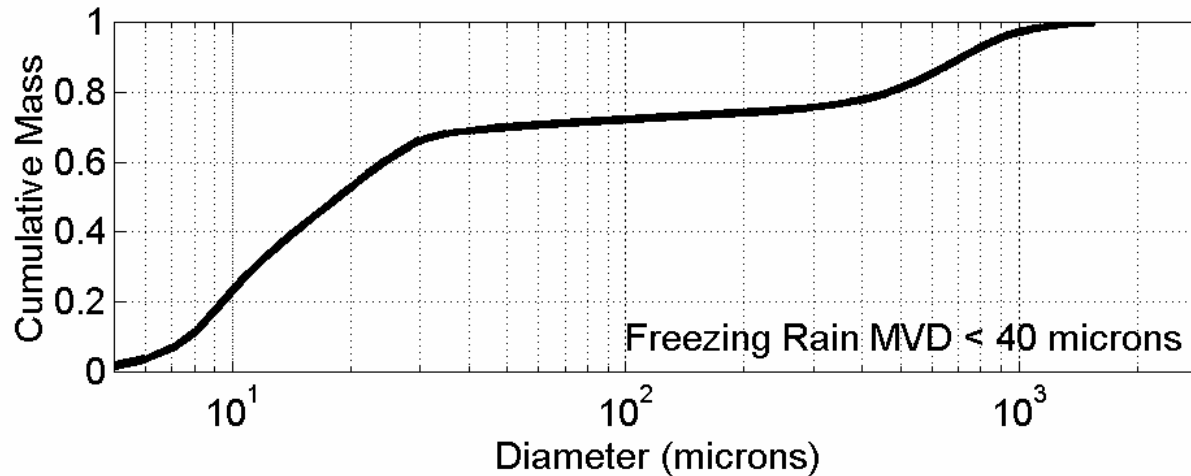
# Appendix O – SLD icing conditions

- Freezing Rain (Conditions with maximum drop diameters greater than 500  $\mu\text{m}$ ):
  - Pressure altitude range: 0 to 3656 m (12000 ft) MSL,
  - Maximum vertical extent: 2134 m (7000 ft),
  - Horizontal extent: standard distance of 32.2 km (17.4 nautical miles),
  - Total liquid water content.

