U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: CERTIFICATION OF PART 23 AIRPLANES FOR FLIGHT IN ICING CONDITIONS

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Initiated by: ACE-100

AC No: 23.1419-2
Change:

1. PURPOSE. This advisory circular (AC) sets forth an acceptable means, but not the only means, of demonstrating compliance with the ice protection requirements in part 23 of the Federal Aviation Regulations (FAR). The Federal Aviation Administration (FAA) will consider other methods of demonstrating compliance which an applicant may elect to present. This material is neither mandatory nor regulatory in nature and does not constitute a regulation.

2. CANCELLATION. AC 23.1419-1, Certification of Small Airplanes for Flight in Icing Conditions, dated September 2, 1986, is cancelled.

3. APPLICABILITY.

a. This material supplements guidance provided in FAA Technical Report DOT/FAA/CT-88-8-1, "Aircraft Icing Handbook," and AC 20-73, "Aircraft Ice Protection," and pertains to multiengine and single-engine ice protection system approvals for airplanes certificated under part 3 of the Civil Air Regulations (CAR) and part 23 of the FAR. The guidance provided herein applies to ice protection systems approval for operating in the icing environment defined by part 25, appendix C. The guidance should be applied to new Type Certificates (TCs), Supplemental Type Certificates (STCs), and amendments to existing TCs for airplanes under part 3 of the CAR and part 23 of the FAR, for which approval under the provisions of § 23.1419 is desired.

b. This AC does not cover any recommendations from the NASA/FAA Tailplane Icing Workshop of November 4-6, 1991. Applicable recommendations from that workshop will be covered in the next revision to this AC.

4. RELATED FAR SECTIONS. By their adoption in amendment 23-14, which shows their requirements are directly related, §§ 23.929, 23.1309, and 23.1419 are applicable to a part 23 airplane icing certification program regardless of the certification basis for the basic airplane. However, for those airplanes certified in accordance with part 3 of the CAR and part 23 of the FAR through amendment 23-13, the application of these sections may be limited to the equipment being used for ice protection. Some systems which were previously approved on the airplane may need to be modified to improve their reliability when those systems are utilized as part of that airplane's icing approval.

The FAA has determined that the previous practice of applying part 25 requirements (which are not specifically cited in part 23) to part 23 airplanes is no longer acceptable. The practice of adding § 25.1323(e) to certification requirements of airplanes approved for icing flights should no longer be pursued. Section 23.1419, paragraph (b), requires an analysis to establish the adequacy of the ice protection system for various components in the airplane. Like other components which are not specifically identified in § 23.1419, the pitot tube(s) is one of the components which should be protected. Because the need to install pitot heat is not novel or unique, a special condition is not necessary.

In addition to the previously mentioned requirements (§§ 23.929, 23.1309, and 23.1419), the following sections should be applied depending upon the ice protection system design and the original certification basis of the airplane:

DATE OF AIRPLANE TYPE CERTIFICATION APPLICATION	CAR/FAR STATUS	ICING CERTIFICATION REQUIREMENTS
Prior to February 1, 1965	Part 3 of the CAR (May 15, 1956, as amended through amendment 3-8)	§§ 3.85(a) and (c), 3.85a(a) and (c), 3.382, 3.383 (including note following (b)), 3.652, 3.652-1, 3.665, 3.666, 3.681, 3.682, 3.685, 3.686, 3.687, 3.690, 3.691, 3.692, 3.712, 3.725, 3.758, 3.770, 3.772, 3.777, 3.778, and 3.779
On or after February 1, 1965	Recodification	§§ 23.65, 23.75, 23.77, 23.773, 23.775, 23.1301, 23.1351, 23.1357, 23.1437, 23.1541, 23.1559(b), 23.1583(h), 23.1585, and 23.1419 (boot requirement before amendment 23-14)
On or after July 29, 1965	Amendment 23-1	Add § 23.1325 to the above part 23 requirements.
On or after February 5, 1970	Amendment 23-8	Add § 23.1529 to the above part 23 requirements.
On or after December 20, 1973	Amendment 23-14	Add §§ 23.853(d) and 23.903(c) to the above part 23 requirements.
On or after September 1, 1977	Amendment 23-20	Add §§ 23.1327 and 23.1547 to the above part 23 requirements.
On or after December 1, 1978	Amendment 23-23	Add §§ 23.853(e), 23.863, and 23.1416 (in lieu of the boot requirement of § 23.1419 before amendment 23-14) to the above part 23 requirements.
On or after February 17, 1987	Amendment 23-34	For commuter category airplanes, add § 23.67(e)(2) and (3) to the above part 23 requirements.

