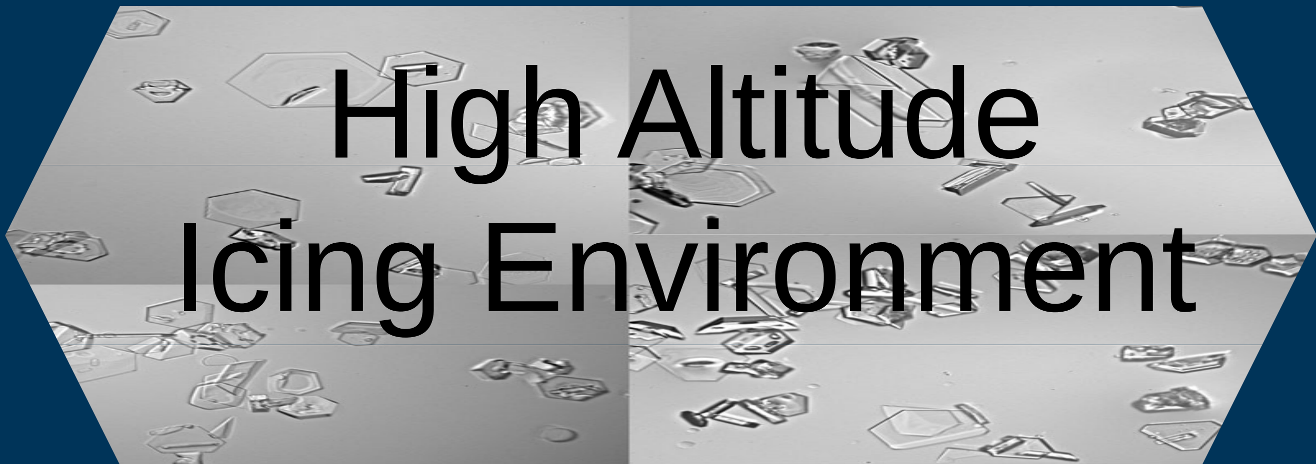
International Air Safety & Climate Change Conference

08-09 September 2010 Cologne, Germany

High Altitude Icing Environment



Eric DUVIVIER

Workshop 1

- Atmosphere / Climate
  - extreme / severe weather events

1.c What are the likely mitigating measures?

This presentation focuses on:

- High Altitude Icing Environment
- Large Aeroplanes (CS 25) and Engines (CS E)

Outline

- Current Certification Icing Environment
- Evidences of exceeded Icing Environment
- Cases Study
- What is « new »
- History of Icing Rule Making
- EASA Initiatives
- Challenges and Future Work
- Considerations

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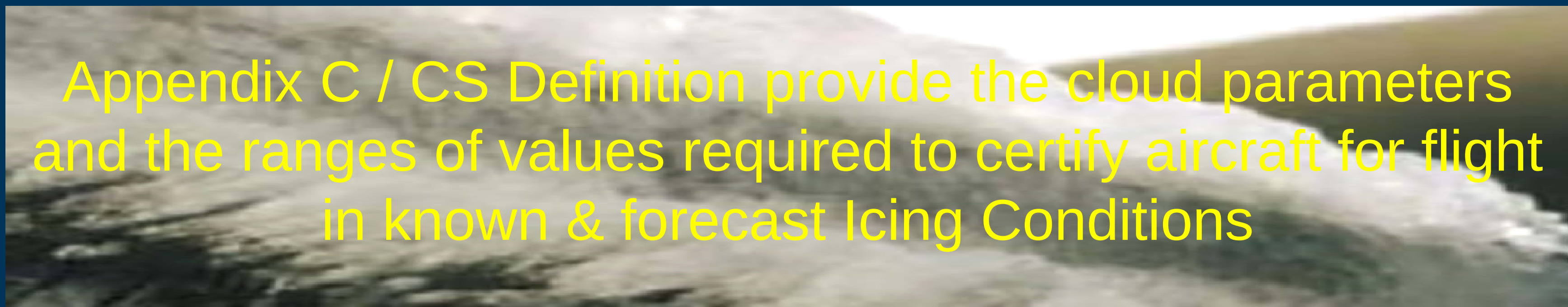
Certification Icing Environment

- **CS 25.1419**
  - *Safe operation in the continuous maximum and intermittent maximum icing conditions of Appendix C*
- **CS E.780**
  - *Satisfactory functioning when operated in the atmospheric icing conditions of CS-Definitions*



App. C & CS Definition:

- 2 atmospheric conditions are considered:
  - Continuous maximum icing = stratiform clouds

Altitude	Temperature	Hz extend
0-6700m (22 kft)	0 to -30°C	32.2 Km (17.4 nm)