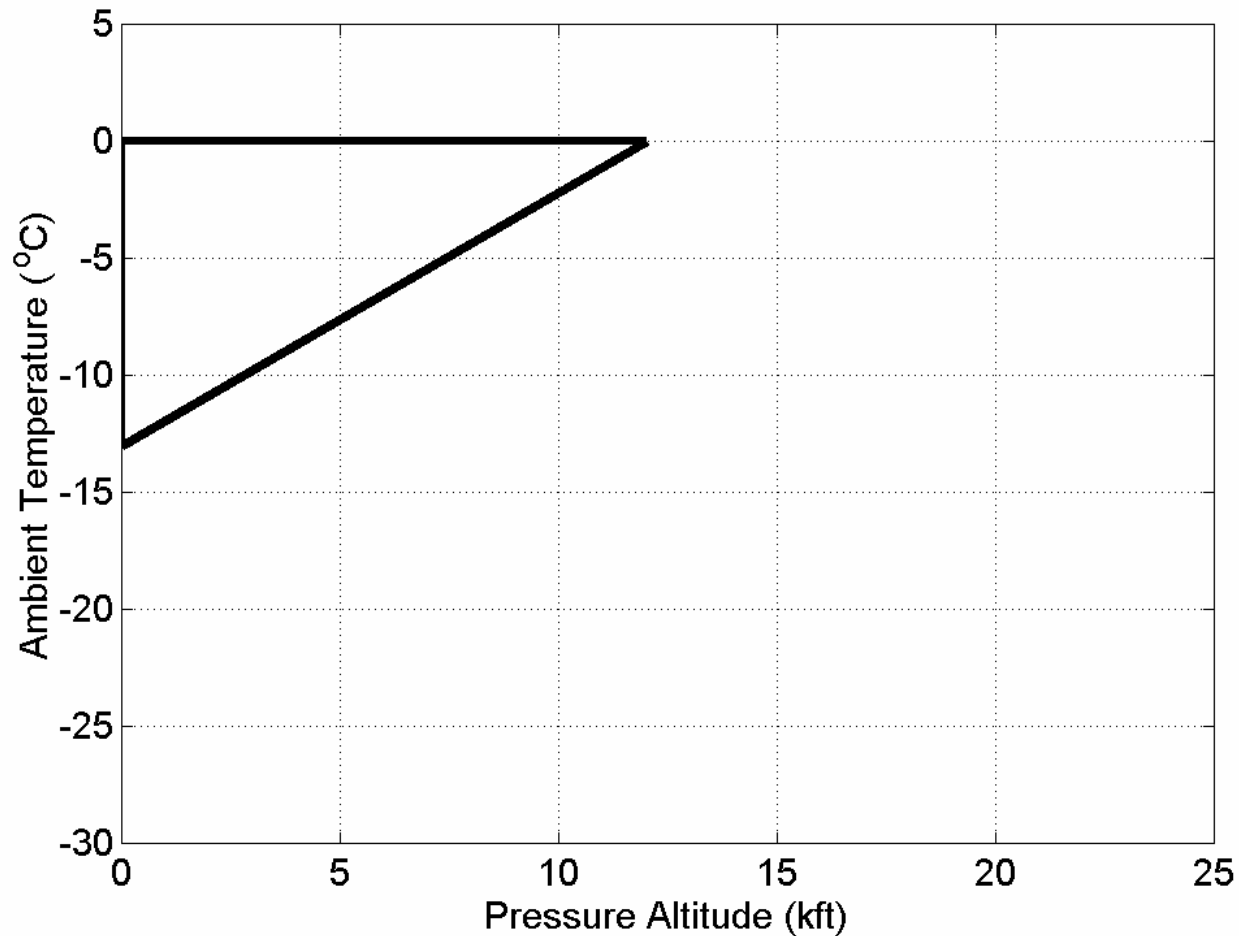
# Appendix O, Freezing Rain, LWC



# Appendix O, Freezing Rain, droplet diameter distribution

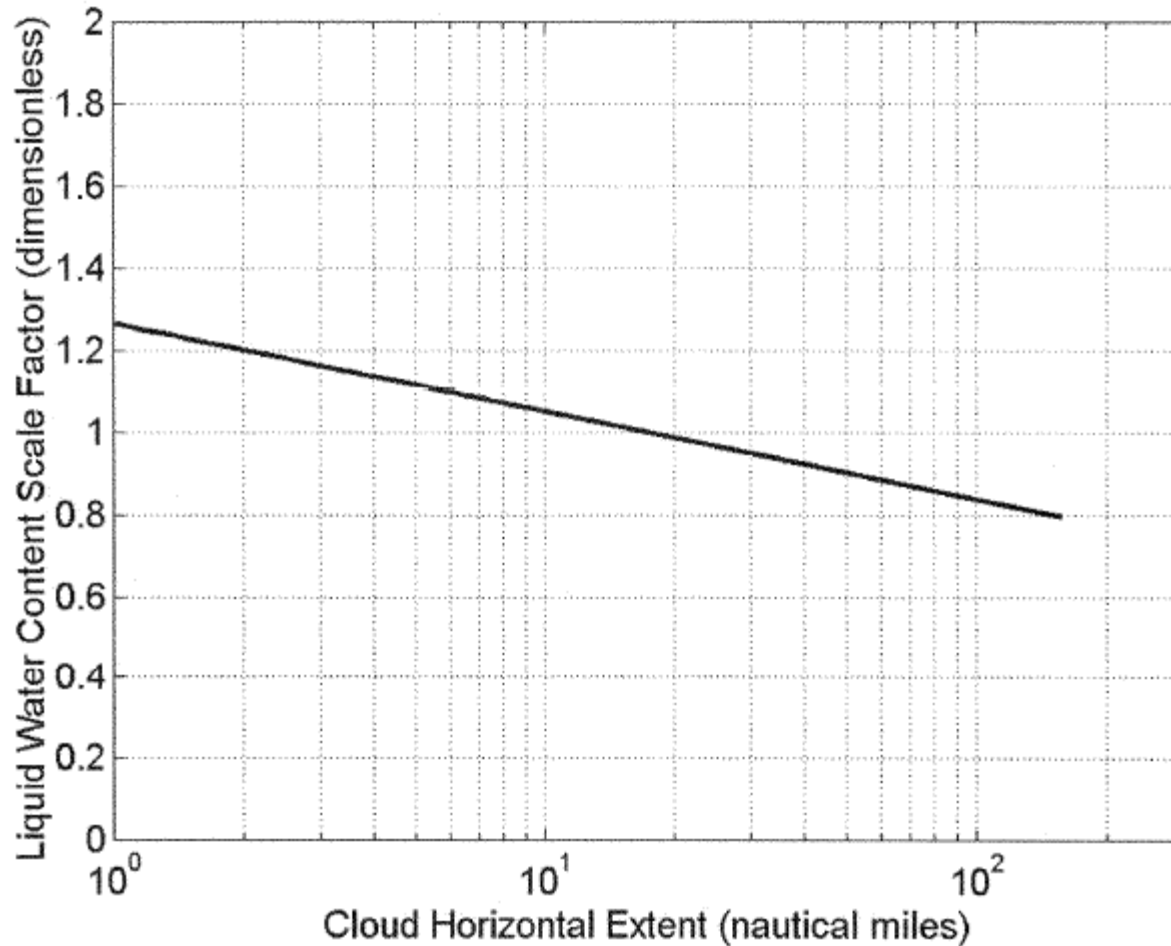


# Appendix O, Freezing Rain, altitude and temperature





# Appendix O, Horizontal Extent, Drizzle and Freezing Rain

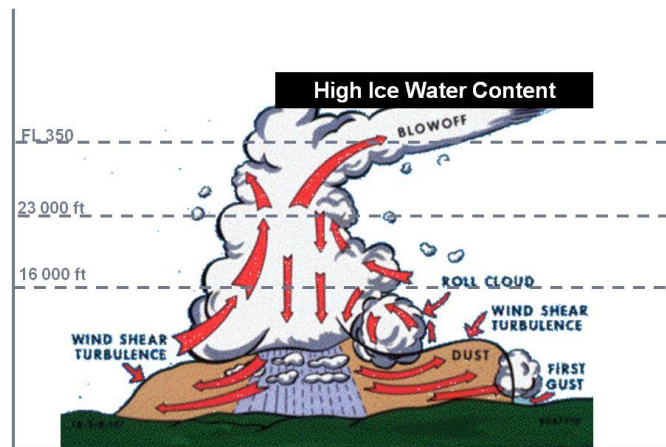


# Appendix P – Mixed phase and ice crystal icing envelope (deep convective clouds)

- High water content is often found in **deep convective clouds** present in the warm tropical regions around the globe.
- These clouds can contain **deep updraft cores** that transport low-level air high into the atmosphere, during which water vapour is continually condensed as the temperature drops.
- In doing so, these updraft cores may produce localized regions where very high concentration of ice particles, or ice crystals, can be encountered. Such conditions are called **glaciated icing conditions**.
- These ice particles can also be found simultaneously with supercooled droplets. Such conditions are called **mixed phase icing conditions**.

# Appendix P – Mixed phase and ice crystal icing envelope (deep convective clouds)

- Ice particles are mainly encountered in high levels of atmosphere (above the freezing level estimated at approximately 20000ft for a standard atmosphere).
- This means that ice particles are present in:
  - high altitude clouds (cirrus, cirrostratus, cirrocumulus),
  - aircraft contrails (condensation trails – artificial cirrus clouds) ,
  - deep convective complexes (anvils of thunderstorms, tropical storms...)

