Advisory Circular

Subject: AIRCRAFT ICE PROTECTION **Date:** 8/16/06 **AC No:** 20-73A

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FOREWORD

This advisory circular (AC) describes an acceptable means, but not the only means of showing compliance with the ice protection requirements of Title 14 of the Code of Federal Regulations (14 CFR) parts 23, 25, 27, 29, 33, and 35. It also offers applicants guidance on how to maintain the aircraft's airworthiness when operating in an icing environment.

/s/

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1. PURPOSE.

a. This advisory circular (AC) tells type certificate and supplemental type certificate applicants how to comply with the ice protection requirements of Title 14 of the Code of Federal Regulations (14 CFR) parts 23, 25, 27, 29, 33, and 35. It also provides guidance for aircraft type certificate holders on how to maintain the aircraft's airworthiness when operating in an icing environment. Applicants seeking an FAA type certificate for their aircraft, aircraft engines, or propellers, or a supplemental type certificate for an existing aircraft model or an aircraft component must adhere to ice protection regulations. You will find these requirements embedded throughout 14 CFR parts 23, 25, 27, 29, 33, and 35. (Ice protection regulations are listed in tables 1 through 4 in section 6 of this AC.) This AC also directs you to other ACs providing guidance for compliance with specific icing-related regulations.

b. This AC is not mandatory and does not constitute a regulation. It describes acceptable means, but not the only means to: (1) gain FAA approval of aircraft ice protection equipment and systems; (2) determine two-engine airplane airworthiness in icing conditions during Extended Range Operation with Two-engine Airplanes (ETOPS)); and (3) evaluate aircraft airworthiness following deicing and anti-icing before takeoff. It also provides guidance on operating aircraft in an icing environment that may affect the airworthiness of the aircraft. However, if you use the means described in this AC, you must follow the guidance in its entirety.

2. CANCELLATION. This AC cancels AC 20-73, Aircraft Ice Protection, dated April 21, 1971.

3. APPLICABILITY. This AC provides guidance to:

a. Applicants for approval of aircraft, aircraft engines, propellers, and airframe ice protection equipment and systems. This guidance applies to applicants seeking certification approval of their aircraft or aircraft engine for flight into known or forecast icing conditions and those applicants not seeking approval for flight in icing conditions. See appendix A of this AC for a list of 14 CFR parts 23, 25, 27, 29, 33, and 35 regulations applicable to aircraft, aircraft engines, and propeller icing certification.

b. FAA personnel accepting information that shows compliance.

c. Type certificate holders seeking ETOPS approval of their airplanes. Guidance provided in this AC addresses airframe ice accretion following a cabin depressurization or engine failure. AC 120-42A, Extended Range Operation with Two-Engine Airplanes (ETOPS), provides additional information on the approval of extended range operations of two-engine airplanes.

d. Operators seeking assurance that their aircraft continues to comply with airworthiness requirements and operating rules that allow the use of deicing and anti-icing fluids to prevent ice, snow, and frost from adhering to the wing.

e. Applicants seeking approval under 14 CFR parts 23, 25, 27, or § 29.1419 for new type certificates, supplemental type certificates, and an amendment to existing type certificates for aircraft certificated under the Civil Aviation Regulations (CAR) parts 3 and 4b.

4. RELATED ADVISORY CIRCULARS, DOCUMENTS, READING MATERIAL, AND NOMENCLATURE.

See appendix A, sections A.2 and A.3, of this document, for additional icing approval information, related guidance material, and reading material. The FAA Aircraft Icing Handbook, DOT/FAA/CT-88/8-1, dated March 1991, provides comprehensive information on weather, icing physics, icing analysis, ice protection system design, ice detection systems, and certification of these systems. See also the Electronic Aircraft Icing Handbook (a subset of the Aircraft Icing Handbook) at: http://aar400.tc.faa.gov/Programs/FlightSafety/icing/eaihbk.htm. Appendix B of this AC defines terms, abbreviations, and symbols used in this document.

5. ICE PROTECTION REGULATORY DEVELOPMENT BACKGROUND.

Appendix C of this AC provides information for type design and supplemental type design applicants to determine the icing regulations that were applicable during the original type design certification of their aircraft. (See 14 CFR § 21.101 for icing requirements that apply to modified products.) Appendix C of this AC also provides background information on the historical development of aircraft, aircraft engine, and propeller icing regulatory requirements.

6. APPLICABLE AIRFRAME, ENGINE, AND PROPELLER ICE PROTECTION REQUIREMENTS.

a. Ice contamination on aircraft surfaces and components, aircraft engines, and propellers may cause unsafe operation of the aircraft. Type certificate applicants may seek approval for operating their aircraft in known or forecast icing conditions. However, if the applicant does not obtain approval, the applicant must protect the aircraft engine and specific aircraft components against ice ingestion and ice contamination during unintended exposure to atmospheric icing conditions. Sections 6.1, 6.2, and 6.3 of this AC discuss these requirements. (See appendix A of this AC for a more detailed listing of icing regulations.)

b. Applicants for certification of an aircraft and an aircraft engine must comply with certification requirements addressing ice accumulation that may form in aircraft engine carburetors, fuel tanks, and fuel lines systems, for all atmospheric conditions. Table 1 lists these requirements.

Table 1. Required Carburetor and Fuel System Ice Protection

Affected Area	14 CFR part 23	14 CFR part 25	14 CFR part 27	14 CFR part 29	14 CFR part 33
Fuel tank and carburetor vapor vents	§ 23.975	§ 25.975	§ 27.975	§ 29.975	
Fuel tanks and fuel lines	§ 23.951(c)	§ 25.951(c)	§ 27.951(c)	§ 29.951(c)	§ 33.67(b)(4)(ii)
Fuel strainers and filters	§ 23.997(e)				
Carburetor icing	§ 23.1093 § 23.1095 § 23.1097 § 23.1099 § 23.1101 § 23.1157 § 23.1189	§ 25.1093 § 25.1101 § 25.1157 § 25.1189	§ 27.1093	§ 29.1093 § 29.1101 § 29.1157 § 29.1189	§ 33.35(b)

6.1 Ice Protection Requirements: Unintended Exposure to Icing Conditions. For aircraft not certificated for operation in known or forecast icing conditions, airframe and aircraft engine type certificate applicants must provide ice protection for aircraft engines, the airframe, and airframe components to address unintended flight operations into icing conditions. (See table 2 below.) The exceptions to some of these requirements are those 14 CFR part 23 and 27 aircraft not certificated for instrument flight rule (IFR) operations. See appendix A, table A.1 of this AC for a detailed list of the applicable regulatory requirements.

Table 2. Ice Protection Requirements for Aircraft not Certified for Operations in Known or Forecast Icing Conditions

Affected Area	14 CFR part 23	14 CFR part 25	14 CFR part 27	14 CFR part 29	14 CFR part 33
In-flight icing conditions	Appendix C of 14 CFR part 25	Appendix C	Appendix C of 14 CFR part 29 (AC 29-2C provides a 10,000-foot altitude-limited envelope for rotorcraft use. For rotorcraft limited to a flight envelope more restrictive than 14 CFR part 29, Appendix C, you may reduce the icing conditions used for approval of the ice protection equipment and systems to that of the limited flight envelope.)	Appendix C of 14 CFR part 29 (AC 29-2C provides a 10,000-foot altitude-limited envelope for rotorcraft use. For rotorcraft limited to a flight envelope more restrictive than 14 CFR part 29, Appendix C, you may reduce the icing conditions used for approval of the ice protection equipment and systems to that of the limited flight envelope.)	
Aeroelastic stability (structural vibration and flutter)		§ 25.629(d)(3)			
Control system design	§ 23.685(a)	§ 25.685(a)	§ 27.685(a)	§ 29.685(a)	
Engine, engine installation, and air induction systems for engines and engine accessories cooling	§ 23.901(d)(2) § 23.903 § 23.905 (e) § 23.929 § 23.939 § 23.975(a)(1) § 23.1093 § 23.1105	§ 25.901(c) § 25.939 § 25.941 § 25.1093 § 25.1093 § 25.1105	§ 27.939 § 27.1093 § 27.1041	§ 29.901(c) § 29.939 § 29.1041 § 29.1093 § 29.1105	§ 33.68 § 33.77 (as required by 14 CFR part 25)
Indication of powerplant IPS or fuel system(s) heater operation installed to prevent ice	§ 23.1305(c)(7)	§ 25.1305(c)(5)	§ 27.1305(p)	§ 29.1305(a)(17)	
Air data systems	§ 23.1323(d) § 23.1325 § 23.1326	§ 25.1323(i) § 25.1325(b) § 25.1326	§ 27.1325(b)	§ 29.1323(f) § 29.1325(c)	

IPS = Ice protection system

Table 3 lists 14 CFR regulations that apply to ice protection equipment and systems.

Table 3. Other 14 CFR Requirements Applicable for all Ice Protection Equipment and Systems

Affected Area	14 CFR part 23	14 CFR part 25	14 CFR part 27	14 CFR part 29	14 CFR part 33	14 CFR part 35
Ice protection equipment and systems design and construction	§ 23.859(i)(2) § 23.601 § 23.603 § 23.605 § 23.607 § 23.609 § 23.611 § 23.613	§ 25.859(i)(2) § 25.601 § 25.603 § 25.605 § 25.607 § 25.609 § 25.611 § 25.613	§ 27.859(k)(2) § 27.601 § 27.603 § 27.605 § 27.607 § 27.609 § 27.611 § 27.613	§ 29.859(i)(2) § 29 .601 § 29.603 § 29.605 § 29.607 § 29.609 § 29.611 § 29.613		
Influence of the IPS on operation of other systems, components, and requirements (e.g., flammability protection and strong electrical fields and electromagnetic interference effects produced by the IPS).	§ 23.863 § 23.1013(d)(2) § 23.1199(b) § 23.1309 § 23.1307 § 23.1327 § 23.1351 § 23.1357	§ 25 .863 § 25.1013(d)(2) § 25.1199(b) § 25.1307(c) § 25.1309 § 25 .1327 § 25.1351 § 25.1353 § 25.1357	§ 27 .863 § 27.1307(d)(2) § 27.1309 § 27 .1327 § 27.1351	§ 29 .863 § 29.1013(d)(2) § 29.1199(b) § 29.1309 § 29.1351 § 29.1353		
Fuel tank ignition prevention		§ 25.981				
IPS equipment proper function and installation	§ 23.1301 § 23.1309	§ 25.1301 § 25.1309	§ 27.1301 § 27.1309	§ 29.1301 § 29.1309		
Miscellaneous equipment		§ 25.1455				
Pilot information and operating limitations.	§ 23.1525 § 23.1559(b) § 23.1583(h) § 23.1585	§ 25.1525 § 25.1583 § 25.1585	§ 27.1525 § 27.1559 § 27.1583 § 27.1585	§ 29 .1525 § 29 .1559 § 29.1583 § 29.1585		
Information on continuing airworthiness of the IPS (may include IPS inspection and maintenance information).	§ 23.1529	§ 25.1529	§ 27.1529	§ 29.1529	§ 33.4	§ 35 .4

6.2 Ice Protection Requirements: Intentional Operations in Known and Forecast Icing Conditions. Aircraft engine and airframe type certificate and supplemental type certificate applicants must provide ice protection for aircraft engine, airframe, and airframe components to ensure the aircraft and aircraft engines operate safely in known or forecast icing conditions. Table 4 contains ice protection requirements for aircraft certificated for flight into known or forecast icing conditions. You must comply with the requirements in table 4 below and those requirements in section 6.3 of this AC.

Table 4. Additional Ice Protection Equipment and System Requirements for Aircraft Certificated for Flight into Known and Forecast Icing Conditions

Affected Area	14 CFR part 23	14 CFR part 25	14 CFR part 27	14 CFR part 29	14 CFR part 33
Aeroelastic stability (structural vibration and flutter)	§ 23.629		§ 27.629	§ 29.629	
Windshield and pilot compartment view	§ 23.775	§ 25.773(b)(1)(ii) § 25.775(d)		§ 29.773(b)(1)(ii)	
Engines and their installation (reevaluated for ice ingestion resulting from extended exposures to icing conditions), and air induction systems for engines and engine accessories cooling	§ 23.901(d)(2) § 23.903 § 23.1093	§ 25.903 § 25.1093	§ 27.1093	§ 29.1093	§ 33.65 § 33.77
Acceptable engine operability with bleed air required for ice protection, engine ice protection, and indication of engine ice protection operation.					§ 33.66 § 33.68 § 33.89(b)
Propellers	§ 23.905(e) § 23.929	§ 25.929			
Airframe icing and safe in-flight operations in icing conditions	§ 23.1416 § 23.1419	§ 25.1403 § 25.1419	§ 27.1419	§ 29.1419	
Air data system	§ 23.1323(d) § 23.1325 § 23.1326				

6.3 Ice Protection Requirements: Operating Safely in Icing Conditions. In order for airplanes certificated to 14 CFR part 23 to operate as safely as possible in icing conditions, applicants must demonstrate their airplane's performance, controllability, maneuverability, and stability is at least equal to the requirements of 14 CFR part 23, Subpart B, as defined in 14 CFR § 23.1419(a). (For additional guidance, see AC 23-8B, AC 23.143-1, and AC 23.1419-2C.) To be able to operate as safely as possible in icing conditions, compliance with specific sections of 14 CFR part 25, Subpart B must be demonstrated. Acceptable means of showing compliance with the certification requirements for flight operations into icing conditions may be found in AC 25-7A and AC 25.1419-1A. Acceptable means of showing compliance with the certification requirements for rotorcraft flight operations into icing conditions may be found in AC 27-1B and AC 29-2C.

7. CERTIFICATION PROCEDURES.

7.1 Certification Procedures: General. At the beginning of the type certification process, applicants should coordinate their icing certification plan with their aircraft certification office (ACO) or engine certification office (ECO). Appendix D of this AC contains typical ice protection equipment design and certification flow charts. Also, when seeking approval for a modified product, you need to comply with 14 CFR § 21.101, commonly known as the "Change Product Rule." You may choose to use AC 21.101-1 as a means of showing compliance with 14 CFR § 21.101.

You should present your certification plan (checklist) for FAA approval at the start of the IPS design and development efforts. Your certification plan should describe all planned tests and evaluations intended to lead to the certification of your IPS. Further, your certification plan should identify specific items to be certificated, relevant certification requirements, and proposed methods of compliance. Your certification plan should clearly identify analyses and tests, or references to similarity of designs, you intend to use for the certification of the IPS. To help you save time and certification cost, it is important to get FAA concurrence before conducting certification tests. At a minimum, your certification plan should include:

a. An aircraft or aircraft engine systems description.

b. The IPS description.

c. A detailed description of aircraft IPS changes.

d. The certification basis for the requested approval.

e. The certification checklist, including the names of specific designated engineering representatives (DER). The checklist should also include the reports documenting compliance with the regulations.

f. Certification schedules for both the applicant and the FAA.

g. Description of existing analyses or tests.

h. Conformity inspection plans, including the conformity demonstration location.

i. Hazard assessments.

j. Software considerations.

k. High intensity radiated fields and lightning considerations.

l. A list of icing certification test results, if complete, requiring special operating procedures.

m. If the ice protection or detection systems contain complex electronic hardware (such as programmable logic devices (PLD) or application specific integrated circuits (ASIC)), provide plans showing the level of design assurance of these devices. The level of design assurance should be equal to the PLD or ASIC's potential contribution to aircraft hazards and system failures that could result from electronic hardware faults or malfunctions.

7.2 Certification Procedures: Airframe Manufacturer.

a. Applicants for part 23 type certificates should follow the IPS certification procedures described in AC 23-8B and AC 23.1419-2C. See AC 25-7A and AC 25.1419-1A for similar guidance for 14 CFR part 25 type certificated applicants. Rotorcraft applicants should follow the guidance in AC 27-1B and AC 29-2C. Supplemental type certificate applicants should also follow the guidance in AC 21-40.

b. Airframe type certificate applicants should present their ACO with a certification plan and checklist showing compliance with the applicable regulatory requirements. This plan should include documented evidence of compliance with the certification requirements. Your design analysis should identify the critical design points and predict the IPS performance for the icing conditions defined in 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C. Present your test proposals to the ACO for their approval before testing. As a reminder, you are responsible for showing compliance with applicable 14 CFR parts 23, 25, 27, or 29 regulations, including those covering the aircraft engine and propeller.

7.3 Certification Procedures: Aircraft Engine Manufacturer.

a. Aircraft engine type certificate applicants should review the regulatory guidance material in AC 20-147 and AC 33-2B, and submit their icing certification plan and checklist to their ECO for acceptance. Those applicants seeking supplemental type certification for their aircraft engines should consult AC 21-40 for guidance material. Aircraft engine manufacturers should present a design analysis showing enough critical design points to ensure the engine will function adequately in icing conditions described in 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C. Your design analysis must also address freezing fog, falling snow, and blowing snow conditions. See 14 CFR §§ 23.1093, 25.1093, 27.1093, and 29.1093. Aircraft engine type certificate applicants should consider guidance provided in this AC when performing the engine ice protection system design analysis. You should present your test proposal and test procedures to the FAA and get approval from the FAA before testing.

> **NOTE:** 14 CFR part 33 tests are typically conducted in icing wind tunnels or on outdoor test stands to simulate in-flight icing envelopes defined in 14 CFR parts 25, Appendix C and 14 CFR part 29, Appendix C. Compliance with 14 CFR §§ 23.1093(b) or 25.1093(b) tests is typically shown in either natural icing conditions or in simulated icing conditions. Simulated icing conditions may include flight behind an icing tanker or testing in climatic test chambers.

b. Your test proposal should include enough data points throughout the engine power or thrust range to show the engine operates satisfactorily under the proposed test conditions.

8. COMPLIANCE MEANS. Airframe type certificate applicants must perform an analysis and testing to show the acceptability of the aircraft's ice protection system. See 14 CFR §§ 23.1419, 25.1419, 27.1419, and 29.1419. You should address all flight configurations of the aircraft. To verify your analysis and icing anomalies, and to show the IPS and associated components are effective for safe operations in icing conditions, you must flight test the aircraft or its components in measured natural atmospheric icing conditions. With prior ACO approval, you may use laboratory dry air or simulated icing tests, dry air flight tests, or flight tests in measured simulated icing conditions to supplement flight tests in measured natural icing conditions. The ACs listed in table 5 provide guidance on means of compliance with the FAA regulations pertaining to IPS certification. For further guidance on supplemental type certificates and amended type certificates, see sections 8.5 and 10.2 of this AC.

Table 5. Means of Compliance for IPS Requirements

Advisory Circular	14 CFR Regulation	Advisory Circular	14 CFR Regulation	Advisory Circular	14 CFR Regulation
AC 20-147	§ 23.901(d)(2) § 23.903 § 23.1093 § 25.903 § 25.1093 § 27.1093 § 29.1093 § 33.68 § 33.77	AC 23.1309-1C	§ 23.1309	AC 25.1419-1A	§ 25.773 § 25.929 § 25.975 § 25.1093 § 25.1323 § 25.1325 § 25 .1326 § 25.1403 § 25.1419 § 25.1419 (safe operation in icing conditions – 14 CFR part 25, Subpart B)
AC 23-8B and AC 23-143.1	§ 23.1419 (safe operation in icing conditions – 14 CFR part 23, Subpart B)	AC 23.1419-2C	§ 23.773 § 23.775 § 23.929 § 23.975 § 23.1093 § 23.1309 § 23.1323 § 23.1325 § 23.1419 § 23.1419 (safe operation in icing conditions – 14 CFR part 23, Subpart B)	AC 27-1B	§27.629 §27.975 §27.1093 §27.1301 §27.1309 §27.1325 §27.1419 §27.1419 (safe operations in icing conditions – 14 CFR part 27, Subpart B)
AC 23-16A	§ 23.901(d)(2) § 23.905(e) § 23.929 § 23.975 § 23.1093	AC 25-7A	§ 25.1419 (safe operation in icing conditions – 14 CFR part 25, Subpart B)	AC 29-2C	§ 29.629 § 29.773 § 29.975 § 29.1093 § 29.1301 § 29.1309 § 29.1325 § 29.1419 § 29.1419 (safe operation in icing conditions – 14 CFR part 29, Subpart B) § 29.1323
AC 23-17A	§ 23.1301 § 23.1323 § 23.1326	AC 25.629-1A	§ 25.629	AC 33-2B	§ 33.75
AC 23.629-1B	§ 23.629	AC 25.1309-1A	§ 25.1309		

8.1 Compliance Means: Analysis.

a. The certification applicant should perform analyses to show compliance with the applicable regulations listed in table 5 of this AC.

b. Information defining the icing conditions in 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C may be found in appendix E of this AC. Appendix F of this AC contains operational factors you should consider in your compliance analyses. For operational purposes, fixed-wing airplanes should operate safely in icing conditions for a 45-minute destination “hold” flight segment in the continuous maximum icing conditions as defined in 14 CFR part 25, Appendix C. See appendix G of this AC for guidance on the 45-minute hold in icing conditions. Note that each turbine engine must operate throughout its flight power range (including idling) without accumulation of ice on the engine and its inlet system, or on airframe components that would adversely affect engine operation, or cause a serious loss of engine power or thrust. (See 14 CFR §§ 23.1093, 25.1093, 27.1093, and 29.1093.) (See section 10 of this AC for guidance applicable for rotorcraft.)

c. When determining compliance with the applicable regulations, you and the ACO personnel should closely review the analyses used to show compliance with the requirements discussed in section 6 of this AC. This scrutiny is necessary because verification of the ice protection equipment and system analyses are typically demonstrated over limited flight test conditions.

d. Airframe and powerplant (aircraft engine or aircraft engine and propeller) IPSs may require different analysis methods. Aircraft surfaces may be more tolerant of ice accretion than the aircraft engine and aircraft engine inlet surfaces. Airframe IPS design methods may also differ somewhat from those applied to the IPS designs for an engine. Note that although the operating envelope can be determined precisely for a specific powerplant/aircraft combination, the powerplant analysis needs to consider the installation of the engine on several airplane models with different required operating envelopes.

e. The IPS design margins are dependent on meteorological factors, airplane-engine operational, and other relevant factors. For an example, the availability of engine bleed air for airframe thermal ice protection systems must be sufficient for safe operation during descent when the engine power may be at idle.

f. Engine and aircraft type certificate applicants should determine the most critical conditions applicable to the aircraft engine inlet and propeller systems’ design, after considering all the meteorological and operational conditions within the operational envelope of the engine. This information will assist the ACO in determining the adequacy of the method used to establish the criticality of those factors. You should define the design points in meteorological and operational terms, for example, in terms of liquid water content (LWC), temperature, drop size, and engine power setting, or propeller pitch and rpm. When you determine the most critical conditions, you should have a specific design objective in mind, with the understanding that some ice buildup may be acceptable for running-wet ice protection systems if it does not risk flight safety.

g. For compliance purposes, be aware that different areas of the aircraft will have different tolerances to ice accumulation and may require different analysis approaches.

8.1.1 **Compliance Means: Airframe Analysis.**

a. As the applicant, you must select the critical surfaces requiring ice protection for safe operation in icing conditions. These surfaces may include:

(1) Airframe/fuselage ice impact areas.

(2) Leading edges of wings, winglets, and wing struts.

(3) Leading edges of horizontal and vertical stabilizers, and other lifting surfaces and control surfaces.

(4) Leading edges of control surface balance areas, if not shielded (such as aileron and elevator horns).

(5) Accessory cooling air intakes that face the airstream and could become restricted due to ice accretion.

(6) Antennas and masts.

(7) External tanks and fairings.

(8) External hinges, tracks, door handles, and entry steps.

(9) Instruments, including pitot tubes (and masts), static ports, angle-of-attack (AOA) sensors, and stall warning sensors.

(10) Forward fuselage nose cone and radome.

(11) Windshields (cockpit).

(12) Landing gear.

(13) Retractable forward landing lights.

(14) Ram air turbines.

(15) Ice detection lights, if required.

(16) Vortex generators and other flow control devices like stall strips, vortilons, and fences.

(17) Other structural protuberances that are exposed to icing conditions.

(18) Fuel tank vents.

(19) Auxiliary power units (APU) inlet, exhaust, and drainpipe.

(20) Propellers.

(21) Engine air induction system.

b. Leading edges of wings are critically sensitive aerodynamically to surface roughness, especially those wings that are not equipped with leading edge high-lift devices (hard wings). Flying in icing conditions with trailing edge flaps extended reduces the wings' angle of attack. This reduced angle of attack causes ice to build up further aft on the wing's upper surface, increasing the aerodynamic sensitivity of the wing to icing. For example, ice further aft on the wing may affect the effectiveness of the ailerons and the airplane handling qualities. The aerodynamic effects depend on the airfoil's aerodynamic characteristics. You must evaluate adverse aerodynamic effects of surface roughness that occur during normal operation of the wing's ice protection system to ensure safe operation of the aircraft (14 CFR §§ 23.1419 and 25.1419). You should consider protecting the leading edges of high-lift devices because, in addition to ice accretion on the leading edge of the wing, the leading edges of slotted trailing-edge flaps may accrete ice during approach and landing. Ice protection is typically not provided for trailing-edge flaps. Ice buildup along the leading edge of the trailing edge flaps may reduce their aerodynamic effectiveness (reduced lift at a fixed angle of attack). This buildup may be evident by airframe buffeting resulting from turbulent airflow over the flaps, and the ice on the flaps may prevent their retraction.

c. You should select the surfaces that require ice protection after careful consideration of icing and operating conditions and the icing requirements discussed in section 6 of this AC.

d. Appendix H of this AC contains information and guidance on ice protection technologies, operating modes, and associated analyses.

e. You should perform a drop impingement and water catch analysis to evaluate the impingement limits and water collection characteristics of aircraft surfaces and components. This analysis also provides the ice collection efficiencies of aircraft surfaces and components. The analysis should consider all the airplane's flight configurations, phases of flight, and operating envelopes (including airspeeds, aircraft configurations, and angles of attack). The analysis should provide information to determine the extent of ice protection required to protect a surface or component from ice accretion, using the icing conditions defined in 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C. Also, determine in your analysis the quantity of heat required for thermal IPSs. Appendix I of this AC provides information about drop impingement and water catch analyses and determining the ice protection coverage.

f. The ice protection for air intakes must ensure satisfactory performance of essential systems that they support.

g. Table 6 shows the meteorological conditions you should consider for a typical compliance analysis for operating in continuous and intermittent maximum icing conditions.

Table 6. Continuous and Intermittent Maximum Icing Conditions

Continuous Maximum Icing Conditions			Intermittent Maximum Icing Conditions		
MVD (μm)	Temperature (°F)	Liquid Water Content (g/m³)	MVD (μm)	Temperature (°F)	Liquid Water Content (g/m³)
15	32	0.8	15	32	2.925
	14	0.6		14	2.5
	-4	0.3		-4	1.925
	-22	0.2		-22	1.1
25	32	0.5		-40	0.25
	14	0.3	25	32	1.75
	-4	0.15		14	1.45
	-22	0.1		-4	1.125
40	32	0.15		-22	0.7
	14	0.10		-40	0.15
	-4	0.06	40	32	0.75
	-22	0.04		14	0.50
				-4	0.35
				-22	0.25
				-40	0.05
			50	32	0.40
				14	0.30
				-4	0.20
				-22	0.10
				-40	0.05

h. Section 6.3 of this AC describes how to determine whether your airframe IPS can support safe operation of the aircraft in icing conditions.

i. Select pressure altitudes that cover the range of altitudes associated with each temperature from figures E-2 and E-5 in appendix E of this AC.

j. In addition to the meteorological conditions, your ice protection system design analysis should consider appropriate operational parameters such as aircraft attitude, airspeed, altitude, and engine power settings for the aircraft's operating envelope. Those operating parameters will identify the combination(s) of meteorological and operating parameters that result in the most critical conditions. Because of the large number of variables involved, more than one critical condition may exist for both intermittent maximum and continuous maximum meteorological conditions.

k. The ice protection system design analysis should show that no hazardous quantity of ice forms on the surfaces that are critical for safe operation of the aircraft when exposed to the intermittent maximum and continuous maximum icing conditions of 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C.

8.1.2 **Compliance Means: Aircraft Engine and Propeller Systems Analyses.** When defining the most severe conditions for the compliance analyses of aircraft engine, propeller, and related components ice protection systems, the applicant should consider the icing envelopes in 14 CFR part 25, Appendix C, Figures 1, 2, 4, and 5, and 14 CFR part 29, Appendix C, Figures 1, 2, 4, and 5. The applicant should also consider the entire environmental and operational envelopes of the aircraft on which the propulsion system will be installed. (You should consult with your FAA ACO or ECO for guidance on the applicable environmental and operational envelopes.)

8.1.2.1 **Compliance Means: Aircraft Engine Analysis.**

a. The applicant should design the aircraft engine and its IPS to protect against the most critical meteorological conditions occurring simultaneously with the most critical aircraft engine (if applicable) operational conditions. For the aircraft engine compliance analysis, you should determine critical design points for both continuous maximum and intermittent maximum conditions. The procedures for determining water catch rate, impingement data, heat available (Q_A), and heat required (Q_R) are similar to those discussed for airframe surfaces in section 8.1.1 of this AC. The flow field around engine surfaces is dependent on the mass of air flowing through the engine.

b. Engine reliability during all icing encounters is essential. The design approaches that apply to airframe and aircraft engine systems are different. Aircraft engines must not experience any serious loss of power or thrust because of induction system ice buildup. (See 14 CFR § 33.68.)

c. The aircraft engine manufacturer may know the make and model of some of the aircraft on which the engine will be installed. You cannot be sure that a future application will not differ from planned installations. Therefore, you should not limit the IPS to a specific airplane installation or to a specific airplane operational envelope.

d. Ice buildup on the aircraft's unprotected surfaces and the aircraft operational conditions during an icing encounter emphasize the need for reliable engine performance. Unprotected aircraft engine struts, spinner cones, and inlet guide vanes may be subject to ice buildup. Therefore, when you use heat to keep these surfaces ice-free, you must guard against the possibility of water runback refreezing inside the air induction system. You should also evaluate the first-stage fan or compressor blades of axial flow engines for possible ice buildup, with the IPS operating. Without the ice protection system operating, ice buildups on these engine components may distort or adversely affect the airflow intake and cause adverse effects on engine operability or thrust. The ice may also shed and damage downstream engine components. Minimizing the ice buildup on an operating engine prevents possible damage from ice ingestion and helps to ensure reliable engine operation. You must demonstrate that the level of ice buildup on the engine permits acceptable engine handling and performance.

e. You should consider a buildup of ice on any aircraft engine surface unsafe, if the ice buildup:

(1) Causes a significant loss of power or thrust;

(2) Causes airflow disturbances that excite harmonic compressor or fan blade frequencies;

(3) Becomes large enough to cause serious engine damage when ingested;

(4) Causes damage to adjacent structure or engine components when shed by centrifugal force from rotating surfaces;

(5) Causes an imbalance of rotating components that produces vibrations greater than those for which the engine had been approved;

(6) Causes damage due to reduced clearance between rotating and stationary components; or

(7) Causes any other hazardous engine operation.

8.1.2.2 **Compliance Means: Propeller Analysis.** Aircraft type certificate applicants installing propellers on their aircraft can find more information on compliance with aircraft requirements associated with propeller IPSs in appendix J of this document. A buildup of ice on a propeller is considered unsafe if the ice causes:

a. A serious loss of thrust;

b. An unsafe engine condition;

c. Damage to adjacent structure when detached by centrifugal force;

d. Vibrations resulting in engine or propeller structural failure; or

e. Any other hazardous engine, propeller, or aircraft operation.

8.1.3 **Compliance Means: Aircraft Engine Inlets Analysis.**

a. Ice buildup on the engine inlet nose cowl, spinner cones, and other areas of the aircraft that may affect engine operation is generally more critical to safety of flight than ice buildup on aircraft surfaces discussed in paragraph 8.1.1 of this AC. Even though meteorological design conditions may be the same, operational conditions that affect engine operation (particularly local surface flow conditions) may vary significantly. Although a fixed-engine operational condition is assumed for certification of the airframe icing system, engine airflow may vary considerably because of changes in engine thrust or power during normal flight maneuvers. These changes in engine thrust or power must be considered when determining the most critical conditions for these airplane areas. Nacelle inlet surfaces are susceptible to slush and ice crystal buildup during operations in glaciated or mixed phase icing conditions. Also, you must evaluate the effects of ice buildups on vortex generators or other boundary-layer control devices, if they are used in or on the engine air induction system, to ensure that these devices continue to perform their intended functions.

b. Design of the airframe ice protection is based on the most probable engine operating condition for a specific airplane operational mode, therefore you should consider the need for increased reliance on engine thrust or power during icing conditions. You should also take into consideration these needs during the design of nacelle inlet ice protection systems because the engine must be able to operate through a wide range of power settings.

c. When determining the most critical design points for engine air inlets, use guidance provided in paragraphs 8.1.1.a(21), 8.1.1.d, 8.1.1.e, 8.1.1.j, and 8.1.1.k of this AC.

(1) The inlet design compliance analysis should show the engine inlet IPS prevents ice formations that adversely affect continued safe engine operation or cause serious power loss. In your analysis, use the meteorological conditions described in 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C and engine operations that meet the aircraft operational needs.

(2) Engine inlet IPSs are often designed to "run dry" (impinging moisture is evaporated) under continuous maximum icing conditions and "run wet" under intermittent maximum icing conditions. Service experience shows that this approach is satisfactory when the formation of hazardous runback ice is prevented.

d. Your analysis should include evaluations of ice collection on inlets for the APU, accessory cooling, and fuel vent areas. The analysis should determine whether ice will collect on the inlets and affect the APU's performance. Improperly located NACA inlet scoops may collect ice, so you should include their location and ice collection potential in the analysis. Results obtained during natural icing flight tests of NACA inlet scoops range from small amounts of ice collection on turboprop engine cooling inlet lips (located on the engine cowling or nacelles) to complete blockage of electronic cooling inlets located on the radome.

e. 14 CFR part 23 airplane type certificate applicants can find guidance on the approval of turbine engine induction system ice protection in AC 23-16A. This AC also includes guidance for testing IPS in falling and blowing snow and in freezing fog.

8.1.4 **Compliance Means: Ice and Icing Conditions Detection Systems Analyses.** Aircraft instrumentation may alert the flight crew or aircraft systems (or both) to the presence of icing conditions or ice buildup on aircraft surfaces. These ice detection systems may be primary or advisory. Appendix K of this document contains guidance for airframe type certificate applicants on obtaining approval of ice detection systems.

8.1.5 **Compliance Means: Windshield Analysis.** Airframe type certificate applicants must provide a means to prevent, or to clear accumulations of, ice from the windshields during icing conditions to ensure pilots' field of vision is not restricted during flight into icing conditions (14 CFR §§ 23.775(f), 25.773(b)(1)(ii), and 29.773(b)(1)(ii)). These surfaces are usually protected by electric heat elements. Your analysis should confirm that the windshield surface temperature is sufficient to prevent ice accumulation without causing structural damage to the windshield. Appendix L of this AC provides added guidance for windshield ice protection.

8.1.6 **Compliance Means: Air Data System Sensors and Probes Analyses.**

a. Airframe type certificate applicants should provide ice protection for flight essential instrument sensors that may be affected by flight into icing conditions. Confirm that instrument surfaces and drainage cavities are protected against ice buildups and blockage by frozen drained water that may adversely affect the instrument.

b. You must provide compliance analyses showing static and pitot pressure ports are either protected against or not affected by ice buildup, frozen runback water from forward surfaces, and water and slush from the landing gear during takeoff and landing. Slush and water ingested into static and pitot pressure ports during takeoff or at a lower altitude might freeze when the airplane climbs to higher altitudes and lower temperatures. Instruments that could be affected include pitot tubes, engine-pressure-ratio total pressure probes, and certain types of stall warning system sensors. These instruments are typically electrically heated.

c. When drafting your compliance analyses for instrument sensing elements or probes located on or near the fuselage, consider varying the water drop concentration to account for a variety of icing conditions. As the aircraft flies through icing clouds, small cloud drops may not impinge directly on the fuselage, but may be carried over the fuselage surface by the airflow. While these diverted drops reduce the collection efficiency in the stagnation regions of the fuselage, the diverted drops can increase water concentration near the fuselage's surface, and significantly increase the water catch of probes, such as pitot tubes and other sensor probes. The resultant ice buildup may adversely affect the probe's function.

8.1.7 **Compliance Means: Ice Protection System Failure Analysis.** Applicants must perform system failure analyses as a means of showing compliance with the applicable certification rules (14 CFR §§ 25.901(c), 27.901(b)(1), 29.901(c), and 14 CFR §§ 23.1309, 25.1309, 27.1309, and 29.1309). You should use the guidance provided in AC 23.1309-1C, AC 25.1309-1A, AC 27-1B, AC 29-2C, or AC 33-2B, to determine the hazardous system failures for your product. You must perform failure modes and effects analyses to ensure that single failures do not result in unsafe conditions. Perform fault-tree analysis of system failures to ensure safety objectives of combined failures are met. Separation, cascading, and common cause analyses ensure system independence if there are various airplane failures. For example, you should consider leading edge wing slat failure conditions and bird-strike conditions for a wing leading edge thermal anti-ice system. Also, under certain failure conditions, the hot air of a thermal IPS may approach temperatures that can affect the integrity of nearby structure and may ignite leaking fuel. You should evaluate these and similar conditions to ensure aircraft safety. When system failures result in unsafe operations, the aircraft must exit icing conditions and be capable of continued safe flight and landing.

8.1.8 **Compliance Means: Flutter Analysis.** Aircraft must be free of flutter and control reversals. (See 14 CFR §§ 23.629(a), (b), (c), or (d), 25.629(a), 27.629, and 29.629.) You may show compliance with the applicable certification rules by following the guidance contained in AC 23.629-1A, AC 25.629-1A, AC 27-1B, and AC 29-2C. For transport category airplanes not approved for operation in icing conditions, you must consider the maximum likely ice accumulation expected, as a result of an inadvertent encounter, to show compliance with 14 CFR § 25.629(d)(3).

8.1.9 **Compliance Means: Power Sources Analysis.** Applicants should evaluate the power (energy) source needs of their IPS (electrical, engine bleed air, pneumatic pumps, etc.). Compliance analyses or tests should show that each power source requirement is adequate for each IPS. You must ensure an IPS component failure does not affect the power available to operate other essential equipment (14 CFR §§ 23.1309, 25.1309, 27.1309, and 29.1309). All power sources that affect engine or engine IPSs for multiengine aircraft must comply with engine isolation requirements contained in 14 CFR §§ 23.903(b) and (c), 25.903(b), and 29.903(d).

8.2 Compliance Means: Tests.

a. Applicants must perform tests to show their aircraft can operate safely in the icing conditions as specified in 14 CFR §§ 23.1419, 25.1419, 27.1419, and 29.1419, and 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C. You must perform flight and ground tests to verify the analyses, and you may use other means to support test data that show your aircraft will perform satisfactorily in icing conditions. You must determine that there are no icing anomalies associated with your design. Flight testing must be performed in measured natural icing conditions. Flight testing may also be performed in dry air, dry air with simulated ice shapes, or in measured simulated icing conditions. (See AC 23-8B, AC 23.1419-2C, AC 25-7A, AC 25.1419-1A, AC 27-1B, and AC 29-2C.)

b. Typically, applicants perform icing flight tests in three stages: (1) dry air tests with the IPS operating, (2) dry air tests with predicted simulated ice shapes, and (3) natural icing flight tests.

8.2.1 **Compliance Means: Natural Icing Flight Tests.**

a. Applicants must show the effectiveness of the ice protection equipment and systems by flight testing in measured natural atmospheric icing conditions. (See 14 CFR §§ 23.1419(b), 25.1419(b), 27.1419(b), and 29.1419(b).) During the natural icing flight tests, you should target the critical design point icing conditions you identified in your compliance analyses. Because natural icing characteristics are probable, performing natural icing tests at each critical design point may be impractical (See appendix M of this AC.) Icing tests should also investigate the effects of runback ice buildups aft of protected surfaces and the buildup of ice on unprotected surfaces to determine whether the ice poses a hazard to continued safe flight. Engine operational characteristics and the aircraft handling qualities and performance should be acceptable when runback ice, buildup ice on unprotected surfaces, or intercycle ice roughness exist on deice protected surfaces.

b. You should use data from the natural icing tests to validate analytical methods used for showing compliance with the icing regulations. You should also use the natural icing tests data to validate the results of simulated ice shape and simulated icing tests used during your icing certification.

c. You must test in natural icing to evaluate the effectiveness of the propeller IPSs and to check for icing anomalies not addressed by laboratory tests and analyses. You should provide a means of measuring aircraft performance with the propeller, and propeller and engine vibration. Also, record propeller ice accretion and shed-ice trajectories.

8.2.1.1 **Compliance Means: Natural Icing Flight Test Icing Conditions Considerations.**

a. You should record the parameters that measured the icing conditions encountered during certification testing in the same units as those used in 14 CFR part 25, Appendix C and 14 CFR part 29 Appendix C. This will assist you in understanding the effectiveness of the IPS. You may use these measurements to verify analyses of the IPS, to understand icing anomalies, and to extrapolate the IPS effectiveness to icing conditions you did not encounter. The parameters (LWC, mean drop diameter, temperature, cloud extent, and altitude) used in 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C are important for thermal IPS designs. The water catch and the required heat density on thermally protected surfaces are dependent on these icing condition parameters. Measure these parameters and airspeed during natural and simulated icing flight tests to characterize the icing environment. You may also use the icing cloud drop median volume diameter (MVD) to determine IPS coverage. (See appendix I of this AC.) You should evaluate the operation of deicing boots at cold temperatures. The LWC and icing intensity are important parameters for defining preactivation and intercycle ice accretion on deicing boots. You should refer to appendix N of this AC for information on measuring natural and simulated icing conditions.

b. Appendix M of this AC contains information on finding meteorological conditions for natural icing flight-testing.

c. Perform flight tests in icing conditions that are within icing condition envelopes described in 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C. Appendix O of this AC provides procedures for converting the contents of 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C icing envelopes to a distance-based format. The quality of an icing event includes the size of the aircraft ice buildups and the rate of ice buildup (icing intensity). Appendix P of this AC describes how to determine the icing intensity of an icing event.

d. Flight testing in convective air currents of cumulus clouds may lead to severe turbulence and hail encounters, and may cause structural damage to test aircraft. Flight testing in intermittent maximum icing conditions may not be necessary when your compliance analyses show the critical ice protection design points in these icing conditions (heat loads, critical ice shapes, ice accretion, and ice accretion rate, etc.) are acceptable and enough test data exist to verify the analyses.

8.2.1.2 **Compliance Means: Natural Icing Flight Test IPS Evaluation.**

a. For non-automatic IPS systems, the flight crew must activate the IPS according to the Airplane Flight Manual (AFM) procedures. You should conduct icing flight tests with delayed IPS activation to simulate icing events when the pilot may unintentionally delay activation of the IPS. You must determine the delay interval based on the icing recognition means and crew procedures. Ice buildup resulting from delay intervals greater than 2 minutes may shed and be ingested into an engine. Per 14 CFR § 33.77, you must ensure acceptable engine operation after ingesting the maximum in-service ice mass that can be shed from the airframe. Determine the delayed-activation ice buildup in the continuous maximum icing conditions of 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C. Include the time required for the IPS to perform its intended function as part of the delayed activation interval. Aircraft handling qualities with the delayed activation ice buildup should remain acceptable and the aircraft must operate safely. You are not required to test for delayed activation of IPSs that use a primary automatic ice detection system.

b. You should evaluate the effects of preactivation ice accretion (ice accumulated before the IPS becomes fully effective). Preactivation ice includes ice buildups that occur before thermal IPSs achieve their operating temperatures, fluid IPSs clear ice accretions, and ice buildups that occur before completion of a deicing cycle. Aircraft handling qualities should remain acceptable, and the aircraft must operate safely with the preactivation ice accretion.

c. Applicants for certification of fluid IPSs should show acceptable distributions of the system's fluid over the protected surfaces. Acceptable distributions of the fluid determined in dry air may result in freezing of the IPS fluid at cold temperatures. You should test windshield fluid anti-ice systems to show the fluid does not become opaque at cold temperatures. A clear and legible means should be used to show fluid flow rates and the fluid quantity remaining. You should provide shutoff valves for systems using flammable fluids. The AFM should include information describing how long it will take to exhaust the fluid.

8.2.1.3 **Compliance Means: Natural Icing Flight Test Ice Detector Evaluation.** Applicants should perform natural icing flight tests of primary and advisory ice detectors to show they detect ice before hazardous ice builds up on aircraft surfaces. The flight test should also demonstrate the intended functions of the ice detector, such as automatic operation of the IPS. Conduct flight tests at near-freezing ambient conditions to evaluate the ice detector's functional reliability. This testing should also evaluate the possible accumulation of hazardous airframe ice in airplane (local) surface areas that have high airspeeds (for example, airfoil or engine inlet surfaces) before the ice detector detects icing conditions. You may determine temperatures for this testing by evaluating conditions when the water catch on critical aircraft surfaces freezes because of high local air velocities while only a small fraction of the water catch on the ice detector's sensor surface freezes. Determining the critical temperatures may require testing the ice detector and critical aircraft surfaces in an icing wind tunnel.

8.2.1.4 **Compliance Means: Natural Icing Flight Test Ice Shedding.**

a. Ice shed from the airframe may be ingested into the engine and may cause engine damage that may result in unsafe operability and thrust loss. This ice may also damage downstream aircraft structure and components. Ice shedding from the forward fuselage and wings may cause significant damage to fuselage-mounted engines and pusher propellers. Airframe type certificate applicants should show by analysis or flight testing that ice shedding from aircraft components (including antennas) does not cause engine or propeller damage that would adversely affect engine or propeller operation. (See 14 CFR §§ 23.1093 and 25.1093.) You should also consider airframe damage that may result from propeller ice shedding.

b. Currently available trajectory and impingement analyses may not accurately predict damage caused by ice shedding. Experience has shown that analyses are unable to accurately predict the trajectories of ice shed from aircraft forward areas, such as from the radome, wing, wing fairings, and control surfaces. Therefore, trajectory analyses are unacceptable predictors of shed ice trajectories. Your damage analysis should conservatively consider the most critical ice mass that shed and its impact with the areas of concern. Also, when predicting the ice trajectories, assume all shed ice is ingested into the engines or propellers, independent of the trajectories. In lieu of a conservative analysis, flight testing has been used for aircraft certificated under 14 CFR part 23 to show that ice shedding does not impact critical areas (see AC 23.1419-2C). Appendix Q of this AC provides information and guidance on ice shedding. AC 33-2B provides guidance on flight-test procedures for engine induction system icing and engine ice ingestion test procedures.

c. You should evaluate failures of the IPS and the resultant hazards from ice shedding (14 CFR §§ 23.1309 and 25.1309). Perform this analysis using the probability of the failure occurrence versus resultant hazard levels.

8.2.1.5 **Compliance Means: Natural Icing Flight Test Additional Guidance and Information.** Information on natural ice testing is in AC 23-8B; AC 23.143-1; AC 23.1419-2C; AC 25-7A; AC 25.1419-1A; AC 27-1B; AC 29-2C; AC 33-2B; and appendix M of this AC.

8.2.2 **Compliance Means: Dry Air Flight Tests.**

a. Dry air flight tests are usually conducted before natural icing tests to evaluate the aircraft with the IPS operating. The initial dry air tests are conducted to verify the IPS (for example deicing boots) operates as intended and does not affect the aircraft's flying qualities, and to measure thermal characteristics for verifying analyses of thermal IPSs.

b. You may use dry air flight tests to verify significant portions of the IPS analyses and to demonstrate the aerodynamic effects of predicted ice shapes. You should perform these tests before conducting natural icing tests. These tests check the function, performance, and compatibility of all systems components. During the dry air flight tests, you can verify the effects of engine bleed air used by the IPS on engine thrust settings. Data collected during dry air tests allow you to analyze heat requirements and availability during various operational conditions. You can also get information about the effects of the local environment on the installed components of the IPS during these dry air flight tests. Examples of the local environments are propeller wash on the wing and empennage and wing downwash on the horizontal stabilizer. You should use these tests to evaluate the aircraft's handling qualities using simulated ice shapes on unprotected and protected surfaces to show compliance with Subpart B of 14 CFR parts 23, 25, 27, and 29.

c. Compliance means for several commonly used IPSs and components are discussed below. They illustrate typical dry air flight test practices. However, you should evaluate your IPS for compliance as your IPS design dictates.

8.2.2.1 **Compliance Means: Dry Air Flight Test Thermal Ice Protection Systems Evaluation.**

a. Dry air flight tests are conducted to verify the system design parameters and thermal performance analysis.

b. Normally, the IPS components are instrumented to measure the heat energy distributed to the heated surfaces and the temperature of the heated surfaces. You can use these measurements to validate your IPS thermal analyses by comparing the predicted with the measured parameters. The test ambient temperature and altitude should cover the temperature-altitude envelope limits of 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C for fixed-wing and rotary-wing aircraft, respectively. You can use measured dry-air surface temperatures to determine the maximum possible surface temperatures and heat transfer characteristics. You can also use the measured surface temperatures to evaluate the adequacy of the heat source. You may use dry air testing to verify that the temperatures measured on the IPS component surfaces are within those allowed for the structure.

8.2.2.2 **Compliance Means: Dry Air Flight Test Pneumatic Ice Protection Systems.** For aircraft designs using pneumatic deicing boots, applicants should perform tests to demonstrate the pneumatic characteristics of the IPS. This includes the deicing boots' inflation and deflation pressure rates and the inflated dwell intervals and pressures. You should evaluate these inflation and deflation rates and air pressures throughout the altitude range defined in 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C, and the aircraft and IPS performance envelopes. The deicing boots must operate effectively within the Continuous Maximum and Continuous Intermittent Envelopes of 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C. Cycling of the pneumatic IPS should have no hazardous effect on the aircraft's performance and handling qualities. Operate the pneumatic IPS in flight at the coldest temperature (-22°F) required by 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C, Continuous Maximum Icing Conditions. Cycling of the boots at the coldest temperature should show acceptable boot performance and that no damage occurs to the boots. Include all airspeed and temperature limitations on use of the deicing boots in the Limitation Section of the AFM. For transport category airplanes, you must show acceptable IPS alerts and cautions required by 14 CFR § 25.1419(c) during dry air testing. For transport category rotorcraft, 14 CFR § 29.1419(e) requires a means be provided to identify or determine the formation of ice on critical parts of the aircraft.

8.2.2.3 **Compliance Means: Dry Air Flight Test Propeller Thermal Ice Protection Systems Evaluation**.

a. For propulsion systems that include propeller thermal IPSs, applicants may perform dry-air flight-tests to show compliance with 14 CFR § 23.903(c) and 14 CFR §§ 25.901(c), 25.903(b), and 25.1419(c).

b. You may perform initial evaluations of the electrothermal IPS power requirements at critical propeller operating and icing conditions during dry air testing. You may accomplish this evaluation by using suitable instrumentation to measure the electrical power consumed.

c. During dry air flight tests, you should monitor various propeller IPS parameters to confirm proper operation of the IPS. Also, monitor the IPS current, brush block voltage between each input brush and the ground brush, and IPS duty cycles to ensure that the IPS power remains within limits.

d. You should check the propeller IPS operation throughout the propeller's expected revolutions per minute (rpm) and cyclic pitch ranges during flight in icing conditions. You should investigate and correct all vibrations deemed unacceptable.

8.2.2.4 **Compliance Means: Dry Air Flight Test Windshield Ice Protection Evaluation.** Airframe type certificate applicants should conduct dry-air flight tests to verify thermal analyses used to show compliance with 14 CFR §§ 23.775(f), 25.773(b)(1)(ii), and 29.773(b)(1)(ii). You may need to measure the inner and outer windshield surface temperatures to verify your thermal analysis. With the windshield IPS on, you should evaluate the visibility, including distortions through the protected windshield area, for both day and night operations. Also, evaluate the size and location of the protected area for adequate visibility during the approach and landing phases of flight. (See appendix L of this AC.)

8.2.2.5 **Compliance Means: Dry Air Flight Test Air-data Instrumentation Ice Protection Evaluation.** Applicants should measure the surface temperature of air-data instruments (for example, pitot tubes, pitot-static pressure probes, and angle-of-attack probes (if ice protected)) during dry air flight tests or icing wind tunnel tests to verify thermal analyses used to show compliance with 14 CFR §§ 23.1323(d), 23.1325(b)(3), 25.1323(i), 25.1325(b), 27.1325(b), and 29.1325(c). You should evaluate the acceptability of the air data instruments' ice protection during natural or simulated icing tests. You must also ensure the acceptability of an indication system for alerting the flight crew when the pitot tube IPS is not heated. (See 14 CFR §§ 23.1326(b)(1)(and (2) and 25.1326(b) (1) and (2).) An acceptable indication system may consist of separate lights or crew alert signals on an electronic display for each pitot source. Further guidance on acceptable means of compliance is in AC 23-17A and AC 25-11.

8.2.2.6 **Compliance Means: Dry Air Flight Test Safe-flight Evaluation with Simulated Ice Shapes.**

a. Airframe type certificate applicants may flight test their aircraft with simulated ice shapes to show safe aircraft performance and handling qualities during flight into icing conditions. (See section 6.3 of this AC.) Using simulated ice shapes will allow you to evaluate the aircraft's flying qualities in stable, dry air. It also allows you to evaluate the flying qualities without melting, sublimation, shedding, and erosion of ice buildups, as would occur with natural ice accretions. Also, dry-air flight testing of aircraft with simulated ice shapes facilitates demonstration of compliance with the required regulations and results in significant decreases in flight test costs, compared to flight testing in natural icing conditions.

b. You should develop and substantiate the simulated ice shape and surface texture using methods acceptable to the FAA. Use conservative methods, and address 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C icing conditions. The ice shapes and texture should represent those for the critical conditions for the flight characteristic and phase of flight under investigation. Alternatively, you can select a single, most critical ice shape and texture for all flight characteristics and phases of flight. Consider ice shapes and textures that form on protected and unprotected aircraft surfaces during the different phases of flight, including a 45-minute destination hold for your airplane.

c. You should determine the effect of the 45-minute hold in continuous maximum icing conditions of 14 CFR part 25, Appendix C. You should assume the airplane remains in a rectangular "racetrack" pattern, with all turns made within the icing cloud. Therefore, you should not use a horizontal extent correction for this analysis. You should also consider ice buildups that may form on protected surfaces before the ice protection system becomes fully effective after activation and during normal operation of the protection system. For example, consider the intercycle ice roughness on deicing IPS surfaces. If the failure analysis required by 14 CFR §§ 23.1309, 25.1309, 27.1309, and 29.1309 shows the need for continued safe flight following a failure in the IPS, such as for a portion of a wing or horizontal stabilizer, flight test the ice shape that results from the critical IPS failure to show the required performance and handling qualities are acceptable.

d. Appendix R of this AC provides information on how to determine ice shapes and textures of protected and unprotected surfaces and how to select critical ice shapes.

e. Information about testing methods and procedures may be found in AC 23-8B, AC 23.1419-2C, AC 25.1419-1A, AC 27-1B, and AC 29-2C.

f. You should conduct flight tests in measured natural icing conditions to evaluate the adequacy of simulated ice shapes used during dry air testing. Icing conditions that result in the simulated critical ice shape may not occur during natural icing testing. Also, the selected critical ice shape may be a composite of different ice features resulting in conservative degradation of performance and handling qualities for several phases of flight, and may not be a shape that would occur during natural icing. Therefore, effects of the simulated ice shapes during testing should be acceptably similar to that of natural ice shapes to provide assurance that the simulated ice shapes are conservative and properly derived. The corroboration should include confirmation that surfaces predicted to be free of ice, do in fact, remain ice-free. Guidance for determining the adequacy of the ice shapes is in appendix R of this AC.

g. Evaluations of performance and handling qualities results with natural ice accretions should be similar to the aircraft's flying qualities with simulated ice shapes. Dissimilarity of results between the natural and simulated ice shape testing may require reevaluation of the simulated ice shapes and retesting, or added testing in natural icing conditions.

h. You should evaluate the effects of ice buildups on unprotected surfaces, such as on the radome or fuselage nose, and on air data system measurements, such as pitot and static pressures, angle-of-attack, stall warning, and airflow conditions. No adverse effects on the air data system measurements should occur. You may perform this evaluation using simulated ice shapes. Record and correct all adverse air data system effects that occur during natural icing tests.

i. You must adjust the aircraft's operating speeds, stall protection system activation schedules, and performance and operating procedures and limits to ensure compliance with the requirements discussed in section 6 of this AC. You should consider thrust losses resulting from the use of engine bleed air for ice protection and from reduced propeller efficiency caused by ice buildups on the propeller blades. Provide this information in the AFM.

j. You should approach simulated-ice-shape flight testing with extreme caution. Pre-flight analyses and flight test planning should result in a safe buildup to the full simulated-ice configuration.

8.2.2.7 **Compliance Means: Dry Air Flight Test Ice-Contaminated Tailplane Stall (ICTS).** Ice accretion on the horizontal stabilizer may cause early airflow separation over the lower horizontal stabilizer surface, resulting in loss of airplane pitch control, loss of elevator authority, and pitch control force anomalies (reversed control forces and high upset recovery control forces). Adverse airplane pitch control and stability resulting from the reduced horizontal stabilizer stall angle (caused by the ice contamination) may occur during airplane configuration changes, such as when wing flaps are extended. This may also occur when engine power settings are changed and during changes in the airspeed. Airframe type certificate applicants should investigate ice-contaminated tailplane stall (ICTS) for all airplane designs, including those with powered controls. Applicants should determine whether this condition is likely to occur, resulting in an unsafe flight operation. Airplanes susceptible to ICTS are those having a near zero or negative tailplane stall margin. This evaluation typically is performed using simulated ice shapes along the leading edge of the horizontal stabilizer. An acceptable flight test procedure for determining susceptibility to ICTS is in AC 25-7A and AC 23.143-1. Appendix S of this AC provides guidance on ice-contaminated horizontal stabilizer stall.

8.2.3 **Compliance Means: Simulated Icing Flight Tests.**

a. Flight-testing in simulated icing conditions has successfully verified analyses required for approval of IPSs. You may use icing tankers or spray rigs installed on the test aircraft to spray supercooled water drops to simulate icing conditions. Use these simulated icing flight tests to verify drop impingement limits and to determine or verify simulated ice shapes. You may also use the testing to measure heat transfer coefficients, and to show ice shedding from selected aircraft components. Because of the limited size of the icing spray plume, testing is typically limited to small surface areas and components: for example, heated air-data probes, antennas, air inlets (including engine induction air inlets), windshields, and local areas on the wing and empennage.

b. You must measure simulated icing conditions as required by 14 CFR §§ 23.1419, 25.1419, 27.1419, and 29.1419. (See appendix N of this AC for information on instrumentation to measure icing conditions.) Your measurements should characterize icing condition parameters that are useful for understanding the test objectives. Calibrate simulated icing plumes before testing, including the plume's LWC and uniformity and the spectra of the water drop diameters. Alternatively, provide information that shows current calibration of the icing plume relative to parameters used to produce the plume (spray array water and air pressures, mass flow of the water, water temperature, etc.).

c. Producing the LWC defined in 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C for small and large drop diameters may be difficult with some spray nozzles. Therefore, the water catch and resulting ice shapes may differ from that resulting from the icing conditions described in 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C. Test results from simulated icing flight tests with icing conditions other than those defined in 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C, should be conservative when compared with results that are in 14 CFR part 25, Appendix C and 14 CFR part 29, Appendix C. Conservatism should be based on the most adverse results expected from an investigation; larger ice buildups may not lead to conservative test results.

d. See appendix T of this AC for information on simulated icing flight-testing.

8.2.4 **Compliance Means: Wind Tunnel Tests.**

a. The applicant may use laboratory dry air or simulated icing tests of the components or component models, as necessary, with flight tests in natural icing conditions to verify the ice protection system analyses required by 14 CFR §§ 23.1419(b)(3), 25.1419(b)(3), 27.1419(b)(3), and 29.1419(b)(3). You may also use these compliance means to check for icing anomalies, and to show the effectiveness of the IPS. Appendices R and U of this AC provide guidance on the use of icing wind tunnels. See appendix R, section R.4.2, of this AC for guidance on the use of dry air wind tunnels for determining the aerodynamic effects of ice shapes.

b. You should design icing wind tunnel tests, test conditions, and models to ensure that scaling parameters, such as Reynolds number and Weber number, are similar to those for full-scale flight conditions. If scaling parameters are not similar, you should clearly show how you extrapolated the small-scale test results to full-scale. The extrapolation procedure must be validated. Install the model in the icing wind tunnel to simulate the flight attitude and airplane configuration associated with the most critical flight condition. If you use flaps or other devices on the model to produce the proper flow field conditions, show an agreement between test and full-scale flow conditions.

c. You should address tunnel effects, such as those from the tunnel walls, model blockage, and model support effects, in your analysis.

d. Fluid ice protection systems tested in an icing tunnel should prevent ice formation on the protection surfaces for the designed period of protection. Also, the flow rate of freezing-point-depressant fluids should be within the design value.

8.3 Compliance Means: Surfaces Without Ice Protection. Ice buildup may be tolerated on some unprotected aircraft surfaces. The aircraft must have acceptable flying qualities and enough power or thrust to offset the added ice-related drag forces. Ice buildup on control surfaces may be more critical than other airframe surfaces. Provide an analysis and reason for leaving these surfaces unprotected from ice buildup. This analysis must show the aircraft will operate safely in icing conditions without ice protection for these surfaces. If there is doubt about the lack of protection and the adequacy of the provided IPS, you should verify the acceptability of the IPS by flight tests.

8.4 Compliance Means: Ice Inspection Lights and Cues.

a. Unless your aircraft is restricted from flight into known or forecast icing conditions at night, 14 CFR §§ 23.1419(d) and 25.1403 require means for identifying hazardous ice buildups on critical airplane surfaces. You should provide satisfactory lighting for ice inspection during night operation unless you provide another acceptable means of ice inspection (such as a primary flight ice detector system (PFIDS)). (See Reference 2 of section 14 for wing inspection light design criteria.) Evaluate ice inspection lights in and out of clouds during flight in darkness to determine that the target area is illuminated without excessive glare, reflections, or other distractions to the flight crew. You may perform these tests during other airplane certification flight tests. You may use airplane-mounted illumination to comply with these requirements. The FAA does not consider use of a handheld flashlight acceptable because of the associated additional flight crew workload. The AFM should describe the expected airframe icing cues and the flight crew action associated with the cues.

b. You should provide the flight crew with a means to determine when to activate the ice protection system. Ice buildup on a reference surface, observable by the flight crew, may be an acceptable means, providing you can confirm the airplane will operate safely with ice buildup on the airplane. You should show acceptable ice inspection cues during natural icing flight tests for the applicable aircraft operation, configurations, and phases of flight. The AFM should identify the icing cues and provide the flight crew action associated with the cues.

c. For some airplanes, the critical control surface for ice accretion may not be the wing, but a control surface on the empennage, which is not observable by the flight crew. If the flight crew cannot see the wings or critical empennage control surface, one acceptable means of compliance with 14 CFR §23.1419(d) and §25.1403 is to install an ice evidence probe in a location visible to the flight crew. You should show that formation of ice on this device precedes or occurs simultaneously with ice accretion on the critical surface. You should consider illuminating this device. Another means of compliance is the use of primary inflight icing detectors, where the ice detector sensor becomes the reference surface. See appendix K of this AC for guidance on using ice detectors.

8.5 Compliance Means: Reference to Previously Accomplished Tests.

a. Approval of an IPS by similarity is allowed if other aircraft have been certificated with an IPS that includes components that are functionally and aerodynamically equivalent. (See 14 CFR § 23.1419(c) and AC 23-1419-2C.)

b. If you are seeking approval of ice protection equipment and systems based on previously approved IPSs, you must specify the aircraft model and the component to which the referenced approval applies. Similarity certification may also apply to replacing an IPS component by supplemental type certificate. You must have all the regulatory compliance information from the referenced certification. You should show specific similarities in the physical, functional, thermodynamic, pneumatic, aerodynamic, and environmental exposure. You should perform analyses to show that the component's installation, operation, ice-protection effectiveness, and the resulting effects on the aircraft's performance and handling are equivalent to those of the previously approved configuration. You should validate the analysis by test. The analysis may include comparative results from icing and aerodynamic wind tunnel tests, flight tests, engineering simulator laboratory tests, service history, materials laboratory tests, and engineering judgment. However, you should carefully review these analyses to ensure that flight safety remains acceptable and the ice-protection effectiveness, integrity, and operating procedures are acceptable.

c. If the similarity certification is brought about by a change to the airplane type design, you should consider whether the changes in the IPS and associated aircraft behavior are sufficient to require flight-crew training or affect the aircraft's airworthiness or operational approvals. An assessment of a new installation should consider changes affecting the aircraft and the operation of other aircraft systems. If there is doubt about the effects of the changes, conduct additional tests and analyses to resolve any issues. If there is doubt about resolution of the effects of the differences, conduct flight tests in measured natural icing conditions.