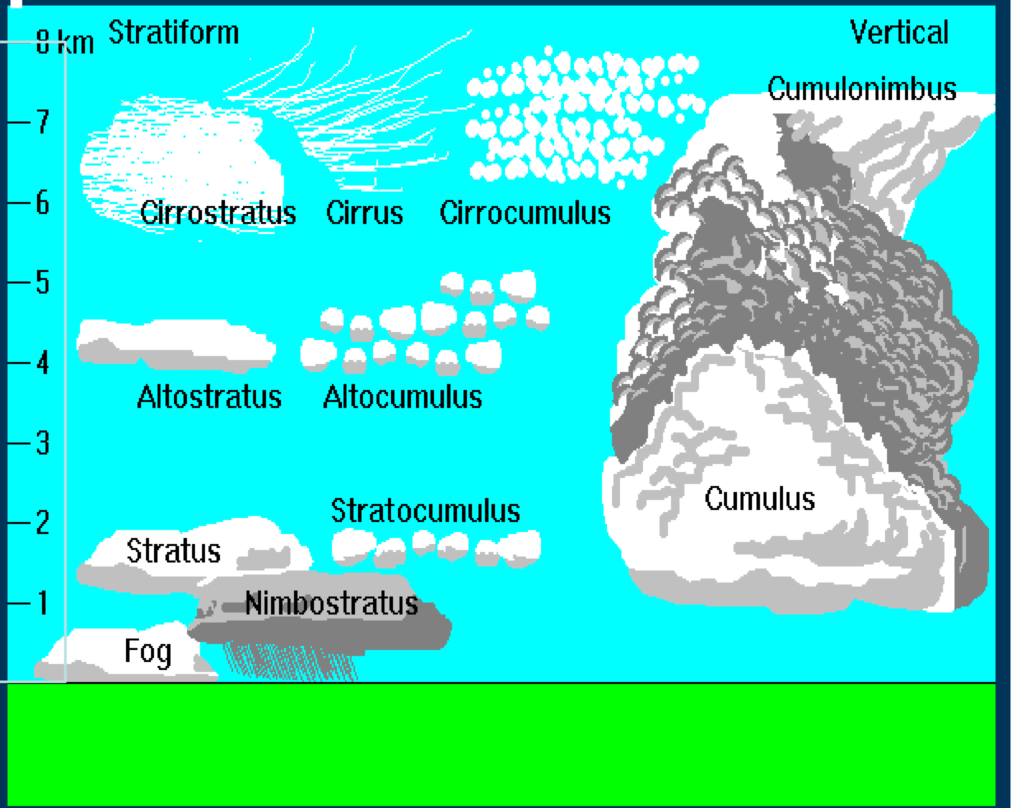
  - Intermittent maximum icing = cumuliform clouds

Altitude	Temperature	Hz extend
1000-9500m (≈ 3 to 31 kft)	0 to -40°C	4.8 km (2·6 nm)

Liquid Conditions

These conditions = **Supercooled** clouds

Droplets remain in a **liquid** state
- @ temperature below freezing
- @ the corresponding altitude/pressure



Continuous maximum icing

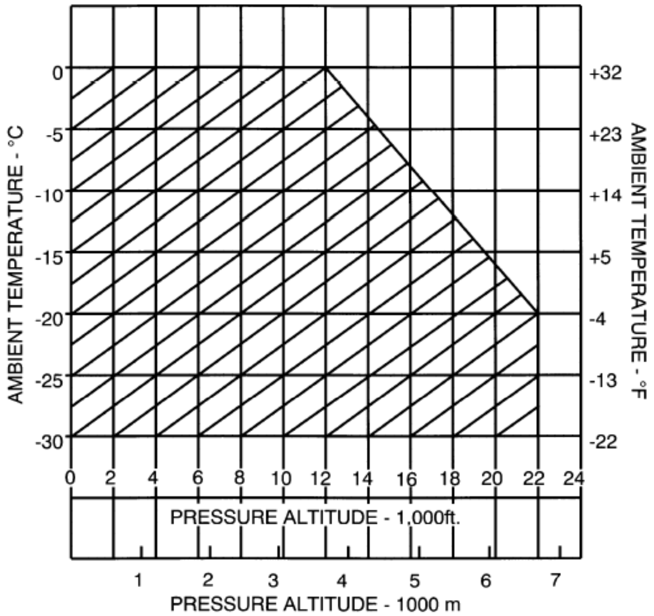


FIGURE 2

CONTINUOUS MAXIMUM (STRATIFORM CLOUDS)
ATMOSPHERIC ICING CONDITIONS
AMBIENT TEMPERATURE VS PRESSURE ALTITUDE

Source of data – NACA TN No. 2569.

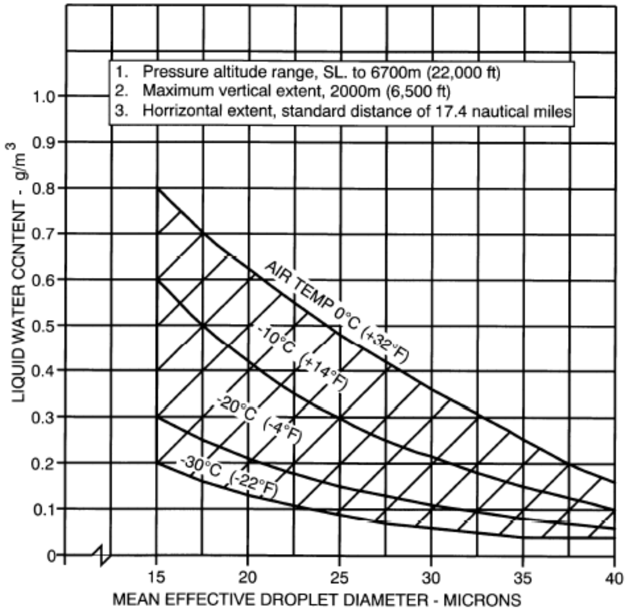


FIGURE 1

CONTINUOUS MAXIMUM (STRATIFORM CLOUDS)
ATMOSPHERIC ICING CONDITIONS
LIQUID WATER CONTENT VS MEAN EFFECTIVE DROP DIAMETER

Source of data – NACA TN No. 1855, Class III –M, Continuous Maximum.

