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Administration

Advisory Circular

Subject: AIRCRAFT ICE PROTECTION **Date:** DRAFT **AC No:** 20-73A
Initiated by: AIR-100

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1. PURPOSE

This Advisory Circular (AC) provides general information related to the approval of aircraft ice protection provisions in accordance with applicable requirements of Title 14 of the Code of Federal Regulations (14 CFR) parts 23, 25, 27, 29, and 33. This AC also provides guidance and general information relative to operation of aircraft in icing environments that may affect the aircraft's airworthiness, including extended range operation of two-engine airplanes (ETOPS). Information contained in this AC supplements, but does not annul, guidance information provided in ACs applicable to specific in-flight icing requirements of 14 CFR parts 23, 25, 27, 29, and 33. This AC is not mandatory and does not constitute a regulation. This AC describes acceptable means, but not the only means, (1) to obtain approval of aircraft ice protection provisions; (2) to determine two-engine airplane airworthiness in icing conditions during extended range operations; and (3) to evaluate aircraft airworthiness aspects following de/anti-icing prior to takeoff.

2. CANCELLATION

This AC provides current general guidance information related to means of compliance for approval of aircraft ice protection provisions, and cancels the 1971 AC 20-73 in its entirety.

3. APPLICABILITY

a. The guidance provided herein applies to aircraft ice protection provisions approval for operating in the icing environment defined by 14 CFR parts 25, Appendix C and 29, Appendix C. Section 1419 of 14 CFR parts 23, 25, 27, and 29 provides specific airframe ice protection system (IPS) requirements that ensure safe aircraft operation within the respective icing envelopes. Additionally, different sections of 14 CFR parts 23, 25, 27, and 29 define ice protection requirements for other systems and components (e.g., engine inlet, air data system probes, propeller blades, and rotary wings). Compliance must be shown for some icing-related regulations even if the aircraft is not approved for flight in icing conditions; e.g., 14 CFR §§ .629 , .903, .975, .1093, .1323 (except for 14 CFR part 23 and 27 aircraft not certified for IFR flight), and .1325 (except for 14 CFR part 23 aircraft not certified for IFR flight). Other guidance materials associated with these requirements are listed in Appendix A – Related Regulations and Documents. Limited information regarding flight tests for icing certification is provided in this AC. Additional information may be found in the following: AC 23-8A, "Flight Test Guide for Certification of Part 23 Airplanes;" AC 25-7A, "Flight Test Guide for Certification of Transport Category Airplanes;" and AC 29-2C, "Certification of Transport Category Rotorcraft."

b. Engine icing requirements are defined by 14 CFR part 33. Limited guidance information relative to approval of engine ice protection provisions is provided in this AC, deferring to the more complete guidance material provided by the FAA Engine and Propeller Directorate. This guidance information can be obtained by contacting the FAA Engine and Propeller Directorate

c. Guidance for approval of extended range operation of two-engine airplanes (ETOPS) is provided in AC 120.42A, "Extended Range Operation with Twin-Engine Airplanes (ETOPS)."

d. Guidance provided in this AC is applicable to new Type Certificates (TCs), Supplemental Type Certifications (STCs), and amendments to existing TCs for aircraft certified under the Civil Aviation Regulations (CAR) parts 3 and 4b, as addressed herein, and for which approval under the provisions of 14 CFR parts 23, 25, 27, or 29 § .1419 is desired.

4. RELATED REGULATIONS, DOCUMENTS, READING MATERIAL, AND NOMENCLATURE.

See Appendix A – Related Regulations and Documents for related regulations, documents, and reading material. See Appendix B – Nomenclature for the terms, acronyms, and symbols used in this AC.

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Note: references in the text are denoted by a number enclosed in square brackets.

5. ICE PROTECTION REGULATORY DEVELOPMENT BACKGROUND

See Appendix C – Ice Protection Regulatory Development Background.

6. ICE PROTECTION REQUIREMENTS

Aircraft surfaces or components that accumulates ice when exposed to atmospheric icing conditions are required to be equipped with an IPS if ice contamination of those surfaces or components result in unsafe operation of the aircraft.

6.1 Applicable Regulations

a. Ice protection of aircraft components, such as the engine induction system, air data system components, windshields and windows, fuel tank vents, and carburetor vapor vents, is required to ensure safe operation of aircraft when in icing conditions , even if the aircraft is not certificated to operate in known or forecast icing conditions and the icing encounter is inadvertent.

1. For the engine(s) and their installation(s), in accordance with 14 CFR part 23 §§.901(d)(2) and .903 and 14 CFR part 25 (which require compliance with § .77 of 14 CFR part 33).

2. For the engine and engine induction system, in accordance with 14 CFR part 33 § .68 , and 14 CFR parts 23, 25, 27, and 29 § .1093.

3. For other engine components such as oil and accessory cooling systems, in accordance with 14 CFR parts 23, 25, 27, and 29 § .1093.

4. For the air data system, in accordance with: 14 CFR part 25 §§ 1323, 1325, 1326; 14 CFR part 27 § 1325; and 14 CFR part 29 § 1327 and 1326.

5. For proper function and installation of the IPS equipment, in accordance with 14 CFR parts 23, 25, 27, and 29, §§ .1301 and .1309.

6. For indication of the operation of the powerplant(s) ice protection equipment or the fuel system heater(s) installed to prevent ice, in accordance with 14 CFR parts 23, 25, 27, and 29 § .1305.

7. For fuel tank and carburetor vapor vents, 14 CFR parts 23 and 25 § .975.

b. For aircraft to be certificated to operate in icing conditions, the following additional requirements must be met:

1. For the airframe, in accordance with: 14 CFR parts 23, 25, 27, and 29 § .1419; 14 CFR part 23 § .1416; and 14 CFR part 25 § .1403.

2. For the engine(s) and their installation, re-evaluation of compliance with 14 CFR part 33 §§ .68 and .77.

3. For the engine installation(s), in accordance with 14 CFR part 23 § .901(d)(2) and 14 CFR parts 23 and 25 § .903.

4. For the engine induction system, in accordance with 14 CFR parts 23, 25, 27, and 29 § .1093.

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5. For other components of the complete engine installation, such as oil and accessory cooling inlets, in accordance with 14 CFR parts 23 and 25 § .929.

6. For propellers, in accordance with 14 CFR part 35 and of 14 CFR parts 23 and 25 § .929.

7. For windshield ice protection and pilot compartment view, in accordance with 14 CFR part 23 § .775, and 14 CFR parts 25 and 29 § .773.

8. For the air data system, in accordance with 14 CFR part 23 §§ .1323, .1325, and .1326.

c. Additionally, requirements have been established to ensure ice considerations for fuel systems, fuel strainers or filters, and for icing of the carburetor and its vapor vents do not result in unsafe aircraft operations:

1. For consideration of ice being formed in fuel tanks and blocking fuel lines, in accordance with 14 CFR parts 23, 25, 27, and 29 §. 951(c), and 14 CFR part 33 § .67(b)(4)(ii).

2. For ice being formed on fuel strainers or filters, 14 CFR part 23 § .997.

3. For carburetor icing, 14 CFR parts 23, 25, 27, and 29 § .1093; 14 CFR parts 23, 25, and 29 §§ .1101, 1157, and .1189; 14 CFR part 23 § .1099, and 14 CFR part 33 § 35 (b).

d. For aircraft that are certificated to operate in known and forecast icing conditions, demonstrations of the adequacy of the ice protection and detection systems and safe operation of the aircraft in icing conditions are required in accordance with 14 CFR part 33 §§ .66, .68, .77, and .89(b); and 14 CFR parts 23, 25, 27, and 29 § .1419, (and subsequently other sections of 14 CFR Subparts B and D of the respective 14 CFR parts 23, 25, 27, and 29):

1. For safe flight of airplanes with ice accretions resulting from encountering inflight icing conditions and the power extraction resulting from operation of IPSs, see applicable sections of AC 23.1419 or AC 25.1419.

2. For consideration of ice accretion mass on aeroelastic stability (structural vibration and flutter) (14 CFR Subpart D), in accordance with 14 CFR parts 23, 25, 27, and 29 § .629.

e. If certification with ice protection provision is desired, the aircraft must be able to operate safely in the continuous maximum and intermittent maximum icing conditions contained in Appendix C of 14 CFR part 25 for airplanes and of 14 CFR part 29 for rotorcraft. The two appendices are identical. AC 29-2C provides a 10,000-foot altitude-limited envelope for rotorcraft use. If an aircraft is limited to a flight envelope more (in this document) restrictive than that of 14 CFR parts 25 and 29, Appendix C, the icing conditions used for approval of the ice protection provisions may be reduced to that of the limited flight envelope. Appendix D – Meteorological Conditions provides information and guidance relative to development and application of 14 CFR parts 25 and 29 Appendix C.

f. Requirements have been established to ensure pilots are provided necessary information and operating limitations for safe operations in inflight icing conditions, in accordance with 14 CFR parts 23, 25, 27, and 29 §§ .1525, .1583, and, .1585; and 14 CFR parts 23, 27, and 29 § .1559.

g. Installation of specific ice protection equipment must be reviewed relative to the influence of its operation on other systems, components, and requirements. For example, use of a fluid IPS may require consideration of the flammable fluid protection requirements of 14 CFR parts 23 and 25 §§ .863, .1199, and .1309. Use of ice protection equipment capable of producing strong electrical fields requires consideration of 14 CFR part 23 §§ .1327, and .1351 and 14 CFR part 25 §§ .1327 and .1353 relative to electromagnetic interference effects.

h. Issues related to turbine engine internal ice protection, carburetor icing, fuel system icing, fuel tank and carburetor vents icing, and the effects of ice accretion mass and aerodynamics on structural vibration stability are not addressed by this Advisory Circular.

i. Ice protection equipment must meet the following design and construction requirements of 14 CFR parts 23, 25, 27, and 29 §§ .601, .603, .605, .607, .609, .611, and .613.

j. Section .1529 of 14 CFR parts 23, 25, 27, and 29 and 14 CFR parts 33 and 35 § .4 require that the applicant provide information relative to the continuing airworthiness of the aircraft. This information may include ice protection equipment inspection and maintenance information.

6.2 Safe Flight in Icing Conditions

Requirements discussed in **6.1 Applicable Regulations** have been established to ensure safe flight in icing conditions. Section .1419 of 14 CFR parts 23, 25, 27, and 29 requires safe aircraft operation for the approval of inflight ice protection provisions. For small airplanes, § 23.1419 defines safe flight as meeting the aircraft performance and handling requirements of 14 CFR part 23, Subpart B. See the applicable advisory circulars (AC 23-8A and 23-8A, Change 1; AC 23.143-1; AC 23.1419-2B; AC 25.7A; AC 25.1419-1; AC 27-1B; and AC 29-2C) for means of demonstrating safe aircraft operation in icing conditions for respective aircraft categories. Also, see AC 23.629-1A and AC 25.629-1A for guidance relative to ensuring the integrity of the airframe, with respect to structural vibration stability during flight in icing conditions.