8.6 Compliance Means: Perform Intended Function in Icing Conditions. All aircraft systems and components should function as intended when the aircraft encounters icing conditions.

8.6.1 **Compliance Means: Engines and Equipment Performance of Intended Function in Icing Conditions.** During icing tests, you must monitor engines and their accessories, such as generators and alternators operating under maximum ice protection load, to ensure that they remain within their limits. (See 14 CFR §§ 23.1041, 25.1041, 27.1041, and 29.1041.)

8.6.2 **Compliance Means: Engine Alternate Induction Air Sources Performance of Intended Functions in Icing Conditions.** Engine alternate induction air sources should remain functional to ensure satisfactory operation of essential engine subsystems.

8.6.3 **Compliance Means: Fuel System Venting Performance of Intended Function in Icing Conditions.** Ice accumulation should not adversely affect fuel venting system.

8.6.4 **Compliance Means: Landing Gear Performance of Intended Function in Icing Conditions.** A retractable landing gear should operate as intended following exposure to icing conditions. Retraction or extension of the landing gear should not cause an unsafe condition or pilot alert because of ice accretion.

8.6.5 **Compliance Means: Stall Warning and Protection Performance of Intended Function in Icing Conditions.** Ice can form on unprotected stall warning and AOA sensors. Therefore, the airframe type certificate applicant should evaluate the performance of these sensors during flight in icing conditions. You should ensure acceptable stall warning (aerodynamic or artificial) for ice accumulations on the aircraft. Also, you should provide the same type of stall warning in icing conditions as you provide in non-icing conditions, except the type of stall warning may differ during the brief period between the initial ice buildup and the time that the ice protection system becomes fully effective. You should ensure acceptable stall warning with ice buildups on aircraft surfaces, including the ice buildup occurring before the first activation of the IPS, the ice buildup occurring between the ice protection activation cycles (intercycle ice), the ice buildup remaining after one cycle of the IPS (before landing), and ice buildups on unprotected surfaces. You may need to change the schedules for activating the artificial stall warning, stall identification, and stall protection, if installed, for operations in icing conditions to provide acceptable stall warning margins and to prevent a stall during flight in icing conditions.

8.6.6 **Compliance Means: Icing Conditions.** You should ensure that ice detection cues used by the pilot to activate the IPS are acceptable at expected aircraft flight attitudes.

8.6.7 **Compliance Means: Primary and Secondary Flight Control Surfaces Performance of Intended Function in Icing Conditions.** Primary and secondary flight control surfaces should operate normally during and after flight into icing conditions. The airframe type certificate applicant should ensure that aerodynamic- and weight-balanced control surfaces are not subject to icing throughout the aircraft's operating envelope (weight, center of gravity, and speed). Ensure that any ice buildup on these surfaces does not interfere with the surface actuation, including the operation of high-lift devices, such as slats and trailing edge flaps for safe landing go-around maneuvers.

8.6.8 **Compliance Means: Ram Air Turbine Performance of Intended Function in Icing Conditions.** The ram air turbine should remain operational during flight in icing conditions. You may not need to perform natural icing tests if the ram air turbine tested satisfactorily in an icing wind tunnel.

8.6.9 **Compliance Means: Pilot Compartment View Performance of Intended Function in Icing Conditions.** Note any obstruction of the pilot's view because of ice buildup to support compliance with 14 CFR §§ 23.773, 25.773(b)(1)(ii), 27.773, and 29.773(b)(1)(ii).

9. AIRPLANE FLIGHT MANUAL (AFM). The AFM must provide the pilot with the information needed to operate the IPS. (See 14 CFR §§ 23.1525 and 23.1583(h), 25.1525 and 25.1583(e), 27.1525 and 27.1583(e), and 29.1525 and 29.1583(e), and 14 CFR §§ 23.1559(c), 27.1559, and 29.1559.)

9.1 AFM: Limitations.

a. You must state in the limitations section of the AFM the atmospheric environments in which the aircraft is approved to operate, including flight into icing conditions. (See 14 CFR §§ 23.1583(h), 25.1583(e), 27.1583(e), and 29.1583(e).)

b. The limitations section of the AFM should include, as applicable, a statement similar to the following: "In icing conditions, the airplane must be operated and its ice protection systems used as described in the operating procedures section of this manual. Where specific operational speeds and performance information have been established for such conditions, this information must be used." Include in the limitations section of the AFM the following, as appropriate. (See 14 CFR §§ 23.1583(e), 25.1583(a), 27.1581(a)(2), and 29.1581(a)(2).)

(1) The minimum operating airspeed for each normal aircraft configuration whenever ice exists on the critical surfaces.

(2) Instructions to activate the engine anti-ice system when the aircraft encounters Instrument Meteorological Conditions (IMC) at an altitude near or above the freezing level.

(3) Landing weight limits that include the effects on aircraft performance when the IPS is activated. You should consider the effects of residual ice on the aircraft lift and drag, thrust loss associated with operation of the IPS, and the airplane performance at the recommended operating speeds. You may present these weight limits in the performance information section of the AFM and include them as aircraft limits by specific reference in the AFM's FAA-approved limitations section.

(4) Limits on operating time for ice protection equipment, if these limitations are based on fluid anti-ice/deice systems capacities and flow rates.

(5) Airspeed limits (if any) and the minimum temperature at which the deicing boots may be operated.

(6) Environmental limits for operating deicer boots, such as minimum temperature and maximum altitude for boot operation.

(7) Minimum engine rpm or power setting necessary for the airframe IPS to function properly.

(8) A list of required placards.

(9) Severe icing warnings. (See AC 23.1419-2C and AC 25.1419-1A.)

9.2 AFM: Operating Procedures.

a. The AFM operating procedures for flight in icing conditions should include instructions for normal operation of the airplane, including operation of the aircraft when the IPS fails. In the AFM, you must also include procedures for managing other airplane system failures that will affect the IPS of the airplane in icing conditions.

(1) You must provide the pilot with recommended procedures that are unique to your aircraft for safe flight. (See 14 CFR §§ 23.1585(a), 25.1585(a), 27.1585(b), and 29.1585(a).) These procedures should include any necessary preflight action that minimizes the potential for enroute emergencies associated with the IPS. You should describe the system components with enough clarity and depth so the pilot can understand the component's function. Unless flight crew actions are accepted as normal airmanship, such as maintaining situational awareness, you should include the appropriate procedures in the FAA-approved AFM or AFM supplement. These procedures should include proper pilot response to cockpit warnings, a way to diagnose system failures, and how to use system(s) safely.

b. Normal operating procedures.

(1) Normal operating procedures in the AFM should reflect the procedures used to certificate the airplane for flight in icing. This includes configurations, speeds, ice protection system operation, and power plant and systems operation. You should provide this information for all phases of flight, including takeoff, climb, cruise, descent, holding, go-around, and landing.

(2) You should provide procedures to optimize aircraft operation during flight in icing conditions. You should provide these procedures for flight phases in which icing conditions are commonly encountered, including climb, holding, and approach, and ETOPS diversions. The AFM should define when the flight crew must activate the ice protection equipment.

(3) For fluid IPSs, provide information and method(s) for determining the remaining flight operation time.

c. Abnormal and emergency procedures.

(1) The AFM must contain an emergency or abnormal operating procedures section describing flight crew actions if annunciated IPS failures and suspected unannunciated failures occur. Also, include any changes to other AFM abnormal procedures resulting from flight in icing conditions.

(2) For aircraft that cannot supply enough electrical power for all systems with an electrical system failure or engine failure, give the pilot load-shedding instructions.

9.3 AFM: Performance Information. You must provide performance information in the AFM for all flight phases affected by flight into icing conditions (14 CFR parts 23 Subpart B, 25 Subpart B, 27 Subpart B, and 29 Subpart B). Provide information to allow the flight crew to determine climb-limited aircraft weight, altitude, and temperature (WAT) limits in icing conditions. These data should include the effects of drag resulting from ice buildups (including ice buildups on unprotected surfaces and intercycle ice on protected surfaces), the power extraction associated with IPS operation, and any changes in operating speeds due to icing. Show the effect on landing distance due to the increased landing speeds and for all landing configurations when landing in icing conditions.

9.4 AFM: Airworthiness Directives for Severe Icing Conditions.

a. In October 1994, an accident occurred involving a transport category airplane operating in severe icing conditions. The accident airplane's loss of control profile was replicated by ice shapes developed during extensive flight testing in simulated large-drop icing conditions. The simulated cloud water drop diameters were consistent with freezing drizzle. This condition created a ridge of ice aft of the wing's upper surface deicing boots and forward of the ailerons, resulting in an uncommanded motion of the ailerons, control force anomalies, and the rapid roll of the aircraft.

b. Following this accident, the FAA determined flight crews are not provided the information necessary to determine when they are likely to experience icing conditions for which the airplane is not certificated. As a result of these findings, the FAA determined that flight crews must be provided the information on current weather conditions, and be made aware of specific visual cues that may indicate when their airplane is operating in atmospheric conditions outside the 14 CFR part 25, Appendix C icing envelopes.

c. The FAA issued a series of airworthiness directives (AD) for airplanes equipped with pneumatic deicing boots and non-powered roll control systems in April 1996 and February 1998.

The ADs required revising the AFM to provide the flight crew with recognition cues and procedures for exiting from severe icing conditions, and to limit or prohibit the use of trailing edge flaps and the autopilot.

d. The limitations and procedures in AD 96-09-25 contain acceptable ways to provide this information. These limitations and procedures should be applied to all airplanes with reversible lateral controls approved for flight in icing, and should include, but are not limited to, the following:

(1) Visual cues that the airplane is in severe icing conditions;

(2) Prohibition on the use of the autopilot when the visual cues are observed;

(3) All icing inspection lights operative before flight into icing conditions at night;

(4) Immediate exiting of the severe icing conditions; and

(5) If the flaps are extended, do not retract them until the airframe is clear of ice.

> **NOTE:** Retracting the flaps is contingent on the existence of a means to determine if the airplane surfaces are clear of ice.

10. ROTORCRAFT.

10.1 Rotorcraft: General.

a. This section contains additional guidance on certificating rotorcraft IPSs. This guidance is necessary because certification considerations for rotorcraft IPSs and fixed-wing airplanes differ due to design and operation differences. Rotor blades operate in a much wider range of airspeeds than that of a fixed-wing of an airplane, resulting in different ice accretion characteristics. Attention to the structural integrity of the main rotor blades and tail rotor blades, rotorcraft vibration, shed-ice hazards, and instrument performance is crucial for rotorcraft. AC 29-2C, Section 29.1419, can guide you on compliance with 14 CFR § 29.1419, and AC 27-1B can guide you on rotorcraft certificated to the requirements of 14 CFR part 27.

b. The objective of rotorcraft icing certification is to show the rotorcraft will operate safely throughout its approved icing envelope. This objective includes determining the rotorcraft's limits when operating in icing conditions, for example, showing that the icing warning means and the IPS are acceptable. A limitation may result, for example, from considerations of aircraft handling qualities, performance, autorotation, asymmetric ice shedding from the rotors, or visibility through the windshield.

c. For rotorcraft operations, icing conditions defined in 14 CFR part 29, Appendix C may be truncated to a pressure altitude of 10,000 feet or the altitude limit of the aircraft if lower than 10,000 feet. Air traffic compatibility constraints discourage approval of a maximum altitude less than 10,000 feet. However, there are operations where a lower maximum altitude has no effect on the air traffic system and would still be operationally useful. If you elect to certificate your rotorcraft with a 10,000 pressure altitude limit based on an equivalent level of safety, you may select icing condition envelopes contained in AC 29-2C. (For pressure altitude above 10,000 feet, AC 29-2C states that 14 CFR part 29, Appendix C icing conditions must be used.)

d. The icing conditions contained in AC 29-2C were derived from an analysis, performed by the FAA William J. Hughes Technical Center during 1985, of the data used to establish the icing conditions contained in 14 CFR part 29, Appendix C. There are significant differences between the two icing environments. For example, the AC 29-2C icing envelopes for altitudes of 10,000 feet and lower specifies temperatures colder than -10 °F and 0 °F need not be addressed for continuous and intermittent icing conditions, respectively. Comparative temperatures in 14 CFR part 29, Appendix C specify -22 °F and -6 °F. Also, the minimum altitude specified in AC 29-2C identifies intermittent icing conditions occurring at 4,000 feet, whereas 14 CFR part 29, Appendix C specifies a value starting at sea level. Since icing conditions identified in AC 29-2C are not regulatory and are less rigorous than those required by 14 CFR part 29, Appendix C (14 CFR §§ 27.1419 and 29.1419), you should consult the FAA before using the AC 29-2C icing conditions for compliance with 14 CFR parts 27 and 29 icing requirements.

e. Use the required icing conditions for determining the most critical combinations of icing and rotorcraft operating conditions as a function of enroute distance. This, combined with a 30-minute destination-hold in icing conditions, is in lieu of the fixed-wing aircraft destination-hold policy. The rotorcraft 30-minute destination-hold assessment, a means of compliance with 14 CFR § 29.1419, should consider the LWC at the standard cloud extents of 17.4 nm and 2.6 nm for continuous maximum and intermittent maximum icing conditions, respectively. (See AC 29-2C.) Carefully evaluate all the required icing condition envelopes during certification of the IPS.

f. The effects of ice accumulation on rotorcraft will vary among makes and models of rotorcraft. Experience gained from certificating a rotorcraft system could provide valuable information but should be used cautiously when using an identical blade profile on a new rotorcraft for which approval for flight in icing is requested. Exercise particular care when drawing from experience gained from fixed-wing icing encounters because the icing conditions effects on rotor blades may be incompatible with fixed-wing results.

g. Although military rotorcraft icing technology and operational experience provide useful background information, you must show compliance with 14 CFR parts 27 and 29 in-flight icing requirements. Information on rotor blade ice protection and rotorcraft ice protection system design is in Reference 3 of section 14.

10.2 Rotorcraft: Compliance.

a. Compliance with the certification requirements for flight into icing conditions is established when:

(1) The engine(s) will not flameout or experience significant power losses or damage because of ingestion of ice shedding from airframe surfaces or clogging of air intake screens;

(2) Approved maximum stress levels are not exceeded with the buildup of ice on the rotorcraft or do not cause serious decreases in component life;

(3) Inlets, vents, and drains (such as a fuel vent, engine inlet, or transmission cooler air inlet) remain unobstructed; and

(4) Autorotation characteristics are acceptable with maximum ice accretion between de-ice cycles.

b. Also, because rotorcraft characteristics, configurations, and critical surface areas can differ within the rotorcraft's flight and operating envelopes, you should:

(1) Show by analysis that your rotorcraft can perform a destination-hold for 30 minutes in the continuous maximum icing conditions of 14 CFR part 29, Appendix C as a means of compliance with 14 CFR § 29.1419. (See AC 29-2C.) The rotorcraft performance may limit the altitude to a value less than that of 14 CFR part 29, Appendix C. For the analysis, you should configure your rotorcraft at the most critical weight, center-of-gravity, and altitude with the IPS operating. Your analyses must be verified by natural or simulated icing tests within the certificated icing environment. (See AC 29-2C.)

(2) Show that your rotorcraft can operate safely in continuous icing conditions for 15 minutes after recognition of any single IPS failure if a single ice protection system and power source is used, as required by 14 CFR §§ 27.1419 and 29.1419 for showing safe operation in icing conditions. (See ACs 27-1B and 29-2C.) You can show the rotorcraft's ability to operate safely for 15 minutes by analysis or test (or a combination of analysis and tests). The icing conditions should be the same as those used for showing that the rotorcraft can hold in 30 minutes of icing. The rotorcraft must be free from excessive and rapid structural divergence within the certificated icing environment and rotorcraft flight and operating envelopes. (See AC 29-2C.)

(3) You must provide a means to advise the crew when the rotorcraft is in icing conditions if the ice protection system does not operate continuously. Flight crews need this information or detection system to activate the IPS according to Rotorcraft Flight Manual (RFM) procedures.

(4) You do not have to provide autorotational performance data for rotorcraft that have a Category A powerplant installation. (Categories A and B rotorcraft are defined in 14 CFR § 29.1.) For safe operations in icing conditions, as required by 14 CFR §§ 27.1419 and 29.1419, rotorcraft certificated for flight in icing conditions must be capable of autorotational landings with the ice protection system operating. You should evaluate the autorotational entry, steady state, and flare-entry flying qualities, and you should evaluate the rotorcraft performance with an ice load.

(5) Since the Category A rotorcraft enroute performance can vary as the ice protection system operates, a mean value of cyclic torque is acceptable provided the rate of climb is not less than zero at any time for complying with the requirement for safe operation during in-flight icing.

(6) Following an icing event, you should address the rotorcraft's hover performance for terminating a mission, such as for hovering or vertical descent.

(7) You must evaluate the rotorcraft's handling qualities if ice can collect on any surface, to show safer operations in icing conditions as required by 14 CFR §§ 27.1419 and 29.1419. When ice can accrete on unprotected surfaces, the rotorcraft must have satisfactory visual flight rules (VFR) and instrument flight rules (IFR) handling qualities.

(8) You must evaluate the maximum effects of icing on the ability of components, such as fuel tank vents, cooling vents, and antennas, to perform their intended functions. See table 1 of this AC for carburetor and fuel system protection requirements.

(9) Show compliance with 14 CFR §§ 27.1309 and 29.1309. You must protect your rotorcraft to minimize lightning strike risks. The general rules of 14 CFR §§ 27.1309(a), (b), and (c) and 29.1309(a), (b), and (c) are designed to ensure acceptable lightning protection.

(10) You must consider ice protection of the air data system sensors, probes, windshields, inlets, and exposed control linkages.

(11) Delayed activation of the ice protection system should not result in hazardous conditions. You should address any rotorcraft characteristic changes as cautionary information in the RFM.

(12) You must address icing-related malfunction of the rotor blade droop stop and resulting potential hazards to the rotorcraft, its occupants, and ground personnel.

(13) You must consider ice shedding hazards to ground personnel or equipment following flight in icing conditions.

c. Assessing icing-related performance losses should include not only the drag and weight of the ice but also electrical or other load demands of the ice protection system and any performance changes resulting from ice accretion on the rotor blades.

d. As with fixed-wing aircraft, you must provide an analysis to show the rotorcraft's IPS is acceptable as required by 14 CFR §§ 27.1419 and 29.1419. Perform this analysis based on the rotorcraft's operational needs, as discussed in section 10.2.1 of this AC. Besides the analysis showing the rotorcraft can operate safely in icing conditions, you must verify the analysis and show the effectiveness of the ice protection system and its components by flight tests of the rotorcraft or its components in measured natural atmospheric icing conditions. You may also use the following, as necessary.

(1) Laboratory dry air or simulated icing tests, or a combination of both.

(2) Flight dry air tests.

(3) Flight tests of the rotorcraft or its components in measured simulated icing conditions.

e. You should provide or identify means for determining the hazardous ice on critical rotorcraft parts, either by a reliable and safe natural warning or by an ice detection system.

10.2.1 **Rotorcraft: Compliance: Analyses.** You should perform analyses to determine the conditions that are critical for safe operation of your rotorcraft in the certificated icing environment (the design points) for your rotorcraft's ice protection, including those for rotor blades, windshield, engine inlet(s), air data sensors, and other components. Present your analyses to the FAA for acceptance before performing flight tests in icing conditions. The analyses should show the rotorcraft will operate safely at the design points. Also, you must address both the continuous maximum and intermittent maximum icing conditions of 14 CFR part 29, Appendix C as limited by the rotorcraft's performance envelope. Verify the IPS design icing conditions used for compliance by test. Pay specific attention to the qualification and design of the ice protection system and its components. Address the effects of ice accretion on component installations, such as search-and-rescue hoists and equipment for emergency landings on water. Also, address the effects of ice on the rotorcraft's structural properties and performance and handling qualities. Use analyses, bench tests, and dry air flight tests or simulated icing tests, as necessary, to achieve these assurances.

a. Your analysis should include an assessment of preactivation and intercycle ice accretion. The analysis should also include performance limits of sensors used in an automated IPS. An automated system using outside air temperature (OAT) should have a total system accuracy of ±1 °C, or better. If an automated system uses measured LWC, or if a warning is provided based on measured LWC, consider conservative use of the measured LWC because of the inaccuracies and poor precision of measured LWC. Also, LWC measurements fluctuate significantly during natural icing conditions. After you review the analyses and find them acceptable, conduct tests to verify the analyses and to confirm the rotorcraft can operate safely in the required icing conditions.

b. You should evaluate rotor blade stability with ice accretions to ensure structural dynamic instability will not occur in icing conditions. You may use analyses to perform this assessment. Your analyses should consider failure of the most critical segment of the rotor blade IPS. You may also use experimental means, such as attaching critical simulated ice shapes to the blades and using a whirl stand or wind tunnel, to perform this analysis.

c. You should also evaluate the effects of ice accretion on the rotorcraft components' structural fatigue and life cycle resulting from vibrations. You must substantiate the static and fatigue strength of the rotor blade with heater mats and consider any effect of the heater mat on fatigue strength of the blades.

d. You should perform a detailed failure modes and effects analysis of the ice protection system.

e. You should give careful attention to the installation, ice protection, and performance of air data sensors and ice detectors. These systems may experience wide ranges of airspeeds and local flow angles. Position error corrections for airspeed, altitude, and angle of attack may be significant. See appendix K of this AC for guidance on installation and acceptance of ice detectors.

f. Icing analysis information is in section 8.1 of this AC.

10.2.2 **Rotorcraft: Compliance: Tests.** As required by 14 CFR §§ 27.1419 and 29.1419, approval of rotorcraft IPS must include flight tests in natural icing conditions. Laboratory, icing wind tunnel, or simulated icing tests cannot be used individually or collectively for showing compliance with rotorcraft ice protection requirements. Currently, laboratories, icing wind tunnels, and tankers cannot duplicate the combinations of LWC, drop size and distribution, flow fields, and random ice-shedding behaviors found in natural icing conditions testing.

10.2.2.1 **Rotorcraft: Compliance: Natural Icing Flight Tests.**

a. You should conduct natural icing tests in conditions as close to the critical design conditions as possible. Also, show enough correlation between the analyses to ensure the rotorcraft will operate safely throughout the required icing envelope. Finding natural icing at all the critical icing conditions may not be practical.

b. Prerequisites for natural icing flight test include:

(1) A rotorcraft conforming to its type design and capable of IFR and IMC flight.

(2) FAA acceptance of an analysis showing that the rotorcraft can operate safely at critical design points in both the continuous maximum and intermittent maximum conditions of 14 CFR part 29, Appendix C. This includes qualification of the ice protection systems, and the analyses of the rotorcraft's structural integrity and the rotorcraft's performance and handling.

(3) A detailed failure modes and effect analysis of the ice protection system.

(4) Assessment of the rotor blade's structural stability with critical ice accretions.This ensures that structural dynamic instability will not occur in icing conditions.

c. Certification flight-testing should be extensive enough to provide assurances that either induced or random ice shedding does not present a hazard. For example, you should consider the effects of vibration from asymmetric ice shedding from rotor blades (imbalance rotor) or the impact of shed ice on the rotorcraft airframe. You may use the following to determine unacceptable ice shedding.

(1) Vibrations sufficient to make flight-deck instruments difficult to read;

(2) Vibrations exceeding the structural or fatigue limits of any rotorcraft part (e.g., rotor blade, mast, or transmission components); or

(3) Dangerous impact of shed-ice on essential parts, such as the tail rotor.(See section 8.2.1.4 of this AC.)

d. You should review certification flight test instrumentation for accuracy and sampling rates. This includes structural strain measurements and optical recordings of ice accretions on critical surfaces. You should use strain measurements to determine ice-imposed structural stress and to verify structural stress and fatigue analyses used for such components as the main rotor blades, main rotor hub components, rotating and fixed controls, horizontal stabilizer, tail rotor, etc. (See section 8.2.1.1 of this AC for additional guidance on rotorcraft compliance tests.)

e. Additional guidance on showing compliance using natural icing flight tests is in section 8.2.1 of this AC.

10.2.2.2 Rotorcraft: Compliance: Dry Air Flight Tests.

a. Dry air flight tests are usually the first evaluation of the IPS. Thermal data from dry air tests may be useful in validating the IPS thermal analysis. See section 8.2.2 of this AC for guidance, recognizing that there are operational and configuration differences between fixed-wing airplanes and rotorcraft.

b. You may use dry air testing with simulated critical ice shapes to show safe rotorcraft performance and handling qualities. You may also use ice shapes to show acceptable structural stability and fatigue characteristics of the rotor blades. Test both normal operation and failed IPS simulated ice shapes. Dry air testing with simulated ice shapes will aid you in showing compliance with the required regulations and significantly reduces flight-test costs.

c. Section 8.2.2.6 of this AC contains flight safety guidance for flights with simulated ice shapes.

10.2.2.3 Rotorcraft: Compliance: Simulated Icing Flight Tests. Icing tankers have not been able to produce icing plumes with drop sizes and distributions that reproduce all the icing envelope conditions required for certification. The large water droplet sizes produced by the icing tankers have typically been a problem in simulation icing conditions. Also, the breadth of the icing tanker plume typically has been inadequate to immerse the entire rotorcraft. However, the tanker should be able to produce a uniform icing cloud that will immerse the entire rotor system. The tanker should also have a means of consistently controlling and changing the cloud characteristics. (See section 8.2.3 of this AC.)

10.2.2.4 Rotorcraft: Compliance: Wind Tunnel Tests. Wind tunnel tests of rotorcraft are typically more complex and difficult than those of fixed-wing aircraft. Rotation of the rotor blades, the scale of wind tunnel model rotor blades, and the complex flow field produced by the rotor disk contribute to the wind tunnel testing difficulty. Although the typical high aspect ratio of rotor blades allows confident use of two-dimensional (2D) analyses, these analyses should address the rotating blade's spanwise flow field and spanwise unfrozen water flow, unless the applicant proves that these considerations are insignificant. You should consider the effects of the rotor's slipstream on ice accretion on other components of the rotorcraft, if appropriate. (See section 8.2.4 of this AC.)

10.3 Rotorcraft Flight Manual.

a. You should include all icing-related limits (including limits for flight into instrumented meteorological conditions), procedures (normal and emergency), and caution notes in the Rotorcraft Flight Manual (RFM). The RFM should state whether the rotorcraft is certificated to operate in freezing rain or freezing drizzle. The cautionary notice should include procedures for identifying and avoiding freezing precipitation. Caution notes provided by the applicant should also address:

(1) The hazard caused by inducing asymmetric ice shedding by using rapid control inputs or rotor speed changes, unless that procedure is a last resort;

(2) Losses in range, climb rate, and hover capability following significant exposure to icing conditions;

(3) The need for clean rotor blade surfaces before flight.Surfaces should be cleaned with an approved cleaning solvent or ground deicing and anti-icing fluids before rotating the rotor blades;

(4) Changes in autorotation characteristics resulting from ice accretion; and

(5) The potential hazards of shed-ice to ground personnel, deplaning passengers, and equipment.

11. AIRCRAFT FROST AND CLEAR ICE CONSIDERATIONS.

Frost and clear ice developed during ground operations may adversely affect safe flight. Appendix V of this AC contains guidance on removing frost and clear ice from airframe surfaces before takeoff.

12. AIRPLANE DE/ANTI-ICING BEFORE TAKEOFF.

a. No person may takeoff in an aircraft when frost, ice, or snow is adhering to the wings, control surfaces, propellers, engine inlets, or other critical surfaces of the aircraft. (See 14 CFR §§ 91.527, 121.629(b), and 135.227(a).) AC 20-117, AC 135-16, AC 135-17, AC 120-58, and AC 120-60 provide additional information on deicing and anti-icing of aircraft before takeoff. Flight Standards Information Bulletins for Air Transportation (FSAT) are published yearly, containing the latest deicing and anti-icing fluid holdover time guidelines and the most recent information available on operating in ground icing conditions. Airplane operators use this information to develop aircraft ground deicing and anti-icing programs required by 14 CFR §§ 121.629(c) and 135.227(b)(3).

b. Aircraft are deiced before takeoff and, as required, anti-iced using thickened pseudo-plastic fluids. This procedure provides temporal protection from ice adhering to the aircraft's surfaces before takeoff. It does not ensure that ice will not accrete on aircraft surfaces during takeoff and in flight. The presence of thickened fluid may affect the airplane's performance and handling qualities because the fluids may not completely flow off the aircraft surfaces before liftoff. Fluid residue may cause increased pilot control forces during takeoff and climb for airplanes with reversible control surfaces. The fluid may also collect in the bays of airplanes with aerodynamically or weight balanced control surfaces, resulting in unbalanced control surfaces, unexpected changes in control forces, and control surface vibrations. Also, anti-icing fluid may collect and evaporate in quiet cove areas, like those along control surface hinge lines.

When the residue of the evaporated anti-icing fluid is rehydrated by rain or during washing of the airplane, it may freeze and lock the control surface when the airplane climbs to altitudes with subfreezing temperatures. The freezing point depressant, usually a glycol compound, evaporates when the anti-icing fluid dries.

c. The Society of Automotive Engineers (SAE) G-12 Committee and the International Standard Organization (ISO) have published aerospace material standards (AMS), and aerospace recommended practices (ARP) for deicing and anti-icing fluids and methods for deicing and anti-icing airplanes. (See section 14, references 4 through 9 for SAE specifications for deicing and anti-icing fluids, recommended aircraft deicing and anti-icing practices, and the functional requirements of deicing and anti-icing vehicles.)

d. The FAA has not published airworthiness standards for showing acceptance of deicing and anti-icing fluids. However, you must comply with the airworthiness requirements of 14 CFR parts 23, 25, 27, and 29 and the operating requirements of 14 CFR parts 121 and 135 before conducting flights into icing conditions. The FAA annually provides deicing and anti-icing fluids holdover time guidelines, a list of available fluids, and other information useful to the aircraft operator for complying with 14 CFR §§ 121.629 and 135.227 in an FSAT.

13. EXTENDED RANGE OPERATION WITH TWO-ENGINE AIRPLANES (ETOPS) ICING CONSIDERATIONS.

a. When seeking approval for extended range operations for a twin-engine airplane, applicants should consider the effects of ice accretion and engine power extraction resulting from operation of IPS. You should follow the guidance provided in AC 120-42A. The Administrator may authorize operation of a two-engine airplane over a route that contains a point farther than 1-hour flying time from an acceptable airport (14 CFR § 121.161). An airplane operating under ETOPS guidelines with a failed engine or following a decompression of the passenger cabin may have to descend and cruise for extended periods at altitudes and airspeeds conducive to icing. It may also be exposed to icing conditions at the diversion terminal area. (See section 14, reference 1.) The exposure to icing conditions during the diversion potentially may be much longer than the time considered acceptable for approval of the IPS in 14 CFR parts 23 and 25.

b. AC 120-42A advises you to address the following:

(1) During type design evaluation, you should show that acceptable engine limit margins exist for conducting extended duration single-engine operation at all approved power levels and in all expected environmental conditions. This assessment should account for the effects of added engine loading demands (anti-ice, electrical, etc.). This may be necessary during the single-engine flight phase associated with the diversion.

(2) You should show the airframe and propulsion ice protection provides acceptable capability (airplane controllability, aircraft performance, etc.) for the intended diversion. This should account for the likely engine-out diversion flight plan, including decent, cruise, holding, approach, and landing.

(3) The critical fuel plan should add 5 percent to the calculated fuel burn from the critical way point. This would allow for errors in wind forecasts. The fuel plan should also allow a 5 percent penalty in fuel mileage if the fuel mileage deterioration is unknown. The critical fuel plan should include fuel burn associated with Configuration Deviation List items, airframe and engine anti-icing. It should also account for ice buildup on unprotected surfaces if icing conditions are likely to be encountered during the diversion.

(4) You should provide airplane performance information in the appropriate section of the AFM. This information should warn about extended range operation environmental hazards that can cause a significant decline in aircraft performance, such as ice buildup on the unprotected surfaces of the airplane.

(5) You should include systems redundancy levels acceptable for extended range operations in the master minimum equipment list (MMEL), including ice protection.

c. AC 120-42A suggests you evaluate the aerodynamic effects of ice accretion on the airplane resulting from icing conditions likely to be encountered during a diversion. Fuel loading should also consider the drag resulting from the ice accreted during a diversion. This accompanies the power extractions associated with operation of the ice protection system. You should ensure the engine limit margins exist to allow operation of the ice protection systems during a one-engine-inoperative diversion to an alternate airport. During the evaluation, consider other engine power extractions (such as cabin pressurization, electrical power, and hydraulics conditions) at the critical airplane weight, altitude, ambient temperature, and airspeed condition. Provide airplane performance information reflecting these considerations in the AFM. You may reference this consideration to other documents in the AFM.

d. Redundancy of the IPS beyond those required by 14 CFR §§ 23.1309 and 25.1309 should conform with the risk analysis method presented in AC 120-42A. The MMEL should be compatible with the results of the safety reliability evaluation. Also, consider the IPS capability with an in-operative engine for acceptable equipment and systems operation during likely icing conditions. Preserve acceptable electrical power, hydraulics, system and equipment cooling, air data system information, and windshield visibility during the diversion.

e. You may select the most critical ice accretion shape, as allowed by AC 120-42A and 14 CFR §§ 23.1419 and 25.1419, to show your compliance with the AC 120-42A and other icing requirements. You may interpret acceptable compliance as safe flight. Section 6.3 of this AC discusses demonstration of safe flight. AC 120-42A addresses ice accretion on unprotected surfaces, focusing only on large turbine-powered transports with thermal anti-icing systems. You should also address normal-operation ice buildups on protected surfaces for types of airplanes where you would expect such accretions. Normal-operation ice buildups include intercycle ice roughness and runback ice resulting from extended operation in icing conditions. You may use simulated ice shapes to show compliance and conformity with the rules and the guidance provided in AC 120-42A. (See appendix R of this AC.) Following the guidance in AC 120-42A may require consideration of ice-related drag at higher airspeeds than those required to show compliance with 14 CFR §§ 23.1419 and 25.1419. You should consider ice buildups on airplane components and surfaces that are no longer ice protected because of an engine failure. You should also consider ice accretion on the inoperative-engine nacelle and engine components and runback ice or intercycle ice accretion resulting from lower ice protection performance with an inoperative-engine.

f. Since AC 120-42A states you should consider icing conditions likely to be encountered during the diversion, you should have enough knowledge of the likely icing conditions for the selected diversion routes to define those icing conditions confidently. You should also provide acceptable information to back up the selected diversion icing condition. Selection of the diversion icing condition likelihoods should be conservative and compatible with the overall safety risk assessment of the airplane for ETOPS operations.

g. Having established the diversion icing conditions and duration, you may determine the critical ice shapes for the diversion as describe in appendix R of this AC.

h. You should show that primary ice detectors are able to perform their intended function reliably during the diversion. (See appendix K of this AC.)

i. You should show the reliability of other essential systems (such as the APU or ram air turbine) in the icing conditions associated with ETOPS.

14. REFERENCES.

1. "**Aircraft Icing Handbook**," FAA Technical Report DOT/FAA/CT-88/8-1 (1991), 3 vols. FAA Technical Center, Atlantic City, N.J. 08405.

2. "**Wing Inspection Lights – Design Criteria**," SAE ARP4087.

3. "**Rotor Blade Electrothermal Ice Protection Design Considerations**," SAE AIR1667A, pp. 13-24.

4. Fluid, Aircraft Deicing/Anti-Icing, Non-Newtonian, (Pseudoplastic), SAE Types II, III, and IV, SAE AMS1428 (Last Revision).

5. Deicing/Anti-Icing Fluid, Aircraft, SAE Type I, SAE AMS1424 (current).

6. Deicing Fluid, Aircraft, Ethylene Glycol Base, SAE AMS1425 (current).

7. Deicing/Anti-Icing Fluid, Aircraft, Propylene Glycol Base, SAE AMS1427 (current).

8. Aircraft Deicing/Anti-Icing Methods (Supplement 1), SAE ARP4737SUP1.

9. Self-Propelled De-Icing/Anti-Icing Vehicles—Functional Requirements, ISO11077.

10. "In Situ Measurements of the Airplane Icing Environment in Winter Storms Over the Western North Atlantic Ocean," Tank, W., Patnoe, Isaac, G., Cober, S., and Stapp, J., AIAA 94-0483, 39th Aerospace Sciences Meeting & Exhibit, 10-13 January 1994, Reno, Nevada.

APPENDIX A. RELATED REGULATIONS AND DOCUMENTS

A.1 REGULATIONS. Table A.1 shows the regulations related to icing certification for 14 CFR parts 23, 25, 27, and 29 aircraft. Table A.2 shows the regulations for icing certification for engines. Table A.3 shows the airworthiness icing regulations for 14 CFR part 35 propellers, and table A.4 shows the operating rules. Regulations noted in the appendix without amendment level are at the latest amendment before the publication date of this AC.

APPENDIX A. RELATED REGULATIONS AND DOCUMENTS (CONTINUED)

Table A-1. Related 14 CFR Parts 23, 25, 27, and 29 Regulations

Subpart	Part 23 - Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes	Part 25 - Airworthiness Standards: Transport Category Airplanes	Part 27 – Airworthiness Standards: Normal Category Rotorcraft	Part 29 – Airworthiness Standards: Transport Category Rotorcraft
B-Flight	§ 23.49, Stalling period § 23.65, Climb: All engines operating § 23.67(e)(2), Climb: One-engine inoperative § 23.67(e)(3), Climb: One-engine inoperative § 23.71, Glide: Single-engine airplanes § 23.75, Landing Distance § 23.77, Balked landing § 23.143, General—Controllability and Maneuverability § 23.171, General – Stability § 23.201, Wing level stall § 23.203, Turning flight and accelerated turning stalls § 23.207, Stall warning § 23.251, Vibration and buffeting	§ 25.103, Stalling speed § 25.117, Climb: general § 25.119, Landing Climb: All-engines-operating § 25.121, Climb: One-engine-inoperative § 25.123, En route flight paths § 25.125, Landing § 25.143, General—Controllability and Maneuverability § 25.171, General – Stability § 25.201, Stall demonstration § 25.203, Stall characteristics § 25.207, Stall warning § 25.237, Wind velocities § 25.251, Vibration and buffeting § 25.253, High-speed characteristics	§ 27.65, Climb: all engines operating § 27.67, Climb: one engine inoperative § 27.71, Glide performance § 27.7, Performance at minimum operating speed § 27.75, Landing § 27.79, Limiting height-speed envelope § 27.141, General—Flight Characteristics	§ 29.45, General—Performance § 29.49, Performance at minimum operating speed § 29.51, Takeoff data: general § 29.64, Climb: General § 29.71, Helicopter angle of glide: Category B § 29.75, Landing: General § 29.87, Height-velocity envelope § 29.141, General—Flight Characteristics

APPENDIX A. RELATED REGULATIONS AND DOCUMENTS (CONTINUED)

Table A-1. Related 14 CFR Parts 23, 25, 27, and 29 Regulations (Continued)

Subpart	Part 23 - Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes	Part 25 - Airworthiness Standards: Transport Category Airplanes	Part 27 – Airworthiness Standards: Normal Category Rotorcraft	Part 29 – Airworthiness Standards: Transport Category Rotorcraft
D-Design and Construction	§ 23.601, General § 23.603, Materials and workmanship § 23.605, Fabrication methods § 23.607, Fasteners § 23.609, Protection of structure § 23.611, Accessibility provisions § 23.613, Material strength properties and design values § 23.629, Flutter § 23.685(a), Control system details § 23.773, Pilot compartment view §§ 23.775(f) and (g), Windshields and windows § 23.859(i), Combustion heater fire protection, drains § 23.863, Flammable fluid fire protection	§ 25.601, General § 25.603, Materials § 25.605, Fabrication methods § 25.607, Fasteners § 25.609, Protection of structure § 25.611, Accessibility provisions § 25.613, Material strength properties and design values § 25.629, Aeroelastic stability requirements § 25.685(a), Control system details § 25.773(b)(1)(ii), Pilot compartment view § 25.775(d), Windshields and windows § 25.859(i), Combustion heater fire protection, drains § 25.863, Flammable fluid fire protection § 25.875, Reinforcement near propellers	§ 27.601, General § 27.603, Materials § 27.605, Fabrication methods § 27.607, Fasteners § 27.609, Protection of structure § 27.611, Inspection provisions § 27.613, Material strength properties and design values § 27.629, Flutter § 27.685(a), Control system details § 27.859(k), Combustion heater fire protection, drains § 27.863, Flammable fluid fire protection	§ 29.601, General § 29.603, Materials § 29.605, Fabrication methods § 29.607, Fasteners § 29.609, Protection of structure § 29.611, Inspection provisions § 29.613, Material strength properties and design values § 29.629, Flutter and divergence § 29.685(a), Control system details § 29.773(b)(1)(ii), Pilot compartment view § 29.859(i), Combustion heater fire protection, drains § 29.863, Flammable fluid fire protection

APPENDIX A. RELATED REGULATIONS AND DOCUMENTS (CONTINUED)

Table A-1. Related 14 CFR Parts 23, 25, 27, and 29 Regulations (Continued)

Subpart	Part 23 - Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes	Part 25 - Airworthiness Standards: Transport Category Airplanes	Part 27 – Airworthiness Standards: Normal Category Rotorcraft	Part 29 – Airworthiness Standards: Transport Category Rotorcraft
E-Powerplant	§ 23.901(d)(2), Installation § 23.903, Engines § 23.905(e), Propellers § 23.929, Engine installation ice protection § 23.939, Powerplant operating characteristics § 23.951(c), Fuel System, General § 23.975, Fuel tank vents and carburetor vapor vents § 23.997(e), Fuel strainer or filter § 23.1013(d), Oil tanks, vent § 23.1041, General - cooling § 23.1093, Induction system icing protection § 23.1095, Carburetor deicing fluid flow rate § 23.1097, Carburetor deicing fluid system capacity § 23.1099, Carburetor deicing fluid system detail design § 23.1101, Carburetor air preheat design § 23.1105, Induction system screens § 23.1157, Carburetor air temperature controls § 23.1189, Shutoff means § 23.1199(b), Extinguishing agent containers	§ 25.901(c), Installation § 25.903, Engines § 25.929, Propeller deicing § 25.939, Turbine engine operating characteristics § 25.941, Inlet, engine and exhaust compatibility § 25.951(c), Fuel System, General § 25.975, Fuel tank vents and carburetor vapor vents § 25.981, Fuel tank ignition prevention § 25.1013(d), Oil tanks, vent § 25.1041, General - cooling § 25.1093, Induction system icing protection § 25.1101, Carburetor air preheat design § 25.1105, Induction system screens § 25.1157, Carburetor air temperature controls § 25.1189, Shutoff means § 25.1199(b), Extinguishing agent containers	§ 27.939, Turbine engine operating characteristics § 27.951(c), Fuel System, General § 27.975, Fuel Tank Vents § 27.1041, General - cooling § 27.1093, Induction system icing protection	§ 29.901(c), Installation § 29.939, Turbine engine operating characteristics § 29.951(c), Fuel Systems, General § 29.975, Fuel Tank Vents and Carburetor Vapor Vents § 29.1013(d), Oil tanks, vent § 29.1041, General - cooling § 29.1093, Induction system icing protection § 29.1101, Carburetor air preheater design § 27.1105, Induction system screens § 29.1157, Carburetor air temperature controls § 29.1189(a), Shutoff means § 29.1199(b), Extinguishing agent containers

APPENDIX A. RELATED REGULATIONS AND DOCUMENTS (CONTINUED)

Table A-1. Related 14 CFR Parts 23, 25, 27, and 29 Regulations (Continued)

Subpart	Part 23 - Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes	Part 25 - Airworthiness Standards: Transport Category Airplanes	Part 27 – Airworthiness Standards: Normal Category Rotorcraft	Part 29 – Airworthiness Standards: Transport Category Rotorcraft
F-Equipment	§ 23.1301, Function and installations § 23.1305(c)(7), Powerplant instruments § 23.1307, Miscellaneous equipment § 23.1309, Equipment, systems, and installations § 23.1323(d), Airspeed indicating system § 23.1325, Static pressure system § 23.1326, Pitot heat indication systems § 23.1327, Magnetic direction indicator § 23.1351, General § 23.1357, Circuit protective devices § 23.1416, Pneumatic de-ice boot system § 23.1419, Ice protection	§ 25.1301, Function and installation § 25.1305(c)(5), Powerplant instruments § 25.1307(c), Miscellaneous equipment § 25.1309, Equipment, systems, and installations § 25.1323(e), Airspeed indicating system § 25.1325(b), Static pressure systems § 25.1326, Pitot heat indication system § 25.1327, Magnetic direction indicator § 25.1351, General § 25.1353, Electrical equipment and installations § 25.1357, Circuit protective devices § 25.1403, Wing icing detection lights § 25.1419, Ice protection § 25.1455, Draining of fluids subject to freezing	§ 27.1301, Function and installation § 27.1305(p), Powerplant instrumentation § 27.1307(d), Miscellaneous equipment § 27.1309, Equipment, systems, and installation § 27.1325(b), Static pressure systems § 27.1327, Magnetic direction indicator § 27.1351, General § 27.1419, Ice protection	§ 29.1301, Function and installation § 29.1305(a)(17), Powerplant instruments § 29.1309, Equipment, systems, and installations § 29.1323(f), Airspeed indicating systems § 29.1325(c), Static pressure and pressure altimeter systems § 29.1351, General § 29.1353, Electrical equipment and installations § 29.1419, Ice protection
G-Operating Limitations and Information	§ 23.1525, Kinds of operations § 23.1529, Instructions for Continued Airworthiness § 23.1559(b), Operating limitations placard § 23.1583(h), Operating limitations § 23.1585, Operating procedures	§ 25.1525, Kinds of operations § 25.1529, Instructions for Continued Airworthiness § 25.1583, Operating limitations § 25.1585(a)(6), Operating procedures	§ 27.1525, Kinds of operation § 27.1529, Instructions for Continued Airworthiness § 27.1559, Limitations placard § 27.1583, Operating limitations § 27.1585, Operating procedures	§ 29.1525, Kinds of operations § 29.1529, Instructions for Continued Airworthiness § 29.1559, Limitations placard § 29.1583, Operating limitations § 29.1585, Operating procedures
Other	Appendix C of Part 25	Appendix C	Appendix C of Part 29	Appendix C

APPENDIX A. RELATED REGULATIONS AND DOCUMENTS (CONTINUED)

Table A-2. Related 14 CFR Part 33 - Airworthiness Standards: Aircraft Engines Regulations

Subpart		
A - General	§ 33.4	Instructions for Continued Airworthiness
D - Design Construction	§ 33.35(b)	Fuel and induction system
E - Design and Construction; Turbine Aircraft Engines	§ 33.65 § 33.66 § 33.67(b)(4)(ii) § 33.68 § 33.77 § 33.89(b)	Foreign object ingestion–ice Bleed air system Fuel system Induction system icing Foreign object ingestion - ice Operational test

Table A-3. Related 14 CFR Part 35 - Airworthiness Standards: Propellers

Subpart		
A - General	§ 35.3 § 35.4	Instruction manual for installing and operating the propeller Instructions for Continued Airworthiness

Table A-4. Related Operating Rules

Subchapter	14 CFR Part	Subpart	Section
F – Air Traffic and General Operating Rules	91, General Operating and Flight Rules	F – Large and Turbine-Powered Multiengine Airplanes	§ 91.527 Operating in icing conditions
G – Air Carriers and Operators for Compensation or Hire: Certification and Operation	121, Operating Requirements; Domestic, Flag, and Supplemental Operations	U – Dispatching and Flight Release Rules	§ 121.629 Operating in icing conditions
	125, Certification and Operations: Airplanes Having a Seating Capacity of 20 or More Passengers or a Maximum Payload Capacity of 6,000 Pounds or More; and Rules Governing Person On Board Such Aircraft	F – Instrument and Equipment Requirements	§ 125.221 Icing conditions: Operating limitations
	135, Operating Requirements: Commuter and On Demand Operations and Rules Governing Person On Board Such Aircraft	D – VFR/IFR Operating Limitations and Weather Requirements	§ 135.227 Icing conditions: Operating limitations

14 CFR SFAR No. 88 Fuel Tank System Fault Tolerance Evaluation Requirements

A.2 ADVISORY CIRCULARS.

Except for ACs 25-7A and 23-8B, you may get the ACs listed below on the FAA web site or from the U.S. Department of Transportation at the following address: Subsequent Distribution Office, SVC-121.23, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785. AC 25-7A is available from the Superintendent of Documents, U.S. Government Printing Office,

APPENDIX A. RELATED REGULATIONS AND DOCUMENTS (CONTINUED)

Washington D.C. (stock number 050-007-01214-4, $33.00). You may buy copies of AC 23-8B from the Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250-7954. Make check or money order payable to the Superintendent of Documents.

AC 20-73	Aircraft Ice Protection
AC 20-115B	Radio Technical Commission for Aeronautics, Inc. (RTCA) Document RTCA/DO-178B
AC 20-117A	Hazards Following Ground Deicing and Ground Operations in Conditions Conducive to Aircraft Icing.
AC 20-147	Turbojet, Turboprop, and Turbofan Engine Induction System Icing
AC 21-16D	RTCA Document DO- 160D
AC 21-40	Application Guide for Obtaining a Supplemental Type Certification
AC 21.101-1	Establishing the Certification Basis of Changed Aeronautical Products
AC 23-8B	Flight Test Guide for Certification of Part 23 Airplanes
AC 23-16A	Powerplant Guide for Certification of Part 23 Airplanes and Airships
AC 23-17A	Systems And Equipment Guide For Certification Of Part 23 Airplanes
AC 23.143-1	Ice Contaminated Tailplane Stall
AC 23.629-1A	Means of Compliance with Section 23.629, Flutter
AC 23.1309-1C	Equipment, Systems, and Installation in Part 23 Airplanes
AC 23.1419-2C	Certification of Part 23 Airplanes for Flight in Icing Conditions
AC 25-7A Change 1	Flight Test Guide for Certification of Transport Category Airplanes
AC 25-11	Transport Category Airplane Electronic Display Systems
AC 25-22	Certification of Transport Airplane Mechanical Systems
AC 25.629-1A	Flutter Substantiation of Transport Category Airplanes
AC 25.1309-1A	System Design Analysis
AC 25.1419-1A	Certification of Transport Category Airplanes for Flight in Icing Conditions
AC 27-1B	Certification of Normal Category Rotorcraft

APPENDIX A. RELATED REGULATIONS AND DOCUMENTS (CONTINUED)

AC 29-2C	Certification of Transport Category Rotorcraft
AC 33-2B	Aircraft Engine Type Certification Handbook
AC 120-42A	Extended Range Operation with Twin-Engine Airplanes (ETOPS)
AC 120-58	Pilot Guide for Large Aircraft Ground Icing
AC 120-60	Ground Deicing and Anti-Icing Program
AC 135-16	Ground Deicing & Anti-icing Training & Checking
AC 135-17	Pilot Guide - Small Aircraft Ground Deicing (pocket)

A.3 RELATED READING MATERIAL.

(1) FAA Technical Report DOT/FAA/CT-88/8-1, "Aircraft Icing Handbook," published March 1991, updated September 1993, includes reference material on ground and airborne icing facilities, simulation procedures, and analytical techniques. This document represents all types and classes of aircraft. The FAA intends it to be a working tool for the designer and analyst of IPSs. The FAA William J. Hughes Technical Center continues with the transfer of material from the Aircraft Icing Handbook (AIHB) to the Electronic Aircraft Icing Handbook (EAIHB) web site:

http://aar400.tc.faa.gov/Programs/FlightSafety/icing/eaihbk.htm

(2) FAA Technical Report ADS-4, "Engineering Summary of Airframe Icing Technical Data," and Report No. FAA-RD-77-76, "Engineering Summary of Powerplant Icing Technical Data," provides technical information on airframe and engine icing conditions. They also provide methods of detecting, preventing, and removing ice accretion on airframes and engines in flight. Although most of the information in ADS-4 and FAA-RD-77-76 is still valid, some is outdated. More usable information is now available through recent research and experience and is included in the Aircraft Icing Handbook referenced in paragraph (1) above.

> **NOTE:** You may get copies of the FAA technical reports listed above from: the National Technical Information Service (NTIS), Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

(3) NACA Technical Note 1855 (1949), "Recommended Values of Meteorological Factors To Be Considered in the Design of Aircraft Ice-Prevention Equipment," NASA Ames Research Center, Moffett Field, California 94035.

(4) NACA Technical Note 2738 (1952), "A Probability Analysis of the Meteorological Factors Conducive to Aircraft Icing in the United States," NASA Glenn Research Center, Cleveland, Ohio 44135.

APPENDIX A. RELATED REGULATIONS AND DOCUMENTS (CONTINUED)

(5) RTCA/DO160D, "Environmental Conditions and Test Procedures for Airborne Equipment," dated July 29, 1997.

(6) RTCA/DO-178B, "Software Considerations in Airborne Systems and Equipment Certification," published December 1, 1992, provides an acceptable means of compliance for software used in airborne systems and equipment.

(7) RTCA/DO-254, "Design Assurance Guidance for Airborne Electronic Hardware."

> **NOTE:** You may request the RTCA documents from: RTCA Inc., 1140 Connecticut Avenue NW, Suite 1020, Washington, D.C. 20036.

(8) SAE AIR5504, "Aircraft Inflight Icing Terminology," (September 1, 2002).

(9) SAE AIR1168/4, "Ice, Rain, Fog, and Frost Protection."

(10) SAE ARP4087, "Wing Inspection Lights – Design Criteria."

(11) SAE ARP4754, "Certification Considerations for Highly-Integrated or Complex Aircraft Systems."

(12) SAE ARP4761, "Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment."

(13) SAE ARP5903, "Droplet Impingement and Ice Accretion Computer Codes," (October 16, 2003).

(14) SAE ARP5904, "Airborne Icing Tankers," (October 21, 2002).

(15) SAE ARP5905, "Calibration and Acceptance of Icing Wind Tunnels," (October 18, 2003).

> **NOTE:** You may get SAE Aerospace Recommended Practices and Aerospace Information Reports from: SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

APPENIDX B. NOMENCLATURE

B.1 TERMS.

Anti-icing: Preventing ice formation or buildup on a protection surface. This occurs by either evaporating the impinging water or by allowing it to run back and off the surface or to run back and freeze on non-critical areas.

Appendix C: The 14 CFR parts 25, Appendix C and 29, Appendix C icing envelopes for continuous maximum and intermittent maximum icing conditions.

Appendix C icing conditions: 14 CFR parts 25, Appendix C and 29, Appendix C certification icing condition standard for approving ice protection provisions on aircraft. The conditions are specified by altitude, temperature, liquid water content (LWC), representative drop size (mean effective diameter (MED)), and cloud horizontal extent.

> **NOTE:** In Appendix C, the term "mean effective diameter" refers to what is now called the "median volume diameter (MVD)." The MED of Appendix C was determined by using rotating multi-cylinders and assuming a Langmuir distribution.

Artificial ice: A structure formed from material other than frozen water, but intended to represent an ice accretion. See "simulated ice shapes."

Clear ice: See "glaze ice."

Collateral icing: Ice accretions that occur on aircraft surfaces other than those typically considered when aircraft certification tests use simulated ice shapes. Examples are ice feathers that accumulate on fuselage, nacelle, nacelle pylons, empennage, antennas, and wing surfaces.

Collection efficiency: See "water catch efficiency."

Computational fluid dynamics (CFD): The science of solving discretized equations for fluid flow on a computer.

Computed ice: An ice shape generated by CFD codes or other analytical means.

Critical ice shape: The aircraft surface ice shape formed within required icing conditions. It results in the most adverse effects for specific flight safety requirements. For an aircraft surface, the critical ice shape may differ for different requirements (for example, stall speed, climb, aircraft controllability, control surface movement, control forces, air data system performance, dynamic pressure probes for control force "feel" adjustment, ingestion and structural damage from shed-ice, engine thrust, engine control, and aeroelastic stability).

Critical aircraft ice shape configuration: The ice-contaminated aircraft configuration that results in the most adverse effects for specific flight safety requirements.

APPENDIX B. NOMENCLATURE (CONTINUED)

Critical surface: A surface whose integrity affects safe aircraft takeoff, flight, and landing. A surface that accretes ice and affects safe aircraft takeoff, flight, and landing is a critical surface for inflight icing.

Deice or deicing: The periodic shedding or removal of ice buildups from a surface. This occurs by destroying the bond between the ice and the protection surface.

Empirical validation/evaluation: Validation or evaluation of analytical results by experimental data.

Euler equations: The title given to equations, developed by L. Euler, for calculating the flow of a frictionless, nonviscous fluid. The equations address compressibility of a fluid. They do not address flowfield discontinuities, such as those from shocks. Flow field rotation can be computed. The Euler equations of fluid flow can be integrated throughout a finite region to determine the dynamic equilibrium of a finite volume of particles, applying Newton's second law (momentum) to the group of fluid particles. This flowfield solution is called Eulerian, compared with a more complex flowfield solution that tracks each fluid particle (the Lagrangian approach). Traditionally, flow field analyses performed using the Euler equations are considered to be between analyses performed using the potential flow and the Navier-Stokes equations, in complexity and sophistication.

Eulerian: See "Euler Equations."

Extended range operations with twin-engine airplanes (ETOPS): Operation of twin-engine airplanes for extended periods beyond alternate airports (AC 120-42A).

Failure ice: Aircraft ice accretion following failure of the ice protection system (IPS), or its components.

Finite wing: A wing having finite span. Vortices, which are shed at the wing tips, affect finite wings. Considerations such as spanwise airflow are more difficult to analyze theoretically.

Forecast icing conditions: Meteorological conditions that an FAA-approved weather provider expects to be conducive to forming ice on aircraft in flight.

Freezing drizzle (FZDZ): Precipitation at ground level or aloft in the form of liquid water drops. The drizzle drop diameters are less than 0.5 mm and greater than 0.05 mm. Freezing drizzle exists at air temperatures less than 0°C and colder (supercooled), remains in liquid form, and freezes on contact with objects on the surface or airborne.

Freezing fraction (*n*): The amount of impinging water that freezes at the point of impingement.

Freezing precipitation: Freezing rain or drizzle falling through or outside a visible cloud.

Freezing rain (FZRA): Precipitation at the ground level or aloft in the form of liquid water drops. The raindrop diameters are greater than 0.5 mm. Freezing rain exists at air temperatures

APPENDIX B. NOMENCLATURE (CONTINUED)

less than 0°C (supercooled), remains in liquid form, and freezes on contact with objects on the surface or airborne.

Glaze ice: Sometimes glaze ice is clear and smooth. Glaze ice usually contains some air pockets that result in a lumpy translucent appearance. Glaze ice results from supercooled drops striking a surface but not freezing rapidly on contact. Glaze ice is denser, harder, and sometimes more transparent than rime ice. Factors, which favor glaze formation, are those that favor slow dissipation of the heat of fusion (i.e., slight supercooling and rapid accretion). With larger accretions, the ice shape typically includes “horns” protruding from unprotected leading edge surfaces. Flight crews are more likely to assess the ice shape, rather than the clarity or color of the ice, accurately from the cockpit. The terms “clear” and “glaze” have been used for essentially the same type of ice accretion. Some reserve “clear ice” for thinner accretions that lack horns and conform to the airfoil.

Gridding: The process of defining elements (finite segments, zones, spaces, volumes, etc.) that describe the surface (body) and its external flow space. The grid elements are used with a flow solver to calculate flow conditions. Typically, the gridding is denser in areas where significant changes in the flow field occur (for example, in the boundary layer, high curvature surface areas, and shocks). Since gridding affects the definition of rapid flowfield changes, it also affects the precision of the flowfield solution and resulting body surface pressures. Gridding may be held fixed for a flowfield solution. It may also be adaptive (automatically changing with a time-stepping flowfield solution according to an algorithm within the CFD code). B-1 shows a gridding example.

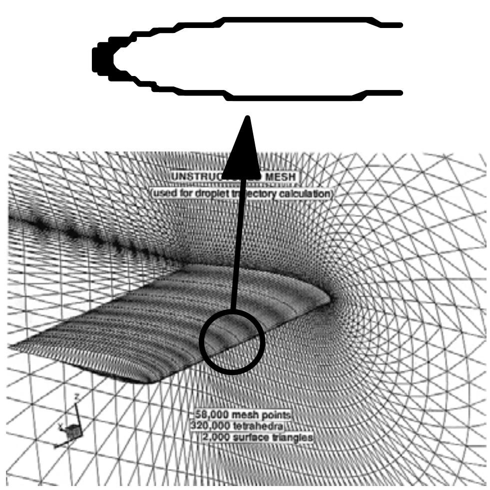


Figure B-1. Gridding of a NACA 0012 Wing Into a Mesh of Finite Volumes for Flow Field Analysis, Drop Impingement Computation, and Ice Accretion Analysis (Reference B1).

Hard wing airplanes: Airplanes without wing leading-edge high-lift devices.

Heavy icing: A descriptor used operationally by flight crews when they report encountered icing intensity to air traffic control. The rate of ice buildup requires maximum use of the ice protection systems to minimize ice accretions on the airframe. A representative accretion rate

APPENDIX B. NOMENCLATURE (CONTINUED)

for reference purposes is more than 3 inches (7.5 cm) per hour on the outer wing. A pilot encountering such conditions should consider immediate exit from the conditions.

Hybrid model: Wind tunnel model truncated aft of the leading edge and designed so the leading edge aerodynamic loading is the same as the full chord airfoil.

Ice bridging: Classic pneumatic deicing boot ice bridging occurs when a thin layer of ice is sufficiently plastic to deform to the shape of the inflated deicing boot. This occurs without the thin ice breaking or shedding during ensuing cycling of the deicing boot. As the deformed ice hardens and accretes more ice, the deicing boot becomes ineffective. Ice bridging may occur when enough supercooled water freezes during the inflated deicing boot dwell period. It will keep that shape after the deicing boot deflates and will form a deformed surface that continues to accrete ice and is unaffected by ensuing cycling of the deicing boot. A deicing boot ice bridge may also form when flying into increasingly colder ambient temperature conditions following a mixed-phase icing encounter at near-freezing temperatures. Ice bridging also refers to the ice "caps" or "bridges" between adjacent component surfaces. For example, unprotected leading edge surfaces of an elevator horn and the horizontal stabilizer.

Ice evidence probe: Device that accretes ice before ice accretes on the airframe or its components. You may use ice evidence probes as a visual icing cue.

Ice ridge: Formation of a ridge of ice typically aft of the ice protection surface. Runback ice or large drops impinging aft of the protection surface can cause ice ridges to form.

Icing encounter: An exposure to continuous or broken icing conditions until a gap or interruption longer than some preselected distance (for example, 1 nautical mile (nm)) or duration (for example, 1 minute) occurs.

Icing in cloud: Icing occurring within visible cloud. Cloud drops (diameter < 50 μm) will be present; freezing drizzle or freezing rain, or both, may be present.

Icing in precipitation: Icing occurring from an encounter with freezing precipitation (supercooled drops with diameters exceeding 0.05 mm, within or outside a visible cloud).

Ice accretion limit: The location farthest aft on a body at which ice accretes. You may measure this distance either as the streamwise distance from the leading edge, or as the surface distance from the stagnation point. This document defines the icing limit as the streamwise distance from the leading edge.

Impingement limit: The location farthest aft on a body where water drops impinge. This distance is usually measured as the surface length from the surface's leading edge.

Intercycle ice: Ice that builds up on a deiced surface and exists immediately before the deice system is activated.

APPENDIX B. NOMENCLATURE (CONTINUED)

Known icing conditions: Atmospheric conditions where ice formation is observed or detected in flight.

> **NOTE:** Because of the variability in space and time of atmospheric conditions, the existence of a report of observed icing does not guarantee the presence or intensity of icing conditions at a later time. A report of no icing does not guarantee the absence of icing conditions at a later time.

Known or observed or detected ice accretion: Ice observed visually on the aircraft by the flight crew or identified by onboard sensors.

Lagrangian drop trajectory computation: A method for calculating the trajectory of water drops in the surrounding airflow. These trajectories are typically calculated by determining the forces exerted on individual drops. The calculation proceeds by sequentially calculating forces and resulting motion as the drop moves through the flowfield surrounding the body of interest (for example, the wing, fuselage, engine inlet, etc.). The drop trajectory calculation finishes when the drop either impacts on the body or passes it.