Intermittent maximum icing

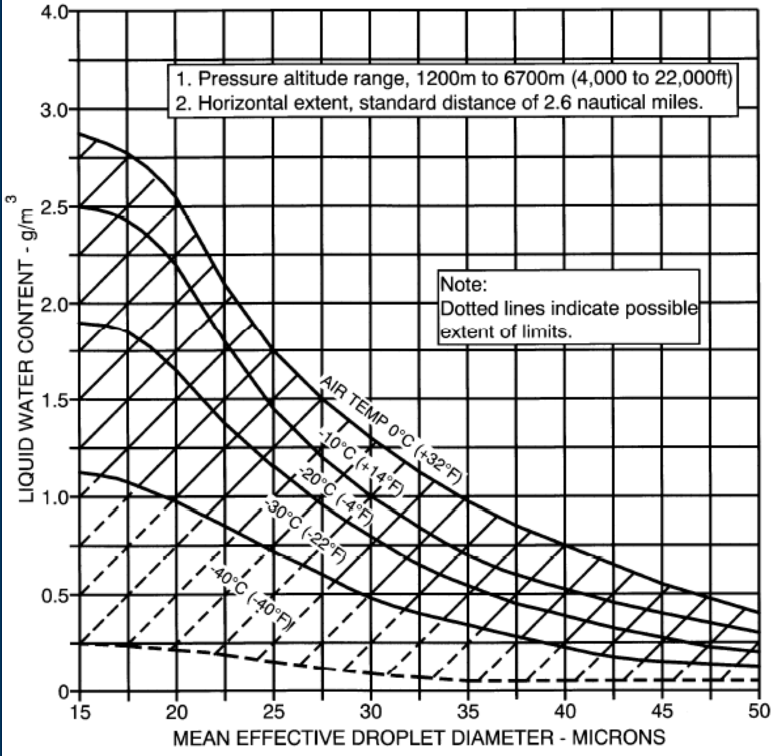


FIGURE 4

INTERMITTENT MAXIMUM (CUMULIFORM CLOUDS)
ATMOSPHERIC ICING CONDITIONS
LIQUID WATER CONTENT VS MEAN EFFECTIVE DROP DIAMETER