6.3 Background Resources and Regulatory Guidance References

a. The FAA Aircraft Icing Handbook provides comprehensive information on weather, icing phenomena, icing analysis, ice protection and detection systems design and certification. Volume I, Chapter I, Section 2 of the FAA Aircraft Icing Handbook, DOT/FAA/CT-88/8-1, dated March 1991 [1], provides detailed information concerning cloud droplet impingement and ice accretion on aircraft surfaces. Volume I, Chapter II, Section 1 provides information relative to ice detector technologies and ice detectors. Volume II, Chapter III provides detailed information relative to ice protection methods, and Chapter V discusses how the adequacy of the ice protection methods may be demonstrated. See also the Electronic Aircraft Icing Handbook (a subset of the Aircraft Icing Handbook) at: http://www.fire.tc.faa.gov/aar421/eaihbpg.html

b. Regulatory compliance guidance information for specific parts of 14 CFR is available in applicable Advisory Circulars listed in Appendix A - Related Regulations and Documents. Also, specific inflight icing considerations may be found in other regulatory guidance material, such as information concerning extended twin-engine airplane operations (ETOPS) (AC 120-42A), and regulatory guidance related to joint certifications with other airworthiness authorities. Inflight icing regulations and guidance material are subject to change, therefore information provided in early guidance material may be superceded by, or may lag, current requirements and means of compliance.

7. CERTIFICATION PROCEDURES

7.1 General

a. Ice protection provisions certification procedures described in AC 23-8A, AC 23-8A Change 1, AC23.1419-2B, AC 25-7A, AC 25.1419-1, AC 27-1B, AC 29-2C, AC 33-2B, and AC 120-42A should be followed. STC programs are accomplished in accordance with AC 21-40. In general, applicants should submit a certification plan at the start of the design and development efforts. The certification plan should describe all of the applicant's efforts intended to lead to certification. Furthermore, this plan should identify, by item to be certificated, relevant requirements and the method of compliance (a certification checklist). The certification plan should clearly identify analyses and tests, or references to similarity of designs that the applicant intends to use for certification of the IPS. These methods of showing compliance

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should be agreed upon between the applicant and the FAA early in the type certification program. It is imperative that the applicant obtain FAA concurrence prior to conducting certification tests. The certification plan should include the following basic information:

1. Airplane or engine systems description
2. IPS description
3. Detailed descriptions of modifications
4. Certification bases for the requested approval
5. Certification checklist, including listing the use of specific DERs for particular regulations, method(s) of compliance, and the reports that will be submitted documenting compliance with specific regulations
6. Certification schedules, for both the applicant and the FAA
7. Description of analyses or tests performed to date
8. Conformity plans, including the location of the conformity demonstration
9. Hazard assessments
10. Software considerations
11. High intensity radiated fields and lightning considerations
12. A list of anomalous 14 CFR part 33 icing certification test results, if completed, that will require special operating procedures
13. If the ice protection or detection systems contain complex electronic hardware (such as programmable logic devices (PLD) or application specific integrated circuits (ASIC)), plans for providing a level of design assurance of these devices commensurate with their potential contribution to aircraft hazards and system failures, which could result from electronic hardware faults or malfunctions.

b. General process flows for the design and certification of aircraft component ice protection provisions are shown in Appendix E – Component Ice Protection System Design and Certification Processes. (Note: the certification process for specific aircraft components should be coordinated and approved by the cognizant Aircraft Certification Office; the process flow charts shown in Appendix E – Component Ice Protection System Design and Certification Processes are provided as general information that describes typical design and certification processes of ice protection provisions.)

7.2 Airframe Manufacturer

The airframe manufacturer should consult regulatory guidance material provided in applicable ACs and submit a certification plan and checklist for demonstrating compliance with the applicable regulatory requirements. Compliance with the regulatory requirements must be demonstrated and documented. A design analysis, whose prime objective should be the determination of critical design points and prediction of the IPS performance within 14 CFR parts 25 and 29, Appendix C, should be submitted. The manufacturer’s test proposals should be submitted and approved before testing is begun. The airframe manufacturer is responsible for showing compliance to all applicable 14 CFR part 23, 25, 27, or 29 regulations, including those covering the engine and propeller.

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7.3 Engine Manufacturer

The engine manufacturer should consult regulatory guidance material provided in applicable ACs and submit an icing certification plan and checklist. The engine manufacturer should submit a design analysis, which has as its prime objective the establishment of sufficient critical design points to ensure that the engine can function adequately in expected icing conditions, including those not included in 14 CFR parts 25 and 29 Appendix C, such as falling and blowing snow. The selection of these points should involve consideration of all the factors covered in this Advisory Circular. The manufacturer's test proposal should be submitted and test procedures agreed upon before testing is begun. For 14 CFR part 33, typically, tests are conducted in icing tunnels or on outdoor test stands and are intended to simulate in-flight 14 CFR parts 25 and 29, Appendix C conditions. For 14 CFR parts 23 or 25 § .1093, tests are typically performed in either natural icing conditions or in flight behind an icing tanker. Testing should be conducted at sufficient points throughout the power or thrust range to demonstrate that no unsatisfactory engine operational feature exists under these conditions.

8. COMPLIANCE MEANS

Compliance with 14 CFR parts 23, 25, 27, and 29 § .1419 requires that an analysis be performed to establish that the ice protection for the various aircraft components is adequate, taking into account the various aircraft operational configurations. To verify the analysis, check for icing anomalies, and to demonstrate that the IPS and its components are effective, the aircraft or its components must be flight tested in the various operational configurations in measured natural atmospheric icing conditions, and, as necessary, by laboratory dry air or simulated ice tests, dry air flight tests, or flight tests in measured artificial icing conditions. For further guidance on STCs and amended TCs, see Section 8.5 ***for fixed wing aircraft and Section 10.2 – Compliance for rotorcraft.

8.1 Analysis.

a. Leading edges of wings not equipped with leading-edge high-lift devices (hard wings) may be very sensitive aerodynamically to leading edge surface roughness, such as that resulting from ice accretion, depending on the selected airfoil characteristics. Careful attentions should be given to the adequacy of the ice protection design of these wings. Also, leading-edge high-lift devices should receive special attention because of their location and functional importance. Leading edges of slotted trailing-edge flaps may accrete ice during approach and landing. Ice protection is typically not provided for trailing-edge flaps, the ability to fully retract the flaps following a balked landing and the influence of ice accretion on flaps therefore should be investigated.

1. For all deice and anti-ice systems in accordance with 14 CFR parts 23, 25, 27, and 29 § .1301.

2. For all deice and anti-ice systems in accordance with 14 CFR parts 23, 25, 27, and 29 § .1309. (See applicable sections of AC 23.1309-1C and AC 25.1309-1A.)

3. For the airframe, in accordance with 14 CFR parts 23, 25, 27, and 29 § .1419 and 14 CFR 25.1403. (See applicable sections of AC 23.1419-2B, AC 25.1419-1, and AC 29.-2C.)

4. For propellers, in accordance with 14 CFR parts 23 and 25 § .929. (See applicable sections of AC 23.1419-2B, AC 25.1419-1, and AC 29.-2C.)

5. For windshield ice protection (pilot compartment view), in accordance with 14 CFR part 23 § .775, and 14 CFR parts 23, 25, and 29 § .773. (See applicable sections of AC 23.1419-2B, AC 25.1419-1, and AC 29.-2C.)

6. For the engine induction system systems and cooling inlets (NACA inlets may accrete ice, depending on their location, and their performance should be evaluated) in accordance with 14 CFR part 33 § .68,

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and 14 CFR parts 23, 25, 27, and 29 § .1093. (See applicable sections of AC 20.xx, AC 23.1419, AC 25.1419-1, and AC 29-2C.)

7. For the air data system, in accordance with 14 CFR parts 23, 25, and 29 § .1323; 14 CFR parts 23, 25, 27, and 29 § .1325; and, 14 CFR parts 23 and 25 § .1326. (See applicable sections of AC 23.1419-2B, AC 25.1419-1, and AC 29.-2C.)

8. For safe flight (14 CFR parts 23, 25, 27, and 29, Subpart B) with ice accretions resulting from encountering inflight icing conditions and the power extraction resulting from operation of IPSs. (See applicable sections of AC 23-8A, AC 23-8A (Change 1), AC 23.1419-2B, AC 25-7A, AC 25.1419-1, and AC 29-2C.)

9. For consideration of ice accretion mass on aeroelastic stability (structural vibration and flutter) (14 CFR parts 23, 25, 27, and 29, Subpart D), in accordance with 14 CFR parts 23, 25, 27, and 29 § .629.

10. For the engine(s) and their installation(s), in accordance with 14 CFR part 23 §.901(d)(2), 14 CFR parts 23 and 25 § .903 (which require compliance with 14 CFR part 33 § .77) and 14 CFR parts 23, 25, 27, and 29 § .1093. (See applicable sections of AC 20-xx.)

11. Fuel tank vents, in accordance with 14 CFR parts 23, 25, 27, and 29 § .975. (See AC 23.1419-2B, AC 25.1419-1, and AC 29.-2C.)

12. Inspection lights and ice accretion cues, in accordance with 14 CFR parts 25 § .1403. (See applicable sections of AC 25.1419-1.)

b. Appendix D - Meteorological Conditions provides information and guidance relative to the required icing conditions of 14 CFR parts 25 and 29 Appendix C. Operational factors that should be considered for the analysis are provided in Appendix F – Operational Factors. To insure that the aircraft is able to operate safely in 14 CFR parts 25 and 29 Appendix C icing conditions, an icing conditions exposure time related to a 45-minute destination “hold” flight segment should be considered for airplanes; Appendix G – Icing Conditions Exposure Time and Appendix R – Ice Shapes provide information and guidance relative to consideration of the 45-minute hold in icing conditions. Note that 14 CFR parts 23, 25, 27, and 29 § .1093 state that each turbine engine must operate throughout the flight power range of the engine (including idling) without accumulation of ice on the engine, inlet system components, or airframe components that would adversely affect engine operation or cause a serious loss of engine power or thrust. For guidance relative to rotorcraft, see this AC, Section 10.1 - General.

c. Since analyses are often used to demonstrate compliance with the above requirements and since verification of the analyses is established only at limited flight test conditions, the design analyses should be closely reviewed.

d. Different design approaches are needed for the airframe and powerplant (engine or engine and propeller) IPSs. Aircraft surfaces may be more tolerant to ice accretion than engine and engine inlet surfaces, and the design approaches applied to an airframe system may differ somewhat from those applied to an engine system. The aircraft operational envelope can be defined precisely for a specific aircraft but the engine and propeller operational envelopes should include all possible applications and installations on as yet unspecified aircraft.

e. Design margins for each system will be established by the simultaneous consideration of meteorological factors, airplane-engine operational factors, and any other pertinent factor which might be involved.

f. The most critical conditions applicable to the design of engine inlet and propeller systems should be developed from consideration of the entire array of meteorological and operational conditions within the operational envelope of the engine. Design points should be sufficiently defined in terms of meteorological

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and operational factors for the FAA to determine how the criticality of these factors was established. The determination of the most critical conditions should be made with a specific design objective in mind. An evaporative system may be permitted to run wet under some conditions, and some ice buildup may be acceptable if safety of flight is not jeopardized.

g. For design purposes, different areas of the aircraft may require a different approach on the basis of the tolerance to ice accumulation.