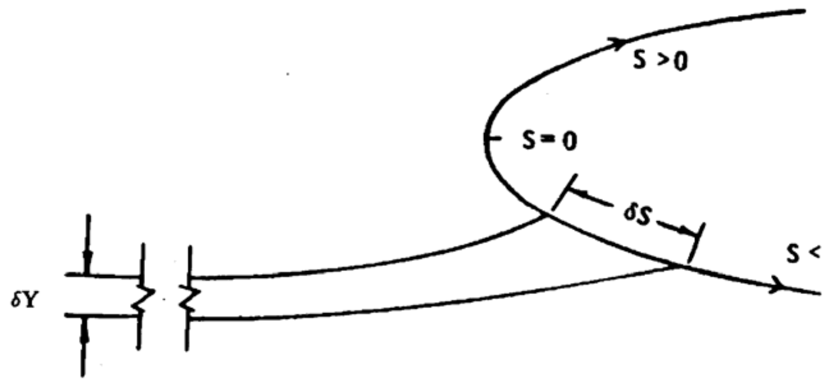
Langmuir distribution: A family of theoretical drop size distributions. The distributions are based on the percentages of liquid water content of each drop size (appendix I of this AC).

Light icing: A descriptor used operationally by flight crews when they report encountered icing intensity to traffic control. The rate of ice buildup requires occasional cycling of manual deicing systems to minimize ice accretions on the airframe. A representative accretion rate for reference purposes is 1/4 inch to one inch (0.6 to 2.5 cm) per hour on the outer wing. The pilot should consider exiting the condition.

Liquid water content (LWC): The mass of water in liquid cloud drops within a unit volume of cloud. It is usually given in units of grams of water per cubic meter of air (g/m^3).

Local water catch efficiency (β): The ratio of dY to ds. dY is the freestream distance between two drop trajectories that intersect a surface near a point P a distance ds apart. Letting ds approach 0, the value of β at P is the derivative dY/ds (figure B-2).

APPENDIX B. NOMENCLATURE (CONTINUED)



$$\beta = \lim_{\delta S \to 0} \frac{\delta Y}{\delta S} = \frac{dY}{dS}$$

Figure B-2. Definition of Local Impingement Efficiency Parameter, β.

Lower horn angle: The angle of the lower horn of a glaze ice shape, θ_{lower}, calculated with the polar direction from the wing chord plane (figure B-3).

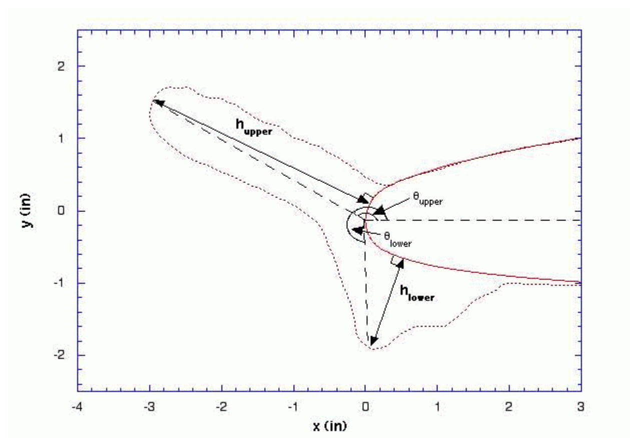


Figure B-3. Definition of Horn Maximum Thickness Angle (Reference B1).

Ludlam limit: The value of LWC when the maximum rate of freezing can occur on a surface for a given combination of surface temperature, airspeed, altitude, and drop collection efficiency.

Mean effective diameter (MED): The drop diameter which divides the total water volume present in the drop distribution in half. So, half the water volume will be in larger drops and half the volume in smaller drops. The value is based on an assumed drop size distribution.

APPENDIX B. NOMENCLATURE (CONTINUED)

Median volume diameter (MVD): The drop diameter that divides the total water volume present in the drop distribution in half. So, half the water volume will be in larger drops and half the volume in smaller drops. The value is obtained by actual drop size measurements.

Mixed ice: A simultaneous appearance or a combination of rime and glaze ice characteristics. Accurate identification of mixed ice from the cockpit may be difficult since the clarity, color, and shape of the ice will be a mixture of rime and glaze characteristics.

Mixed-phase icing conditions (mixed conditions): Partially glaciated clouds at an ambient temperature below 0°C. The clouds contain ice crystals and supercooled liquid water drops.

Moderate icing: A descriptor used operationally by flight crews to report encountered icing intensity to traffic control. The rate of ice buildup requires frequent cycling of manual deicing systems to minimize ice accretions on the airframe. A representative accretion rate for reference purposes is 1 to 3 inches (2.5 to 7.5 cm) per hour on the outer wing. The pilot should consider exiting the condition as soon as possible.

Monitored surface: The surface of concern regarding ice hazard (for example, the leading edge of a wing).

NACA inlet: A flush mounted divergent channel that creates vortices that entrain air into the inlet. Sometimes it is called a submerged inlet. NACA developed these inlets in the late 1940s and early 1950s.

Natural icing flight tests: Flight tests performed in icing conditions that occur in a naturally formed cloud.

Navier-Stokes: The name given to the equations of motion for flow of a compressible, viscous fluid. A Navier-Stokes solver is typically a computer code algorithm that provides a numerical solution of the Navier-Stokes equations. A Navier-Stokes computer code is a computational fluid-dynamics code that contains a Navier-Stokes solver and computes the flow of a compressible or incompressible, viscous fluid. Accurate determination of the motion of a fluid (air) at high Reynolds number becomes important in the thin layer of air bounding the surface of a body. As the flow of boundary-layer transitions from laminar to turbulent, and then to separation, the viscosity and compressibility of the fluid must be addressed. Solutions for the flow field in the boundary layer may be approximate. Those using solvers other than a full solution of the Navier-Stokes equations are further limited by additional approximations used to avoid solving the full equations. These lesser solvers typically average the Reynolds stresses across the turbulent boundary layers by using empirically based approximations. The robustness of the various approximations varies. Some provide reasonable information as the intensity of the boundary-layer turbulence increases. Using these approximations is questionable with separated boundary-layer flow. The types of flow conditions for which the empirical data are valid, therefore, limit these approximations. Full numeric solution of the Navier-Stokes equations is difficult and costly. The five equations must be solved simultaneously for a multitude of very small finite volumes for surface area of high curvature to obtain good accuracy. A common practice is to limit the volume in which the full equations are solved to the region next to the

APPENDIX B. NOMENCLATURE (CONTINUED)

surface. The less complex far field flow solutions are computed using simplified solutions of the equations. The far field flow viscosity and compressibility effects are less important. Attention must be given to the interface between the two flow solutions.

Panel code: A computational fluid-dynamics code that solves for the average flow over finite panels that define a body surface.

Potential flow: Given a flow field specified by a vector function, V, if V can be written as:

$$V = \nabla\varphi \qquad \text{(Eqn. B-1)}$$

for some scalar function φ, then the flow is referred to as a potential flow (and φ is called the potential function.) Inviscid, irrotational flows are potential flows. For example, potential flow equations can be used to calculate the influence of a flow phenomenon (for example, a source or sink) on the velocity potential elsewhere in an irrotational, nonviscous fluid flow field. The fluid may be incompressible or compressible. Potential flow codes are the simplest of the flowfield solvers. However, they do not address the issues of the real fluid rotational flow and viscosity. The flowfield solutions produced by the potential flow equation provide useful aerodynamic information for problems where flow rotation and viscosity effects are insignificant.

Potential icing conditions: Atmospheric icing conditions that airframe manufacturers typically define in terms of temperature and visible moisture that may result in aircraft ice accretion on the ground or in flight. The potential icing conditions are typically defined in the airplane flight manual or in the airplane operation manual.

Preactivation ice: Protected surface ice accretion that occurs before the ice protection system becomes fully effective.

Protected surface: A surface containing ice protection. The protected surface is typically located at the surface's leading edge.

Protection surface: The active surface of an ice protection system (for example, the surface of a deicing boot or thermal ice protection system).

Reference surface: The observed (directly or indirectly) surface used as a reference for ice presence on the monitored surface. Ice presence on the reference surface must occur before —or coincidentally with—ice presence on the monitored surface. Examples of reference surfaces include windshield wiper posts, ice evidence probes, propeller spinners, and the metric sensor surface of ice detectors. The reference surface may also be the monitored surface.

Residual ice: Ice that remains on a protected surface immediately after deicing system actuation.

Reynolds averaged Navier-Stokes (RANS): Navier-Stokes solver schemes that approximate the momentum changes due to turbulence (Reynolds stresses). The momentum changes are calculated in the boundary-layer wake through a set of equations.

APPENDIX B. NOMENCLATURE (CONTINUED)

Reynolds number: A dimensionless parameter that is the ratio of the inertia force to viscous force for a fluid. It is calculated according to the formula:

$$Re = \rho_a VL/\mu \qquad \text{(Eqn. B-2)}$$

V is a characteristic velocity, ρ_a is the density of the fluid, μ is the viscosity of fluid, and L is a characteristic length. Flow within the boundary layer of a surface correlates strongly with the Reynolds number of that flow. The Reynolds number also correlates with the transition between laminar and turbulent flow in the boundary layer. This occurs at a critical Reynolds number for a flat plate. Reynolds number parameters also characterize the behavior of a separated boundary layer. The Reynolds number is a scaling parameter for fluid flow over a surface since it controls transition and separation of the flow across the surface. To get similar full-scale aerodynamic parameter estimates (surface pressures) through testing of scaled models, the Reynolds number of the scaled model test should be similar to that of the full-scale aircraft in flight. Testing techniques, such as early tripping of the laminar boundary layer (that occur at low Reynolds numbers) to simulate regions of full-scale turbulent boundary-layer flow, have been used to avoid the expense of testing at Reynolds numbers approaching full-scale. Typically, testing at high Reynolds numbers requires the expensive use of pressure or cryogenic wind tunnels.

Rime ice: A rough, milky, opaque ice formed by the rapid freezing of supercooled drops after they strike the aircraft. The rapid freezing results in trapped air. The trapped air gives the ice its opaque appearance and makes it porous and brittle. Rime ice typically accretes along the stagnation line of an airfoil and is more regular in shape and conforms more to the airfoil than glaze ice. Crew are more likely to assess the ice shape, rather than the clarity or color of the ice accurately from the cockpit.

Runback ice: Ice that forms from the freezing or refreezing of water leaving protected surfaces and running back to unprotected surfaces.

Running wet: Defines heat requirements for running wet anti-icing that are based on maintaining an above-freezing surface temperature. This allows some of the impinging water to run back and freeze aft of the heated area or off the surface.

Running wet system: Any anti-icing system that supplies enough heat to prevent impinging water drops from freezing on the heated surface. A running wet system does not supply enough heat for complete evaporation.

s/c: The surface distance, normalized by chord length, aft of the leading edge of the surface (airfoil).

Separated flow: A flow condition in which the flow is no longer attached to the surface. This phenomenon is associated with vortex formation and large energy losses in the flow. Separated flow typically results in losses in lift, increased drag, and reduced control effectiveness of lifting surfaces.

APPENDIX B. NOMENCLATURE (CONTINUED)

Severe icing: A descriptor used operationally by flight crews reporting encountered icing intensity to traffic control. The rate of ice buildup results in the inability of the ice protection systems to remove the buildup of ice satisfactorily. Also, ice builds up in locations not normally prone to icing, such as areas aft of protected surfaces and any other areas identified by the manufacturer. Immediate exit from the condition is necessary.

Shedding: Ice shedding is the act of separating or breaking away accreted ice from an aircraft part. Ice may shed by passive means for any aircraft surface (for example, by the natural aerodynamic or centrifugal forces) or by active means for protected surfaces of the aircraft (for example, by a deicing system).

Simulated ice shapes: Ice shapes made of wood, epoxy, or other materials by any construction technique. Simulated or artificial ice shapes can be designed and manufactured to reproduce ice shapes accumulated during simulated icing conditions. Simulated critical ice shapes may be tested during certification of ice protection systems. (See critical ice shapes and validation.)

Simulated icing: The process of creating simulated ice, for example, accumulating ice on an aircraft or aircraft surface by using a spray array, in an icing tunnel or behind an icing tanker.

Supercooled drops: Water drops that remain unfrozen at temperatures below 0°C. Supercooled drops exist in clouds, freezing drizzle, and freezing rain in the atmosphere. These drops may impinge and freeze after contact on aircraft surfaces.

Supercooled large drops (SLD): Liquid drop with diameters greater than 0.05 mm at temperatures less than 0°C, i.e., freezing rain or freezing drizzle.

Total water catch efficiency (E): The total amount of water or ice that impinges on the aircraft surface. It is the integrated value of the local catch. For a two-dimensional (2D) body (for example, on an airfoil) the total catch is more conveniently expressed as a unit span. An alternative (and equivalent) measurement (for a 2D case) is the weighted average of the water catch efficiencies shown in equation B-3.

$$E \quad \frac{\int \beta ds}{\int ds} \qquad \text{(Eqn. B-3)}$$

Upper horn angle: The angle of the upper horn of a glaze ice shape, θ_{upper}, calculated with the polar direction from the wing chord plane (figure B-3).

Validation: The process that confirms that a computer code is functioning correctly; documentation and code version control meet the standards of the validating organization; and that predicted ice shapes match accepted experimental data, according to accepted validation standards (within established tolerances).

Verification: The process of determining that implementation of algorithms (for example, a computer code) accurately represents the developer's conceptual description of a problem

APPENDIX B. NOMENCLATURE (CONTINUED)

solution. The code should accurately implement the mathematical rules or procedures used to solve the problem.

Water catch: The mass of water captured between the upper and lower impingement limits during a specified interval of time.

Water catch efficiency (β): The ratio of actual water drops mass flux at the surface to the water drops mass flux in the freestream when water drop paths are straight lines. It is also known as the collection efficiency, impingement efficiency, or local impingement efficiency.

Weber number: A dimensionless parameter that is the ratio of the inertia of air to the surface tension force at the air/water interface. It could also be the ratio of these parameters for any two fluids. For the interface of air and water, the Weber number (*We*) is:

$$We_l = \rho_w V_\infty^2 L / \sigma_{w/a} \qquad \text{(Eqn. B-4)}$$

V_∞ is a characteristic velocity, ρ_w is the density of water, $\sigma_{w/a}$ is the water surface tension, and L is a characteristic length (for example, water film thickness and drop diameter). Similar to Reynolds number, the Weber number is a scaling parameter for liquid fluids and is used to explore liquid flow behavior or ice accretion by using scaled models or when testing with scaled icing cloud drops. Typically, it is not possible to hold the Reynolds number and Weber number constant for a scaled test. Resolution of this dilemma typically results in a compromise with favor given to one or the other parameter. This depends on the scaling parameter's influence on the desired test results. For some cases of ice accretion, determining the scaled freestream velocity by holding model-scale and full-scale Weber number (based on leading edge water film thickness) constant and holding the freestream temperature the same has resulted in satisfying comparisons between full and model scale ice shapes. Alternatively, the model scale freestream velocity may be determined by averaging the values determined by holding the Weber and Reynolds number constant between full scale and model scale.

B.2 ACRONYMS AND SYMBOLS.

ac	Aerodynamic center of lift (sectional)
A, A_c	Accumulation parameter, $[V(LWC)t]/[\rho_{ice}L]$
A/C	Aircraft
AC	Advisory Circular
AD	Airworthiness Directive
AFIDS	Advisory flight ice detector system
AFM	Airplane Flight Manual
AIAA	American Institute of Aeronautics and Astronautics
AGL	Above ground level
AOA	Angle-of-attack, degrees
APMS	Aerodynamic Performance Monitoring System
Appendix C	Appendix C of 14 CFR Part 25
APU	Auxiliary power unit

APPENDIX B. NOMENCLATURE (CONTINUED)

ARP	Aerospace Recommended Practice
AS	Aerospace Specification
ASIC	Application specific integrated circuits
ASL	Altitude with respect to sea level
BITE	Built-in test equipment
b	Relative heat factor, $[LWC\beta_0 c_{p,ws}]/h_c$
C	Celsius
c	Chord
c_d	Drag coefficient (sectional)
c_l	Lift coefficient (sectional)
c_m	Pitching-moment coefficient (sectional)
c_p	Specific heat of air
$c_{p,ws}$	Specific heat of water at the surface temperature
C_P	Pressure coefficient
CAR	Civil Air Regulations
CIRA	Centro Italiano Ricerche Aerospaziali
CFD	Computational fluid dynamics
CFR	Code of Federal Regulations
d	Twice the airfoil's leading edge radius
DER	Designated engineering representative
DES	Detached eddy simulation
DNS	Direct numerical simulation
E	Total water catch efficiency
ECDS	Eddy current deicing system
EEDS	Electro-expulsive deicing system
EIDI	Electro-impulse deicing system
Eqn.	Equation
ETOPS	Extended range operation with twin-engine airplanes
F	Fahrenheit
FAA	Federal Aviation Administration, United States
FIDS	Flight ice detection systems
FMEA	Failure modes and effects analysis
Ft	Feet
FZDZ	Freezing drizzle
FZRA	Freezing rain
g	Gram(s)
h	Height
h_f	Water film thickness
h_c	Convective heat-transfer coefficient
h_G	Gas-phase mass-transfer coefficient
HE	Horizontal extent
ICTS	Ice-contaminated tailplane stall
IFC	Instrument flight conditions
IFR	Instrument flight rules
IMC	Instrument meteorological conditions

APPENDIX B. NOMENCLATURE (CONTINUED)

In	Inch(es)
IPS	Ice protection system
KOEL	Kind of equipment list
K	Drop inertia parameter, [$\rho_w MVD^2 V$]/[$18d\mu$], (c is sometimes used rather than d in the denominator.)
K_0	Modified drop inertia parameter, $[\lambda/\lambda_{Stokes}]K$
k	Height of the surface roughness or protuberance
k/c	Height of the surface roughness or protuberance normalized by surface chord
kt	Knots
LES	Large eddy simulation
LWC	Liquid water content
M	Mach number
m	Meter(s)
MED	Mean effective diameter
Microns	Micrometer
min	Minute
mm	Millimeter(s)
MMEL	Master minimum equipment list
mph	Miles per hour
MVD	Median volume diameter
n	Freezing fraction, $[c_{p,ws}/ \Lambda_f][\varphi + \theta/b]$
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NASA-GRC	National Aeronautics and Space Administration Glenn Research Center
NLF	Natural laminar flow
nm	Nautical miles
OAT	Outside ambient temperature
p	Static pressure
PFIDS	Primary flight ice detector system (also known as PIIDS – primary in-flight ice detection system)
PLD	Programmable logic devices
p_w	Vapor pressure of water in the atmosphere
p_{ww}	Vapor pressure of water at the icing surface
Q_A	Heat available
Q_R	Heat required
r	Recovery factor
rpm	Revolutions per minute
RANS	Reynolds-averaged Navier-Stokes
R, Re	Reynolds number
RFM	Rotorcraft Flight Manual
RTCA	Radio Technical Commission for Aeronautics, Inc.
SAE	Society of Automotive Engineers
s	Surface length
s, sec	Second(s)
SFAR	Special Federal Aviation Regulations

APPENDIX B. NOMENCLATURE (CONTINUED)

SLD	Supercooled large drops
t	Time
t_f	Freezing temperature
t_s	Surface temperature
t_{st}	Static temperature
T	Temperature
T_S	Static air temperature
TAS	True airspeed
TN	Technical note
V	Velocity
V_D	Dive velocity
V_{MO}	Maximum operating velocity
V_{NE}	Never exceed velocity
VFR	Visual flight rules
W	Ice accretion rate
We	Weber number
We_l	Weber number based on surface length
We_h	Weber number based on water-film thickness and water properties
$W_{detector}$	Ice accretion rate of the ice detector sensor
W_{engine}	Ice accretion rate of the engine
W_{wing}	Ice accretion rate of the wing
x/c	Longitudinal distance aft of the surface's (airfoil's) leading edge normalized by the chord of the surface (airfoil)
y/c	Vertical distance above the surface's (airfoil's) reference line normalized by the chord of the surface (airfoil)
2D	Two-dimensional
3D	Three-dimensional
α	Angle-of-attack, degree(s)
β	Local water catch efficiency
β_0	Collection efficiency at the stagnation line
Λ	Leading edge sweep angle
Λ_f	Latent heat of freezing
Λ_v	Latent heat of condensation
λ	Drop range
λ_{Stokes}	Drop range if Stokes Law applies
φ	Water drop energy transfer parameter, $t_f - t_{st} - V^2/[2c_{p,ws}]$
^{o}	Degree(s)
ρ_a	Density of air
ρ_i	Density of ice
ρ_w	Density of water
θ	Air-energy transfer parameter, $(t_s - t_{st} - [\mathrm{r}V^2]/[2c_{p,ws}]) + ([h_G/h_c][p_{ww}\text{-}\ p_w])\ \Lambda_v$
$\sigma_{w/a}$	Surface tension of water divided by surface tension of air
μ	Absolute viscosity of air
µm	Micrometer, micron
§	Section of the Code of Federal Regulations

APPENDIX B. NOMENCLATURE (CONTINUED)

″	Inch(s)
$>$	Greater than
$<$	Less than
∇	Divergence

B.3 REFERENCES.

B1. "Ice Accretion and Droplet Impingement Codes," SAE ARP5903.

APPENIDX C. BACKGROUND OF ICE PROTECTION REGULATORY DEVELOPMENT

The following background information is provided to determine the certification basis for approved aircraft ice protection systems, as needed for STC applications, and for tracking icing requirement changes.

C.1 TRANSPORT CATEGORY AIRPLANES (14 CFR PART 25).

The FAA certified airplanes under the Civil Air Regulations (CAR) part 04 until 1953. Civil Air Regulations § 4a.5814 required that if manufacturers installed deicing boots, then they had to provide positive means to deflate all wing boots. There were no other references to an airplane ice protection system (IPS) in CAR part 04.

The FAA codified Part 4b of the CAR on December 31, 1953. The requirement for positive means of deflating deicing boots was incorporated, with change, in CAR § 4b.640. CAR § 4b.640 stated that:

> "When an ice protection system is installed, it shall be of an approved type. If pneumatic boots are used, at least two independent sources of power and a positive means for the deflation of the boots shall be provided."

CAR § 4b.351(b)(ii) provided requirements for pilot compartment vision in icing conditions. CAR § 4b.406 provided propeller-deicing requirements. CAR § 4b.461 provided for preventing and eliminating ice buildups in engine air induction systems. CAR § 4b.612(a)(5) required that the airspeed indicating system have a heated pitot tube or equivalent means of preventing malfunctioning due to icing.

CAR Amendment 4b-2, effective August 25, 1955, introduced icing envelopes similar to the current 14 CFR part 25, Appendix C. The graphs added by CAR Amendment 4b-2 (figures 4b-24a, 4b-24b, 4b-24c, 4b-25a, 4b-25b, and 4b-25c) were identical in substance and format to the current 14 CFR part 25, Appendix C envelopes with a few exceptions. These envelopes described the liquid water content (LWC), the mean effective diameter (MED) of drops, the temperature, and horizontal and vertical extent of the supercooled icing cloud environment. In the figures introduced by CAR Amendment 4b-2, the units of the distances shown on the graphs were expressed in statute miles instead of nautical miles. If the correction for the difference in value between nautical and statute miles is made, the LWC is identical between the CAR Amendment 4b-2 figures and the current 14 CFR part 25, Appendix C envelopes.

There are two significant differences between the CAR Amendment 4b-2 envelopes and the current 14 CFR part 25, Appendix C. Originally, the minimum MED in the intermittent maximum conditions was 20 micrometers versus the current MED of 15 micrometers. The LWC-versus-distance factor chart minimum cloud horizontal extent was 1.5 statute miles, compared with the current 0.26 nautical miles (0.3 statute miles). The selected icing cloud envelopes were considered to be important for the design of thermal ice protection systems on

APPENDIX C. BACKGROUND OF ICE PROTECTION REGULATORY DEVELOPMENT (CONTINUED)

transport category airplanes, as opposed to more complete scientific "characterizations" (Reference C1). A complete characterization may cover a wider range of parameters and values. Traditionally, "Continuous Maximum" conditions are applied to airframe ice protection and "Intermittent Maximum" conditions are applied to engine ice protection (Reference C2). Statistical analysis of data used to establish CAR part 4b, figures 4b-24a and 4b-25a and subsequent data shows that 99 percent of the data are in the temperature variant LWC envelopes (Reference C1).

CAR Amendment 4b-6, effective August 12, 1957, changed the icing envelopes to the current requirements and changed CAR § 4b.461, "Induction system deicing and anti-icing provisions." The preamble to the amendment states:

> "There are included herein changes which extend the currently effective provisions governing intermittent maximum icing conditions so as to cover conditions which might be critical insofar as the turbine engine induction system is concerned. In this regard, the data are being extended in accordance with NACA Technical Note 2738 and involve a revision of figure 4b-25a to cover drop diameters as low as 15 microns and a revision of figure 4b-25c to cover distances down to 0.3 mile. The icing conditions prescribed in the currently effective regulations are applicable in the main to the airframe. The changes made in CAR § 4b.461 required the turbine powerplant to be subjected to the same icing conditions and required that the induction system be protected to prevent serious engine power loss. A similar requirement is incorporated with respect to certification of turbine engines by an amendment to part 13 which is being made concurrently with this amendment."

The FAA recodified CAR Part 4b into 14 CFR part 25, effective January 1, 1965. After recodification, with minor editorial changes, the content of CAR § 4b.640, Ice protection, became 14 CFR § 25.1419; CAR § 4b.406, Propeller deicing provisions, became 14 CFR § 25.929; CAR § 4b.612(a)(5), Airspeed indicating systems, became 14 CFR § 25.1323(e); CAR § 4b.351(b)(1)(ii), Pilot compartment view, became 14 CFR § 25.773(b)(1)(ii). In 14 CFR part 25, the FAA changed the CAR § 4b.351 reference to the most severe icing conditions for which approval of the airplane is sought to reference the icing conditions specified in 14 CFR § 25.1419. CAR § 4b.461, Induction system deicing and anti-icing provisions, became 14 CFR § 25.1093.

Amendment 25-5, (30 FR 8261, June 29, 1965) effective July 29, 1965, changed 14 CFR § 25.1325(b) to require that each static port be designed and located so there is no change in the correlation between air pressure in the static pressure system and true ambient atmospheric static pressure when the airplane encounters the continuous and intermittent maximum icing conditions defined in 14 CFR part 25, Appendix C.

Amendment 25-11, (32 FR 6913, May 5, 1967) effective June 4, 1967, changed 14 CFR § 25.1585 to require that the Airplane Flight Manual (AFM) include information on using ice protection equipment.

APPENDIX C. BACKGROUND OF ICE PROTECTION REGULATORY DEVELOPMENT (CONTINUED)

Amendment 25-23, (35 FR 5679, April 8, 1970) effective May 8, 1970, changed 14 CFR § 25.1419 to require that the effectiveness of the IPS and its components be shown by flight tests of the airplane or its components in measured natural icing conditions. Before this amendment, the FAA considered flight tests in natural icing conditions as one means of compliance but they were not mandatory. Amendment 25-23 also changed 14 CFR § 25.1309 to include extra requirements for certificating equipment, systems, and installations. The FAA changed the regulation to require a comprehensive systematic failure analysis, supported by suitable tests, to ensure that the safety objectives of the probability of occurrence decrease as the hazard of a failure increases.

Amendment 25-36, 39 FR 35432, October 1, 1974, (effective October 31, 1974), added the falling and blowing snow requirements to 14 CFR § 25.1093. The FAA changed requirements insuring acceptable induction system's icing protection during ground operations icing conditions in 1977 and again in 1984 by Amendment 25-40, 42 FR 15034, March 17, 1977 and Amendment 25-57, 49 FR 6832, February 23, 1984, respectively.

Amendment 25-38, (41 FR 55468, December 20, 1976) effective December 20, 1976, added 14 CFR § 25.1403 to require a means for illuminating, or otherwise determining, ice accretion on the parts of the wings that are critical for ice buildup. The requirement is not applicable if the aircraft is prohibited from flight in icing conditions at night.

Amendment 25-43, (43 FR 10339, March 13, 1978) effective April 12, 1978, added 14 CFR § 25.1326 to require installing a pitot heat indication system on airplanes equipped with flight instrument pitot heating systems.

Amendment 25-46, (43 FR 50598, October 30, 1978) effective December 1, 1978, added 14 CFR § 25.1416 to require specific standards for pneumatic deicing boots.

Amendment 25-72, (55 FR 29785, July 20, 1990) effective July 20, 1990 transferred 14 CFR §§ 25.1416 to 25.1419 for clarification and editorial improvement and deleted 14 CFR § 25.1416.

APPENDIX C. BACKGROUND OF ICE PROTECTION REGULATORY DEVELOPMENT (CONTINUED)

Table C-1. Chronology of 14 CFR Part 25 Icing Certification Requirements

DATE OF APPLICATION FOR AIRPLANE TYPE CERTIFICATION	CAR/TITLE STATUS	ICING CERTIFICATION REQUIREMENTS
Before December 31, 1953	CAR Part 4	CAR § 4.5814
On or after December 31, 1953	CAR Part 4b (December 31, 1953, as amended through Amendment 4b-16)	CAR §§ 4b.351(b)(ii), 4b.406, 4b.461, 4b.612(a)(5)4b.640
On or after August 25, 1955	Amendment 4b-2	CAR § 4b.640 amended to incorporate continuous maximum and intermittent maximum icing conditions which might be reasonably expected during normal operations
On or after August 12, 1957	Amendment 4b-6	Changed the intermittent maximum icing conditions to include mean effective drop diameters as small as 15 µm (figure 4b-25a). Extended the liquid water content factor, F, to distances as short as 0.3 miles. Amended CAR § .461 to require turbine powerplants and induction systems to be subjected to the continuous maximum and intermittent maximum icing conditions. (The preamble stated that the then current icing conditions requirements were mainly applicable to the airframe.)
On or after February 1, 1965	Recodification, 29 FR 18291, December 24, 1964	14 CFR § 25.1419 (originally CAR § 4b.640, with minor editorial changes), 14 CFR § 25.929 (originally § 4b.406), 14 CFR § 25.1323(e) (originally CAR § 4b.612(a)(5)), 14 CFR § 25.773(b)(1)(ii) (originally CAR § 4b.351(b)(1)(ii)), and 14 CFR § 25.1093 (originally CAR § 4b.161). The CAR § 4b.351 reference to the most severe icing conditions for which approval of the airplane is sought, was changed to reference the icing conditions specified in 14 CFR § 25.1419.
On or after July 29, 1965	Amendment 25-5, 30 FR 8261, June 29, 1965	14 CFR § 25.1325(b) changed to require that the calibration of the static pressure source not change when the airplane encounters 14 CFR part 25, Appendix C icing conditions.
On or after June 4, 1967	Amendment 25-11, 32 FR 6913, May 5, 1967	14 CFR § 25.1585 changed to require that the AFM include information on use of the ice protection equipment.

APPENDIX C. BACKGROUND OF ICE PROTECTION REGULATORY DEVELOPMENT (CONTINUED)

Table C-1. Chronology of 14 CFR Part 25 Icing Certification Requirements, Continued

DATE OF APPLICATION FOR AIRPLANE TYPE CERTIFICATION	CAR/TITLE STATUS	ICING CERTIFICATION REQUIREMENTS
On or after May 8, 1970	Amendment 25-23, 35 FR 5679, April 8, 1970	14 CFR § 25.1419 changed to require that the effectiveness of the IPS and its components be shown by flight test of the airplane or its component in measured icing conditions. 14 CFR § 25.1309 changed to include added requirements for certificating equipment, systems, and installations.
On or after October 31, 1974	Amendment 25-36, 39 FR 35461, October 1, 1974	Falling and blowing snow added to 14 CFR § 25.1093.
On or after December 20, 1976	Amendment 25-38, 41 FR 55468, December 20, 1976	14 CFR § 25.1403 added to require a means to illuminate or otherwise determine ice accretion on parts of the wing that are critical for ice buildup, unless the airplane is limited from night operations.
April 12, 1978	Amendment 25-43, 43 FR 10339, March 13, 1978	14 CFR § 25.1326 added to require a pitot heat indication system, for airplanes with a heated pitot system.
December 1, 1978	Amendment 25-46, 43 FR 50598, October 30, 1978	14 CFR § 25.1416 added to require specific standards for pneumatic deicing boots.
July 20, 1990	Amendment 25-72, 55 FR 29785, July 20, 1990	14 CFR § 25.1403 transferred to 14 CFR § 25.1419 for clarification and editorial improvement. 14 CFR § 25.1416(c) changed to allow use of the “dark cockpit” concept (a warning when failure occurs rather than continual pilot monitoring).

C.2 NORMAL, UTILITY, ACROBATIC, AND COMMUTER CATEGORY AIRPLANES (14 CFR PART 23)

The FAA certificated airplanes under CAR part 04 until 1945. CAR § 04.5814 required that if deicing boots were installed, they would have a positive means of deflation. There were no other references to an IPS in CAR part 04. When the FAA wrote separate regulations (CAR part 03) for normal category airplanes, they incorporated (without change) this requirement for positive means of deflating deicing boots in CAR § 03.541. In 1949, the FAA renumbered CAR § 03.541 as CAR § 3.712.

The FAA did not address ice protection again until they changed CAR part 03 in 1962 by Amendment 3-7. This amendment added CAR § 3.772 and CAR § 3.778. The amendment requires that the applicant provide information in the form of a placard in clear view to the pilot

APPENDIX C. BACKGROUND OF ICE PROTECTION REGULATORY DEVELOPMENT (CONTINUED)

specifying the types of operation and the meteorological conditions to which the airplane is limited by the equipment installed. This section places icing as a specific example of the meteorological conditions to be described. This change required a list of all installed equipment affecting the airplane operation limitations. The list also identified this equipment according to its operational function. This list of equipment later became known as the "Kind of Equipment List (KOEL)."

In 1964, the FAA recodified CAR part 03 (29 FR 17955, December 18, 1964) into 14 CFR part 23. After recodification, CAR § 3.712 became 14 CFR § 23.1419, and CAR §§ 3.772 and 3.778(h) became 14 CFR §§ 23.1559 and 23.1583(h), respectively. In 1965, Amendment 23-1 (30 FR 8261, June 29, 1965) changed 14 CFR § 23.1325 to include the effect of icing conditions on instruments that depend on static pressure. In 1969, Amendment 23-7 (34 FR 13095, August 13, 1969), added the requirement in 14 CFR § 23.1093(b) for turbine engines to operate in 14 CFR part 25, Appendix C icing conditions. These requirements apply to all airplanes regardless of whether they have an IPS approved under 14 CFR § 23.1419. Amendment 23-8 (35 FR 303, January 8, 1970), added 14 CFR § 23.1529, effective February 5, 1970. In the latter part of 1968, the FAA began an extensive review of the airworthiness standards of 14 CFR part 23. Because of this review, the FAA issued Amendment 23-14 (23 FR 31822, November 19, 1973), which made several substantive changes in the interest of safety to 14 CFR part 23. This amendment introduced a new 14 CFR § 23.929, which required engine installation ice protection and completely changed 14 CFR § 23.1419 to establish standards for IPSs. It also introduced a new 14 CFR § 23.1309, which established reliability and noninterference requirements for installed equipment and systems. These three sections are directly related (as defined in 14 CFR § 21.101) to IPS certification because of the increased reliance on this system when operating the airplane in an icing environment.

Amendment 23-26 (45 FR 60154, September 11, 1980), changed 14 CFR § 23.1529 and added requirements for preparation of Instructions for Continued Airworthiness in 14 CFR part 23, Appendix G, effective October 14, 1980.

The FAA unintentionally omitted specific standards for pneumatic deicing boots, that were in the former 14 CFR § 23.1419, when they adopted Amendment 23-14 (23 FR 31822, November 19, 1973). The FAA realized that a specific standard for pneumatic deicing boot systems was needed and in Amendment 23-23 (43 FR 50593, issued October 30, 1978) we added 14 CFR § 23.1416(c), pneumatic deicing boot system. Current certification requirements are limited to those icing conditions produced by clouds that contain supercooled water drops as defined by 14 CFR part 25, Appendix C. The certification requirements do not require design or proof of capability to operate in freezing rain and drizzle, snow, or mixed conditions.

In 1974, the FAA added engine operation requirements for falling and blowing snow to 14 CFR § 23.1093 by Amendments 23-15 (39 FR 35460, October 1, 1974). Amendment 23-18 (42 FR 15041, March 17, 1977) and Amendment 23-29 (49 FR 6847, February 23, 1984) changed requirements insuring acceptable induction system's icing protection during ground operation icing conditions.

APPENDIX C. BACKGROUND OF ICE PROTECTION REGULATORY DEVELOPMENT (CONTINUED)

When the FAA adopted Amendment 23-41 (55 FR 43309, October 26, 1990), 14 CFR § 23.1309 kept the existing reliability requirements adopted by Amendment 23-14, (38 FR 31822, dated November 19, 1972), for airplane equipment, systems, and installations that are not complex and do not perform critical functions. If the applicant finds it necessary or desirable to include complex systems or systems that perform critical functions, or both, then 14 CFR § 23.1309 as amended by Amendment 23-41, provides more requirements for identifying and certificating such equipment, systems, and installations. This amendment allowed the approval of more advanced systems capable of performing critical functions.

When Amendment 23-42 (56 FR 354, dated January 3, 1991) became effective on February 4, 1991, it added 14 CFR § 23.1323(e) to require a heated pitot tube, or an equivalent means of preventing malfunction due to icing. The FAA also took this opportunity to clarify why a heated pitot tube must be part of the system approval for flight in icing conditions. Also included by this amendment is 14 CFR § 23.1325(g) allowing airplanes that are forbidden to fly in instrument meteorological conditions (IMC) to be certificated without an alternate static air source.

Amendment 23-43 (58 FR 18973, dated April 9, 1993), became effective May 10, 1993, resulting in 14 CFR § 23.905(e) requiring that ice shed from the airplane not damage a pusher propeller. The FAA added 14 CFR §§ 23.1093(a)(5) and (6) to address aircraft with fuel injected engines. The FAA stated the ice protection requirements for fuel injection system designs with and without metering components on which impact ice may accumulate in 14 CFR § 23.1093(a)(6). Also, the FAA added 14 CFR § 23.1307(c) to require the airplane type design to include all the equipment necessary for operation according to the limitations required by 14 CFR § 23.1559. The FAA also changed 14 CFR § 23.1419 to continue the current minimum ice protection requirements that have been found necessary for safe operation in icing conditions. Lastly, this revision provides specific test requirements, to clarify the requirements for information that must be provided to the pilot, and to allow approval of equivalent components that have been previously tested and approved, and that have shown satisfactory service if the installations are similar.

Amendment 23-45, 58 FR 42165 (dated August 6, 1993), became effective September 7, 1993, and added the following sections:

(1) 14 CFR § 23.773(b) to provide requirements for the pilot compartment view to address the environment expected in all the operations sought for certification;

(2) 14 CFR § 23.775(f) to clarify the criteria for determining the cleared windshield area that is necessary to ensure safe operation in icing conditions;

(3) 14 CFR § 23.775(g) to require that a single failure of a transparency heating system not adversely affect the integrity of the airplane cabin nor increase the danger of fire; and

APPENDIX C. BACKGROUND OF ICE PROTECTION REGULATORY DEVELOPMENT (CONTINUED)

(4) 14 CFR § 23.1525 was changed to require establishing and including the kinds of operations authorized in the Airplane Flight Manual (AFM) as specified by 14 CFR § 23.1583(h).

Amendment 23-48 (61 FR 5168, dated February 9, 1996), became effective March 11, 1996, by revising 14 CFR § 23.1325(g) to exempt airplanes that are forbidden to fly in instrument meteorological or icing conditions from the requirements of 14 CFR § 23.1325(b)(3). Also, the FAA added 14 CFR § 23.1326 to require installing a pitot tube heat-indicating system on those airplanes required to have heated pitot tube. Airplanes that are approved for instrument flight, or for flight in icing conditions, would need to have a heated pitot tube and a heated pitot tube indicator by this amendment.

Because of the large fleet of small airplanes that have been certificated under the requirements of earlier regulations, the applicability of later regulations to previously approved ice protection provisions may vary as those aircraft are modified.

With Amendment 23-14 (38 FR 31822, dated November 19, 1973), 14 CFR §§ 23.929, 23.1309, and 23.1419 applied to the icing certification of all 14 CFR part 23 airplanes regardless of the original certification basis for the basic airplane. The application may be limited to the equipment used for ice protection on airplanes certificated according to CAR part 3 and 14 CFR part 23 through Amendment 23-13. When some systems are used as part of that airplane’s icing approval, the previously approved systems on the airplane may need to be modified to improve their reliability.

When the FAA adopted Amendment 23-43 (58 FR 18973, dated April 9, 1993), they changed 14 CFR § 23.1419 to continue the current minimum ice protection requirements found necessary for safe operation in icing conditions. The amendment also provides specific test requirements and clarifies the requirements for information that must be provided to the pilot. The amendment also allows approval of equivalent components which were previously tested and approved, and which showed satisfactory service (if the installations are similar).

Besides the previously mentioned requirements (14 CFR §§ 23.929, 23.1309, and 23.1419), table C-2 lists the sections that should be applied depending on the IPS design and the original certification basis of the airplane. Many of the requirements listed in table C-2 also apply, even without approval for flight into known icing.

APPENDIX C. BACKGROUND OF ICE PROTECTION REGULATORY DEVELOPMENT (CONTINUED)

Table C-2. Chronology of 14 CFR Part 23 Icing Certification Requirements

DATE OF APPLICATION FOR AIRPLANE TYPE CERTIFICATION	CAR/TITLE STATUS	ICING CERTIFICATION REQUIREMENTS
Before February 1, 1965	Part 3 of the CAR, (May 15, 1956, as amended through Amendment 3-8)	§§ 3.85(a) and (c), 3.85a(a) and (c), 3.382, 3.383, 3.446, 3.575, (including note following (b)), 3.652, 3.652-1, 3.665, 3.666, 3.681, 3.682, 3.685, 3.686, 3.687, 3.690, 3.691, 3.692, 3.712, 3.725, 3.758, 3.770, 3.772, 3.777, 3.778, and 3.779
On or after February 1, 1965	Recodification, 29 FR 17955, December 18, 1964 and 30 FR 258, January 9, 1965.	§§ 23.65, 23.75, 23.77, 23.773, 23.775, 23.1301, 23.1351, 23.1357, 23.1437, 23.1541, 23.1559(b), 23.1583(h), 23.1585, and 23.1419 (boot requirement before Amendment 23-14)
On or after July 29, 1965	Amendment 23-1, 30 FR 8261, June 29, 1965	Add § 23.1325 to the above part 23 requirements.
On or after September 14, 1969	Amendment 23-7, 34 FR 13095, August 13, 1969	Added the requirement in 14 CFR § 23.1093 for turbine engines to operate in 14 CFR part 25, Appendix C icing conditions.
On or after February 5, 1970	Amendment 23-8, 35 FR 303, January 8, 1970	Add § 23.1529 to the above part 23 requirements.
On or after December 20, 1973	Amendment 23-14, 33 FR 31822, November 19, 1973.	Add §§ 23.853(d), 23.929, 23.903(c), and 23.1309 to the above part 23 requirements. Amended § 23.1419 to require test and analysis to show safe operation in 14 CFR part 25, Appendix C icing conditions
On or after October 31, 1974	Amendment 23-15, 39 FR 35460, October 1, 1974	Falling and blowing snow and ground ice fog requirements added to 14 CFR § 23.1093. Amendments 23-18, 42 FR 15041, March 17, 1977 and Amendment 23-29, 49 FR 6847, February 23, 1984, respectively, changed the ground ice fog requirements.
On September 1, 1977	Amendment 23-20, 42 FR 36969, July 18, 1977	Add §§ 23.1327 and 23.1547 to the above part 23 requirements.
On or after December 1, 1978	Amendment 23-23, 43 FR 50593, October 30, 1978	Add §§ 23.863, and 23.1416 (instead of the boot requirement of § 23.1419 before Amendment 23-14) to the above part 23 requirements.
On or after October 14, 1980	Amendment 23-26, 45 FR 60154, September 11, 1980	Changed 14 CFR § 23.1529 and added requirements for preparation of Instructions for Continued Airworthiness as 14 CFR part 23, Appendix G.

APPENDIX C. BACKGROUND OF ICE PROTECTION REGULATORY DEVELOPMENT (CONTINUED)

DATE OF APPLICATION FOR AIRPLANE TYPE CERTIFICATION	CAR/TITLE STATUS	ICING CERTIFICATION REQUIREMENTS
On or after February 17, 1987	Amendment 23-34, 52 FR 1833, January 15, 1987	For commuter category airplanes, add §§ 23.67(e)(2), 23.67(e)(3), 23.997(e), and 23.1199(b) to the above part 23 requirements.
On or after February 4, 1991	Amendment 23-42, 56 FR 354, January 3, 1991	Add §§ 23.1323(e) and 23.1325(g) to the above part 23 requirements.
On or after May 10, 1993	Amendment 23-43, 58 FR 18973, April 9, 1993	Add §§ 23.905(e), 23.1093(a)(6), and 23.1307(c) to the above part 23 requirements. Amended § 23.1419 to require compliance with Subpart B regulations in icing.
On or after September 7, 1993	Amendment 23-45, 58 FR 42165, August 6, 1993	Add §§ 23.773(b), 23.775(f), 23.775(g), and 23.1525 to the above part 23 requirements.
On or after February 9, 1996	Amendment 23-49, 61 FR 5168, February 9, 1996	Changed 14 CFR § 23.1325(g) and added requirements for pitot heat-indication system as 14 CFR § 23.1326.

C.3 AIRCRAFT ENGINES (14 CFR PART 33).

Until the late 1950s, the only icing requirements for engines were carburetor icing requirements that were applied to reciprocating engines and then to induction system icing. During the late 1950s, with the introduction of turbine engines, the FAA introduced CARs for turbine engines and fuel and induction systems icing. Amendment 4b-6 (dated August 12, 1957), changed CAR § 4b.461, "Induction system deicing and anti-icing provisions." The preamble to the amendment states:

> "There are included herein changes which extend the currently effective provisions governing intermittent maximum icing conditions so as to cover conditions which might be critical insofar as the turbine engine induction system is concerned. In this regard, the data are being extended in accordance with NACA Technical Note 2738 and involve a revision of figure 4b-25a to cover drop diameters as small as 15 microns and a revision of figure 4b-25c to cover distances down to 0.3 miles. The changes made in section 4b.461 required that the turbine powerplant be subjected to the same icing conditions as the airframe and that the induction system be protected to prevent serious engine power loss. A similar requirement is incorporated with respect to certification of turbine engines by an amendment to part 13 which is being made concurrently with this amendment."

During 1965, the FAA codified Federal Aviation Regulations (FAR) from the CAR. They placed turbine engines icing requirements in 14 CFR 33.66, 33.67, and 33.89. They introduced 14 CFR § 33.68 in Amendment 33-6, 39 FR 35463, October 1, 1974. The extracted requirements from 33.67, fuel and induction system requirements. 14 CFR § 33.68 is entitled

APPENDIX C. BACKGROUND OF ICE PROTECTION REGULATORY DEVELOPMENT (CONTINUED)

"induction system icing," however turbine engines do not typically include the "induction system" (for example, inlet, or other air delivery ducting) in the engine Type Design. Therefore, turbine engine 14 CFR 33.68 icing issues are mainly "internal" to the engine (including the spinner, fan blades, compressor stators and blades, etc.) and typically reside in the category of unprotected surfaces. Table C-3 summarizes the chronology of engine ice protection requirements.

Table C-3. Chronology of 14 CFR Part 33 Engine Icing Certification Requirements

DATE OF APPLICATION FOR ENGINE TYPE CERTIFICATION	CAR/TITLE STATUS	ICING CERTIFICATION REQUIREMENTS
Before August 12, 1957	Part 13 of the CAR, (May 15, 1956, as amended through Amendment 13-1)	§§ 13.110(b), 13.155 (Reciprocating engines and fuel induction systems only)
On or after August 12, 1957	Part 13 of the CAR, (May 15, 1956, as amended through Amendment 13-5)	§§ 13.110(b), 13.155 (Recip. Engines) §§ 13.210(b), (c) and (e), 13.255 (Turbine Engines)
On or after February 1, 1965	Recodification, 29 FR 7453, June 10, 1964	§§ 33.35, 33.51 (Recip. Engines) §§ 33.66, 33.67, 33.89 (Turbine Engines)
On or after October 1, 1974	Amendment 33-6, 39 FR 35463, October 1, 1974	Replaced § 33.67 with § 33.68 and added § 33.77
On or after March 26, 1984	Amendment 33-10, 49 FR 6851, February 23, 1984	Changed § 33.77 to require ice slab size based on a two-minute delayed engine IPS activation, rather than 30 seconds.

C.4 ROTORCRAFT (14 CFR PARTS 27 AND 29).

In CAR part 6, the only icing requirement for Normal Category rotorcraft concerned carburetor preheat, CAR § 6.462 "Induction system deicing and anti-icing provisions." This requirement was carried over to 14 CFR § 27.1093. The FAA did not address the approval of other ice protection provisions for a type of operation in icing conditions, CAR § 6.718, before the 1964 regulation recodification.

CAR § 7.392, the earlier Transport Categories Rotorcraft airworthiness requirements, addressed approval of ice protection provisions for icing conditions that apply to the design's operating limitations. This CAR part 7 requirement was carried over into 14 CFR § 29.877 and now as 14 CFR § 29.1419. CAR part 7 addressed pilot compartment vision, requiring "sufficiently extensive view to permit safe operation" in the most severe icing conditions in which operation of the rotorcraft is approved. The pilot compartment requirement was carried over into 14 CFR § 29.773. Engine air induction and engine air induction system screens ice protection provisions, CAR §§ 7.461 and 7.464, were carried over into 14 CFR §§ 29.1093 and 29.1105.

APPENDIX C. BACKGROUND OF ICE PROTECTION REGULATORY DEVELOPMENT (CONTINUED)

C.5 REFERENCES.

C1. **"Recommended Values of Meteorological Factors to be Considered in the Design of Aircraft Ice-Prevention Equipment,"** NACA Technical Note 1855 (1949), NASA/Ames Research Center, Moffett Field, California 94035.

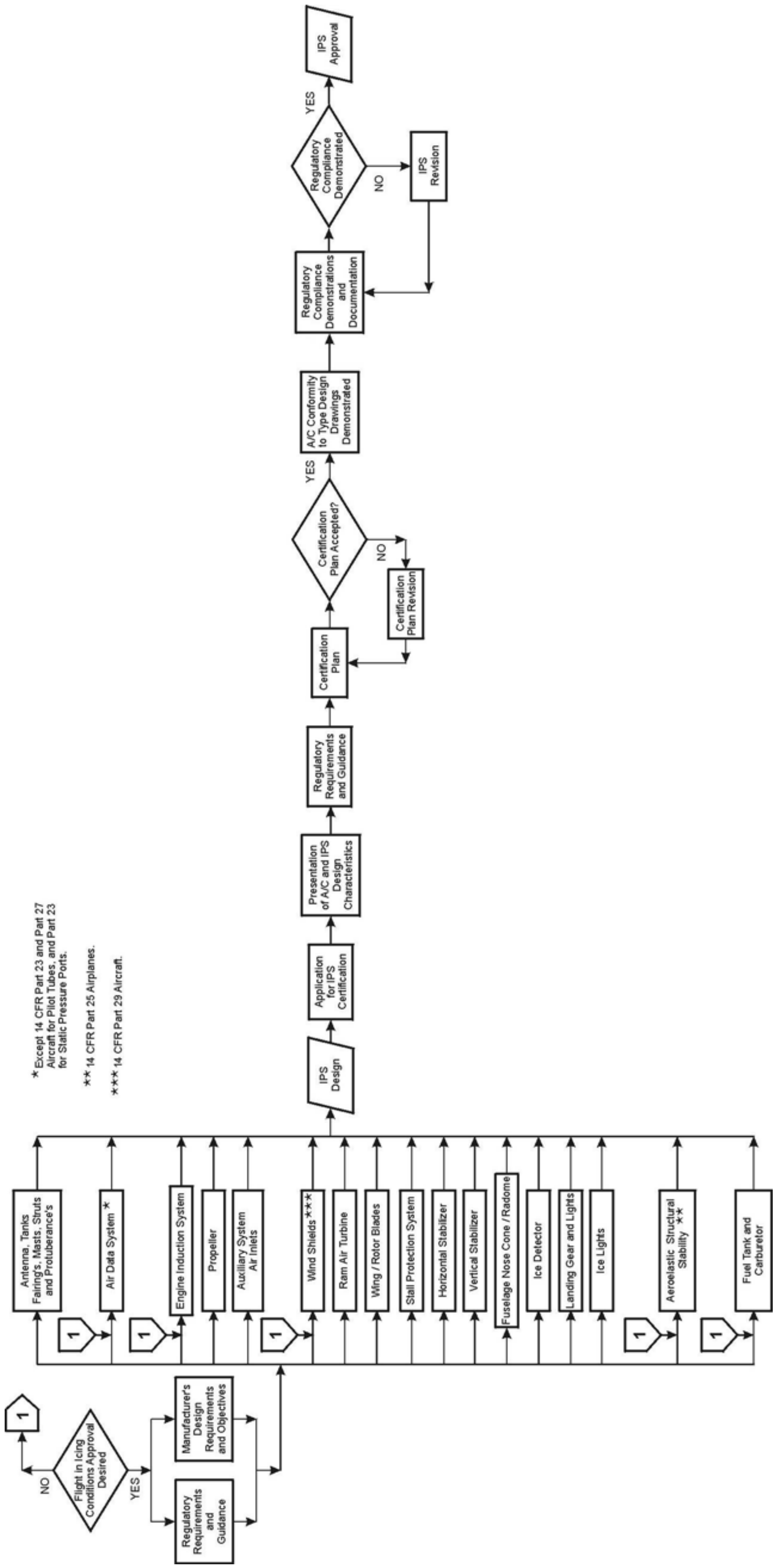
C2. **"Review of Icing Criteria,"** Lewis, William, Aircraft Ice Protection, Report of Symposium, April 28-30, 1969.

APPENIDX D. COMPONENT ICE PROTECTION SYSTEM DESIGN AND CERTIFICATION PROCESS FLOWCHARTS

Figure D-1 shows the flow of a typical inflight icing certification program. Figures D-2 through D-7 provide typical program flowcharts for the design and certification of critical surfaces, engine, propeller, airframe components, and probes ice protection. These program flowcharts are general in nature and may not be applicable to all icing certification programs. Applicants should assess their aircraft for design features that warrant added considerations to ensure safe flight in icing conditions.

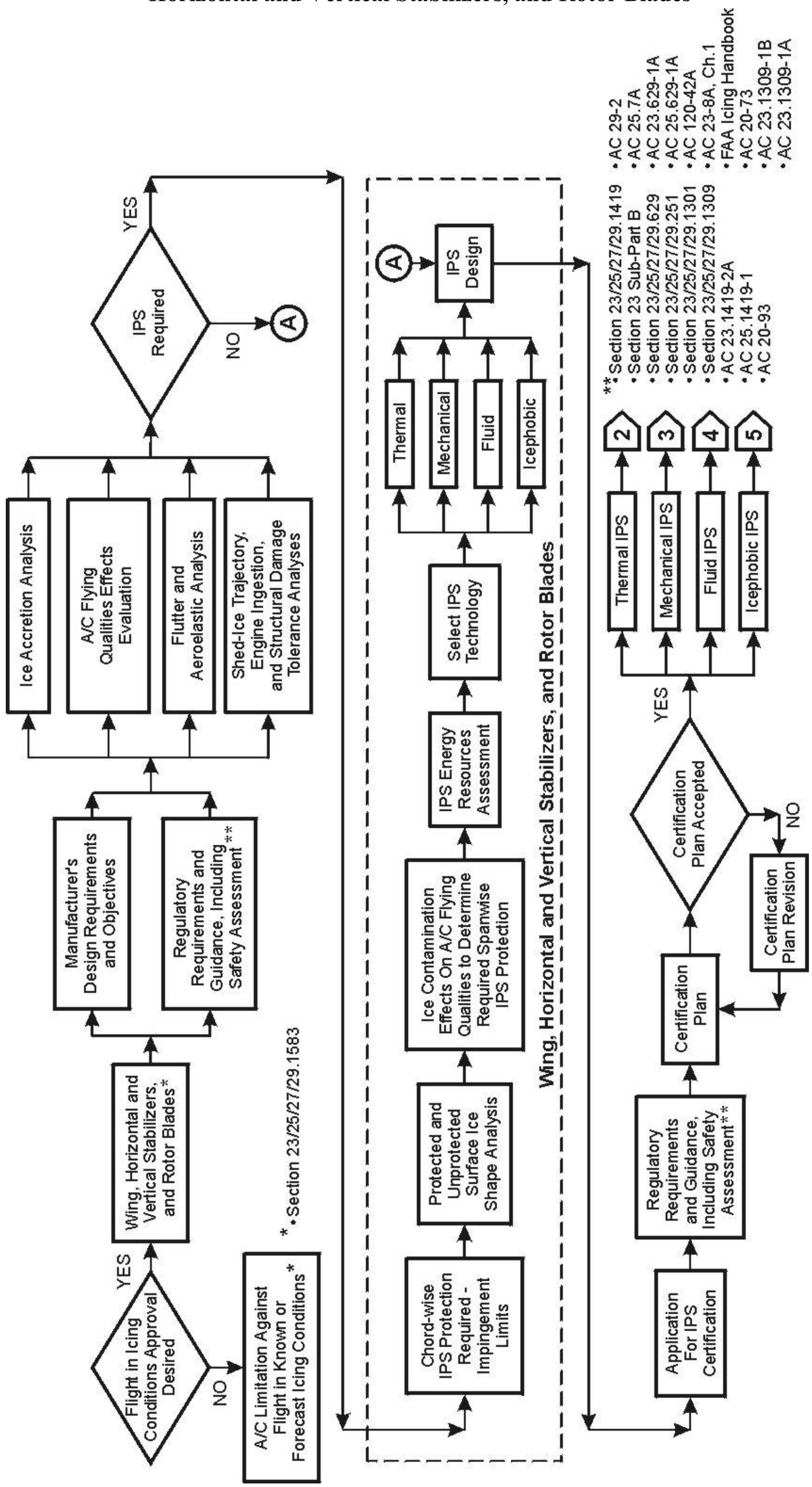
APPENDIX D. COMPONENT ICE PROTECTION SYSTEM DESIGN AND CERTIFICATION PROCESS FLOWCHARTS (CONTINUED)

Figure D-1. Typical Aircraft Inflight Icing Certification Process



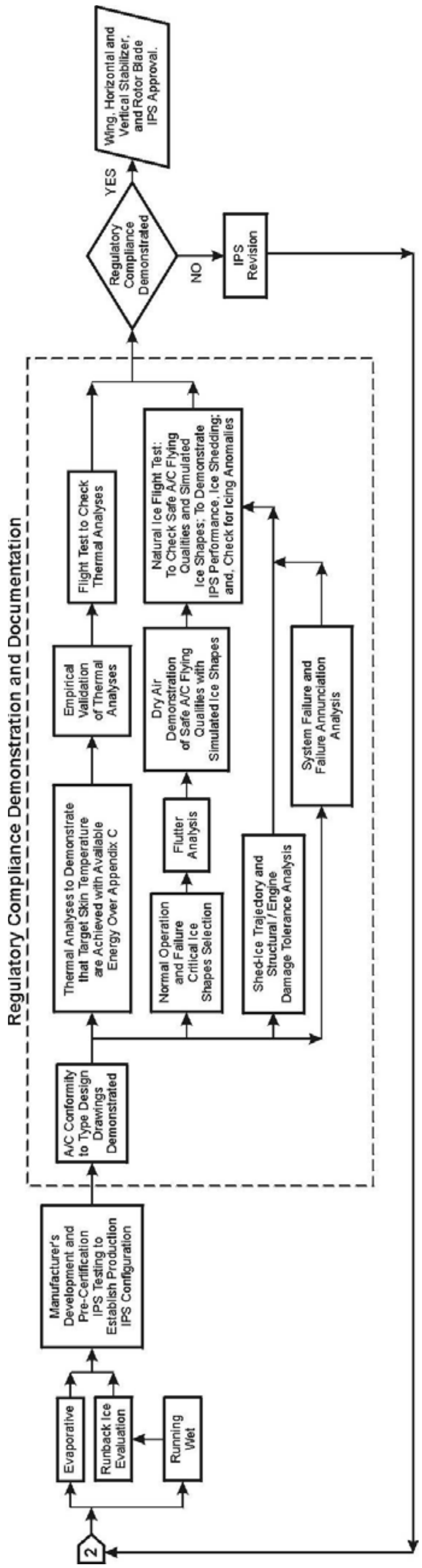
APPENDIX D. COMPONENT ICE PROTECTION SYSTEM DESIGN AND CERTIFICATION PROCESS FLOWCHARTS (CONTINUED)

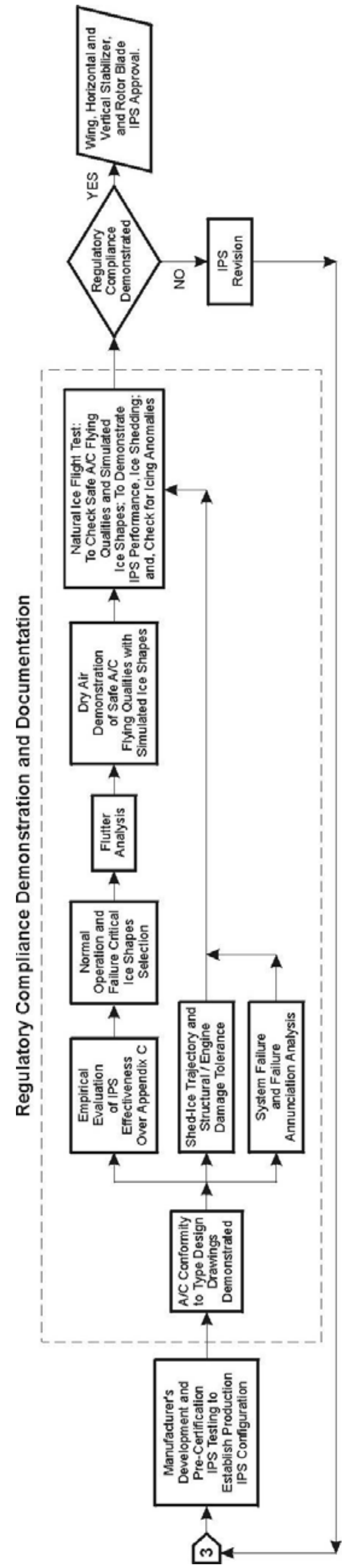
Figure D-2. Typical Inflight Icing Certification Processes for Wings, Horizontal and Vertical Stabilizers, and Rotor Blades



APPENDIX D. COMPONENT ICE PROTECTION SYSTEM DESIGN AND CERTIFICATION PROCESS FLOWCHARTS (CONTINUED)

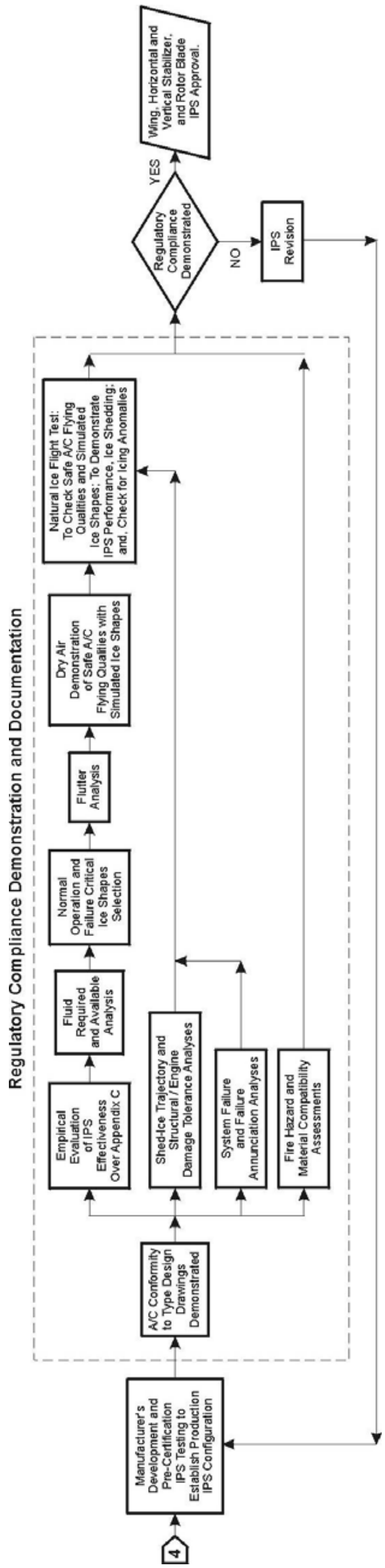
Figure D-2. Typical Inflight Icing Certification Processes for Wings, Horizontal and Vertical Stabilizers, and Rotor Blades (Continued)

