Test and Certification of Pitot Probes

Ice and Rain Protection Aspects

Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa de Engenharia COPPE UFRJ
Engenharia Mecânica Politécnica • COPPE UFRJ

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Objectives

- ✓ *Perform a bibliographic research and present a basic overview to WAS audience about certification and testing of de-icing and anti-icing of Pitot probes:*
  - Technical literature, regulations and standards
  - Current certification and qualification requirements;
  - Icing tunnel testing selected topics;
  - Some aspects of similitude tunnel vs. Flight;
  - Documents for audience further reading.

Presentation focus

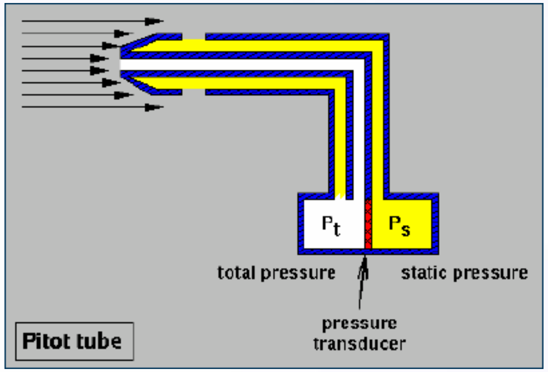
- ✓ *Current certification documents and standards*
- ✓ *Aspects of thermal ice protection of pitot probes*
- ✓ *Probes certification is a broader and more complex subject than icing*
- ✓ *Main reason → Knowledge and specialization of authors*

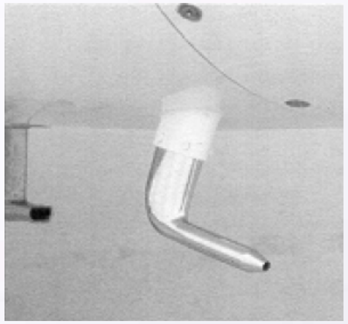
Not covered herein

- ✓ *NO other certification subjects or requirements not related to ice protection*
- ✓ *NO safety assessment, failure mode analysis or functional hazard topics*
- ✓ *NO aspects of Probes design or Air data system development*
- ✓ *NO discussions about new rules or non-standard atmospheric conditions*

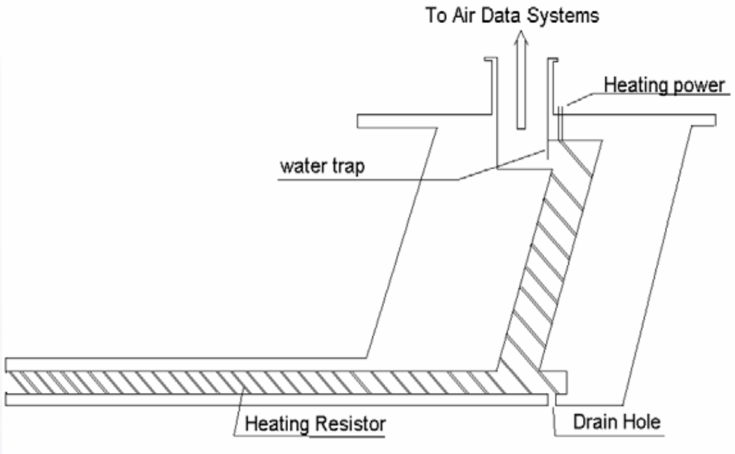
Air Data Probes Ice Protection:

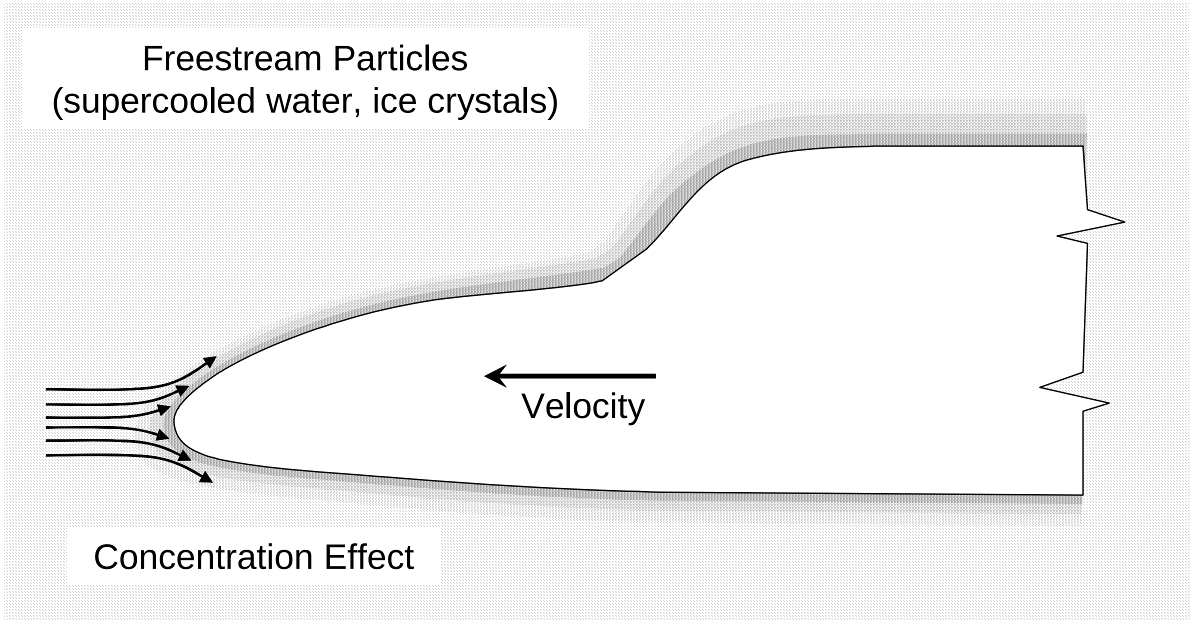
- ✓ *High water droplets collection efficiency (by definition)*
- ✓ *Usually fuselage mounted*
- ✓ *Local AOA differs from aircraft AOA because installation*
- ✓ *Local LWC may differ from freestream LWC cloud value due installation*
- ✓ *Typically electrical anti-icing and de-icing heaters installed*
- ✓ *Certification based on FAA TSO-C16a and FAA FAR 25 sections and Ap. C*
- ✓ *New rules and standards under discussions at ARAC, IPHWG and SAE*





