Inclement Weather Regulations for Turbofan Engines, the Need for More Comprehensive Requirements and Methods of Compliance

McVey, Pullen, Oliver, Pritchard et al
GE Aviation

Introduction

Modern Gas Turbine engines are capable of operating in environments far beyond those required for certification just 15 years ago.

Certification requirements now define multiple atmospheres for rain, hail & icing which attempt to cover all inclement weather threats.

The small number of in-service events demonstrates the success of certification requirements in the modern fleet. However it has also been recognized that expansion of these requirements for mixed-phase/glaciated (MP/G) atmospheres more thoroughly may be desirable.

This presentation discusses the current & proposed certification requirements for all atmospheres, their adequacy & relevancy.

Inclement Weather Rule History - Icing

Current icing regulations have been used for over 30 years

- **FAR25 Appendix C atmosphere defined over 40 years ago, and is based on extensive data from the 1940's & 50's.**
- **Industry experience & certification test history using AC20-73 and now AC20-147 have defined standard test points which, along with other manufacturer defined 'critical points' appear to have given an excellent service record**
  - **Many standard test points not required in JAR/EASA, questions their need ?**
- **Helped achieve an excellent service record**

Continuous Maximum Icing (FAR25 Appendix C)

* Stratiform-type icing clouds from sea-level to 22,000ft altitude, with horizontal extents up to 300nm. LWC up to 0.8g/m^3, droplet sizes 15-40μ, temperatures from –22 to 32°F.

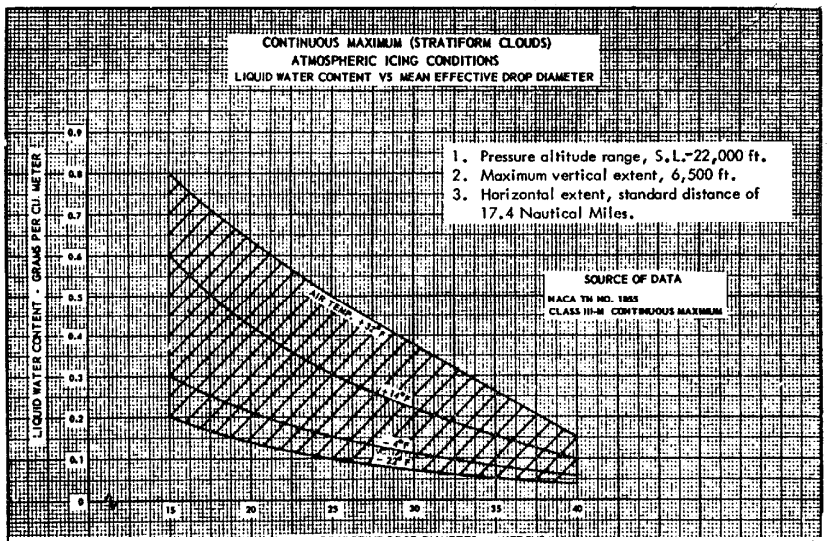


FIGURE 3

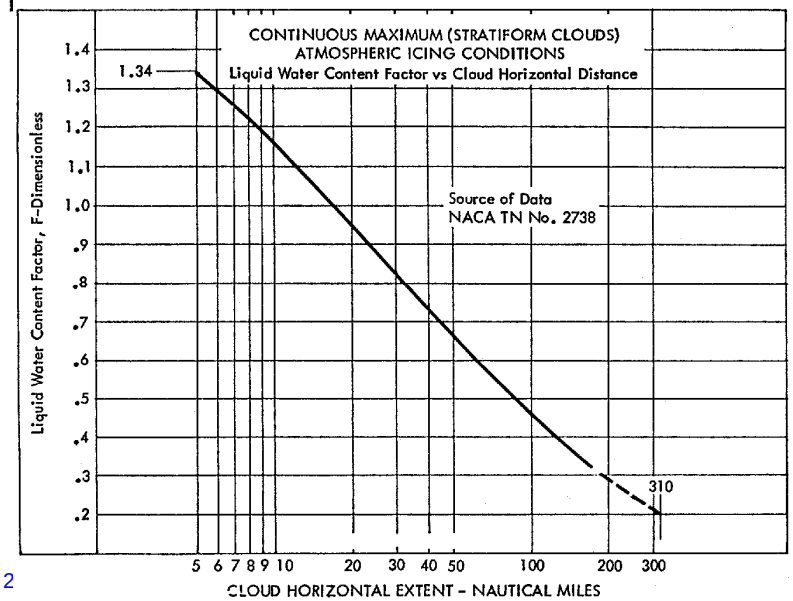
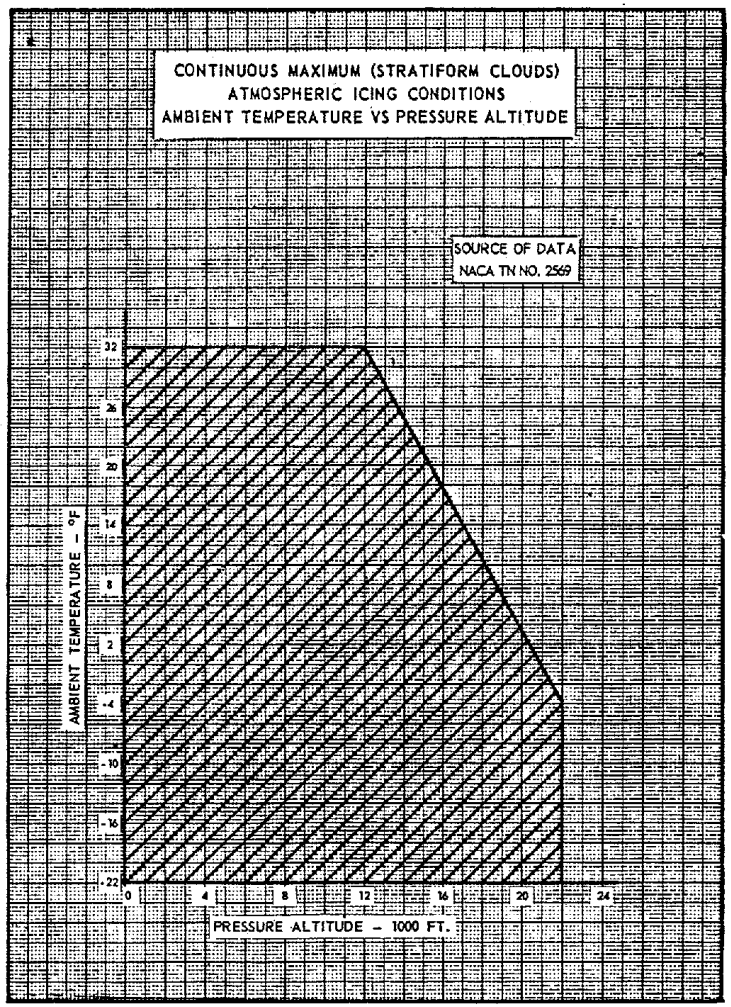