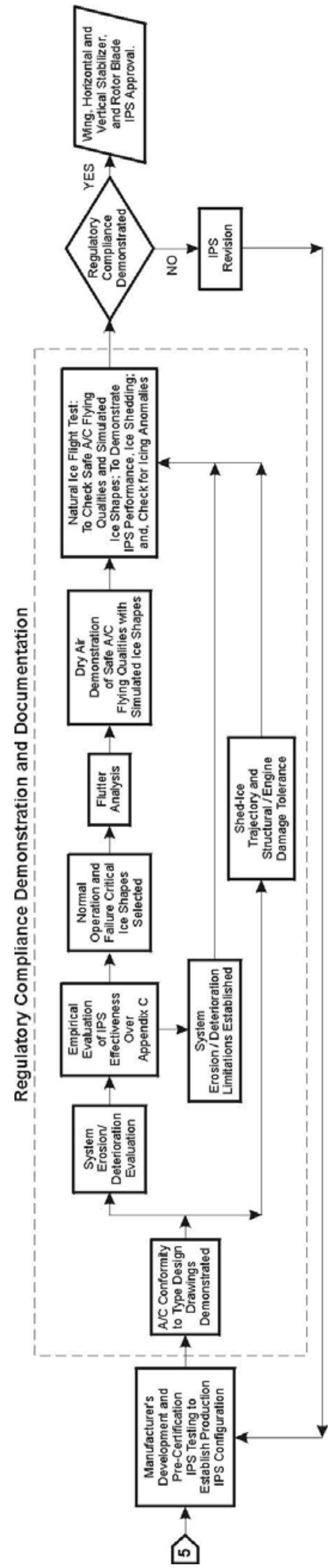




APPENDIX D. COMPONENT ICE PROTECTION SYSTEM DESIGN AND CERTIFICATION PROCESS FLOWCHARTS (CONTINUED)

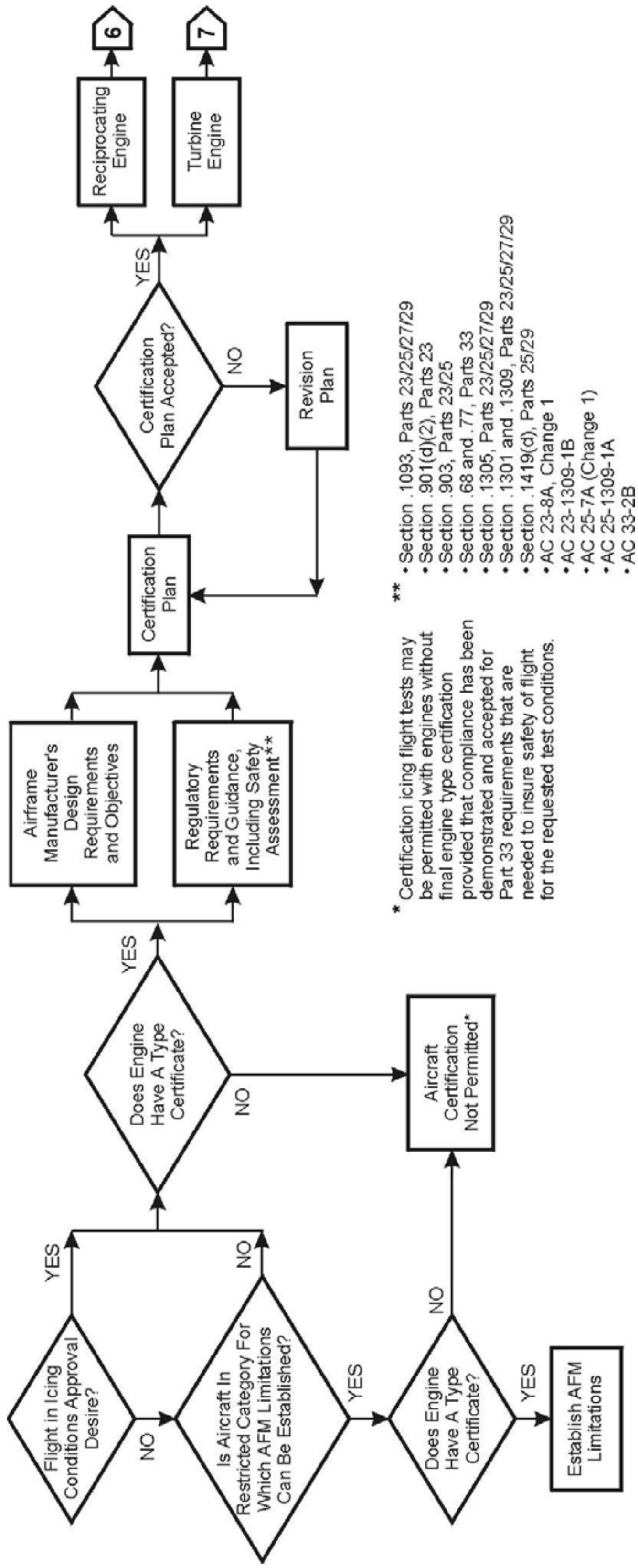
Figure D-2. Typical Inflight Icing Certification Processes for Wings, Horizontal and Vertical Stabilizers, and Rotor Blades (Concluded)





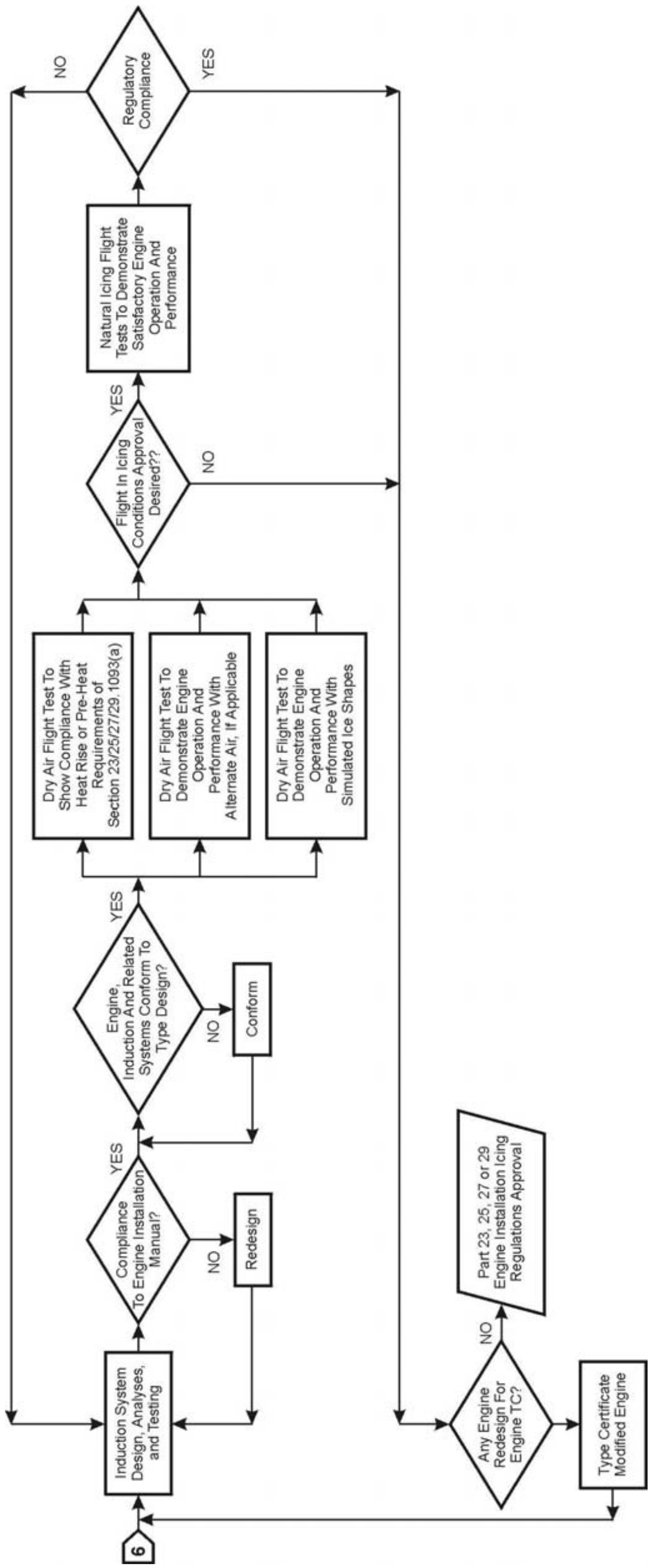
APPENDIX D. COMPONENT ICE PROTECTION SYSTEM DESIGN AND CERTIFICATION PROCESS FLOWCHARTS (CONTINUED)

Figure D-3. Typical Inflight Icing Certification Process for Engine Induction Systems



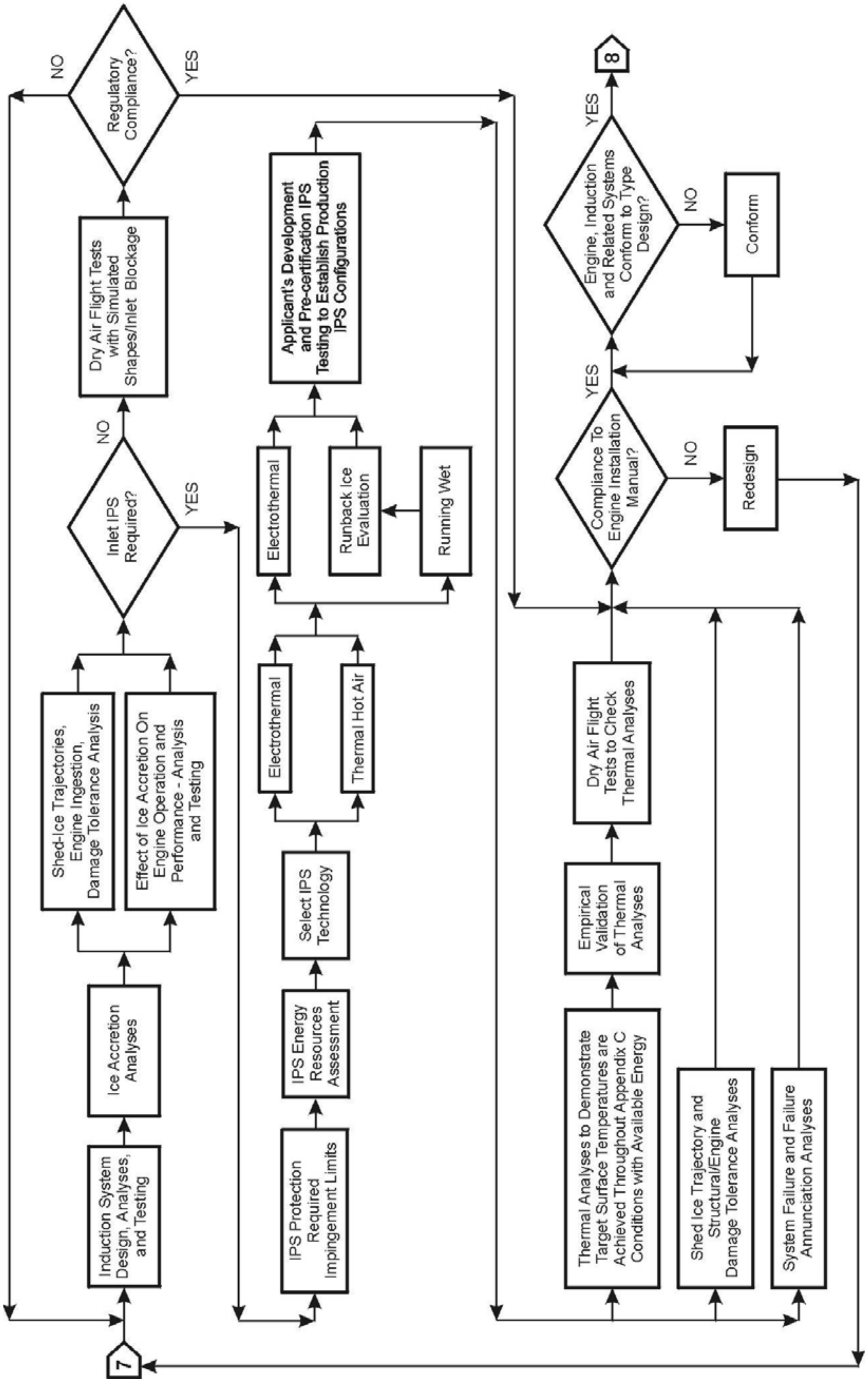
APPENDIX D. COMPONENT ICE PROTECTION SYSTEM DESIGN AND CERTIFICATION PROCESS FLOWCHARTS (CONTINUED)

Figure D-3. Typical Inflight Icing Certification Process for Engine Induction Systems (Continued)



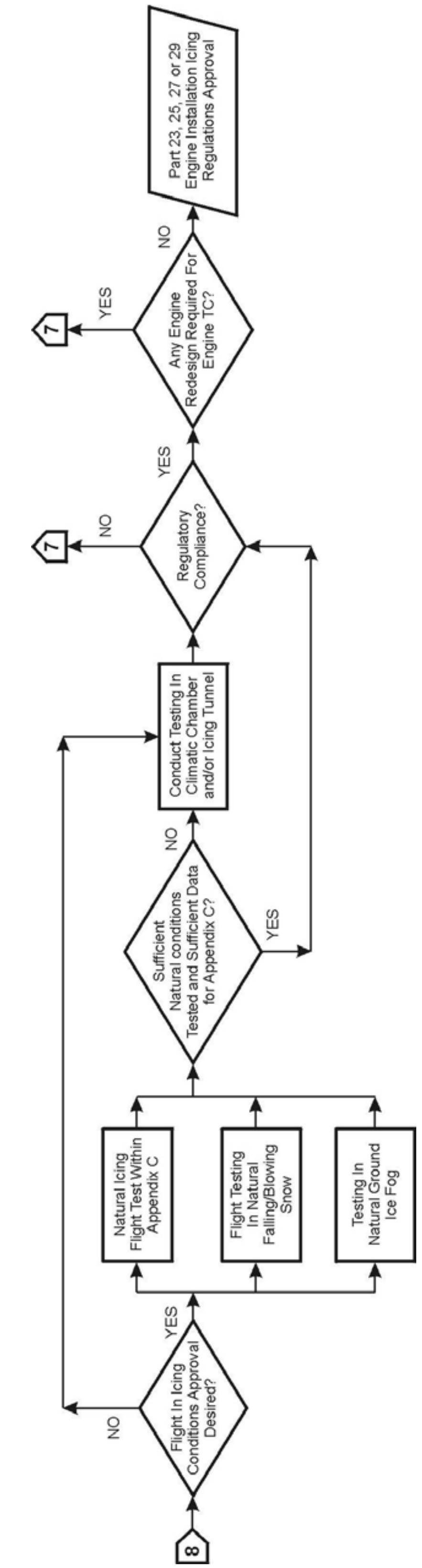
APPENDIX D. COMPONENT ICE PROTECTION SYSTEM DESIGN AND CERTIFICATION PROCESS FLOWCHARTS (CONTINUED)

Figure D-3. Typical Inflight Icing Certification Process for Engine Induction Systems (Continued)



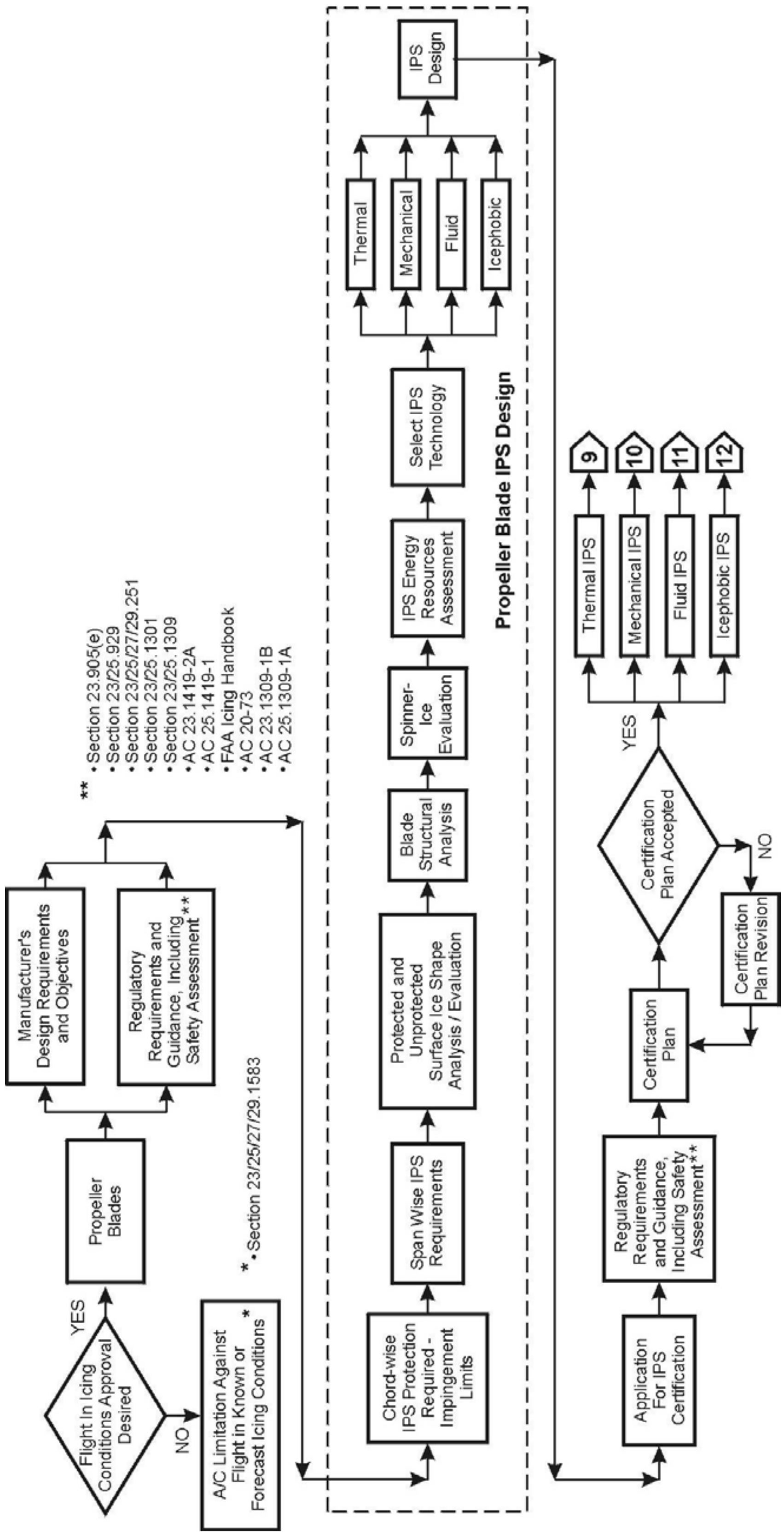
APPENDIX D. COMPONENT ICE PROTECTION SYSTEM DESIGN AND CERTIFICATION PROCESS FLOWCHARTS (CONTINUED)

Figure D-3. Typical Inflight Icing Certification Process for Engine Induction Systems (Concluded)



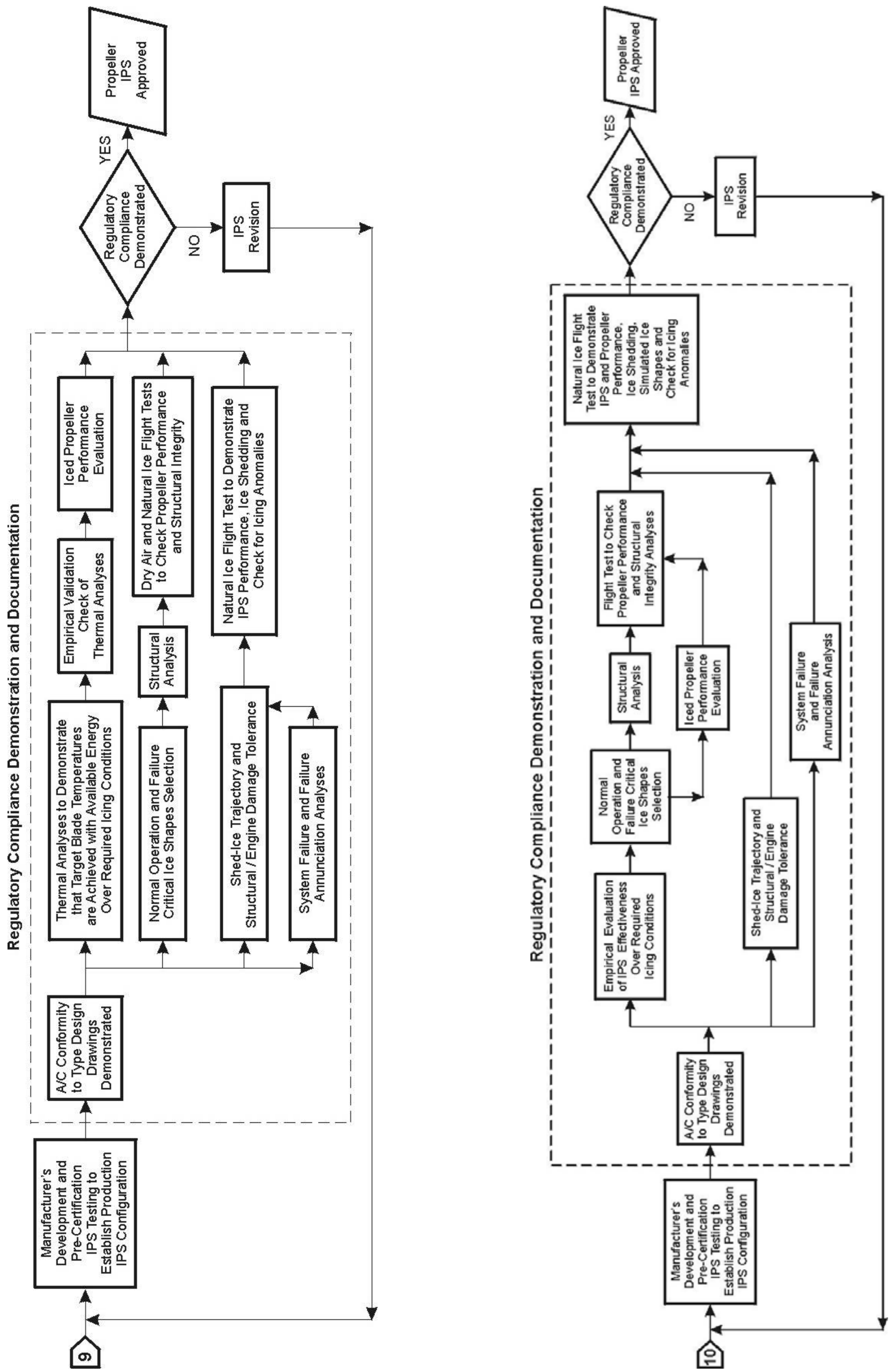
APPENDIX D. COMPONENT ICE PROTECTION SYSTEM DESIGN AND CERTIFICATION PROCESS FLOWCHARTS (CONTINUED)

Figure D-4. Typical Inflight Icing Certification Process for Propellers



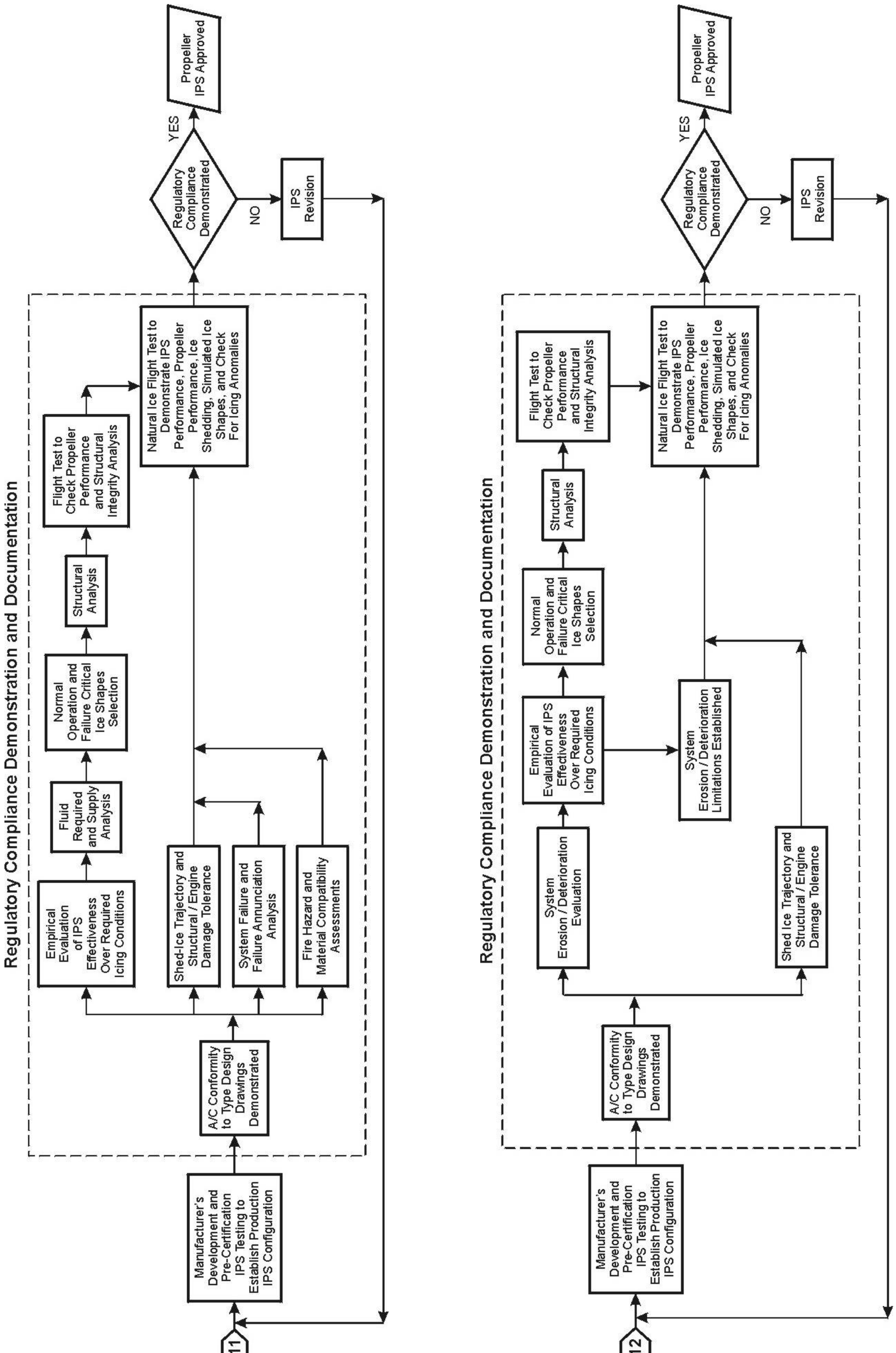
APPENDIX D. COMPONENT ICE PROTECTION SYSTEM DESIGN AND CERTIFICATION PROCESS FLOWCHARTS (CONTINUED)

Figure D-4. Typical Inflight Icing Certification Process for Propellers (Continued)



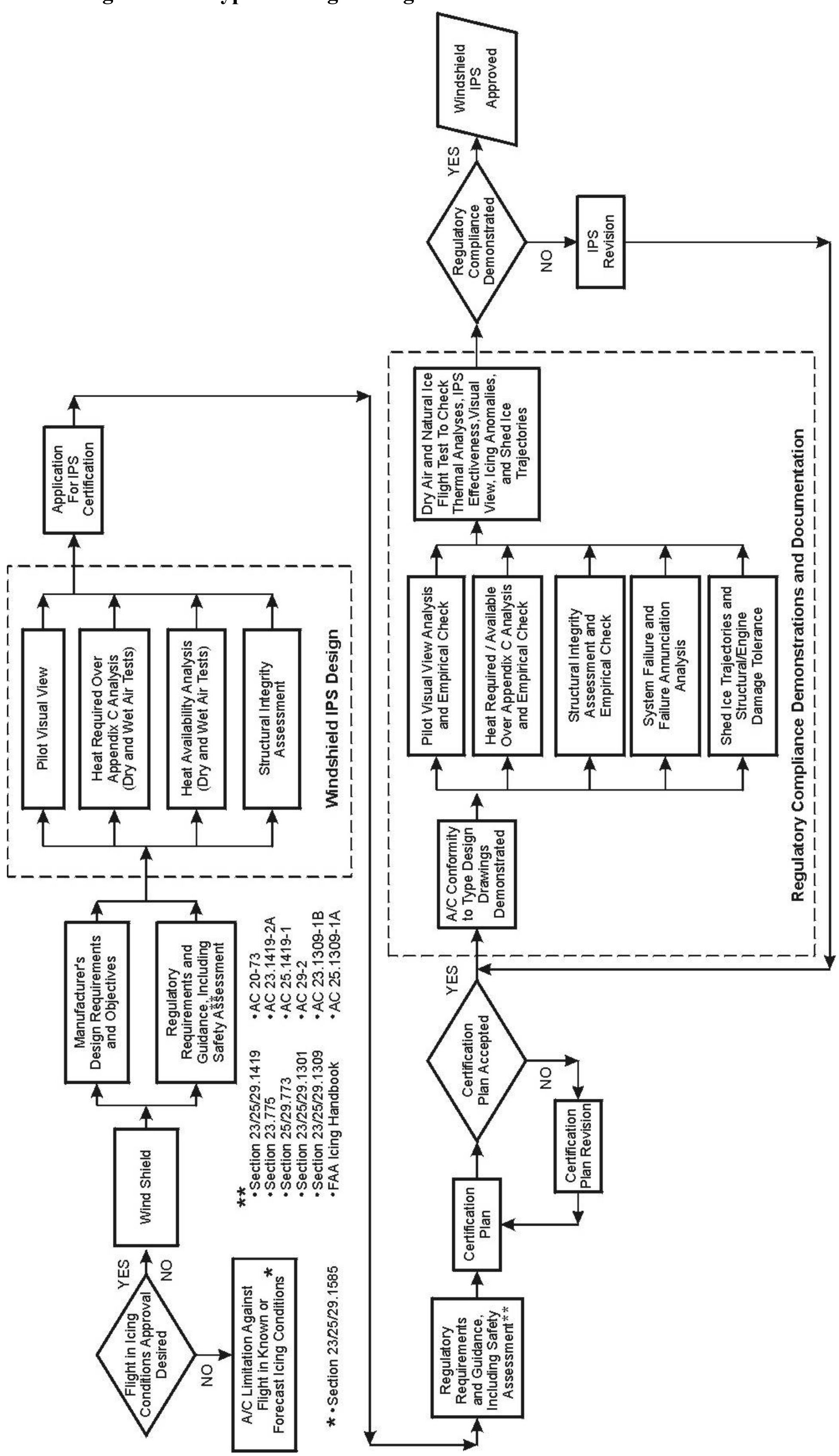
APPENDIX D. COMPONENT ICE PROTECTION SYSTEM DESIGN AND CERTIFICATION PROCESS FLOWCHARTS (CONTINUED)

Figure D-4. Typical Inflight Icing Certification Process for Propellers (Concluded)



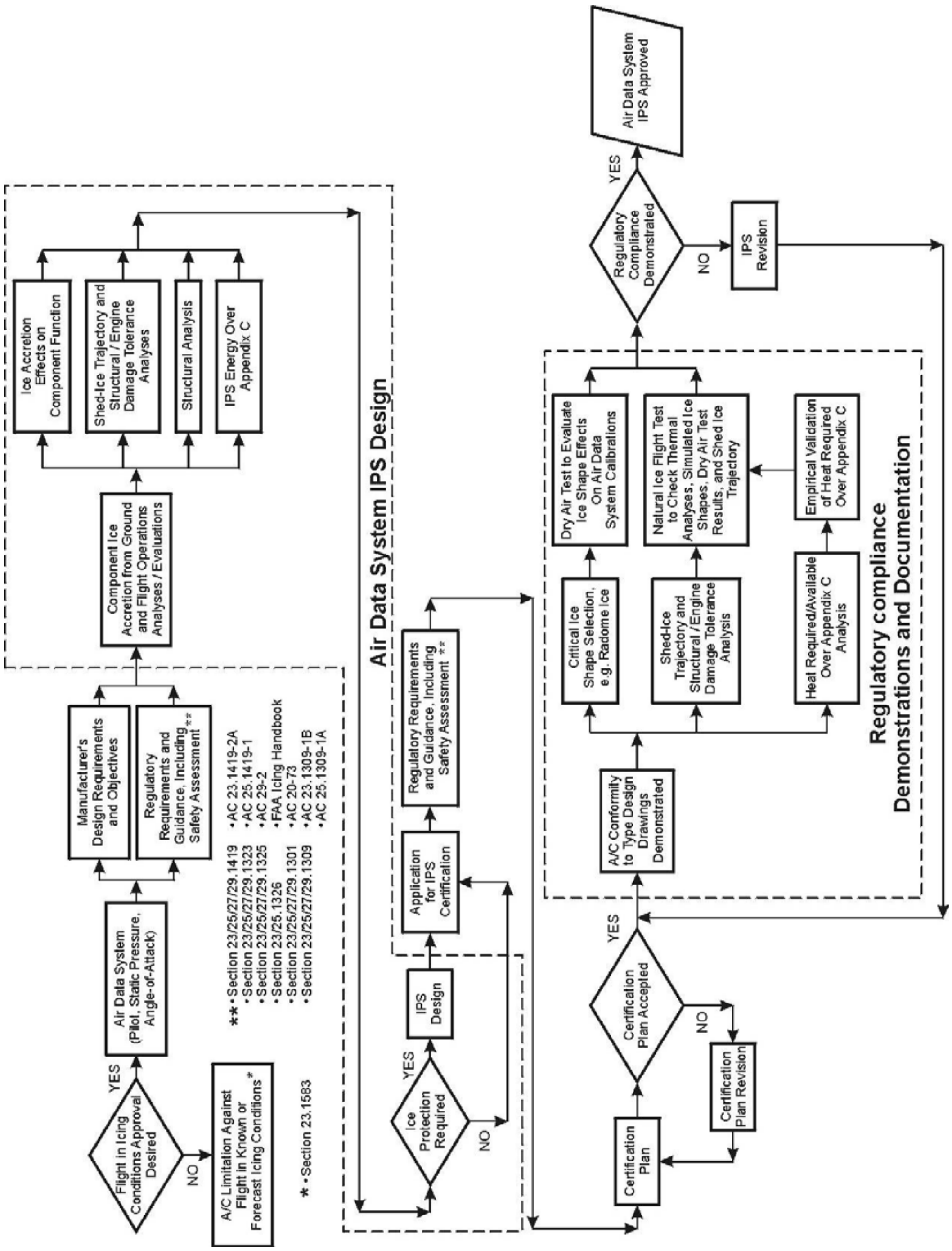
APPENDIX D. COMPONENT ICE PROTECTION SYSTEM DESIGN AND CERTIFICATION PROCESS FLOWCHARTS (CONTINUED)

Figure D-5. Typical Inflight Icing Certification Process for Windshields



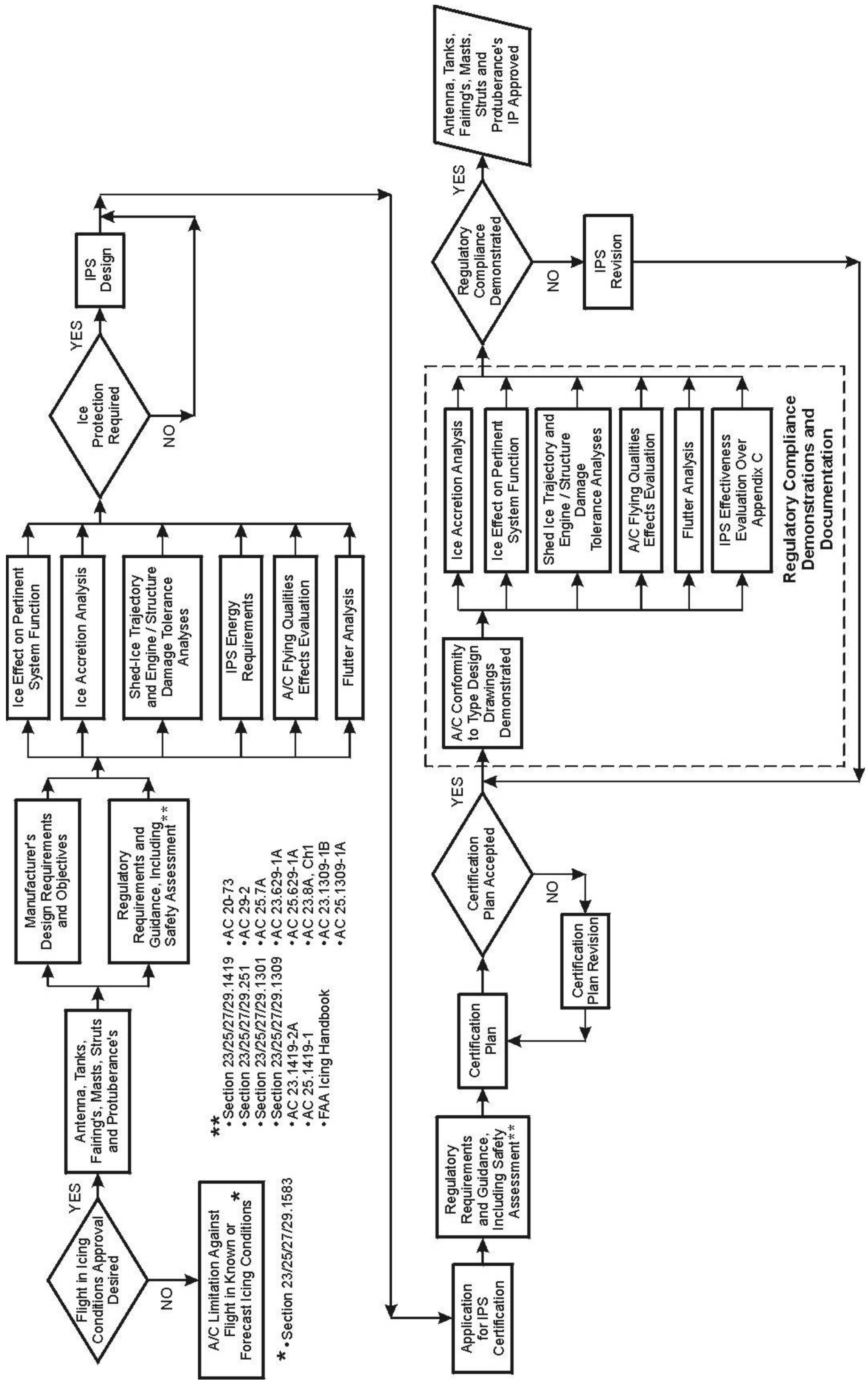
APPENDIX D. COMPONENT ICE PROTECTION SYSTEM DESIGN AND CERTIFICATION PROCESS FLOWCHARTS (CONTINUED)

Figure D-6. Typical Inflight Icing Certification Process for Air Data Probes and Sensors



APPENDIX D. COMPONENT ICE PROTECTION SYSTEM DESIGN AND CERTIFICATION PROCESS FLOWCHARTS (CONTINUED)

Figure D-7. Typical Inflight Icing Certification Process for Antenna, Tanks, Fairings, Masts, Struts, and Other Miscellaneous Protuberances



APPENIDX E. METEOROLOGICAL CONDITIONS

Aircraft must be able to operate safely in the continuous maximum and intermittent maximum icing conditions of 14 CFR part 25, Appendix C to be certificated with ice protection provisions. The following provides background about the development of 14 CFR part 25, Appendix C and guidance about its proper use.

E.1 ICING CLOUD SPECIFICATIONS.

14 CFR parts 25, Appendix C and 29, Appendix C provide the cloud parameters and the ranges of values required for the approval of aircraft inflight ice protection equipment (Reference E1). CAR 4b Amendment 4b-2 dated August 25, 1955, introduced Appendix C envelopes for 14 CFR parts 25 and 29. The charts were derived from tabulations presented in Reference E2. One of the principal investigators stated that the icing conditions in 14 CFR parts 25, Appendix C and 29, Appendix C do not present physical relations among the variables used to define icing conditions (Reference E3). Instead, they represent combinations of the three variables (liquid water content (LWC), drop size, and temperature) believed to occur often enough to warrant consideration in design.

Drop diameter correlates only weakly correlated with either water content or temperature. Efforts to define standard design icing conditions, as described in Reference E1 of this appendix, began with the use of wing heated anti-icing systems. Most of the flight measurements of LWC and effective drop diameter were made by the rotating-cylinder technique. Theoretical relations involving drop diameter, cylinder diameter, collection efficiency, and airspeed were used to derive average LWC and effective drop diameter. The method also yielded a rough measure of the spread in the size distribution. More dependable information on the distribution could have been obtained from counts of drops captured in oil. There were few determinations of drop diameter distributions.

When selecting design conditions, the applicant should consider the ability of thermal anti-icing system to recover from severe, temporary overloads. 14 CFR parts 25, Appendix C and 29, Appendix C icing conditions are envelopes of maximum-severity icing that occur in winter stratiform and cumulus clouds. The FAA chose conditions for each icing condition category based on the belief that thermal anti-icing systems should provide full protection in roughly 99 percent of icing encounters. Also, slight, temporary impairment of ice protection performance would be accepted. Rare occasions of exceptional severe icing might require evasive action.

Figures E-1 through E-6 reproduce Figures 1 through 6 of 14 CFR parts 25, Appendix C and 29, Appendix C. Figures E-1 and E-4 (14 CFR parts 25, Appendix C and 29, Appendix C, Figures 1 and 4) estimate the "probable maximum" (99^{th} percentile) value of cloud water concentration (commonly known as LWC) that is expected. The LWC is provided as an average over a reference distance, for a given temperature and drop size (Reference E4). In defining the envelopes combining LWC, MED, and T, the investigators of Reference E5 determined that the condition that 99 percent of cases lie within the envelopes was roughly equivalent to a probability of 1/1000 that all three variables represented by a single point would be exceeded

APPENDIX E. METEOROLOGICAL CONDITIONS (CONTINUED)

simultaneously. For figure E-1 (14 CFR parts 25, Appendix C and 29, Appendix C, Figure 1) this reference distance is 20 statute miles (17.4 nm) in stratiform icing conditions. For figure E-4 (14 CFR parts 25, Appendix C and 29, Appendix C, Figure 4) it is 3 statute miles (2.6 nm) in convective icing conditions. These are arbitrary reference distances but are based on the NACA research flights in the late 1940s. NACA and Weather Bureau researchers estimated these probable maximum values of LWC in the early 1950s. They proposed them as the basis for the present-day 14 CFR parts 25, Appendix C and 29, Appendix C (References E2 and E5). Review of recent icing cloud characterizations that used modern instrumentation shows the 1940 data used for 14 CFR parts 25, Appendix C and 29, Appendix C, acceptably accurate.

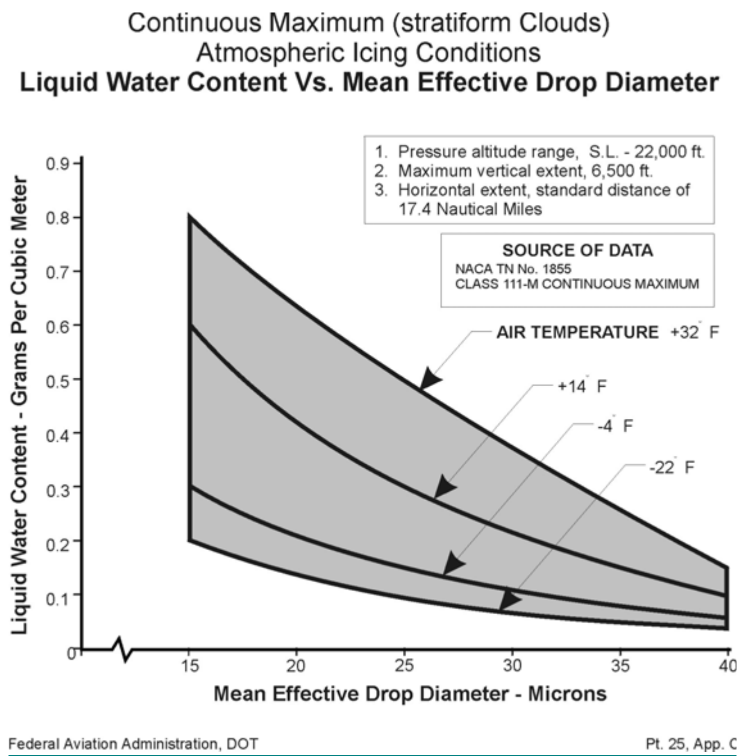


Figure E-1. 14 CFR Parts 25 and 29 Appendix C Continuous Maximum (Stratiform Clouds) Atmospheric Icing Conditions, Liquid Water Content Vs. Mean Effective Drop Diameter (14 CFR Parts 25 and 29 Appendix C, Figure 1).

APPENDIX E. METEOROLOGICAL CONDITIONS (CONTINUED)

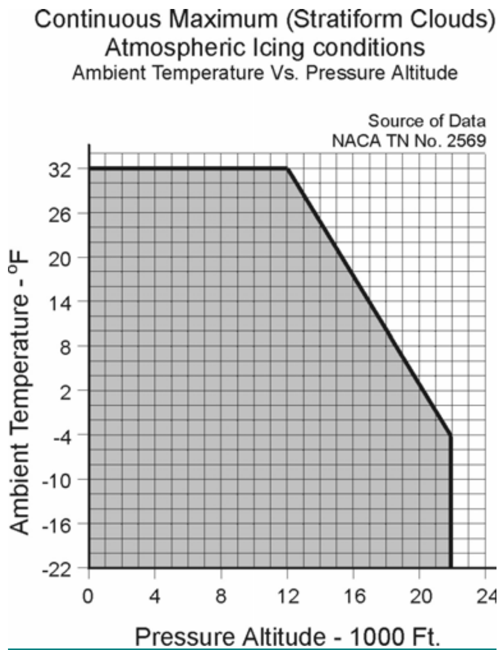


Figure E-2. 14 CFR Parts 25 and 29 Appendix C Continuous Maximum (Stratiform Clouds) Atmospheric Icing Conditions, Ambient Temperature Vs. Pressure Altitude (14 CFR Parts 25 and 29, Appendix C, Figure 2).

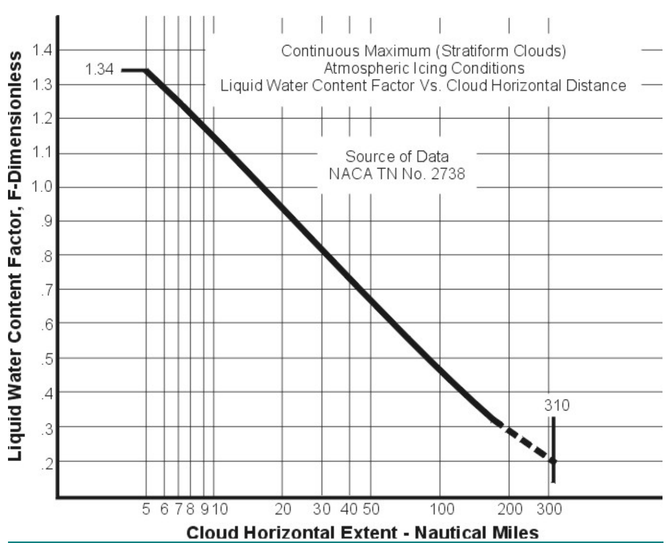


Figure E-3. 14 CFR Parts 25 and 29 Appendix C Continuous Maximum (Stratiform Clouds) Atmospheric Icing Conditions, Liquid Water Content Factor Vs. Cloud Horizontal Distance (14 CFR Parts 25 and 29, Appendix C, Figure 3).

APPENDIX E. METEOROLOGICAL CONDITIONS (CONTINUED)

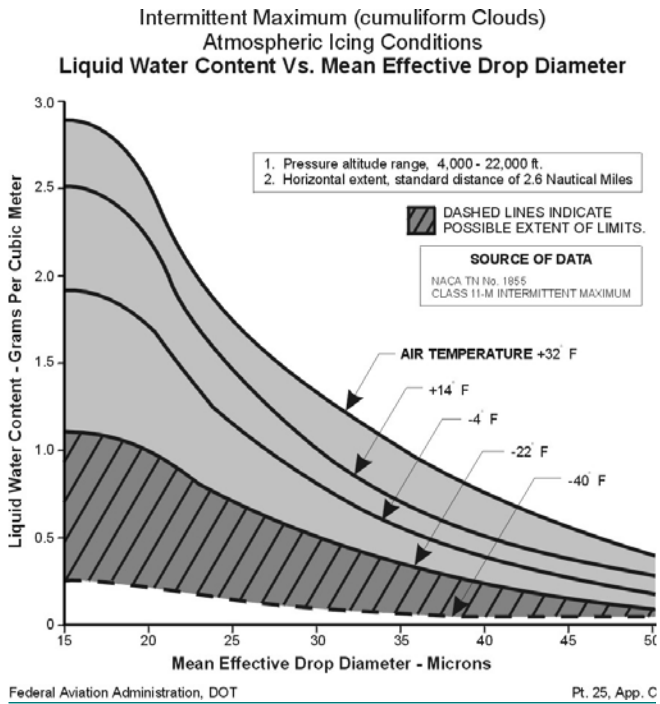


Figure E-4. 14 CFR Parts 25 and 29 Appendix C Intermittent Maximum (Cumulus Clouds) Atmospheric Icing Conditions, Liquid Water Content Vs. Mean Effective Drop Diameter (14 CFR Parts 25 and 29, Appendix C, Figure 4).

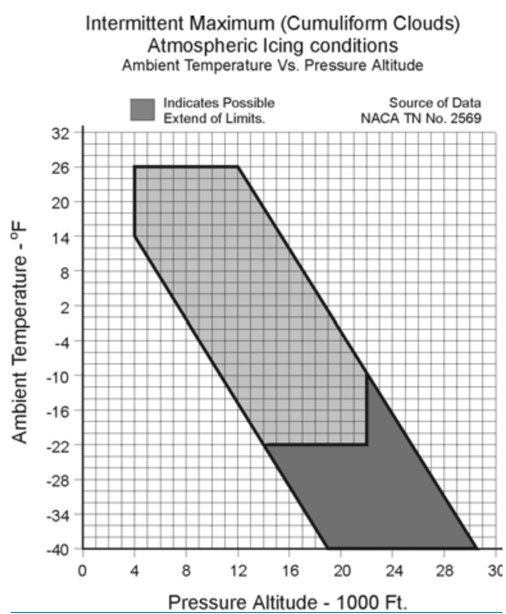


Figure E-5. 14 CFR Parts 25 and 29 Appendix C Intermittent Maximum (Cumulus Clouds) Atmospheric Icing, Ambient Temperature Vs. Pressure Altitude (14 CFR Parts 25 and 29, Appendix C, Figure 5).

APPENDIX E. METEOROLOGICAL CONDITIONS (CONTINUED)

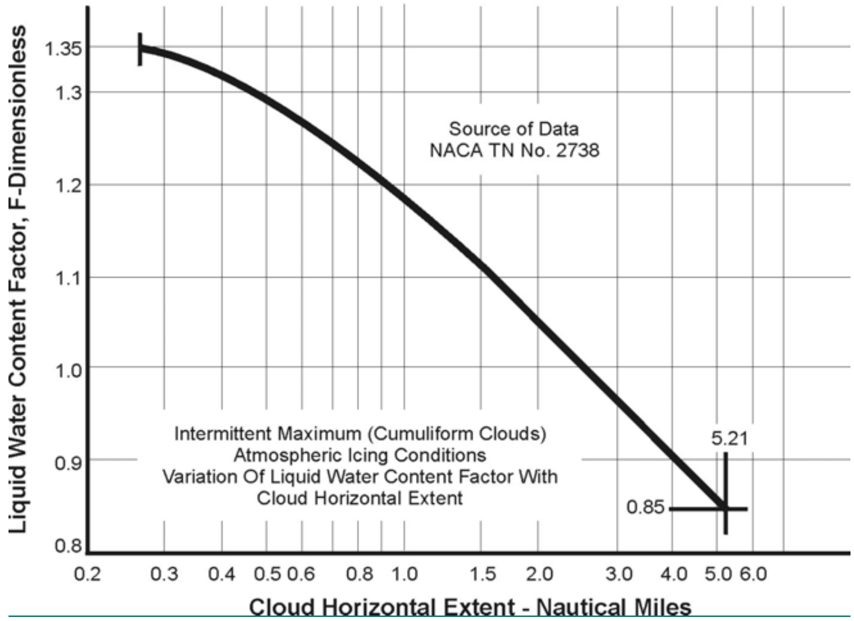


Figure E-6. 14 CFR Parts 25 and 29 Appendix C Intermittent Maximum (Cumulus Clouds) Atmospheric Icing Conditions, Liquid Water Content Factor Vs. Cloud Horizontal Distance (14 CFR Parts 25 and 29, Appendix C, Figure 6).

The FAA extended the Intermittent Maximum envelopes below -22°F (-30°C) "for completeness" in the original data source (Reference E2). The exact values of LWC are uncertain because of the lack of data at these low temperatures. Nevertheless, these extensions appear in the regulations (Reference E1) and applicants should consider them for design of IPSs.

> **NOTE:** Figure E-4 shows LWC for a temperature of 32°F. The warmest temperature in figure E-5 is 26°F. The inconsistency in 14 CFR parts 25, Appendix C and 29, Appendix C may be because of the lack of data at temperatures above 26°F at the time of the investigation. Consider the LWC shown in figure E-4 for 32°F as the figure E-5 LWC value at 32°F.

In these icing applications, a single variable called the drop median volume diameter (MVD) (or, in the older use, an equivalent variable called the MED) represents the drop size distribution (typically 10-30 μm diameter) in clouds. The MVD is the midpoint of the LWC distribution over the range of cloud drop sizes that happen to be present at the time. The MVD varies with the number of drops in each size category. The overall average for layer clouds is about 15 μm and about 19 μm for convective clouds. This is based on data reviewed by the FAA. The MVD has proven useful as a simple substitute for the full drop size distributions in ice accretion estimates.

For certification of rotorcraft IPSs, you may truncate the icing conditions in 14 CFR part 29, Appendix C to a pressure altitude of 10,000 feet or the altitude limit of the aircraft. Advisory

APPENDIX E. METEOROLOGICAL CONDITIONS (CONTINUED)

Circular (AC) 29-2C states that applicants who elect to certify rotorcraft with a 10,000 feet pressure altitude limit based on equivalent safety may select icing conditions envelopes in AC 29-2C. AC 29-2C states that you must use 14 CFR part 29, Appendix C icing conditions for pressure altitude above 10,000 feet.

The AC 29-2C icing conditions envelopes resulted from a 1985 FAA William J. Hughes Technical Center analysis of the data used to establish 14 CFR part 29, Appendix C. The AC 29-2C icing conditions envelopes are significantly different from those in 14 CFR part 29, Appendix C. For example, the AC 29-2C icing conditions envelopes for altitudes of 10,000 feet and lower show that you do not need to address temperatures colder than -10°F and 0°F for continuous and intermittent icing conditions, respectively. Comparative temperatures in 14 CFR part 29, Appendix C are -22°F and -6°F for continuous maximum and intermittent maximum icing conditions, respectively. Also, the AC 29-2C intermittent icing conditions minimum altitude is truncated at 4,000 feet, compared to sea level for 14 CFR part 29, Appendix C intermittent maximum icing conditions. Since AC 29-2C icing conditions are less rigorous and differ from that required by 14 CFR § 27.1419 and 14 CFR § 29.1419, you must consult with the FAA before using them.

E.2 USING 14 CFR PARTS 25 AND 29, APPENDIX C.

There is no comprehensive guidance available for using 14 CFR parts 25, Appendix C and 29, Appendix C icing conditions for design purposes. Engineers typically select a drop MVD, temperature, and altitude of interest. They use these parameters to determine the probable maximum LWC from figure E-1 or E-4 (14 CFR parts 25, Appendix C and 29, Appendix C, Figures 1 or 4). Other suggested or conventional practices are in this AC and in other references (References E6 through E10).

You may select temperatures from the corners (extremes) of the temperature vs. altitude envelopes (14 CFR parts 25, Appendix C and 29, Appendix C, Figures 2 and 5 and figures E-2 and E-5 of this AC). Or you may select from average or extreme values for the flight altitude under consideration. Reference E9 contains several example applications.

The values of LWC gotten directly from figures E-1 or E-4 (14 CFR parts 25, Appendix C and 29, Appendix C, Figure 1 or 4) are valid only for the reference distances of 17.4 nm or 2.6 nm, respectively. NACA researchers recommended these distances as "appropriate" for ice protection system design considerations when designing an IPS (Reference E2).

For different IPS design considerations with different exposure distances, you may change the originally selected LWC by a factor from figures E-3 (14 CFR parts 25, Appendix C and 29, Appendix C, Figure 3) or E-6 (14 CFR parts 25, Appendix C and 29, Appendix C, Figure 6). This is because for both types of clouds, longer averaging distances will result in lower maximum values of LWC. To account for this behavior, the NACA researchers developed LWC adjustments (F-factors). (See 14 CFR parts 25, Appendix C and 29, Appendix C, Figures 3 and 6 and figures E-3 and E-6 of this AC.)

APPENDIX E. METEOROLOGICAL CONDITIONS (CONTINUED)

The choice of exposure distance depends on the application. One application is to estimate ice buildup amounts on unprotected surfaces during a long exposure, perhaps 100 or 200 miles (Reference E9, page 4.1-10). In this case, you reduce the LWC from figure E-1 by an amount gotten from figure E-3 for the selected exposure distance. For example, to find the maximum probable LWC during flight through 100 nm of stratiform icing clouds, use the multiplying factor (0.46 in this example) from figure E-3. Thus, for stratiform clouds in which the MVD is 15 µm and the temperature is -10°C (+14°F), the maximum average LWC over 100 nm is expected to be 0.46 x 0.6 g/m^3 = 0.28 g/m^3. This procedure raises or lowers the LWC curves in figure E-1 or E-4, depending on the exposure distance.

Another use is to estimate ice buildups on unprotected surfaces during a 45-minute hold. For the 45-minute hold discussed in section 8 of this AC, use the LWC from Figure 1 of 14 CFR part 25, Appendix C at full value. Guidance for the 45-minute hold assumes the conservative case when the holding pattern remains within 17.4 nm and the LWC is changed from that shown in Figure 1 of 14 CFR part 25, Appendix C.

Note the only valid use of the F-factor curves is for adjusting 14 CFR parts 25, Appendix C and 29, Appendix C LWCs to get probable maximum values of LWC for other distances. Do not use the F-factor curves any other way, including applying the F-factors to measured flight test LWCs to:

a. Extrapolate available flight-test LWCs to values they supposedly would have if the exposures had been over the design distances of 17.4 nm or 2.6 nm;

b. Compensate in flight for smaller-than-desired LWCs by extending the exposure distances by some calculable amount to achieve an exposure that is supposedly equivalent to the wanted LWC over the design exposure distance; or

c. Create some rating system for comparing available test exposures to design exposures.

Appendix N of this AC provides acceptable ways of documenting variable length icing exposures without using the F-factor.

E.3 REFERENCES.

E1. Code of Federal Regulations, Title 14, Parts 1-59; Office of the Federal Register, National Archives and Records Administration, Washington, DC 20408; (full text available at http://www.access.gpo.gov/nara).

E2. **"Recommended Values of Meteorological Factors to be Considered in the Design of Aircraft Ice-Prevention Equipment,"** NACA Technical Note 1855 (1949), NASA/Ames Research Center, Moffett Field, California 94035.

E3. **"Review of Icing Criteria**," Lewis, William, Aircraft Ice Protection, Report of Symposium, Engineering and Manufacturing Division, Flight Standards Service, Department of Transportation, Federal Aviation Administration, dated April 28-30, 1969.

APPENDIX E. METEOROLOGICAL CONDITIONS (CONTINUED)

E4. **"Review of Icing Criteria,"** Lewis, William, Aircraft Ice Protection, Report of Symposium, April 28-30, 1969.

E5. **"A Probability Analysis of the Meteorological Factors Conducive to Aircraft Icing in the United States,"** NACA Technical Note 2738 (1952), NASA/Lewis Research Center, Cleveland, OH 44135.

E6. **"Certification of Part 23 Airplanes for Flight in Icing Conditions,"** Advisory Circular 23.1419-2B (1998); Federal Aviation Administration, Washington, DC 20591.

E7. **"Certification of Transport Category Airplanes for Flight in Icing Conditions,"** Advisory Circular 23.1419-2C (2004); Federal Aviation Administration, Washington, DC 20591.

E8. **"Certification of Transport Category Rotorcraft,"** Advisory Circular 29-2C (1999); Federal Aviation Administration, Washington, DC 20591.

E9. **"Engineering Summary of Airframe Icing Technical Data,"** D.T. Bowden et al., Technical Report ADS-4 (1963); Federal Aviation Administration, Washington, DC 20591.

E10. **"Aircraft Icing Handbook,"** FAA Technical Report DOT/FAA/CT-88/8-1 (1991), 3 vols., FAA William J. Hughes Technical Center, Atlantic City International Airport, NJ 08405.

APPENIDX F. OPERATIONAL FACTORS

F.1 AIRPLANE OPERATIONAL FACTORS.

The applicant should consider the airplane's flight envelope when determining the most critical conditions for designing an IPS. Explore flight regimes such as climb, cruise, hold, and descent at various altitudes. For airplanes with high-lift devices, the flight regime during which these devices are used may be the most critical. In other cases, the cruise configuration may be the most critical because of the lift, drag, or control problems associated with the buildup of ice on critical surfaces. Service experience shows that you should consider holding in icing conditions for as long as 45 minutes (appendix G of this AC).

The airplane's attitude affects the buildup of ice on critical surfaces. The airplane's airspeed and attitude affect the type and shape of ice buildups that occur (appendix R, sections R.1.1 and R.4 of this AC).

For a given set of meteorological conditions, the rate and extent of ice buildup is a function of flight speed as well as airfoil or body geometry. Small bodies moving at high speeds encountering large liquid water drops will have high collection efficiencies. The flow field associated with larger bodies deflects small drops. This results in lower collection efficiencies for larger bodies.

The ice accretion on the airplane depends, in part, on the airplane's speed and the horizontal extent of the icing cloud. However, icing tunnel tests show that the ice buildup rates on a surface are not always linear – especially for glaze ice. Ice buildups change the airfoil characteristics and cause a continuous change in collection rate above the initial rate. So, extrapolating ice buildups linearly with time can be misleading.

Airplanes not approved for inflight icing may encounter icing unintentionally. Therefore, the FAA requires the powerplants of these airplanes be protected against hazardous ice effects. Continued exposure of these aircraft to icing conditions may cause them to become incapable of flight. See 14 CFR § 23.901(d)(2) for engines and engine installations. For engine induction systems, see 14 CFR § 23.1093 and 14 CFR § 25.1093.

F.2 ROTORCRAFT OPERATIONAL FACTORS.

Rotorcraft may unintentionally encounter icing conditions even though they are not approved for flight in icing conditions. Therefore, the powerplants of these helicopters must be protected against hazardous effects of ice. However, continued exposure to icing conditions may cause the helicopter to become incapable of flight (section 10.1 of this AC and AC 29-2C).

F.3 ENGINE OPERATIONAL FACTORS.

Considerations for determining the most critical icing conditions for engines are related to the aircraft's operating procedures. This relationship exists because changes in engine power requirements usually accompany changes in airplane speed and attitude. Important considerations include evaluating the quantity and temperature of air available from the engine for ice protection and the airflow through the engine during the most critical operating mode. For example, the engine's flight-idle thrust may need to be increased to ensure the engine is able to provide the bleed air required by the ice protection system. These considerations are especially critical when evaluating thermal IPSs, where the heat source is the engine. The engine air mass flow and aircraft flight speed determine the flow field around the engine inlet. Designers must know the inlet flow field to determine the heat transfer between the heated surfaces, the hot air needed for the engine installation ice protection, and the quantity of water impinging on the surfaces. During some operating modes, the inlet static pressure and temperature are below ambient. In marginal icing conditions, this drop in temperature may be enough to cause ice to form in the inlet at ambient temperatures above freezing. AC 20-147 discusses these factors, as well as scoop factor, in more detail.

Engine inlets, inlet air screens, and inlet lips are critical because the ice buildups on the surfaces are exposed to engine airflow. This ice buildup may shed and be ingested by the engine. Ice ingestion can cause serious damage to compressor or fan blades. Runback water can also refreeze on unprotected surfaces of the inlet. If this runback ice is excessive, it can reduce engine airflow or distort the flow pattern to excite compressor or fan blades to critical frequencies.