Source: Duvivier, E. (EASA) "Flight Instrument External Probes", 1st SAE Aircraft & Engine Icing International Conference, Seville, 2007





Source: Duvivier, E. (EASA) "Flight Instrument External Probes", 1st SAE Aircraft & Engine Icing International Conference, Seville, 2007

Source2: SAE AS5562 Draft

Certification

Aircraft Certification

✓ *Aircraft Icing Envelope*

- As defined per USA's FAR 25 - Appendix C
- Icing condition defined by:
  - Air temperature (SAT or TAT)
  - Liquid Water Content (LWC)
  - Mean Effective Diameter (MED) ≈ Median Droplet Diameter (MVD)
  - Cloud Extension (correction of LWC)
- Two types:
  - Maximum Continuous (smaller LWC, longer clouds)
  - Maximum Intermittent (higher LWC, shorter clouds)
- Discussion Forums:
  - FAA Aviation Rulemaking Advisory Committee (ARAC) → new rules
  - Ice Protection Harmonization Working Groups (IPHWG) → FAA and EASA rules
  - SAE Aircraft Icing Technology Committee (SAE AC-9C) → new standards

FAR 25.1419 Ice protection.

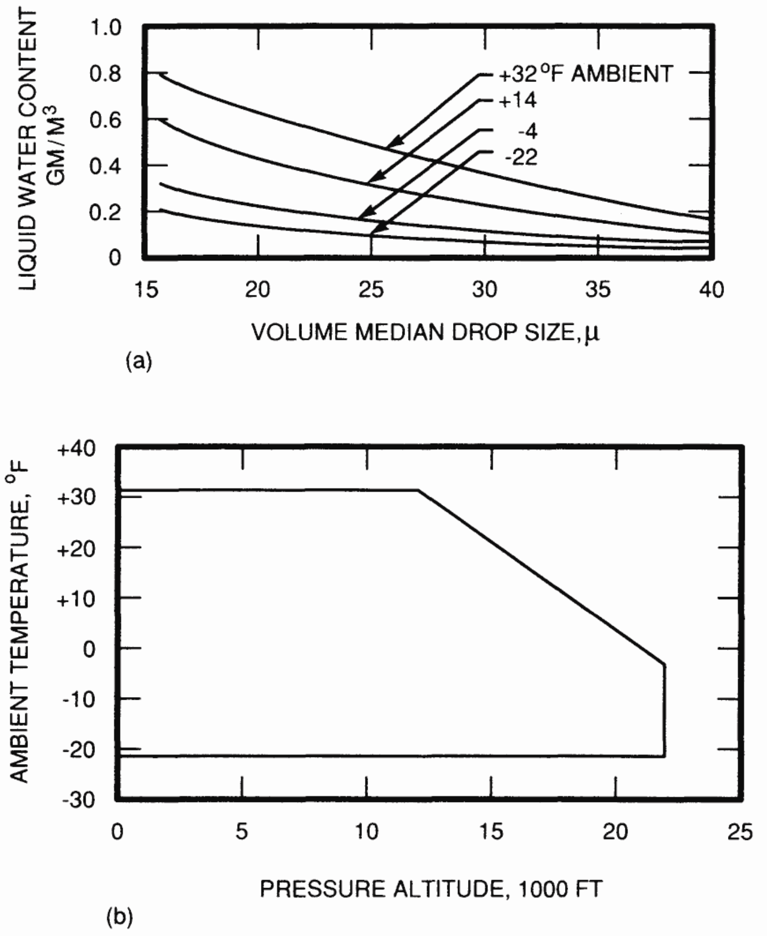
If the applicant seeks certification for flight in icing conditions, the airplane must be able to safely operate in the continuous maximum and intermittent maximum icing conditions of appendix C

FAA TSO C16a Ellectrically Heated Pitot and Pitot-Static Tubes

Use test conditions defined in 14 CFR part 25, Appendix C (b) Intermittent maximum icing, for the icing test conditions.

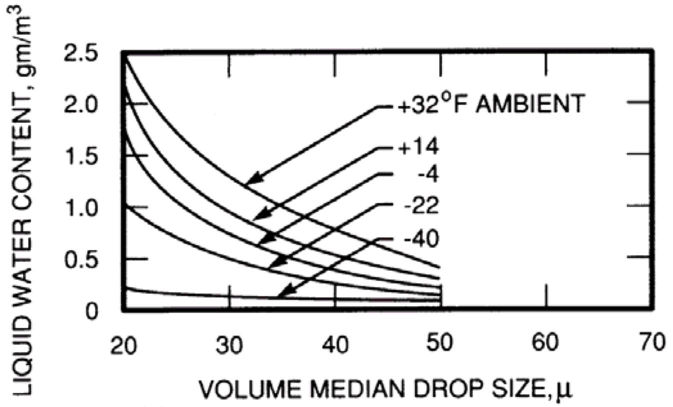
In addition, use the liquid water content tests of the supercooled liquid water test No.1 of paragraph 8.7.2(1), and test No.2 of paragraph 8.7.2(2) of the British Standards Institution (BSI) 2G 135,