FIGURE 2



Intermittent Maximum Icing (FAR25 Appendix C)

* Cumuliform-type icing clouds from 4,000 to 30,000ft altitude, with horizontal extents up to 5.2nm. LWC up to 2.9g/m^3, droplet sizes 15-50μ, temperatures from –40 to 26°F.

FIGURE 4

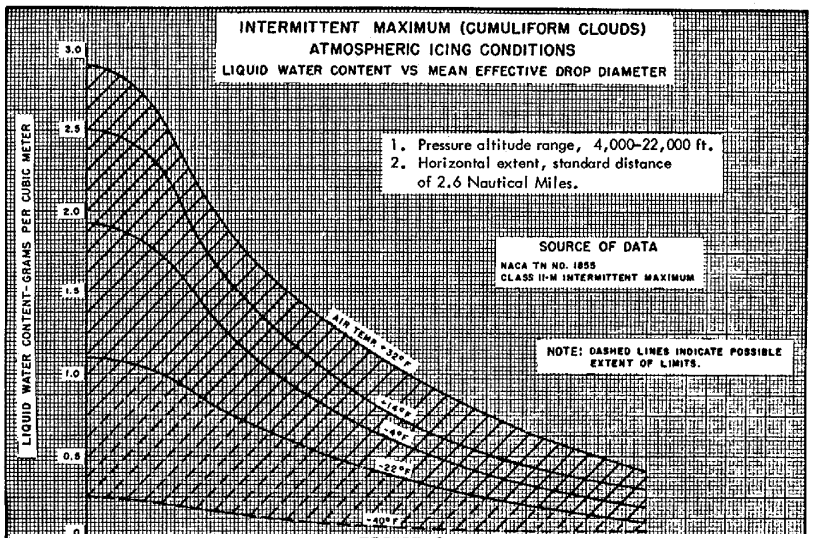
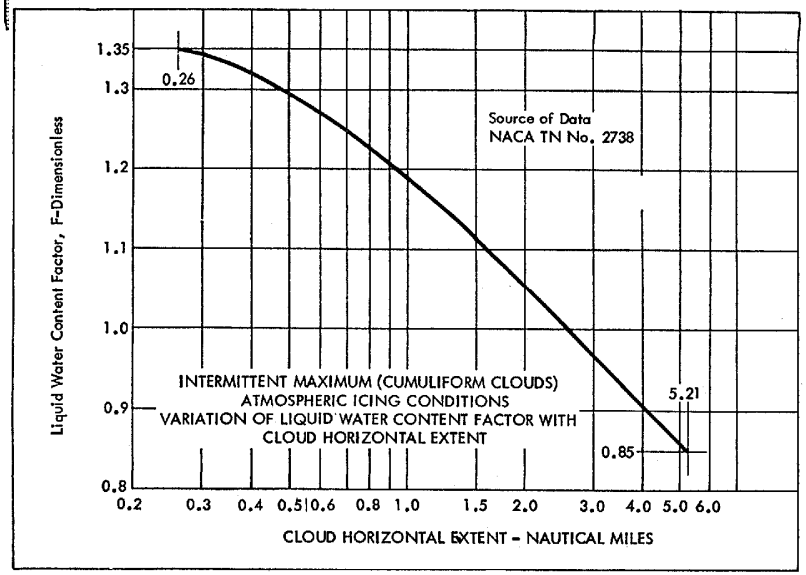
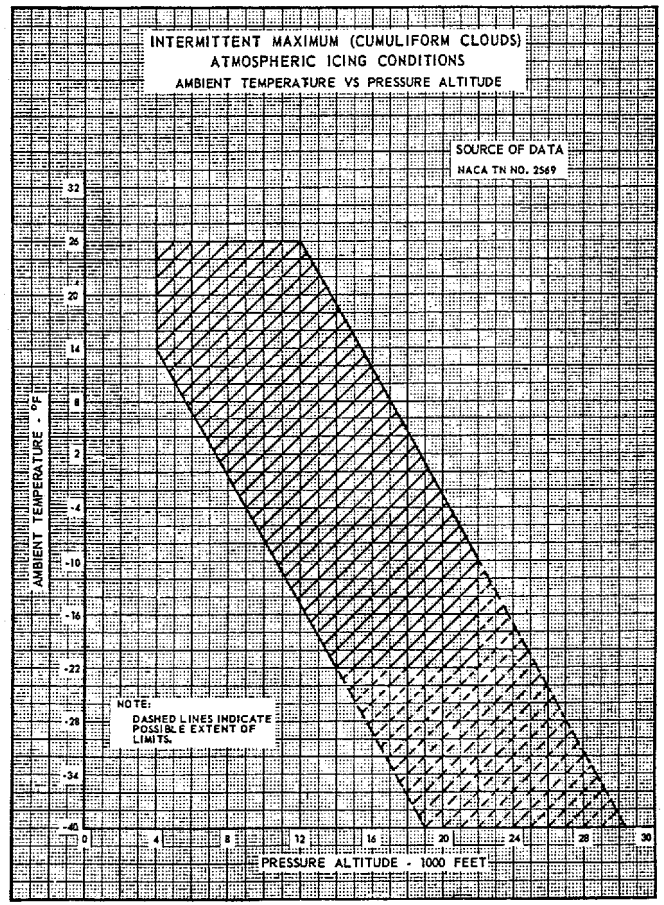