Various engine operating modes have an effect on propeller ice. Propeller surfaces are evaluated similarly to other surfaces in determining the extent and degree of required ice protection. The greatest quantity of ice normally collects on the spinner and inner radius of the propeller. Propeller and spinner ice may be ingested into the engine. You may use inertial separation within the engine to avoid ice ingestion by the engine. You may also use anti-ice, rather than deice systems, to reduce the hazard of ice being shed into the engine. Airplane performance changes that may result from ice buildup on unprotected surfaces and on the propeller further emphasize the need to preserve acceptable aircraft power or thrust.

You should discuss details about approval of turbine engine induction system ice protection and turbine engine ice ingestion with the FAA Engine and Propeller Directorate. ACs 23-8B and 20-147 contain added guidance.

APPENIDX G. ICING CONDITIONS EXPOSURE TIME

To show an airplane's tolerance to continuous icing, the applicant should perform analyses and consider flight tests of the airplane for a representative air traffic imposed "holding" condition in the continuous maximum icing conditions of 14 CFR part 25, Appendix C. You should show that recommended holding configurations and airspeeds are safe. Perform flight tests that include a continuous exposure to icing of at least 45 minutes with the IPSs working. Appendix R of this AC, paragraph R.4.1, provides added guidance on icing exposure times and critical ice shapes for these exposure times. Appendix R of this AC, paragraph R.3 contains guidance on icing exposure times following an IPS failure. AC 20-147 contains guidance on 14 CFR part 33 compliance icing conditions exposure times.

APPENIDX H. ICE PROTECTION SYSTEMS

H.1 ICE PROTECTION TECHNOLOGIES AND OPERATING MODES.

Applicants may use various ice protection technologies to comply with ice protection requirements. These technologies, discussed in section 7 of this AC, include:

- Thermal (hot air and electrothermal).
- Mechanical (pneumatic boots, electro-impulsive).
- Fluid (weeping systems).
- Icephobic.

These ice protection technologies use the following techniques to achieve protection against ice buildup:

- Heating the impinging supercooled water drops to above the freezing point.
- Using mechanical, thermal, or pneumatic energy to shed accreted ice.
- Lowering the freezing point of the impinging water below the local air temperature.
- Providing an aircraft component surface that prevents adhering ice.

You may use hybrid IPSs that combine two or more of the techniques for specific applications. You may also use ice protection technologies either as anti-icers or as deicers.

Anti-icing IPSs prevent ice buildup on protection surfaces. Periodic cycling of deicing IPSs removes ice that collects on protection surfaces. You should address intercycle ice when certifying a deicer IPS. The IPS mode of operation used for certification should be the same as that used in service. For example, if you use the IPS as an anti-icer during certification, the AFM should recommend use of the IPS as an anti-icer.

Unless used in a deicing mode, evaporative anti-icing systems have no ice accretion on the protection surfaces or runback ice aft of the protection surfaces during normal operations in icing conditions. Therefore, there is less change in the aircraft's aerodynamics caused by an evaporative anti-icing system (compared with the aerodynamics of the uncontaminated aircraft) than that caused by a deicing IPS.

> **NOTE:** Running-wet IPSs may accrete ice aft of the protection surface when used as either an anti-icer or as a deicer. Runback ice may change the aircraft aerodynamics.

Anti-icing IPSs require greater energy than deicing IPSs. The greater energy required by anti-icing IPSs could result in significant decreases in available airplane thrust and airplane performance if the engines provide energy for ice protection. On the other hand, sometimes the thrust levels required for evaporative anti-ice protection may not allow the aircraft to descend using normal procedures. Without enough heat from the engines, the evaporative IPS may run wet and require runback ice evaluation.

APPENDIX H. ICE PROTECTION SYSTEMS (CONTINUED)

Adverse aerodynamic effects may result from ice accretion roughness on the protected and unprotected surfaces before IPS activation and its full effectiveness. (Figures R-1 through R-3 in appendix R of this AC show examples of ice accretion roughness that may exist before the IPS becomes fully effective.) Preactivation ice accretion roughness on these surfaces may be significant. You should address preactivation ice accretion roughness aerodynamic effects during the airworthiness approval of IPSs. You should also evaluate intercycle ice roughness and shapes for deicing IPSs during certification.

Detailed descriptions of ice protection methods and systems are in Chapter III of the FAA Aircraft Icing Handbook, DOT/FAA/CT-88/8-1, dated March 1991 (Reference H1). Most of this material is also available at the Electronic Aircraft Icing Handbook (EAIHB), web site, http://aar400.tc.faa.gov/Programs/FlightSafety/icing/eaihbk.htm

The next section provides a review of aircraft IPSs. This review includes comments relevant to their compliance with regulatory requirements.

H.1.1 Ice Protection Technologies.

H.1.1.1 Thermal Ice Protection Systems.

Thermal IPSs may operate as either anti-icers or deicers. The protection surface of a thermal IPS is typically heated to temperatures above freezing. Thermal IPS designs that heat the protection surface enough to evaporate the impinging liquid water drops for all required icing conditions are called “evaporative” thermal IPSs. Thermal IPSs that heat the protection surface only to temperatures above freezing are called “running wet” thermal IPSs. This IPS technology allows the impinging drops to flow on the surface without freezing. Running-wet thermal IPSs may evaporate impinging liquid water drops for portions of the required icing conditions.

Applicants often select evaporative IPSs over running wet IPSs since they do not need to consider frozen run-back water with evaporative systems. However, evaporative IPSs require greater thermal energy. You may provide the thermal energy required electrically or by heated air. Because of the high heat energy required by thermal ice protection, electric thermal ice protection is typically used for small surfaces (propellers, air data probes, control surface horns, windshields, carburetor components, and turboprop engine inlets). It is also used for other surface areas that are not easily protected with heated air (helicopter rotor blades). Heated air for hot air thermal IPSs is typically bled from turbine engines. You may salvage the hot air or fluids from other heat sources, including oil coolers and heat exchangers. High by-pass ratio turbofan engines with their small turbines provide limited hot air. This scarcity of thermal energy is leading to an increased use of running-wet thermal IPSs and to a decrease in the extent of the airframe ice protection. For example, on many recent transport airplane designs there is no protection on the horizontal and vertical stabilizers and wing leading edges may have limited protection.

You should determine the energy required for safe flight of the aircraft. You may do this through flight tests in critical icing conditions. This approach is costly, time-consuming, and runs the risk of not finding critical icing conditions. Alternatively, you may use thermal

APPENDIX H. ICE PROTECTION SYSTEMS (CONTINUED)

analyses, verified by dry air and natural icing flight tests with instrumented aircraft. These analyses are complex since the heat required is a function of many parameters, including:

- Evaporation of the impinging water loading.
- The target surface temperature distribution for a running-wet IPS.
- External airflow speed and temperature.
- Heat distribution on the protection surfaces.
- Heat transfer between the freestream and heated surfaces.
- Radiant heat transfer.
- Internal heat transfer. (For heated air systems, internal heat transfer may be a function of engine power settings, altitude, ambient temperature, and system losses.)
- The heat conduction and convection coefficients of the protection surface material.

You may use computer codes, analytical methods, or previous experience in the analyses to estimate the required heat. SAE ARP5903 (Reference H2) contains guidance on using computer codes. (References H3 through H5 contain more information on determining the required heat.)

Typically, you perform thermal analyses for IPS components; however, you should integrate the component analyses into a single analysis for the complete thermal IPS. This should include all duct heat losses (for hot air IPSs) to determine the available and required IPS heat. Analysis should also show that temperatures resulting from the IPS, including ducting immediately downstream of the engine bleed ports, do not cause fire hazards or adversely affect the integrity of the structure.

Because you may need estimates in the analyses, you can determine empirical corrections for the estimates using icing wind tunnels and icing tankers (SAE ARP5905 (Reference H6) and ARP5904 (Reference H7)). You should use dry and wet air flight tests to verify the heat required to achieve the needed IPS surface temperatures.

Because of the influence of the water loading on the energy required for thermal IPSs, you may consider the icing conditions defined by appendix C more important for determining the design of thermal IPSs than mechanical IPSs.

Typically, dedicated energy sources provide the energy for thermal IPSs. The energy may be provided by engine-driven electric generators or alternators, or by extraction of hot air from the turbine engine compressor. The needed thermal energy may result in a significant loss of engine thrust and a significant increase in fuel flow. You should verify the bleed air extraction required by the IPS against the engine installation handbook for compatibility. While most engines incorporate flow-limiting valves in the bleed ports, these valves are usually designed to choke at

APPENDIX H. ICE PROTECTION SYSTEMS (CONTINUED)

higher flows than those expected for normal operation. You must show the aircraft performance losses resulting from the engine-bleed air in the AFM. Also, ensure the needed bleed air is available at low thrust levels. This may require the engine to run at higher thrust levels during some phases of flight (such as during descent). Also, ensure the needed bleed air is available during one-engine-inoperative operations. This may result in IPS design or procedure changes. For some type designs, there may be a requirement to use the autothrottle to keep the necessary engine thrust and bleed airflow. This will ensure acceptable ice protection during descent. Thermal IPSs may operate sequentially or periodically as deicing systems to reduce energy requirements. You must show the adequacy of the heat source to provide satisfactory ice protection for safe aircraft operation in the icing conditions of 14 CFR parts 25, Appendix C and 29, Appendix C. Also include the required IPS procedures in the AFM.

"Running-wet" thermal airframe IPSs may result in runback ice accretions. You should consider runback-ice accretions as part of the surface roughness expected during normal operations in icing conditions. Ice accretion shapes resulting from runback water are difficult to predict analytically. You may need to test in natural icing conditions, simulated icing conditions, or in an icing wind tunnel to determine the extent and characteristics of runback ice. Section H.2 of this appendix, and References H3 through H5 contain more information on design methods that will reduce runback icing.

Perform similar thermal analyses to show the adequacy of electrical energy sources. These sources should provide enough thermal energy to protect surfaces during inflight icing. Also pay attention to showing compliance for related regulations, like pilot visibility, air data probes, propellers, and induction systems.

You should consider safe aircraft operation in icing conditions when failures of electric generators occur. You should also consider failures of the engine bleed air valves and controls, the cross-over duct valve and control, and IPS sequencing equipment to ensure symmetric ice protection on both sides of the aircraft during one-engine-inoperative operations. Also, review the reliability of the protection surface temperature controls to ensure the protection surface's structural integrity.

You should evaluate preactivation surface roughness—resulting from ice accretion that collects before the IPS becomes fully effective after activating the IPS following AFM procedure (paragraph 6.2 of this AC). Appendix R, section R.1.1 of this AC, contains added information about preactivation ice shapes. Section 8.2, of this AC, contains means to evaluate aircraft safe flight with preactivation ice accretion.

You may use airframe thermal IPSs as deicers. This reduces the ice protection energy requirements. As with any deicer, intercycle ice accretion on the protected surfaces will occur. You should evaluate the effects of the intercycle ice accretion roughness. Assess intercycle surface roughness when showing safe inflight icing operation of the aircraft. You should pay attention to adverse aerodynamic effects caused by sequential deicing and asymmetric ice buildups. Consider guidance presented in appendix Q of this AC for the presence and shedding of the intercycle ice when using thermal IPSs as deicers.

APPENDIX H. ICE PROTECTION SYSTEMS (CONTINUED)

Electrothermal ice protection is typically used for ice protection of air data sensors. Ice bridging may occur with local thermal ice protection. Also, for running-wet thermal IPSs, runback ice may grow forward and bridge the heated surface. Applicants should address this issue during the design of thermal IPSs

Reference H8 provides information about rotor blade ice protection and rotorcraft IPS design.

H.1.1.2 Mechanical Ice Protection Systems.

Mechanical IPSs use mechanical energy to shed ice from protection surfaces. Inflating, deflating, and flexing of elastic tubes apply mechanical energy to break the adhering ice. Applicants can also use mechanical force transferred through aircraft surfaces to break the adhering ice. The freestream shear force and the mechanical energy transferred to the ice then cause the ice to shed. Since the IPSs allow ice to build up before shedding, these IPSs are deicers.

Pneumatic deicing boots use rapid inflation, deflation, and flexing of elastic tubes to break and eject adhering ice. The elastic tubes are installed streamwise or chordwise.

The mechanical energy may be delivered electrodynamically by dynamically charging ribbon-like coils rigidly supported beneath the protection surface. The strong, short-period electromagnetic field formed by the charged coils induces eddy currents in the aircraft surface above the coil. The eddy current causes the aircraft skin to respond to the strong repulsive electromagnetic force field. The small but rapid skin deflection of the electro-impulse deicing (EIDI) IPSs provides a sharp force to break and eject adhering ice.

Alternatively, impulsive movements of the protection surface can deliver the debonding and ejecting mechanical force of an electroexpulsive deicing system (EEDS). This impulsive surface movement is caused by pulsing an electrical current in opposite directions through closely spaced parallel conductors, or conductive layers, embedded in a nonconducting elastomeric blanket beneath the protection surface. An eddy current deicing system (ECDS) provides an impulsive movement of the protection surface by a reaction to electrical current pulsed through planar coils embedded within and spanwise along the leading edge of the protected surface.

Deicing IPSs, such as EIDI, EEDS, and ECDS, may produce strong electromagnetic fields. Consider the effects of these electromagnetic fields on the operation of other electrical or magnetic equipment, such as high-lift devices' magnetic near-far sensors, magnetic compasses, and shielding of wiring and electrical controls (14 CFR §§ 23.1327, 23.1351, and 23.1547 and 14 CFR §§ 25.1327, 25.1351, and 25.1547). Also, these types of IPSs typically operate with brief, but high levels of energy. These high-energy levels could produce a significant ignition source during failures of either the IPS or in combination with external events (for example, bird strikes). You should evaluate aircraft level flammable fluid and system safety requirements when installing these types of IPSs close to flammable fluids (14 CFR §§ 23.853, 23.863, and 23.1309; 14 CFR §§ 25.853, 25.863, and 25.1309; 14 CFR §§ 27.853, 27.863, and 27.1309; 14 CFR §§ 29.853, 29.863, and 29.1309; 14 CFR § 25.981; and SFAR 88).

APPENDIX H. ICE PROTECTION SYSTEMS (CONTINUED)

An emerging technology uses hydrogen and oxygen pressure produced by electrolysis of water. Electrolysis of ice melted at the boundary of the ice accretion and the protection surface debonds and ejects the remaining ice accretion. This technology is not mature enough to be considered for an aircraft ice protection system. Of all these mechanical ice protection technologies, pneumatic deicing boots are most commonly used.

The ice shedding efficiency of mechanical IPSs depends on many factors, including:

- The strength of the bond between the ice and the protection surface.
- The shearing force of the local airflow.
- The fracture strength and modulus of elasticity of the adhering ice.
- The ability of the IPS to break the ice into small enough particles so the local airflow shears them from the protective surface.
- The ability of the mechanical force and elasticity of the surface material to peel and eject the broken ice.
- The characteristic dimensions of the IPS components.
- The variations of the protection surface's modulus of elasticity and pliability with temperature.
- Characteristics of the applied mechanical force.
- The surface condition of the protection surface.
- The intercycle interval and thickness of the adhering ice.
- Characteristics of the applied air pressures (inflation and deflation, and inflated dwell time).

Because of the many variables involved, the ice shedding efficiency of mechanical IPSs depends on the aircraft design.

Because of a lack of acceptable analysis methods and our inability to test full-size aircraft in icing wind tunnels, you may need to perform full-scale flight tests in natural or simulated icing conditions, or icing tunnel tests with full-scale wing sections or engine inlets. SAE ARP5904 (Reference H7) provides useful information about the use of icing tankers for evaluating deicing efficiency. You should evaluate changes to the IPS that change the IPS' ice shedding efficiency. Appendix Q of this AC provides more information on adverse effects that may result from ice shedding.

APPENDIX H. ICE PROTECTION SYSTEMS (CONTINUED)

Applying icephobic material can significantly reduce ice adhesion to the deicing boot surface. However, operators need to reapply these materials periodically to ensure their effectiveness. Do not use icephobic material on deicing boots for certification. This is because of the difficulty of ensuring proper use of these materials during normal, in-service operations. Another reason is the variability of material's icephobic effectiveness as the material erodes from the boot surface during normal operations.

The protection surface roughness of mechanical IPSs depends on the residual ice that remains on the surface after cycling of the IPS and the intercycle ice that collects between cycles. You should consider that this protection surface roughness is present during normal operation of the aircraft in icing conditions. You should consider effects of the residual ice that remains on the aircraft after exiting icing conditions and cycling of the deicing IPS on the aircraft's flying qualities and stall protection. You should describe the characteristics of the normal-operations protection surface roughness. You should determine these ice buildup characteristics by icing wind tunnel tests, or during natural or simulated icing flight tests. The character of the normal-operation protection surface roughness varies with the mechanical IPS's design, how it is operated, the aircraft configuration, how the aircraft is operated, and the icing conditions. Appendix R, section R.1.2, of this AC, has more intercycle ice information.

You must ensure that the pneumatic deicing boots are effective during continuous flight in the icing conditions defined by 14 CFR parts 25 and 29. The horizontal extent of icing clouds do exceed the arbitrary standard horizontal extents of 17.4 nm and 2.6 nm defined in Appendix C of 14 CFR parts 25, Appendix C and 29, Appendix C. Showing the effectiveness of the IPS for only the number of cycles required to transit those distances is not enough for complying with the intent of § .1419 of 14 CFR parts 23, 25, 27, and 29.

Deicing boot ice bridging and the ice shedding characteristics of early deicing boot designs have led to the recommended procedure of cycling deicing boots after collecting ¼ to 1½ inches of ice on the boot surface. This practice originates from the belief that a bridge of ice could form if the boots are operated prematurely. Classical deicing boot ice bridging occurs when a thin layer of ice is plastic enough to deform to the shape of the inflated deicing boot tube without breaking or shedding following tube deflation. As the deformed ice shape hardens and builds up added ice, the deicing boot becomes ineffective in shedding the "sheath" of ice. Icing tunnel and natural icing flight tests have shown the concern over ice bridging is considered unnecessary with modern boots. Modern boots are defined as those that use small diameter tubes (up to 1.75 inches), nominal working pressures of 15 psig and higher, and fast inflation and deflation times.

It is difficult for the flightcrew to determine the thickness of the ice accurately by visual observation. Also, constant checking of the ice thickness may unacceptably increase the pilot's workload. Therefore, the recommended AFM procedure for boot operation should be to operate the boots at the first sign of ice accretion and not wait for a specific amount of ice to collect.

The critical intercycle ice roughness may be sensitive to temperature and altitude. At colder temperatures the adhesive characteristics of rime ice are high and the ice is rough. An "alligator-skin-like" surface roughness may occur as fractures of the residual ice act as "seeds" for added

APPENDIX H. ICE PROTECTION SYSTEMS (CONTINUED)

ice accretion between deicing boot cycles. Also, temperature may affect the flexibility of boot material. Near freezing temperatures often result in aerodynamically adverse ice ridges that develop from residual ice along the trailing edges of individual deicing boot tubes. These ice ridges result from residual ice that remains on the aft portion of individual deicing tubes if the ice is not shed by the lower local airspeed (and shear) when the tube inflates. The localized ice accretion acts as an efficient ice collector for the impinging and runback water during the periods of tube deflation and inflation. You should show the effectiveness of the boots in flight throughout the altitude range of the required icing conditions. Operate the boots at the coldest temperature of the required icing conditions to show proper operation of the boots and to verify boot structural integrity.

Many inflight icing accidents and incidents occur during near-freezing icing conditions. If you base the boot air supply on gage air pressure, you should evaluate ice shedding performance and intercycle ice roughness throughout the temperatures and altitudes defined by 14 CFR parts 25, Appendix C and 29, Appendix C or as limited by the aircraft's flight envelope. Because boot pressure is dependent on bleed air mass flow, you should use dry air flight-testing to show boot operation and pressures at minimum engine power settings. You should perform this demonstration at the altitudes defined by 14 CFR parts 25, Appendix C and 29, Appendix C or as limited by the aircraft's operational envelope. You must provide the minimum engine power setting, if determined, in the AFM. You should address deicing boot air pressure variation resulting from air pressure regulator tolerances when you show the effectiveness of the deicing boots. Also, some cockpit annunciation lights are set below these tolerances. You should determine ice shedding performance and intercycle ice roughness at these lower pressures.

You should consider the potential for liquid water collection in the pneumatic deicing boots. This water may freeze and prevent proper operation of the boots. Examine the pneumatic boot arrangement for low points, which may collect water. You should also consider installing water drains. Provide periodic inspection and drainage procedure instructions in the proper manuals. Drainage or "weep" holes may become blocked on some aircraft. Therefore, you should provide water/air separators or heaters to prevent blockage. You should evaluate the effectiveness of water/air separators and drainage holes by flying through rain, followed by flight at altitudes with temperatures below the freezing point.

System failure analyses of mechanical IPSs should include an assessment of the deicing boots' pressure control valves, and the annunciation of IPS failures to the flight crew.

The boots should not result in hazardous effects on aircraft performance and handling qualities. Perform tests to evaluate possible hazardous changes to handling qualities and performance when the boots are operated. This is necessary because inflated leading-edge pneumatic deicing boots distort the surface's contour and change surface flow conditions. You should evaluate these effects on the aircraft's handling qualities by running the boots at speeds ranging from stall speed to $(V_{NE}+V_D)/2$ or $(V_{MO}+V_D)/2$. Include any deicing boot limits, such as altitude, temperature, airspeed, aircraft configuration, or flight phase, in the AFM. Also include information about anomalous aircraft behavior associated with operation of the deicing boots.

APPENDIX H. ICE PROTECTION SYSTEMS (CONTINUED)

H.1.1.3 Fluid Ice Protection Systems.

Fluid (freezing point depressant) IPSs introduce a freezing point depressant agent, typically a glycol compound, on the surface at the leading edge. The freezing point depressant causes the impinging water to have a freezing point lower than the local airflow temperature. The impinging water mixture then evaporates or sheds from the surface. The freezing point depressant fluid may be introduced on the protection surface by being:

- Pumped through a porous surface;
- Channeled along the protection surface in grooves by centrifugal force;
- Sprayed from external spray bars; or
- Contained in compounds (such as grease) that have been applied to the protection surfaces, such as propellers.

This ice protection technology is associated with products developed during World War II by TKS Ltd., a conglomerate of Tecalemit Ltd., Kilfrost Ltd., and Sheepbridge Stokes in Great Britain. However, systems made by other companies are in current use. These systems work by pumping a liquid freezing point depressant through the porous skin of the protection surfaces. Applicants can use the IPS as an anti-icer or a deicer. These systems also have the potential of being simple and reliable; however, the supply of fluid limits the protection. You should ensure an acceptable supply of fluid and evaluate the effectiveness of the IPS within the required icing conditions, for all phases of flight, and for the needed aircraft configurations. Also consider fire hazards and possible fire extinguisher requirements associated with the ice protection fluid (14 CFR §§ 23.863 and 23.1199(b)).

H.1.1.4 Icephobic Ice Protection Systems.

Icephobic materials are occasionally considered for use as an aircraft IPS. Typically the hydrophobic material is applied to the protection surface. The objective of the icephobic material is to prevent supercooled water and ice from adhering to aircraft surfaces. This ice protection technology is not commercially available. As discussed in paragraph H.1.1.2, of this appendix, appliances may use icephobic silicon compounds to supplement the ice shedding effectiveness of mechanical IPSs. However you may not take credit for its use during approval of the IPS since preserving its effective use is difficult to control.

H.1.2 Ice Protection System Operation.

All IPSs are activated by some means to ensure safe flight in icing conditions. This may be accomplished by:

- The flight crew seeing the presence of icing conditions or ice buildup on monitored surfaces and then activating the IPS.

APPENDIX H. ICE PROTECTION SYSTEMS (CONTINUED)

- Some means that alert the flight crew to activate the IPS before hazardous ice buildup on critical surfaces. Or, the means may alert the flight crew that icing conditions exist.

- Automated operation of the IPS by a means that detects the existence of icing conditions or ice buildup on monitored surfaces.

- Operation of the IPS based on visible moisture and temperatures provided in the AFM or RFM.

Activation of the airframe IPS should also, as necessary, adjust the stall warning and protection schedules to ensure acceptable stall margin and protection for flight in icing conditions.

Requirements have been set up to ensure pilots are provided necessary information and limits for safe flight in inflight icing conditions (14 CFR §§ 23.1525, 23.1583, 23.1585, and 23.1559; 14 CFR §§ 25.1525, 25.1583, and 25.1585; 14 CFR §§ 27.1525, 27.1583, 27.1585, and 27.1559; and 14 CFR §§ 29.1525, 29.1583, 29.1585, and 29.1559). The applicant should provide pilots required or recommended means and procedures for operating the IPS.

Pilots may detect aircraft icing and icing conditions on some aircraft simply by seeing ice on reference surfaces. These reference surfaces include windshield wiper blades, windshield posts, and other small protuberances that are efficient ice collectors. These surfaces collect ice before ice accretion is observable elsewhere on critical aircraft surfaces. Reference surfaces used as icing cues should show the presence of icing before or simultaneously with ice accretion that has been shown to be safe on monitored surfaces of that aircraft. You must provide acceptable lighting, other than a flashlight (because of crew workload), to detect ice on critical wings surfaces at night (14 CFR § 23.1419(d), 14 CFR § 25.1403, 14 CFR § 27.1419(e), and 14 CFR § 29.1419(e)). Consider lighting ice evidence probes for flight at night. You should show the illumination provides acceptable visibility, without excessive glare, reflections, or other distractions, in and out of clouds. If cues of icing are not visible at night, aircraft approved for flight in icing conditions should not fly at night.

For some aircraft, no icing cues are visible from the normal work position of the flight crew. For those aircraft, and generally for operation of engine ice protection, you may use visible moisture and temperatures colder than those determined by the designer as indication of icing conditions. The threshold you select must ensure that no hazardous amount of ice will build up on the engine induction system or other critical surface at a temperature above this limit. You should provide these conditions in the AFM. Alternatively, you may install approved ice detectors, airplane performance monitors, or icing conditions detectors to alert the flight crew to follow AFM procedures when the aircraft is accreting ice or when icing conditions are encountered.

The FAA has issued Airworthiness Directives (AD) requiring activation of wing deicing boots on regional air transports at the first detection of airframe ice or when ice detectors detect icing conditions. The ADs also require cycling the deicing boots once the aircraft has exited the conditions. This is a fundamental shift from previous practices, where flight crews would cycle the boots when they saw a recommended thickness of ice to avoid deicing boot ice bridging. In-

APPENDIX H. ICE PROTECTION SYSTEMS (CONTINUED)

flight icing accident investigations have shown that flight crews have lost control of the aircraft while judging whether the recommended thickness of ice had built up on the wing for activation of the deicing boots. Wind tunnel and flight test results have shown that continued cycling of modern deicing boots will shed the thin, first ice buildup during following cycling of the boots. When compared with older deicing boot designs, modern boots run at higher air pressures and inflation/deflation rates, and have small tubes. Activation of the deicing boots ensures the IPS is used during icing conditions. It also ensures the ice buildup on the deicing boot surface is minimized.

The proper manual should describe the expected icing cues, the flight-crew procedure associated with seeing the cues, and when the flight-crew should activate the IPS (14 CFR §§ 23.1583, 23.1585, and 23.1559; 14 CFR §§ 25.1583 and 25.1585; 14 CFR §§ 27.1583, 27.1585, and 27.1559; and 14 CFR §§ 29.1583, 29.1585, and 29.1559). You should provide procedures such as emergency or abnormal procedures, including procedures in the AFM for when the IPS fails or when warnings or alerts occur. For fluid IPS, include information and methods for determining the remaining time of protection provided by the fluid.

H.2 REFERENCES.

H1. **"Aircraft Icing Handbook,"** FAA Technical Report DOT/FAA/CT-88/8-1 (1991), 3 vols., FAA William J. Hughes Technical Center, Atlantic City International Airport, NJ 08405.

H2. **"Ice Accretion and Droplet Impingement Codes,"** SAE ARP5903.

H3. FAA Technical Report ADS-4, **"Engineering Summary of Airframe Icing Technical Data."**

H4. Report No. FAA-RD-77-76, **"Engineering Summary of Powerplant Icing Technical Data."**

H5. NACA Technical Note 1855 (1949), **"Recommended Values of Meteorological Factors To Be Considered in the Design of Aircraft Ice-Prevention Equipment,"** NASA Ames Research Center, Moffett Field, California 94035.

H6. **"Calibration and Acceptance of Icing Wind Tunnels,"** SAE ARP5905.

H7. **"Airborne Icing Tankers,"** SAE ARP5904.

H8. **"Rotor Blade Electrothermal Ice Protection Design Considerations,"** SAE AIR1667A, pp. 13-24.

APPENIDX I. DROP IMPINGEMENT AND WATER CATCH

I.1 DROP IMPINGEMENT AND WATER CATCH.

Applicants seeking FAA approval of the IPS (as discussed in section 7 of this AC) need to determine which aircraft surfaces will accrete ice, the extent of surface protection, and the energy needed to protect the surface from icing. You should supply an impingement analysis to confirm the extent of the IPS. FAA Icing Handbook (Reference I1) contains more guidance on developing this analysis.

Information needed to determine the chordwise extent of most IPSs includes drop impingement limits and the related water catch. Finding the supercooled water drop impingement limits and the resulting water catch are dependent on several variables. These variables include the surface contour, attitude, local flow angularity, local airspeed and Reynolds number, drop sizes (mass), catch efficiency, exposure time, and the LWC of the atmosphere. Perform studies for all phases of flight and aircraft configurations. These studies determine the chordwise extent of drop impingement on the surface and the required protection to prevent or remove ice accretion from the surface. Show safe flight in icing conditions for the configurations and phases of flight used to define the IPS's coverage. Also, you should provide the configurations used with different phases of flight in the AFM. This prevents the use of configurations for which the IPS was not designed, and for which safe flight in icing conditions has not been shown. An example is using only the cruise configuration for holding in icing conditions.

Surface moisture at and below the freezing point is required for ice to accrete. Some surface leading edges, such as antennae, antennae fairing, and air data probe and vent masts may be in "shadow" areas. The cloud drops (in a certain size range) in this area do not impinge on the aircraft. The freestream airflow carries them away from the aircraft surfaces. Analysis has shown at least one case where drops in an intermediate size range did not impinge on a fuselage-mounted ice detector while smaller and larger drops did impinge (Reference I2).

Also, the splashing and bouncing of cloud drops as the drops impinge on surfaces (and later ice shapes) will influence the buildup of ice. Larger cloud drops may break up as they traverse regions of high shear stress resulting from changes in the airflow speed.

Some conditions may result in runback ice buildups aft of the protected surfaces. Runback ice buildups result either through partial evaporation (by design in a running-wet IPS) or through aerodynamic heating at outside air temperatures slightly below freezing. This aerodynamic heating can result in a freezing fraction of less than one, causing water to run aft of protected surfaces, freeze, and form runback ice.

Although other analytical methods exist to determine the drop impingement limits on airfoils, computer codes are commonly used. You may use these codes to calculate the impingement area and limits, the water mass flux of the surface, the local water catch efficiency (β), and the total water catch efficiency (E). The codes also provide useful information on whether an aircraft surface is exposed to atmospheric moisture (and ice accretion). If the airflow is not separated from the surface, these tools offer the advantages of accurately determining local airflow angularities and speeds, the effects of the drop mass and aerodynamics, and the impingement for

APPENDIX I. DROP IMPINGEMENT AND WATER CATCH (CONTINUED)

a drop spectrum (rather than a single drop size). You may use Navier-Stokes CFD codes if the airflow is highly turbulent or separated. You should provide experimental confirmation in the form of wind tunnel, natural icing, or tanker data to support the calculated flow field and drop impingement.

You should provide justification for using a computer code to determine drop impingement information. The technical document, SAE ARP5903 (Reference I3), provides useful information on available drop impingement codes, their common use, limits, software verification, validation, and code administration. You should consider SAE ARP5903 when judging the acceptability of drop impingement analyses performed using computer codes.

Empirical evaluations have shown that 2D impingement codes are acceptable when properly used for simple, planar surfaces and drop sizes within 14 CFR part 25, Appendix C and part 29, Appendix C. Reference I3 discusses use of 2D impingement codes for impingement limit analyses of swept wings and stabilizers. At the AOA of interest, airfoil sections and pressure distributions are determined by following the direction of the airflow over the wing or stabilizer surfaces. Rather than tracking the streamlines across the surface, some manufacturers have approximated the streamline airfoil by using sections that are either normal to the surface's leading edge or normal to the surface's quarter-chord, and then straight aft from the quarter-chord to the trailing edge. You can determine this wing streamline information accurately either empirically or by using CFD codes. Without separated flow, you may use potential flow or Euler computer codes to calculate the flow over the surface. The 2D drop impingement code is then used to determine the impingement. Streamwise sections are used for straight wings and stabilizers.

You will find limited empirical validation of impingement codes for 3D surfaces (for example, wing tips, swept wings, bodies of revolution, fairings, and junctures of bodies).

Three-dimensional codes are available to perform impingement and ice shape prediction of 3D components on airplanes. However, 3D analyses can be costly in both time and resources. Sometimes these analyses require up to 6 weeks to calculate the drop impingement for a single 3D surface. Less costly 2D methods have been used to estimate drop impingement and ice shapes for symmetrical 3D surfaces. This is done using the centerline profile of each symmetrical surface. Examples of symmetrical surfaces include radomes, wing mounted fuel tanks, antenna fairings that form symmetric bulges in the fuselage, and light fairings.

Using 2D codes for such analyses does not address 3D flow conditions (for example, cross-flow). These 3D conditions affect the drop trajectory and impingement. Three-dimensional codes, depending on their sophistication, may not fully account for cross-flow effects either. When using 2D codes in this manner, account for the effects of nonzero pitch and yaw angles of attack. You should provide justification for the use of drop impingement and ice shape prediction codes in the form of an analysis. The analysis should show why you may ignore the 3D flow effects and should account for the effects of nonzero angles of attack. You should also validate the acceptability of your drop impingement and ice shape prediction codes. This validation may include one or more of the following:

APPENDIX I. DROP IMPINGEMENT AND WATER CATCH (CONTINUED)

- Icing wind tunnel results.
- Icing tanker results.
- Flight in natural icing conditions results.
- Similarity to other aircraft that have data from one of the above 3 validation methods.

> **NOTE:** Reference I3 discusses the use of 2D impingement codes on swept-wing airplanes.

You should justify the drop size or drop distribution used to determine the impingement limits. Advisory Circular (AC) 20-73, replaced by this AC, stated that an MED drop of 50 µm had been successfully used for certification purposes. Also, the document stated that MED drop of 20 µm had been successfully used to determine water catch rate. FAA Technical Report DOT/FAA/CT-88/8-1 (Reference I1) states that for design purposes, a drop size of 40 µm is often used for determining impingement limits. However, the largest drop size within Appendix C will determine the maximum impingement limits.

The variation of atmospheric cloud water drop diameters is high. Since the MED or MVD is the median drop diameter, water drops having larger diameters than the MED or MVD exist. NACA researchers used the Langmuir distribution in table I-1 to calculate MED for the data used to define 14 CFR parts 25, Appendix C and 29, Appendix C icing conditions (Reference I4). So, the Langmuir distribution is used to describe the variation of 14 CFR parts 25, Appendix C and 29, Appendix C cloud drop diameters. Since drops larger than the MVD exist, consider using the Langmuir D distribution with the 50 µm maximum median drop diameter of 14 CFR parts 25, Appendix C and 29, Appendix C to determine impingement limits.

Table I-1. Langmuir Distributions

Fractional Liquid Water Content in Each Size Group ~ %	**Langmuir Distribution ~ (Drop Diameter)/Median Drop Diameter**				
	A	B	C	D	E
5	1.00	0.56	0.42	0.31	0.23
10	1.00	0.72	0.61	0.52	0.44
20	1.00	0.84	0.77	0.71	0.65
30	1.00	1.00	1.00	1.00	1.00
20	1.00	1.17	1.26	1.37	1.48
Fractional Liquid Water Content in Each Size Group ~ %	**Langmuir Distribution ~ (Drop Diameter)/Median Drop Diameter**				
	A	B	C	D	E
10	1.00	1.32	1.51	1.74	2.00
5	1.00	1.49	1.81	2.22	2.71

If you fail to consider drop diameters larger than the maximum mean value and ignore water catch below a selected local water catch efficiency (β) (for example, 0.10), you may be ignoring

APPENDIX I. DROP IMPINGEMENT AND WATER CATCH (CONTINUED)

the buildup of thin, rough ice at the impingement limits that may cause adverse aerodynamic effects. Provide justification when selecting local water catch efficiencies other than zero for the impingement limits. Also provide justification when choosing not to consider the drop spectrum around a median diameter of 50 μm for determining the chordwise extent of the ice protection surface.

Analyze each ice-protected surface for different drop sizes and phases of flight. This analysis finds the drop diameter associated with the largest water catch. The water catch may determine the maximum heat requirements for thermal anti-icing IPSs. See the earlier discussion on median drop diameter and drop distributions. It may be proper to consider other drop diameters when addressing other IPS design requirements.

You may also determine drop impingement information empirically by using natural icing conditions flight tests, icing wind tunnels, or icing tankers. These methods may provide information on ice accretion limits, which should approximate drop impingement limits in rime conditions. Impingement and icing limits may differ substantially in glaze icing conditions. You may use these data to validate results from code-derived drop impingement limits.

During natural icing flight tests to determine icing limits, you should measure the icing cloud characteristics (including LWC, temperature, drop size), airplane airspeed, angle of attack, and altitude. Get enough information to ensure that icing limit results address the drop impingement issues and the phases of flight and associated airplane configurations being approved for flight in icing conditions.

You may use icing wind tunnels to determine drop impingement information. Techniques have been developed to calibrate water catch with the color intensity of captured dyed water. When possible, icing wind tunnels are useful for determining drop information for full-scale, 3D configurations. Carefully examine the use of scale models for impingement analysis since effective impingement scaling requires matching the modified drop inertia parameter, K_0. Appendix R of this AC contains details on using scaled wind tunnel models to determine impingement limits, water catch, and ice shapes.

Get FAA approval for use of scale models for impingement. Acceptance of scale model data may be based on repeating ice wind tunnel shapes, or by correlating ice shapes for models of different scales. This approach gives better results with rime ice accretions.

You should consider SAE ARP5905 (Reference I5) when judging the acceptability of icing tunnel drop impingement investigations.

You may also use icing tankers to get drop impingement limits, even though the drop MVDs may exceed 50 μm. Tanker tests allow testing of full-scale configurations, but are limited by the spray array's plume size and ability to match 14 CFR parts 25, Appendix C and 29, Appendix C drop sizes and LWC—especially at an MVD of 50 μm. However, drop impingement limits determined with MVDs exceeding 50 μm under rime icing conditions have been considered to provide conservative estimates of the impingement limits for some applications. You should justify and conservatively use icing tanker data. You should show the icing tanker, associated

APPENDIX I. DROP IMPINGEMENT AND WATER CATCH (CONTINUED)

instrumentation, and icing cloud plumes are calibrated. You should also show the impingement evaluation was performed using commonly accepted practices. You should consider SAE ARP5904 (Reference I6) when judging the acceptability of icing tanker drop impingement investigations.

The wing's lower surface impingement limit analysis typically suggests the ice protection should extend over a large percentage of the lower wing surface to encompass the entire impingement area. Structural (front spar location) and IPS energy considerations typically determine the extent of the IPS on the wing's lower surface. Airplane drag is usually the most significant aerodynamic effect of lower surface ice accretion roughness aft of the airflow's stagnation point (line) at airplane stall. Aircraft manufacturers will typically accept the drag penalty on performance rather than extending the IPS too far aft on the wing's lower surface.

You should consider the aerodynamic effects of ice accretion aft of the selected lower surface aft ice protection limit when showing safe flight of the aircraft in icing conditions. Simulated ice shapes are typically used. Since the aircraft horizontal stabilizer may lift in both directions, the design philosophy used for the ice protection on the wing may not be suitable for the horizontal stabilizer. These considerations reflect the use of engineering judgment and experience in design of IPSs. You must show safe operation of the aircraft in natural icing conditions with the proposed IPS (14 CFR § 23.1419, 14 CFR § 25.1419, 14 CFR § 27.1419, and 14 CFR § 29.1419). You may supplement this demonstration by analyses and laboratory tests (as necessary) to verify adequacy of the IPSs for icing conditions throughout the required icing environment.

I.2 REFERENCES.

I1. **"Aircraft Icing Handbook,"** FAA Technical Report DOT/FAA/CT-88/8-1 (1991), 3 vols., FAA William J. Hughes Technical Center, Atlantic City International Airport, NJ 08405.

I2. **"Certification and Integration Aspects of a Primary Ice Detection System,"** D. Jackson, D. Owens, D. Cronin, and J. Severson, paper no. AIAA-2001-0398, AIAA 39th Aerospace Sciences Meeting, Jan. 8-11, 2001. Reprints available from American Institute of Aeronautics and Astronautics, Reston, VA 20191-4344.

I3. **"Ice Accretion and Droplet Impingement Codes,"** SAE ARP5903.

I4. **"Mathematical Investigation of Water Droplet Trajectories**," *The Collected Works of Irving Langmuir,* New York, *Published by Pergamon Press* [c 1960-62], p. 348-393.

I5. **"Calibration and Acceptance of Icing Wind Tunnels,"** SAE ARP5905.

I6. **"Airborne Icing Tankers**," SAE ARP5904.

APPENIDX J. PROPELLER ICE PROTECTION

J.1 PROPELLER ICE PROTECTION.

When the airplane's powerplant installation includes propellers, the propellers' IPS must meet the applicable requirements of 14 CFR §§ 23.929, 23.1419, 23.1301, 23.1309, 25.929, 25.1091, 25.1419, 25.1301, and 25.1309. Each installed propeller must have means to prevent or remove hazardous ice accretion within icing conditions for which the applicant is seeing airplane certification. With the IPS installed, the propeller assembly must meet the requirements of 14 CFR part 35. The propeller IPS should prevent or remove hazardous ice buildup that could put engine performance at risk and enable satisfactory functioning without significant loss of thrust. If you are showing compliance with propeller ice protection requirements, you should consider the following:

- Airplane performance loss.
- Thrust requirements for airplane handling qualities evaluations, such as when showing stall warning and stall recovery.
- Vibrations.
- Engine ice ingestion.
- Airframe damage from ice shed from the propeller.
- Propeller structural behavior (integrity) resulting from functioning or failure of the propeller IPS.
- Power requirements for ice protection.
- Margins for operation in icing conditions, which may exceed certification requirements.

You should base compliance with regulatory requirements on flight tests in measured natural icing conditions and necessary analyses, or laboratory tests (14 CFR § 23.1419, 14 CFR § 25.1419, 14 CFR § 27.1419, and 14 CFR § 29.1419). You should verify analyses used to support compliance with icing requirements by test.

Perform analyses to determine:

- The most critical flight icing condition.
- The required zones of ice protection.
- The use of and operational modes for electrothermal ice protection. Include heat transfer characteristics, power requirements assuming an atmospheric temperature of

-30°C, intercycle intervals and critical ice shapes, if required, and their effects, runback ice and its effects, and deicer timer cycle.

- AFM limits for fluid systems, to prevent exhaustion of the fluid before exiting the icing conditions.

- The maximum size and trajectory of the ice that sheds from the propeller (propeller inter-cycle ice). This ensures that the energy of the shed-ice does not damage the airframe structure, resulting in unsafe conditions.

- The integrity of the propeller and the propeller IPS when subjected to high temperatures due to hot weather operation or failure of the thermal regulator.

Other concerns include:

- The effect of deicer boot installation on the propeller blade.
- The effect of the slip ring or equivalent accessories on the hub structural integrity.
- Blade surface temperatures.
- Voltage and current transmission losses from the airplane to the deicer boot.
- Timer and other control system component reliability.
- Spinner ice buildup.
- Brush block or slip ring hydroplaning when exposed to moisture.
- Reliability of wiring, brush blocks, slip rings, and other components.

The propeller must not adversely affect engine operation throughout the engine's power range (including idle). There must be no loss of thrust throughout the full rotational speed and pitch range expected during icing conditions that would result in unsafe airplane performance or handling qualities. Propeller ice shedding should not cause structural damage. You must confirm this performance in flight test, targeting the predicted critical icing conditions within 14 CFR part 25, Appendix C.

Because of possible hazards, you should pay attention to propeller ice accretion with an operative propeller IPS in icing conditions that temporarily exceed 14 CFR part 25, Appendix C icing conditions. Figure J-1 shows a coating of ice along the leading edge of the propeller blade, underscoring the need for this attention. The ice is on top of and beyond the protected area of the blade. This type of propeller ice buildup may severely affect thrust. In addition, icing tunnel testing and flight testing of propellers' runback have shown propeller performance losses of up to 20 percent. Airframe and propeller ice accretion in conditions that temporarily exceed 14 CFR part 25, Appendix C icing conditions may impact the ability of the airplane to accelerate out of stall warning and stall entry events by increasing propeller power.

APPENDIX J. PROPELLER ICE PROTECTION (CONTINUED)

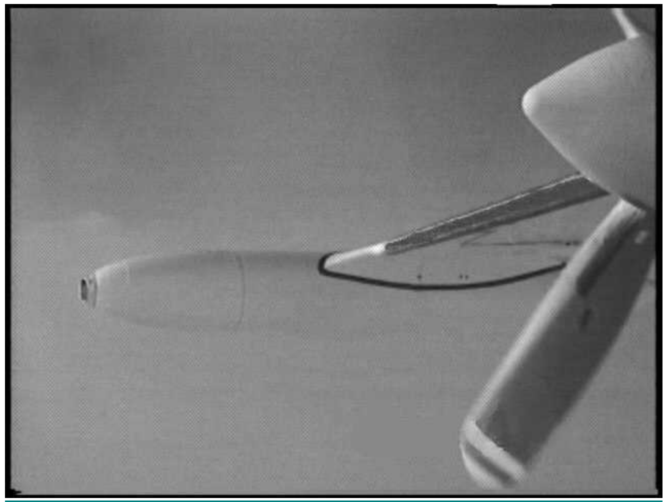


Figure J-1. Propeller Ice Accretion During an SLD Encounter With the Propeller Ice Protection System Operating (Reference J1).

Examine any significant vibrations while testing. Also consider the maximum temperatures which a composite propeller blade may experience during operation of the IPS. This includes unintentional operation on the ground during hot day conditions or during dry air flight. Check electrically protected propellers, the IPS current, brush block voltage (between each input brush and the ground brush), and IPS duty cycles during tests to ensure that proper power is applied to the deicer protection surfaces. You should also check the IPS during flight in rain to ensure proper operation.

The propeller must not adversely affect engine operation throughout the engine's power range, including idle. There must be no loss of thrust throughout the full rotational speed and propeller pitch angle range expected during icing conditions that would result in unsafe airplane performance and handling qualities. Propeller ice shedding should not cause structural damage. You must show compliance with these requirements during flight tests, targeting the predicted critical 14 CFR part 25, Appendix C icing conditions.

J.2 REFERENCES.

J1. **"SLD Encounter, MU-2B-60, March 5, 2000, ABQ-ABQ, Alt = 16,100 ft, IOAT = -7C."** Timmons, Larry, FAA In-Flight Icing/Ground Deicing International Conference and Exhibition, June 16-20, 2003.

APPENIDX K. ICE AND ICING CONDITIONS DETECTION

K.1 ICE AND ICING CONDITIONS DETECTION.

Ice detectors may provide information to the flight crew or aircraft systems about aircraft icing. The ice detector may be intrusive or nonintrusive to the airflow. It may be directly or indirectly sensitive to the buildup of ice or sensitive to meteorological conditions conducive to icing. These devices may be classified as inflight icing detection system (FIDS), ground icing detection system (GIDS), or icing conditions detectors. Some possible ice detector technologies include: latent heat of fusion, changes in electrical fields, changes in the natural frequency of vibrating components, visual cues, ultrasonic waves, optical methods such as infrared or laser devices, and friction between a rotating cylinder and scraper. Chapter 2, Section 1 of the Aircraft Icing Handbook (Reference K1) and SAE AS5498 (Reference K2) contain more information on ice detector technologies and ice detectors. GIDS are associated with detecting ice on aircraft before takeoff. Appendix V of this AC contains guidance on GIDS. The following discussion focuses on FIDS.

A FIDS that detects ice buildups will, after detecting ice, signal the flight crew or aircraft systems (such as the IPS and stall protection system), or both, about ice buildup on monitored aircraft surfaces. It may also provide information about ice thickness, ice buildup rate, LWC, cloud drop size, and where the ice is. Current FIDS will detect ice buildup resulting from the airspeed, temperature, and moisture content near the ice detector's sensor. Since dynamic heating depends on airspeed, ice may not build up on the ice detector's sensor or on aircraft surfaces even though those conditions may be within those defined in 14 CFR parts 25, Appendix C and 29, Appendix C. Since local airspeeds and temperatures depend on the surface curvature, AOA, aircraft speed, and other variables, ice buildup will not occur at all locations at the same time. Applicants may install a FIDS on or remote from aircraft lifting surfaces, engine inlets, or other critical, monitored surfaces. Since critical surfaces may not be the reference surfaces, you must correlate ice buildup on critical surfaces with ice on the ice detector's reference surface (sensor). You need this correlation to ensure safe flight in icing conditions (14 CFR §§ 23.1419, 25.1419, 27.1419, and 29). The FIDS should detect aircraft icing within the icing conditions described in 14 CFR parts 25, Appendix C and 29, Appendix C.

A FIDS that detects icing conditions signals the flight crew or aircraft systems that the aircraft is in atmospheric conditions that are conducive to aircraft icing. Sensor components of the FIDS are intrusive or nonintrusive to the airflow. A FIDS that detects icing conditions by sensing a temperature threshold and the presence of moisture, is not necessarily sensitive to the presence of airframe ice buildup.

FIDS are divided into two categories:

- Advisory flight ice detector system (AFIDS) and
- Primary flight ice detector system (PFIDS).

APPENDIX K. ICE AND ICING CONDITIONS DETECTION (CONTINUED)

K.1.1 AFIDS.

An AFIDS provides an advisory alert to flight crews about of the presence of ice accretion or icing conditions. However, applicants should not use an AFID as the only means for ice or icing conditions detection since an AFID may not have adequate reliability. Therefore, the flight crew is responsible for monitoring icing conditions as directed in the AFM. Typical methods pilots use to monitor icing conditions include:

- Total air temperature.
- Visible moisture criteria.
- Visible ice buildups on specific areas, such as on windshield wiper blades and arms or on ice evidence probes.

Typically, the flight crew activates the aircraft IPS after the AFIDS provides an icing alert and after the flight crew confirms existence of the icing condition. Some AFIDSs activate the IPS automatically. Activation of the IPS may activate other systems (for example, activation of the IPS may adjust the stall protection schedule to provide acceptable stall margin for flight in icing conditions). The AFIDS tells the flight crew about the presence of ice accretion or icing conditions, but the crew only uses this information with other information, as described in the AFM, to determine the need for activating the IPSs.

K.1.2 PFIDS.

A PFIDS provides an alert to the flight crew about the presence of ice on the aircraft or the presence of icing conditions. The PFIDS may also give information to other aircraft systems. Applicants can use a PFIDS, along with approved AFM procedures, as the only means of detecting aircraft icing or icing conditions. PFIDSs are either primary automatic or primary manual. After detecting aircraft icing or icing conditions as a primary automatic system, the PFIDS automatically activates the airframe IPSs, may activate the propulsion system IPS, and may adjust the stall protection system attitude schedules, as necessary. Activation of the propulsion system IPS may occur earlier than the airframe IPS.

In a primary manual PFIDS, the flight crew activates the IPSs based on the PFIDS alert. Either the automatic PFIDS or manual activation of the IPS should adjust the stall protection schedules to ensure acceptable stall speed margins and stall characteristics during flight in icing conditions. A PFIDS must be self-monitoring and should provide an indication to the flight crew when there is an ice detector fault. The flight crew can then perform AFM procedures to ensure continued safe flight and landing.

K.1.3 Ice Detector Sensor Characteristics.

To ensure the acceptability of the FIDS, the aircraft manufacturer should understand its characteristics, limits, and abilities. This understanding should include:

APPENDIX K. ICE AND ICING CONDITIONS DETECTION (CONTINUED)

- Sensor ice detection technology.
- Limits.
- Atmospheric conditions and aircraft flight regimes in which the sensor will detect ice or icing conditions.
- Ice accretion rate on the sensor.
- Sensor ice collection efficiency.
- Ice or icing conditions detection response time.
- Deicing cycle of the ice detector sensor.
- Tendencies of the FIDS sensor signal to become saturated during icing conditions.

K.1.4 Freezing Fraction (*n*) Considerations.

The response time for an ice accretion detector to sense the presence of ice varies with the sensor's design and technology. As the local temperature of the ice detector sensor approaches 0ºC, all the cloud water drops that impinge on the detector's sensor may not freeze. Some of the impinging water drops may remain in the liquid phase and may shed from the detector's sensor, resulting in a delayed detection of icing. However, local flow fields with higher velocities elsewhere on the aircraft, such as turbine engine inlets and at areas of high local velocities on lifting surfaces, may display lower local temperatures and higher rates of ice buildups. Therefore, there are conditions where significant amounts of ice may build up on critical surfaces without detection by the ice detector.

Freezing fraction is the amount of water that freezes at contact on a surface divided by the surface's total water catch. Applicants must consider the effects of freezing fractions less than one when installing a FIDS that detects ice buildups on an airplane. At local temperatures well below the freezing point, icing clouds water drops freeze on contact with the ice detector's sensor, resulting in predictable ice detection response times. As the freezing fraction drops below 1, the ice detection response times for ice detectors may increase significantly. You should show that the ice detector alerts the flight crew to the presence of icing for all icing conditions that cause the airframe and engine induction system to build up unsafe quantities of ice. This requires showing that the ice accretion rate (W) of the ice detector's sensor is higher than for any other part of the aircraft for all 14 CFR parts 25, Appendix C and 29, Appendix C icing conditions. It also requires that the airframe and propulsion system induction system ice buildups are not hazardous when the ice detection response time is delayed. Reference K3 provides one means of doing this. Current ice accretion computer codes do not provide accurate results at low freezing fractions (glaze icing conditions), therefore you should evaluate your ice detector installation using an icing wind tunnel or an icing tanker if possible, or by natural icing flight tests at freezing fractions below 1.

APPENDIX K. ICE AND ICING CONDITIONS DETECTION (CONTINUED)

K.1.5 Drop Splashing, Runback, and Shedding.

Other considerations that applicants should examine for ice accretion detectors are water drop splashing, runback, and shedding. Splashing occurs when the impact of a drop on the surface causes the drop to break into smaller water particles. The fragment drop particles may bounce off the sensor surface into the airstream. The drop may remain in the airflow or reimpinge on the sensor. Runback icing occurs when impinging drops do not immediately freeze on contact with the sensor surface. The drops remain in a liquid state and may coalesce with other drops. The shear force of the local airflow may force these large drops downstream and they may shed from the sensor surface before freezing. Runback and shedding are associated with freezing fractions less than 1 and become more pronounced as the freezing fraction approaches zero. You should examine ice detector drop splashing for all conditions when the freezing fraction is less than 1.

Splashing or shedding may occur on the ice detector sensor, but not on larger airplane surfaces. This may result in delayed ice detection by the ice detector, even though ice is building up on aircraft surfaces. Failure or delay in the ice detector's detection of ice could result in hazardous ice buildup on surfaces (for example, on the wing, horizontal stabilizer, or the engine induction system inlets). You should ensure safe flight in all icing conditions.

Some impingement computer codes calculate the quantity of runback icing. They do not address the runback ice characteristics nor water mass loss because of drop splashing or shedding. Also, the runback results of these codes have not been validated using wind tunnel or flight tests. Therefore, you should use icing wind tunnel tests to examine the splashing, shedding, and runback characteristics of the ice detector.

K.2 INSTALLATION LOCATION.

Applicants should install the ice detector where it can detect aircraft icing reliably before there is hazardous ice on the airframe or engine inlets. After mounting the ice detector, you must ensure that it announces icing before there is unsafe ice accretion on monitored surfaces. Proper location is critical to ensure adequate detection of icing. Locate the ice detector on the airframe surface where the sensor is adequately exposed to the icing environment. Proper location of the ice detector requires flow field and boundary layer thickness analyses of candidate sensor locations. Perform the analysis at AOAs, airspeeds, sideslip angles, and with aircraft configurations approved for flight in icing. Local flow conditions and boundary-layer conditions may shield the sensor from acceptable sampling of the icing environment. If this is true, finding a better location for the ice detector is important. Understand that local flow conditions may:

- Alter the freestream icing characteristics by preventing drops of certain sizes from impinging on the ice detector sensor (shielding or shadowing the sensor location by carrying off drops not having enough momentum to penetrate local flow conditions);

- Result in unacceptable airspeeds when compared with the freestream airspeed; and

APPENDIX K. ICE AND ICING CONDITIONS DETECTION (CONTINUED)

- Result in unacceptable variation in orientation of the sensor to local flow angularity and airspeed with changes of the airplane's configuration and flight regime.

You should show acceptable performance of the ice detector when installed on the aircraft. To ensure locating the ice detector properly on the aircraft, you may model the airplane three-dimensionally in a viscous-flow CFD code analysis. Examine effects of the aircraft boundary layer on the ability of the ice detector to detect icing. (Reference K3 provides useful information on the acceptable installation of a magnetostrictive technology PFIDS). If the wing or other aircraft components do not influence the airflow at the candidate ice detector location, you may confine the CFD analysis to the aircraft area of interest (for example, the forward fuselage). Consider the effects of the propulsion system, such as the propeller slipstream and flow field variations that may occur with thrust changes if the detector is located in and near turbine engines. You may need to perform wind tunnel, tanker, and natural icing tests to verify these analyses.

Pilots have occasionally detected ice before receiving the PFIDS alert. This can occur because of poor ice detector placement (as well as other reasons like other components on the airplane having higher ice collection efficiency or low freezing fraction conditions). Poor sensor placement can cause a delay or failure of an ice detector to detect ice buildup or icing conditions. This may result in a hazardous condition. Reference K3 documents that improper placement of an ice detector sensor can result in the detection of large drops and small drops, but that medium-sized drops can be aerodynamically shadowed and prevent ice detection in a timely manner. This result is counterintuitive and shows that you must perform thorough analyses and testing to ensure proper placement of PFIDS sensors on an airframe and selection of PFID sensors that will detect all drop sizes. Helicopters may require a system to induce airflow across PFIDS sensors during low speed flight. You should conduct similar analyses and testing to ensure detection of ice buildups or icing conditions before an unsafe condition occurs on rotorcraft. CFD codes are a practical way to perform the placement analysis. Validation of the analyses is typically done during natural icing flight tests. Verify the ability of the ice detector to detect icing before there is ice accretion on the monitored surface during measured natural icing flight tests.

Besides the proper placement of the FIDS' sensors for ice detection, you should show that ice buildups forward of the sensor (for example, on the radome) do not interfere with the ice detector's performance. You should show that shed-ice will not damage the detectors. Also, other probes installed forward of the ice detector should not adversely interfere with the ice detector's performance.

K.3 SYSTEM CONSIDERATIONS.

During previous certifications, the FAA considered an extremely improbable unannunciated failure to detect ice or icing conditions to be the ice detector's top-level system requirement. This failure is not expected to occur during the life of the fleet. The assumed hazard level is catastrophic. Applicants may consider reduced hazard levels for a specific aircraft when showing compliance with 14 CFR §§ 23.1309, 25.1309, 27.1309, and 29.1309 for new PFIDS certifications, if you have enough evidence of the reduced hazard. You should get concurrence from the FAA before using reduced hazard levels in designing a PFIDS.

There should be at least dual ice detector systems. You should separate the detector systems to ensure that a common fault or condition will not interfere with ice detection. Each detector should have an independent failure monitoring system. You must show the effectiveness of the PFIDS during the icing flight tests for 14 CFR parts 23, 25, 27, and §§ 29.1093 and 29.1419. The PFIDS should also have the following minimum abilities:

- The threshold ice buildup, or icing condition, chosen to activate the detector's alert of icing or icing conditions and the ice buildup that occurs before the IPS becomes effective must allow safe flight of the aircraft. Do this by ensuring that preactivation ice is not hazardous and that when the ice buildup sheds there will be no hazardous or unsafe damage to the engines and airframe.

- The ice detector should not be excessively sensitive and produce nuisance alerts or IPS activation. Nuisance alerts (frequent changes from "on" to "off") may encourage pilots to ignore ice detector information. However, the ice detector must be sensitive enough to detect sudden exposure to icing conditions reliably throughout the icing conditions of 14 CFR parts 25, Appendix C and 29, Appendix C.

- If overheating of structural material (such as the engine inlet cowl) can result from automatic activation of the IPS by the PFIDS (including nuisance and false alerts), provide the flight crew an alert so they perform IPS shutdown procedures as provided by the AFM.

- The AFM must address the use of the PFIDS and its limits. The AFM must also provide procedures that should be performed following failure alerts.

The PFIDS must be reliable and meet the requirements of 14 CFR §§ 25.901(c), 23.1309, 25.1309, 27.1309, 29.901(c), and 29.1309. This means that combinations of system failures that result in undetected ice or icing conditions must be extremely improbable. The requirement exists because flight crews must be informed when the PFIDS has failed. This allows the crew to revert to other acceptable methods of ice detection, such as monitoring temperature, atmospheric moisture, and other icing cues. You may consider multiple and independent ice detectors, automatic fault monitoring, built-in test equipment (BITE), and preflight status tests, for example, when showing the required ice detector reliability. More detailed guidance is in ACs 23.1309-1B, 25.1309-1A, 27-1B, 29-2C, and 33-2B.

K.4 CERTIFICATION OF ICE DETECTORS.

K.4.1 Certification of an AFIDS.

When used to get approval for flight in icing conditions, ice detector equipment become a part of the aircraft's IPS. The ice detector performance must allow the ice protection of the airframe, engine, engine induction system, propeller, windshields, and air data system to comply with the

APPENDIX K. ICE AND ICING CONDITIONS DETECTION (CONTINUED)

requirements discussed in section 6 of this AC. An AFIDS should detect ice within the icing environment defined by 14 CFR parts 25, Appendix C and 29, Appendix C or as limited by the rotorcraft's flight envelope. Applicants should show this for the requested aircraft configurations and airspeeds. The AFIDS and the primary methods of ice detection (for example, temperature and moisture, visible ice accretion) should advise the pilot to begin operation of the IPS using AFM procedures before there are hazardous buildups of ice or unsafe flight.

Following ice detection, you should define the ice buildups on the aircraft when the IPS becomes effective. These ice buildups should account for reasonable time delays in detecting ice and in activating the IPS. With these ice buildups, you should evaluate aircraft performance and handling qualities to ensure safe flight, as discussed in section 6.3 of this AC. The AFIDS should perform its intended functions for all aircraft configurations and flight regimes, and in the required icing environment.

To install an AFIDS properly on an aircraft, you should perform analyses similar to those performed for a PFIDS. You should understand the characteristics and limits of the AFIDS. Pilots may place the same reliance on an AFIDS as they would place on a PFIDS—even though the AFIDS may not have the same reliability. This underscores the importance of performing these necessary analyses and providing suitable AFM information to ensure proper functioning and use of the AFIDS.

An AFIDS approval should include flight tests in measured natural icing conditions to verify analyses and laboratory test results. The natural icing flight tests should show that the ice detector performs its intended function within the required icing environment and for the requested aircraft configurations and flight regimes. You may use laboratory tests, such as icing wind tunnel testing or icing tanker testing, to show the ice detector's ability to perform properly in 14 CFR parts 25, Appendix C and 29, Appendix C icing conditions not found during natural icing flight tests. An AFIDS should meet reliability requirements if the AFIDS is used with other icing cues to show the reliability of the IPS (14 CFR §§ 23.1301, 23.1309, 25.901(c), 25.1301, 25.1309, 27.901(b)(1), 27.1301, 27.1309, 29.901(c), 29.1301, and 29.1309). Consider the probability of flying in icing conditions as 1. ACs 23.1309-1C, 25.1309-1A, 27-1B, 29-2C, and 33-2B provide detailed guidance on equipment reliability. You should provide procedures for using the ice detector as part of the IPS in the AFM (14 CFR §§ 23.1585, 25.1585(a)(6), 27.1585, and 29.1585).

K.4.2 Certification of a PFIDS.