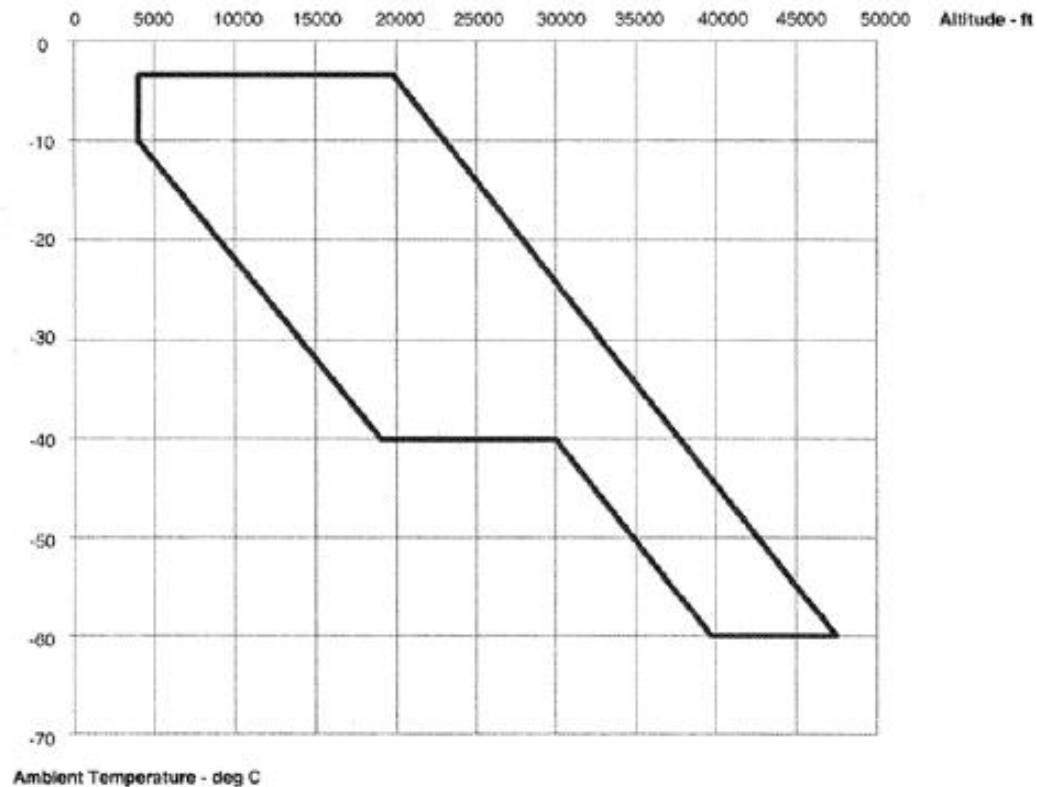


## Appendix P – Mixed phase and ice crystal icing envelope (deep convective clouds)

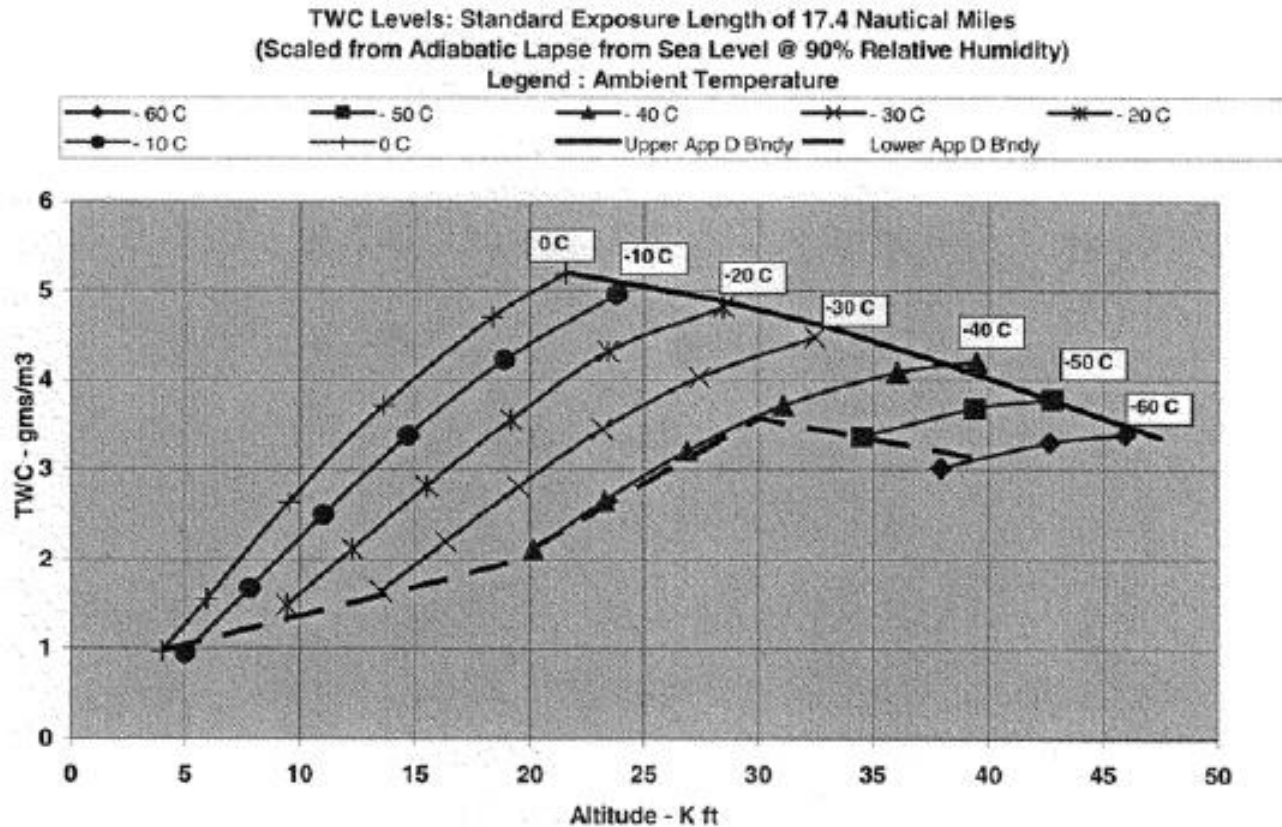
- Defines the ice crystal and mixed phase icing environment requiring any flight instrument external probe (mostly pitot probe) to operate normally.
- Within the envelope, total water content (TWC) has been determined based upon adiabatic lapse defined by the convective rise of 90% relative humidity air from sea level to higher altitudes and scaled by a factor of 0.65 to a standard cloud length of 17.4 nm.