Maximum Continuous

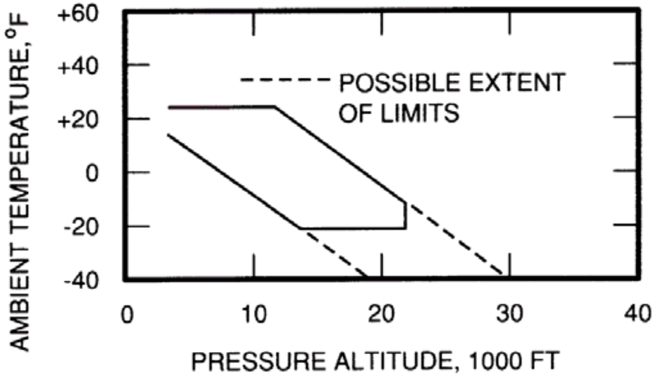


Sources: FAR 25 and SAE 1168/4

Maximum Intermittent

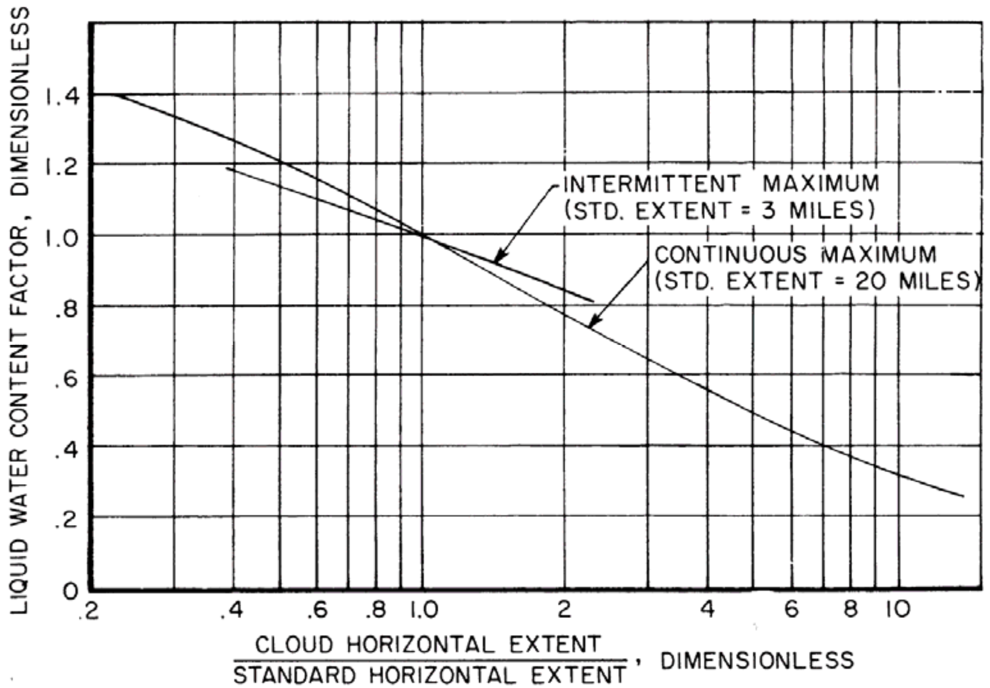


(a)



(b)

Cloud Extension Correction



Sources: FAR 25 and SAE 1168/4

Current Probe Qualification Documents

- ✓ *FAA – TSO C16a (refs. AS8006, BS2G.135 and FAR 25 AP. C)*
- ✓ *SAE - AS390, AS393, AS403A, AS8006*
- ✓ *British Standard Institution - BSI 2G.135*
- ✓ *MIL - MIL-T-5421B, MIL-T-5421A, MIL_P-83206, MIL-P-25632B*

Coverage

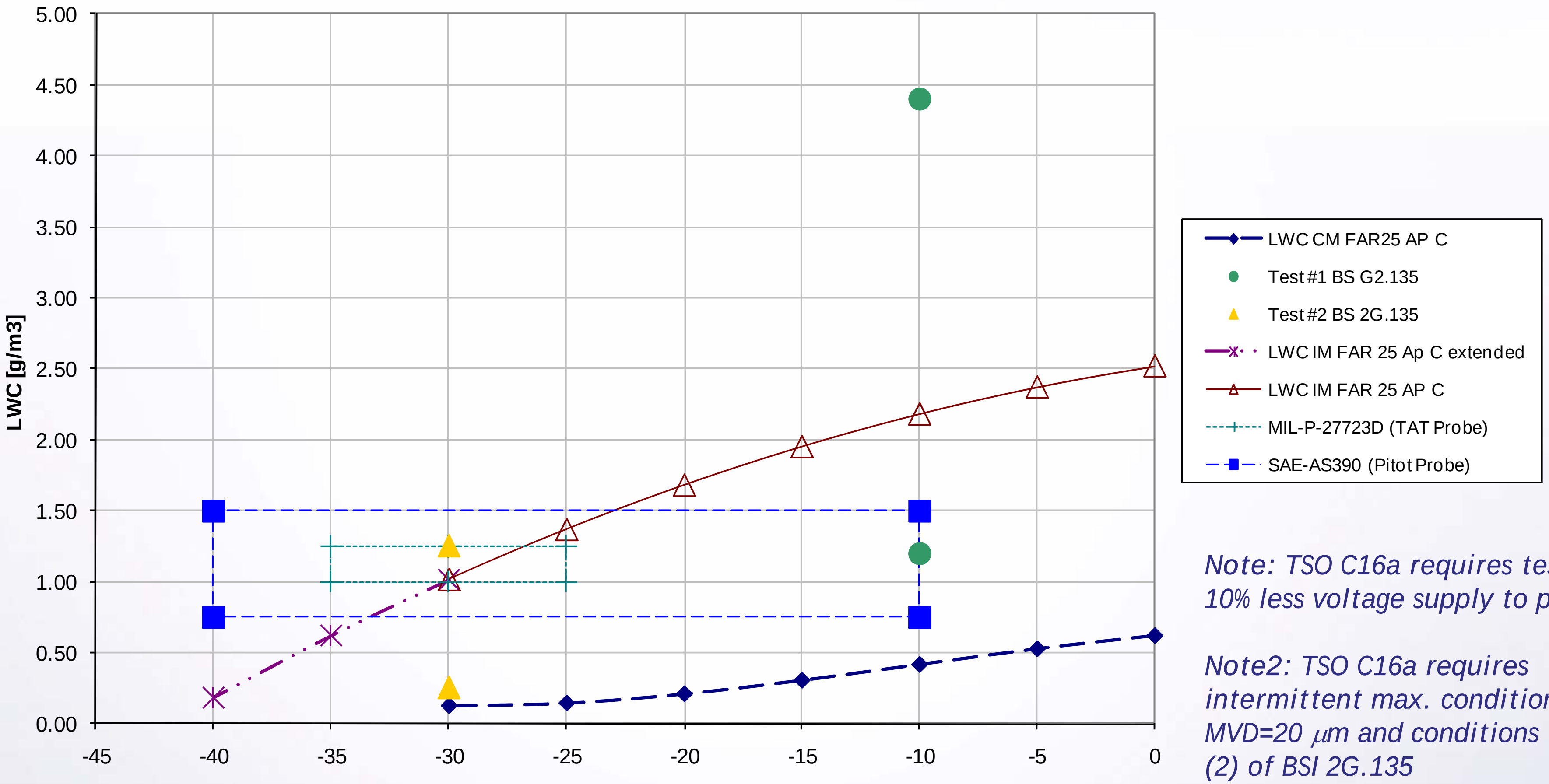
Environmental Conditions: Temperature, Altitude, Vibration, Radio Interference, Magnetic Effect