8.1.1 Airframe

a. Selection of surfaces requiring ice protection and the required IPS are made in the early design stages of the aircraft. These surfaces are usually determined as being critical for safe operation of the aircraft in icing conditions. Typically, these surfaces of the airframe are directly exposed to stagnation flow conditions that usually accumulate the largest quantity of ice. These may include:

1. Airframe/fuselage ice impact;
2. Leading edges of wings, winglets, and wing struts;
3. Leading edges of horizontal and vertical stabilizers, and other lifting surface 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/or could otherwise 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, 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. APU inlet, exhaust, and drain pipe;

20. Propellers; and

21. Engine air induction system.

b. Leading edge high-lift devices should receive special attention because of their location and functional importance.

c. The selection of the surfaces to be protected is made after a careful consideration of required icing and operating conditions, and inflight icing requirements discussed in Section 6.1 – Applicable Regulations.

d. Information and guidance relative to ice protection technologies and operating modes, IPSs, IPS operation, and associated analyses are provided in Appendix H - Ice Protection Systems.

e. Droplet impingement and water catch analyses should be performed to evaluate ice accretion propensity of aircraft surfaces and components. This analysis should consider the various airplane operational configurations, phases of flight, and operating envelopes (including airspeeds and attitudes). The droplet impingement and water catch analyses should provide the information needed to determine the extent of ice protection required to protect a surface or component from ice accretion, and impart the quantity of heat required for thermal IPSs. Information and guidance relative to droplet impingement and water catch analyses and the determination of the ice protection coverage are provided in Appendix I - Droplet Impingement and Water Catch.

f. The extent of the icing protection needed for various air scoops is directly related to the need for such protection to maintain satisfactory operation of an essential system.

g. Table 1 illustrates the meteorological conditions considered in a typical design analysis. However, other conditions may be required.

Table 1. Continuous and Intermittent Maximum Icing Conditions

Continuous Maximum Icing Conditions			**Intermittent Maximum Icing Conditions**		
MVD ~ µm	Temperature ~ °F	Liquid Water Content ~ g/m^3	MVD ~ µm	Temperature ~ °F	Liquid Water Content ~ g/m^3
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	0.2		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

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h. Considerations for demonstrating the adequacy of airframe IPSs to ensure safe operation of the aircraft in icing conditions are discussed in Section 6.2 – Safe Flight in Icing Conditions.

i. The pressure altitude associated with each temperature should be selected from Figures D2 and D5 in Appendix D – Meteorological Conditions.

j. In addition to the meteorological conditions under consideration, appropriate operational parameters, including such factors as aircraft attitude, airspeed, altitude, engine power setting, etc., should be varied over the aircraft operating envelope to determine the combination or combinations of meteorological and operating parameters which result in the most critical design point or points. Because of the large number of variables involved in these design considerations, more than one critical design point may exist for both intermittent maximum and continuous maximum meteorological conditions.

k. The design analysis should indicate that no hazardous quantity of ice would form on the surfaces under consideration when exposed to intermittent maximum and continuous maximum icing conditions.

8.1.2 Engine and Propeller Systems

In defining the most severe conditions for the design of icing systems for the engine, propeller, and related components, the manufacturer should not only give consideration to the icing envelopes in Figures 1, 2, 4, and 5 of Appendix C, 14 CFR parts 25 and 29, but to the entire environmental and operational envelopes. (The cognizant ACO should be contacted for guidance for information relative to the applicable environmental and operational envelopes.)

8.1.2.1 Engine

a. The engine along with its IPS, when provided, should be designed to cope with the most critical meteorological conditions occurring simultaneously with the most critical engine and/or propeller (if applicable) operational conditions. Critical design points for both continuous maximum and intermittent maximum conditions should be developed. Procedures for determining water catch rate, impingement data, heat available (Q_A), and heat required (Q_R) are similar to those previously discussed for aircraft systems. The flow field around engine surfaces should be based on the pressure and velocity relationships of the air flowing through the engine.

b. The principal differences in the design approach applicable to airframe and engine systems arise from the need for engine reliability during all icing encounters. During the engine’s 14 CFR § 33.68 compliance process, no power loss or degraded engine operation is permissible.

c. Although engine manufacturers generally may have some idea of the eventual application of their engine, they cannot be sure that some future application will not be totally different from that planned. Therefore, the IPS should not be limited to a specific application or specific airplane operational envelope.

d. In addition to the foregoing, the buildup of ice on unprotected surfaces of the aircraft and the aircraft operational conditions during an icing encounter place further emphasis on the necessity for reliable engine performance. Engine struts, spinner cones, and inlet guide vanes, if unprotected, may be subject to accumulating excessive ice deposits. When heated surfaces are employed for keeping these surfaces free of ice, the possibility of runback and re-freezing must be considered. The first-stage fan or compressor blades of axial flow engines should also be evaluated for possible ice accumulation, with the IPS operating, when provided. However, ice accumulation on the first stage fan or compressor blades of axial flow engines is usually minor due to the centrifugal forces present. The larger fan blades may, however, develop accumulations at low rpm near the blade root areas. It is not considered essential to eliminate ice buildup at the engine face, but any ice buildup allowed on an operating engine should be kept to a minimum to

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prevent possible damage from ice ingestion and to ensure reliable engine operation. The level of ice buildup at the engine face must be shown to be acceptable with respect to engine handling and performance.

e. An accumulation of ice on any engine surface would be considered unsafe if it:

1. Caused a serious loss of power or thrust

2. Caused airflow disturbances which excited harmonic compressor or fan blade frequencies

3. Became large enough to cause serious engine damage when ingested

4. Caused damage to adjacent structure or engine components when detached by centrifugal force from rotating surfaces

5. Caused an imbalance of rotating components that produced vibrations greater than those for which the engine had been approved

6. Caused damage due to reduced clearance between rotating and stationary components

7. Caused any other hazardous engine operation

8.1.2.2 Propeller

Propeller operation would be considered unsafe if an accumulation of ice caused:

a. A serious loss of thrust horsepower

b. An unsafe engine condition to develop

c. Damage to adjacent structure when detached by centrifugal force

d. Vibrations which could result in engine or propeller structural failure

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

See Appendix J – Propeller Ice Protection for additional information and guidance for the approval of propeller IPSs.

8.1.3 Engine Inlets

a. The accumulation of ice on the engine inlet nose cowl, spinner cones, and other areas of the aircraft which could affect engine operation (such as surface leading edges forward of the engines) is generally more critical from the standpoint of continued safe operation than ice accumulation on aircraft surfaces discussed in 8.1.1 - Airframe. Design meteorological conditions remain the same, but operational conditions, particularly with respect to the surface flow conditions, may vary considerably. Although a fixed-engine operational condition is assumed for design of the airframe icing system, engine airflow may vary considerably during a relatively stable airplane operational condition. This is due in part to the variation in airplane response to changes in engine thrust or power output. This lag or variation is a factor in the determination of the most critical conditions for these areas of the airplane. Long curved inlets are particularly susceptible to snow, slush, and ice crystal impingement on the curved surfaces. Vortex generators or other boundary-layer control devices should be evaluated to determine the effects of ice accumulations on these surfaces.

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b. The most probable engine operational mode associated with a particular airplane operational mode is normally the basis for the design of airframe icing systems. However, due consideration should be given to the need for increased reliance on engine thrust or power output during icing conditions and to the possibility that the engine may actually be operated through a wide range of power settings during such an encounter.

c. The techniques for determining the most critical design points are similar to those discussed in 8.1.1 Airframe:

1. The design analysis should indicate that the engine inlet IPS will preclude the formation of any ice which could adversely affect continued safe engine operation or cause serious loss of power when exposed to the meteorological conditions as defined in Appendix C of 14 CFR parts 25 and 29 in combination with the aircraft operational needs and aircraft envelope.

2. Engine inlets are frequently designed to be evaporative under continuous maximum icing conditions and to run wet under intermittent maximum conditions. Service experience indicates that this approach has been satisfactory provided adequate precautions are taken to prevent hazards due to possible runback and refreeze.

d. Inlets for APU and accessory cooling, and for fuel venting, should be evaluated to determine if ice can accumulate and cause engine overheating or prevent system operation. NACA inlets, if not properly located, can accrete ice and must be included in this evaluation. Natural icing flight test experiences of NACA inlets range from small amounts of ice accretion 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. The Small Airplane Directorate provides guidance relative to the approval of induction system ice protection for turbine engines in Policy Statement ACE-01-23.1093(b) dated 11/7/2001, including the guidance relative to testing in falling and blowing snow and for testing in freezing fog.

8.1.4 Ice and Icing Conditions Detection Systems

Icing instrumentation systems may provide information to the flightcrew and/or aircraft systems concerning inflight icing encounters. These ice detection systems may be primary or advisory. Information and guidance relative to the approval of ice detection systems are provided in Appendix K – Ice And Icing Conditions Detection.

8.1.5 Windshields

The forward surfaces of windshields should be protected to provide visibility during the icing conditions specified by applicable regulations (14 CFR §§ 23.775, 25.773, 29.773). These surfaces are generally protected by electrical resistance systems because of the small areas involved. Analysis should substantiate that the windshield surface temperature is sufficient to maintain anti-icing capability without causing structural damage to the windshield. Information and guidance relative to windshield ice protection are provided in Appendix Q - Windshield Ice Protection.

8.1.6 Air Data System Sensors and Probes

a. Ice protection should be provided for all instruments essential for safe operation of the airplane as well as for all sensors which are subject to ice impingement or to runback and refreeze. Analysis should substantiate that the instrument surfaces and drainage cavities are sufficiently protected against the freezing of impinging water drops and drained water that may adversely affect the function of the instrument system.

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b. The functioning of essential static ports should not be adversely affected by ice accumulation, freezing of runback water from forward surfaces, or water and slush from the landing gear during takeoff and landing. It is possible that slush and water ingested at a lower altitude might freeze when the airplane ascends to higher altitudes and lower temperatures. Some of the instruments that might be affected are pitot tubes, EPR total pressure probes, and certain types of stall indicators. These instruments are generally protected by electrical resistance IPSs because of the small areas involved and because of the need to maintain ice-free operation in all icing conditions.

c. Design analysis of instruments located in close proximity to the fuselage should consider the droplet concentration effect of the airflow diverted around the fuselage. As an object (such as a fuselage) penetrates the air/icing conditions, small droplets tend to divert around the object. While these diverted droplets reduce the collection efficiency in the stagnation region, the diverted droplets can increase the concentration of water contained within a boundary area around the object. This effect can increase the local water content significantly for probes that are in close proximity to the fuselage (such as pitot probes).

8.1.7 Ice Protection System Failure Analysis

The need for system failure analysis is common for all IPSs, as required by 14 CFR §§ 25.901(c), 27.901(b)(1), 29.901(c), and § .1309 of 14 CFR parts 23, 25, 27, and 29. Applicable guidance information on system design analysis, such as AC 23.1309-1C and AC 25.1309-1A, should be used for determining hazards that may result from system failures. Failure modes and effects analyses are usually required to ensure that any single failure does not result in an unsafe condition. Fault tree analysis ensures that unsafe-combinations-of-failures safety objectives are met. Separation, cascading, and common cause analyses ensure system independence in the presence of various airplane failures. For example, for a thermal anti-ice system forward of the leading edge spar, slat failure conditions and bird-strike conditions may need to be considered during the course of analysis. Additionally, under certain failure conditions, the hot air of a thermal IPS may approach temperatures that can affect integrity of nearby structure and may spontaneously ignite leaking fuel. These and similar conditions should be evaluated to ensure aircraft safety. When system failures result in unsafe operations, the aircraft is required to exit icing conditions. Safe exiting of icing conditions following a critical system failure must be ensured, including continued safe flight and landing. Additional guidance information on equipment reliability is provided in ACs 27-1B, 29-2C, and 33-2B.

8.1.8 Flutter Analysis

Section .629 of 14 CFR parts 23, 25, 27, and 29 requires that aircraft be free of flutter and divergence. Section .629 of 14 CFR parts 23 and 25 also requires that the airplane be free of control reversals. Advisory Circulars 23.629-1A and 25.629-1A provide guidance relative to compliance with 14 CFR parts 23 and 25 § .629, respectively. For inadvertent icing encounters, 14 CFR § 25.629(d)(3) requires the consideration of the effects of the associated ice accretion.