# Appendix P – Mixed phase and ice crystal icing envelope

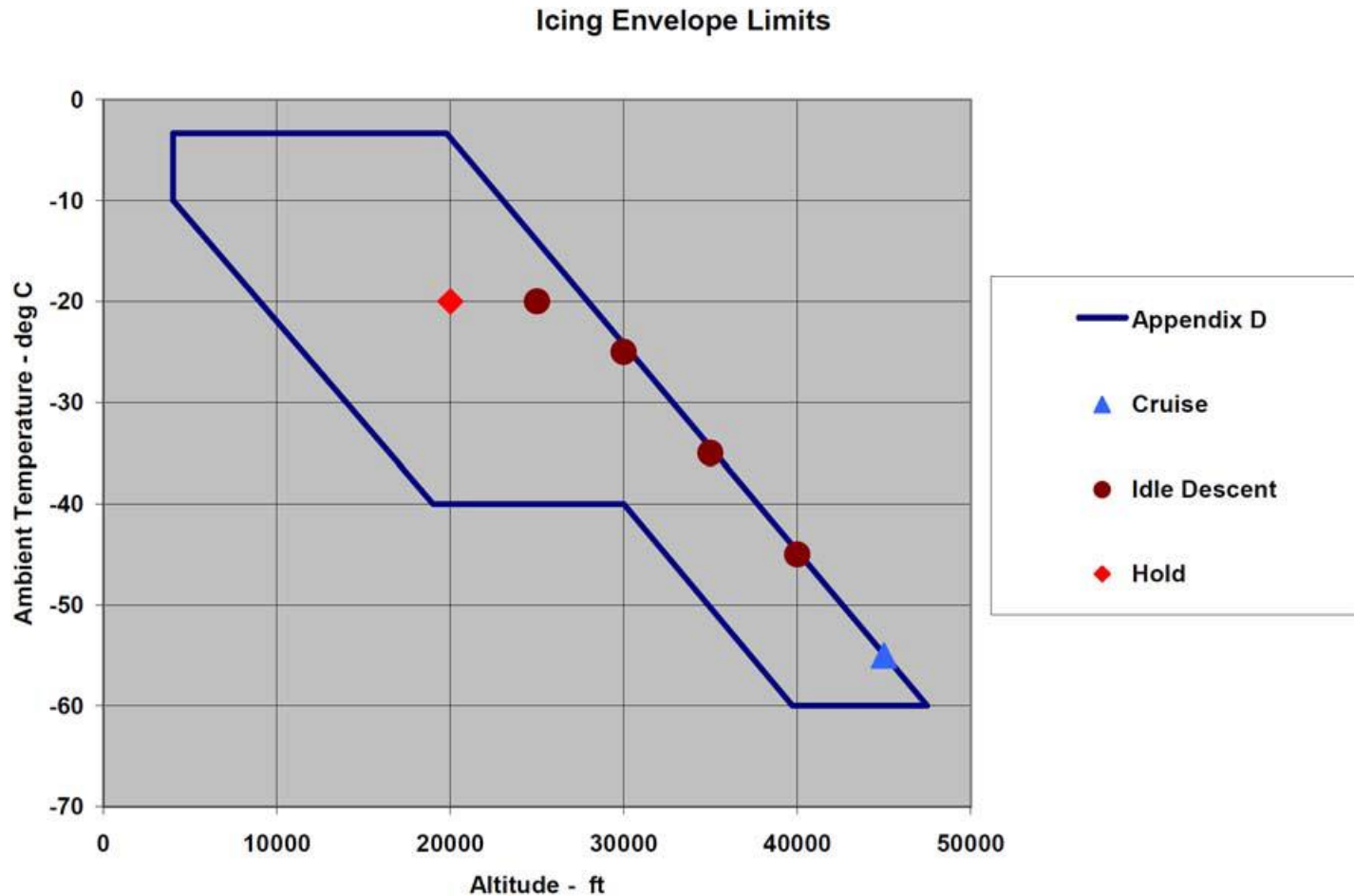
Figure 1 – Convective cloud ice crystal envelope



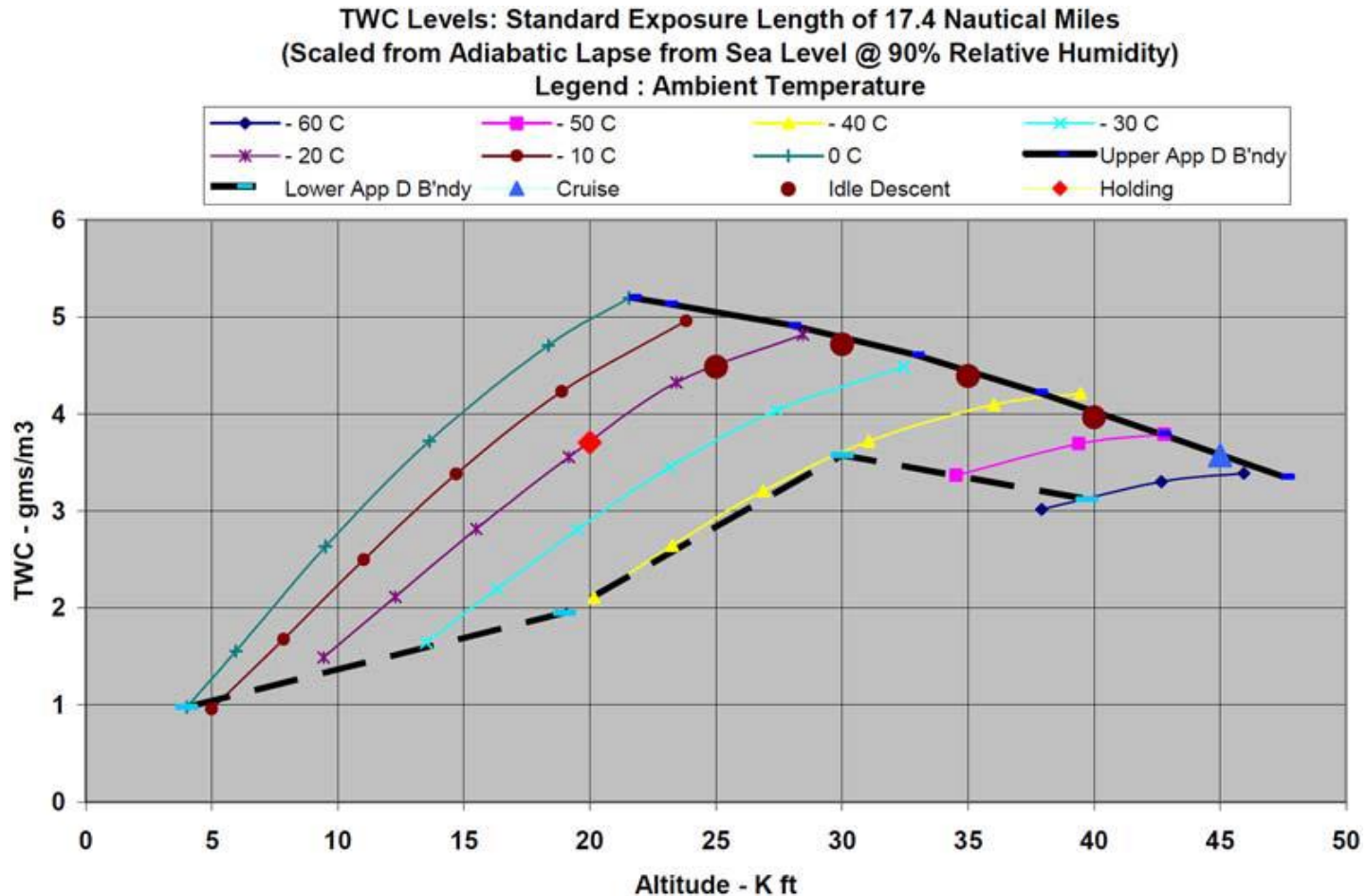
# Appendix P – Mixed phase and ice crystal icing envelope