5. RELATED READING MATERIAL. FAA Technical Report DOT/FAA/CT-88/8-1, "Aircraft Icing Handbook" (March 1991), includes reference material on ground and airborne icing facilities, simulation procedures, and analytical techniques. This document represents all types and classes of aircraft and is intended as a working tool for

the designer and analyst of ice protection systems. FAA Technical Report ADS-4, "Engineering Summary of Airframe Icing Technical Data," and Report No. FAA-RD-77-76, "Engineering Summary of Powerplant Icing Technical Data," provide technical information on airframe and engine icing conditions, and methods of detecting, preventing, and removing ice accretion on airframes and engines in flight. Although most of the information contained in ADS-4 and FAA-RD-77-76 reports is still valid, some is outdated, and more usable information is now available through recent research and experience and is included in the Aircraft Icing Handbook. AC 20-73, "Aircraft Ice Protection," provides information on substantiation of ice protection systems on aircraft. The information provided by AC 20-73 as it pertains to part 23 airplanes is supplemented by this AC. Also, AC 23.629-1A, "Means of Compliance with Section 23.629, Flutter," provides guidance on part 23 airplane flutter investigation which may be applicable to ice accumulation.

The advisory circulars listed above can be obtained from the U.S. Department of Transportation, Utilization and Storage Section, M-443.2, Washington, D.C. 20590.

The FAA technical reports listed above can be obtained from the Department of Commerce, National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161. The NTIS telephone number is (703) 487-4650. If you do not have a technical report's stock number, you can call the NTIS Title Identification Office at (703) 487-4780.

6. BACKGROUND. Prior to 1945, airplanes were certified under part 04 of the CAR. Section 04.5814 required that if deicer boots were installed, they would have a positive means of deflation. There were no other references to an ice protection system in part 04.

When separate regulations (part 03 of the CAR) were written for normal category airplanes, this requirement for positive means of deflating deicer boots was incorporated without change in § 03.541. In 1949, § 03.541 was renumbered as § 3.712.

Ice protection was not addressed again until part 3 of the CAR was revised in 1962 by amendment 3-7. This amendment added §§ 3.772 and 3.778 which require that information be provided to the crew specifying the types of operation and the meteorological conditions to which the airplane is limited by the equipment installed. This section gave icing as a specific example of the meteorological conditions to be delineated. This change required a list of all installed equipment affecting the airplane operations limitations. The list also identified this equipment as to its operational function. This list of equipment later became known as the Kinds of Operation Equipment List (KOEL).

In 1964, part 3 of the CAR was recodified into part 23 of the FAR. After recodification, § 3.712 became § 23.1419 and §§ 3.772 and 3.778(h) became §§ 23.1559 and 23.1583(h), respectively. In 1965, § 23.1325 was revised by amendment 23-1 to take into account the effect of icing conditions on static pressure dependent instruments. This requirement applies to all airplanes regardless of whether or not they have an ice protection system approved under § 23.1419. In the latter part of 1968, the FAA instituted an extensive review of the airworthiness standards of part 23 of the FAR. As a result of this review, the FAA issued amendment 23-14 (November 1973) which made several substantive changes in the interest of safety to part 23 of the FAR. This amendment introduced a new § 23.929 requiring engine installation ice protection and completely revised § 23.1419 to establish standards for ice protection systems. It also introduced a new § 23.1309 which established reliability and noninterference requirements for installed equipment and systems. These three sections are directly related as defined in § 21.101 to the certification of an ice protection system because of the increased reliance on this system when operating the airplane in an icing environment.

