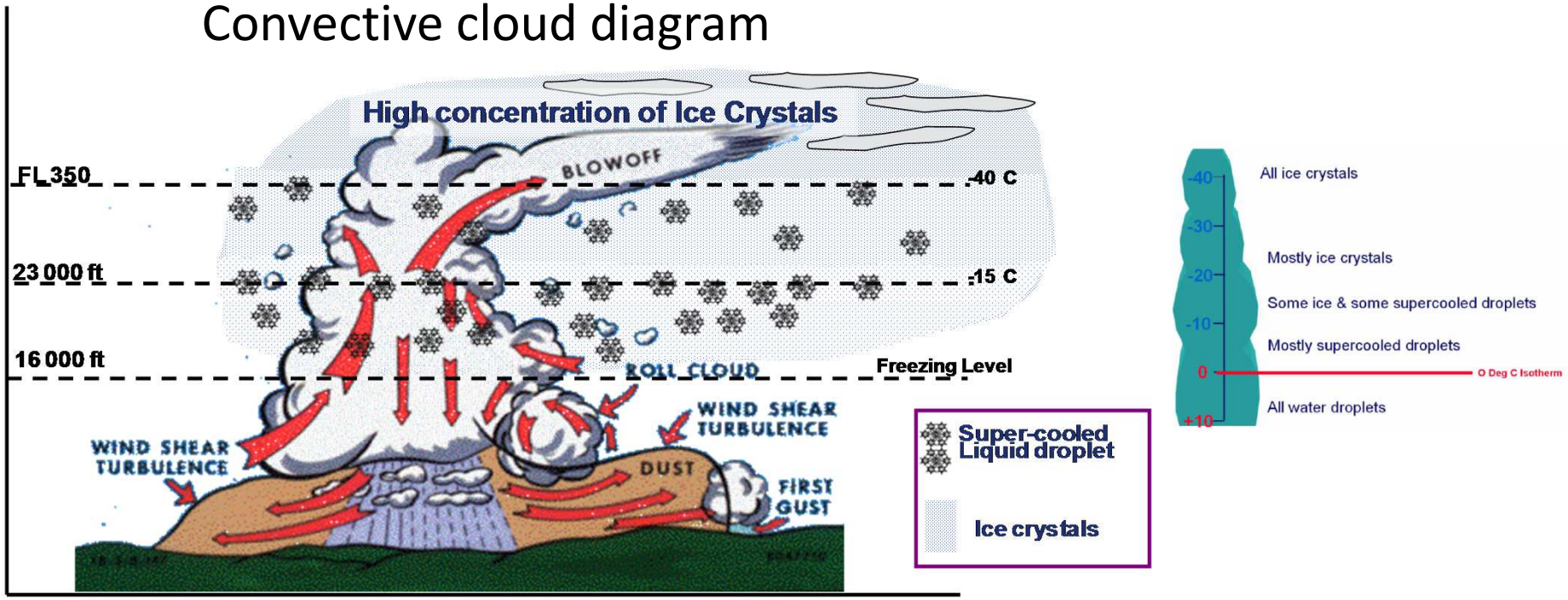
Priority In-service Engine icing Considerations

Rolls-Royce plc and SNECMA

Atmospheric Icing conditions

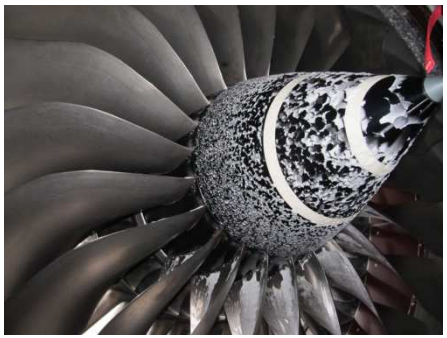
Convective cloud diagram



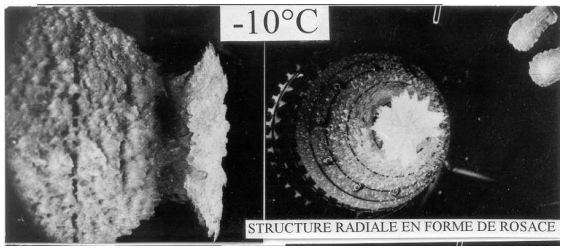
- Description of atmosphere provided in :
  - Appendix C : Supercooled liquid water
  - Appendix O : Supercooled Large Drops (SLD)
  - Appendix P : Ice crystals and mixed phase