When used to get approval for flight in icing conditions, ice detector equipment becomes a part of the aircraft's IPS. The ice detection equipment must meet the requirements of 14 CFR §§ 23.1419, 23.1301, 23.1309, 25.901(c), 25.1419, 25.1301, 25.1309, 27.901(b), 27.1419, 27.1301, 27.1309, 29.901(c), 29.1419, 29.1301, and 29.1309. A PFIDS must detect aircraft icing in the icing conditions of 14 CFR parts 25, Appendix C and 29, Appendix C, or the icing environment that is limited by the rotorcraft's flight envelope. The PFIDS must also detect icing for the icing conditions required for aircraft components (for example the engines), unless there are alternate AFM procedures for these components. The PFIDS must detect aircraft icing for all aircraft configurations and airspeeds requested. An icing condition PFIDS must detect icing

APPENDIX K. ICE AND ICING CONDITIONS DETECTION (CONTINUED)

conditions of 14 CFR parts 25, Appendix C and 29, Appendix C or as limited by the rotorcraft's flight envelope. The PFIDS must ensure safe flight by either alerting the pilot to use the IPS according to AFM procedures or by automatically activating the IPS before hazardous or unsafe buildups of ice on the airframe, engine, or engine inlets, unless the applicant shows that the undetected icing is not hazardous to the aircraft. Follow the safe flight requirements discussed in section 6.3 of this AC. The PFIDS must be able to perform its intended functions for all aircraft configurations, flight regimes, and in the required icing environment. The PFIDS performance should account for reasonable time delays in the activation and effectiveness of the IPS. The PFIDS performance should also account for the effects of residual and intercycle ice if the PFIDS is part of an automated deicing system.

You should describe the aircraft's ice buildups when the IPS becomes fully effective after detection of icing. You should show that the aircraft's performance and handling qualities, as well as the engine's performance and operability, comply with the requirements of safe flight with these ice buildups. As part of the ice protection system, approval of the PFIDS must include natural icing flight tests to verify analyses and laboratory test results (14 CFR §§ 23.1419, 25.1419, 27.1419, and 29.1419). PFIDS approval must also verify that the ice detector performs its intended function. Laboratory tests should show the ice detector's ability to perform properly with the required icing environment and requested flight regimes (for example, airspeed, angle of attack, altitude, and Mach number). You may not experience these conditions during flight tests.

To show the performance and reliability of a PFIDS, you will need to perform detailed analysis (14 CFR §§ 23.1301, 23.1309, 25.901(c), 25.1301, 25.1309, 27.901(b)(1), 27.1301, 27.1309, 29.901(c), 29.1301, and 29.1309). The analyses should include a thorough understanding of the characteristics of the ice detector's sensors and their influences on airframe and engine icing. Detailed equipment reliability guidance information is in ACs 23.1309-1C, 25.1309-1A, 27-1B, 29-2C, and 33-2B. Consider the probability of flying in icing conditions as 1. Provide procedures for using the ice detector as part of the IPS in the AFM (14 CFR §§ 23.1585, 25.1585(a)(6), 27.1585, and 29.1585). Analyses that may be required include analyses of the ice detector's: sensor characteristic; installation location; freezing fraction; the effects of impinging drop splashing, shedding, and runback on the ice detectors' response time; and reliability.

K.5 REFERENCES.

K1. **"Aircraft Icing Handbook,"** FAA Technical Report DOT/FAA/CT-88/8-1 (1991), 3 vols., FAA William J. Hughes Technical Center, Atlantic City International Airport, NJ 08405.

K2. "**Minimum Operational Performance Specification for Inflight Icing Detection Systems,"** SAE AS5498, October 2001.

K3. **"Certification and Integration Aspects of a Primary Ice Detection System,"** D. Jackson, D. Owens, D. Cronin, and J. Severson, paper no. AIAA-2001-0398, AIAA 39th Aerospace Sciences Meeting, Jan. 8-11, 2001. Reprints available from American Institute of Aeronautics and Astronautics, Reston, VA 20191-4344.

APPENIDX L. WINDSHIELD ICE PROTECTION

Applicants should show the acceptability of the windshield IPS by testing. You should perform inner and outer windshield surface temperature surveys of the protected areas to verify design thermal analyses. The thermal analyses should show that surface temperatures are warm enough to provide acceptable anti-icing protection without causing damage to the windshield. Evaluate the transparency of the protected windshield area, including optical distortion effects, for day and night operations. Also review the size and location of the protected area for adequate visibility, especially for approach and landing conditions. A probable single failure of a transparency heating system should not adversely affect the integrity of the airplane cabin or create a potential fire hazard. You should develop safety analysis using guidance provided in AC 23.1309-1C and AC 25.1309-1. This shows the windshield IPS meets reliability and safety requirements.

APPENIDX M. FINDING NATURAL ICING CONDITIONS FOR TEST PURPOSES

M.1 BACKGROUND.

Icing conditions for flight-testing may be elusive, especially when aircraft program schedules require testing during seasons with weather that is not conducive to inflight icing conditions. Even when the weather is conducive to inflight icing conditions, the prevailing icing intensity may not be enough to achieve test objectives. Figure M-1 shows statistical information on the occurrence of atmospheric icing conditions. Information in the following section describes how to get icing conditions forecasts that may ease planning for natural icing flight tests.

M.2 STATISTICAL GUIDANCE.

The LWC values graphed in figures E-1 and E-4 of appendix E of this AC are about the 99th percentile values expected during random flights in icing conditions. Applicants will seldom find these large values in practice. Test flights usually experience much smaller values. The FAA William J. Hughes Technical Center compiled about 28,000 nm of inflight measurements of cloud water content, drop sizes, temperatures, and other variables in supercooled clouds over portions of North America, Europe, and the northern oceans. This information provides more practical statistical data on icing conditions. The following paragraphs describe some of the results.

M.2.1 Natural Probabilities for LWC Averages in Stratiform Icing Conditions.

Figure M-1 depicts the statistical probability of finding various average values of LWC versus averaging distance in continuous stratiform clouds. The 50 percent curve shows that half of all random icing events will yield less than 0.2 g/m^3, depending on the event distance. The 90 percent curve shows that 90 percent of the events will contain less than 0.45 g/m^3.

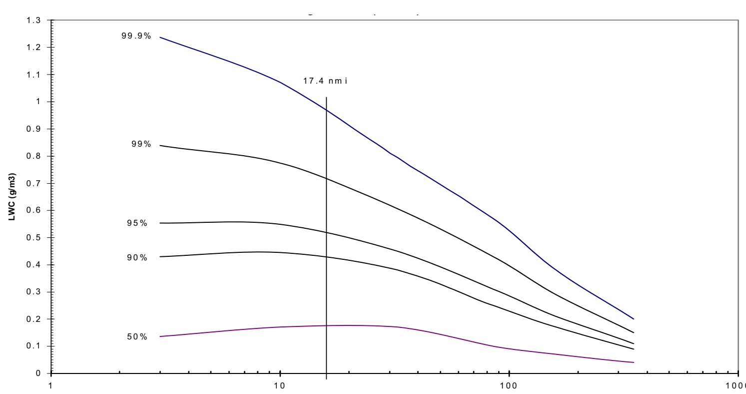


Figure M-1. Natural Proba bilities for LWC Averages in Stratiform Cloud Icing Conditions at 32°F to 14°F, With an Average MVD of 15 µm.

APPENDIX M. FINDING NATURAL ICING CONDITIONS FOR TEST PURPOSES (CONTINUED)

These curves are for typical MVDs of around 15 µm and for flight-level temperatures between 0°C and -10°C. The LWCs are even less for other MVDs or lower temperatures.

Applicants can convert the LWC axis to icing rate for any particular airframe component or for an icing rate meter, if needed (Reference M1). You can plot measured LWC averages (or icing rates) on figure M-1 as a useful way to compare the test events with nature. Reference M2 provides other statistical information.

M.2.2 Natural 99 Percent LWC Limits vs. Altitude.

Figure M-2 depicts the variation of the 99 percent value of LWC with altitude and the icing event distance. For events between about 6 nm and 50 nm, the largest LWC averages are expected between 10,000 ft and 15,000 ft AGL. For longer events, the largest LWC averages are found between 5,000 ft and 15,000 ft, with a slight preference for clouds with tops near 5000 ft AGL. Again, applicants can convert the LWC axis to icing rate, if needed. Plot measured averages of LWC or icing rate for the icing event distance to compare with the probable maximum values.

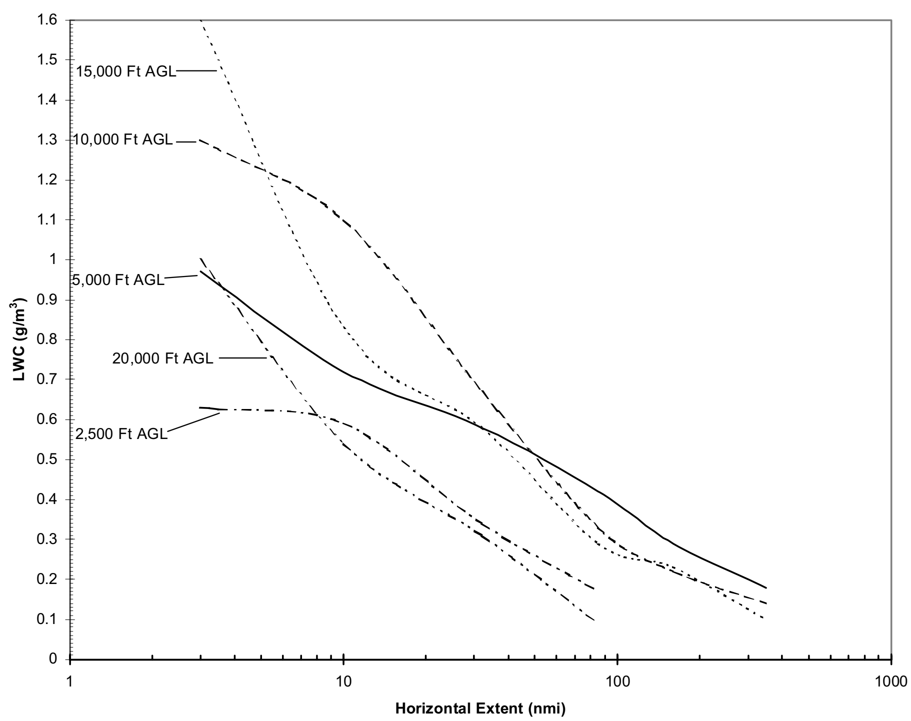


Figure M-2. Natural 99 Percent LWC Limit Envelopes at the Highest Icing Temperatures Available at Indicated Altitude as a Function of Cloud Horizontal Extent (for all clouds containing supercooled water drops with MVD = 15-20 µm).

APPENDIX M. FINDING NATURAL ICING CONDITIONS FOR TEST PURPOSES (CONTINUED)

M.2.3 Probability of Finding Large MVDs.

Figure M-3 shows the statistics for MVDs in stratiform clouds. There is a marked preference for MVDs close to 15 µm. Stratiform clouds with an MVD of about 15 µm clearly are the most stable. They are more common, can contain larger maximum LWCs, and can extend over far greater distances than clouds (or portions of clouds) with larger MVDs. The larger the MVD, the less likely it is to occur. Stratiform clouds containing larger MVD drops will contain less LWC and persist over shorter horizontal distances. Since about two thirds of all random icing events contain MVDs smaller than 15 µm, applicants will delete much of their natural icing flight test data if they use the 14 CFR parts 25, Appendix C and 29, Appendix C cutoff at 15 µm as a lower limit. If MVD is not critical for the test objectives, you can show data for MVD less than 15 µm.

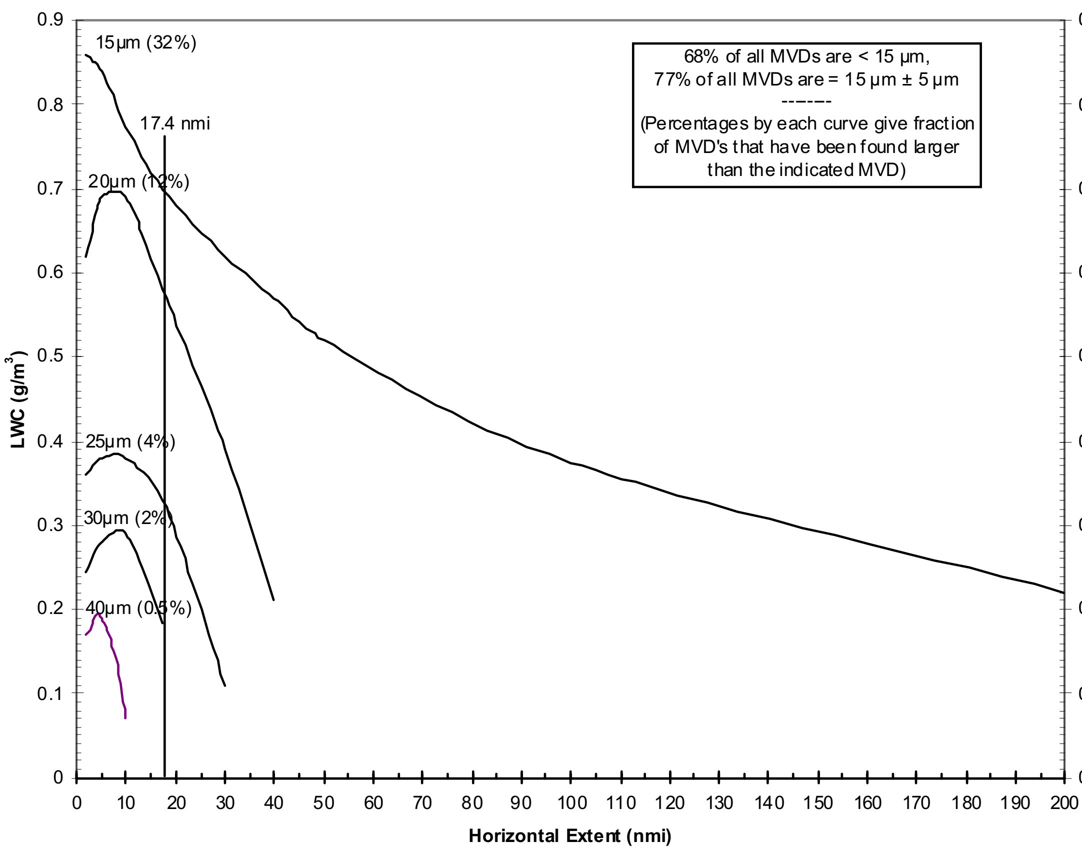


Figure M-3. Natural Cloud Horizontal Extent Limits and 99 Percent LWC Limits for Selected, Sustained Cloud Drop MVDs in Stratiform Clouds at Ambient Temperatures of 32°F to 14°F.

APPENDIX M. FINDING NATURAL ICING CONDITIONS FOR TEST PURPOSES (CONTINUED)

If large MVDs are still of interest for test flight purposes, the statistics suggest the following strategy. Look for:

- Maritime air masses (for example, Pacific coast of North America or the North Atlantic Ocean east of the Canadian Maritime Provinces);

- Flight altitude temperatures warmer than about -17°C;

- Altitudes from 7,000 to 14,000 ft ASL; and

- Convective clouds (more suitable than layer clouds).

Expect to find:

- Horizontal extents (of large-MVD conditions) less than 10 nm and
- MVDs in the normal range of 10-20 μm most of the time.

M.3 EXPERIENCE.

M.3.1 Continuous Maximum Conditions.

Continuous maximum icing conditions of 14 CFR parts 25, Appendix C and 29, Appendix C usually exist in stratiform clouds. Applicants usually need stratiform cloud decks with depths greater than 1000 ft to get worthwhile LWCs for icing flight tests. Layer clouds composed of water drops seldom exist with layer depths greater than about 6000 ft. The LWC generally increases with height in the cloud, so the larger LWCs will usually exist in the upper quarter of the layer.

In the United States, you often find wintertime stratus clouds in the Great Lakes area. But other areas are also suitable. The commercial or public weather maps on television or on the Internet (References M3 and M4) are helpful.

M.3.2 Intermittent Maximum Conditions.

Intermittent maximum icing conditions of 14 CFR parts 25, Appendix C and 29, Appendix C typically occur in cumuliform clouds. These icing conditions usually occur during vigorous convective activity that is rare when the freezing level is low. Normally you have to look for springtime or summer weather where the freezing level is above 5,000 ft to 10,000 ft AGL. A strategy that cloud physics researchers use is to penetrate the tops of isolated “feeder” cells or growing cumulus towers on the edge of existing or growing, isolated thunderstorms. This provides fairly large LWCs without having to perform risky penetrations of the main thunderstorm core.

APPENDIX M. FINDING NATURAL ICING CONDITIONS FOR TEST PURPOSES (CONTINUED)

M.3.3 Glaciated Conditions.

14 CFR parts 25, Appendix C and 29, Appendix C do not include glaciated clouds. Applicants should expect little or no icing in glaciated (snow or ice crystal) clouds. The presence of snow at ground level in wintertime (nonthunderstorm) conditions is a good hint that the clouds above the 0°C level are glaciated and have little or no potential for icing an airframe.

Glaciated clouds in any season are recognizable by their lack of texture from both the inside and outside. From the outside they look like cotton candy. The inside of most widespread, deep, stratiform-like glaciated conditions is not uniform. It may look uniformly gray in all directions outside the aircraft, but neither cloud puffs nor visible cloud may pass by the wings. Snow may be present, yet unnoticeable unless lit up by the landing lights or wingtip strobe lights. You will see a dull, featureless overcast from underneath the cloud.

Water drop clouds are typically lumpy. They look like a cauliflower on the outside, especially on the sides and top. These clouds are denser, and puffs or cloudy parcels can be seen passing by the wing. Sometimes they partially or completely obscure the wingtip.

M.3.4 Mixed-Phase Conditions.

14 CFR parts 25, Appendix C and 29, Appendix C do not include mixed-phase icing conditions. Mixed-phase icing conditions consist of ice crystals interspersed with liquid drops. Applicants can expect to find mixed-phase icing conditions in about 40 percent of continuous and intermittent maximum icing conditions. Take care to account for these ice crystals when determining the liquid and total water content of clouds. Distinguishing between water drops and ice crystals requires special instrumentation such as a total water content probe. You can also use an instrument that discriminates between spherical water drops and crystalline frozen water (the PMS-2D-C probe). This discrimination is time-consuming and requires detailed investigation. The investigation includes differentiation between LWC and frozen water content to determine total water content.

M.3.5 Large Drop Conditions.

Although no requirements exist for IPS design and approval in large drop icing conditions (commonly called supercooled large drop (SLD) conditions), they are discussed below for completeness. Large drop conditions include freezing drizzle and freezing rain.

Freezing drizzle (FZDZ) contains drops from 50 µm up to 500 µm in diameter. The meteorological conditions that produce these large drops are not well understood. Freezing drizzle aloft is difficult to predict. Thin layers of it have been observed at altitudes as high as 20,000 feet, at temperatures as cold as -20°C. It occurs occasionally in or below stratiform clouds. Freezing drizzle can occur as a diffuse supercooled mist aloft in some northerly maritime areas such as coastal Alaska and Newfoundland (Reference M5).

APPENDIX M. FINDING NATURAL ICING CONDITIONS FOR TEST PURPOSES (CONTINUED)

Freezing rain (FZRA), also known as ice storms, occurs when snow falls through a warmer-than-freezing layer of air where the snowflakes melt into raindrops and fall to the ground through an underlying layer of subfreezing air in contact with the ground. Aircraft (like trees, power lines, roads, and other objects) can become coated with a hard layer of clear ice. Freezing rain will affect aircraft during approach, landing, taxiing, takeoff, and transiting in the lowest few thousand feet above ground level. In the United States, freezing rain is most common east of the Rocky Mountains. It is usually easy to forecast and its expected location will be included in the daily weather forecasts.

M.4 USING FORECASTS OF ICING CONDITIONS.

Icing forecasts have been traditionally imprecise. This is due mainly to the current difficulty of knowing when, whether, and where a given cloud interval above the freezing level will be liquid or glaciated. Forecasts typically read something like “icing in cloud and in precipitation above the freezing level.” This language allows for the fact that clouds above the freezing level may be liquid in some places and therefore capable of icing an aircraft.

Icing forecasts are improving, at least in narrowing the vertical and horizontal boundaries of existing and expected icing-prone cloudiness. New, experimental, or operational graphical presentations of icing conditions are available on the Internet at:

- http://aviationweather.gov/exp/cip/
- http://weather.noaa.gov/
- http://www.dispatcher.org/brief/adfbrief.html

These can provide a quick and easy way to assess current icing conditions.

M.5 PROFESSIONAL GUIDANCE.

Applicants may find certified consulting meteorologists and forecasting services for hire in a professional directory kept by the American Meteorological Society (Reference M6). Some of those listed will be knowledgeable in aircraft icing.

The Society of Automotive Engineers (SAE) has an active Aircraft Icing Technology committee (AC-9C) of icing practitioners who produce helpful, icing-related SAE publications (Reference M7).

The FAA publishes an Advisory Circular listing Designated Engineering Representatives (DERs) who are available for consulting work (Reference M8). Some of these have experience in aircraft icing applications.

APPENDIX M. FINDING NATURAL ICING CONDITIONS FOR TEST PURPOSES (CONTINUED)

M.6 REFERENCES.

M1. "**Icing Design Envelopes (14 CFR-25, 29, Appendix C) Converted to a Distance-Based Format,**" Richard K. Jeck, FAA Technical Report DOT/FAA/AR-00/30 (2000), FAA William J. Hughes Technical Center, Atlantic City International Airport, NJ 08405.

M2. **"A New Database of Supercooled Cloud Variables for Altitudes up to 10,000 Feet AGL and the Implications for Low Altitude Aircraft Icing,"** Richard K. Jeck, FAA Technical Report DOT/FAA/CT-83/21 (1983), FAA William J. Hughes Technical Center, Atlantic City International Airport, NJ 08405.

M3. Aviation Weather Center: http://aviationweather.gov

M4. National Weather Service: http://weather.noaa.gov

M5. **"An Inferred Climatology of In-Flight Icing and SLD for North America,"** Bernstein, B.C., Proceedings of the 10th American Meteorological Society Aviation Range and Aerospace Meteorology Conference, Portland, Oregon, May, 2002, pp. J21-J24.

M6. American Meteorological Society, 45 Beacon Street, Boston, MA 02108-3693. Tel: 617-227-2425. Internet: http://www.ametsoc.org.

M7. Society of Automotive Engineers: http://forums.sae.org/access/dispatch.cgi/TEAAC9C_pf

M8. **"Designated Engineering Representatives Consultant Directory,"** Advisory Circular No. 183.29-1HH (2000), Federal Aviation Administration, 800 Independence Ave. SW, Washington, DC 20591.

APPENIDX N. INSTRUMENTATION

N.1 INSTRUMENTATION.

Applicants must measure icing conditions during certification flight-testing in natural and simulated icing conditions (14 CFR §§ 23.1419, 25.1419, 27.1419, and 29.1419). Measurements should characterize the icing conditions that are useful for understanding the IPS's performance and effectiveness. The measurements should:

- Verify the IPS analysis;
- Provide information to understand icing anomalies; and
- Allow extrapolation of the IPS performance and effectiveness to other conditions within 14 CFR parts 25, Appendix C and 29, Appendix C.

The FAA considered the variables selected to define 14 CFR parts 25, Appendix C and 29, Appendix C important for the design of thermal IPSs. These variables include liquid water content (LWC), mean drop diameter, temperature, cloud extent, and altitude. They are typically measured during natural and simulated icing flight tests to characterize the icing conditions.

Modern flight tests have used hot-wire type probes for LWC measurement, and a laser-based (electro-optical) drop size spectrometer for counting and sizing cloud drops (References N1 and N2).

You may use a research icing rate sensor, such as the Goodrich model 871FA, as a part of the instrument suite. Appendix P of this AC discusses use of the icing rate meter information.

You should continuously record the selected variables with 1-second resolution during the icing events. Spot measurements or long-distance averages are less desirable.

The older methods of measurement (rotating cylinders for LWC, and coated slides for dropsize analyses) are less desirable because of their serious limitations. These limitations include measurement errors, spot sampling, and the difficulty of data analysis (Reference N2). But hot-wire and electro-optical instruments often present problems, too. Experienced technicians should calibrate, install, and run this specialized instrumentation. You should install the icing rate meters at proper locations on the aircraft (appendix K of this AC). Only those who know how to recognize subtle errors in the probe performance or have experience in using these modern instruments should analyze their data. If necessary, several commercial enterprises are available to supply this service.

You should use video cameras with adjustable zoom lenses to document ice buildups on the wings, probes, or other surfaces of interest. A video view of the wing tip area also provides a good qualitative record of the density and continuity of cloud conditions during icing events. A cloud that is dense enough to obscure the wing tip on a general aviation airplane will usually be a convective (or intermittent maximum) cloud. Stratiform clouds are usually less dense. You may also use the video for recording the presence of precipitation that is lit up by the wingtip strobe lights or landing lights.

N.2 REFERENCES.

N1. **"Aircraft Icing Handbook, Volume 1 of 3,"** FAA Report number DOT/FAA/CT-88/8-1 (1991), FAA William J. Hughes Technical Center, Atlantic City International Airport, NJ 08405.

N2. "**Cloud Physics Instruments for Measuring Icing Conditions,**" Richard K. Jeck, FAA Technical Report DOT/FAA/AR-02/120 (2003), FAA William J. Hughes Technical Center, Atlantic City International Airport, NJ 08405.

APPENIDX O. WAYS TO EVALUATE ICING EXPOSURES RELATIVE TO APPENDIX C

O.1 BACKGROUND.

Applicants should document measured natural icing flight test conditions. You may use the methods in paragraph O.2, of this appendix, to compare the measured natural ice test conditions to 14 CFR parts 25, Appendix C and 29, Appendix C.

The 14 CFR parts 25, Appendix C and 29, Appendix C envelopes, as shown in figures D-1 and D-4 of appendix D of this AC, are valid *only* for averaging distances of 17.4 nm and 2.6 nm, respectively. Most of the time, icing encounters in flight will cover shorter or longer distances. To compare the flight data with the envelopes, you should average the in-flight data over the same distances for which the envelopes are drawn. This is not always possible, especially if the encounters are shorter than the design distances. It is improper to use the F-factor curves in figures D-3 (14 CFR parts 25, Appendix C and 29, Appendix C, Figure 3) and D-6 (14 CFR parts 25, Appendix C and 29, Appendix C, Figure 6) of appendix D of this AC to adjust the encounter-averaged LWC to equivalent values over 17.4 nm or 2.6 nm. Use the F-factor curves to adjust the LWC curves in 14 CFR parts 25, Appendix C and 29, Appendix C to match each of the actual averaging distances obtained from the test flights.

The 14 CFR parts 25, Appendix C and 29, Appendix C envelopes treat LWC and MVD as principal variables with exposure distance treated as a constant. Distance may be a more useful variable for comparison with test data. You may redraw the envelopes for fixed values of MVD. Statistical analysis of MVD measurements in the atmosphere suggest that MVDs are much less variable than may be generally realized∗. You should provide redrawn MVD envelopes for each icing encounter when presenting certification data.

O.2 APPENDIX C CONVERTED TO DISTANCE- OR TIME-BASED ENVELOPES.

Applicants can use the F-factor curves to convert figures D-1 and D-4 of appendix D of this AC to an equivalent LWC versus Horizontal Extent (HE) format (Reference O1).
Figure O-1 shows conversion of figures D-1 and D-4, 14 CFR parts 25, Appendix C and 29, Appendix C icing envelopes in a distance-based format for temperatures of 0°C, -10°C, -20°C, and -30°C and for an MVD of 15 µm. As explained in Reference O1, after you enter the basic coordinates into a computerized spreadsheet, you can create variations or customized versions of the envelopes easily using the spreadsheet charting capabilities. For

∗ Statistics compiled at the FAA William J. Hughes Technical Center from 12,000 nm of measurements in stratiform icing conditions revealed that about 75 percent of all MVDs are within ±5 µm of 15 µm in stratiform clouds.

example, in figure O-1 a logarithmic HE scale has been chosen to accommodate both the short HEs of the Intermittent Maximum envelopes and the long HEs of the Continuous Maximum envelopes.

You can plot natural icing atmospheric measurements on Figure O-1 for MVDs near 15 µm, or on similar graphs for other MVDs.

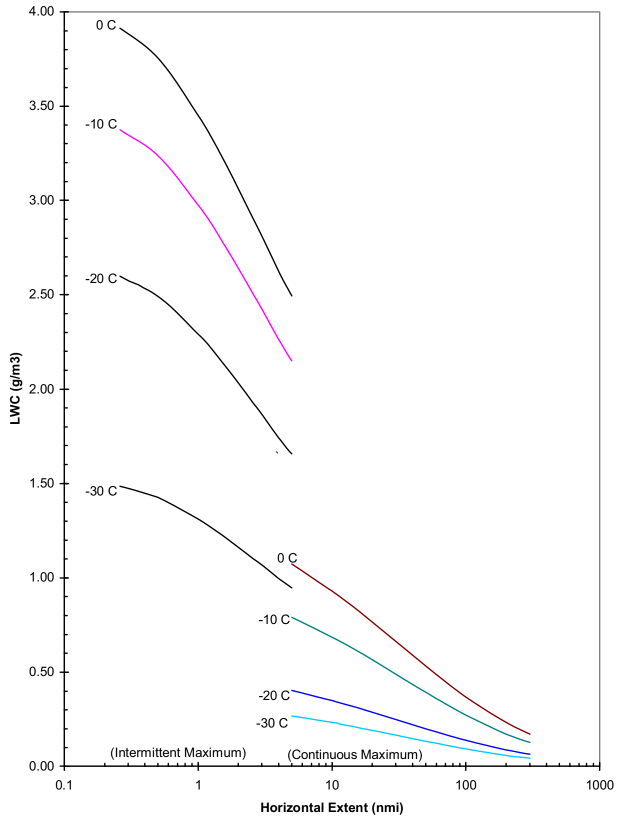


Figure O-1. 14 CFR Parts 25 and 29, Appendix C Icing Envelopes Converted to a Distance-Based Format (for MVD=15 µm).

APPENDIX O. WAYS TO EVALUATE ICING EXPOSURES RELATIVE TO APPENDIX C (CONTINUED)

You may define measured inflight exposures by the distance flown in the icing condition or by elapsed time. Icing wind tunnel exposures and computer simulations are typically reported as timed exposures. You can convert the distance-based format to a time-based format by dividing the distance scale by the airspeed, provided the flight speed is approximately constant during the cloud penetration. For example, at 200 knots, the 200 nm mark is also the 60-minute mark. The 20 nm mark is also the 6-minute mark, and so on.

In using the time-based format, you must renumber the time scale for each airspeed in use. If the airspeeds are similar, then using this time-based format allows you to plot wind tunnel, computer simulated exposures, and flight test averages on the same time-based 14 CFR parts 25, Appendix C and 29, Appendix C envelopes.

O.3 REFERENCES.

O1. "**Icing Design Envelopes (14 CFR-25, 29, Appendix C) Converted to a Distance-Based Format,**" Richard K. Jeck, FAA Technical Report DOT/FAA/AR-00/30 (2000), FAA William J. Hughes Technical Center, Atlantic City International Airport, NJ 08405.

APPENIDX P. USING ICING RATE TO DOCUMENT ICING EXPOSURES

P.1 BACKGROUND.

Applicants have always needed to document the characteristics or quality of flight test icing events, besides documenting the MVD, LWC, temperature, and event time. Without previous guidance, applicants or icing data analysts devised various schemes. Some of these schemes are inaccurate, and none of them are legitimate or satisfactory. To promote a sound, useful, and understandable way to document icing exposures, you may use the method described in paragraph P.2 of this appendix.

You may use an icing rate sensor during icing flight tests. These instruments are small, inexpensive, and easy to use. Aircraft may have a related ice detector as standard equipment.

P.2 DATA FROM AN ICING RATE SENSOR.

To show the use of icing rate for documentation purposes, we will use data from a Goodrich model 871FA ice detector as an example. This model is used as an ice detector. It provides an analog signal from which the user can calculate an icing rate. This model provides a voltage signal that usually increases from 1 to 5 volts as ice builds up on a ¼-inch-diameter sensing rod. The signal is 1 volt when the rod is ice-free. The signal increases to 5 volts when about 0.5 mm of ice has built up on the rod. At 5 volts, the heater is energized for a few seconds to deice the rod. The ice build up resumes and starts a new cycle when the rod cools again to below 0°C.

A trace of this signal, as shown in figure P-1, gives clear evidence of when icing occurred during the flight – three main events and two brief ones. A close-up view of the signal (figure P-2) shows the detailed characteristics of the signal and shows how the icing rate is calculated for each of the cycles. An average icing rate over each of the icing intervals seen in figure P-1 is enough to document the icing rate for the interval.

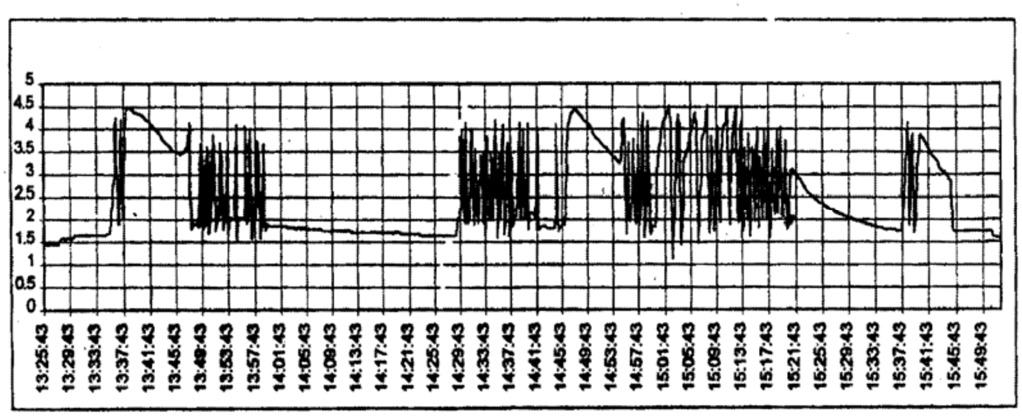


Figure P-1. Example of the Analog Output Volt age From a Model 871FA Ice Detector During an Icing Encounter.

APPENDIX P. USING ICING RATE TO DOCUMENT ICING EXPOSURES (CONTINUED)

The record in figure P-1 clearly shows when icing events occurred. The number of up-and-down cycles for each unit time gives an idea of the icing intensity on the time-compressed display shown. You can calculate precise values of the icing intensity from the individual cycles when recorded at one-second intervals, or when displayed on an expanded time scale, as in figure P-2.

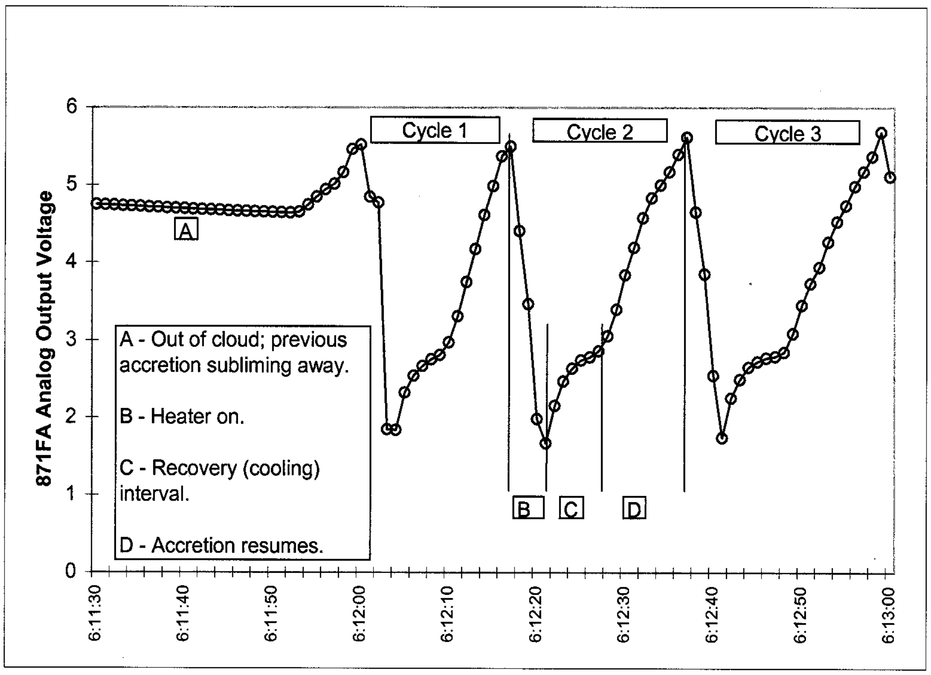


Figure P-2. High Resolution Example of Analog Output Voltage From an 871FA Ice Detector.

The Model 871FA icing detector normally has a sensitivity of 0.5 mm of ice over a 4-volt range (about 1-5 v), the ice accretion rate in mm/min is given by

$$\text{Rate} = 7.5 \times dV/dt \qquad \text{(Eqn. P-1.)}$$

dV/dt is the ratio of the voltage increase (dV, in volts) over a time interval (dt, in seconds) during the ice build up phase of an individual cycle. The conversion factor is 7.5. You can calculate the icing rate if you record the voltage signal every second, as in figure P-2. The icing rates calculated for the ice build up phase of cycles 1-3 in this example are 3.1, 2.1, and 1.9 mm/min, respectively.

P.3 CONVERTING ICING RATE TO ICING INTENSITY.

Applicants may convert the icing rate (mm/min) provided by the ice detector to familiar icing intensity terms, as shown in table P-1. For example, a rate of 1 mm/min suggests a moderate icing rate on the ¼-inch sensing rod. These intensities apply at any airspeed. All that matters is the rate of accretion.

APPENDIX P. USING ICING RATE TO DOCUMENT ICING EXPOSURES (CONTINUED)

Table P-1. Measurable Definitions of Icing Intensity[1]

Intensity	Rate (mm/min)	Equivalent Rate
Light	0.1 to 0.4	¼ to 1 inch/hour
Moderate	0.4 to 1.3	1 to 3 inches/hour
Heavy	> 1.3	> 3 inches/hour

As explained in References P1 and P2, these rates apply universally to any aircraft component. If the wing is collecting ice at the rate of 0.9 mm/min (2 inches per hour), then that is a moderate icing rate for that wing. A different aircraft at a different airspeed may collect ice at a different rate in the same icing conditions.

The rate measured by the icing rate sensor will be different from the rate of ice build up on the wing. This is because of the difference between the sizes of the wing leading edge and the ice detector sensor, and therefore different water collection efficiencies. You may estimate the icing rate and intensity on the wing from the rate provided by the icing rate sensor. You can do this by using the ratio of the collection efficiencies.

$$Rate_{wing} = (ß_{wing}/ß_{sensor})xRate_{sensor} \qquad \text{(Eqn. P-2.)}$$

Where the peak local collection efficiencies, ß, can be calculated by LEWICE or other ice accretion computer codes (Reference P3). At a ratio of $ß_{wing}/ß_{sensor}$ = (0.3/0.9) = 0.33, the wing will collect ice at a third of the rate on the icing detector.

P.4 DATA SHEET FOR DOCUMENTING ICING EXPOSURES.

Table P-2 suggests a format for documenting icing events by icing rates and intensities. The top half of the form lists relevant information about the test aircraft and the icing conditions. The lower half of the form contains details of the individual icing events, as follows:

- Columns A-D identify the selected icing intervals from figure P-1.
- Column F lists the average icing rates calculated as shown in figure P-2.

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[1] This scale has been proposed as part of a revision to the official icing intensity definitions promulgated in the Aeronautical Information Manual (AIM). The revisions have been recommended by an interagency working group assembled in response to Task 1-B of the FAA Inflight Aircraft Icing Plan of 1997.

APPENDIX P. USING ICING RATE TO DOCUMENT ICING EXPOSURES (CONTINUED)

- Column G lists the equivalent icing intensities on the ¼-inch diameter sensor, using table P-1.
- Columns I and J are the estimated rates and intensities for the aircraft component of interest – in this case the leading edge of the outer wing.
- Column K contains the cumulative product of Rate x Duration, as provided by columns I and C.
- Columns P and Q track use of the IPS.
- Columns S-W document the performance and handling qualities of the aircraft experienced during the icing events. The numerical entries in these columns are based on the level-of-effects scale shown in table P-3.
- Use columns Y-AA for documenting other data, such as data from an LWC meter, a drop-sizing instrument, or drop-impactor slide.

APPENDIX P. USING ICING RATE TO DOCUMENT ICING EXPOSURES (CONTINUED)

Table P-2. Suggested Data Sheet for Documenting Icing Exposures

Icing Exposure Record for Flight Tests (hypothetical numbers inserted for illustrative purposes.)

Aircraft model & S/N:___B-210, S/N=1416_________ Component(s) of interest:____outer wing LE_________

Type of ice protection system:___boots_________

Date of Flight Test:__Nov. 12, 2007_________ Flight Number:___2___

Location:___western Kansas_________

General cloud type(s) and conditions:__deep, widespread stratus & low ceiling:(cloud base = 1000 Ft AGL @ -2C, cloud tops = 4200 Ft AGL @ -12C)

Height of freezing level (AGL):__sfc to 500_________ (feet)

Starting with an ice-free aircraft (and no descent into warm air for de-icing)

Exposure				On 871FA Icing Rate Meter		On Component of Interest**			Other Conditions					Aircraft Performance and Handling					Auxiliary Data		
												No. of IPS cycles		Level of Effect (1,2,3, or 4) on Aircraft***					Average		
No.	Start-End Time (hhmm:)	Duration (min.)	Distance (nmi)	Average Icing rate (mm/min)	Equivalent Intensity* (T,L,M,H)	Average Icing rate (mm/min)	Equivalent Intensity* (T,L,M,H)	Cumulative Ice Depth (mm)	Altitude (Ft, ASL)	OAT deg C	TAS (kt)	during exposure	after exposure	Speed	Power	Climb	Control	Vibration	LWC (g/m3)	MVD (µm)	Engine Pwr or EPR
1	1430 - 1441	11	28	0.7	M	0.35	L	3.9	7500	-11	150	2	1	1	1	untested	1	1			
2	1455 - 1459	4	10	0.4	L	0.2	L	4.7	7400	-10	"	0	1	1	1	"	1	1			
3	1502 - 1514	12	30	0.2	L	0.1	T-L	5.9	7000	-9	"	0	0	1	1	"	1	1			
4	1514 - 1521	7	18	1	M	0.5	L-M	9.4	7500	-11	"	2	1	1	2	2	1	1			
	Sums:	34	86																		

Notes:

* Icing intensity scale is that proposed by FAA Icing Plan Task-1B working group (2001). (T= <0.1 mm/min, L = 0.1 - 0.4 mm/min, M = 0.4 - 1.3 mm/min, H = >1.3 mm/min)

** These amounts are merely approximations for estimation and comparison purposes only. They are computed from the 871FA data simply by using the ratio of the collection efficiencies.. They give a rough idea of what may accumulate if no IPS is active on the component of interest.

*** Level-of-effect scale is that proposed by FAA Icing Plan Task-1B working group (2001). (See separate Table of Effects with definitions.)

Although table P-3 is used for aircraft having approved IPS, it may be used to report effects of icing events on any aircraft.

The data in table P-2 show that the outer wing of the test airplane experienced mostly light icing for 34 minutes (86 nm). After the end of the combined 86 nm exposure, only the power and climb performance showed any significant (level 2) degradation. This degradation occurred even though the boots cycled several times during the event. If the boots had not been used, an estimated 9.4 mm (3/8 inch) of ice would have built up on the outer wing.

The data sheet in table P-2 is an acceptable way to document icing events for natural icing flights, icing wind tunnels, or spray tankers. If an icing rate sensor is not available, you should use the data sheet as much as possible. Reference P-4 provides other acceptable ways of graphing and comparing icing-related effects.

APPENDIX P. USING ICING RATE TO DOCUMENT ICING EXPOSURES (CONTINUED)

Table P-3. Effects on Aircraft[2]

Aircraft Effect (AE)	Speed (Note a)	Power (Note b)	Climb (Note c)	Control (Note d)	Vibration (Note e)
Level 1	Less than 10 knot loss	Less than 10% increase required	No effect or less than 10% loss	No effect	No effect
Level 2	10-19 knot loss	10%-19% increase required	10%-19% loss rate of climb	No effect	No effect
Level 3	20-39 knot loss	20%-39% increase required	20% or more loss rate of climb	Unusually slow or sensitive response from control input	Controls may have slight vibration
Level 4	40 or more knot loss	Not able to maintain speed	Not able to climb	Little or no response to control input	May have intense buffet and/or vibration

Notes:

a. SPEED: Loss of speed because of aircraft icing. This is based on the airspeed before the buildup of ice on the aircraft. This is also before applying added power to keep original airspeed.

b. POWER: Added power required to keep aircraft speed and performance that was being flown before the buildup of ice on the aircraft. Refers to primary power settings, that is, torque, rpm, or manifold pressure.

c. CLIMB: Estimated decay in rate of climb (ROC) due to aircraft icing. For example, 10 percent loss in ROC, 20 percent loss in ROC, or not able to climb at normal climb speed with maximum climb power applied.

d. CONTROL: Effect of icing on the aircraft's response to control inputs.

Levels 1 and 2. No noticeable effect on response to control input.

Level 3. Aircraft is slow to respond to control input. Aircraft may feel sluggish or very sensitive in one or more axes.

Level 4. Little or no response to control input. Controls may feel unusually heavy or unusually light.

e. VIBRATION/BUFFET: May be felt as a general airframe buffet or sensed through the flight controls. It is not intended to refer to unusual propeller vibration (for airplanes so equipped) in icing conditions.

[2] The Task 1-B working group devised this table under the 1997 FAA Aircraft Icing Plan. It was developed for use with pilot reports (PIREPs) for icing conditions, but it is also suitable as a checklist for icing test flights. The table lists four increasingly worsening levels of effects due to icing conditions on three performance factors (speed, power, and climb capability) and two handling aspects (control and vibration). See reference P2.

APPENDIX P. USING ICING RATE TO DOCUMENT ICING EXPOSURES (CONTINUED)

Table P-4 complements table P-2 by presenting a checklist for you to evaluate systems and engines during icing events. You may delete nonapplicable items or add items for a particular design.

Table P-4. Checklist of Items to be Evaluated in Icing Conditions.

Aircraft S/N: ___________ Flight No.: __________ Date: _____________

Encounter:	1	2	3	4	Comments
Crew visibility					
Air data					
Airspeed					
Altitude					
Alternate static air					
Temperature					
Stall warning operation					
Autopilot operation					
Electrical load					
Engine operation:					
Normal air or mode					
Alternate air or mode					
Engine cooling					
Propeller IPS operation					
Engine inlet IPS operation					
Ice detection					
Ice detector operation					
AFM ice detection (day)					
AFM ice detection (night)					
Ice Accretions:					
Protected surfaces? (specify)					
Radome?					
Spinner?					
Inlets? (list)					
Side windows?					
Nacelles?					
Pitot probe?					
Temperature probe?					
AOA probe or vanes?					
SW sensor?					
Ice detector probe?					
Antennae (list)					
Instrumentation? (list)					
Aft of IPS?					
Other? (list)					
Ice Shedding:					
Propeller					
IPS normal operation					
IPS delayed activation					
Radome					
Antennae					
Avionics:					
Magnetic heading deviation					
Com/Nav					
Landing gear operation					
Flap operation					
APU operation					
Other (RAT, T/R, etc.)					

APPENDIX P. USING ICING RATE TO DOCUMENT ICING EXPOSURES (CONTINUED)

P.5 REFERENCES.

P1. **"A Workable, Aircraft-Specific Icing Severity Scheme,"** R. Jeck, reprint No. AIAA-98-0094, 36th Aerospace Sciences Meeting (1998), American Institute of Aeronautics and Astronautics, Reston, Va. 20191-4344.

P2. **"A History and Interpretation of Aircraft Icing Intensity Definitions and FAA Rules for Operating in Icing Conditions,"** Richard K. Jeck, FAA Technical Report DOT/FAA/AR-01/91 (2001), FAA William J. Hughes Technical Center, Atlantic City International Airport, N.J. 08405.

P3. **"Ice Accretion and Droplet Impingement Codes,"** SAE ARP5903.

P4. **"Icing Design Envelopes (14 CFR-25, 29, Appendix C) Converted to a Distance-Based Format,"** Richard K. Jeck, FAA Technical Report DOT/FAA/AR-00/30 (2000), FAA William J. Hughes Technical Center, Atlantic City International Airport, N.J. 08405.

APPENIDX Q. ICE SHEDDING

Q.1 ICE SHEDDING.

Applicants must give attention to the ingestion of ice shed from protected and unprotected aircraft surfaces into the engine(s) (14 CFR §§ 23.901(d)(2), 23.903, 23.1093, 25.903, 25.1093, 27.1093, and 29.1093). Evaluate the trajectories and energy of shed-ice to ensure safe flight of the aircraft. This includes the integrity of the airframe and the operation of the engines and other systems. During or after an icing event, shed-ice may create a hazard by entering engine inlet ducts. This may cause damage or affect the operability of the engine. Shed-ice may also strike and damage other parts of the aircraft or block moving control surfaces. The aircraft design should consider these hazards and take suitable steps to prevent unwanted buildup and release of large pieces of ice.

Maximum ice shedding usually occurs after an ice event when the aircraft flies into temperatures above freezing. Ice may shed from wing and empennage leading edges, windshields, fuselage nose, pitot masts, antennae, propellers, or rotors, for example. Experience indicates that small turbine engines are more sensitive to compressor blade damage and adverse engine operation during ice ingestion than are the larger turbine engines. Ice shedding that impacts aircraft instrumentation may also adversely affect other airplane systems, for example, AOA vanes and pitot systems.

An analytical assessment of the shed-ice trajectories is difficult since the trajectories are influenced by local and downstream flow conditions; the shape, size, and lift-to-drag ratio of the ice fragment; and ice fragment tumbling. Reference Q1 contains information on the use of impingement and ice accretion codes for estimating shed-ice trajectories. Ice shedding is analyzed conservatively since an analytical model of the entire shedding process is not currently available. This compensates for the inexact nature of the analysis.

The role of drop impingement and ice accretion codes in ice shedding studies has been to predict the ice shape, size, and mass before the shedding event occurs. Drop impingement and ice accretion codes cannot predict the frequency of shedding, the shedding event itself, the breakup of ice as it sheds, or the trajectory of shed fragments. The trajectory calculations of drop impingement and ice accretion codes apply only to small particles that are not influenced significantly by gravity. In contrast, shed-ice fragments are large enough to experience gravitational effects and are highly influenced by aerodynamic forces dependent on their shape, orientation, and rotation. If you only evaluate ice shedding by analysis, then a damage analysis should account for the most critical ice shapes that will shed and impact the area of concern.

Many variables (for example, ice fragment shape and mass, aircraft attitude and altitude, airspeed, the airflow around the aircraft, and the manner in which the ice detaches) affect the path of ice shed from the aircraft. Therefore, you may have difficulty showing that shed ice will not enter engine inlet ducts or strike and damage aircraft components. Installing anti-icing protection in critical areas is a desirable approach for resolving an “ice shedding” problem.

You should understand shed-ice trajectories as much as possible before flight-testing. You should also understand the differences between shed-ice trajectories resulting from tanker tests and those from natural icing conditions before accepting tanker testing for evaluating shed-ice trajectories. Reference Q2 provides added information about the use of icing tankers for evaluating shed-ice trajectories.

Ice ingested by the engines should not interfere with the engines' operation and thrust. The ice protection of airframe surfaces whose ice buildup affects the integrity of the engines should be considered part of the engine's IPS. Structural damage analyses may be required if ice shed from forward aircraft surfaces can strike downstream surfaces. Also consider shed-ice damage of aircraft components (including control surfaces and their horns, hinges, control cables, and spoilers) and load-bearing structure.

If you do not install anti-icing protection on critical ice shedding surfaces, then you should conduct an investigation to show that ice shed from these surfaces will not cause an unsafe condition. Conduct "ice shedding" investigations during and after icing events. You should evaluate enough events in all intended operational conditions to ensure there is no hazard associated with ice shedding. Besides the usual measurements and observations made during icing tests, we suggest the following instrumentation or observations:

- Motion pictures to record the trajectory of ice released from the aircraft;
- A data acquisition system for turbine-engine-powered aircraft to record exhaust gas temperature, engine pressure ratio, and rpm to detect adverse effects on engine operation; or
- Visual examination of the aircraft for damage before and after ice events, especially near the engine compressor and inlet.

In addition, a damage analysis should consider that the most critical ice shapes will shed and impact the areas of concern.

Q.2 REFERENCES.

Q1. **"Ice Accretion and Droplet Impingement Codes,"** SAE ARP5903.

Q2. **"Airborne Icing Tankers,"** SAE ARP5904.

APPENIDX R. ICE SHAPES

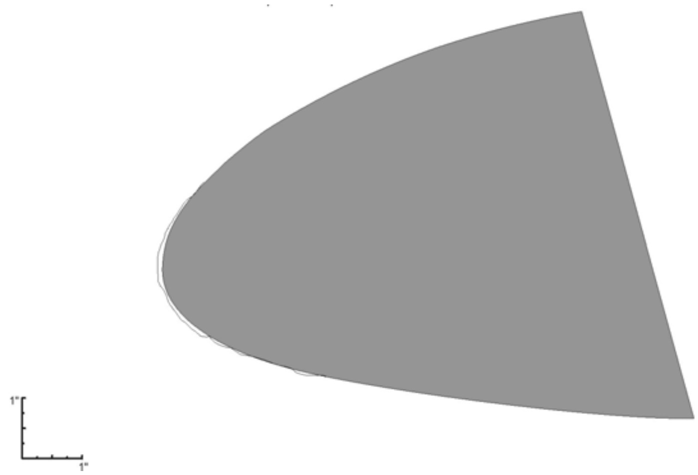
R.1 PROTECTED SURFACES.

R.1.1 Preactivation Ice Roughness.

When showing safe flight in icing conditions, applicants should consider the ice accretion roughness on unprotected and protected aircraft surfaces that occurs before the IPS is effective. Section 8.2.1.2.b, of this AC discusses preactivation ice. This surface roughness may seem small, but the resulting adverse aerodynamic effects may be significant. Also, since safe flight considerations may require adjustments to the uncontaminated aircraft stall protection and other systems, you may need to adjust AFM performance and maneuvering airspeeds of the uncontaminated aircraft (ACs 23.1419-2B, 25.1419-1, 27-1B, and 29-2C). Safe flight considerations for preactivation ice accretion should include acceptable stall warning and safe flying qualities at and above stall warning. Icing conditions event times should include delay times associated with detecting the first buildup of ice, flight crew reaction time to activate the IPS using recommended procedures, and the time required for the IPS to become effective.

Preactivation ice accretion roughness varies with the aircraft's IPS technology and use as a deicer or anti-icer, the aircraft's design, and the IPS operating procedures. Therefore, you should determine the preactivation ice roughness for your aircraft and show safe flight before the IPS becomes fully effective. You should base the roughness you select on the time required for the IPS to become fully effective and the icing condition that results in the most critical effects on airplane flying qualities. Figures R-1, R-2, and R-3 are photographs of preactivation ice on the leading edge of a hybrid NACA 23012 2-dimensional icing wind tunnel model. The reader can gauge the sand roughness of the preactivation ice by the grids formed by the one-inch apart chordwise lines and the two 1-1/4 inch spanwise lines along the leading edge of the model. Castings of the model surface roughness (shown in figures R-1 and R-2) are available from the FAA William J. Hughes Technical Center, Flight Safety Branch. Figure R-1 shows the surface roughness that may build up during the time required for an ice detector to detect ice accretion. The preactivation time used included 11 seconds for the first deicing cycle of a magnetostrictive type ice detector in maximum continuous icing conditions and an added 30 seconds to allow the pilot to begin recommended anti-icing procedures. You should provide the preactivation ice roughness to the FAA for our acceptance.

APPENDIX R. ICE SHAPES (CONTINUED)



a.

b.

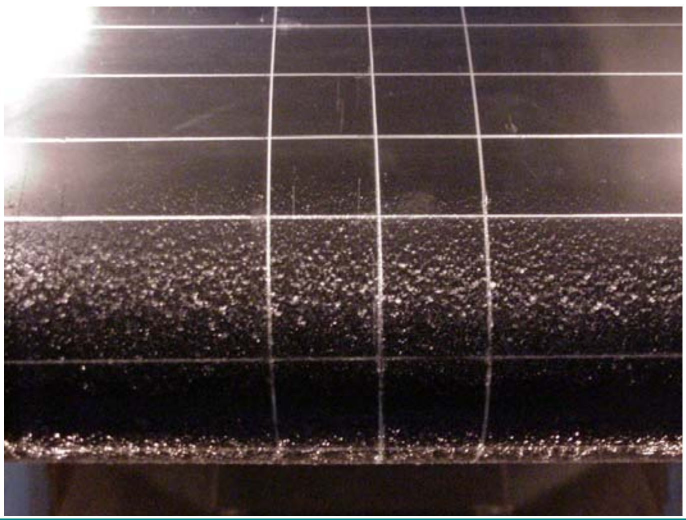


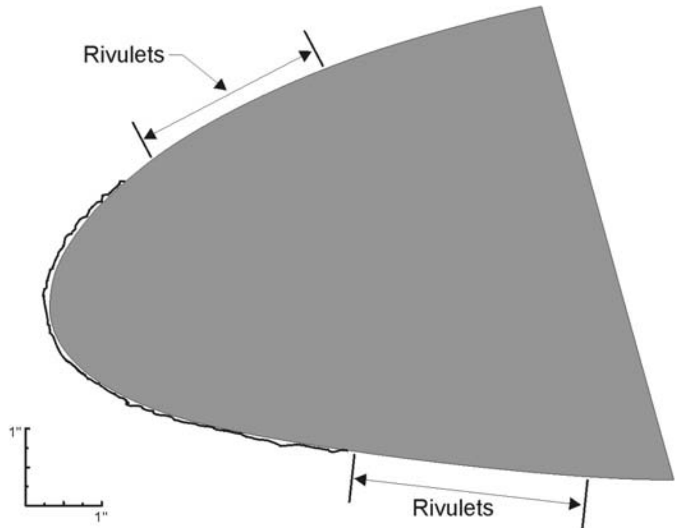
Figure R-1. Hybrid NACA 23012 2D (Simulating a 72-inch Chord Airfoil) Model Leading Edge Ice Roughness Before Activation of the IPS. Exposure time included 11 seconds for an ice detector alert and 30 seconds for the flight crew to activate the IPS. The test was performed in 14 CFR part 25, Appendix C Continuous Maximum Icing Conditions. (Static temperature = 14°F, LWC = 0.45 g/m^3, MVD = 20 micrometers, spray time = 41 sec., tunnel airflow speed = 195 mph, Model AOA = 4°.) (Reference R1).

APPENDIX R. ICE SHAPES (CONTINUED)

Figure R-2 shows the model's preactivation surface roughness that occurred during exposure to an intermittent maximum icing condition. The preactivation time included three seconds for the first cycling of the ice detector and 30 seconds for the pilot to begin recommended procedures for actuation of the IPS. Figure R-3 shows the model's leading edge surface roughness that resulted from a visual observation of ¼ inch of ice accretion and an added 30 seconds of exposure to maximum continuous icing conditions. The 30 seconds allows the pilot to begin recommended deicing procedures.

If you select more than one deicing cycle of an ice detector to avoid nuisance ice detection warnings or activation of the IPSs, then include this time in the preactivation exposure to the icing conditions. Also, flight crews may take up to two minutes to recognize icing conditions and begin recommended procedures for propulsion IPS. When determining the delay time for pilots to begin recommended ice protection procedures, consider the means provided to the flight crews for detecting the first accretion of airframe icing and the flight crew workload. The time required for the IPS to become fully effective varies with each IPS, for example the time for thermally protected surfaces to reach the design temperature. For IPSs that activate components sequentially, consider the time required for activation of the complete system as part of the preactivation exposure to icing conditions.

APPENDIX R. ICE SHAPES (CONTINUED)



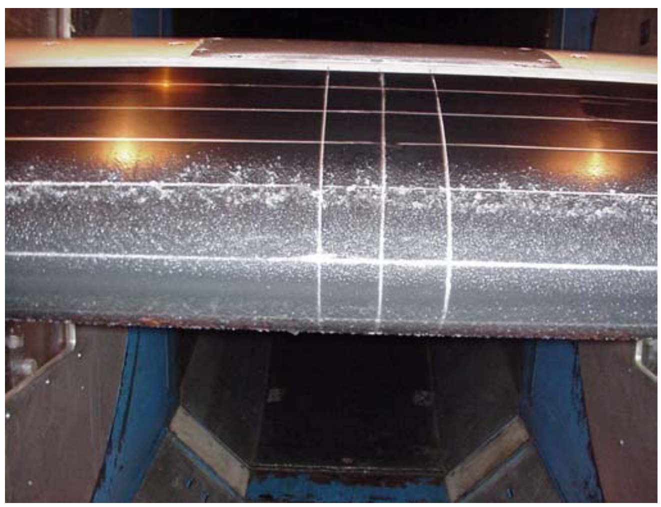
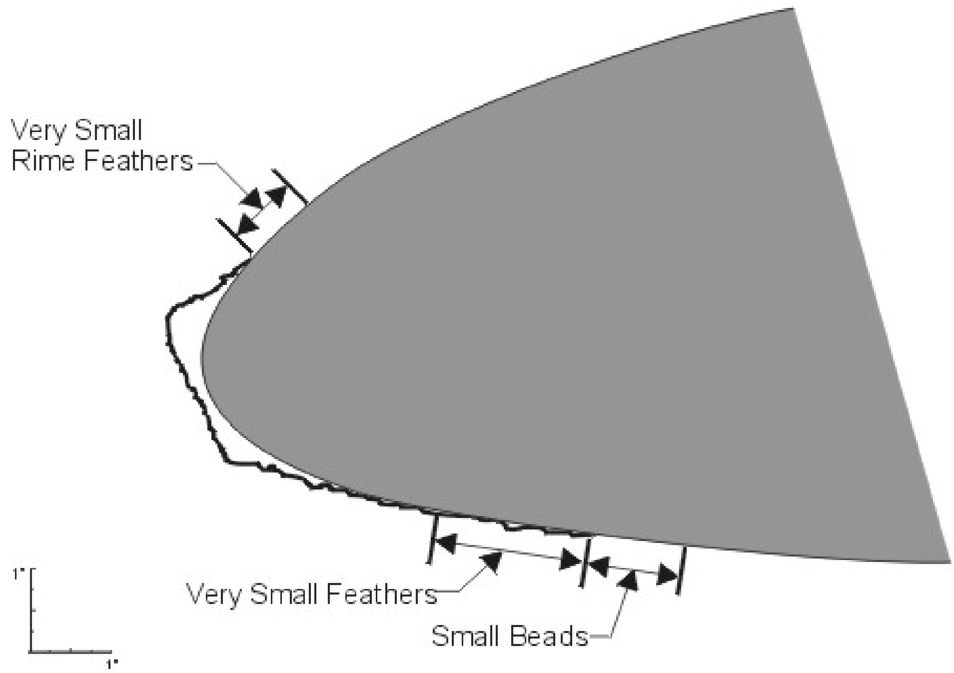


Figure R-2. Hybrid NACA 23012 2D (Simulating a 72-inch Chord Airfoil) Model Leading Edge Ice Roughness Before Activation of the IPS. Exposure time included allowing 3 seconds for an ice detector alert and 30 seconds for the flight crew to activate the IPS. The test was performed in 14 CFR part 25, Appendix C Intermittent Maximum Icing Conditions. (Static temperature = 14°F, LWC = 1.95 g/m^3, MVD = 20 micrometers, spray time = 33 sec., tunnel airflow speed = 195 mph, model AOA = 4°.) (Reference R1).

APPENDIX R. ICE SHAPES (CONTINUED)



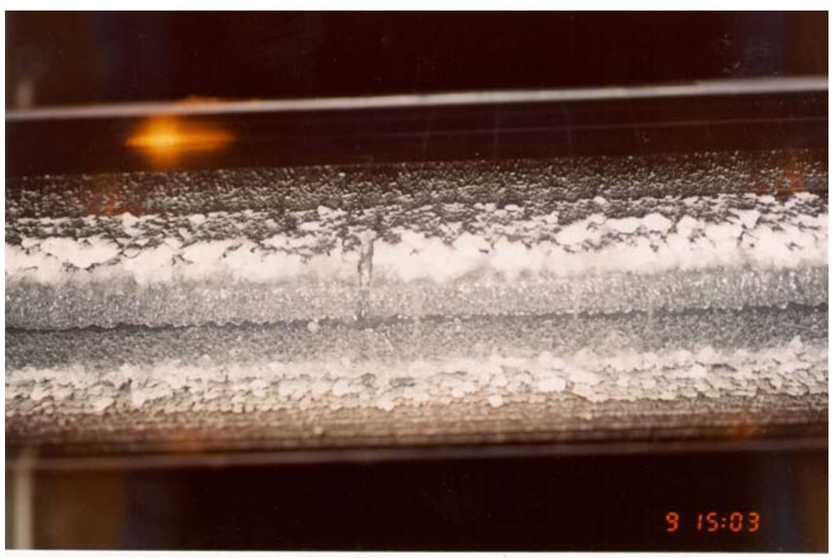


Figure R-3. Hybrid NACA 2301 2 2D Model (Simulating a 72-inch Chord Airfoil) Leading Edge Ice Roughness Before Activation of the IPS. Exposure time included the time required for an observation of ¼ inch of ice and 30 seconds for the flight crew to activate the IPS. The test was performed in 14 CFR part 25, Appendix C Continuous Maximum Icing Conditions. (Static temperature = 14°F, LWC = 0.45 g/m^3, MVD = 20 micrometers, tunnel airflow speed = 195 mph, model AOA = 4°.) (Reference R1).