Detail Requirements: Drainage, Marking, Power Variation, **Anti-Icing / De-Icing**

Individual Performance Tests: Leakage, Dielectric, Heater Operation, Insulation Resistance, Aerodynamic Tests

Qualification Tests: Vibration, Endurance, Scale Error @ 0 deg AoA, Scale Error @ various AoA, Scale Error @ various angles of Yaw, Magnetic Effect, **Anti-Icing / De-Icing**, Cold soak, Shock, Salt Spray, Sand and Dust, Humidity, Power Consumption, Heat Conductivity, Status, Weight, Repeatability

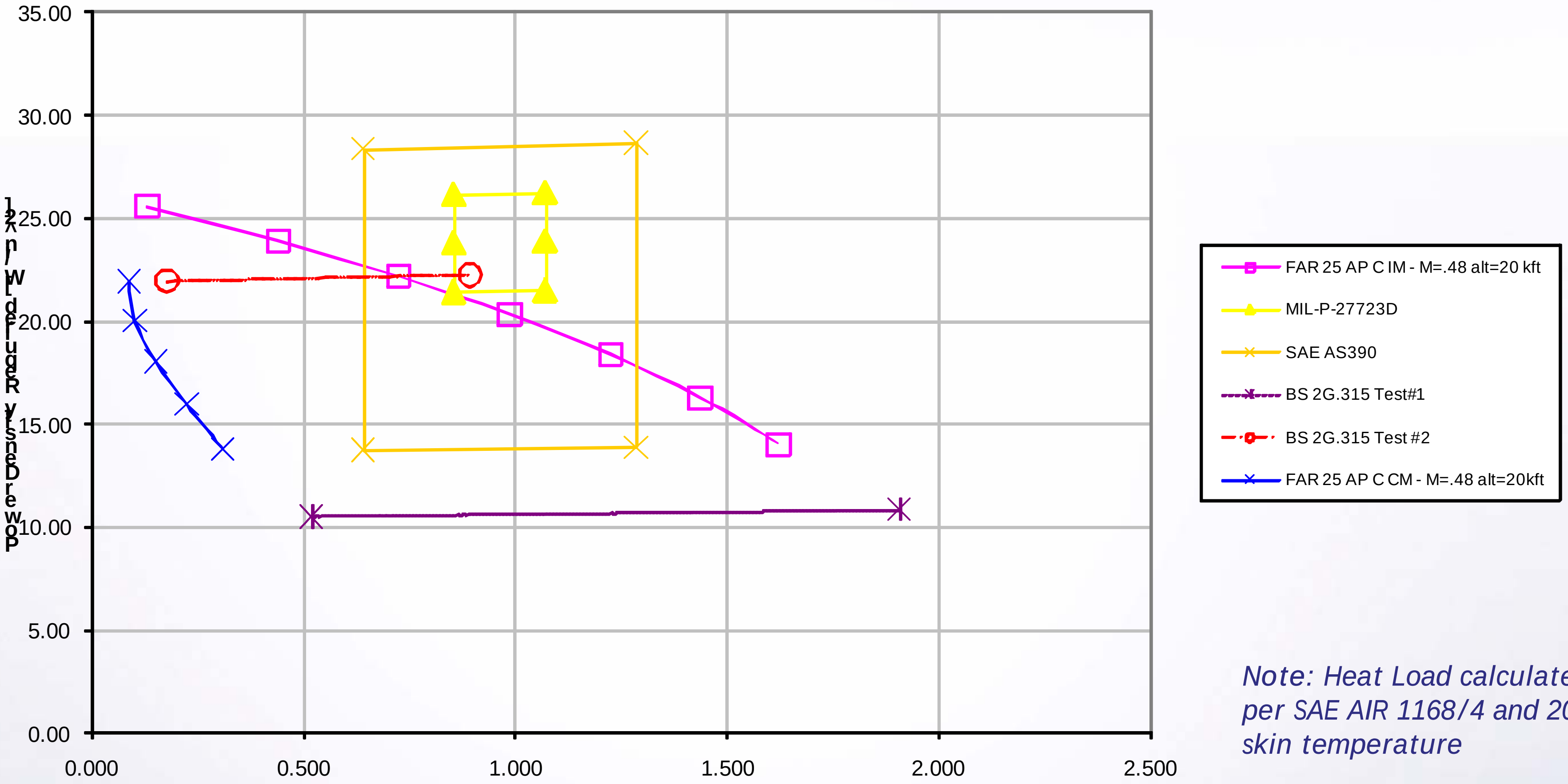
LWC vs. Static Air Temperature (SAT) Comparison