Source of data – NACA TN No. 1855, Class II – M, Intermittent Maximum

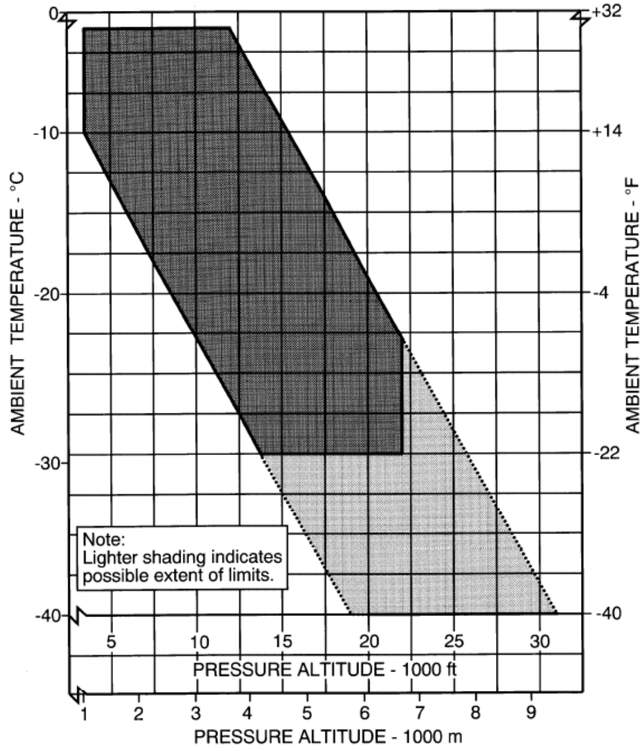


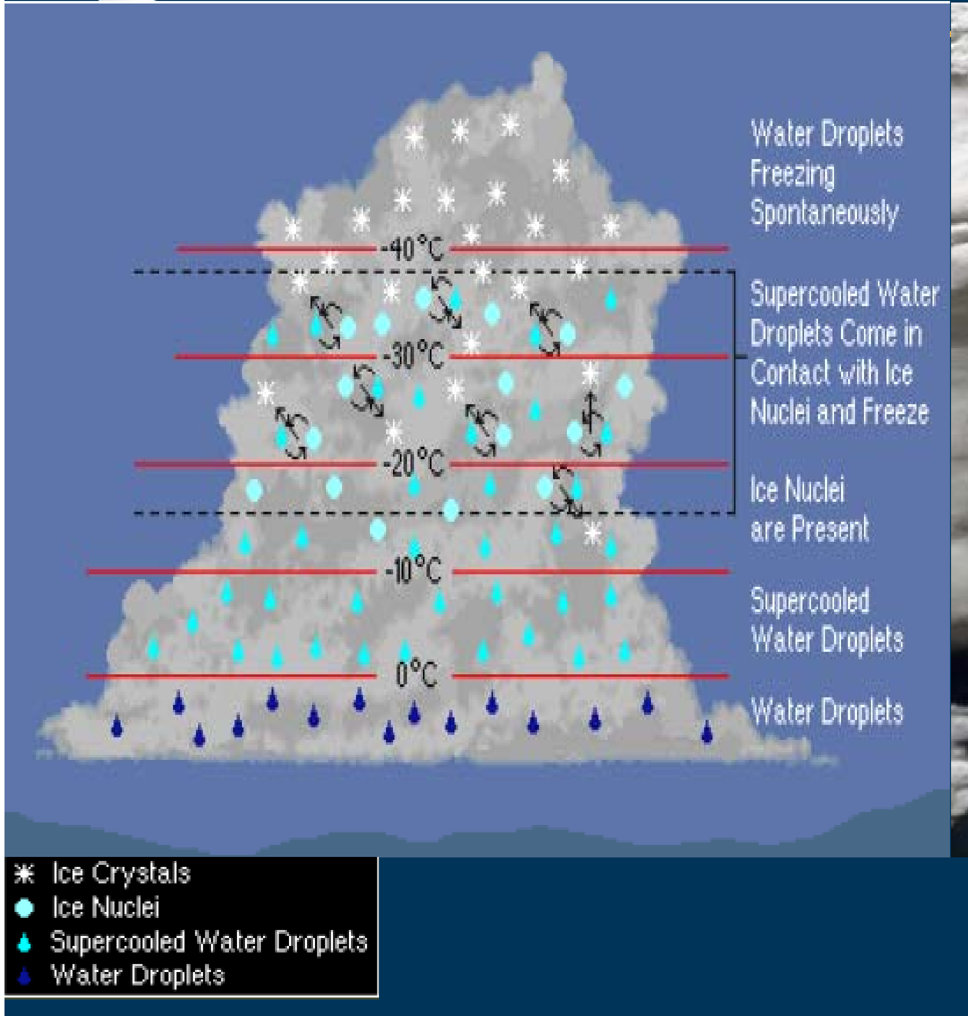
FIGURE 5

INTERMITTENT MAXIMUM (CUMULIFORM CLOUDS)
ATMOSPHERIC ICING CONDITIONS
AMBIENT TEMPERATURE VS PRESSURE ALTITUDE

Source of data – NACA TN No. 2569.

Certification Icing Environment

- AMC of CS 25.1419 and CS E.780 also refer to ***Ice Crystal Conditions*** **& Mixed phase conditions**
- **Ice Crystal = Glaciated conditions**
  - conditions containing only ice crystals and no supercooled liquid
- **"Mixed phase conditions"**
  - conditions containing both ice crystals and supercooled liquid.
- **Both conditions are usually present in**
  - Convective weather of all sizes,



A series of mature thunderstorms in southern Brazil (source NASA)

AMC 25.1419

"An assessment should be made into the vulnerability of the aeroplane and its systems"

"The parts most likely to be vulnerable are

a. Turbine engine intakes with bends,

b. Pitot heads, etc.

Air Temperature (°C)	Altitude Range (ft)	Altitude Range (m)	Maximum Crystal Content (g/m^3)	Horizontal Extend (km)	Horizontal Extend (n miles)	Mean Particle Diameter (mm)
0 to −20	10 000 to 30 000	3000 to 9000	5·0 2·0 1·0	5 100 500	(3) (50) (300)	1.0
−20 to −40	15 000 to 40 000	4500 to 12 000	5·0 2·0 1·0 0·5	5 20 100 500	(3) (10) (50) (300)	

CS E.780 & AMC

- *"Where the Engine is considered to be vulnerable to operation in ice crystal cloud conditions, in mixed ice crystals … additional tests may be necessary to establish satisfactory operation in these conditions"*
- *"Engines with 'Pitot' type intakes have not proved to be susceptible to ice crystal difficulties…."*
- *Ice Crystal Conditions in AMC E.780 = AMC 25.1419*

- Current Certification Icing Environment
- **Evidences of exceeded Icing Environment**
- Cases Study
- What is « new »
- History of Icing Rule Making
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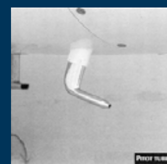
Evidences...