APPENDIX R. ICE SHAPES (CONTINUED)

R.1.2 Intercycle Ice Roughness.

For continued operation of the deicing IPSs, the flight crew may activate the IPS on visual observation of a recommended monitored surface ice thickness. This ice thickness typically ranges from ¼ to 1½ inches. Figure R-3 shows the surface roughness that may be expected following visual observation of ¼ inch of ice accretion and an added 30 seconds of exposure to maximum continuous icing conditions. The added 30 seconds allows the pilot time to activate the deicing IPS. Since the cycling sequence time may be lengthy for some IPS designs, you should also consider ice buildups on the protection surfaces during the cycling sequence. Other mechanical systems may have different intercycle ice accretion characteristics. You should show that asymmetric intercycle ice accretion resulting from sequential operation of the elements of the IPS does not result in unsafe flight. Alternatively, you may automatically operate the deicing IPS continuously using preselected cycle intervals.

You should determine and prove intercycle ice roughness.

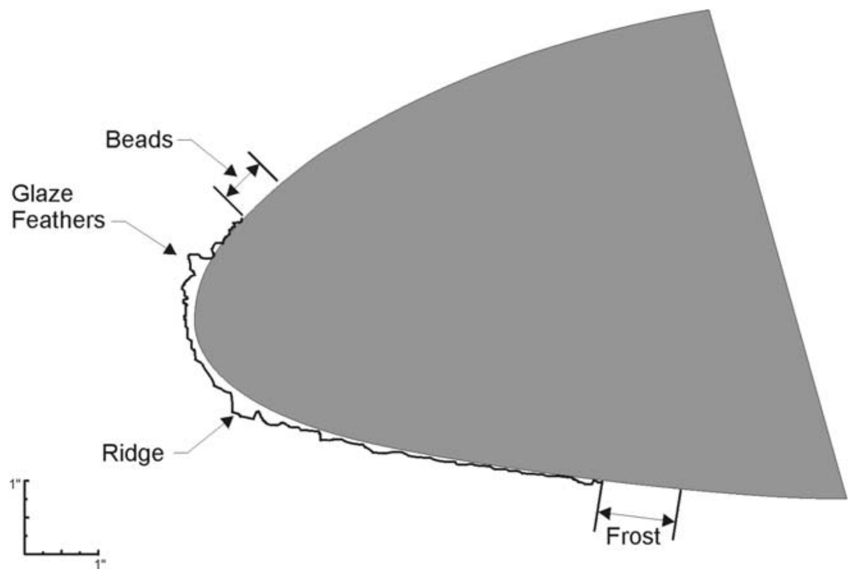
Figures R-4(a) and R-4(b) show intercycle ice roughness for a wind tunnel model using three-minute and one-minute intervals between cycling of the deicing boots in typical icing conditions. You can gauge the texture of the intercycle ice by using the grids formed by the one-inch apart chordwise and spanwise lines shown in the photographs. Castings of the intercycle ice in figures R-4 (a) and R-4(b) are available from the FAA William J. Hughes Technical Center, Flight Safety Branch.

For smaller surfaces, such as the horizontal stabilizers of regional air transports, figure R-5 shows intercycle ice roughness on a 2D, 36-inch NACA 23012 airfoil wind tunnel model using three- and one-minute intervals between cycling of the deicing boots.

Figure R-6 shows that the intercycle ice roughness in figures R-4 and R-5 compare favorably with that seen during flight. The wing leading edge deicing boots in figure R-6(a) were cycled just before landing after the aircraft had experienced heavy icing conditions. Figure R-6(b) is a photograph, taken in flight during a revenue flight, of wing leading edge deicing boots' intercycle ice accretion. The losses in maximum lift, maximum lift AOA, and increases in drag at operational angles-of-attack and as maximum lift is approached underscore the need for proper modeling of the surface roughness of protected surfaces when the IPS is working normally. This is important when showing safe performance and handling qualities in icing conditions.

Aerodynamic effects of intercycle ice surface roughness can be significantly adverse. Figure R-7 shows the aerodynamic effects of intercycle ice surface roughness that resulted from icing wind tunnel and high Reynolds number wind tunnel tests of a 36-inch NACA 23012 airfoil. Texture of the intercycle ice is available from castings of the intercycle ice shown in figure R-5(b). (These castings are available from the FAA William J. Hughes Technical Center, Flight Safety Branch.) Figure R-8 shows that the aerodynamic effects of uniformly distributed roughness, such as Carborundum grit, do not result in aerodynamic effects similar to those of the tested intercycle ice surface roughness. You should verify the use of uniformly distributed roughness to simulate intercycle ice shapes.

APPENDIX R. ICE SHAPES (CONTINUED)



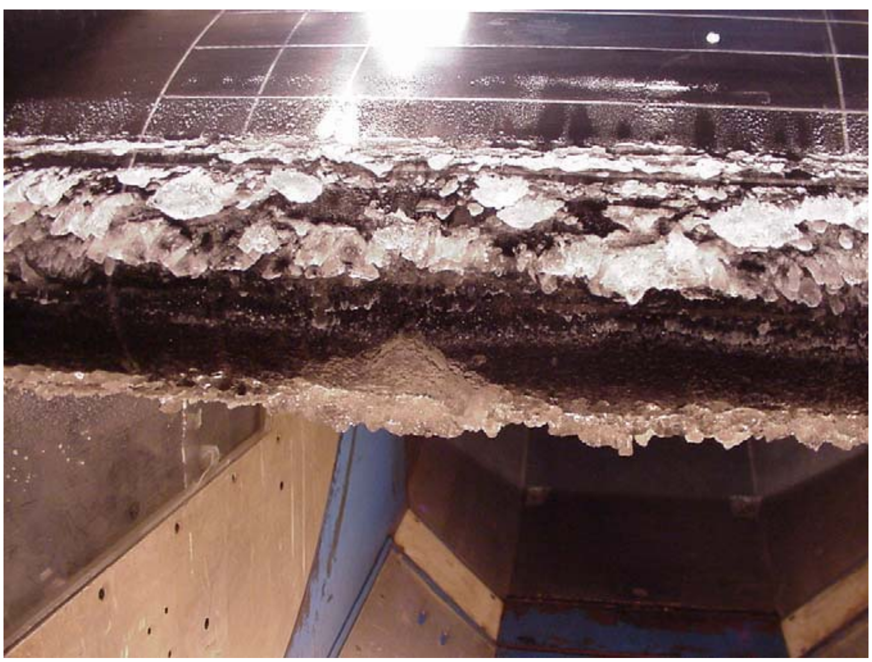
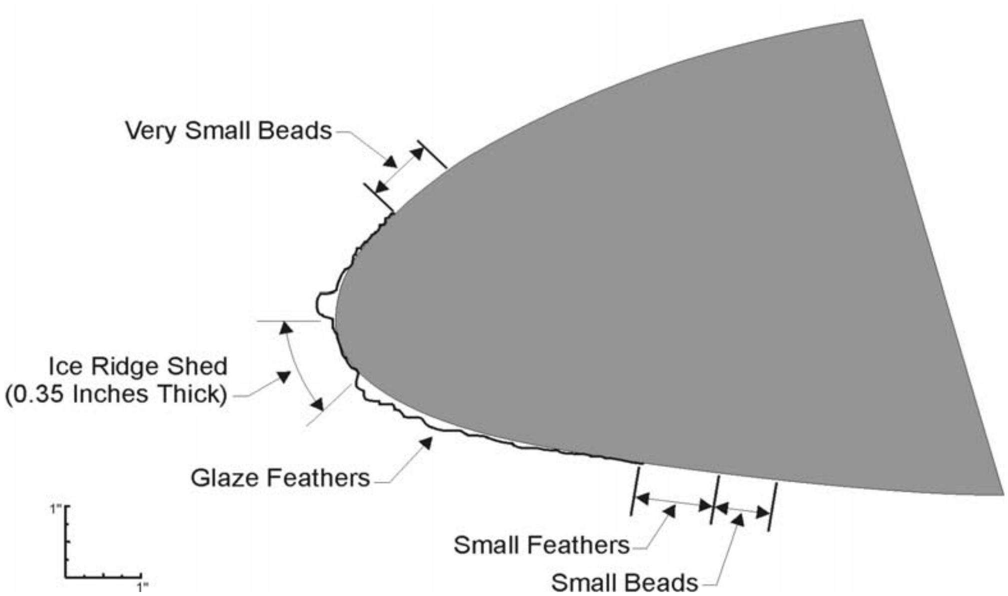


Figure R-4(a) Hybrid NACA 23012 2D (simulating a 72-inch chord airfoil) mode 1 intercycle ice before the third cycle of a pneumatic deicing boot. Three-minute boot cycle intervals were used. The test was performed in 14 CFR part 25, Appendix C Maximum Continuous Icing Conditions. (Static temperature = 14°F, LWC = 0.45 g/m^3, MVD = 20 micrometers, Spray time = 6:11 min., Tunnel airflow speed = 195 mph, Model AOA = 4°.)

APPENDIX R. ICE SHAPES (CONTINUED)



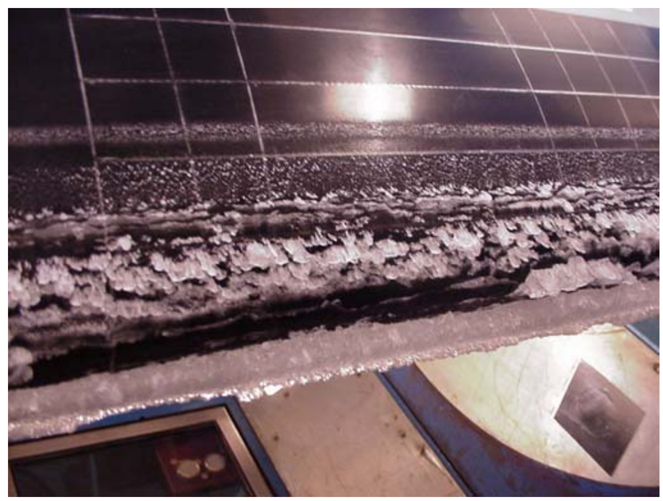


Figure R-4(b). Hybrid NACA 23012 2D (simulating a 72-inch chord airfoil) model intercycle ice before the sixth cycle of pneumatic deicing boot. One-minute boot cycle intervals were used. The test was performed in 14 CFR part 25, Appendix C Maximum Continuous Icing Conditions. (Static temperature = 14°F, LWC = 0.45 g/m^3, MVD = 20 micrometers, Spray time = 6:11 min., Tunnel airflow speed = 195 mph, Model AOA = 4°.)

Figure R-4. Typical Surface Roughness on the Leading Edge of a NACA 23012 Resulting From Normal Operation of Wing Pneumatic Deicing Boots (Reference R1).

APPENDIX R. ICE SHAPES (CONTINUED)

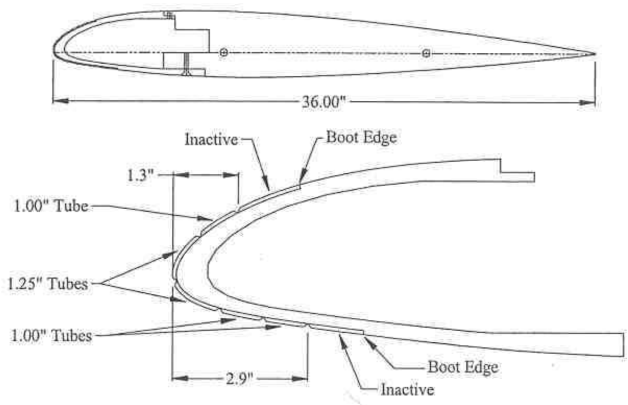
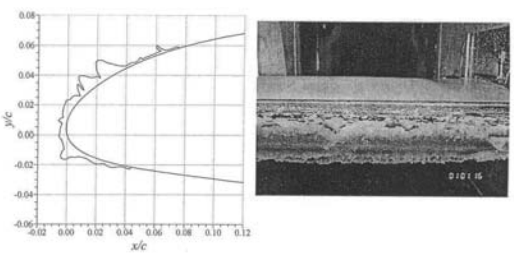
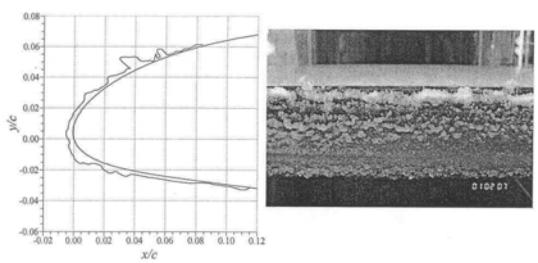


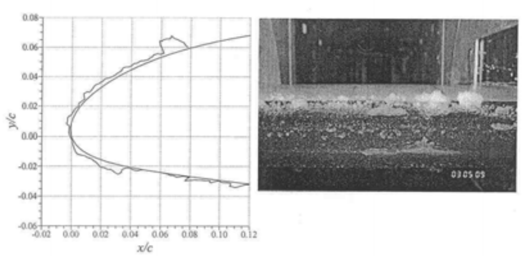
Figure R-5(a). Ice protection design (pneumatic deicing boots) for the NACA 23012 airfoil tested to examine intercycle ice buildup.



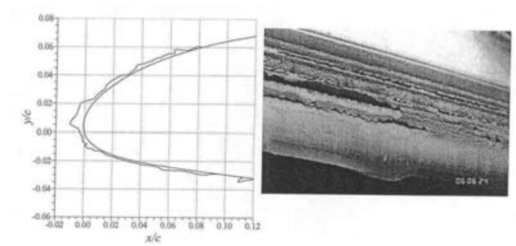
Ice shape 290



Ice shape 296



Ice shape 312



Ice shape 322

Ice Shape	Angle of Attack (deg.)	Drop MVD (μm)	Static Temp. (deg. F)	LWC (g/m^3)	Spray Time (min.)	Boot Cycle Period (min.)
290	0	20	14	0.45	12	3
296	0	20	21	0.65	12	3
312	0	40	21	0.25	12	3
322	0	40	-4	0.40	3	1

Figure R-5(b). Icing wind tunnel intercycle ice accretions for the figure R-5(a) model.

Figure R-5. Intercycle Ice Roughness for a 2D 36-inch NACA 0012 Airfoil Wind Tunnel Model.

APPENDIX R. ICE SHAPES (CONTINUED)

Figure R-6(a). Residual ice following cycling of the deicing boots after an inflight icing event and before landing.

Figure R-6(b). Wing deicing boots intercycle ice accretion photographed during revenue service.

Figure R-6. Wing Deicing Boots Residual and Intercycle Ice Buildups.

APPENDIX R. ICE SHAPES (CONTINUED)

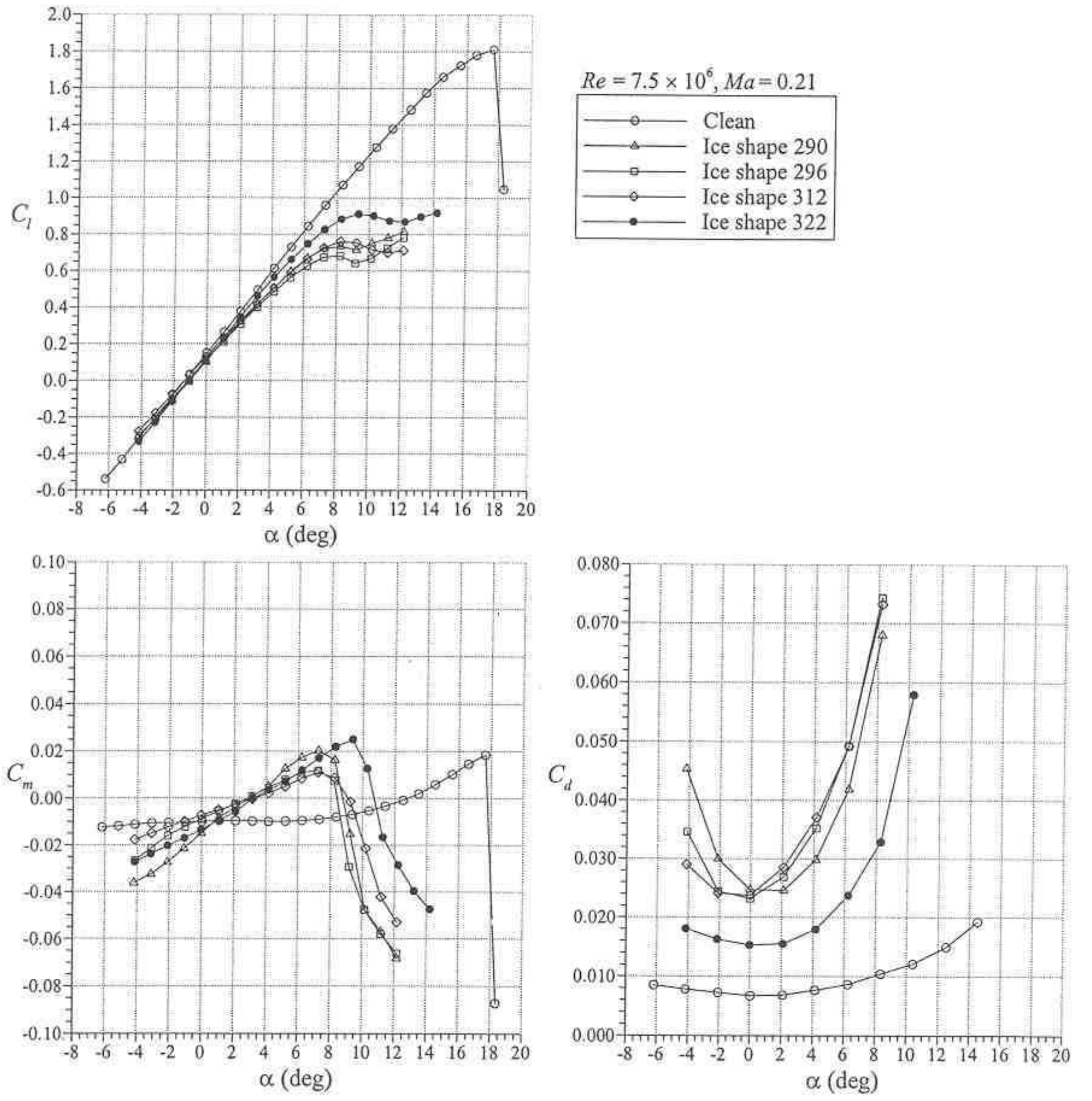


Figure R-7. Aerodynamic Effects Resulting From Deicing Intercycle Ice Shapes for a 2D 36-inch NACA 23012 Airfoil Wind Tunnel Model at a Reynolds Number of 7.5x10^6.

APPENDIX R. ICE SHAPES (CONTINUED)

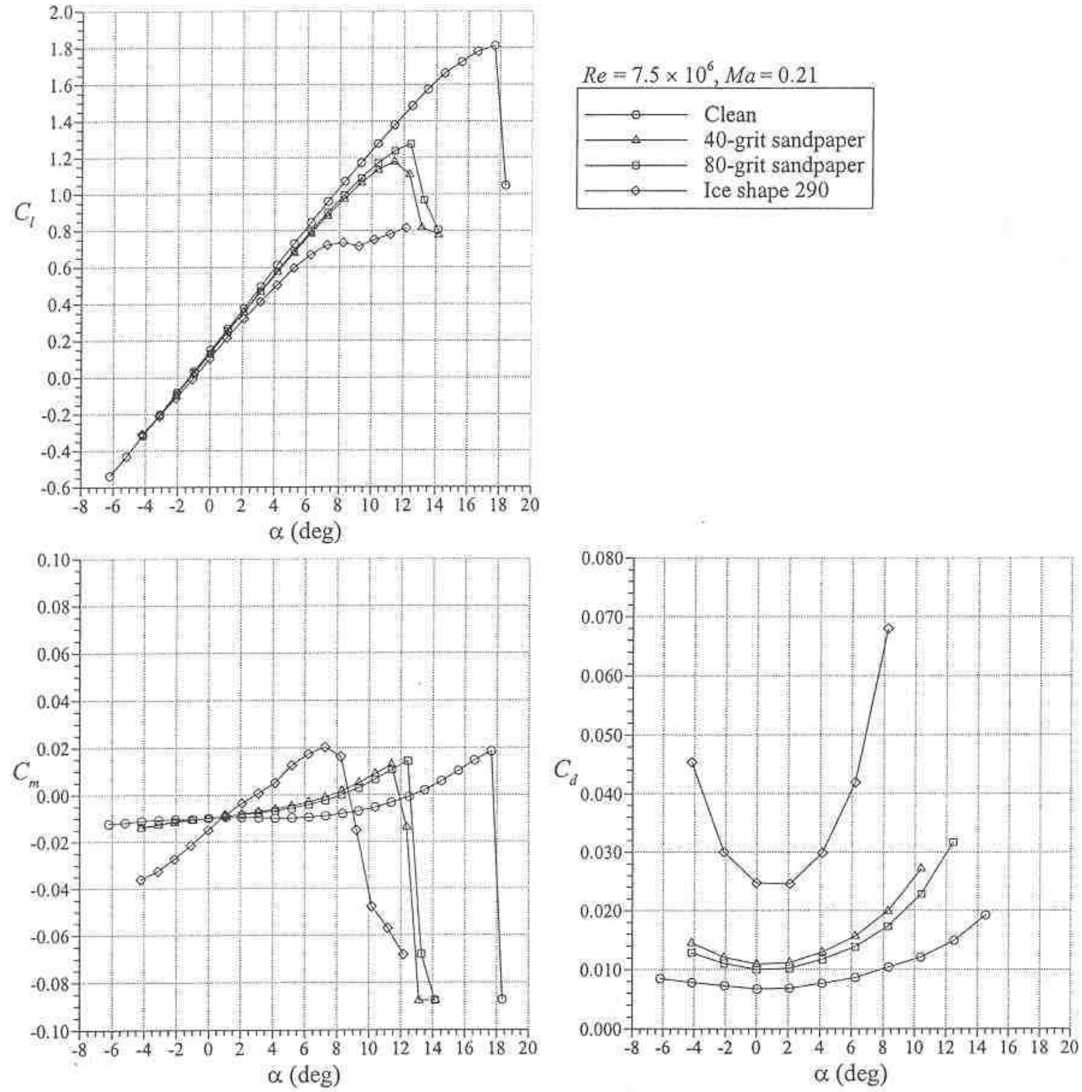


Figure R-8. Aerodynamic Effects of Distributed Roughness Along the Leading Edge of a NACA 23012 Airfoil (c = 36 inches, Re = 7.5x10^6, M = 0.21) (Reference R2).

R.1.3 Runback Ice.

Water not evaporated by a thermal IPS and unfrozen water during near-freezing conditions may run aft of the ice protection surfaces and form runback ice. During near-freezing conditions, the freezing fraction (n) of the water is less than 1.0.

Figure R-9 is a photograph of runback ice for a 36-inch NACA 0012 duty airfoil model after 5 minutes of exposure to icing conditions. The model was equipped with an electrothermal IPS. The IPS ran wet (surface temperature of about 50°F with an icing wind tunnel static temperature of 0°F). The tunnel icing conditions were mixed-phase, with 20 μm liquid water drops. The

APPENDIX R. ICE SHAPES (CONTINUED)

LWC was 0.35 g/m^3 and the IWC of the shaved ice was 0.35 g/m^3. Appendix C does not include mixed phase icing conditions. However, the runback buildups shown have similar characteristics to those produced in Appendix C liquid-phase conditions.

Figure R-9. Lower Surface Runback Ice on a 36-inch NACA 0012 Airfoil Model. The model was equipped with an electro-thermal IPS. The IPS ran wet with a constant protection surface temperature of about 50°F. The mixed-phase icing cloud exposure time was 5 minutes. (Static Temperature = 0°F, LWC = 0.35 g/m^3, MVD = 20 micrometers, IWC (shaved ice) = 0.35 g/m^3, tunnel airflow speed = 120 mph, model AOA = 0°).

Computer codes may be unable to estimate the characteristics of the runback water or the resultant ice shapes. Some codes may be able to estimate the mass of the runback ice. Until computer codes are developed and accepted, determine runback ice empirically by natural icing tests, icing tanker tests, or icing wind tunnel tests.

You determine and verify runback ice buildups. Consider the effects of runback ice resulting from a 45-minute hold when showing the safe flight. The required water catch may be impractical to get in natural icing conditions. Instead of natural icing tests alone, use icing tanker, icing tunnel tests, or analyses with flight tests to determine runback ice buildups. You can then flight test simulated ice shapes to evaluate the effect of runback ice on aircraft flying qualities. For thermal IPSs that do not evaporate the impinging water under holding conditions (running-wet systems), evaluate the shedding and engine ingestion of runback ice from airframe and engine inlet surfaces.

APPENDIX R. ICE SHAPES (CONTINUED)

R.2 UNPROTECTED SURFACES.

Aircraft will typically have surfaces that collect ice, but require no ice protection. Applicants must show their aircraft can operate safely in icing conditions with these surfaces unprotected against ice buildup (section 6.1 of this AC).

You can determine ice shapes of unprotected surfaces by tests in measured natural icing. You can also predict them by simulated icing (icing tanker) flight tests, icing wind tunnel tests, computer codes, and other analytical methods validated by test experience. You must perform flight-testing in measured natural icing conditions to verify the ice protection analyses and to check for icing anomalies (14 CFR §§ 23.1419, 25.1419, 27.1419, and 29.1419). Therefore, you must verify predicted ice shapes by flight tests in measured natural icing conditions. It is not intended that natural icing flight tests verify all the features of predicted ice shapes. Finding specific, critical conditions during natural icing flight tests may not be likely (appendix M of this AC). Use natural icing flight tests to corroborate the general physical characteristics and location of the simulated ice shapes. Also, you should corroborate their effect on airplane handling characteristics.

R.3 ICE PROTECTION SYSTEM FAILURE ICE SHAPES.

It may be necessary for an aircraft to exit icing conditions after the IPS fails. The following describe IPS failure ice accretion scenarios:

- If the IPS failure condition is annunciated and AFM procedures require the aircraft to exit icing conditions, the ice buildups on normally protected surfaces should be that resulting from normal operation of the IPS until the annunciated failure. Also include the ice that would build up during the exiting maneuver.

- If the IPS failure condition is annunciated and the AFM procedures do not require the aircraft to exit the icing conditions, ice on protected surfaces with ice protection failure may build up after the failure.

- If the IPS failure condition is not annunciated, ice buildups on normally protected surfaces should be the same as that on unprotected surfaces.

Applicants may select ice on normally protected surfaces where ice protection has failed to be half of what builds up on an unprotected surface for aircraft that are required to exit icing conditions following failure of the IPS. Alternatively, if the IPS failure is annunciated, you may select the ice that builds up on an unprotected surface during the time required for exiting the icing condition. You must calculate the time required to exit the icing conditions conservatively. Get FAA acceptance of the icing conditions exit time.

For airplanes, you may select the time to exit the icing condition as half of a 45-minute hold, or as you verified. AC 23.1419-2C provides guidance for 14 CFR part 23 airplanes for exit times other than 22.5 minutes. AC 29-2C states that the time to exit the icing conditions for a rotorcraft is 15 minutes. For a failed IPS, ice accretion on unprotected surfaces should be

APPENDIX R. ICE SHAPES (CONTINUED)

unaffected and expected to build up as described in paragraph R.2, of this appendix. See paragraph R.2 for means of determining ice shapes for unprotected surfaces. You may use analyses to determine ice accretion on a failed protected surface. For certain design features (for example stall strips and vortex generators), natural icing or simulated icing conditions (tankers and icing wind tunnels) may be required.

You should determine if exiting of icing conditions is required based on results of the system failure modes and effects analysis required by 14 CFR §§ 23.1309, 25.1309, 27.1309, and 29.1309. If you select continued flight in icing conditions, you must show that the aircraft can fly safely, as described in paragraph 6.2, of this AC. Simulated ice shapes developed to evaluate the aircraft's performance and handling qualities should reproduce the allowable failures of the IPS. If exiting icing conditions is required, you must show the aircraft has the ability to continue safe flight and landing. Also include the proper procedures in the AFM. For guidance on ways of showing safe flight after an IPS failure that requires exiting the icing condition see AC 23-8B, AC 23.1419-2C, AC 25.7A, AC 25.1419-1A, AC 27-1B, and AC 29-2C.

R.4 CRITICAL ICE SHAPES.

R.4.1 Considerations for Critical Ice Shapes.

A critical ice shape may be defined as the aircraft surface ice shape (formed within icing conditions defined by 14 CFR parts 25, Appendix C or 29, Appendix C) that results in the most adverse effects for specific flight safety requirements. The critical ice shape may differ for different flight safety requirements. For example, the critical ice shape may differ for stall speed, climb, aircraft controllability, control surface movement, control forces, air data system performance, "artificial feel" adjustments, ingestion and structural damage from shed-ice. Engine thrust, engine control, and aeroelastic stability considerations may result in different critical ice shapes.

Critical ice shapes may vary with aircraft configuration and flight phase. The applicant may design one aircraft surface ice shape to be critical for all flight safety considerations, configurations, and flight phases. Critical ice shape determination also includes consideration of unsatisfactory effect on the aircraft's aeroelastic stability (14 CFR §§ 23.629, 25.629, 27.629, and 29.629). Other considerations include shed-ice ingestion related to engine operation, control, and ice protection (14 CFR §§ 23.901(d)(2), 23.903, and 25.903 (which require compliance with 14 CFR § 33.77); § 33.68; and §§ 23.1093, 25.1093, 27.1093, and 29.1093).

Flight-testing with the critical ice shapes can be dangerous if approached with inadequate caution. To avoid extensive flight-testing, you can simulate the most critical unprotected and protected surface ice shapes and surface roughness as a means to show compliance with safe flight requirements. Subpart B of 14 CFR parts 23, 25, 27, and 29 provide the requirements for safe flight.

If you cannot determine a single critical ice shape, you should test each critical ice shape in the associated phase-of-flight configuration to examine the aircraft's controllability, maneuverability, stability, performance, trim, and stall characteristics. For large turbojet air

APPENDIX R. ICE SHAPES (CONTINUED)

transports with large thrust margins, you should consider ice shapes that are handling-qualities critical. Also consider conservative estimates of performance effects. You should perform all flight-testing at the most critical weight, center-of-gravity, flap, and gear configuration for the aircraft characteristic of interest.

Determination of critical ice shape configurations is not straightforward and may require engineering judgment. The aircraft critical ice configuration should include expected ice buildups on all surfaces, protected and unprotected (including flow control devices such as vortex generators, stall strips, vortilons, and fences). You should consider phases of flight where ice buildups may occur and those where ice buildups may continue after exiting conditions conducive to icing. Consideration of the ice buildup effects on the aircraft should include:

- Lift, including maximum lift.
- Drag.
- Pitching moments.
- Control forces.
- Control surface movement.
- Freezing of critical seals.
- Ice ridges aft of protection surfaces.
- Runback ice.
- Vibration and aeroelastic stability.
- Stall warning.
- Stall characteristics.
- Power.
- Air induction inlet airflow.
- Stability.
- Controllability.
- Trim.
- Control surface aerodynamic balance.
- Maneuverability.
- Horizontal stabilizer and elevator stall.
- Vertical stabilizer and rudder stall.
- Wake effects on engine operability and downstream aircraft components and systems.
- Engine operability and aircraft structural damage resulting from shed-ice.

You should select the critical ice shape configuration(s) and verify that the selected ice shape configuration is most critical for the considered flight safety concern. Selection of the ice shape and its features typically requires surveying ice shapes that may build up on a surface within the required icing conditions. Select critical ice shape candidates from this survey, with an understanding that a surface ice shape that is critical for flight safety may not be that of an unprotected surface with the largest and most aerodynamically intrusive ice buildup. Protect surfaces considered critical for safe flight. You should consider:

APPENDIX R. ICE SHAPES (CONTINUED)

- Preactivation ice accretion roughness.

- Protection surface intercycle ice buildup.

- Runback ice, or thin, rough ice buildups on the horizontal stabilizer (resulting from preactivation ice, intercycle ice, or from being an unprotected surface).

- Expected ice buildups on unprotected surfaces.

You can determine the shape and characteristics of ice buildup by flight in natural or artificial (icing tanker) icing conditions, icing wind tunnel tests, ice accretion codes or analysis methods, or by combinations of the different methods. You must perform flight-testing in measured natural icing conditions to verify the ice protection analysis, to check for icing anomalies, and to show the effectiveness of the IPS (14 CFR parts 23, 25, 27, and 29, § .1419). When using icing tankers, icing wind tunnels, or ice accretion codes and analytical methods, consider the comments about use of these icing simulators in paragraphs R1 and R2.

Inflight icing accident investigations and experience suggest that glaze and high intensity icing conditions during descent may result in the most critical ice shapes. Glaze icing conditions will exist at near-freezing temperatures (about -5°C or warmer). The largest ice mass occurs at conditions of maximum water catch. Hazardous ice accretions may also occur at colder mixed and rime ice conditions for intercycle ice and for running-wet thermal IPSs.

You may use experience from previous certifications of similar aircraft designs as guidance for determining the icing conditions that produce candidate critical ice shapes. Unprotected critical surface ice shapes should reflect the icing exposure time associated with the respective phase of flight. For the holding configuration, consider the 45-minute holding period. Guidance material contained in the JAA ACJ 25.1419, states that from service experience ice on the most critical unprotected main airfoil surfaces do not usually exceed a pinnacle height of three inches in a plane towards flight (Reference R4).

A 1962 airframe manufacturer's magazine article is often referenced as giving credence for accepting critical ice shapes with peak heights of no more than 3 inches. This article discussed elimination of the B707/720 airplanes' horizontal and vertical stabilizers ice protection (Reference R4). The magazine article provided an analysis of a "maximum possible ice (based on CAR icing conditions envelopes)" mission profile that resulted in a maximum ice shape of 3.31 inches, following:

- A dispatch hold of 10.4 minute at 250 KTAS;
- Climb of 4.5 minutes at 290 KCAS;
- Cruise at an altitude of 15,000 feet for 22 minutes at 360 KIAS;
- A destination hold of 31 minutes at 15,000 feet with at 250 KTAS.

Flight tests showed that simulated 3-inch ice shapes did not hamper these Boeing airplanes. Minimum control speeds and other stability and control characteristics were explored. The article only addressed the horizontal and vertical stabilizers of the B707/720 models. It also

APPENDIX R. ICE SHAPES (CONTINUED)

stated that the analysis only applied to turbine-powered airplanes. The 3.31-inch analysis ice shape and the flight test three-inch ice shape discussed in the magazine article may lead to the conclusion that service experience shows that ice on critical unprotected wing and stabilizer surfaces need not exceed a peak height of three inches. Certification experience has shown that peak heights on the critical unprotected surfaces may exceed three inches, such as on the unprotected leading edges of the horizontal or vertical stabilizers or the wing of airplanes smaller in scale than the B707. Therefore, you should not truncate the peak height of ice shapes to three inches.

Also, the magazine article's combination of a 15-minute dispatch takeoff hold and a 30-minute destination hold may be correlated to the 45-minutes destination hold (based on operational fuel requirements) ice shape guidance. You should determine the preactivation and intercycle ice shapes for your aircraft. However, you may use sections R.1.1 and R.1.2 of this appendix as guidance. Castings of these ice accretions, which you may use as a guide for producing simulated ice roughness, are available at the FAA William J. Hughes Technical Center. For larger ice shapes that build up on unprotected surfaces, the ice shape surface texture should either reflect the empirically determined ice shape texture or be about 3 mm in height with a particle density of 8 to 10 per cm^2. Thin, rough layers of ice, commonly called "sandpaper ice" should reflect empirical results. (Carborundum paper no. 40 has been used during certification for ice contaminated tail stall.) However, you should verify use of the 40-grit Carborundum paper to simulate intercycle ice roughness (as discussed in sections R.1.1 and R.1.2 of this appendix).

Runback ice and ice ridges that may occur aft of deicing or running wet protection surfaces may form critical ice shapes. You should determine these critical shapes empirically by using icing tankers or icing wind tunnels. Use these empirical methods until the ability of an ice accretion code or analysis method to perform this task is validated.

Determining the critical aircraft ice shape configuration requires integrating knowledge about all the aircraft surfaces' critical ice shapes into one overall configuration. The integration may reveal that the critical ice shape for one surface may not be consistent with developing critical ice shapes on other surfaces. For example, sandpaper ice roughness on the horizontal stabilizer may be critical for contaminated tail stall testing. The wing's extended holding and intercycle ice configurations may be critical for airplane performance and handling qualities. Also, when showing stall recovery and drag for aircraft with low power margins, you should consider propeller ice contamination.

You may use simulated critical ice shapes to show safe flight in icing conditions. To minimize the number of configurations necessary to show safe flight in icing with simulated ice shapes, you should show that the selected configurations are most critical. Wind tunnel testing at full-scale Reynolds and Mach numbers, or a verified Navier-Stokes full-configuration CFD analysis may be necessary to determine the critical ice shape configuration without applicable information from a similar certificated aircraft, and for other than the simplest aircraft configuration. (Section R.4.2, of this appendix contains CFD codes guidance.) Also, when incrementally adjusting flight test data for other critical ice shape considerations by using wind tunnel data (like drag), paying attention to the effects of Reynolds and Mach number on those increments is important. Ice buildups may be difficult to reproduce at a small-scale. The ratio of

APPENDIX R. ICE SHAPES (CONTINUED)

the ice buildup height to the model's boundary-layer height may be different at low Reynolds number from that at flight Reynolds number. Also, scaling the ice shape roughness may be difficult.

You may simulate three-dimensional (3D) characteristics of critical ice shapes for flight as long as you provide enough empirical information to verify the simulated shapes. For surfaces whose chord and leading edge shape significantly vary across the span of the unprotected surface, the critical ice shape may reflect the effects of the varying surface geometry on ice accretion. You may create a 3D critical ice shape by first lofting 2D critical ice shapes at enough spanwise locations. Then apply suitable surface texture, as discussed above. Low Reynolds number wind tunnel test data, shown in figure R-10, shows that a continuous ice shape produces conservative aerodynamic effects when compared with those for ice shapes segmented spanwise. These results are for the model, ice shapes, and testing conditions tested. You may use segmented ice shapes to simulate known spanwise variations in ice buildups.

The FAA will closely review the use of simulated ice shapes that you assume conservative when compared with critical ice shapes reflecting ice buildups. This is also true for the use of devices that make surfaces aerodynamically ineffective differently than how the airflow would behave with critical ice shapes. The objective of showing safe flight in icing conditions is to have the aircraft behave as if it has collected critical ice shapes in those icing conditions. Arbitrarily developed aircraft surface flow conditions may not produce aircraft flying qualities that would occur with natural icing critical ice shapes. Without knowing the aircraft flying qualities with natural icing critical ice shapes, you may have difficultly verifying that arbitrarily developed flow-disturbance devices are acceptable.

Simulated critical ice shapes used to show safe flight should include collateral icing that may collect on aircraft surfaces. Figure R-6(a) shows an aircraft that experienced heavy icing before landing, showing that collateral icing can be significant. Ice accretion codes may not predict icing that may collect at aircraft surface discontinuities. Although drag may be the most significant effect of the collateral ice, address these ice buildups when showing safe flight (14 CFR §§ 23.65, 23.67(e)(2), 23.67(e)(3), 23.75, 23.77, 25.119, 25.121, and 25.123).

APPENDIX R. ICE SHAPES (CONTINUED)

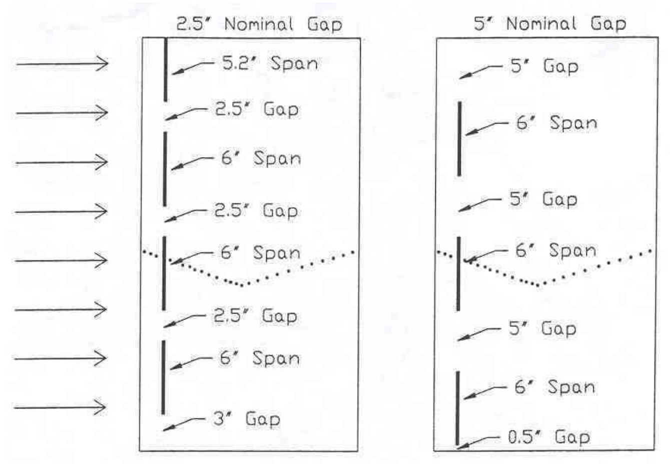


Figure R-10(a). Segmented 0.25-inch, forward-facing, quarter-round simulated ice shapes on the upper surface of an 18-inch chord NACA 23012m airfoil 2D model.

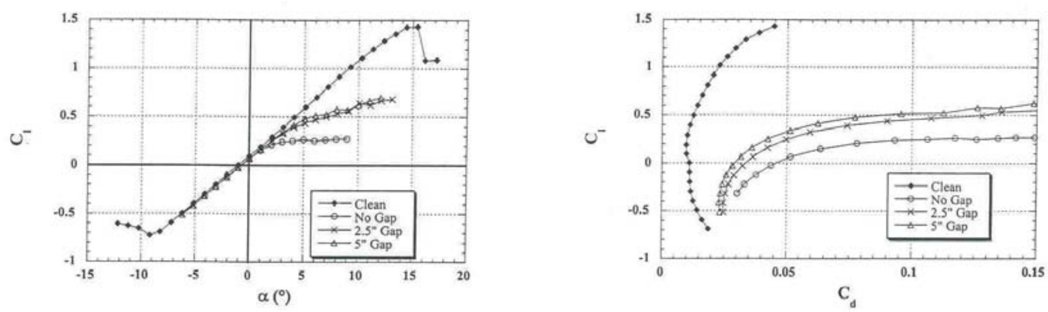


Figure R-10(b). Aerodynamic effects of continuous and segmented 0.25-inch, forward-facing, quarter-round simulated ice shapes on the upper surface of an 18-inch chord NACA 23012m airfoil 2D model (Re = 1.8×10^6, M=0.185).

Figure R-10. Aerodynamic Effects of Continuous and Segmented 0.25-inch, Forward-Facing, Quarter-Round Simulated Ice Shapes on the Upper Surface of an 18-inch Chord NACA 23012m Airfoil 2D Model (Re = 1.8 x10^6, M=0.185). (Reference R5).

APPENDIX R. ICE SHAPES (CONTINUED)

R.4.2 Aerodynamic Considerations for Determining Critical Ice Shapes.

Aerodynamic effects of ice accretions result mainly from the effects of the ice accretion on the surface's boundary-layer behavior. Ice accretions that occur in areas favorable to keeping the boundary layer attached to the aircraft surface will result in effects that are less aerodynamically adverse than ice accretions that occur in areas less favorable to attached boundary-layer conditions. Ice shapes that build up in areas of local airflow deceleration (positively increasing surface pressure), or result in conditions unfavorable to keeping attached flow conditions, as the airflow negotiates the ice surface, will result in the most adverse effects.

For example, an ice accretion at the same chordwise location on different airfoils may result in different aerodynamic effects. Figure R-11 shows the surface pressure distributions for uncontaminated NACA 23012 and NLF 0414 airfoils for about the same lift. The NACA 23012 airfoil upper pressure is forward-loaded and shows a severe pressure recovery downstream of the suction pressure peak near the airfoil's leading edge. The severe pressure recovery results from deceleration of the local airspeed to produce more positive pressures. The NLF 0414 airfoil's pressures and local airspeeds are much more constant, with a pressure recovery occurring about 0.7c. This delayed pressure recovery provides conditions conducive to keeping a well attached, laminar boundary layer over most of the airfoil's upper surface.

Figure R-12 shows low Reynolds number wind tunnel test results. These data resulted from installing a ¼-inch simulated ice shape (quarter-round) at various chordwise locations on 18-inch models of each airfoil. Figure R-13 shows the maximum lift values. Although these aerodynamic characteristics are Reynolds number dependent, the data show where the ice builds up is important and show the influences of the ice buildup on the behavior of the boundary layer and the airfoil aerodynamic performance.

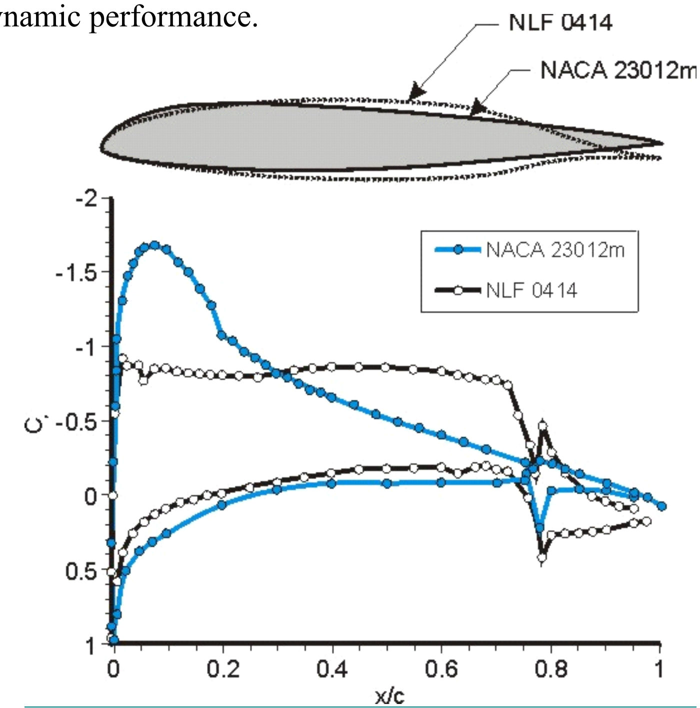
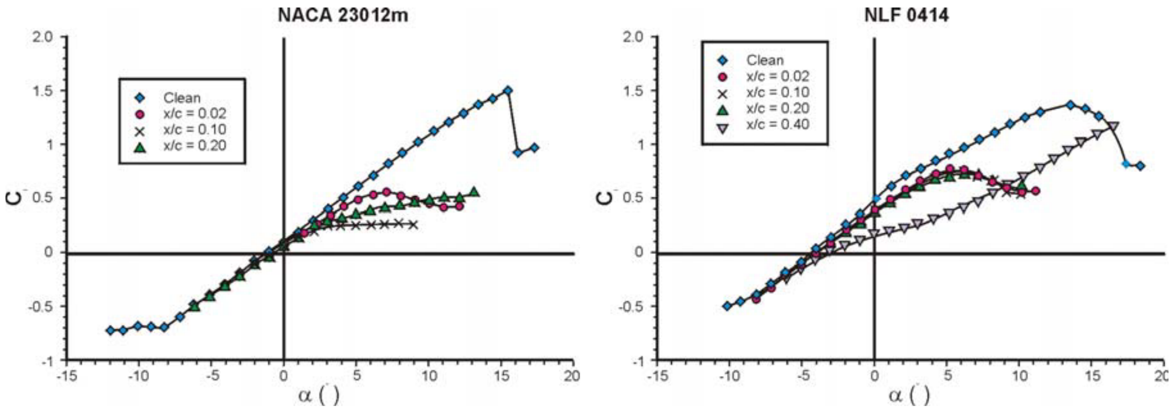


Figure R-11. Comparison of NACA 23012m and NLF 0414 Clean Airfoil Model Experimental Pressure Distributions ($C_l \sim 0.6$, Re = $1.8\text{x}10^6$, M = 0.185) (Reference R5).

APPENDIX R. ICE SHAPES (CONTINUED)



NACA 23012m **NLF 0414**

Figure R-12. Effect of an Upper Surface Simulated Quarter-Round Ice Shape at Various Chordwise Positions on Lift for Forward- (NACA 23012m) and Aft-Loaded (NLF 0414) Airfoils (k/c = 0.0139, Re = 1.8x10^6, M = 0.185) (Reference R5).

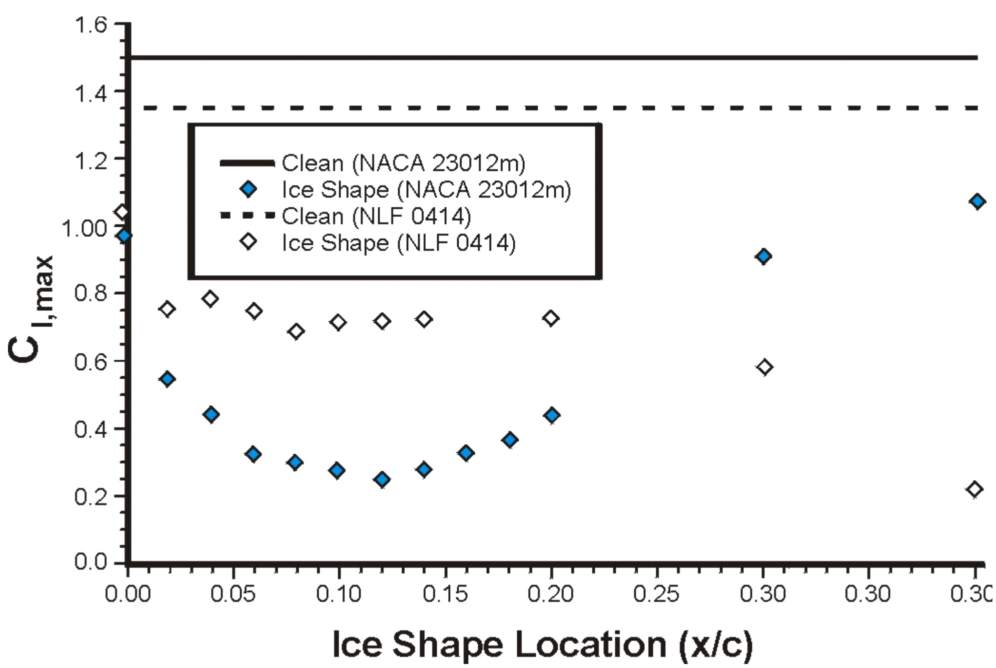
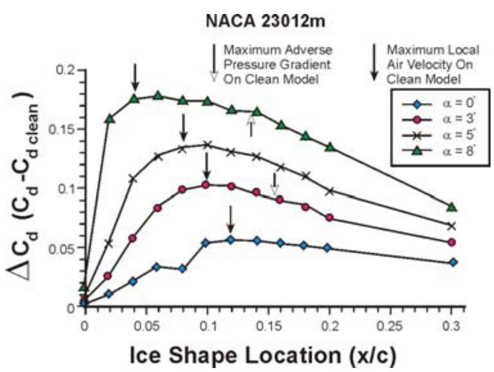


Figure R-13. Variation of $C_{l\,max}$ for NACA 23012m and NLF 0414 Airfoils With and Without an Upper Surface 0.25-inch, Forward-Facing, Quarter-Round Simulated Ice Shape at Various Chord Positions (Re = 1.8x10^6, M = 0.185) (Reference R5).

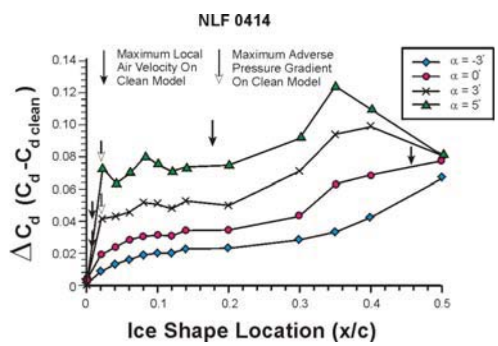
APPENDIX R. ICE SHAPES (CONTINUED)

The critical location, for maximum lift, for the simulated ice accretion on the NACA 23012 airfoil is about 0.125c. Comparatively, the lowest maximum lift occurs at 0.40c (not shown) for the NLF 0414 airfoil. In both cases, the critical ice accretion location occurs near the area of the most severe pressure recovery (or flow deceleration) for their respective stall AOA. (Note the pressure distributions shown in figure R-17 are for normal operation attitudes.) Visual flow studies reveal the separation bubble that forms downstream of the simulated ice shape on the NACA 23012 airfoil fails to reattach immediately downstream of the ice shape. This is because of the adverse pressure recovery gradient, and results in a much longer separation bubble and a larger loss in maximum lift. Because of the less severe pressure recovery gradient on the NLF 0414 airfoil, the separation bubble is not as long. The resultant maximum lift loss is not as severe as that of the NACA 23012 airfoil.

For drag, the critical ice shape location for the forward-loaded NACA 23012 airfoil correlates with the area of highest local airspeed, not the area of most severe pressure recovery. Figure R-14 shows this. However, the NACA 23012 ice shape location correlation does not apply to the results for the NLF 0414 airfoil, as shown also in figure R-14. For the NLF 0414 airfoil ice shape drag increment, the critical ice shape location suggests a sensitivity of the ice shape boundary-layer disturbance to the ability of the boundary layer to remain well attached during the pressure recovery at the aft part of the airfoil.



NACA 23012m



NLF 0414

Figure R-14. Drag Increase for NACA 23012m and NLF 0414 Airfoils With a 0.25-inch, Forward-Facing, Quarter-Round Simulated Ice Shape Located on the Upper Surface at Various Chord Positions (Re = 1.8×10^6, M = 0.185) (Reference R5).

APPENDIX R. ICE SHAPES (CONTINUED)

The comparison of rime and glaze ice shapes that have about the same mass is another example of how important it is to understand the ice accretion shape's influence on the boundary-layer behavior when determining critical ice shapes. A rime ice leading edge ice shape that conforms with the profile of the surface may effectively improve the surface's camber and aerodynamic performance. The rime may improve the local boundary-layer conditions and increase the lifting chord length. Conversely, the rime ice accretion may also thicken and weaken the boundary layer because of the rime ice roughness. This causes the boundary layer to become turbulent or separated earlier than a contamination-free boundary layer. However, the resulting increased drag and reduced maximum lift will usually be much less than that of a glaze ice shape of similar mass. The glaze ice is usually characterized by upper and lower horns that the airflow and boundary layer must negotiate. In fact, complete separation of the flow often occurs behind the horns. Also, the character of the boundary layer and its wake (for example, turbulence intensity, tendency to remain turbulent, tendency to remain attached or to separate from the surface, and the periodicity of separation from the surface) may vary. These viscous flow effects will vary, depending on:

- Reynolds number;
- The size, shape, and surface roughness of the ice accretion;
- The heights of the ice accretion protuberance and its surface roughness when compared with the surface's characteristic length;
- The boundary-layer characteristics of the uncontaminated surface (that depend on the surface's camber, thickness distribution, surface finish, and aoa); and
- The location of the ice shape.

The boundary-layer effects resulting from the ice accretion typically reveal themselves in a small loss of lift within the normal operating envelope of the aircraft. However, there is a significant loss in maximum lift and a significant decrease in the AOA at which maximum lift occurs (figure R-8). The loss in maximum lift may affect stall-speed margins, maneuverability margins to buffet, and stall warning margins unless maneuvering airspeeds and the stall protection AOA schedules are adjusted. Significant drag increase will occur at operational angles-of-attack. The drag increase will increase with increasing AOA as the aircraft approaches maximum lift. The boundary-layer effects will adversely affect rotary wings and propeller thrusting efficiency. Changes in the contaminated airfoil's pressure loading usually increase the airfoil's nose-down pitching moments (more negative pitch stability). These effects are obvious in figure R-8. The increased negative stability may adversely affect airplane stability and control, stall characteristics, and trim. The boundary layer effects may also adversely affect rotary wing and propeller performance.

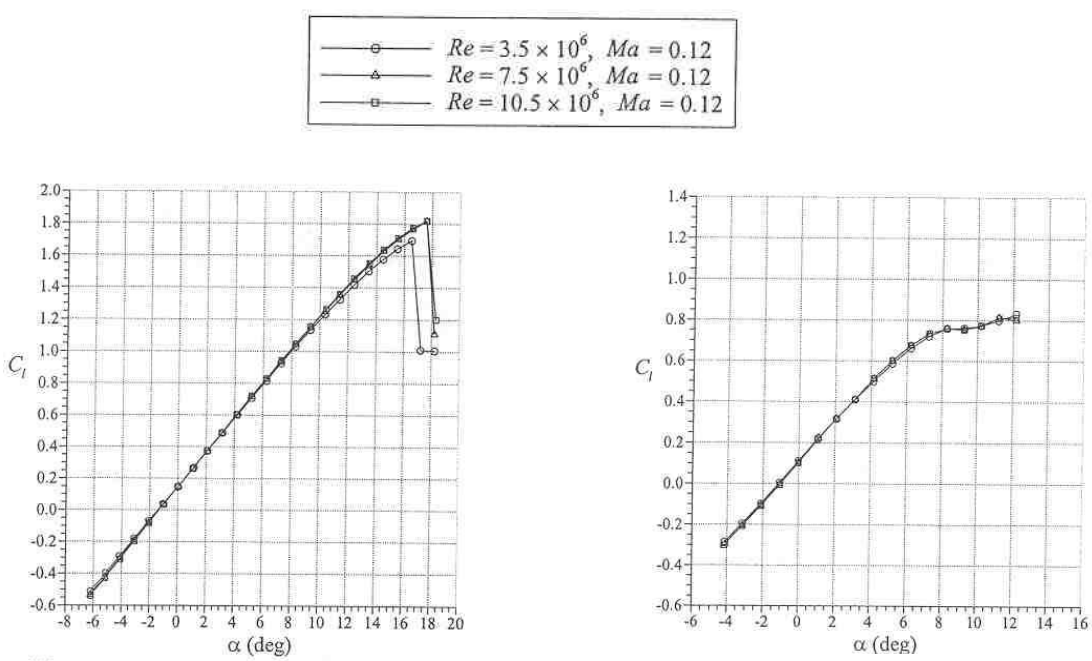
Figure R-15 shows the effects of Reynolds and Mach numbers on the performance of an airfoil with an ice accretion for a 36-inch NACA 23012 airfoil with and without intercycle ice. For the clean airfoil, increasing the Reynolds number favorably influences the behavior of the boundary layer. The boundary layer remains attached to the airfoil at higher angles of

APPENDIX R. ICE SHAPES (CONTINUED)

attack. Also, for the uncontaminated airfoil, the improved boundary-layer behavior reduces drag at higher Reynolds numbers. However, for the airfoil with a simulated ice shape, the Reynolds number effects are much less significant. Figure R-15 shows the effect of Mach number on airfoils with and without the simulated ice shape. Aerodynamic characteristics of contaminated surfaces do not always show large variation with Reynolds number, as shown in figure R-15. Applicants should provide an evaluation of Reynolds number effects when using low Reynolds number testing for the analysis of the aerodynamic effects of ice buildups.

Consider the effects of Mach and Reynolds numbers when determining the critical ice shape for a specific flight safety concern. For example, when comparing the coefficients of lift and drag for clean and contaminated airfoils, Reynolds and Mach numbers significantly affect the aerodynamic differences.

Critical ice shapes may result in reduced control surface authority, hinge moment and control force anomalies, uncommanded control surface movement, and may affect downstream control surface pressure loading. The change in surface pressure loading and periodic separation of the surface airflow may also affect surface vibration and tendencies for surface flutter.

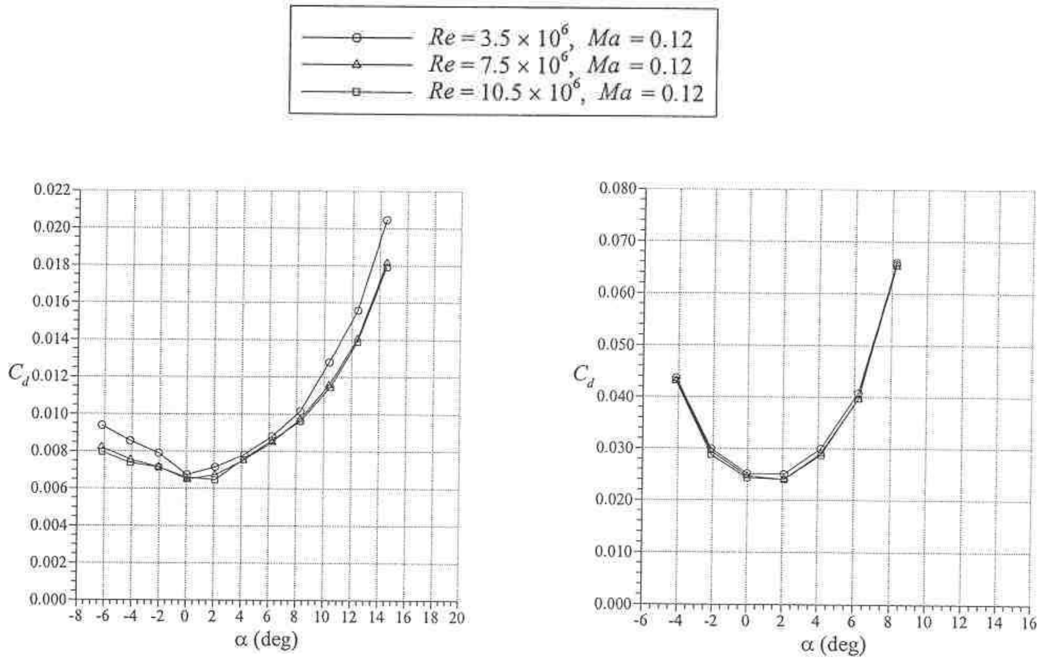


Clean NACA 23012 airfoil

NACA 23012 airfoil with Ice Shape 290 (figure R-5).

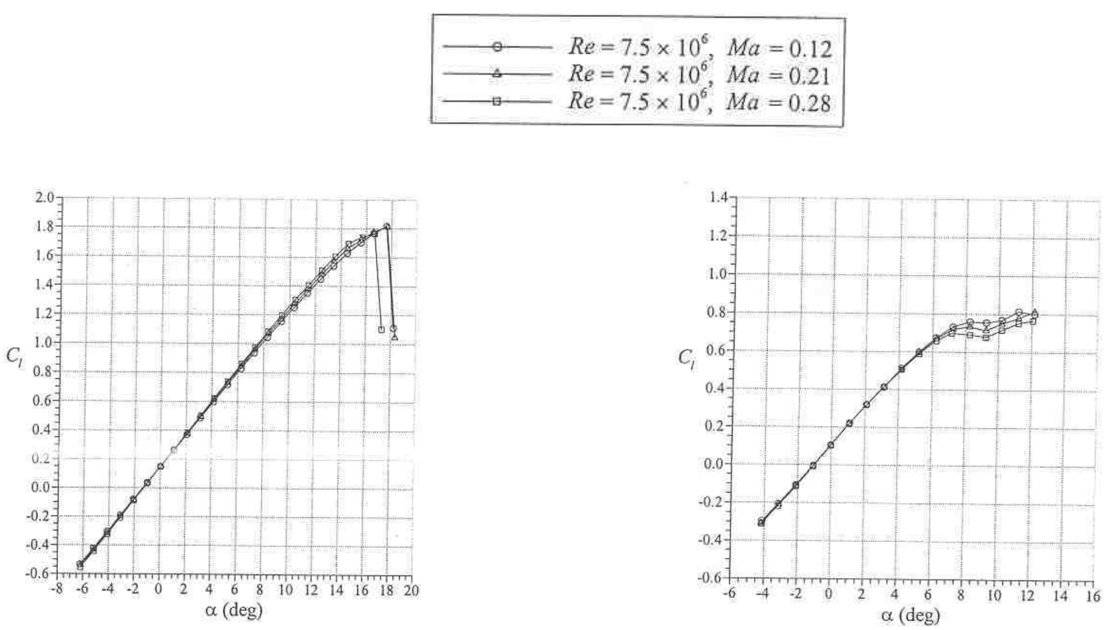
Figure R-15(a). Reynolds number effect on lift for a NACA 23012 airfoil with and without a simulated ice shape.