Specific standards for pneumatic deicer boots which were contained in the former § 23.1419 were inadvertently omitted in amendment 23-14. The FAA, realizing that a specific standard for pneumatic deicer boot systems was needed, issued amendment 23-23 in 1978 which added § 23.1416, Pneumatic deicer boot system. As currently configured, certification requirements are limited to those icing conditions produced by supercooled clouds as defined by part 25, appendix C, and do not require design or proof of capability to operate in freezing rain and drizzle, snow, or mixed conditions.

In 1987, with the creation of the commuter category, airplanes which had weight, altitude, and temperature limitations for takeoff, en route and landing distance were being certificated. Since the operational rules preclude takeoff with ice on the airplane, the FAA determined that ice accretion on unprotected surfaces should not be a consideration until the airplane climbs through 400 feet above ground level (AGL).

7. PLANNING. The applicant should submit a certification plan at the start of the design and development effort. The certification plan should describe all of the applicant's efforts intended to lead to certification. This plan should identify, by item to be certified, the certification methods that the applicant intends to use. It should provide for a certification checklist; and with regard to § 23.1419, it should clearly identify analyses and tests, or references to similarity of designs which the applicant intends for certification of the ice protection system. These methods of showing compliance should be agreed upon between the applicant and the FAA early in the type certification program, and it is imperative that the applicant obtain FAA concurrence prior to conducting certification tests. The certification plan should include the following basic information:

a. Airplane and systems description.

b. Ice protection systems description.

c. Certification checklist.

d. Analyses or tests performed to date.

e. Analyses or tests planned.

f. Projected schedules of design, analyses, testing, and reporting.

8. DESIGN OBJECTIVES. The applicant should demonstrate by analyses, tests, or a combination of analyses and tests that the airplane is capable of safely operating throughout the icing envelope of part 25, appendix C, or throughout that portion of

the envelope within which the airplane is certificated for operation where systems or performance limitations not related to ice protection exist. Appendix 1 to this AC lists various influence items which should be examined for their effect on safety when operating in icing conditions.

9. ANALYSES. The applicant normally prepares analyses to substantiate decisions involving application of selected ice protection equipment to areas and components and to substantiate decisions which leave normally protected areas and components unprotected. Such analyses should clearly state the basic protection required, the assumptions made, and delineate the methods of analysis used. All analyses should be validated either by tests or by reference to previous substantiation using methods documented in accepted icing literature, such as FAA Technical Report DOT/FAA/CT-88/8-1, "Aircraft Icing Handbook." These substantiations should include a discussion of the assumptions made in the analyses and the design provisions included to compensate for these assumptions. Analyses are normally used for the following:

a. Areas and Components to be Protected. The applicant should examine those areas listed below to determine the degree of protection required:

(1) Leading edges of wings, winglets, and wing struts; horizontal and vertical stabilizer; and other lifting surfaces.

(2) Leading edges of control surface balance areas if not shielded.

(3) Accessory cooling air intakes which face the airstream and/or could otherwise become restricted due to ice accretion.

(4) Antennas and masts.

(5) Fuel tank vents.

(6) External tanks.

(7) Propellers.

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

(9) Instrument transducers including pitot tube (and mast), static ports, angle of attack sensor, and stall warning transducers.

(10) Forward fuselage nose cone and radome.

(11) Windshields.

(12) Landing gear.

(13) Retractable forward landing lights.

An applicant may find that protection is not required for one or more of these areas and components. If so, the applicant should include supporting data and rationale in the analysis for allowing them to go unprotected. The applicant should demonstrate that allowing them to go unprotected does not adversely affect the handling or performance of the airplane.

b. The 45-minute Hold Condition. The 45-minute hold criterion should be used in developing critical ice shapes for which the operational characteristics of the overall airplane are to be analyzed. The airplane's tolerance to continuous ice accumulation on the unprotected surfaces should be evaluated in accordance with the information contained in AC 20-73, paragraphs 12a and 18b. The applicant should determine the effect of the 45-minute hold in continuous maximum icing conditions. A median droplet diameter of 22 microns and a liquid water content of 0.5 gm/m^3 with no horizontal extent correction is normally used for this analysis. The analysis should consider that the airplane would remain in an icing cloud based on a rectangular course with leg lengths not exceeding the cloud horizontal extent and all turns being made within the icing cloud. The applicant may elect to use more severe liquid water contents which are more representative of expected holding altitudes. The critical ice shapes derived from this analysis should be compared to critical shapes derived from other analyses (climb, cruise, and descent) to establish the most critical artificial ice shapes to be used during dry air flight tests. Should this analysis show that the airplane is not capable of withstanding the 45-minute hold, then a reasonable hold period may be established for the airplane and a limitation placed in the Airplane Flight Manual (AFM).