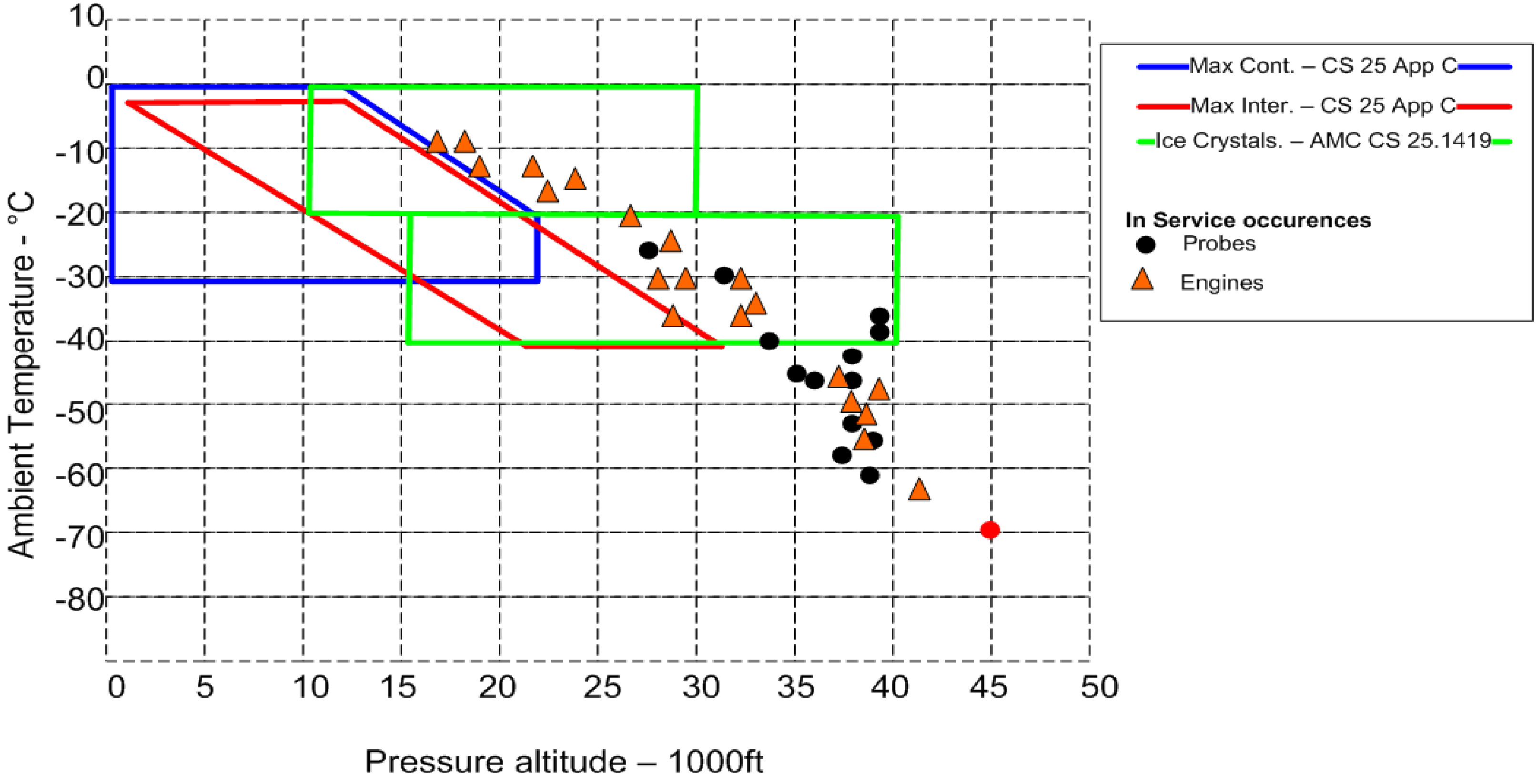
- Several reports of jet engine powerloss events have been attributed to flight in and around areas of deep convection



- Several occurrences reported on:
  - Airspeed discrepancy
  - potential multiple Pitot probes blockages

Lawson, R.P., Angus, J.J., and Heymsfield, A.J., 1998: Cloud Particle Measurements in Thunderstorm Anvils and Possible Threat to Aviation, J. Aircraft, Vol. 35, No.1, 113-121.

Mason, J.G., J.W. Strapp, and P. Chow, 2006: The Ice Particle Threat to Engines in Flight, 44th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV, Jan 9-12, 2006, AIAA 2006-206.


Ambient Temperature - °C
10
0
-10
-20
-30
-40
-50
-60
-70
-80
0
5
10
15
20
25
30
35
40
45
50
Pressure altitude – 1000ft
Max Cont. – CS 25 App C
Max Inter. – CS 25 App C
Ice Crystals. – AMC CS 25.1419
In Service occurences
Probes
Engines

- Current Certification Icing Environment
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Ice Crystals Accretion

- Understanding of ice crystal accretion physics needs to be improved
- Ice crystals do not adhere to cold airframe surfaces
  - ice crystals bounce off
- crystals can partially melt and stick to warm surfaces