8.1.9 Power Sources

The applicant should evaluate the power (energy) sources of the IPS (e.g., electrical, engine bleed air, pneumatic pumps, etc.). Analyses or tests should be conducted on each power source to determine that it is adequate to supply the necessary power to the IPS while maintaining its support of other essential equipment and systems. The effect of an IPS component failure on the power availability to other essential loads should be evaluated in accordance with 14 CFR parts 23, 25, 27, and 29 § 1309. All power sources that affect engine or engine IPSs for multi-engine aircraft must comply with the engine isolation requirements of 14 CFR parts 23, 25, and 29 § .903.

8.2 TESTS

a. To establish that an aircraft can operate safely in the continuous maximum and intermittent maximum icing conditions of 14 CFR parts 25 and 29 Appendix C, testing is required to verify the analyses and other

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means used to demonstrate safe operations of the aircraft, to check for icing anomalies, and to demonstrate that the IPS and its components are effective. Flight tests in measured natural icing conditions are required for this verification. Other testing of the IPS or its components may be necessary to verify the analyses, including laboratory dry air or simulated ice tests, dry air flight tests, or flight tests in measured simulated icing conditions.

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

c. See AC 23-8A, AC 23-8A Change 1, AC 23.1419-2B, AC 25.7A, AC 25.1419-1, AC 27-1B, and AC 29-2C for further information regarding testing methods and procedures.

8.2.1 Natural Icing Flight Tests

a. Section .1419 of 14 CFR parts 23, 25, 27, and 29 requires that if certification with ice protection provisions is desired, the aircraft must be able to operate in the continuous maximum and intermittent maximum icing conditions defined by 14 CFR part 25 and 29, Appendix C, envelopes. Furthermore, 14 CFR parts 23, 25, 27, and 29 § .1419 requires that the effectiveness of the ice protection provisions be demonstrated by flight testing in measured natural atmospheric icing conditions. Natural icing tests should be conducted as closely as possible to design point conditions to reduce the uncertainty associated with extensive extrapolations. These tests should demonstrate the effectiveness of the icing system under natural conditions. The tests should also provide the means by which the buildup of ice aft of running wet protection surfaces and on unprotected surfaces, and intercycle ice roughness on deice protection surfaces can be evaluated with respect to the engine operational characteristics and with respect to aircraft's performance, maneuverability, and controllability.

b. Data obtained during natural icing tests may be used to validate the analytical methods used and the results of any preceding simulated icing tests.

c. Testing in natural icing is required to evaluate the effectiveness of the propeller IPSs and to check for icing anomalies not addressed by laboratory tests and analyses. Means of measuring propeller efficiency, propeller and engine vibration, shed-ice impact energy on the airframe, and means to record propeller ice accretion and shed-ice trajectories should be provided.

8.2.1.1 Test Icing Conditions Considerations

a. Section .1419 of 14 CFR parts 23, 25, 27, and 29 requires the measurement of icing conditions during flight testing in natural icing conditions. Measurements should characterize the icing conditions relative to parameters useful to understand the performance and effectiveness of the IPS, to verify the IPS analysis, to understand icing anomalies that may be observed, and to allow extrapolation of the observed IPS performance and effectiveness to other conditions within 14 CFR parts 25 and 29 Appendix C. Parameters selected to define 14 CFR parts 25 and 29 Appendix C were considered those important for the design of thermal IPSs (LWC, mean drop diameter, temperature, cloud extent, and altitude) and are typically measured during natural and artificial icing flight tests, along with airspeed, to characterize the test icing environment. Median volume diameter (MVD) is also used to define IPS coverage. Proper functioning of deicing boots should be evaluated at cold temperatures. LWC is an important parameter for defining pre-activation and intercycle ice accretion on deicing boots. See Appendix L – Instrumentation for information and guidance relative to measurement of flight test natural and artificial icing conditions.

b. Appendix M – Finding Natural Icing Conditions For Test Purposes provides information and guidance relative to finding natural icing conditions for flight testing.

c. Flight tests should be performed in icing conditions that are within 14 CFR parts 25 and 29 Appendix C. Appendix N – Ways To Evaluate Icing Exposures Relative To Appendix C provides information and

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guidance relative to procedures for comparing flight test natural icing conditions with those of 14 CFR parts 25 and 29 Appendix C. The quality of an icing exposure may be assessed by the icing intensity encountered. Appendix O – Using Icing rate to Document Icing Exposures provides a mean to assess the icing intensity of an icing encounter.

d. Experience indicates that flight testing in convective air currents within cumulus clouds that are typically associated with natural intermittent maximum icing conditions may lead to severe turbulence and hail encounters that MAY cause structural damage to the test aircraft. When design analyses show that the critical ice protection design points (e.g., heat loads, critical ice shapes, ice accretion, and ice accretion rate, etc.) are adequate under these conditions, and sufficient ground or flight test data exist to verify the analysis, the flight test in intermittent maximum icing conditions may not be necessary. For 14 CFR part 23 airplanes, AC 23.1419-2B advises that intermittent maximum icing conditions should be avoided.

8.2.1.2 IPS Evaluation

a. For non-automatic systems, IPSs are to be activated by the flightcrew when icing conditions exist in accordance with AFM procedures proposed by the applicant. However, for anti-ice components, tests should also be conducted with delayed activation of the IPS to simulate inadvertent icing encounters in which the pilot may not recognize that the aircraft has entered an icing condition and the anti-ice component may not be activated until actual ice build-up is noticed. The delay should be based on the icing recognition means available to the flightcrew and recommended crew procedures. If it is determined that the delay assumptions result in more than a two-minute delay in anti-ice activation from icing onset, and the resultant liberated ice can be ingested into an engine, then the engine ice slab airworthiness standard of 14 CFR § 33.77 may no longer provide adequate demonstration of the maximum possible ice slab ingestion in-service, and a new assessment at the aircraft level may need to be considered. (Testing of delayed activation of IPSs that utilize a primary automatic ice detection system is not required.) An ice accretion should be determined that would accumulate in the continuous maximum icing conditions of 14 CFR parts 25 and 29 Appendix C, during the selected delayed activation period plus the time required for the IPS to perform its intended function. Handling qualities should remain acceptable to the test pilot, and the airplane should be capable of operating safely with the delayed-activation ice accretion.

b. Also, the effect of pre-activation ice accretion (ice accreted prior to when the ice protection becomes fully effective, e.g., achieving the operating temperature of thermal IPS, the ice accretion prior to a complete cycle of deicing for a deicing system, etc.) should be evaluated. Handling qualities should remain acceptable to the test pilot, and the airplane should be capable of operating safely with the pre-activation ice accretion.

c. For fluid IPSs, flight testing should include evaluation of fluid flow paths to confirm that adequate and uniform fluid distribution over the protected surfaces is achieved. In cold temperatures, fluid flow paths determined in dry air may result in the de/anti-ice fluid freezing on the protected surface. The means provided for indicating fluid flow rates, fluid quantity remaining, etc., should be evaluated to determine that the indicators are plainly visible to the pilot and that the indications provided can be effectively read. A shutoff valve should be provided in systems using flammable fluids. Windshield fluid anti-ice systems should be tested to demonstrate that the fluid does not become opaque at low temperatures. The AFM should include information so the flightcrew will know how long it will take to deplete the amount of fluid remaining in the reservoir.

8.2.1.3 Ice Detector Evaluation

For ice detection systems, both primary and advisory, flight tests in natural icing conditions are typically performed to correlate the detection of icing conditions with the presence of ice on the aircraft ice-protected surfaces and to demonstrate that the ice detector is performing its intended functions, such as automatic operation of the IPS for some primary ice detection systems. Evaluation of ice detection systems at ambient temperatures within the temperature range of 30 °F (-1 °C) to 32 °F (0 °C) should be included.

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8.2.1.4 Ice Shedding

a. Ice shed from the airframe may be ingested into the engine, resulting in engine damage and affecting the operability of the engine. Also, the shed ice may structurally damage downstream aircraft surfaces and components. For fuselage-mounted turbojet engines (and pusher propellers that are very close to the fuselage and well aft of the airplane's nose), ice shedding from the forward fuselage and from the wings may cause significant damage. Ice shedding from components, including antennas, of the airplane should cause no more than cosmetic damage to other parts of the aircraft, including engines and propellers (compliance with 14 CFR parts 23 and 25 § .1093). Consideration should also be given to airplane damage that can occur due to ice shedding from the propellers.

b. **Trajectory and impingement analyses may not adequately predict such damage.** Unpredictable ice shedding paths from forward areas such as radomes and forward wings (canards) have been found to negate the results of these analyses. For this reason, regardless of the trajectory analyses, a damage analysis should consider that the most critical ice shapes will shed and impact the areas of concern. Also for engines, the applicant must assume and take into consideration the situation where all shaded ice is ingested into the engines, independent of the trajectories. Appendix P – Ice Shedding provides information and guidance relative to ice shedding. See AC 33-2B relative to test procedures for engine induction system icing and engine ice ingestion test procedures.

8.2.1.5 Additional Guidance and Information

Relevant information concerning natural ice testing is provided in ACs 23-8A, Change 1; 23.143-1; 23.1419-2B; 25-7A; 25.1419-1; 27-1B; 29-2C; 33-2B; and Appendix H - Ice Protection Systems.

8.2.2 Dry Air Flight Tests

a. Dry air flight tests are usually the first flight tests conducted to evaluate the aircraft with the IPS operating. The initial dry air tests are conducted to verify that the IPS operates as intended, does not affect the flying qualities of the aircraft (for example, deicing boots) in clear air and to obtain thermal characteristics of an operating thermal IPS for verifying analyses required by 14 CFR parts 23, 25, 27, and 29 § .1419.

b. Dry air flight tests can be used to verify significant portions of the IPS analyses and to demonstrate the aerodynamic effects of predicted ice shapes. These tests should be conducted prior to natural icing tests to check the function and performance of all system components and to check the compatibility of systems. Calculated engine bleed air mass flows for developing thrust setting curves can be verified, and simulated ice shapes can be installed on unprotected and protected surfaces and evaluated in terms of their effects on aircraft performance, maneuverability, and controllability. An analysis of heat requirements and availability at various operational conditions can be performed from data collected during dry air tests. Also, information concerning the effects of the local environment of the installed components of the IPS can be obtained, such as the effects of propeller wash on the wing and empennage and the effects of wing downwash on the horizontal stabilizer.

c. Several commonly used IPSs and components are discussed below to illustrate typical dry air flight test practices. Other types of equipment should be evaluated as their specific design dictates.

8.2.2.1 Thermal Ice Protection Systems

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

b. Normally, the system components are instrumented to measure the heat energy distributed to the heated surfaces and the temperature of the heated surfaces. Validity of the IPS thermal analysis can be checked by comparing predicted and measured parameters that include 14 CFR parts 25 and 29 Appendix C temperature envelope limits. The measured dry-air surface temperatures can be used to determine the

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maximum possible surface temperatures, heat transfer characteristics, and to evaluate the adequacy of the heat source. Also, the dry air testing will provide information to verify that the temperatures measured on the IPS component surfaces are within those allowed relative to structural integrity.