Note: TSO C16a requires tests with 10% less voltage supply to probe

Note2: TSO C16a requires intermittent max. conditions with MVD=20 μm and conditions (1) and (2) of BSI 2G.135

Power Density vs. Water Catch Comparison



Note: Heat Load calculated as per SAE AIR 1168/4 and 20 °C skin temperature

SAE AS5562 (Draft) - Ice and Rain Qualification Standards for Airdata Probes

- ✓ *Not yet released, under development by SAE AC-9C Committee*
- ✓ *Types of Probes:*
  - Pitot, Static Pressure, Angle of Attack and Temperature Probes
- ✓ *Conditions*
  - Liquid, Mixed and Solid Phase Icing
  - Rain
  - Super Large Droplets (SLD)*
    - Freezing Rain
    - Freezing Drizzle
- ✓ *Aircraft installation effects, including concentration factor*
- ✓ *Testing*
  - Setup Effects
  - Operational limitations
  - Test Procedure

(*) SLD envelope also under discussions by FAA and EASA at IPHWG Task 2.

Typical Probe Qualification Process

- Choose altitude and Aircraft Mach (or True Air Speed)
- From flight envelope get minimum and maximum AOA (angle of attack)
- Calculate the local probes AOA ranges
- Assume Maximum Intermittent or Continuous envelope
- Get the Lowest and Highest temperatures (range) from Appendix C
- Get the LWC associated with temperatures and MVD from Appendix C
- Include LWC, MVD, temperature conditions from other standards, if required
- Calculate concentration factors with CFD (or, if possible, LEWICE3D)
- Assemble critical cases flight cases matrix
- Select a calibrated tunnel facility
- Obtain tunnel characteristics (speed, pressure, temperature, MVD and LWC)
- Use similitude criteria to define tunnel test condition matrix
- Place probe in tunnel and test
- Analyze results and check pass fail criteria

Testing

Selected SAE Standards

- ✓ *Icing Testing*
  - ➢ ARP5905 Calibration and Acceptance of Icing Wind Tunnels
  - ➢ AIR5504 Aircraft Inflight Icing Terminology
  - ➢ AIR5906 Ice Shape Measurement and Comparison Techniques Workshop
  - ➢ ARP5904 Airborne Icing Tankers
  - ➢ AIR5320 Summary of Icing Simulation Test Facilities
  - ➢ AIR4906 Droplet Sizing Instrumentation Used in Icing Facilities
- ✓ *Icing Analysis*
  - ➢ ARP5903 Droplet Impingement and Ice Accretion Computer Codes
  - ➢ AIR1168/4 Ice, Rain, Fog, and Frost Protection

Icing Tunnels Facilities Worldwide (SAE AIR5320)