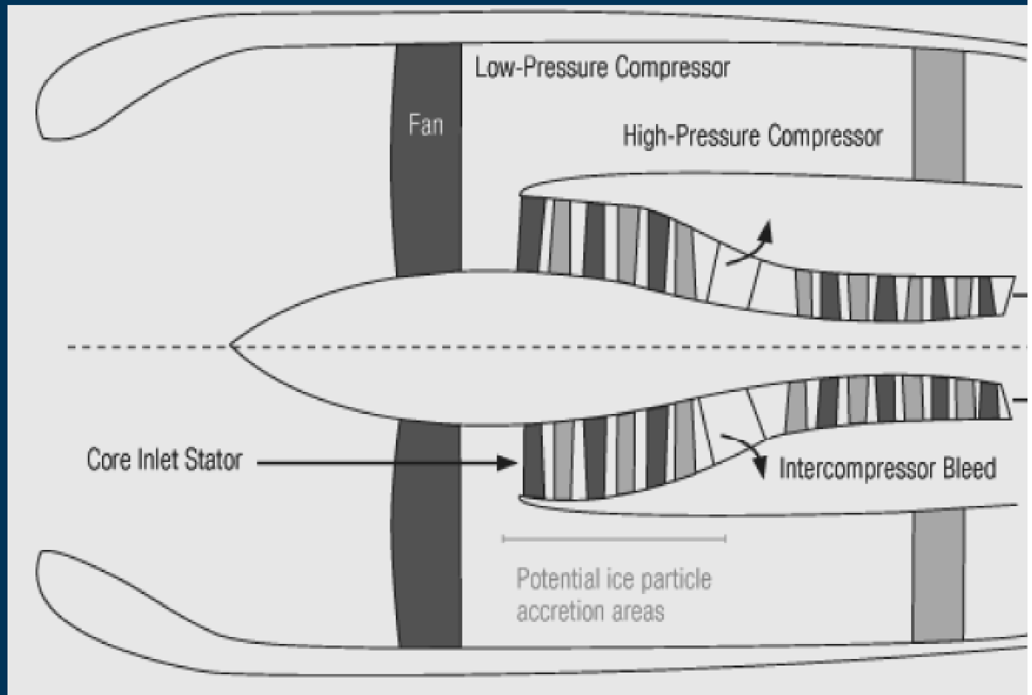
⇨ **Main areas of focus:**

- Engines & Engines Air Intakes (Bended)
- External Probes

Engine Case

Accretion mechanism is thought to be (*):

- Ice particles enter the engine, and possibly melt on warm surfaces to create a liquid film
- liquid film captures incoming ice particles, and heat transfer takes place
- Heat is removed from the metal until the freezing point is reached,
- Ice begin to form and possibly shed from compressor surfaces to cause engine instability such as surge, flameout, or engine damage

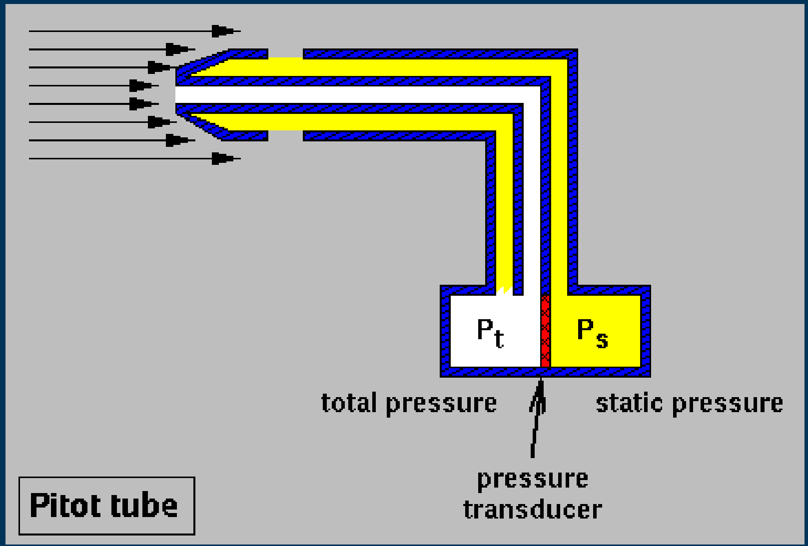


(*)ref Mason et al. 2006

Pitot Probe Case

Conventional Pitot / Static :

- Tube act as particle collector
- If heating is not sufficient to melt completely the ice crystals or
- If water is not completely evacuated and refreeze



Various failure modes

- Current Certification Icing Environment
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What is « NEW »

- Ice Crystals already identified as relevant to Pitot Probes & Engines in European Specifications
  - since JAR 25 Ch. 3, Eff. 31.12.76

But .....