8.2.2.2 Pneumatic Ice Protection Systems

Tests should demonstrate the pneumatic characteristics of the IPS, including the inflation and deflation pressures and rates and the inflated dwell pressure. These inflation/deflation rates and air pressures should be evaluated throughout the altitude range defined by 14 CFR parts 25 and 29 Appendix C, and the aircraft/IPS performance envelope. Cycling of the IPS should have no hazardous effect on the aircraft's performance and handling qualities. The pneumatic IPS should be operated in flight at the minimum Appendix C Continuous Maximum icing condition temperature (-22 °F) to demonstrate adequate performance and to demonstrate that no damage occurs during cycling of the system. The system shall be capable of being operated within the Continuous Maximum and Continuous Intermittent envelopes of Appendix C. Appropriate speed and temperature limitations (if any) on use of the system should be included in the Airplane Flight Manual (AFM). By simulating a loss of pressure to the IPS, functioning of caution information required by 14 CFR § 25.1419(c) should be checked.

8.2.2.3 Propeller Thermal Ice Protection Systems

a. Information for demonstrating compliance with: 14 CFR part 23 § .903(c) and 14 CFR part 25 §§ .901(c), .903(b), and .1419(c) can be obtained during dry-air flight testing of propeller thermal IPSs.

b. Dry air testing with thermocouples placed on thermally-protected propeller surfaces and with instrumentation to measure consumed electrical power may be used to assess electrothermal IPS power requirements at the critical propeller operating condition for ice protection. Structural integrity of the propeller IPS if operated in hot weather may also be evaluated during dry air testing.

c. When flight testing in dry air, various system parameters should be monitored to confirm proper function. It is suggested that the system current, brush block voltage (i.e., between each input brush and the ground brush) and system duty cycles be monitored to ensure that adequate power is supplied to the IPS. The measured surface temperatures are useful for correlating analytically-predicted dry air temperatures with actual measurements, and as a general indicator that the system is functioning and that each element of the system is operating effectively.

d. The system operation should be checked throughout the full r.p.m. and propeller cyclic pitch range expected during flight in icing. Any significant vibrations should be investigated.

e. Consideration should be given to the maximum temperatures to which a composite propeller may be subjected when the IPS is energized. Monitoring the surface temperatures on bond-side of the thermal heating elements should be considered. When performing this evaluation, the most critical conditions should be investigated (e.g., aircraft on the ground with non-rotating propellers) on a hot day with the system inadvertently energized.

8.2.2.4 Windshield Ice Protection

Dry-air flight tests should be conducted to verify the thermal analysis. Both inner and outer windshield surface temperature measurements of the protected area may be needed to verify the thermal analysis. An evaluation of the visibility, including distortion effects through the protected area, should be made for both day and night operations. In addition, the size and location of the protected area should be evaluated for adequate visibility, especially during the approach and landing phases of flight. See Appendix Q - Windshield Ice Protection for further guidance and information.

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8.2.2.5 Air-data Instrumentation Ice Protection

Surface temperature measurements should be made for air-data instruments, such as pitot tubes, pitot-static pressure probes, and angle-of-attack probes (if ice protected), to verify thermal analyses. Also, compliance with 14 CFR parts 23 and 25 § .1326 should be checked relative to the acceptability of a required indication system for alerting the flight crew when the pitot tube heating system is not operating. An acceptable indication system may consist of separate lights or crew alert indication on an electronic display for each pitot source. Additional guidance on acceptable means of compliance with 14 CFR §§ 23.1326 and 25.1326 is provided in ACs 23-17A and 25-11, respectively.

8.2.2.6 Safe-flight Evaluation with Simulated Ice Shapes

a. Flight testing of an aircraft with attached simulated ice shapes may be used to demonstrate safe aircraft performance and handling qualities during flight in icing conditions. (See Section 6.2 Safe Flight in Icing Conditions.) Use of the simulated ice shapes allows the aircraft's flying qualities to be evaluated in stable, dry air and without melting, sublimation, shedding, and erosion of ice accretions, 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 reductions in flight test costs, relative to flight testing in natural icing conditions.

b. The simulated ice shape and surface texture should be developed and substantiated using methods found acceptable to the FAA. These methods should be conservative and should address the icing conditions defined in 14 CFR parts 25 and 29 Appendix C. The ice shapes and texture should be critical for the flight characteristic and phase of flight being investigated. Alternatively, a single, most critical ice shape and texture relative to all flight characteristics and phases of flight may be selected. Ice shapes and textures that form on protected and unprotected aircraft surfaces during the different phases of flight, including a 45 minute destination hold, should be considered for airplanes. Ice accretion that may form on protected surfaces prior to when the ice protection becomes fully effective following activation and during normal operation of the protection system, such as inter-cycle ice roughness on deicing systems, should also be considered. If the failure analysis required by 14 CFR parts 23, 25, 27, and 29 § .1309 indicates the need to demonstrate safe flight following a failure in the IPS, the resulting critical failure ice shape may be flown on the aircraft to demonstrate the required performance and handling qualities.

c. Appendix R – Ice Shapes provides information and guidance relative to determining the ice shapes and textures of protected and unprotected surfaces and for selection of critical ice shapes.

d. For information and guidance regarding testing methods and procedures, see ACs: 23-8A; 23-8A, Change 1; 23.1419-2B; 25.1419-1; 27-1B; and, 29-2C.

e. Flight test in measured natural icing conditions should be conducted to evaluate the adequacy of simulated ice shapes used during dry air testing. Guidance for establishing the quality of the ice shapes is provided in Appendix R – Ice Shapes. Note, 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 that result 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. The effects of the simulated and natural ice shapes during testing should be similar enough to establish confidence that the simulated ice shapes are conservative and were determined appropriately. The corroboration should include verification that ice is not forming in locations not predicted to accrue ice.

f. Also, performance and handling qualities evaluations performed with natural ice accretions should yield results comparable to the aircraft's performance and handling qualities demonstrated with the simulated ice shapes. Dissimilarity of results between the natural and simulated ice shape testing may require re-evaluation of the simulated ice shapes and re-testing, or additional testing in natural icing conditions.

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g. The effects of unprotected surface ice accretions, such as those on an unprotected radome or fuselage nose, on the operation of air data sensors (e.g., pitots, static air pressure sources, pitot-static pressure probes, angle-of-attack sensors, stall warning sensors) should be evaluated. No adverse effects on the operation of the sensors should occur. This evaluation may be performed using simulated ice shapes and checked during natural icing tests.

h. Necessary adjustments to operating speeds, stall protection system schedules, aircraft performance (including thrust loss resulting from the use of engine bleed air/power for ice protection or resulting from ice accretion on the propellers), and operating procedures and limitations should be implemented and the resulting information should be included in the AFM.

i. Testing with simulated ice shapes should be approached with extreme caution. Pre-flight analyses and flight test planning should result in a safe build-up to the full simulated-ice configuration.

8.2.2.7 Ice-Contaminated Tailplane Stall (ICTS)

Ice accretion on the horizontal stabilizer may cause early separation of the airflow over the control surface and loss of airplane attitude control and elevator authority. The reduced stall angle of the ice-contaminated horizontal stabilizer may occur with changes in the airplane configuration (e.g., increase flap extension), power, and flight conditions. Aerodynamic effects of reduced tailplane lift should be considered for all airplanes, including those with powered controls. An evaluation should be made to determine if this unsafe flight condition is likely to occur. Airplanes susceptible to this phenomenon are those having a near zero or negative tailplane stall margin with tailplane ice contamination. The 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 provided in AC 25.7A and AC 23.143-1. Appendix S - Ice-Contaminated Horizontal Stabilizer (Tailplane) Stall provides additional information and guidance relative to ice-contaminated horizontal stabilizer stall.

8.2.3 Artificial Icing Flight Tests

a. Flight testing in artificial icing conditions produced by supercooled water droplets sprayed from an array of nozzles has been successfully used to verify analyses required for approval of IPSs. The artificial icing conditions may be produced by icing tankers or by spray rigs installed on the test aircraft. Uses of artificial icing flight tests include determining or verifying the extent of droplet impingement, information to determine or verify simulated ice shapes, measurements of heat transfer coefficients, and to demonstrate ice shedding from selected aircraft components. Due to the limited size of the icing spray, testing is usually limited to components that have small exposed surfaces, such as heated air-data probes, antennas, air inlets (including engine induction air inlets), windshields, and local areas on the wing and empennage.

b. Section .1419 of 14 CFR parts 23, 25, 27, and 29 requires that artificial icing conditions, if used as a method of compliance, be measured. (See Appendix L.) Measurements should characterize the icing conditions relative to parameters useful for understanding the test objectives. Artificial icing plumes should be measured prior to testing, including an investigation of the liquid water content and drop diameter uniformity of the plume.

c. Alternatively, information should be provided to show current calibration of the icing plume relative to parameters used to produce the plume (e.g., spray array water and air pressures, mass flow of the water, water temperature, etc.).

d. Obtaining the LWC of small and large drop diameters of CFR parts 25 and 29 Appendix C may be difficult with some spray nozzles, therefore droplet impingement areas and ice shapes may differ from that produced in Appendix C icing conditions. Test results from artificial icing flight tests with icing conditions outside of that defined by 14 CFR parts 25 and 29 Appendix C should be shown to be conservative when compared with results that would have been obtained within Appendix C.

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e. Appendix T - Artificial Icing Flight Tests: Airborne Icing Tankers And Spray Rig Tests provides further information and guidance relative to artificial icing flight testing.

8.2.4 Wind Tunnel Tests

a. Section .1419, 14 CFR parts 23, 25, 27, and 29 states that, as necessary, laboratory dry air or artificial icing tests, or a combination of both, of the components or models of the components may be used with flight tests in measured natural icing conditions to verify the ice protection analyses, check for icing anomalies, and to demonstrate the effectiveness of the IPS. [Note that artificial icing tests are referred to as "simulated icing tests" in 14 CFR parts 23, 25, 27, and 29 § .1419.] Appendix U – Icing Wind Tunnel Tests and Section R.5.3 – Use of Icing Wind Tunnels to Predict Unprotected Surfaces Ice Shapes provides information and guidance relative to the use of icing wind tunnels. Section R.4.2 Aerodynamic Considerations for Determining Critical Ice Shapes of Appendix R – Ice Shapes provides information and guidance relative to the use of dry air wind tunnels for determining the aerodynamic effects of ice shapes.

b. For icing wind tunnel tests, test conditions and models should be designed to ensure that scaling parameters are maintained as closely as possible to the full-scale flight conditions. Test models should be mounted to simulate the flight attitude associated with the most critical condition. If flaps or other devices are used to produce the proper flow field conditions, instrumentation should be provided to show that test and design parameters are in agreement. In an icing tunnel test of an evaporative system, all of the impinging water should evaporate.

c. Liquid systems tested in an icing tunnel should prevent ice formation on the protection surfaces for the designed period of protection, with flow of freezing point depressant fluids within the design value.

8.3 Surfaces without Ice Protection

Ice buildup may be tolerable on some surfaces if the airplane has sufficient power or thrust to offset the additional lift and drag forces and if no unsatisfactory operating conditions result from the buildup. Control surfaces may be more critical than airframe surfaces in this respect. An analysis together with the rationale for leaving these surfaces unprotected from ice accumulation should be provided and should show that safe operation of the aircraft in icing conditions is possible with the ice protection that is elsewhere on the aircraft. If there is uncertainty about the lack of protection and about the adequacy of the provided ice protection to ensure safe operation of the aircraft in icing conditions, flight test demonstration should determine the effects of leaving the selected surface unprotected.