Facility No.	Facility Identification	Organization & Location	Contact	Facility Name	Facility No.	Facility Identification	Organization & Location	Contact	Facility Name
1	ACT (Artington)	The Artington Cold Store New Pond Road Guildford, Surrey, GU31JP England	Mr. Glenn Howard Phone: 01483 566876 Fax: 01483 301949	Artington Icing Wind Tunnel	11	CEPr (R6)	Centre d"Essai des Propulseurs CEPr Saclay 91895 ORSAY CEDEX, FRANCE	Ms. Sophie Le Berre Phone: (33) 1 69 85 09 40 Fax: (33) 1 69 85 01 02	Altitude Test Cell R6
2	AERAZUR	AERAZUR 4 Rue Lesage-Maille 76320 Caudebec-les-Elbeuf France	F. Averous Phone: 33(0)1 41 23 23 23 Fax: 33(0)1 46 48 88 52	Tunnel de Givrage	12	CEPr (PAG)	Centre d'Essai des Propulseurs CEPr Saclay 91895 ORSAY CEDEX, FRANCE	Ms. Sophie Le Berre Phone: (33) 1 69 85 09 40 Fax: (33) 1 69 85 01 02	Petit Anneau Givrant
3	AIT	Aero & Industrial Technology Ltd. P.O. Box 46 Burnley BB11 4BX Lancashire, England	Mr. R. J. Park Phone: (0) 282 831199 Fax: (0) 282 416969	Altitude Test Facility	13	FluiDyne	FluiDyne Engineering Corporation 5900 Olsen Memorial Highway Minneapolis, MN 55422	Mr. Julian Idzorek Phone: (612) 544-2721 Fax: (612) 546-5617	22 X 22 Icing Wind Tunnel
4	AEDC (T-1,2,4)	Arnold Engineering Development Center Arnold Air Force Base, TN 37389-5000	Maj. J. Davis Phone: (615) 454-5853 Fax: (615) 454-7205	Engine Test Facilities T-1, T-2, T-4	14	G.E.	General Electric Peebles Test Operation 1200 Jaybird Road Peebles, OH 45660	Mr. J. R. Bennett Phone: (513) 243-7432 Fax: (513) 243-4068	Site 6
5	AEDC (J-1,2)	Arnold Engineering Development Center Arnold Air Force Base, TN 37389-5000	Maj. J. Davis Phone: (615) 454-5853 Fax: (615) 454-7205	Engine Test Facilities J-1, J-2	15	NASA LeRC (IRT)	NASA Lewis Research Center 21000 Brookpark Road Cleveland, OH 44135	Mr. Thomas B. Irvine Phone: (216) 433-5369 Fax: (216) 433-8551	Icing Research Tunnel
6	AEDC (C-2)	Arnold Engineering Development Center Arnold Air Force Base, TN 37389-5000	Maj. J. Davis Phone: (615) 454-5853 Fax: (615) 454-7205	Engine Test Cell C-2	16	NRC (#4)	National Research Council Montreal Road Ottawa, Ontario Canada K1A OR6	Mr. M. S. Chappell Phone: (613) 993-9900 Fax: (613) 952-7686	Gas Turbine Icing Test Facility Test Cell #4
7	AEDC (R-1D)	Arnold Engineering Development Center Arnold Air Force Base, TN 37389-5000	Maj. J. Davis Phone: (615) 454-5853 Fax: (615) 454-7205	Altitude Chamber R-1D	17	NRC (ITF)	National Research Council Montreal Road Ottawa, Ontario Canada K1A OR6	Dr. Myron Oleskiw Phone: (613) 993-5339 Fax: (613) 954-1235	Icing Tunnel Facility
8	BFG	BF Goodrich Deicing Systems 1555 Corporate Woods Parkway Uniontown, OH 44685-1277	Mr. Thomas Wilson Phone: (330) 374-3632 Fax: (330) 374-2290	Icing Tunnel	18	NRC (HIF)	National Research Council Montreal Road Ottawa, Ontario Canada K1A OR6	Dr. Myron Oleskiw Phone: (613) 993-5339 Fax: (613) 954-1235	Helicopter Icing Facility
9	Boeing (BRAIT)	Airplane System Lab The Boeing Commercial Airplane Group P.O. Box 3707, MS 1S-HL Seattle, WA 98124-220	Mr. Ferd Reichlin Phone: (206) 662-4272 Fax: (206) 662-0453	Boeing Research Aerodynamic Icing Tunnel	19	ONERA (SIMA)	Office National d'Etudes et de Recherches Aerospatiales Centre de Modane-Avrieux BP25 73500 MODANE - France	Mr. J. Pricur Phone: 33 1 46 73 40 90 Fax: 33 1 46 73 41 44	SIMA Wind Tunnel
10	CEPr (S1)	Centre d'Essai des Propulseurs CEPr Saclay 91895 ORSAY CEDEX, FRANCE	Ms. Sophie Le Berre Phone: (33) 1 69 85 09 40 Fax: (33) 1 69 85 01 02	Altitude Test Cell S1	20	Rolls-Royce (WT)	Rolls-Royce plc P.O. Box 31 Derby De2-8BJ England	Ms. Susan Riley Phone: 332-249375 Fax: N/A	Hucknall 15 Inch Icing Tunnel

Icing Tunnels Facilities Worldwide (SAE AIR5320) - Cont.

Facility No.	Facility Identification	Organization & Location	Contact	Facility Name
21	Rolls-Royce (WT & AC)	Rolls-Royce plc P.O. Box 31 Derby De2-8BJ England	Mr. Keith Wakefield Phone: 332-246708 Fax: N/A	Derby ATF
22	Rosemount	Rosemount Aerospace Division 14300 Judicial Road, M.S. F-9 Burnsville, MN 55337	Mr. Richard Feely Phone: (612) 892-4381 Fax: (612) 892-4430	Icing Wind Tunnel
23	T & EE Pyestock	Ministry of Defense (PE) Directorate General Test & Evaluation T & EE Pyestock Farnborough, Hants GU14 OLS England	Mr. A. R. Osborn Phone: 0252-544411 Ext. 4132 Fax: 0252-373513	Pyestock Altitude Test Facility
24	Textron ***Inactive**	Textron Lycoming Corporation 550 S. Main Street Stratford, CT 06497	Mr. Dick Norris Phone: (203) 385-2667 Fax: (203) 385-2469	Small Engine/Inlet Icing Ground Test Facility
25	Textron ***Inactive**	Textron Lycoming Corporation 550 S. Main Street Stratford, CT 06497	Mr. Dick Norris Phone: (203) 385-2667 Fax: (203) 385-2469	Turbofan Engine Icing Ground Test Facility
26	UQAC IWT	University of Quebec at Chicoutimi 555, boul, de Universite, Chicoutimi Quebec, G7H 2B1	Jean-Louis Laforte Phone: (418) 545-5047 Fax: (418) 545-5012	Icing Wind Tunnel
27	UQAC FRFD	University of Quebec at Chicoutimi 555, boul, de Universite, Chicoutimi Quebec, G7H 2B1	Jean-Louis Laforte Phone: (418) 545-5047 Fax: (418) 545-5012	Freezing Rain/ Drizzle Chamber

- *not included: Cox & Co (NY), McKinley Climatic Chamber (US AFB Englin), others...*

Some Typical Icing Tunnel Limitations

- ✓ *Maximum true air speed (TAS) lower than in-service*
- ✓ *Operational pressure is usually higher (lower altitude) than in-service*
- ✓ *Cloud characteristiscs (LWC and MVD) different than in-service*
- ✓ *Tunnel minimum temperature may be higher than in-service*

Tunnel Condition Adjustment Rules (as per AS5562 draft) :

- ✓ *Mass air flow at the probe be equivalent or greater than at the in-service*
- ✓ *Water drop mass flux be no less than at the in-service condition*
- ✓ *Total air temperature be no greater than at the in-service condition*
- ✓ *To compensate higher temperatures, increase mass airflow to realize a desired lower probe surface temperature and/or decrease probe power.*
- ✓ *Rules related to MVD and LWC under discussion*