- « Recent » occurrences show:
  - Higher altitudes / Lower Temperatures
  - Engines fitted with Pitot type air inlets are also exposed

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History of Icing RM

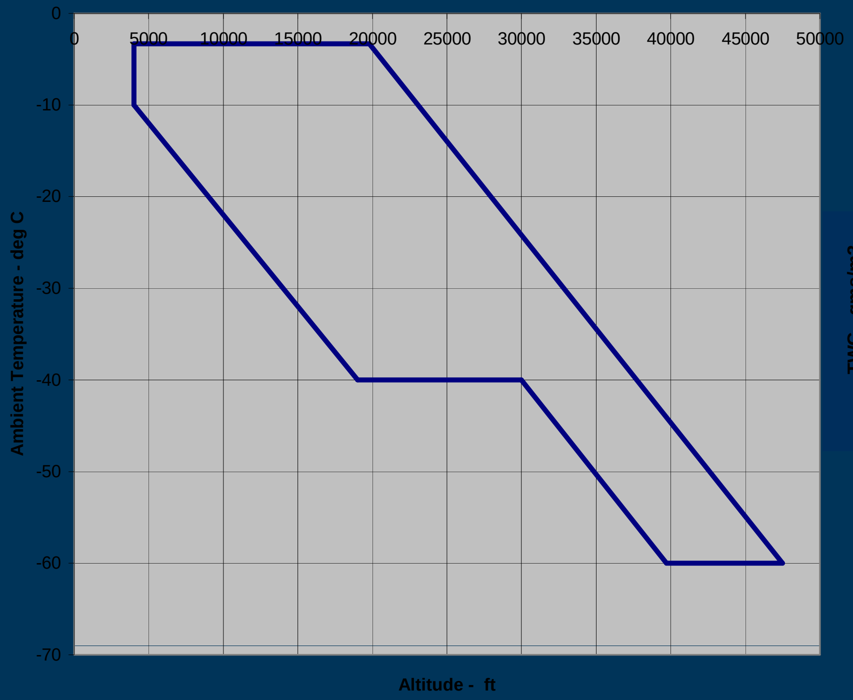
- 1994: an ATR-72 crashed at Roselawn
  - NTSB Recommendations were made to identify and define exceedance conditions (outside Appendix C) and develop new regulations
- 1997: FAA tasked ARAC
- 1998: ARAC started the IPHWG
  - Detection, SLD
- 2003: IPHWG tasked the EHWG
  - engine issues related to Ice Crystals & mixed-phase clouds

History of Icing RM

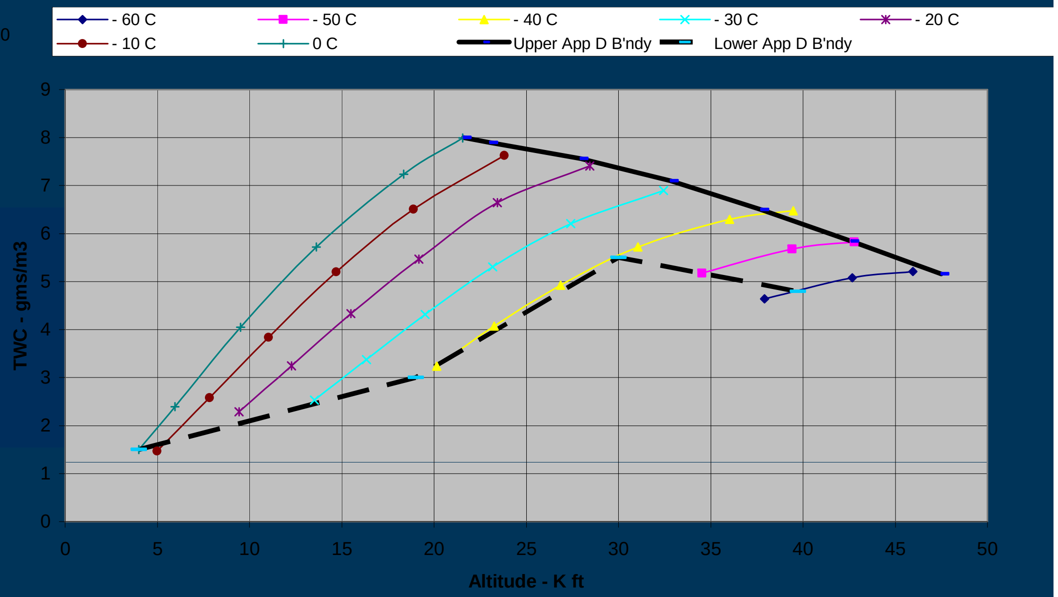
- 2007: EHWG, The "Appendix D" for FAR Part 33.
  - a new icing envelope for deep convective clouds
- 2010 (June) : Publication in the FAA NPRM 10-10 of the Appendix D
  - 33.68: Each engine must Operate ….. in the icing conditions defined in appendix D