8.4 Ice Inspection Lights and Cues

a. Unless the aircraft is limited from operations at night into known or forecast icing conditions, 14 CFR part 25 § .1403 and 14 CFR part 23 § .1419(d) require that an adequate means be provided for determining ice accretion on airplane surfaces that are critical relative to ice accumulation. Adequate lighting must be provided for ice inspection during night operation unless another acceptable means of ice inspection is provided (such as a primary flight ice detector system [PFIDS]) [2]. Ice inspection lights should be evaluated both in and out of clouds during flight to determine that adequate illumination of the component of interest is available without excessive glare, reflections, or other distractions to the flight crew. These tests may be conveniently accomplished during the airplane certification flight tests. Typically, airplane-mounted illumination has been used as a means of compliance with these requirements. Use of a hand-held flashlight has not been considered acceptable due to the associated flight crew workload. The appropriate manual should identify the airframe icing cue that the flight crew is expected to observe and the flight crew action associated with the observation.

b. Note that for some airplanes the critical surface for ice accretion may not be the wing, but may be a control surface on the empennage which is not observable by the flightcrew. For these airplanes, means must be provided to alert the flightcrew prior to the ice accretion on the critical empennage surface.

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c. Sections .1419 of 14 CFR parts 23, 25, 27, and 29 require that an airplane must be able to operate safely in the conditions of 14 CFR parts 25 and 29 Appendix C. In order for the airplane to operate safely it is necessary that there be a means identified or provided for determining when the IPS must be activated. Ice accretion that occurs on a reference surface, observable by the flightcrew, may be acceptable providing the applicant can substantiate that the airplane can safely operate with the associated ice accretions that form on the airplane. Adequacy of these ice inspection cues should be evaluated during natural icing flight tests for the applicable types of aircraft operation, configurations, and phases of flight. The appropriate manual should identify the icing cues that the flight crew is expected to observe and should also identify the flight crew action associated with the observation.

d. If the flight crew cannot observe the wings or critical empennage control surface, one acceptable means of compliance with these regulations would be the installation of an ice evidence probe located in a position where the flight crew can observe the ice accumulation. Formation of ice on this device should be shown to precede or occur simultaneously with the formation of ice on the wings. Consideration should be given to the need for illuminating this device. Another means of compliance with these requirements is the use of primary inflight icing detectors, where the ice detector sensor becomes the reference surface. See Appendix K – Ice And Icing Conditions Detection for guidance relative to use of ice detectors.

8.5 Similarity Certification

a. Section .1419(c) of 14 CFR part 23 specifically permits approval of IPSs by similarity to previously-approved IPSs. Certification by similarity is allowed for other 14 CFR parts. Guidance for approval of ice protection provisions varies, depending on the certification basis of the airplane. (See AC 23.1419-2B.) For the approval of ice protection provisions based on similarities to other aircraft previously approved for flight in icing conditions, the applicant should specify the aircraft model and the component to which the referenced approval applies. Similarity certification may also apply to the replacement of an IPS component through the STC process. In addition, the applicant must possess all the regulatory compliance substantiation information from the referenced certification on which the similarity approval is based. Specific similarities should be shown in the areas of physical, functional, thermodynamic, pneumatic, aerodynamic, and environmental exposure. Analyses should be conducted 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. 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, these analyses should be carefully reviewed to ensure that flight safety remains acceptable and that the ice-protection effectiveness, integrity, and operating procedures are not adversely affected.

b. Similarity requires an evaluation of both the system and installation differences relative to the referenced aircraft that may adversely affect the system's functionality, performance, and subsequent effects on the aircraft's performance. If the similarity certification is for a change to the reference aircraft, the evaluation should also consider changes in system and aircraft behavior that may be perceived by the flight crew and influence flight-crew training or affect the aircraft's airworthiness or operational certification compliance. An assessment of a new installation should consider differences affecting the aircraft and the operation of other aircraft systems. If there is uncertainty about the effects of the differences, additional tests and/or analyses should be conducted as necessary to resolve these issues.

c. Results of the evaluation should be used to determine if the IPS should be re-tested in measured natural icing conditions. If there is uncertainty about the effects of the differences, flight tests should be conducted in measured natural icing conditions, within the applicable icing environment envelopes.

8.6 Perform Intended Function In Icing

All systems and components of the aircraft should continue to function as intended when operating in an icing environment including, for example:

8.6.1 Engines and Equipment.

Engines and equipment (such as generators and alternators operating under maximum ice protection load) should be monitored during icing tests for adequate cooling (14 CFR parts 23, 25, 27, and 29 § .1041) and be found acceptable for this operation (of 14 CFR parts 23,25, 27, and 29§§ .1093 and .1301).

8.6.2 Engine Alternate Induction Air Sources.

Engine alternate induction air sources should remain functional.

8.6.3 Fuel System Venting.

Fuel system venting should not be adversely affected by ice accumulation.

8.6.4 Landing Gear.

A retractable landing gear should operate as intended following an icing encounter. Gear retraction should not result in an unsafe indication because of ice accretion.

8.6.5 Stall Warning and Protection.

Ice could form on stall warning and AOA sensors if these devices are not protected. Therefore, the sensors' functions should be evaluated for operation in the icing conditions of 14 CFR parts 25 and 29 Appendix C. Adequate stall warning (aerodynamic or artificial) should be provided with ice accumulations on the aircraft. The type of stall warning in icing conditions should be the same as provided in non-icing conditions. Ice accumulations that should be considered are those on unprotected surfaces, those that occur prior to the initial activation of the IPS, those that occur between the ice protection activation cycles (intercycle ice), and those that remain after one cycle of the IPS (prior to landing). The activation points of artificial stall warning and stall identification/protection systems, if installed, may need to be reset for operations in icing conditions to provide adequate stall warning margins and to prevent inadvertent stalling or loss of control, respectively.

8.6.6 Ice Detection Cues.

Ice detection cues that the pilot relies on for timely operation of ice protection equipment should be evaluated in anticipated flight attitudes.

8.6.7 Primary and Secondary Flight Control Surfaces.

Primary and secondary flight control surfaces should remain operational after exposure to icing conditions. Demonstrate that aerodynamic balance surfaces are not subject to icing throughout the aircraft's operating envelope (weight, center of gravity, and speed) or that any ice accumulation on these surfaces does not interfere with or limit actuation of the control for these surfaces, including retraction of flaps for a safe go-around from an aborted landing.

8.6.8 Ram Air Turbine.

The ram air turbine should remain operational. It does not need to be tested in natural icing conditions if tested in the icing wind tunnel.

8.6.9 Pilot Compartment View.

In support of compliance with 14 CFR parts 23, 25, 27, and 29 § .773, pilot compartment view, any obstruction of the pilots' view due to ice accumulation should be noted.

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9. AIRPLANE FLIGHT MANUAL

The AFM should provide the pilot with the information needed to operate the IPS, as required by: 14 CFR parts 23, 25, 27, and 29, §§ .1425 and .1583; and 14 CFR parts 23, 27, and 29 § .1559.

9.1 Operating Limitations Section.

1. The minimum airspeed that should be maintained for each normal aircraft configuration whenever ice exists on the critical surfaces.

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

3. Landing weight limitations should be presented for flight in icing that reflect any effects on lift, drag, thrust, and operating speeds related to operating in icing conditions. These weight limitations may be presented in the Performance Information Section of the AFM and included as limitations by specific reference in the Limitations Section of the AFM.

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

5. Speed limitations (if any) and minimum temperature for deicing boot operation for aircraft equipped with boots.

6. Environmental limitations for equipment operations as applicable (e.g., minimum temperature for boot operation or maximum altitude for boot operation).

7. Minimum engine speed if the airframe IPS does not function properly below this speed.

8. A list of required placards.

9. For specific information on severe icing warnings, see AC 23.1419-2B and AC 25.1419-1.

9.2 Operating Procedures Section.

1. Section 1585 of 14 CFR parts 23, 25, 27, and 29 requires that the pilot be provided with recommended procedures that are peculiar to a specific aircraft or are required for safe flight. This should include any preflight action necessary to minimize the potential of enroute emergencies associated with the IPS. The system components should be described with sufficient clarity and depth that the pilot can understand their function. Unless flightcrew actions are accepted as normal airmanship, the appropriate procedures should be included in the FAA-approved AFM, AFM revision, or AFM supplement. These procedures should include proper pilot response the cockpit warnings, a means to diagnose system failures, and the use of the system(s) in a safe manner.

2. Procedures should be provided to optimize aircraft operation during penetration of icing conditions, including climb, holding, and approach configurations and speeds. The AFM should define when the ice protection equipment should be activated.

3. Emergency or abnormal procedures, including procedures to be followed when IPSs fail and/or warning or monitor alerts occur, should be provided.

4. For fluid anti-ice/deice systems, information and method(s) for determining the remaining flight operation time should be provided.

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5. For aircraft that cannot supply adequate electrical power for all systems at low engine speeds, load-shedding instructions should be provided to the pilot for approach and landing in icing conditions.

9.3 Performance Information Section.

Data should be provided so that climb-limited aircraft weights can be determined in icing conditions. These data should include the effect of drag due to residual ice on protected and unprotected surfaces, the power extraction associated with IPS operation, and any changes in operating speeds due to icing. The effect on landing distance due to revised approach speeds, and/or landing configurations, should be shown.

9.4 Airworthiness Directives for Severe Icing Conditions.

1. In October 1994, an accident involving a transport category airplane occurred in which severe icing conditions were reported in the area. During extensive testing the accident profile was replicated by ice shapes developed from testing in an icing cloud having droplets in the size range of freezing drizzle at a temperature near freezing. This condition created a ridge of ice aft of the deicing boots and forward of the ailerons, which resulted in uncommanded motion of the ailerons and rapid roll of the aircraft.

2. Following this accident the FAA determined that flightcrews are not currently provided with the information necessary to determine when the airplane is operating in icing conditions that have been shown to be unsafe and for which the airplane is not certificated; or what action to take when such conditions are encountered. Therefore, the FAA determined that flightcrews must be provided with such information, and must be made aware of certain visual cues that may indicate when the airplane is operating in atmospheric conditions that are outside the 14 CFR part 25, Appendix C icing envelope.

3. The FAA issued a series of Airworthiness Directives (ADs) in April 1996 and February 1998 on airplanes equipped with pneumatic deicing boots and non-powered roll control systems. The ADs require revising the AFM to provide the flightcrew with recognition cues for, and procedures for exiting from, severe icing conditions, and to limit or prohibit the use of various flight control devices.

4. The limitations and procedures specified in AD 96-09-25 are an acceptable means of providing this information. These limitations and procedures should be applied to all airplanes approved for flight in icing with reversible lateral controls, and should include, but are not limited to, the following:

    a. Visual cues that the airplane is in severe icing conditions;

    b. Prohibition on the use of the autopilot when the visual cues are observed;

    c. All icing detection lights operative prior to flight into icing conditions at night;

    d. Immediate exiting of the severe icing conditions; and

    e. If the flaps are extended, do not retract them until the airframe is clear of ice. (Note: The retraction of the flaps is contingent upon the existence of a means to determine if the airframe is clear of ice.)