# Appendix P icing envelope



# Appendix P icing envelope



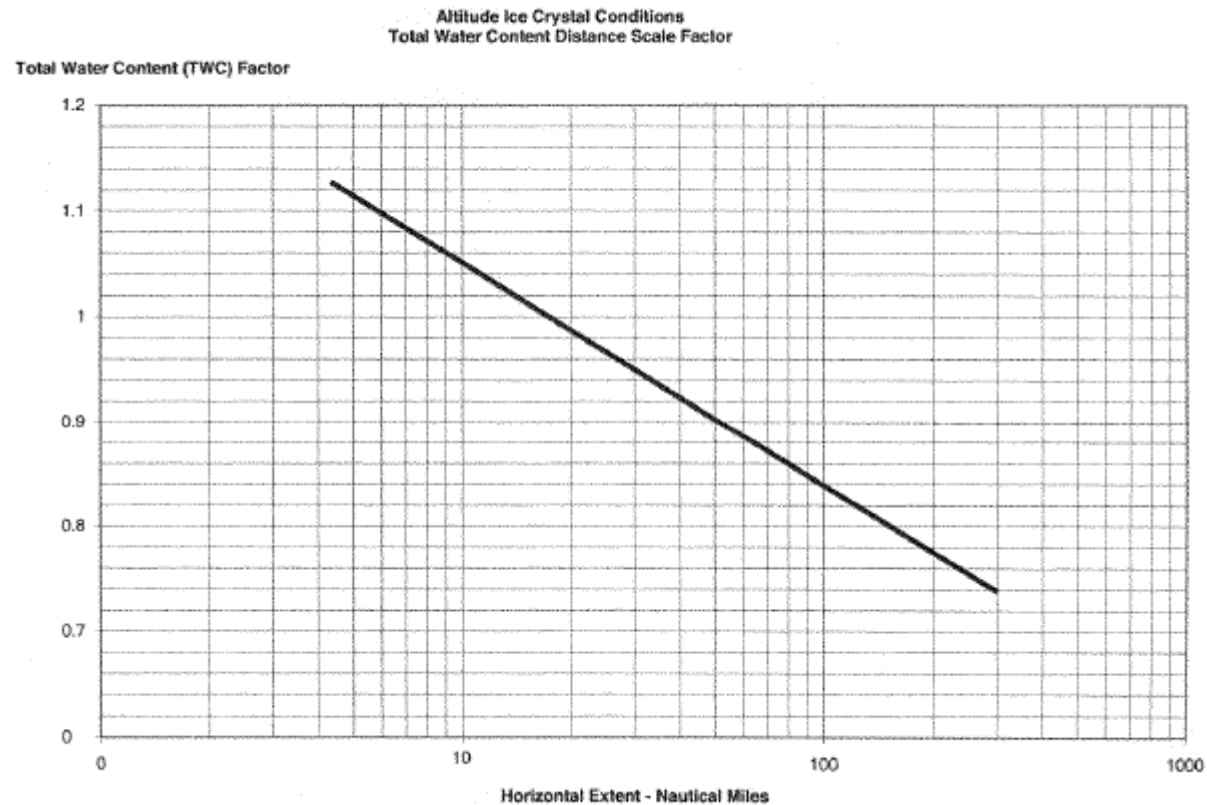


# Appendix P – Supercooled liquid portion of TWC

- Ice crystal size mass dimension (MMD) range is 50-200 microns (equivalent spherical size) based on measurements near convective storm cores.
- The TWC can be treated as completely glaciated (ice crystal) except:

Temperature range - deg C	Horizontal cloud length	LWC - g/m <sup>3</sup>
0 to -20	≤92.6 km (50 nautical miles)	≤1.0
0 to -20	Indefinite	≤0.5
< -20		0