FIGURE 6



Pt. 25, App. C — 14 CFR Ch. I (1-1-89 Edition)

FIGURE 5



Federal Aviation Administration, DOT

Pt. 25 Federal Aviation Administration, DOT

Pt. 25, App. C

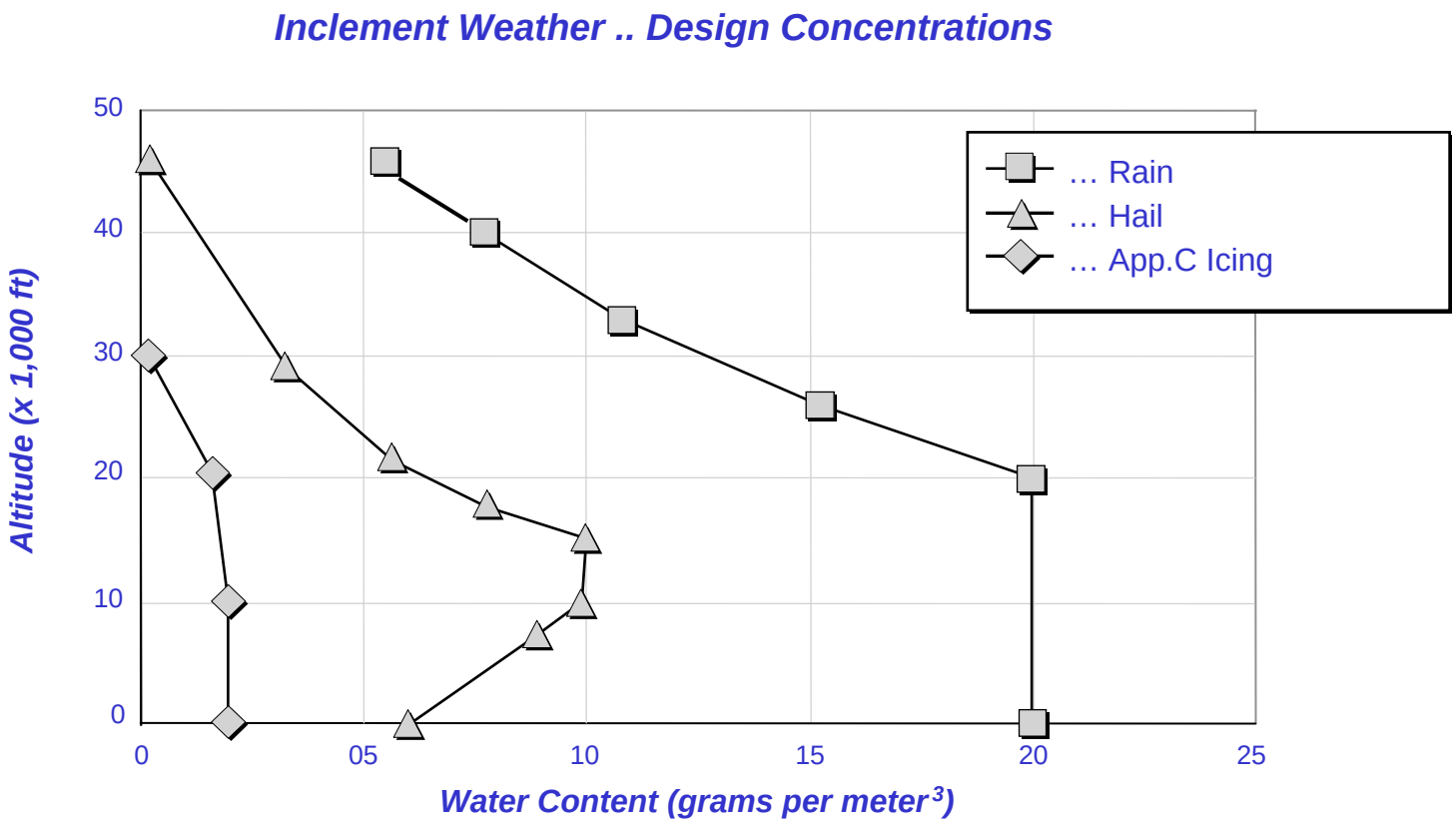
Inclement Weather Rule History - Rain & Hail

- Old rain regulations were simply 4% water by weight into the inlet, no hailstorm requirement.

- In late 80's a rulemaking committee was formed to address in-service events - separate Rain & Hailstorm atmospheres were defined – intended to address the 'Extremely Remote' threat at 10^{-8} probability
  - Rain up to 20g/m3 at 20,000ft (3% by weight)
  - Hailstorm up to 10g/m3 at 15,000ft
  - Critical point analysis required

- Events reduced by several orders of magnitude as a result

Rain & Hail Atmospheres



Inclement Weather Rules

There are substantially different threats :

Rain & Hail are continuous ingestion events, at extremely high threat levels, need to show Steady-State margins/capability.

The icing atmosphere is on the order of 10^{-2} to 10^{-3} encounter or exceedence probability, the threat is in two phases, accretion & shed.