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10. ROTORCRAFT

10.1 General

a. Guidance contained in this section is provided for completeness of this document since rotorcraft ice protection considerations differ in some respects from those for fixed-wing airplanes. Because of design and operation differences between fixed wing airplanes and rotorcraft, in-flight icing certification considerations differ. The rotor blades operate in a much wider range of airspeeds, and attention to the structural stability and integrity of the main rotor blades and tail rotor blades, rotorcraft vibration, shed-ice hazards, and instrument performance is important. Section 29.1419-ICE PROTECTION of AC 29-2C provides detailed guidance relative to demonstrating compliance with 14 CFR § 29.1419.

b. The objective of rotorcraft icing certification is to verify that throughout the approved operating envelope, the rotorcraft can operate safely in icing conditions expected to be encountered in service (14 CFR part 29 Appendix C, or as limited by altitude). This entails determining that no icing limitations exist or defining what the limitations are, as well as establishing the adequacy of the ice warning means (or system) and the ice protection system. A limiting condition may result, for example, from considerations of aircraft handling qualities, performance, autorotation, asymmetric ice shedding from the rotors, or visibility through the windshield.

c. Icing conditions defined by 14 CFR part 29 Appendix C may be truncated to a pressure altitude of 10,000 feet or the altitude limitation of the aircraft. Due to air traffic system compatibility constraints, approval of a maximum altitude less than 10,000 feet should be discouraged. However, there are operations where a lower maximum altitude has no effect on the air traffic system and would still be operationally useful. AC 29-2C states that icing conditions envelopes contained in AC 29-2C may be selected by applicants who elect to certify rotorcraft with a 10,000 pressure altitude limit on the basis of equivalent safety. (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 AC 29-2C icing conditions envelopes resulted from an analysis (performed by the FAA W. J. Hughes Technical Center during 1985) of the data used to establish 14 CFR part 29 Appendix C and are significantly different than those provided in 14 CFR part 29 Appendix C. For example, the AC 29-2C icing conditions envelopes for altitudes of 10,000 and lower indicate that temperatures colder than –10 °F and 0 °F need to be addressed for continuous and intermittent icing conditions, respectively. Comparative temperatures contained 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, as compared to sea level for 14 CFR part 29 Appendix C intermittent maximum icing conditions. Since icing conditions requirements provided by AC 29-2C differ and are less stringent than that required by 14 CFR parts 27 and 29 § .1419, FAA Legal General Counsel should be consulted prior to allowing their use.

e. The required icing conditions should be used for design assessment of the most critical combinations of conditions as a function of enroute distance. This, in combination with a capability to hold in icing conditions for 30 minutes at the destination, is commensurate with policies established for fixed-wing aircraft. As for fixed-wing aircraft, the 30 minutes destination hold design assessment should consider the LWC at the standard cloud extents of 17.4 Nmi and 2.6 Nmi for continuous maximum and intermittent maximum icing conditions, respectively. Care should be taken to assess the entire ranges of the parameters used to define the required icing conditions envelopes during the design, development, and certification efforts.

f. The effects of ice can vary considerably from rotorcraft to rotorcraft. Experience gained for a rotor system with an identical blade profile could provide valuable information but should be used cautiously when applied to another rotorcraft. Particular care should be exercised when drawing from fixed-wing icing

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experience as the widely different and varying conditions seen by the rotor blades make many comparisons with fixed-wing results invalid.

g. Most rotorcraft icing technology has been developed for military aircraft. Although this experience provides useful background information, compliance with 14 CFR parts 27 and 29 in-flight icing requirements must be fully demonstrated. Information concerning rotor blade ice protection and rotorcraft ice protection system design is provided in [3].

10.2 Compliance

a. In general, compliance can be established when there is reasonable assurance that while operating in the required icing environment:

1. The engine(s) will not flameout or experience significant power losses or damage.
2. Stress levels are not reached with ice accumulations that can endanger the rotorcraft or cause serious reductions in component life.
3. Inlet, vent, or drain blockage (such as fuel vent, engine, or transmission cooler) is not excessive.
4. Autorotation characteristics are acceptable with maximum ice accretion between deice cycles.

b. Also, since rotorcraft characteristics, configurations, and critical areas can differ widely, the following should be among other appropriate considerations:

1. The rotorcraft should be shown by analysis and confirmed by either natural or artificial icing tests to be capable of holding for 30 minutes in the critical design conditions of the continuous maximum icing conditions of 14 CFR part 29 Appendix C or the altitude-limited continuous icing conditions at the most critical weight, center-of-gravity, and altitude with a normal operating ice protection system.
2. A single ice protection system and power source may be considered acceptable provided that after any single failure of the ice protection system, the rotorcraft can be shown by analysis and/or test to be capable of safe operation (no hazard) for 15 minutes following failure recognition in the continuous icing conditions used for consideration of the 30 minutes hold criteria. The rotorcraft must be free from excessive and rapid divergence
3. If the ice protection system is not operated continuously, there must be a means to advise the crew when the rotorcraft is in icing conditions so that they activate the system using Rotorcraft Flight Manual (RFM) procedures.
4. No autorotational performance data are required for rotorcraft that have Category A powerplant installations. All rotorcraft certified for flight in icing conditions must be capable of full autorotational landings with the ice protection system operating. Autorotational entry, steady state, and flare entry flying qualities and performance should be evaluated with an ice load.
5. Since the Category A enroute performance can vary as the ice protection system operates, a mean value of cyclic torque is acceptable provided the rate of climb is less than zero at no time.
6. The hover performance should be addressed following an icing encounter for the termination of a mission.
7. The engines must be protected from the adverse effects of ice and snow. When ice and snow accumulate on the inlets, screens, etc., their effects on engine performance, operating characteristics, and rotorcraft performance must be addressed.

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8. Handling qualities of the rotorcraft must be evaluated if ice can accumulate on any surface. When ice can accrete on unprotected surfaces, the rotorcraft must exhibit satisfactory VFR/IFR handling qualities.

9. Components, such as fuel tank vents, cooling vents, antennas, etc. must be evaluated with maximum ice effects relative to the components performing their intended function.

10. Compliance with 14 CFR parts 27 and 29 § .1309 must be demonstrated.

11. The rotorcraft must be protected to minimize lightning strike risks. The general rules of 14 CFR parts 27 and 29 § .1309(a), (b), and (c) are applicable to ensure adequate lightning protection.

12. Ice protection of the air data system sensors/probes, windshields, inlets, exposed control linkages, etc., must be considered.

13. Delayed activation of the ice protection system should not result in hazardous conditions. Any rotorcraft characteristic changes should be addressed as cautionary information in the RFM.

14. Icing-related droop stop malfunction and potential hazards to the rotorcraft, it occupants, and ground personnel must be assessed.

15. Ice-shedding hazards to ground personnel or equipment following flight in icing conditions should be considered.

c. Assessment of 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 for fixed-wing aircraft, 14 CFR parts 27 and 29 § .1419 requires that an analysis must be performed to establish, on the basis of the rotorcraft's operational needs as discussed above, the adequacy of the ice protection system for the various components of the rotorcraft. In addition to the analysis and physical evaluation that the rotorcraft can be operated safely in the required icing conditions, the effectiveness of the ice protection system and its components must be shown by flight test of the rotorcraft or its components in measured natural atmospheric icing conditions and, as necessary, by:

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. There should be a means identified or provided for determining the formation of ice on critical parts of the rotorcraft that can be met by a reliable and safe natural warning or by an ice detection system.

10.2.1 Analysis

a. Analyses should be performed, submitted, and accepted by the FAA (prior to flight tests in icing conditions) to determine the design points for the ice protection systems for the various rotorcraft components (windshield, engine inlet(s), rotor blades, etc.). Analyses submitted for approval at validated critical points should demonstrate that the rotorcraft is capable of operating safely at the identified critical design points that address both the continuous maximum and intermittent maximum icing conditions of 14 CFR part 27 and 29 Appendix C, or the altitude-limited icing envelopes. Critical icing conditions should be verified by test. Specific attention should be given to:

1. Qualification and design of the ice protection systems and components.

2. Component installation and ice formation effects on basic rotorcraft structural properties and performance and handling qualities. (These assurances can be established from analyses, bench tests, and/or dry air flight tests or artificial icing tests, as appropriate.)

b. The analyses should include an assessment of pre-activation and intercycle ice accretion, including that resulting from performance limitations of sensors used in automated ice protection systems. An automated system utilizing outside ambient temperature (OAT) should have a total system accuracy of ± 0.5 °C within the temperature range of ± 5 °C and ± 1 °C throughout the remaining temperature range. If an automated system uses measured LWC or a warning is provided based on measured LWC, consideration should be given to conservative use of the measured LWC because of the accuracy and precision of the measured LWC and the fluctuation of LWC during natural icing conditions. After the analyses are reviewed and found adequate, tests should be conducted to validate the analyses and to confirm that the rotorcraft can operate safely in the required icing conditions.

c. The applicant should assess rotor blade stability with ice accretions to insure that dynamic instability will not occur in icing conditions. This assessment may be accomplished by analysis, including consideration of failure of the most critical segment of the rotor blade ice protection system. (This assessment may be accomplished by experimental means, such as attaching critical simulated ice shapes to the blades and using a whirl stand or wind tunnel.)

d. The applicant should also perform an assessment of the effects on the rotorcraft components' structural fatigue and life cycle resulting from vibrations caused by the accretion of ice. The static and fatigue strength of the rotor blade with heater mats must be substantiated. Any effect of the heater mat on fatigue strength of the blades must be considered.

e. A detailed failure modes and effects analysis (FMEA) of the ice protection system should be performed.

f. Careful attention should be given to the installation, ice protection, and performance of air data sensors and ice detectors because of the wide ranges of airspeeds and local flow angles that these instruments may experience. Position error corrections may be significant. See Appendix K – Ice and Icing Conditions Detection for guidance relative to the installation and acceptance of ice detectors.

g. See Section 8.1 – Analysis for additional guidance.

10.2.2 Tests

Neither laboratory, icing wind tunnel, nor artificial icing tests, individually or collectively, can satisfy the full requirements for certification of rotorcraft ice protection provisions. None can presently duplicate the combinations of LWC, droplet size and distribution, flow fields, and random ice-shedding behaviors found in natural icing conditions testing. Until an icing simulation method has been successfully validated, approval of rotorcraft ice protection provisions should include flight tests in natural icing conditions.

10.2.2.1 Natural Icing Flight Tests

a. Natural icing tests should be conducted in conditions as close to the critical design conditions as possible, and sufficient correlation shown with the analyses to assure that the rotorcraft can operate safely throughout the required icing conditions. Natural icing at all of the critical icing conditions may be impractical.

b. Prerequisites for natural icing flight test include:

1. The rotorcraft must be in conformity with type design drawings and capable of IFR and IMC flight.

2. Sufficient analyses should be submitted and accepted by the FAA that show that the rotorcraft is capable of operating safely at the critical design icing conditions within both the continuous maximum and intermittent maximum conditions of 14 CFR part 29 Appendix C including qualification of the ice protection systems, rotorcraft structural integrity, and rotorcraft performance and handling.

3. A detailed FEMA of the ice protection system should be performed.

4. An assessment of the rotor blade stability with critical ice accretions to insure that dynamic instability will not occur in icing conditions should be performed.

c. Certification flight-testing should be extensive enough to provide reasonable assurance that either induced or random ice shedding does not present a hazard. For example, vibration from asymmetric ice shedding from rotor blades (imbalance rotor) or the impact of shed ice on the rotorcraft airframe should be considered. The following should be considered sufficient cause for rejection:

1. Vibrations sufficient to make the instruments difficult to read accurately.

2. Vibrations sufficient to exceed the structural or fatigue limits of any rotorcraft part, such as blade, mast, or transmission components.