# Appendix P – Exposure length influence on TWC



# Appendix P – Glaciated Conditions

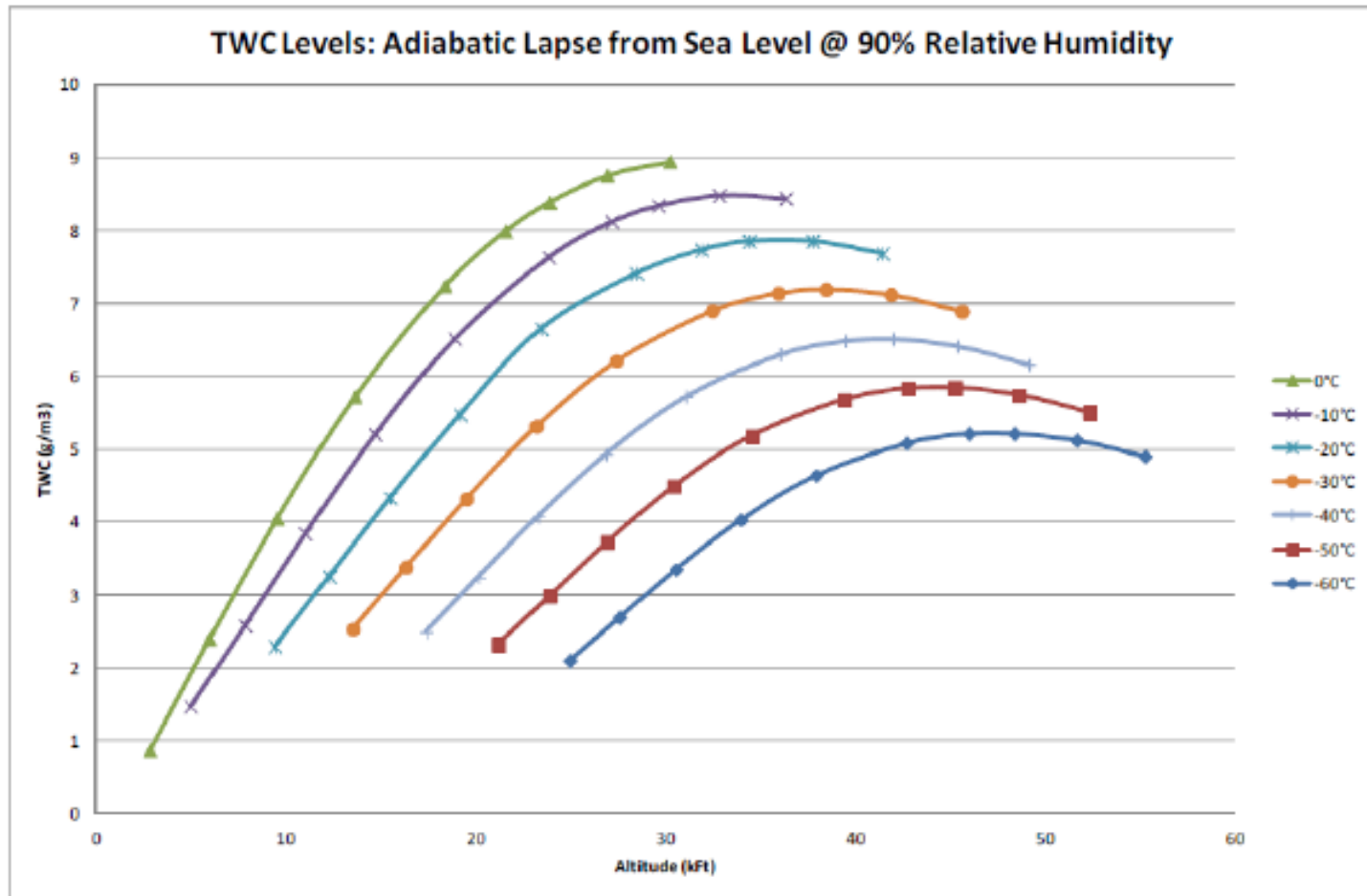
- In service occurrences show that several Pitot Icing events in Glaciated Conditions above 30 000 ft are outside of the Appendix P domain in terms of altitude and outside air temperature.
- A reported event occurred at  $-70^{\circ}\text{C}$ .
- Testing may not be possible at such a low temperature due to simulation tool limitations.
- However, presence of ice crystals has been observed and it is anticipated that an extrapolation of existing data at higher temperature should allow assessing the predicted performance of the probe heating down to this minimum temperature.



# Appendix P – Glaciated Conditions

- The standard cloud of 17.4 nm and the associated average TWC concentration values provided by Appendix P may not provide the most conservative conditions for Flight Instrument External Probes testing.
- The “maximum” or “peak” TWC concentration values should be considered instead of the 17.4 nm values provided by Appendix P. They correspond to 17.4 nm values multiplied by a factor of  $1.538=1/0.65$ .