c. Flutter Analysis. A flutter investigation (see AC 23.629-1A) should be made to show that flutter characteristics are not adversely affected taking into account the effects of mass distribution of ice accumulations. This investigation relates to unprotected surfaces and to protected surfaces where residual accumulations are allowed throughout the normal airspeed and altitude envelope; however, the effect of ice shapes on aerodynamic properties need not be considered for flutter analysis.

d. Power Sources. The applicant should evaluate the power sources in his ice protection system design. Electrical, bleed air, and pneumatic sources are normally used. A load analysis or test should be conducted on each power source to determine that the power source is adequate to supply the ice protection system plus all other essential loads throughout the airplane flight envelope under conditions requiring operation of the ice protection system. The effect of an ice protection system component failure on power availability to other essential loads should be evaluated and any resultant hazard should be prevented on multiengine designs and minimized on single-engine designs. The applicant should show that there is no hazard to the airplane in the event of any power source failure during flight in icing conditions. Two separate power sources (installed so that the failure of one source does not affect the ability of the remaining source to provide system power) are adequate. If a single source system is planned, additional reliability evaluation of the power source under system loads and environmental conditions may be required. All power sources that affect engine or engine ice protection systems for multiengine airplanes must comply with the engine isolation requirements of § 23.903(c).

e. Failure Analysis. All identifiable failures or malfunctions should be examined to determine their probability of occurrence and their individual effects on the airplane. Those failures which are determined to be probable should not cause a hazard to the airplane and its occupants. If the hardware design cannot be changed, other provisions or compensating features may be added so that a hazard does not result from any probable failures.

In addition to single failures, multiple failures or malfunctions should be examined when the first malfunction would not be detected during normal operation and would lead to or cause other malfunctions. Findings of compliance with § 23.1309 must include an evaluation of the consequences of a single failure in combination with latent or undetected failures. AC 23.1309-1, "Equipment, Systems, and Installations in part 23 Airplanes," provides additional guidance for airplanes with a certification basis prior to amendment 23-34.

A failure modes and effects analysis (FMEA) is one method used for identifying hazards that may result from failures. During the analysis, each identifiable failure within the system should be examined for its effect on the airplane and its occupants. FMEA and hazards analysis techniques are outlined in Society of Automotive Engineers (SAE) document ARP-926A, "Fault/Failure Analysis Procedure." Examples of failures which are hazardous include:

(1) Those which allow ice to accumulate beyond design levels; or,

(2) Those which allow asymmetric ice accumulation to the extent that it results in loss of control.

Identified failures should then be evaluated for the probability of their occurrence. If sufficient service history or environmental test data does not exist to establish the probability of occurrence of a failure, then that failure can be considered probable or substantiated by more formal analysis techniques as discussed above and in AC 25.1309-1A, "System Design Analysis". When the evaluation identifies failures that are both probable and hazardous, provisions in the design should be made to minimize on single-engine or prevent on multiengine airplanes any hazard which may result from that failure. Several provisionary means have been used to minimize or prevent a hazard as a result of failure. Among these are the use of dual components, maintenance and pilot inspections, and alternate procedures to be used by the pilot.

A probable malfunction or failure is any single malfunction or failure which is expected to occur during the life of any single airplane of a specific type. This may be determined on the basis of past service experience with similar components in comparable airplane applications. This definition should be extended to multiple malfunctions or failure when:

(1) The first malfunction or failure would not be detected during normal operation of the system, including periodic checks established at intervals which are consistent with the degree of hazard involved; or

(2) The first malfunction would inevitably lead to other malfunctions or failures.

A failure whose consequence dictates that the only path of survival is to exit the icing condition is not acceptable because there are no positive means for the pilot to exit icing condition.