3. Hazardous shed-ice impact danger to essential parts, such as the tail rotor. See Section 8.2.1.4-Ice Shedding for additional guidance.

d. Instrumentation for certification flight tests, including structural strain measurements and optical documentation of ice accretion on critical surfaces to record the ice protection system efficacy and critical ice shapes, should be reviewed for adequacy. Flight strain measurements should be made to assess ice-imposed structural stress and to verify structural stress and fatigue analyses for such components as the main rotor blades, main rotor hub components, rotating and fixed controls, horizontal stabilizer, tail rotor, etc. For guidance relative to the required measurement of the natural icing conditions experienced during the flight test, see Section 8.2.1.1 – Test Icing Conditions Considerations.

e. See Section 8.2.1 – Natural Icing Flight Tests for applicable additional guidance.

10.2.2.2 Dry Air Flight Tests

a. Dry air flight tests are usually the first stems conducted to evaluate the operation of the ice protection system. Thermal data acquired during dry air tests may be useful in validating the ice protection system thermal analysis. See Section 8.2.2 –Dry Air Flight Tests for guidance, acknowledging operational and configuration considerations that are unique to rotorcraft.

b. Dry air testing with simulated critical ice shapes may be used to demonstrate safe rotorcraft performance and handling qualities and structural stability and fatigue characteristics of the rotor with normal operation and failed ice protection systems. Dry air testing with simulated ice shapes facilitates demonstration of compliance with the required regulations, and results in significant reductions in flight test costs, relative to performing similar testing in natural icing conditions.

c. See Section 8.2.2.6-Safe – Safe-flight Evaluation with Simulated Ice Shapes for additional guidance.

10.2.2.3 Artificial Icing Flight Tests

Generally, icing tankers have not been able to produce icing plumes with droplet sizes and distributions that replicate the full icing condition envelopes required for certification. The large droplet sizes produced by the icing tankers have been typically been a problem. Also, the breadth of the icing tanker plume typically has been insufficient to fully immerse the entire rotorcraft. The tanker should be able to produce a uniform icing cloud

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that immerses the entire rotor system as a minimum, and should have a means of consistently controlling and changing the cloud characteristics. See Section 8.2.3 – Artificial Icing Flight Tests for further guidance.

10.2.2.4 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 disc contribute to the wind tunnel testing difficulty. Although the typical high aspect-ratio of rotor blades permit confident use of two-dimensional analyses, these analyses should address the rotating blade's spanwise flow field and spanwise unfrozen water flow unless these considerations are proven insignificant. Similarly, ice accretion on other components of the rotorcraft should consider the effects of the rotor's slip-stream, if appropriate. See Section 8.2.4 – Wind Tunnel Tests for further guidance.

10.3 Rotorcraft Fight Manual

a. As for fixed-wing aircraft, appropriate icing-related operating limitations, normal operating procedures, emergency, and caution notes should be included in the RFM. Considerations of rotorcraft relatively low altitude operations and possible significant vibration resulting from asymmetric ice-shedding warrant a caution notice in the RFM advising that the rotorcraft is not certified for operation in freezing rain or freezing drizzle. Avoidance procedures (e.g., climb or descent) may be provided. Caution notes should also advise or address:

1. Against inducing asymmetric ice-shedding using rapid control inputs or rotor speed changes, except as 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 and use of approved cleaning solvents or ground de/anti-icing agents prior to start of rotor turning.

4. Changes in autorotation characteristics resulting from ice accretion.

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 – Aircraft Frost And Clear Ice Considerations provides guidance and information relative to considerations of frost and clear ice.

12. AIRPLANE DE/ANTI-ICING PRIOR TO TAKEOFF

a. Section .527 of 14 CFR part 91, 14 CFR part 121 § .629, and 14 CFR part 135 § .227 state that no person may take off an aircraft when frost, ice, or snow is adhering to the wings, control surfaces, propellers, engine inlets, or other critical surfaces of the aircraft. Advisory Circulars AC 20-117, AC 135-16, AC 135-17, AC 120-58, and AC 120-60 contain relevant information to these operating requirements. Additionally, Flight Standards Information Bulletins for Air Transportation (FSAT) are frequently published. These bulletins contain latest holdover time guidelines and the most recent information available on operating in ground icing conditions.

b. In compliance with this requirement, prior to takeoff, aircraft are deiced and, as required, anti-iced using thickened pseudo-plastic fluids. This procedure prevents the adherence of ice to the aircraft's surfaces prior to takeoff, but does not insure that ice will not accrete on aircraft surfaces during and after takeoff.

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Also, the presence of thickened fluid may affect the airplane's performance and handling qualities since the fluids may not completely flow off the airplane surfaces prior to liftoff. Fluid residue may cause increased control forces during takeoff and takeoff climb for airplanes with reversible control surfaces. The fluid may also collect and not fully drain from the bays of airplanes with aerodynamically and/or weight balanced control surfaces. Weight of the collected fluid may result 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, such as that along control surface hinge lines. When the residue of the evaporated anti-icing fluid is re-hydrated by rain or during washing of the airplane, it may freeze and lock the control surface when the airplane reaches sub-freezing 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 International Standard Organization (ISO) have established aerospace material standards (AMS), and aerospace recommended practices (ARP) for de/anti-icing fluids methods of de/anti-icing airplanes [4] to [9]. As part of the specifications, operators are requested to ask their airframe manufacturers to approve the use of specific de/anti-icing fluids. The FAA has not established standards for demonstrating the acceptability of these fluids relative to aircraft performance and handling requirements.

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

a. Consideration of the effects of ice accretion and engine power extraction resulting from operation of ice protection systems should be addressed when approving airplanes for extended range operations for twin-engine. To be eligible for extended range operations, the airframe-engine combination should be certificated to the appropriate transport airplane airworthiness standards and should be evaluated relative to guidance provided in AC 120-42A. All twin-engine airplanes operated under 14 CFR part 121 are required to comply with 14 CFR § 121.161. 14 CFR §121.161 states that the Administrator may authorize operation of a two-engine over a route that contains a point farther than one-hour flying time from an adequate airport. AC 120-42A provides guidance for such approval. Relative to extended exposure to icing conditions, the significant implication of ETOPS is that following and engine failure or cabin pressurization malfunction, the airplane may have to descend and cruise for extended periods at altitudes and airspeeds conducive to airframe icing while diverting to the nearest alternate airport. The time of the diversion may be much longer than the 45 minute holding in icing conditions considered for approval of ice protection systems under 14 CFR parts 23 and 25.

b. AC 120-42A states that the following should be addressed:

1. It should be shown during type design evaluation that adequate engine limit margins exists for conducting extended duration single-engine operation during the diversion at all approved power levels and in all expected environmental conditions. This assessment should account for the effects of additional engine loading demands (e.g., anti-ice, electrical, etc.) which may be necessary during the single-engine flight phase associated with the diversion.

2. Airframe and propulsion ice protection should be shown to provide adequate capability (airplane controllability, etc.) for the intended operation. This should account for prolonged exposure to lower altitudes associated with the engine-out diversion, cruise, holding, approach, and landing.

3. The critical fuel scenario should allow for: (1) a contingency figure of five percent added to the calculated fuel burn from the critical point to allow for errors in wind forecasts, (2) a 5 percent penalty in fuel mileage if the actual fuel mileage deterioration is not known, and (3) Configuration Deviation List items, both airframe and engine anti-icing; and account for ice accumulation on unprotected surfaces if icing conditions are likely to be encountered during the diversion.

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4. Airplane performance information should be provided, including detail of any conditions relevant to extended range operations which can cause significant deterioration of performance, such as ice accumulation on the unprotected surfaces of the airplane.

5. Systems redundancy levels appropriate to extended range operations should be reflected in the Master Minimum Equipment List (MMEL), including ice protection.

c. Relative to airplane icing, demonstrating conformity with AC 120-42A means that the aerodynamic effects of ice accretion on the airplane resulting from icing conditions likely to be encountered during a diversion should be evaluated. Fuel loading should also consider the drag resulting from the ice accreted during a diversion in addition to the power extractions associated with operation of the ice protection system. Sufficient 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, other engine power extractions, such as for cabin pressurization, electrical power, and hydraulics conditions should be considered at the critical airplane weight, altitude, ambient temperature, and airspeed condition. Airplane performance information reflecting these considerations should be provided in the Airplane Flight Manual or be referenced in the Airplane Flight Manual.

d. Ice protection systems redundancy beyond those resulting from 14 CFR § 23.1309 and 14 CFR § 25.1309 should conform with the risk analysis method presented in AC 150-42A, and the airplane's MMEL should be compatible with the results of the safety reliability evaluation. Consideration should be given to the ice protection system capability with an in-operative engine relative to acceptable equipment and systems operation during likely icing conditions during the diversion. Adequate electrical power, hydraulics, system and equipment cooling, air data system information, and windshield visibility should be maintained.

e. Demonstration of adequate capability (airplane controllability, etc.) may be accomplished during the demonstration of safe flight as required by 14 CFR parts 23 and 25 § .1409, provided ice accretion resulting from icing conditions likely to be encountered during the diversion are less aerodynamically adverse than the critical Appendix C ice accretions. Adequate capability may be interpreted as safe flight. Demonstration of safe flight is discussed in 6.2 – Safe Flight in Icing Conditions. Although AC 120-42A only addresses ice accretion on unprotected surfaces, since the advisory circular focused on large turbine-powered transports with thermal ice protection systems, normal-operation ice accretions on protected surfaces should also be addressed. Normal-operation ice accretions include intercycle ice roughness and runback ice resulting from extended operation in icing conditions. Simulated ice shapes may be used to demonstrate conformity with AC 120-42A (see Appendix R – ICE SHAPES). The applicant may select the most adverse ice accretion shape to show compliance with 14 CFR parts 23 and 25 § 1409 and conformity with AC 120-42A. Note, conformity with AC 20-42A may require obtaining additional contaminated airplane drag at higher airspeeds than those airspeeds required to demonstrate compliance with 14 CFR parts 23 and 25 § 1409, and with ice accretion on airplane components that are no longer ice protected as a result of an engine failure. For example, ice accretion on the inoperative-engine nacelle and engine components and runback ice or intercycle ice accretion resulting from lower ice protection performance with a inoperative-engine should be considered during demonstrating conformance with AC 120-42A.

f. Since AC 120-42A states that icing conditions likely to be encountered during the diversion should be considered, applicants should have adequate knowledge of the likely icing conditions for the selected diversion routes to confidently define those icing conditions. An acceptable means is for the applicant to have sufficient information to define the probability of a not-to-exceed icing storm supercooled water content (SLWC) for the maximum diversion route. Knowing the likely supercooled drop size distribution and the SLWC probability densities and probability distributions, the supercooled water catch exceedance probability can be estimated as a function of supercooled water catch for a given diversion route and length, temperature, and airplane configuration. Selection of the appropriated supercooled water catch exceedance probability would then determine the supercooled water catch for the airplane. (This process is explained more fully in [10].) The relationship between the supercooled water catch exceedance probability and supercooled water catch will vary with the likely icing conditions over the diversion route, the duration of the diversion, and the airplane's configuration and performance characteristics. No icing conditions standard nor adjustments for cloud extent variation, such as 14 CFR part 25 Appendix C, have been established. The applicant should provide acceptable information to substantiate the selected diversion icing condition. Selection of the diversion icing condition probabilities should be conservative and compatible with the overall safety risk assessment of the airplane for ETOPS operations and since the airplane may be operated on ETOPS routes unconsidered during the initial ETOPS approval.

g. Having established the diversion icing conditions and duration, critical ice shapes for the diversion may be determined as describe in Appendix R – Ice Shapes.

h. Since the likely diversion icing condition may not conform with Appendix C, the ability of ice detectors to reliably perform their intended function during the diversion should be demonstrated.

14. REFERENCES

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

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

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

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.

Signed by:

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