Accretion can disrupt/restrict airflow

Steady-state margin

Shed can cause damage and/or operability effects

Transient margin

Inclement Weather Rule Developments

Due to in-service accidents, NTSB recommended that icing rules be expanded to cover super-cooled Large Droplets (SLD) & MP/G

- **1998 IPHWG formed**
  - **Attempted to develop SLD rules**
  - **MP/G not considered a threat to aircraft**
- **Since engines are needed to exit adverse conditions, EHWG formed in 2003 to address requirements**
  - **Collected service event data from manufacturers**

EHWG Event Database

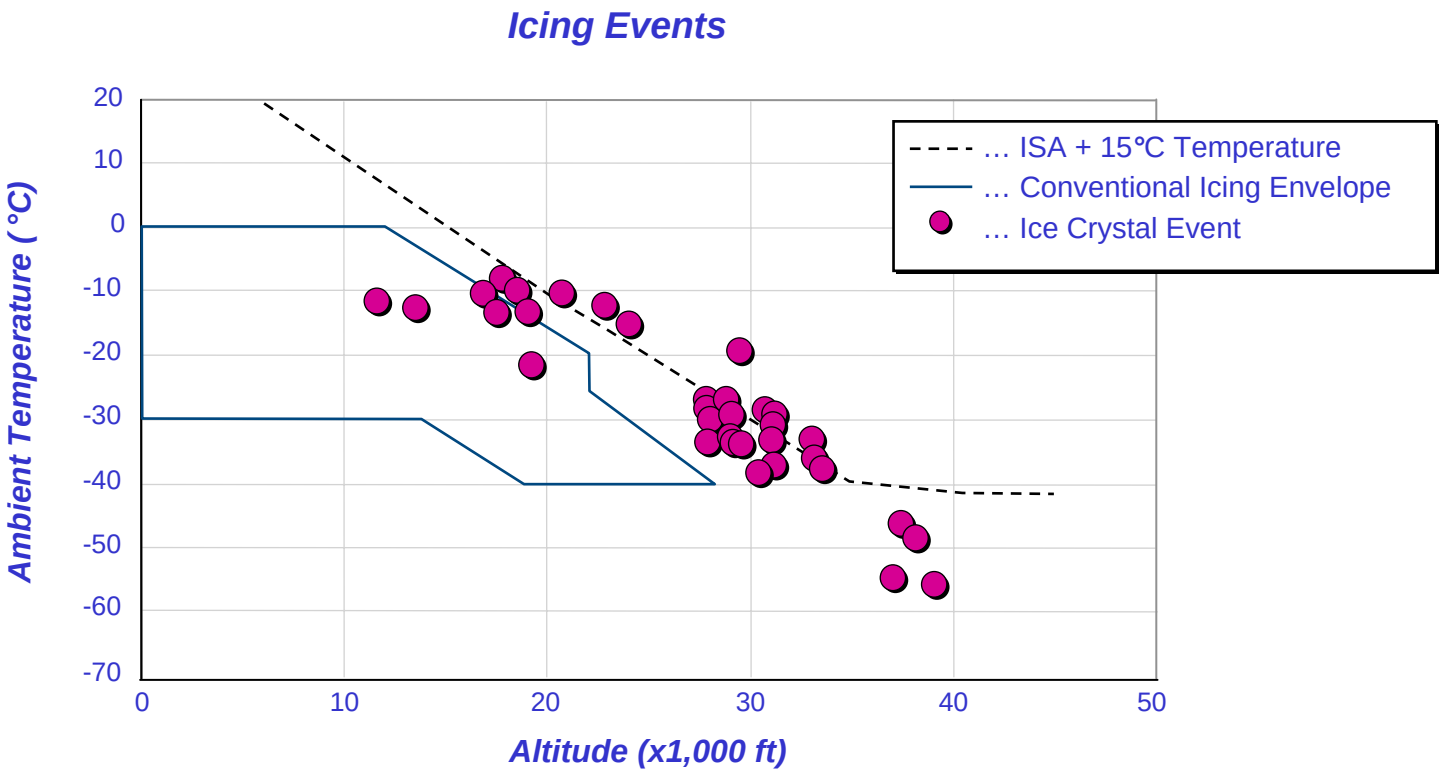
Icing event database compiled

- **1991-2003, 230 million flights (ACAS data)**
- **177 aircraft events, 236 engines**
- **1 event per 1.3 million flights**
- **Most no safety consequence to flight, vibration, minor engine damage, flameouts, rollbacks.**
- **No accidents.**
- **Nearly half of these events identified as possibly due to MP/G, 82 aircraft 123 engines, an event every 2.8 million flts.**