When dual components or systems are used, each component or system should be isolated from the effects of failures in the other component or system. Maintenance or pilot inspections may be used as a means of identifying imminent failure; for example, cracks, loosening of fasteners, or cracked or deteriorated boots and seals.

Pilot functional checks during preflight may be credited for determining reliability provided that:

(1) The check includes the functioning of the complete system so that all faults would be detected.

(2) The check is easily conducted by the pilot and requires little time or effort.

(3) The limitations section of the Airplane Flight Manual (AFM) requires the check to be accomplished prior to flight.

(4) The AFM identifies the criticality of the system and the need to accomplish the preflight check.

NOTE: ACO flight test and systems personnel should examine in-depth the applicant's proposed preflight check to ensure that the above factors are provided. If the check is lengthy; requires several pilot actions to accomplish; requires more than one person, e.g., simultaneous action inside and outside the cockpit; provides limited information regarding the criticality of the system; and the importance of the preflight check is not provided for the pilot in the AFM, then no credit should be allowed.

f. Similarity Analyses. In the case of certification based on similarities to other type certificated airplanes previously approved for flight in icing conditions, the applicant should specify the airplane model and the component to which the reference applies. Specific similarities should be shown for physical, functional, thermodynamic, pneumatic, aerodynamic, and environmental areas. Analyses should be conducted to show that the component installation and operation is equivalent to the previously approved installation.

g. Impingement Limit Analyses. The applicant should prepare a droplet trajectory and impingement analysis of the wing, horizontal and vertical stabilizers, propellers, and any other leading edges which may require protection. This analysis should examine all critical conditions within the airplane's operating envelope as well as those in the icing envelope of part 25, appendix C. This analysis is needed to establish the upper and lower aft droplet impingement limits which can then be used to establish the aft ice formation limit and the protective coverage needed. Typically, 40 micron droplets are used to establish the aft impingement limits while 20 micron droplets are used to establish the water collection rate.

h. Induction Air System Protection. The induction air system for turbine engine airplanes is certificated for icing encounters in accordance with § 23.1093(b). Although this certification is generally oriented towards inadvertent encounters, certifications must be adequate for flight in icing conditions. Thus, ice protection systems installed on previously type certificated airplanes to protect the engine induction air system should be adequate and need not be reexamined.

10. FLIGHT TEST PLANNING. When operating any airplane in an icing environment, degradation in performance and flying qualities may be expected. One of the primary purposes for flight testing an airplane equipped for flight in icing conditions is to evaluate such degradation, determining that the flying qualities remain adequate and that performance levels are acceptable for this flight environment.

a. The flight tests and analyses of flight tests should be oriented towards:

(1) Demonstrating normal operation of the airplane with the ice protection system installed in non-icing flight.

(2) Demonstrating operation of the airplane with anticipated in-flight accumulations of ice.

(3) Verification of the analyses conducted to show adequacy of the ice protection system throughout the icing envelope of part 25, appendix C.

(4) Development of procedures and limitations for the use of the ice protection system in normal, abnormal, and emergency conditions.

b. Icing flight tests are generally conducted in three stages:

(1) initial dry air tests with ice protection equipment installed;

(2) dry air tests with predicted artificial ice shapes installed; and

(3) icing flight tests.

Initial dry air tests are primarily conducted to extend the basic airplane certification to cover the airplane with the ice protection system installed. Often it is more economical to verify specific analyses by ground tests where the design variables can be controlled to some extent. Flight tests are normally employed to demonstrate that the ice protection system performs under flight conditions as the analysis or ground test indicated. These demonstrations should be made at various points in the icing envelope of part 25, appendix C, to verify the airplane's ability to safely operate throughout that icing envelope.

11. FLIGHT TESTS. The following sections cover the major flight tests and/or analyses normally performed to substantiate the flight aspects of an ice protection system.

a. Initial Dry Air Tests with Ice Protection Equipment Installed. Depending upon the detail design of the ice protection system, some preliminary ground tests of the equipment may be warranted to verify the basic function of each item. Quantitative data on such items as temperatures of thermal devices, fluid flow rates and flow patterns on liquid devices, or operating pressures of pneumatic components may be obtained as necessary to verify the system designs.