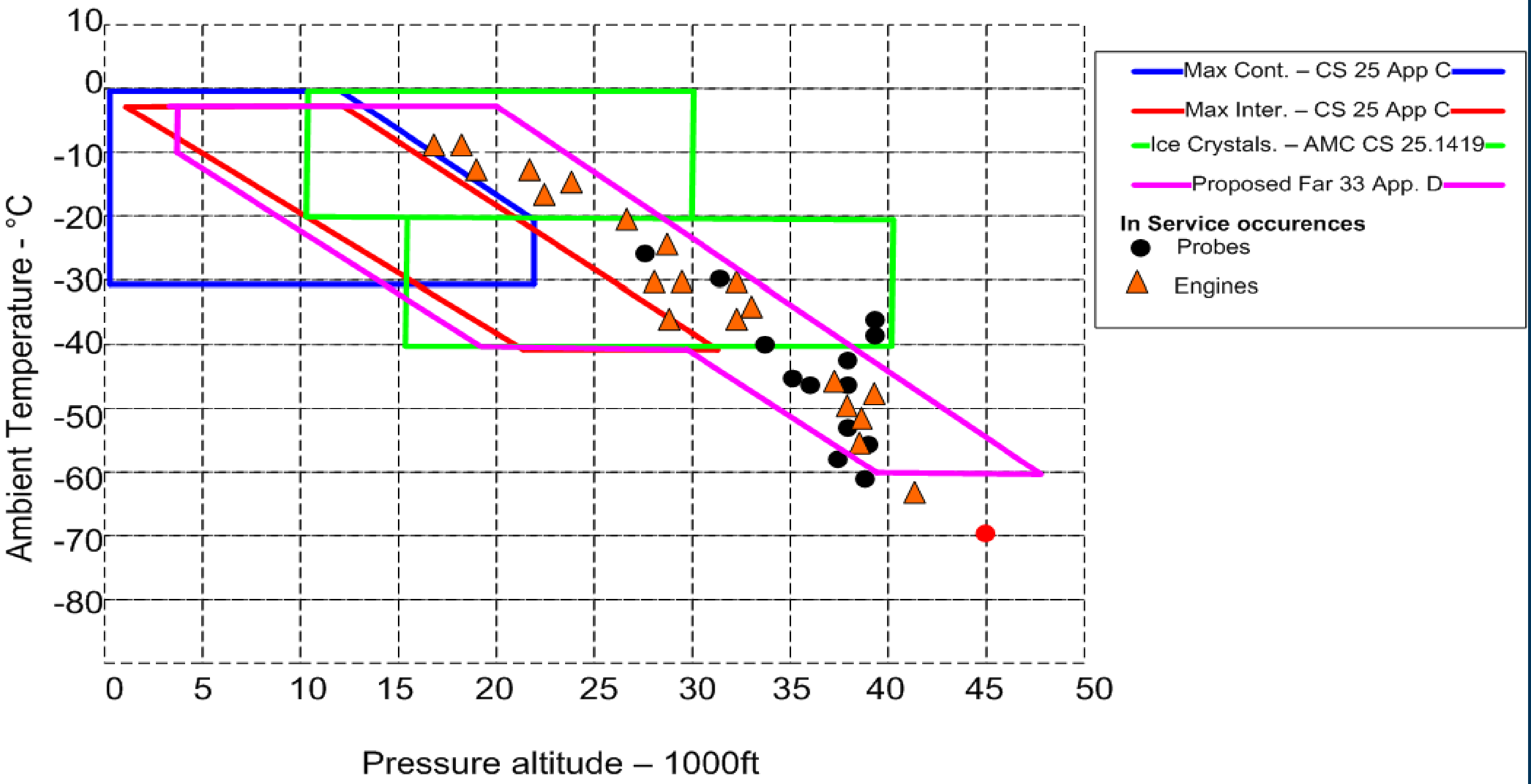
Proposed Appendix D

FAR 33 Appendix D Icing Envelope Limits



TWC Levels: Adiabatic Lapse from Sea Level @ 90% Relative Humidity
Legend : Ambient Temperature

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EASA Initiatives

- Certification
- Rule Making

Certification

- **Flight Instrument External Probes**
  - **All applications received after 31/01/10**
    - – CRI / Special Condition
      - » Appendix D +....
- **Engines**
  - **CRI / Interpretative Material**
  - **"statement in AMC E 780 is no longer acceptable as means of compliance of CS E.780 (d)"**
    - – *'Engines with Pitot' type intakes* <u>*need also*</u> *to be assessed against AMC E.780 conditions*

Rule Making

- Task 25.058 Large Aeroplane Certification Specifications
  - Supercooled Large Droplets, Mixed phase, and Ice Crystal Icing Conditions
  - Based on FAA NPRM 10-10 BUT …
    - Appendix D also for ALL Flight Instrument External Probes
  - EASA NPA is expected by the End of November 2010

Rule Making

- Task E.009 related to Engine Specifications CS-E 780
  - Assessment of icing specifications against certification experience
  - Develop CS-E 780 and associated AMC in line with NPRM 10-10
  - Review FAA AC 20.147 and identify elements that could be incorporated into AMC E.780
- Eurocae WG 89
  - Revision of ETSO-C16a (Pitot probes)based on service experience
    - *Ice crystals & mixed phase*
    - *Work start in September 2010*

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Challenges & Future Work

- Fundamental Physics of Ice Crystal Accretion
- Development of measurement techniques
- Validation in flight of the App. D
- Development / Improvement of Simulation tools (Analysis & Laboratories)

ref. FAA/NASA/NRC/EC/TC & Industry (Boeing , Airbus) programme

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Considerations

Impact of Climate Changes on the actual rate of events ??

- **Thunderstorms & cumulonimbus activity might be more intense or more frequent (?)**
- **More flights in geographic areas which are more prone to high ice water content (IWC)**
- **Airspace congestion ⇨ More flights closer to convection than previously**
- **Better recognition and reporting than in the past**

Thank You