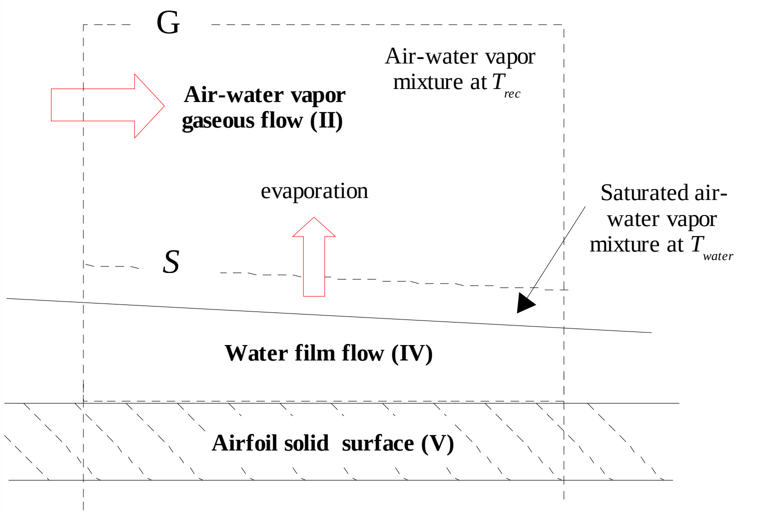
Typical Similitude Parameters

- *Flow*
  - Reynolds number (Re)
  - Mach or True Air Speed (TAS)
- *Water Droplets Impingement and Trajectories*
  - Water catch
  - Droplets inertia parameter
- *Heat and Mass Transfer*
  - Water evaporation rate (runback=impinged-evaporated)
  - Heat and mass transfer rate (heat load)
  - Skin Temperature
  - Total Air Temperature (TAT)

- *Others depending on test and installation*
- *When is impossible to keep all fixed, choose parameter values to have a conservative tunnel condition*

Coupled Heat and Mass Transfer

- ✓ *As expected, heat transfer coefficient (or* **St***) depends on* **Re** *and* **Pr***;*
- ✓ *Higher the* **Re***, higher* **St***, higher the mass transfer coefficient (by analogy);*
- ✓ *Mass transfer driven force depends on surface temperature (saturation pressure) and ambient pressure (water vapor partial pressure);*
- ✓ *But higher the mass transfer, thicker the thermal boundary layer, lower the* **St** *(important for surface temperature > 40 C) ...*
- ✓ *Higher the ambient pressure, higher the Re and* **St** *but lower the driven force ...*
- ✓ *Higher the lost by evaporation, lower the temperature but lower the evaporation, higher the temperature...*
- ✓ *Solution by 1st Law ! Only thermal analysis will determine what effect is more important.*



Coupled Heat and Mass Transfer (Spalding)

Evap. mass flux and mass transfer conv. coefficient: $\dot{m}''_{evap} = g_m \cdot B_m$ &

$$g_m = g_h \cdot Le^{2/3} = \frac{h_{conv}}{c_p} \cdot Le^{2/3}$$

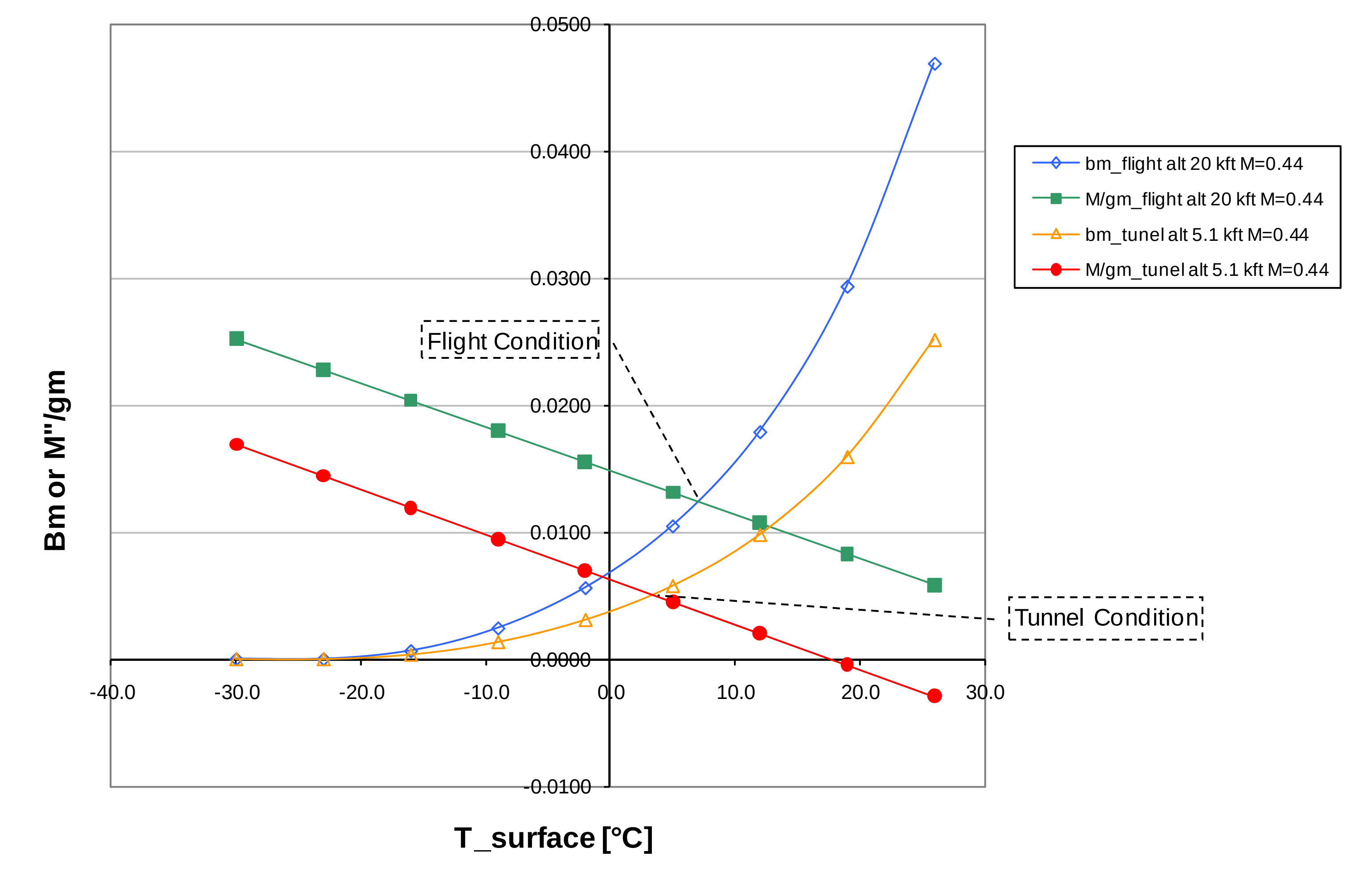
Mass transfer driven force: $B_m = \dfrac{m_{H2O,S} - m_{H2O,G}}{m_{H2O,S} - 1}$