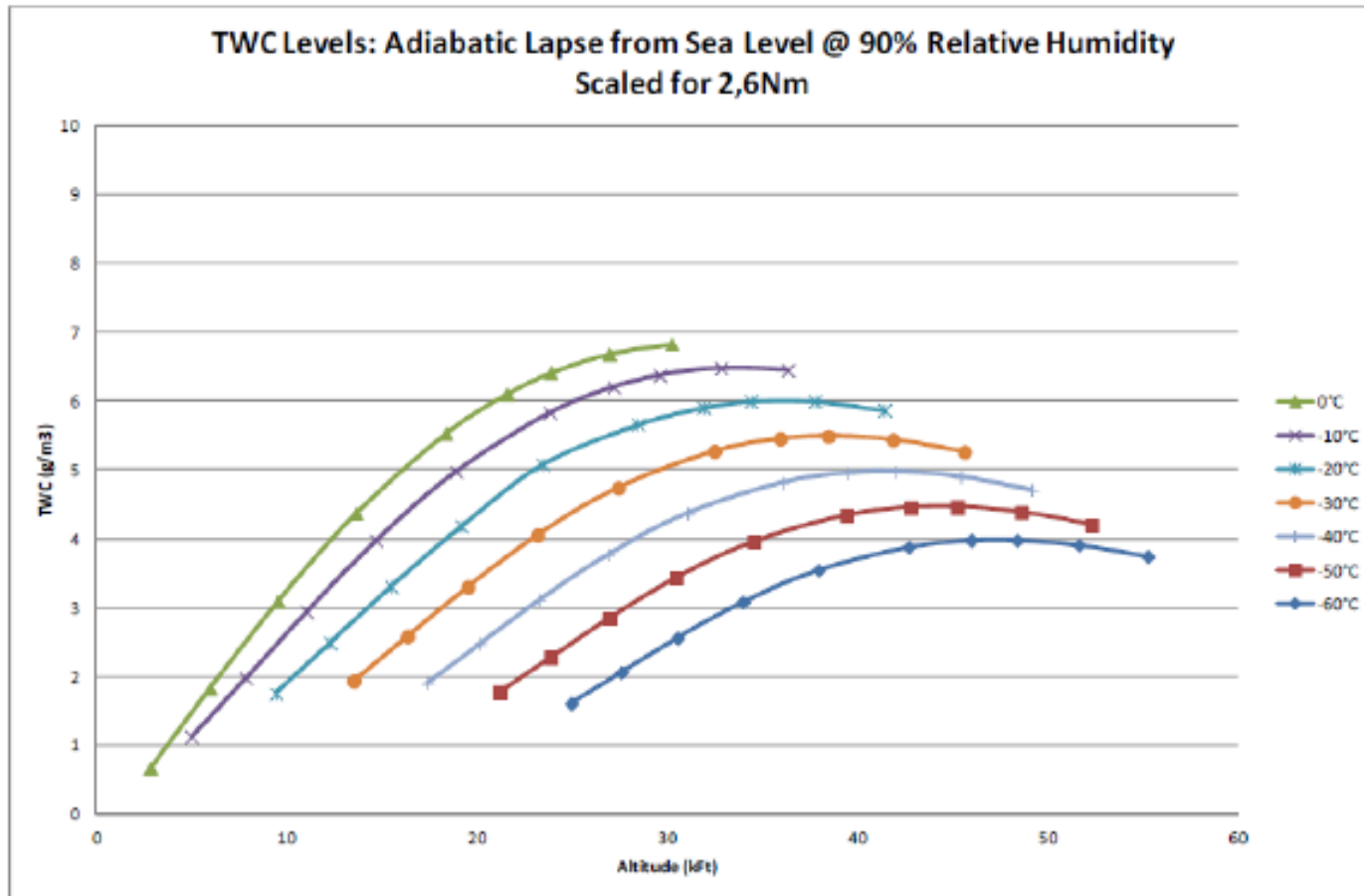
# Appendix P – Max concentration values (TWC) Glaciated conditions



# Appendix P – Mixed phase Conditions

- In service occurrences show several Pitot Icing events in Mixed Phase Conditions, between 20 000 - 30 000 ft are outside of the Appendix P domain in terms of altitude and outside air temperature.
- The 2.6 nm TWC concentration values should be considered instead of the 17.4 nm values provided by Appendix P. They correspond to 17.4 nm values multiplied by a factor of 1.175.

# Appendix P – Max concentration values (TWC) Mixed Phase conditions



# Appendix P – Ice particles

- There are several methods for generating ice particles used in testing which produce a wide range of particle sizes.
- Some methods for generating ice particles result 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 ice particles.



# Appendix P – Ice particles

- Particles in the range of 50-1000 microns tend towards ballistic trajectories with collection efficiencies approaching one on conventional pitot probes.
- Past experience shows that an ice crystal MMD size of 150 microns is the more practical size to be tested in a wind tunnel.
- For mixed phase conditions, it should be tested together with supercooled droplet MVD size of 20 microns.



# References

- EASA, Notice of Proposed Amendment (NPA) 2011-03
- EASA, Notice of Proposed Amendment (NPA) 2012-22
- EASA, Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes, CS-25, Amendment 16.