MP/G recognized as potential safety threat

- **SLD considered insignificant for engines (SAE G-12)**

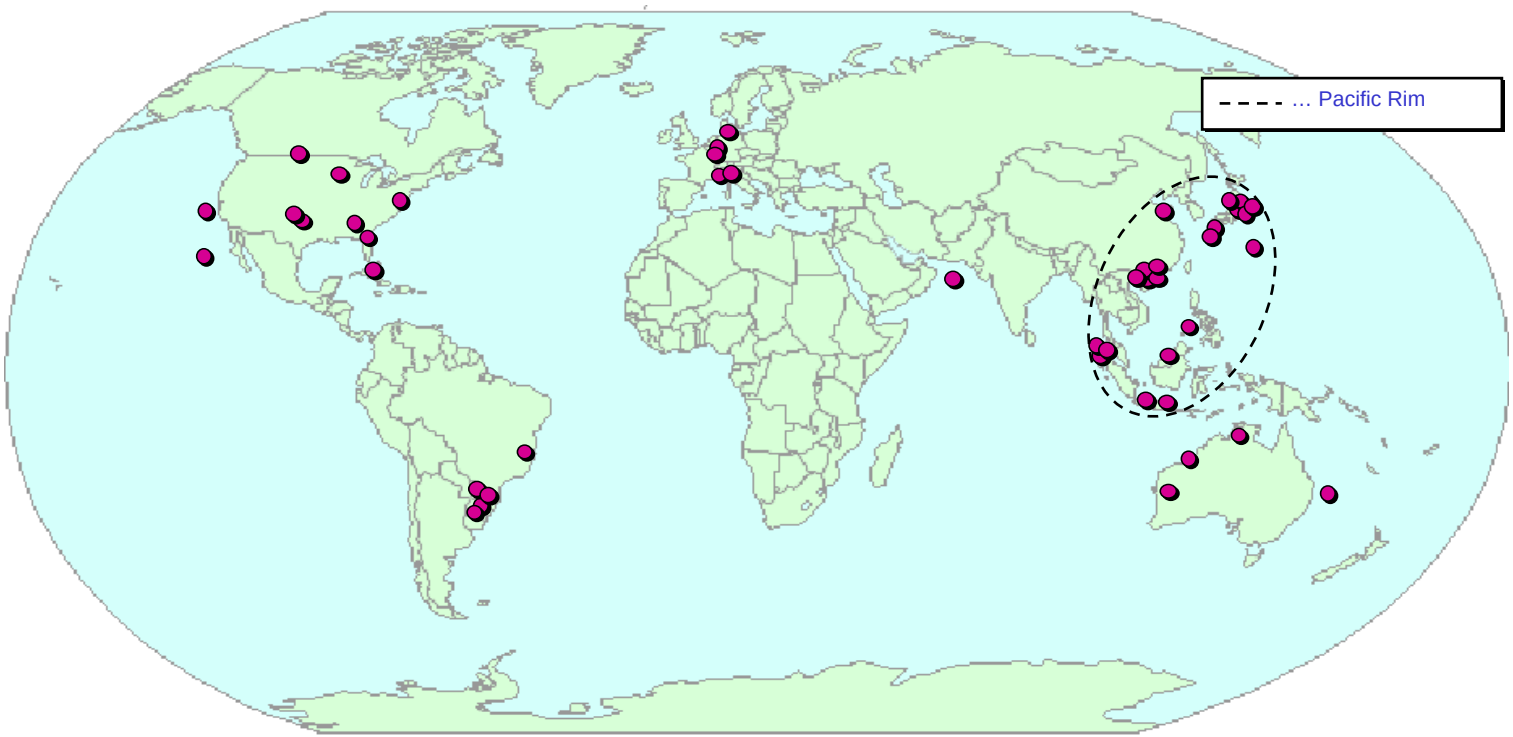
MP/G events occur outside Appendix C envelopes, typically at ISA+ temperatures



P S2J #lyhqw#orfdwlrqv

Events typically occur in convective atmospheres, majority in Pacific rim during tropical wet seasons

Event Locations



MP/G Reported Weather Characteristics

- Crews reported a full range of weather conditions
  - Icing
  - Heavy Icing
  - Turbulence
  - No Icing
  - Heavy Rain
  - Clouds
  - Avoiding clouds
- It is not always clear whether they were in severe conditions

Z kdwÍV#wkrxjkw#wr#eh#gliihuhqw#derxw#P S2J#flqj#B

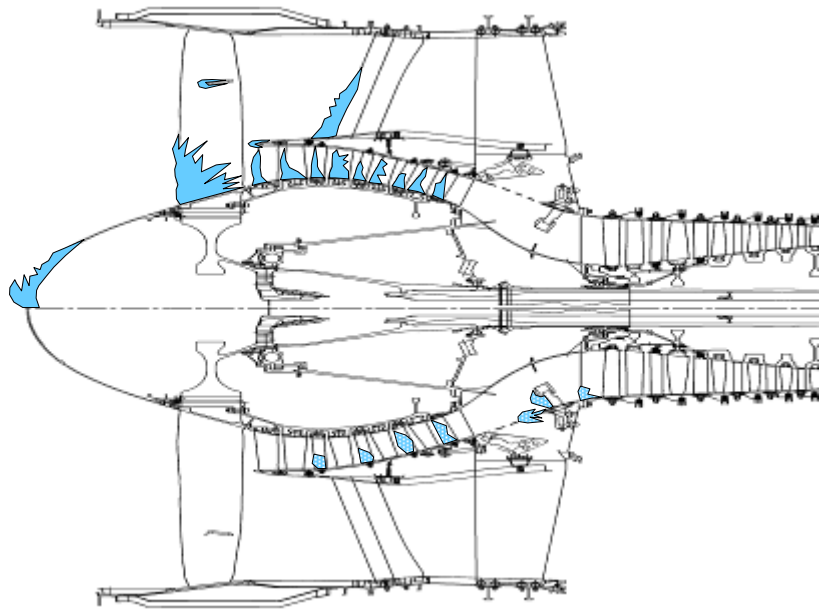
- In a conventional icing environment, super-cooled liquid droplets form rime or glaze ice on the surfaces impacted first.

vxshu0frrdng#dtxlg

Ifh#Fu|vwdov

- In an ice crystal icing environment, theory suggests ice bounces off first surfaces impacted, and accrete on warmer downstream surfaces due to more complex thermodynamic process.