Mass fraction close to water film surface: $m_{H2O,S} = \dfrac{p_{vap}(T_{surface})}{1.61 \cdot p_{amb} - 0.61 \cdot p_{vap}(T_{surface})}$

Mass fraction in compressible flow near B.L. edge: $m_{H2O,G} = \dfrac{p_{vap}(T_{recovery})}{1.61 \cdot p_{amb} - 0.61 \cdot p_{vap}(T_{recovery})}$

The evaporative mass flux by First Law of Thermodynamics: $\dfrac{\dot{m}''_{evap}}{g_h} = B_h = \dfrac{c_{mix} \cdot (T_{rec} - T_{surf}) + \dfrac{\dot{q}''_{surf}}{g_h}}{h_{lv}}$

Coupled Heat and Mass Transfer Effects



Conclusions

Certification

- ✓ *Aircraft must comply with respective FAR 25 sections and Appendix C*
- ✓ *Probes must comply with FAA TSO-C16a*
- ✓ *New atmospheric conditions being proposed in AS5562 (draft) by SAE AC-9C*
- ✓ *New rules and icing envelope under discussion at ARAC and IPHWG*
- ✓ *Atmospheric research has been carried out in USA, Europe and Canada*

Testing

- ✓ *Icing tunnels are important and necessary tools*
- ✓ *Literature of calibration, operation and selection of tunnels is rich*
- ✓ *Tunnel tests must be always conservative*
- ✓ *More research required about similitude flight vs. tunnel*

Presentation References

- ✓ *Certification/Qualification Documents*
  - ➢ Regulations – FAR 25 and **TSO C16a**
  - ➢ Standards – SAE AS390, SAE AS393, SAE AS403A, SAE AS8006, BSI 2G.135, MIL-T-5421B, MIL-T-5421A, MIL_P-83206, MIL-P-25632B
- ✓ *SAE Standard in preparation*
  - ➢ **SAE AS5562 (Draft)** - Ice and Rain Qualification Standards for Airdata Probes
  - ➢ AC-9C, Air Data Probe Standards Panel, SAE, 2006 (presentation)
  - ➢ AC-9C, Design Requirement Cross Reference List Rev6, SAE (excel spreadsheet)
- ✓ *SAE , SAE Aerospace Applied Thermodynamics Manual, "Ice, Rain, Fog, and Frost Protection", SAE AIR1168/4, Proposed Draft, 2006*
- ✓ *Spalding, D. B., "Convective Mass Transfer, an Introduction", McGraw–Hill, New York, 1963.*
- ✓ *Duvivier, E. (EASA) "Flight Instrument External Probes", 1st SAE Aircraft & Engine Icing International Conference, Seville, 2007 (conference presentation)*

Further Reading

- ✓ Mason, J., "The Physics of Clouds", 2nd Ed., Claredon Press, Oxford, 1971 (book)
- ✓ Johns, D. (TC Canada), "Future Rulemaking – Ice Protection Harmonization Working Group – Update", 1st SAE Aircraft & Engine Icing International Conference, Seville, 2007 (conference presentation)
- ✓ Bernstein, B., Ratvasky , T. P., Miller, D.R., "Freezing Rain as an in-Flight Icing Hazard", NASA TM--2000-210058, NCAR, Colorado, June (NASA Report)
- ✓ Jeck, R. K., "Representative Values of Icing-Related Variables Aloft in Freezing Rain and Freezing Drizzle", DOT/FAA/AR-TN95/119, Federal Aviation Administration, U.S. Department of Transportation,1996 (FAA Technical Note)
- ✓ Jeck, R. K., "Advances in the Characterization of Supercooled Clouds for Aircraft Icing Applications", DOT/FAA/AR-07/4, Federal Aviation Administration, U.S. Department of Transportation,2008 (FAA Report)
- ✓ European Aviation Safety Agency (EASA), ETSO C16 update , Terms of Reference, ToR Task number ETSO.009, Issue 1, August 31, 2009 (EASA document)
- ✓ Ice Protection Harmonization Working Group (IPHWG), Tasks 5 & 6 Working Group Report, October 2006, Rev A March 2007 (IPHWG report)
- ✓ Ice Protection Harmonization Working Group (IPHWG), "Task 2 Working Group Report on Supercooled Large Droplet Rulemaking", December 2005 (IPHWG report)

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- ✓ *E. Zerbini e O. Silvares acknowledges to University of São Paulo*
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- ✓ *The team acknowledges to WAS organization and COPPE-UFRJ for sponsoring the travel expenses;*