Types of Icing

- Atmospheric icing conditions exist in various forms:
  - Supercooled liquid water
    - Freezing fog and in stratiform or cumuliform clouds
    - Small droplets (MVD ~15-50 µm)
    - Appendix C
  - Supercooled Large Drops (SLD)
    - Freezing rain (up to 2000 µm) and freezing drizzle (up to 500 µm)
    - In or below stratiform clouds
    - Proposed Appendix O
  - Ice crystals and mixed phase
    - Solid high altitude ice crystals (~50-200 µm equivalent)
    - Near convective storms, particularly mesoscale convective systems (MCS)
    - Proposed Appendix P
- Ice accretes differently according to conditions
  - Rime : milky white ice formed at low temperature
  - Glaze : Clear, hard ice which forms close to freezing



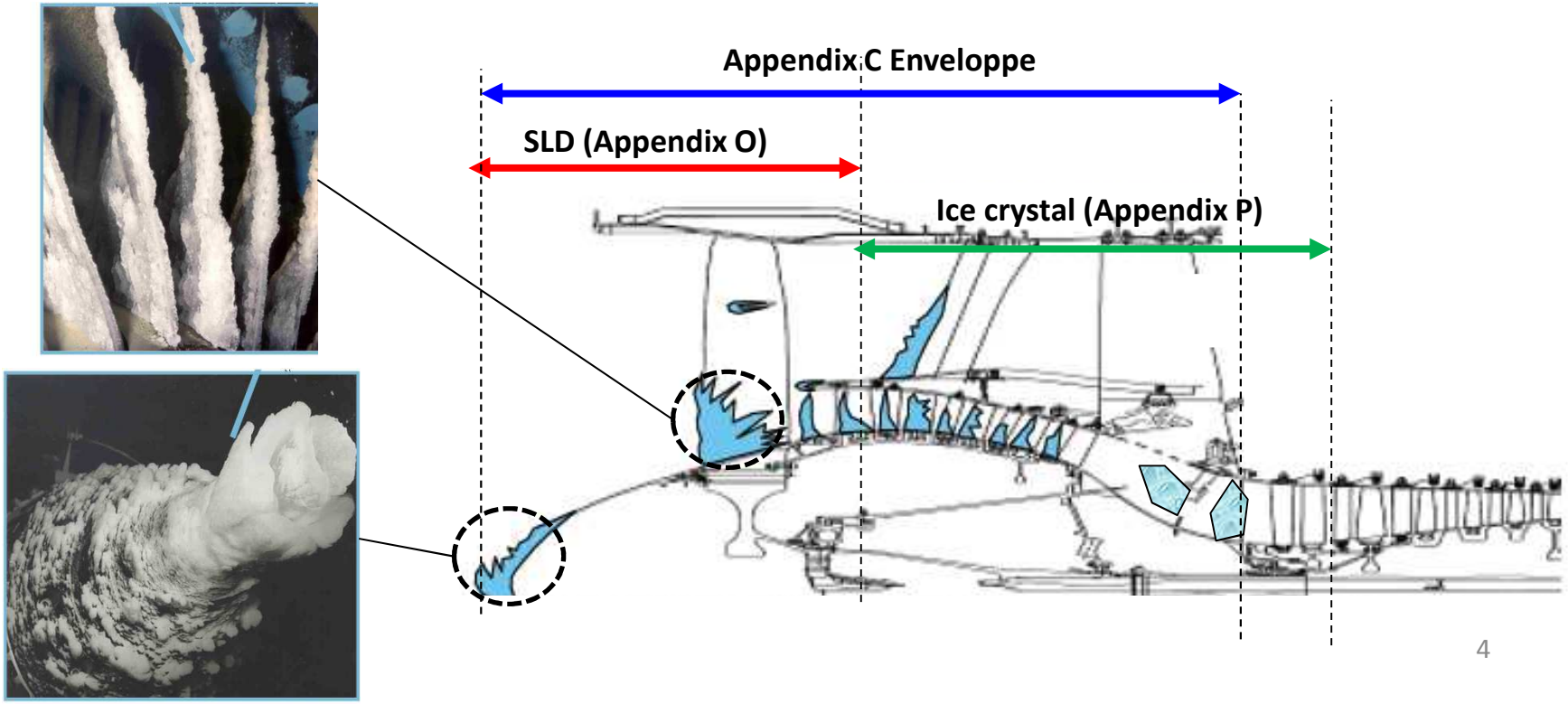
Rime Ice



Glaze ice

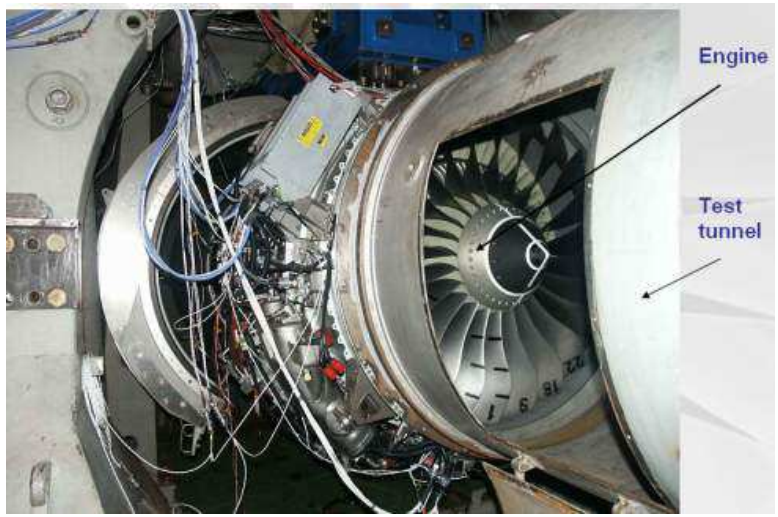
Engine Icing

- Areas where ice accretes is related to type of Icing atmosphere :
  - Supercooled liquid droplets : spinner, fan, initial stages of low compressor
  - Ice crystals : low compressor, intermediate casing, initial stages of HP compressor



Certification and Testing for Engine Icing (1/2)

- Supercooled liquid water (Appendix C)
  - Certification by engine test
  - Open air (e.g. GLACIER, Winnipeg) and simulated altitude (e.g. AEDC, DGA Saclay, CIAM) test facilities exist



Certification and Testing for Engine Icing (2/2)

- Supercooled Large Droplets (SLD) (Appendix O)
  - In flight, only effect on engine behaviour is intake icing, certified through fan ice slab ingestion item
  - On ground, certification by analysis, compared to well-proven design
- Ice crystals and mixed phase (Appendix P)
  - Certification by analysis, compared to known in-service event(s), supported by research into physics. Use of proposed MoC such as draft AC-20-147A & NPA 2012-23