Icing Locations

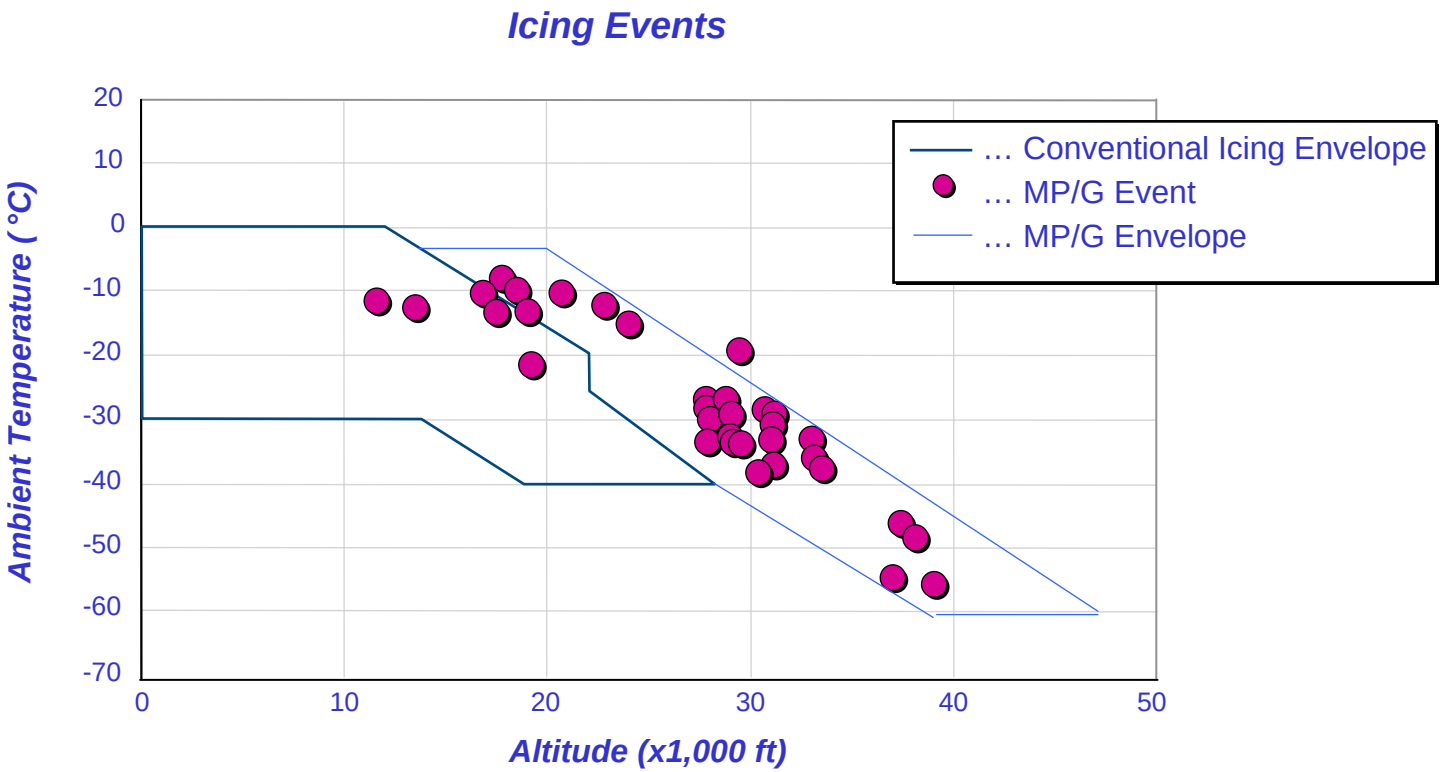


EHWG Proposals

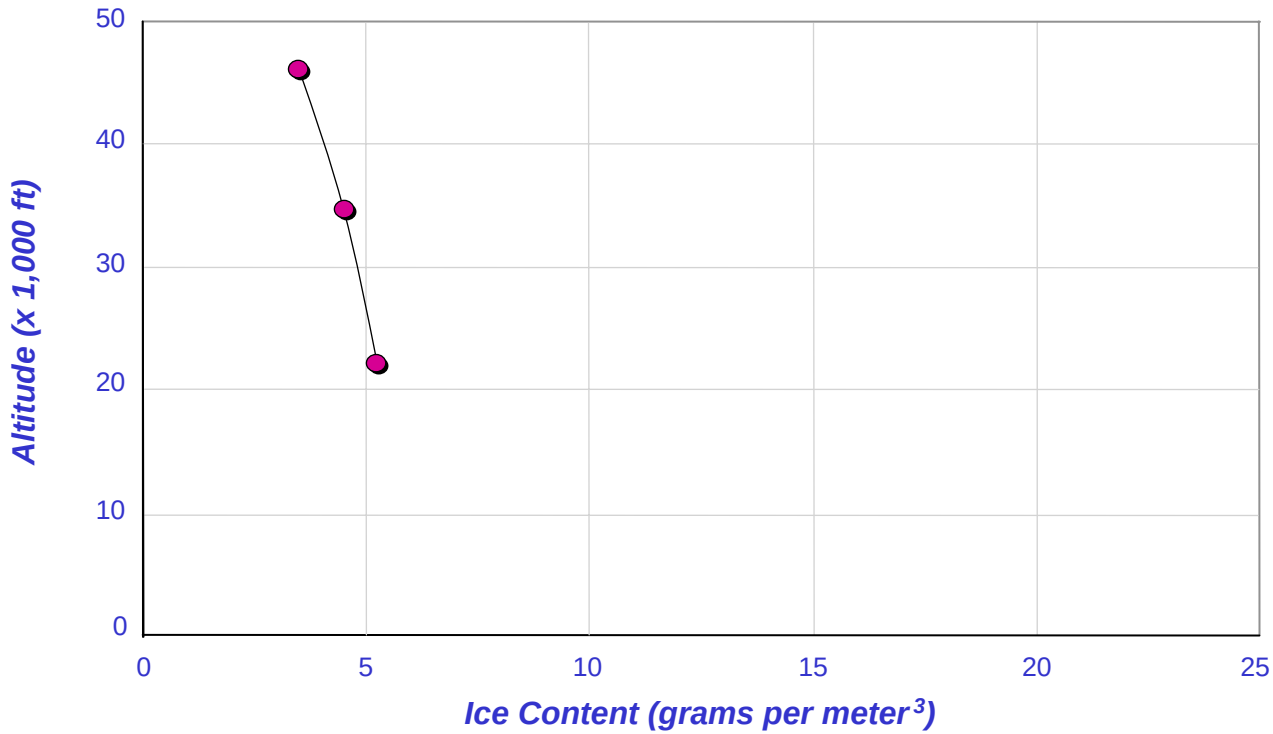
2005 EHWG proposed rules to address engine icing in all recognized icing atmospheres