APPENDIX R. ICE SHAPES (CONTINUED)



Clean NACA 23012 airfoil **NACA 23012 airfoil with Ice Shape 290 (figure R-5)**

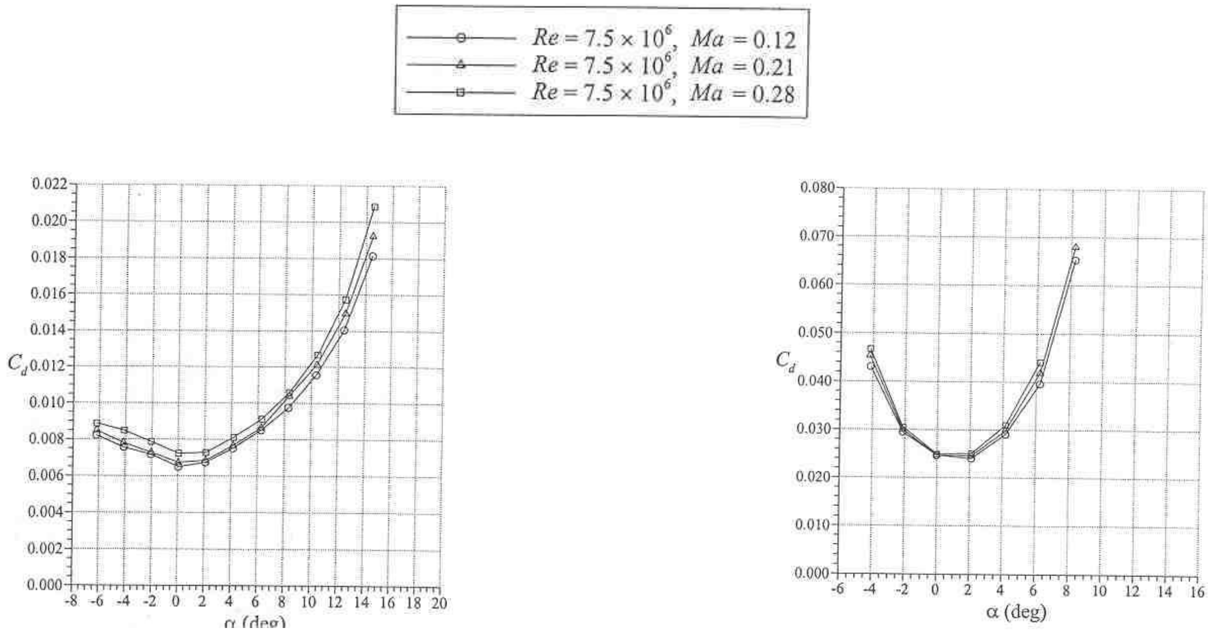
Figure R-15(b). Reynolds number effect on drag for a NACA 23012 airfoil with and without a simulated ice shape.



Clean NACA 23012 airfoil **NACA 23012 airfoil with Ice Shape 290 (figure R-5).**

Figure R-15(c). Mach number effect on lift for a NACA 23012 airfoil with and without a simulate ice shape.

APPENDIX R. ICE SHAPES (CONTINUED)



Clean NACA 23012 airfoil **NACA 23012 airfoil with Ice Shape 290 (figure R-5)**

Figure R-15(d). Mach number effect on drag for a NAC A 23012 airfoil with and without a simulate ice shape.

Figure R-15. Reynolds and Mach Numbers Effects on Lift an d Drag for a NACA 23012 Airfoil With and Without Simulated Ice Shape 290 (Reference R2).

The mass of the critical ice accretion on aerodynamically balanced control surfaces (for example, elevator and aileron horns) may change the effectiveness of the surface's aerodynamic balance and may adversely affect hinge moments and control forces. Ice accretion mass on surfaces may also affect the control surface's tendency to vibrate or flutter.

Empirical aerodynamic data are typically used to determine the effects of critical ice accretions. When used carefully, Navier-Stokes CFD computer codes may provide useful information.

The empirical aerodynamic data used should apply to the surface of interest since the aerodynamic effects of the ice accretion depend on the boundary layer's behavior over the surface and ice accretion. Empirical data are usually recorded for specific surfaces during flight with simulated ice accretions, or in natural icing conditions. You may also use scaled model data from dry air wind tunnels at the proper Reynolds and Mach numbers. You should use these data carefully since reproduction of ice shapes at small scales is difficult and since data corrections beyond test Reynolds and Mach numbers may be required to get results applicable to flight. If you choose to use scale models, you must verify the wind tunnel model's performance adequately matches the performance that would occur at full-scale.

You may also have applicable empirical ice accretion effects data from similar or predecessor aircraft designs. Information available in the technical literature may be applicable. However,

APPENDIX R. ICE SHAPES (CONTINUED)

data examination is necessary to show the data applies to the aircraft design under consideration. Limited flight Reynolds number data is available. A survey of ice accretion effects, drawn from the open literature, and discussions of critical ice shapes are in Reference R6. Also, Reference R7 provides added information on the aerodynamic effects of ice accretions. You may consider the ranking of ice shape features for their adverse aerodynamic effects provided in section R.6 of this appendix when determining critical ice shapes.

You may use verified CFD codes to determine the aerodynamic characteristics of critical ice accretions. Because the air's viscosity highly affects the airflow behavior over the complex ice accretion shapes and roughness, CFD codes based on estimated solutions of the viscous flow Navier-Stokes equations, if carefully used, may provide useful information. Take care to ensure that the gridding of the surface geometry and flow field is acceptable and the wake turbulence models used produce acceptable estimates of the boundary layer behavior and its wake. The behavior of the boundary layer and its wake strongly influence the code's ability to predict maximum lift and drag levels accurately. Viscous flow CFD codes based on Reynolds-Averaged Navier-Stokes (RANS) equations (such as NSU2D and WIND), with enough attention given to gridding of the ice accretion shape and roughness and the flow field, provide good information when there is little or no flow separation on the aircraft (at low angles-of-attack).

However, at attitudes where airflow separation occurs (such as near maximum lift) the RANS codes may not robustly and accurately predict lift, drag, and pitching moments. Various causes contribute to this failure. One of those causes is the inability of RANS codes to capture the vortex shedding physics of airflow separation. This flow separation is of particular interest for complex ice shapes and roughness. Figure R-16 shows this RANS codes limit for an NLF 0414 airfoil with a simulated upper surface ice shape horn. An ice shape that displays insignificant vortex shedding at maximum lift may produce good correlation with empirical data using an RANS code. The code may provide misleading information for other ice shapes that display significant vortex shedding. Figure R-17 shows the periodic vortex shedding predicted by a Detached Eddy Simulation (DES) code for the NLF airfoil. (Reference R8 contains added information about DES codes.) Also, because of the vortex shedding and its effects on the surface pressures, values of lift, drag, and pitching moment may become time-dependent. The code may fail to converge on a solution that provides acceptable time-averaged aerodynamic coefficients.

APPENDIX R. ICE SHAPES (CONTINUED)

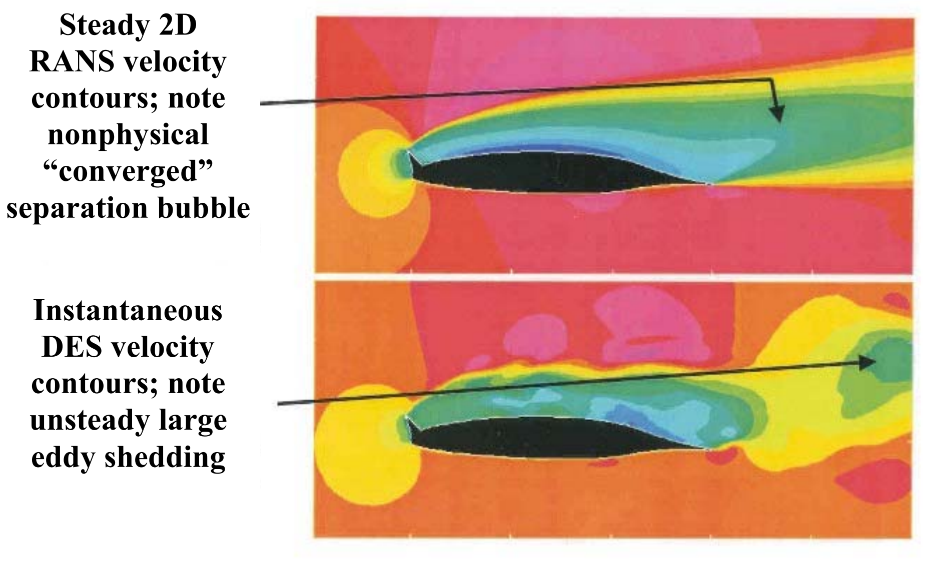


Figure R-16. Comparison of Computed Flow Fields Using Reynolds-Averaged Navier-Stokes (RANS) and Detached Eddy Simulation (DES) Navier-Stokes CFD Codes (NLF 0414 airfoil at an AOA of 7° and a Reynolds number of 1.8×10^6 with a 0.034 k/c simulated ice shape horn) (Reference R8).

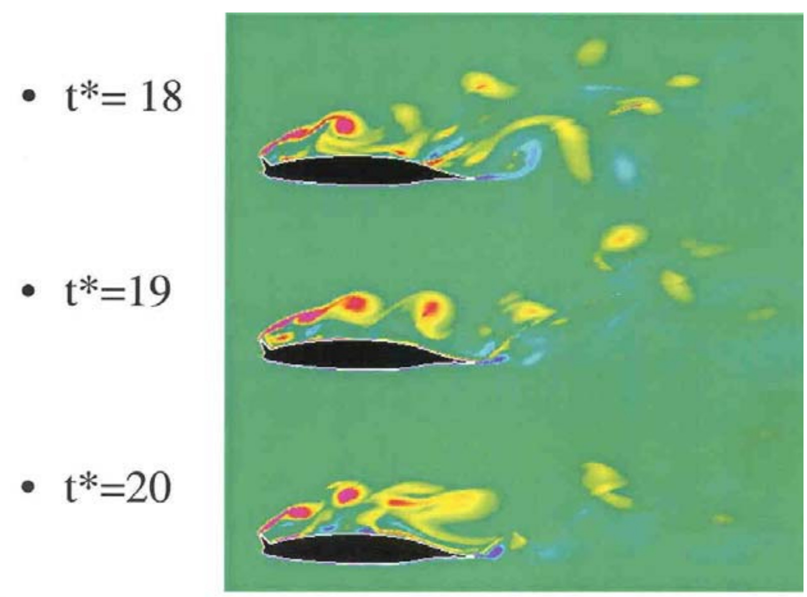


Figure R-17. Time-Dependent Vortex Shedding (Vorticity Contours) From an NLF 0414 Airfoil With a 0.034 k/c Simulated Ice Shape Horn Calculated Using a DES Navier-Stokes CFD Code (Reference R8).

APPENDIX R. ICE SHAPES (CONTINUED)

Flow separation is 3D, with lateral flow movement. This is especially true for surfaces that present significant cross-flow, such as on swept finite wings. The 3D character of flow separation raises questions about the accuracy of 2D Navier-Stokes flow solutions when significant boundary-layer separation exists.

Figure R-18 shows the differences in upper surface flow separation and vortex shedding at the same time instant between 2D and 3D DES Navier-Stokes solutions. This solution is for an 18-inch chord NACA 23012m model with a 0.25-inch, quarter-round simulated ice shape. The ice shape is attached at ten percent of the airfoil's chord. To predict aerodynamic performance confidently near and at maximum lift, you may need to use Direct Numerical Simulation (DNS) Navier-Stokes CFD codes that fully solve the Navier-Stokes equations or Large Eddy Simulation (LES) codes. Reference R9 contains definitions and further discussions on RANS, LES, and DNS Navier-Stokes CFD codes. The cost of carrying out LES or DNS solutions for complex geometry and the need to consider 3D flow effects are high. Perhaps this restricts their use when you are investigating several candidate critical ice shapes. Using DES Navier-Stokes CFD codes (a hybrid between RANS and LES codes) may offer good, cost-effective information, however, these codes have not been fully evaluated for predicting flow behavior for surfaces with ice accretion shapes and roughness (Reference R9).

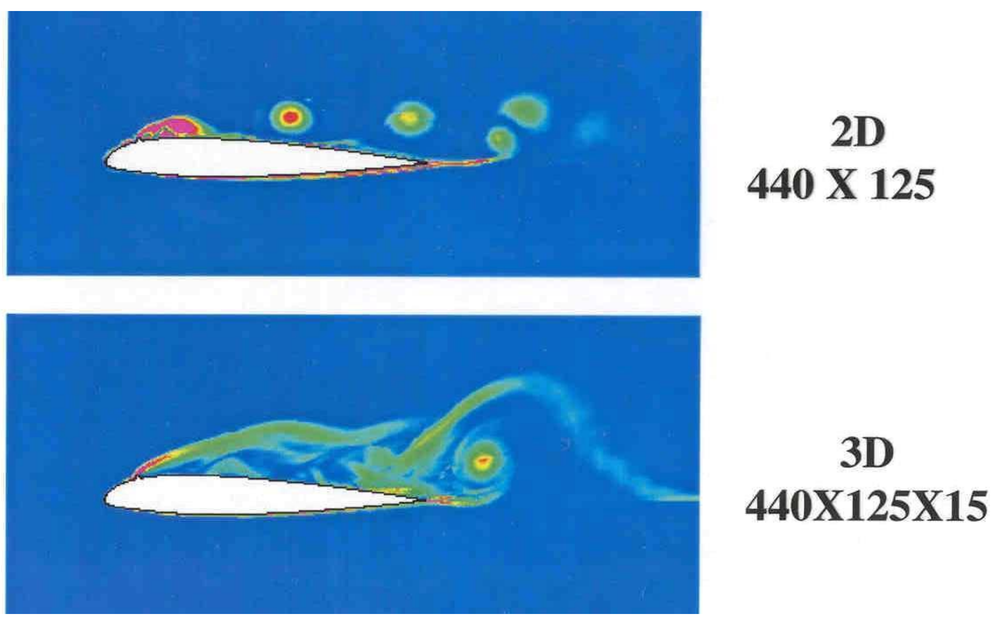


Figure R-18. Vorticit y Contours for 2D and 3D DES Navier-Stokes Computational Fluid Dynamics Code Analysis of the Flow Field Around a NACA 23012m Airfoil With a k/c = 0.0139 Forward-Facing, Quarter-Round Simulated Ice Shape at the Same Time Instant ($Re = 1.8x10^6$) (Reference R8).

APPENDIX R. ICE SHAPES (CONTINUED)

R.5 METHODS FOR DETERMINING (PREDICTING) ICE SHAPES.

R.5.1 Natural Icing Flight Tests.

Applicants may determine critical ice shapes during flight tests in natural icing conditions. You should perform tests for showing that the aircraft can fly safely with natural icing critical ice shapes. This should occur unless means are available to document the natural icing flight tests ice shapes accurately for fabrication and installation of simulated ice shapes. You can then use the aircraft with the simulated ice shapes to assess flying qualities. Issues associated with showing safe flight with natural ice shapes include availability of the icing conditions that produce the critical ice shapes and partial shedding, melting, and sublimation of the ice accretion during flying qualities flight tests.

R.5.2 Use of Icing Tankers to Predict Unprotected Surfaces Ice Shapes.

Applicants may use icing tankers to evaluate critical ice shapes. Icing tankers are useful for complex, 3D surfaces whose ice shapes are difficult to predict with computer codes or other analytical methods. Using icing tankers allows evaluation of ice shapes at full-scale, and without concerns for ice accretion code or icing tunnel limits. The larger drops of tanker icing cloud plumes are considered conservative for applications where a larger and more extensive ice shape is conservative.

You should ensure that the icing tanker, associated instrumentation, and icing plume are calibrated. You should consider the commonly accepted practices, described in SAE ARP5904 (Reference R10), when judging the acceptability of ice shapes from icing tanker flight tests. However, consistency of ice shapes produced by the different icing tankers for a given test article and similar simulated icing conditions is unknown.

R.5.3 Use of Icing Wind Tunnels to Predict Unprotected Surfaces Ice Shapes.

Applicants may use icing wind tunnels to predict critical ice shapes, especially for complex 3D surfaces. Also, you may use icing wind tunnel ice shapes for simple, 2D surfaces to verify ice shapes from computer codes or other analytical methods.

Test full-scale models of aircraft surfaces when possible. Consider immersion of the model in the calibrated test volume of the tunnel, tunnel blockage effects, and tunnel wall effects. The model's geometry should conform to type design drawings. When the full-scale model of the aircraft surface is too large for the icing wind tunnel test section, consider hybrid or scaled models.

You may use the hybrid scaling method for airfoil testing. Hybrid models reproduce the full-scale airfoil or the airfoil's leading edge. The models use a trailing-edge flap to produce the full-scale flow conditions at the model's leading edge (References R11, R12, and R13). This method allows the use of a truncated model that produces less tunnel blockage and the use of full-scale ambient temperature, airspeed, liquid water content, drop size, and icing times. Limits of the

APPENDIX R. ICE SHAPES (CONTINUED)

method include truncation of the model and the need to build several models if a large angle-of-attack (AOA) range is of interest.

You may use the basic Ruff method, or equivalent, for design of scaled icing wind tunnel models (References R14 and R15). This method requires matching:

- The modified icing cloud water drop inertia parameter, K_0;

- The accumulation parameter, A_c; and

- The two energy-balance terms: the freezing fraction, n and, either the water-energy transfer parameter, φ, or the air-energy-transfer parameter, θ, for icing wind tunnels with atmospheric total-pressure test sections.

For pressurized icing wind tunnels, the Ruff method requires you to match all the similarity variables. You can determine the scaled tunnel airspeed by matching either the Weber number (We) or the Reynolds number (Re). Determining the scaled airspeed by holding model-scale and full-scale Weber number (based on leading edge water film thickness) constant and holding the freestream temperature the same have produced good results (References R16 and R17).

The drop sizes involved should not be subject to splashing. You should verify:

- Calibration of the icing tunnel and associated instrumentation;
- Cleaning of spray nozzles using the facility's procedures;
- Consideration of model-mounting effects; and
- Installation of the model within the calibrated test volume of the icing wind tunnel.

(Reference R18 contains information on calibration of icing wind tunnels.) The icing wind tunnel model should conform to the aircraft's TC design. The IPS pressures, temperatures, and electrical current or voltage should account for tolerances.

You may adjust spray times to reproduce the water catch (or the same scaling accumulation parameter A_c) for 14 CFR part 25, Appendix C cloud lengths. A common practice of adjusting spray time to get the same water catch when the target LWC cannot be achieved because of the icing wind tunnel's LWC limits is inappropriate. Varying only LWC results in different values of the scaling freezing fraction parameter, n_0. Scaling of obtainable test icing conditions to get ice shapes for target icing conditions should follow the recommended Ruff method (Reference R14). Evaluate spray times up to 45 minutes. You may have to adjust spray times for the time required for spray bar stabilization. The facility should document this adjustment.

Figure R-19 correlates ice shapes for a 53-cm reference NACA 0012 airfoil model with those for a 27-cm half-scale model. For this test, the icing condition variables of the half model were scaled by holding the full model K_0, A_c, n, ϕ, and We_h constant. The data, produced in the NASA Glenn Research Center Icing Research Tunnel (IRT), are shown for freezing fractions, n, ranging from 1.0 to 0.28. They show the robustness of the scaling for freezing conditions ranging from rime ice to near-glaze ice.

APPENDIX R. ICE SHAPES (CONTINUED)

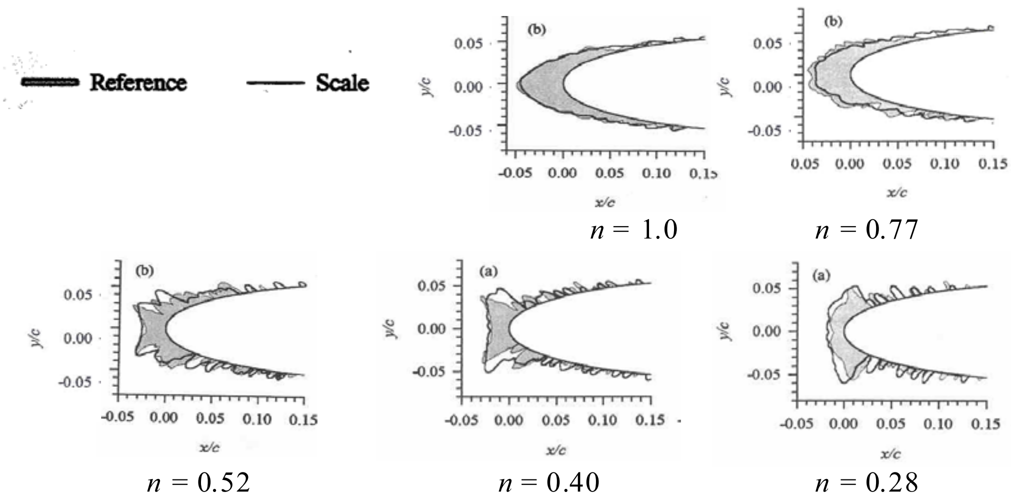


Figure R-19. Correlation of Full-Model (55 cm NACA 0012 Airfoil) and Half-Model Ice Shapes by Holding the Full Model K_0, A_c, n, ϕ, and We_h Constant (Reference R17).

Comparisons between icing wind tunnel and natural-ice simulated ice shapes are limited. However, visual comparisons of the detailed characteristics of 3D wind tunnel (NASA IRT) and natural-ice ice accretions on a 30º swept wing model, shown in figure R-20, provide confidence in using IRT ice shapes for the icing conditions evaluated (Reference R19). You should consider conformance with SAE ARP5905 (Reference R18) when judging the acceptability of icing wind tunnel ice shapes. The SAE AC-9C Subcommittee is evaluating the consistency of ice shapes produced by different icing wind tunnels for a given test article.

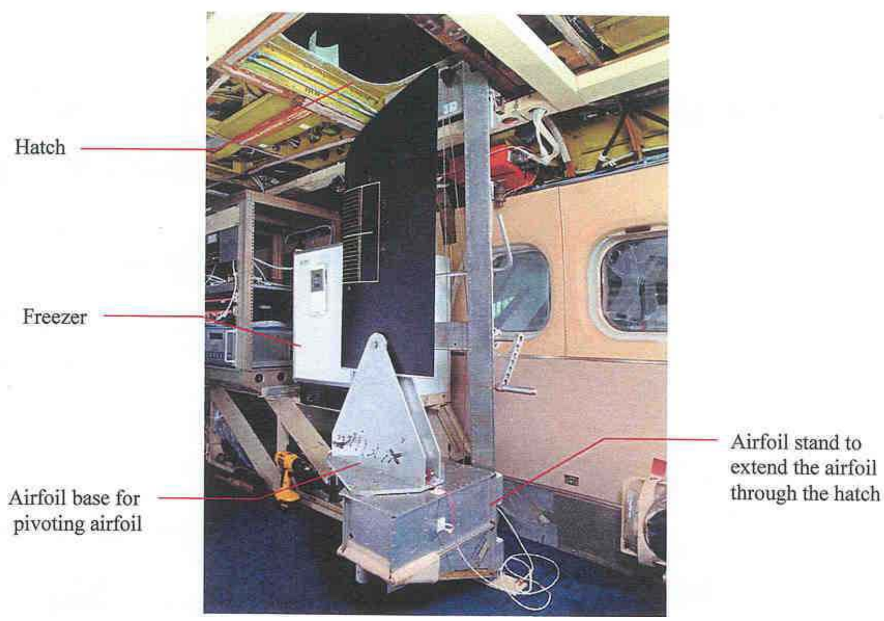


Figure R-20(a). View of the NACA 0012 swept wing model inside the NASA Glenn Research Center Icing Research Aircraft (DHC-6 Twin Otter).

APPENDIX R. ICE SHAPES (CONTINUED)

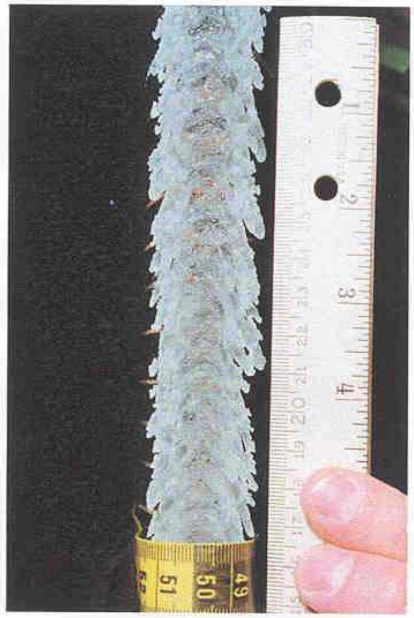


Figure R-20(b). Natural-ice ice accretion (scalloped) obtained with the NASA-GRC Twin Otter (Λ=30º, V=144 mph, T=21ºF, LWC=0.45 g/m^3, MVD=13 µm, t=8 min.

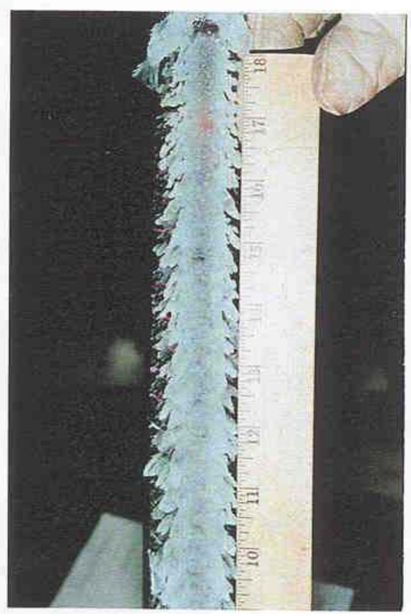


Figure R-20(c). Artificial-ice accretion (scalloped) obtained in the NASA-GRC IRT (Λ=30º, V=150 mph, T=25ºF, LWC=0.5 g/m^3, MVD=20 µm, t=10 min.

Figure R-20. Comparison of Natural and Icing Wind Tunnel Ice Shapes (Reference R19).

APPENDIX R. ICE SHAPES (CONTINUED)

R.5.4 Drop Impingement and Ice Accretion Computer Codes and Other Analytical Methods.

Applicants may use verified computer codes and analytical methods to predict ice shapes. The predicted ice shape is the result of calculations that define the flowfield, the drop trajectories, water loading, and the ice accretion physics. Many icing codes are available. They differ to varying degrees in their manner of modeling the ice accretion process. SAE ARP5903 (Reference R20) provides information that describes several available drop impingement and ice accretion codes.

Confidence in 2D icing codes to predict ice shapes accurately is mixed when their results are compared with icing wind tunnel ice. Figures R-21 through R-24 show reasons for this mixed confidence. The figures compare ice shapes predicted by several icing codes with those produced in two icing wind tunnels. The data from Reference R21 show that even at colder, rime ice conditions, where confidence in predicted ice shapes is highest, there are significant differences between predicted and empirical ice shapes.

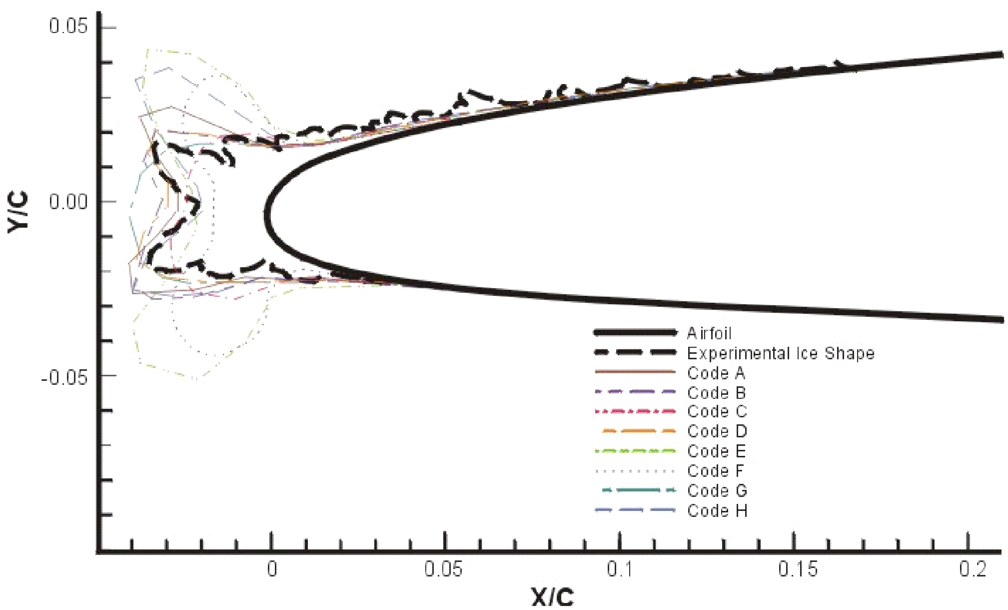


Figure R-21. Comparison of Drop Impingement and Ice Accretion Code Results With Experimental Ice Accretion Produced in the NASA IRT (V = 135.8 kts, T_S = -15.8°C, LWC = 1.16 g/m^3, MVD = 50.0 µm, icing duration = 517.1 s, GLC305-836-23 airfoil model chord = 0.9144 m) (Reference R21).

APPENDIX R. ICE SHAPES (CONTINUED)

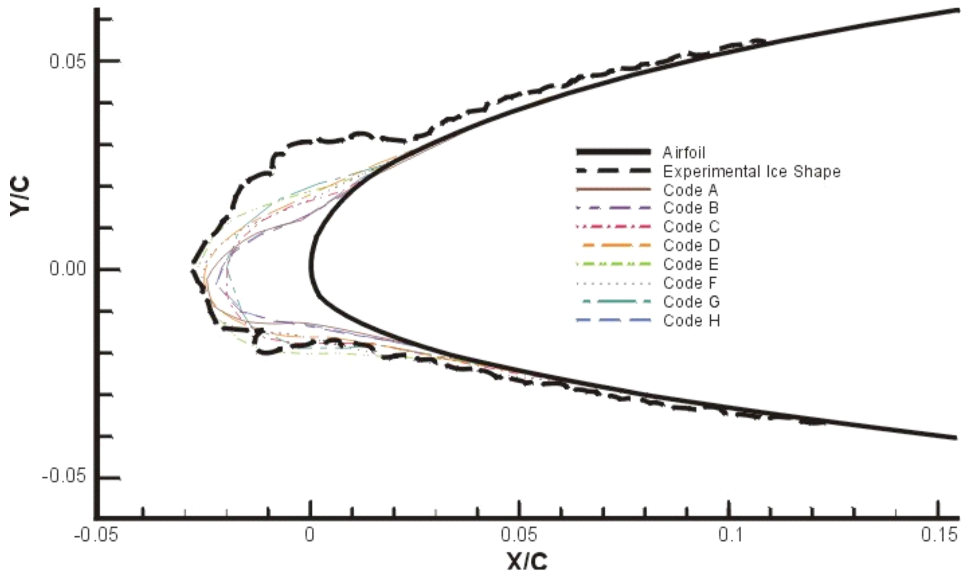


Figure R-22. Comparison of Drop Impingement and Ice Accretion Code Results With Experimental Ice Accretion Produced in the NASA IRT (V = 179.8 kts, T_S = -15.6°C, LWC = 0.33 g/m^3, MVD = 20.0 µm, icing duration = 1224.0 s, NLF0414-611 airfoil model chord = 0.9144 m) (Reference R21).

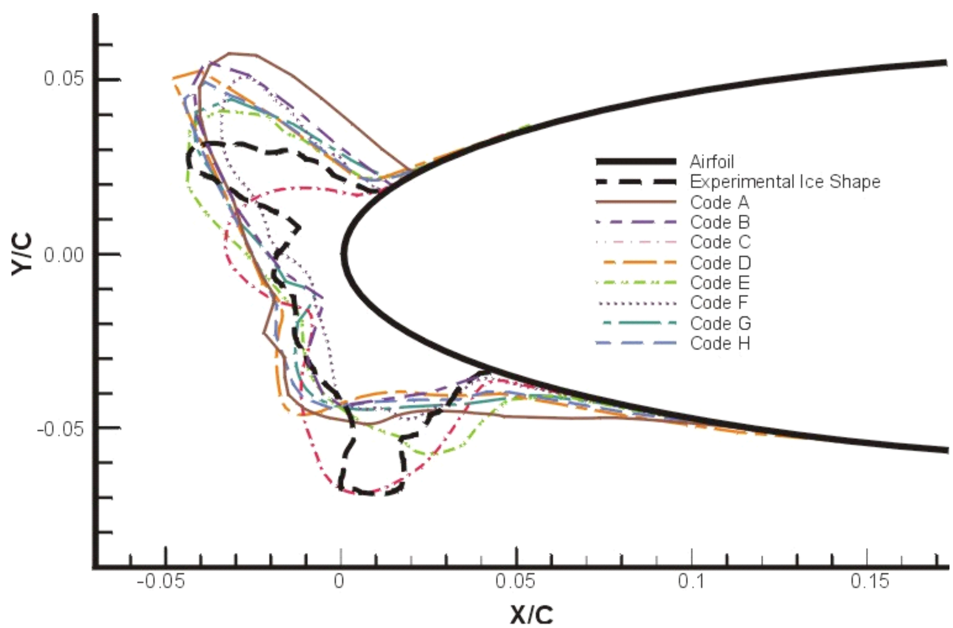


Figure R-23. Comparison of Drop Impingement and Ice Accretion Code Results With Experimental Ice Accretion Produced in the Boeing Research Aerodynamic and Icing Wind Tunnel (V = 130.2 kts, T_S = -7.2°C, LWC = 1.0 g/m^3, MVD = 24.8 µm, icing duration = 1200.0 s, airfoil model chord = 0.914 m) (Reference R21).

APPENDIX R. ICE SHAPES (CONTINUED)

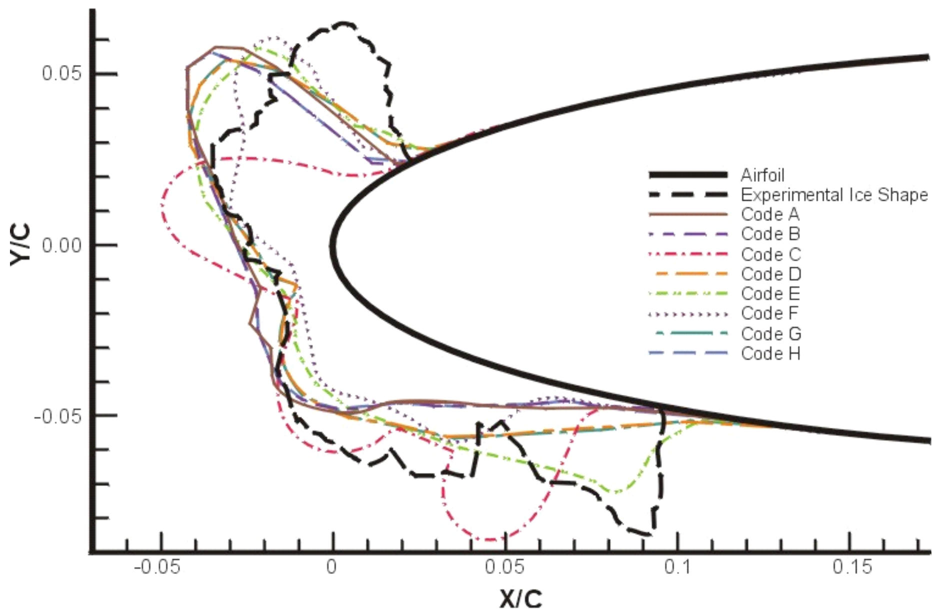


Figure R-24. Comparison of Drop Impingement and Ice Accretion Code Results With Experimental Ice Accretion Produced in the Boeing Research Aerodynamic and Icing Wind Tunnel (V = 130.2 kts, TS = -7.2°C, LWC = 1.0 g/m^3, MVD = 38.8 µm, icing duration = 1200.0 s, airfoil model chord = 0.914 m) (Reference R21).

Ice accretion codes with 3D flow field and drop trajectory abilities, coupled to a 2D ice accretion calculation, have been developed to predict 3D ice shapes. The experimental ice shape data available for verifying these pseudo 3D ice accretion codes is limited. Therefore, confidence in these ice accretion codes is limited. Also, none of the codes predict the periodic “scalloped” or “lobster tail” ice shapes that develop from ice feathers on swept wings.

Many considerations contribute to the acceptability of icing codes. These include:

- Selecting an icing code that has been developed to address the application of interest.
- Verification of the code for the application.
- Administration of the code software (including software control and suitable documentation).
- The skill of the user.

Useful information on judging the acceptability of icing codes is in SAE ARP5903 (Reference R20).

As discussed above, confidence in the accuracy of ice accretion codes is mixed. You should evaluate ice accretion code ice shapes conservatively for their ability to ensure safe flight in icing conditions. When compared with referenced (experimental) ice shapes, conservative results

APPENDIX R. ICE SHAPES (CONTINUED)

from calculated ice shapes will show more adverse effects on aircraft handling qualities and performance (section R.4 of this appendix). You should show that ice shapes selected from icing codes and analytical methods are conservative. You should also evaluate the effects on aircraft handling, performance, structural vibration, ice shedding, and airflow disturbance affecting downstream components and systems. Such information may be difficult to produce without providing a suitable ice shape for reference. This may result in the need to verify the calculated ice shape with an empirically determined ice shape (preferably from natural icing flight tests).

R.5.5 Prediction of Landing Gear and Strut Ice Shapes.

Applicants may conservatively estimate or use artificial (tanker) icing tests to determine ice shapes for the landing gear.

R.5.6 Prediction of Protected Surfaces Ice Shapes.

Applicants may use full-scale natural icing flight test or simulated icing tests (tankers and icing wind tunnels) to determine ice buildups on protected surfaces, such as intercycle ice for deicers (sections R.5.1, R.5.2, and R.5.3 of this appendix). You may test full-scale protected surfaces in icing wind tunnels using the hybrid-model method if the IPS conforms with the aircraft's type design. Compare time histories of pressure or temperature increases during activation to the aircraft. With pneumatic deicing boots, this may require adding air volume in the system test set-up. The test should include longer times in Continuous Maximum conditions to evaluate the stability and cyclic nature of intercycle and residual ice. Certain unique design features (for example stall strips mounted on deicing boots) may not readily shed ice.

Confidence has not been shown for the use of scaled models with scaled IPSs to predict intercycle ice, runback ice, and to evaluate other ice protection design considerations.

R.6 CORRELATION OF PREDICTED (SIMULATED) AND NATURAL ICE SHAPES.

To verify safe flight in icing conditions, compare the flying qualities of the aircraft with simulated critical ice shapes to those of the aircraft with natural ice shapes. Comparison of the simulated ice testing with that in natural icing may be difficult and require engineering judgment. There may be a limited amount of quantitative flight characteristic data available for comparing the natural and simulated ice shape test results. Natural icing conditions are variable, especially during lengthy exposures or during a series of brief exposures required to build up the desired ice thickness. Close examination of the resulting natural ice shapes on the flight test aircraft is often impractical. The icing conditions used to determine the simulated ice shapes may not match the natural icing conditions encountered. The simulated ice shapes also may reflect a composite of critical ice shape considerations (such as horn length, location, angle, and mass). Natural icing tests, however, are required to provide overall checks of the aircraft's safe flight in icing conditions, IPS analyses, simulated ice shape analyses, and unforeseen icing anomalies. Aircraft performance and handling qualities shown during natural icing flight tests should be equivalent to or less affected by ice accretion than those shown with the simulated ice shapes.

APPENDIX R. ICE SHAPES (CONTINUED)

Applicants may use the lists of ice shape and water catch evaluation parameters in tables R-1 and R-2, ranked against their adverse airplane effects, to compare simulated and natural ice shapes. These lists are from SAE ARP5903 (Reference R20).

Table R-1. Ranking of Ice Shape Evaluation Parameters

Rank	Parameter	Units	Conservatism Criteria
1	Upper (suction surface) horn height	-	Equal or greater horn peak thickness (height)
2	Upper Horn Angle	Degrees	Criticality of location (at upper peak thickness)
3	Lower (pressure surface) height	-	Equal or greater horn peak thickness (height)
4	Lower Horn Angle	Degrees	Criticality of location (at lower max. thickness)
5	Total ice cross-sectional area	-	Equal or greater area
6	Leading edge minimum thickness	-	Equal or smaller thickness
7	Upper accretion limit	% x/c*	Equal or greater x/c
8	Lower accretion limit	% x/c*	Equal or greater x/c

NOTE: The first four parameters assume that icing horns exist. This is not always the case.

* Percent of local component chord

Table R-2. Ranking of Water Catch Evaluation Parameters

Rank	Parameter	Units	Conservatism Criteria.
1	Upper impingement limit (suction surface)	% x/c*	Equal or greater x/c
2	Lower impingement limit (pressure surface)	% x/c*	Equal or greater x/c
3	Total water catch efficiency, E	-	Equal or greater magnitude
4	Maximum local water catch magnitude	-	Equal or greater efficiency, βmax
5	Water catch efficiency (Beta) curve	-	Equal or more adverse β distribution

* Percent of local component chord

Reasons why ice shapes produced by various icing wind tunnels, computer codes, and other analytical methods may vary include:

- Calibration of the icing wind tunnel.
- The uniformity and qualities of the tunnel's flow and icing cloud.
- Other tunnel testing considerations.

Reasons why ice shapes produced by various ice accretion computer codes, and other analytical methods, vary include:

- Differing algorithms and assumptions used in the computer codes and analytical methods.

- The use of various computer code versions and inputs.

- The use of empirical ice shapes from different sources to "tune" computer codes and other analytical methods (to account for unknown icing physics and other effects).

APPENDIX R. ICE SHAPES (CONTINUED)

Once you have satisfactory correlations between icing wind tunnel, computer codes, and analytical methods with the verification database, use version control of these simulation ice shape methods to keep confidence in the correlation. Understanding the limits of the correlation requires engineering judgment. For example, a correlation may continue for changes in a single-element airfoil's thickness, thickness distribution, and camber. But, you should question applying a correlation for a single element airfoil to a multielement airfoil. Also, a correlation for 2D airfoils may not apply for 3D surfaces.

R.7 REFERENCES.

R1. **"A Study of Inter-cycle, Residual, and Preactivation Ice,"** Riley, J. T., et al., AIAA-2001-0089, 39th AIAA Aerospace Sciences Meeting and Exhibit, January 8-11, 2001, Reno, Nevada.

R2. **"Effect of Intercycle Ice Accretions on Airfoil Performance,"** Broeren, A.Pl, Addy, H.E. Jr., and Bragg, M.B., AIAA-2002-0240.

R3. **"NPA 25F-219; Flight Characteristics in Icing Conditions,"** Joint Aviation Authorities Letter JAA/SEC/3-9-2, dated 23 April 1993.

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R5. **"Effects of Large-Droplet Ice Accretion on Airfoil and Wing Aerodynamics and Control,"** Bragg, Michael B. and Loth, Eric, Aeronautical and Astronautical Engineering, University of Illinois at Urbana-Champaign, August 16, 1999.

R6. **"Report of the 12A Working Group on Determination of Critical Ice Shapes for the Certification of Aircraft,"** FAA Report Number DOT/FAA/AR-00/37, Office of Aviation Research, Washington, D.C. 20591.

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R10. **"Airborne Icing Tankers,"** SAE ARP5904.

R11. von Glahn, U.H **., "Use of Truncated Flapped Airfoils for Impingement and Icing Tests of Full-Scale Leading-Edge Sections,"** NACA RM E56E11, July 1956.

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R13. Saeed, F., Se lig, M.S., and Bragg, M.B., **"Experimental Validation of the Hybrid Airfoil Design Procedure for Full-Scale Ice Accretion Simulation,"** AIAA-98-0199, January 1998.

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R15. Anderson, D.N., **"Manual of Scaling Methods,"** Ohio Aerospace Institute (to be published).

R16. Anderson, D.N., **"Effect of Velocity in Icing Scaling Tests,"** AIAA-2000-0236, January 2000.

R17. Kind, R.J., **"Assessment of Importance of Water-Film Parameters for Scaling of Glaze Icing,"** AIAA-2001-0835, January 2001.

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R19. **"Ice Accretion Formations on a NACA 0012 Swept Wing Tip in Natural Icing Conditions,"** Vargas, M., Giriunas, J.A., and Ratvasky, T.P., AIAA-2002-0244.

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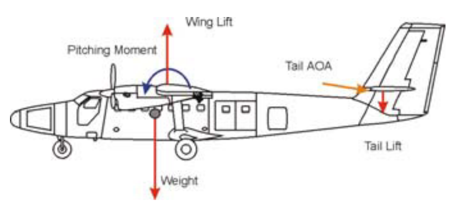
R21. " **Ice Accretion Simulation Evaluation Test**," NATO RTO Technical Report TR-038, November 2001.

APPENIDX S. ICE-CONTAMINATED HORIZONTAL STABILIZER (TAILPLANE) STALL

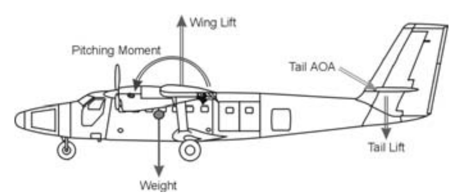
S.1 ICE-CONTAMINATED HORIZONTAL STABILIZER (TAILPLANE) STALL.

As discussed in section 6.1, of this AC, safe flight of airplanes in icing conditions requires compliance with 14 CFR §§ 23.143 and 25.143. Many accidents have resulted from stalling of an ice-contaminated horizontal tail. This phenomenon is commonly called ice-contaminated tailplane stall (ICTS). The accidents typically occur during the approach phase of flight with the wing flaps extended.

The horizontal tailplane produces down-lift to balance the pitching moment created between the wing lift and the center of gravity, as shown in figure S-1. The down-lift required by the horizontal tail to balance the pitching moments varies with the airplane flap configuration and flight condition (thrust and airspeed (angle-of-attack (AOA))). When extending the flaps, the wing center of lift moves further aft of the center of gravity. This results in increased nose-down pitching moment (figure S-1). Also, the extended wing flap increases the wing camber, resulting in an increased wing lift for a given AOA and an increased circulation of chordwise airflow around the wing. The flight condition also has an effect on the pitching moment. Decreasing airspeed (increasing aircraft AOA) requires an increase in tail down-lift. Increasing the thrust may also affect the pitching moment. This depends on the position of the thrust line with the center of gravity. All of these effects require an increase in the tail down-lift to balance the airplane in the pitch axis.



Cruise Configuration



Trailing Edge Flaps Extended

Figure S-1. Airplane Forces and Pitching Moments.

An increase in the AOA at the tailplane or deflecting the elevator position to modulate the tail down-lift balances the moments in the pitch axis. The wing trailing edge flap position strongly affects the AOA at the tailplane. Extending the trailing-edge flaps significantly increases the downwash at the tailplane. This increased downwash increases the tailplane's AOA. The increase in the AOA at the tailplane effectively increases the tail down-lift. A trimmable horizontal stabilizer can compensate for the change in the tailplane's AOA. Otherwise, deflecting the elevator trailing-edge up can provide the down-lift required for balance.

The tail down-lift requirements remain the same when ice builds up on the horizontal tail. However, the aerodynamic effects of the ice buildup degrade the ability of the horizontal tail to produce the down-lift. Figure S-2 shows that light roughness, such as that resulting from thin ice accretion on the leading edge of a horizontal stabilizer, may cause the horizontal tail to stall at a lower AOA (when compared with the uncontaminated tail). Flight-testing with 'sandpaper' ice shows that the light roughness can be more severe than the larger critical ice shapes on some aircraft. Applicants should evaluate the acceptability of using the sandpaper ice during the certification program. Wind tunnel testing of a 36-inch NACA 23012 airfoil at a Reynolds number of $7.5x10^6$, as shown in figure R-8, points out that intercycle ice surface roughness may be more adverse than sandpaper ice.

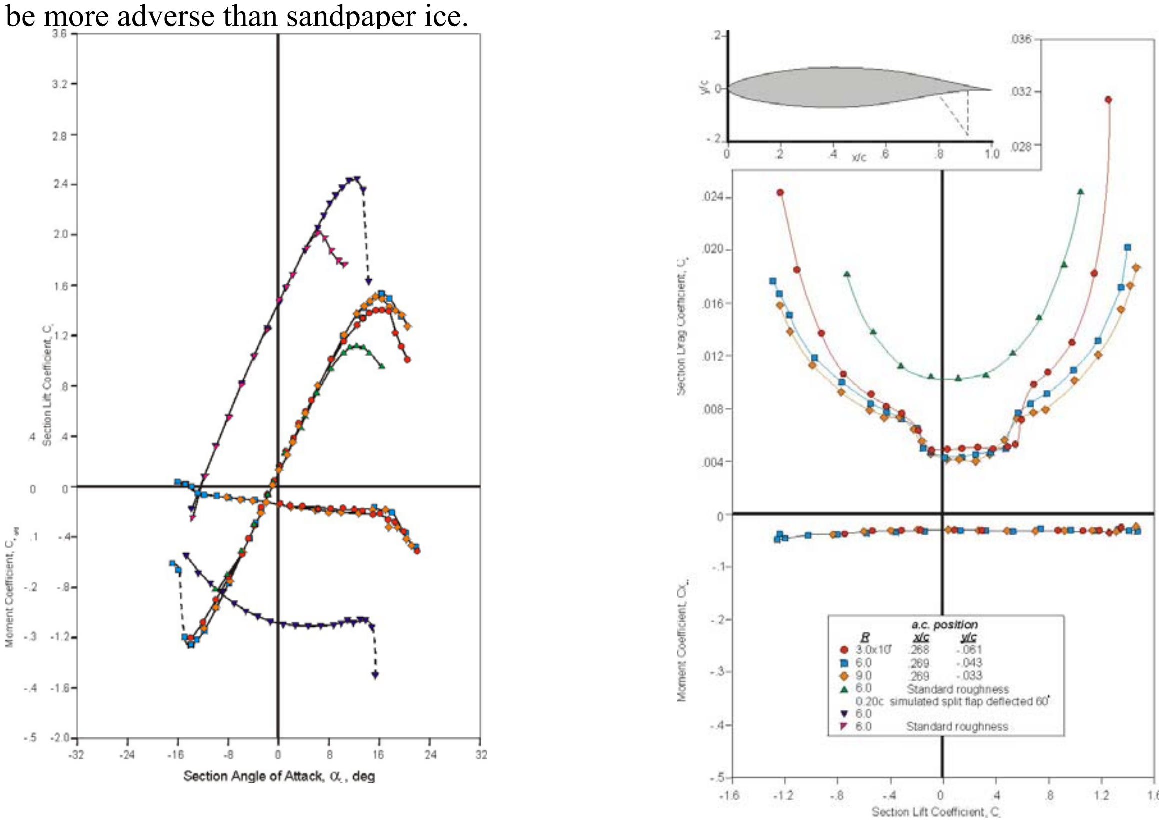


Figure S-2. Aerodynamic Effects of Standard Roughness (0.011-inch Carborundum Grains) for a NACA 652-215 Airfoil. (The Carborundum grains were uniformly distributed at a density of 5 to 10 percent of the area that extended from the airfoil's leading edge to 0.08c of the 24-inch model.) (Reference S1).

In ICTS, the flow separation of interest typically starts at the leading edge and progresses aft over the lower surface of the tailplane to some line where the flow reattaches. As the AOA increases, the line-of-reattachment moves further aft. If the flow separation moves aft to the elevator control surface, a significant hinge moment in the trailing edge down direction occurs because of redistributed pressures on the elevator. If this occurs with an unboosted elevator control system, the increased hinge moment may snatch the control column forward from the pilot and require significant pilot strength to oppose. The elevator will automatically deflect trailing edge down until the hinge moment reaches zero (as the air loading moments balance on elevator's upper and lower surfaces). This reduces the pitch controllability and stability.

ICTS occurs when the iced stall AOA is exceeded. The tail stall AOA may vary with different ice shapes. The primary driver for increasing the AOA at the tail is the wing trailing-edge flap as discussed above. However, other reasons that can lead to exceeding the iced tail stall angle are nose-down pitch motion (to capture a glide slope), reduced airplane AOA to increase airspeed, wind gusts, and changes in engine power. The local flow interactions emanating from the

APPENDIX S. ICE-CONTAMINATED HORIZONTAL STABILIZER (TAILPLANE) STALL (CONTINUED)

juncture of the horizontal and vertical stabilizers for cruciform and T-tail designs may adversely affect the airflow around the tailplane during high sideslip maneuvers.

Accidents caused by ICTS have occurred when the airplanes were on approach and at low altitude. Flight near the ground does not allow much time for the crew to distinguish between a wing stall and tail stall. Subsequently, the crew will not be able to perform the proper piloting technique to recover control of the airplane. If ICTS occurs, the pilot technique to recover control is to reduce the AOA at the tailplane by raising the flaps and pulling back on the control column to raise the nose.

You should consider the aerodynamic effects of ice-contaminated horizontal stabilizers for all airplanes. This includes those with tab driven controls and those with powered controls. You should perform an evaluation to determine if this unsafe flight condition is likely to occur. Airplanes susceptible to this phenomenon are those that have little or no margins to stall with uncontaminated horizontal stabilizers. ACs 23.143-1 and 25-7A provide acceptable flight test procedures for determining the susceptibility of an airplane to ice contaminated tail stall. AC 23.1419-2C and AC 25-1419-1 provide more guidance on this subject.

S.2 REFERENCES.

S1. **"Theory of Wing Sections,"** Abbot, Ira H. and Von Doenhoff, Albert E., Dover Publications, Inc., 180 Varick Street, New York, N.Y., 10014, 1959, p. 626-627.

APPENIDX T. SIMULATED ICING FLIGHT TESTS: ICING TANKERS AND SPRAY RIG TESTS

T.1 ICING TANKER TESTS.

Simulated icing conditions developed by icing tankers have been used successfully to check analyses required for showing regulatory compliance. These simulated icing methods have provided drop impingement information, checks on and information to develop simulated ice shapes, heat transfer measurements, and ice-shedding information. Applicants may use icing tanker test information to check small-scale tunnel test results. You may also use this information to extend natural icing tests results to icing not found during natural icing flight tests. You must show that the results are both accurate and conservative. Icing tankers, especially those that have hydraulically aspirated nozzles, may not reproduce all the icing conditions in 14 CFR parts 25, Appendix C and 29, Appendix C (Reference T1).

T.2 SPRAY RIG TESTS.

Applicants may install spray rigs on their aircraft to evaluate the icing characteristics of some surfaces. Some of the limits that apply to tanker tests also apply to spray rig tests. Test rigs of this nature are expensive to develop and install on test aircraft. An advantage of this testing is the ability to control the distance between the spray rig and the test surface. You should ensure that the drop transit time is long enough for the drops to become supercooled.

The major disadvantage of this method is that the aerodynamic disturbance caused by the spray rig may disrupt the flow field around the test surface. This feature may produce unrealistic impingement characteristics that are difficult to evaluate. You may need to perform studies, such as wind tunnel tests, to ensure that the spray rig does not aerodynamically affect the surface ice buildup. The size and weight limits of the spray rig also limit the area that can be sprayed. Because of these limits, small spray rigs are typically not used for certification. This does not eliminate the use of this test method as a development tool for evaluating the icing of small surfaces.

T.3 REFERENCES.

T1. **"Airborne Icing Tankers,"** SAE ARP5904.

APPENIDX U. ICING WIND TUNNEL TESTS

U.1 ICING WIND TUNNEL TESTS.

Several types of wind tunnel designs (including closed and open loop, refrigerated and atmospherically cooled) have the ability to simulate icing conditions. These facilities have the ability to produce controlled, steady state plumes of supercooled water drops for a range of temperatures, LWC, drop size, and airspeeds to simulate various icing conditions. They allow access to examine ice accretions and to measure IPS performance accurately. Instrumentation for measuring the icing cloud is more extensive and accurate than flight test instrumentation. Also, the icing wind tunnel provides direct control of the icing conditions. The icing tunnel should be in calibration, following the practices described in SAE ARP5905 (Reference U1). Consider SAE ARP5905 when judging the acceptability of information obtained in icing wind tunnels. The disadvantages of ice tunnel tests are their limited size, their inability to simulate altitude effects (except the CIRA IWT), and their inability to simulate the variability of natural icing conditions.

Most tunnels are small when compared with the full-scale test articles. For models of large articles having tunnel blockage of about 10 percent or more, getting accurate aerodynamic and thermodynamic similarity may be difficult. Applicants should also address wind tunnel flow characteristics, icing plume uniformity, wall effects, model effects, model support, and model scaling issues. Perform dimensional analyses of the aerodynamic and thermodynamic parameters that characterize the full-size article before conducting a small-scale model test. Use this information to ensure similarities between the full-scale article and small-scale model, including considerations of Reynolds and Weber numbers. Also, you should perform error analyses to ensure that test results are useful after considering expected experimental errors. Appendix I and appendix R, section R.5.3 of this AC contain more information on using scaled models for drop impingement and ice shape investigations. You can determine full-scale data from natural icing flight tests, dry air flight tests, spray rig tests, tanker tests, or a combination of these tests.

Design test conditions and models to ensure that Reynolds number and other scaling parameters are close to full-scale values. You should mount your test models to simulate the flight attitude associated with the most critical condition. If you use flaps or other devices to produce the proper flow field conditions, provide instrumentation to show that test and full-scale design parameters agree. Liquid IPSs tested in an icing wind tunnel should prevent ice formation on the protected surfaces at the design fluid flow-rate.

U.2 REFERENCES.

U1. **"Calibration and Acceptance of Icing Wind Tunnels,"** SAE ARP5905.

APPENIDX V. AIRCRAFT FROST AND CLEAR ICE CONSIDERATIONS

V.1 AIRCRAFT FROST AND CLEAR ICE CONSIDERATIONS.

Frost is a form of ice and can adversely affect aircraft handling qualities and performance. Frost forms on aircraft surfaces if the surface temperature is below the surrounding dew and freezing points (resulting in condensation and freezing of the moisture on the surface). Frost commonly forms on aircraft parked outside overnight, even when surrounding temperatures may be above freezing. This is because the aircraft surfaces may radiate heat to the atmosphere and become cooler than the surrounding air. Also the aircraft's surface temperature rise may lag that of the surrounding air because of the thermal mass of the aircraft. Aircraft surfaces exposed to sunlight will have a temperature rise because of radiant heating and may not form frost. Surfaces protected from the sunlight may have frost during subfreezing ambient temperatures. Frost may occur in different crystalline formations that range from a thin, fairly smooth coating to a thick, granular, rough coating, such as hoarfrost. Thick hoarfrost may blot out painted marking on fuselages.

Fuel at subfreezing temperatures may result in frost formation or clear ice on aircraft surfaces. Subfreezing fuel stored in wing fuel tanks may result in frost or clear ice on the upper or lower surfaces (or both) of the wing spar-box, or the spar-boxes of empennage surfaces if fuel is stored in the vertical or horizontal stabilizer. Typically this frost or clear ice occurs during descent or after landing with fuel that had been cold-soaked during cruise. Clear ice and frost resulting from cold-soaked fuel may occur even in warm, tropical conditions, especially during periods of high humidity. It may occur in rain, drizzle, or fog at temperatures above freezing. Clear ice is difficult to detect. It may shed and be ingested into the engines for some aircraft designs or it may shed and cause damage to the aircraft. Engine ingestion of undetected clear ice and failure to remove frost from aircraft lifting surfaces have resulted in catastrophic accidents.

Failure to remove frost from the wing results in increased stall speeds and drag. Maximum lift may be reduced by 20 to 30 percent and stall speed margins at takeoff safety speeds may be significantly reduced. Increased drag from frost will reduce the rate-of-climb during takeoff. This loss of climb ability is significant following an engine failure. Hard wing airplanes (wings without leading-edge, high-lift devices) may show large adverse effects on handling qualities, stall warning and stall protection, and performance because of frost and clear ice surface roughness on the wing's leading edge. (Handling qualities and performance of these airplanes may also be sensitive to in-service loss of wing-leading-edge surface smoothness and leading edge surface roughness caused by insect carcasses). To provide a margin of safety for this class of airplanes, consider over-speed takeoffs and adjustments to stall warning and stall protection schedules during conditions conducive to frost and clear ice.

No person may takeoff an aircraft when frost, ice, or snow is adhering to the wings, control surfaces, propellers, engine inlets, or other critical surface of the aircraft (14 CFR §§ 91.527, 121.629, 125.221, and 135.227). The Administrator may authorize takeoffs with lower wing surface frost around the fuel tanks (14 CFR § 121.629(b)). Underwing frost typically results in increased drag and has little or no adverse effects on stall speed. Fuselage frost to a thickness that does not blot out painted markings may be acceptable. Applicants should show that the

APPENDIX V. AIRCRAFT FROST AND CLEAR ICE CONSIDERATIONS (CONTINUED)

effects of under-wing frost on airplane performance and handling qualities are insignificant. You should provide suitable airplane performance information in the AFM. Frost may occur on the upper surface for some airplane designs. Takeoffs with frost on the wings or control surfaces are allowed if "that frost has been polished to make it smooth" (14 CFR §§ 91.527(a)(3) and 135.227(a)(1)). Unless you restrict this procedure in the AFM Limitations section, you should show that the effects of "polished" frost on performance and flying qualities are not hazardous. You should provide suitable information to flight crews on how to polish the frost (including guidance on how to know when the surfaces have been polished enough to be hydraulically smooth).

The frost and clear ice must be removed from the upper surface. Protect the surface from further frost development by applying anti-icing fluids. If ice or frost from cold-soaked fuel conditions could result in unsafe takeoffs and flight, you may install a ground ice detector(s) on the airplane upper surface where frost or clear ice initially forms. Visual inspection aids, such as tufts and decals, are not acceptable since they are inadequate and unreliable for detecting ice on wing upper surfaces. A ground ice detection system (GIDS) does not relieve the operator from the requirement to show compliance with 14 CFR §§ 91.527, 121.629, 125.221, and 135.227, requiring the aircraft surfaces be free of adhering frost, snow, and ice before takeoff.

You should show that the GIDS, if installed, is of a kind and design suitable for detecting wing cold-soaked fuel and that it will ensure safe flight. You should install the ice detector according to the limits of the ice detector and its related systems.

You should show that you have installed the ice detector in the wing area where ice or frost resulting from cold-soaked wing fuel initially forms, and that it is the last place the ice or frost melts. You should also show that the ice detector detects the ice formations reliably. You many need to perform analysis, ground tests, laboratory tests, flight tests, or a combination of these.

The GIDS should conform with SAE AS5116.

You should install the ground ice detector so it performs its intended function, considering physical damage from foreign objects and damage during airplane maintenance.

The GIDS must detect ice caused by cold-soaked wing fuel in the following environmental conditions:

- Outside air temperature from +20°C to -40°C;
- Expected humidity levels;
- Frost;
- Snow (wet or dry);
- Fog or freezing fog;
- Freezing drizzle;
- Light freezing rain; and
- Freezing rain.

APPENDIX V. AIRCRAFT FROST AND CLEAR ICE CONSIDERATIONS (CONTINUED)

Show ice detection:

- With no anti-icing fluid;
- With each type of deicing and anti-icing fluid approved for use on the airplane; and
- With expected contaminants, such as engine fuel, lubricants, and hydraulic fluids.

Proper function is detection of clear ice with a thickness no greater than that which is a hazard to the airplane or engine.

You may use flight test or vendor data to show that the ice detector detects ice in the required icing conditions.

You should minimize nuisance alerts and show acceptable performance during flight tests.

You should show the ice detector's effectiveness and its ability to perform its intended function reliably by flight test under high humidity conditions with cold-soaked fuel:

- To verify the use of vendor data for the installed ice detector and other information;
- To check the installation of the ice detector;
- To show the effectiveness of the installed ice detector; and
- To check for ice formation anomalies.

Use AC 25.1309-1A and AC 23.1309-1C for guidance on compliance with § .1309 of 14 CFR parts 23, 25, 27, and 29. The unannunciated failure to detect ice resulting from cold-soaked fuel on both wings results in a catastrophic failure condition. This category remains a catastrophic failure unless you show the characteristics of the airplane with clear ice on the upper wing surfaces result in a less severe hazard category. You should also evaluate the scenario where there is ice on only one wing and an annunciated failure to detect that ice. The annunciated failure of a ground ice detector is considered minor. The failure requires visual and physical checks by the operator for upper wing ice.

The ice that develops on the wing upper surfaces before detection, caused by cold soaked fuel:

- Should allow safe flight of the aircraft according to 14 CFR §§ 23.1093 and 25.1093;
- Should be accounted for in stall speeds recommended operating speeds; and
- Should not degrade stall warning unacceptably.

The AFM should address:

- Use of the GIDS and its limits and
- Failure alerts and associated crew procedures.

APPENDIX V. AIRCRAFT FROST AND CLEAR ICE CONSIDERATIONS (CONTINUED)

The AFM should contain the following CAUTION:

> Ice shedding from the wing upper surface during takeoff can cause severe damage to engines, leading to surge, vibration, or complete thrust loss. Ice can also degrade stall margins, stall characteristics, and airplane performance. Ice can form on wing surfaces during exposure of the airplane to normal icing conditions. Clear ice can also form on the wing upper surfaces when the fuel in the wing fuel tanks is cold-soaked, and the airplane is exposed to conditions of high humidity, rain, drizzle, or fog at atmospheric temperatures well above freezing. Often, the ice is clear and difficult to see. Often the ice forms on the top of the main wing tanks. The Ground Ice Detection System detects the ice or frost only in this area. The Ground Ice Detection System does not detect ice, frost, or snow on other parts of the wing or airplane. The Ground Ice Detection System does not relieve the operator from the requirement to show compliance with 14 CFR §§ 91.527, 121.629, 125.221, and 135.227, which require that the aircraft surfaces be free of adhering frost, snow, and ice before takeoff.

V.2 REFERENCES.

V1. **"Performance Standards for Airplane Ground Ice Detection Systems,"** SAEAS5116.