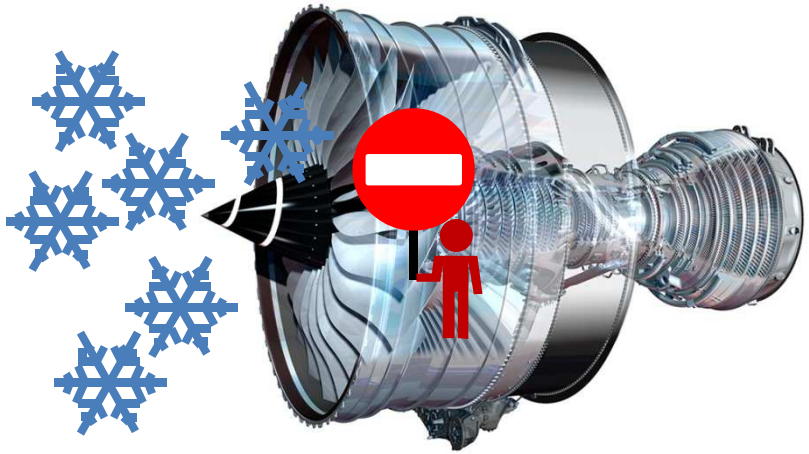
In-Service Icing Events

- Rolls-Royce & Snecma in-service icing events in the past decade
  - Appendix C envelope
    - No noticeable effect on engine performance and operability
  - Freezing fog
    - Long exposures
    - Conditions colder than CS-E
  - Ice crystal encounters
    - Usually at high altitude at very low ambient temperature
    - Concentration of events in Pacific Rim region
  - SLD Conditions
    - No events in flight
    - events on ground taxi conditions for old generation engine

- Update of requirements for appendix C conditions is not required
- For freezing fog and ice crystal, updates considered adequate for engine icing protection
- Engines now designed for improved operation in freezing fog and ice crystals

Design Considerations for Icing

- Engine geometry to “manage” icing
  - Minimize ice accumulation by optimization of geometry gas path (steps & gaps, curvature)
  - Avoid accreting by directing droplets and crystals away from critical accretion sites
- Heating
  - Avoid accretion
  - Promote shedding
  - e.g. Trent 1000 & Trent XWB ESS Anti-Icing + CFM LEAP
- Water/ice shed handling
  - Direct shed water and ice away to protect engine operability (e.g. VBV doors)
  - Ensure that components have impact resistance wherever ice will hit them
  - Promote localized sheds



CS-E Icing requirements

- Existing certification requirements adequate to ensure engine safety in icing conditions
- Current area of improvement for :
  - Freezing fog, particularly at low temperatures
    - Addressed in EASA NPAs 2011-04 and 2012-23 and via CRIs
  - Ice crystals
    - Addressed in EASA NPAs 2011-04 and 2012-23 and via CRIs

EASA NPAs 2011-04 & 2012-23

- Main concerns are :
  - Means of compliance are not fully developed
  - Service history shows that SLD conditions does not result to a engine threat for safety of flight
  - Severization of requirements for appendix C conditions (increase of duration from 30 to 45 minutes) is not justified by in-service experience
  - Use of §25.1324 aircraft probes Requirements for engine probes may be inadequate :
    - Thermodynamic environment is quite different
    - Engine probes may be not anti-iced

Future regulation & way forward

- Future regulation will address Ice crystals threat
- Need to develop Means of compliance
  - Test methods for creating representative crystal environment do not exist
  - Elaborate and validate simulation & models
  - Develop set up for test facility to produce and measure Ice Crystal environment
- Multiple working groups & research program started to develop such MoC :
  - Through international working groups
    - EHWG/ ICC (Engine Harmonization Working Group / Ice Crystal Consortium)
  - Through Collaborative Research programs
    - WEZARD (European Cooperative Support Action - SLD, Crystals, Volcanic Ashes – Started on 2011)
    - HAIC (Ice crystals European Collaborative Project – Submitted on 2011)
    - STORM (icing research Project for turbo machinery - Submitted on 2012
  - Engine manufacturers provides full support to these PGM's
- On board crystals ice Detection may be an option

Conclusion

- Current regulations, combined with proposed changes for freezing fog and ice crystals, provide good protection for engines in icing conditions
- Engine manufacturers using innovative methods of protecting engines against icing
- Research activities ongoing to address less well understood phenomena