- **Needs technology plan to further develop understanding of internal engine icing in MP/G**
- **Needs atmospheric definition of and new instrumentation to measure MP/G threats**

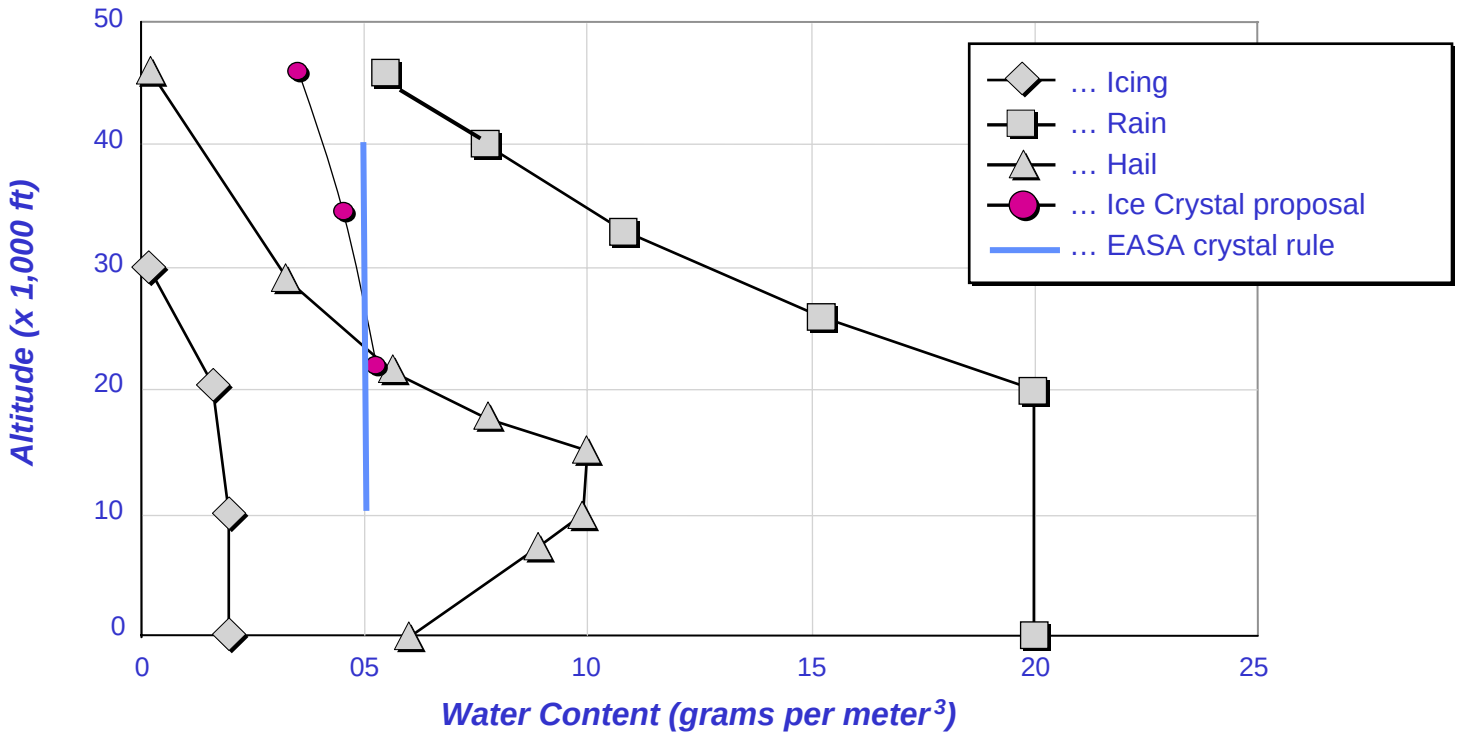
Sursrvhg#P S2J#Hqyhorsh



EHWG developed an atmospheric requirement based on early measurements, analytics & 99th percentile probability



Frp sdulvrq#Z lwk#rwkhu#dwp rvskhuhv#



Dwp rvskhuh#frp sdulvrqv

It is generally accepted that water does not exist in liquid form below –40C

Below –20C likely to be Mixed Phase or Glaciated

Thus above 25,000ft altitude in a Tropical atmosphere (ISA+17C) the FAR33.78 rain atmosphere will probably be MP/G

Above 25,000ft the current rain atmosphere exceeds the water content and duration requirement proposed for crystals, droplet size is probably too large since smallest rain drops are 500 microns.

Below 25,000ft the current hail atmosphere covers the ice content requirement proposed for crystals, particle size is too large since smallest hail are 5,000 microns.

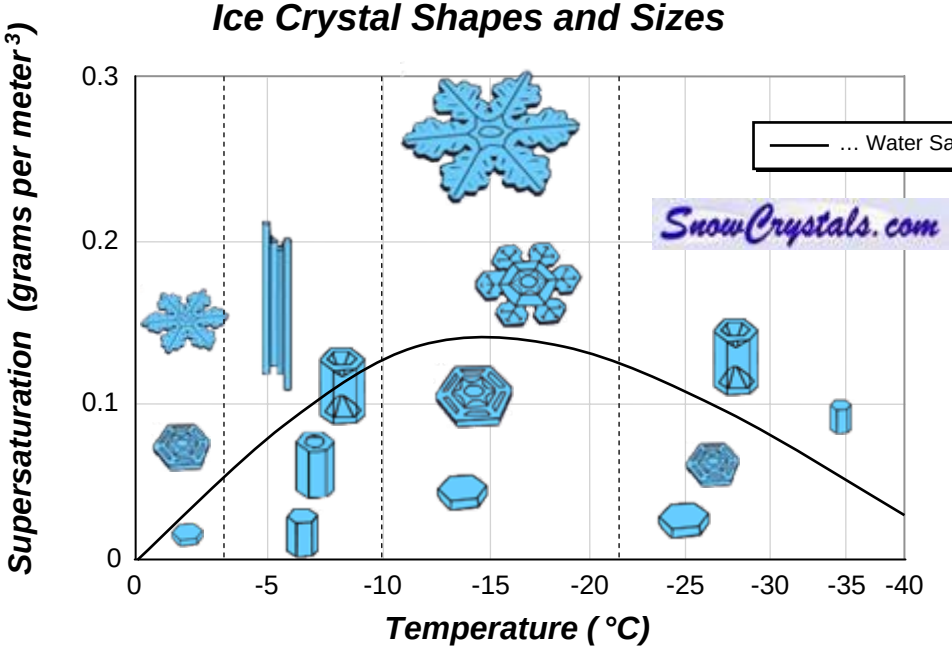
EASA regulation has up to 5g/m3 crystals at 40k altitude, and mixed phase component

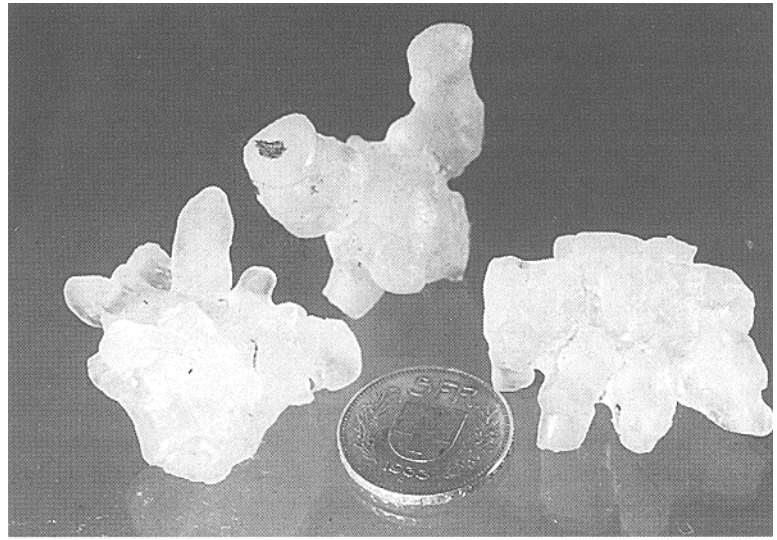
Frqfhuqv#2#Txhvwlrqv

Fu|vwdo#2#Kdlo

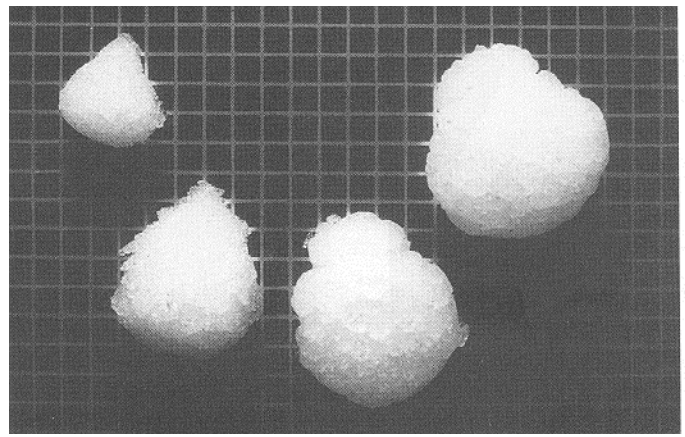
What is a 'crystal'

Size, shape effects, what is critical ?





Hailstones



Graupel

Crystals <5mm, hail >5mm - however, after impacts what is left ?

If rain doesn't exist above 25k, what happened to it?

Size distribution changed ? Larger/heavier particles precipitated leaving smaller crystals at higher levels

What happens when super-cooled rain droplets break-up in the engine inlet, potential mixed-phase ?

Is a 99th percentile Crystal atmosphere based on limited measurements what we need ?

Higher IWC isn't necessarily worse

Erosion effects

Critical thermal balance

Study of the EHWG data shows there are relatively few events

- ***Very few engine models***
- ***Several different event types***
- ***Several different atmospheric threats***

Would the new 'Crystal Atmosphere' requirement really have prevented these events ?

Z kdw#lv#qhhghg#lq#uhjxodwlrqv#B

Clearly there is overlap in the current rules

- ***The proposed MP/G atmosphere appears to be covered by existing defined atmospheres in some way***

Need to rationalize the atmospheres, make them logical extensions of each other, where there is overlap they need consistency with advisory material on MOC

Remove requirements which have become unnecessary due to technology advances

Harmonize with EASA

Research over the coming years will better define the MP/G threat and engine effects, should the rule definition slow down and use this knowledge ?

Z kdw#ho vh#fdq#eh#grqh#B

Better detection is necessary

Weather radar is critical to detection, but :

It doesn't show small crystals – could they ?

The bands are too narrow – can they be changed ?

Modern engines are capable of 'red zone' operation, crews who fly it regularly may become over-confident.

Icing detectors designed for super-cooled liquid often don't trigger in crystals, crystal sensor needed ?

Crews need information regarding icing in engines, since the airframe doesn't ice in crystals the assumption is still that crystals are benign.

Vxp p du

- ***There appears to be a threat from Mixed Phase / Glaciated atmospheres***

- ***We need a thorough understanding of how this threat affects the engine***

- ***Any new atmosphere must be carefully defined to encompass lessons learned into any rule***

- ***Overlap & redundancy should be eliminated***

- ***Harmonization is needed***