The airplane should be shown to comply with the certification requirements when all icing components are installed and functioning. This can normally be accomplished by performing tests at those conditions found to be most critical to basic airplane aerodynamics, ice protection system design, and powerplant functions. Pneumatic boots and all other anti-ice/deice equipment should operate throughout the certified limits of the airplane; not just to 22,000 feet and -22° F. Section 23.1419(b) requires that the adequacy of the airplane's ice protection system be established based on operational needs, and in addition, the part 25, Appendix C envelope be substantiated. Several commonly used ice protection system components are discussed below to illustrate typical flight test practices. Other types of equipment should be evaluated as their specific design dictates.

(1) Pneumatic Leading Edge Boots. Tests should demonstrate a rapid rise in operating pressures for effective ice removal. This pressure rise time, as well as the maximum operating pressure for each boot, should be evaluated throughout the altitude band - mean sea level (MSL) to 22,000 feet above MSL - unless performance constraints in the AFM restrict the airplane to a lesser altitude range. Boots should be operated in flight at the minimum envelope temperature (-22°F) of part 25, appendix C, to demonstrate adequate performance and throughout the entire flight envelope to demonstrate that no damage occurs. The operation of the boots (i.e., inflation) should have no hazardous effect on airplane performance and handling qualities. For example, some boot inflation sequencing schemes result in abnormal pitch attitude changes. This can be shown by inflating the boots at several speeds in the flight envelope from stall speed to (V_{NE}) or $\frac{(V_{MO}) + V_D}{2}$ and observing the reaction of the airplane.

(2) Electric Propeller Boots. When flying in dry air, the systems should be monitored to confirm proper function. It is suggested that system current, brush block voltage (between each input brush and the ground brush) and system duty-cycles be monitored to ensure that proper power is applied to the deicers. Surface temperature measurements may be made during dry air tests if not furnished by the manufacturer. These surface temperature measurements are useful for correlating analytically predicted dry air temperatures with measured temperatures or as a general indicator that the system is functioning and that each deicer is heating.

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

Consideration should be given to the maximum temperatures that a composite propeller blade may be subjected to when the deicers are energized. It may be useful to monitor deicer bond-side temperatures. When performing this evaluation, the most critical conditions should be investigated. Example: This may occur on the ground (propellers non-rotating) on a hot day with the system inadvertently energized.

(3) Electric Windshield Anti-Ice. Dry air flight tests should be conducted in support of the systems design, as required. Inner and outer windshield surface temperature evaluation of the protected area may be needed to support thermal analyses. Thermal analysis should substantiate that the surface temperature is sufficient to maintain anti-icing capability without causing structural damage to the windshield. In the case of add-on plates, temperatures of the basic airplane windshield, inside and out, may also be needed, particularly with pressurized airplanes.

An evaluation of the visibility including distortion effects through the protected area should be made in both day and night operations. In addition, the size and location of the protected area should be reviewed for adequate visibility, especially for approach and landing conditions.

(4) Pitot-Static and Static Pressure Sources. If the aerodynamic configuration of either the pitot or the static source(s) differs from that of the basic airplane, then airspeed and altimeter system calibrations should be evaluated for compliance with the certification requirements. A component surface temperature evaluation may be necessary to verify thermal analyses.

(5) Heated Stall Warning Transducer. When the icing approval requires installation of a new stall warning transducer, that new transducer's function as a stall warning device should be evaluated for compliance with the certification requirements. A surface temperature evaluation may be necessary to verify thermal analyses.

(6) Fluid Anti/Deice Systems. Dry air testing should include evaluation of fluid flow paths to determine that adequate and uniform fluid distribution over the protected surfaces is achieved. Means of indicating fluid flow rates, 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. An accessible shutoff should be provided in systems using flammable fluids. The fluid anti-ice/deice systems may be used to protect propellers and windshields as well as leading edges of airfoils. The fluid for windshield fluid anti-ice systems should be tested to demonstrate that it does not become opaque at low temperature.

(7) Compressor Bleed Air Systems. The effect of any bleed air extraction on engine and airplane performance should be examined and shown in the AFM performance data. The surface heat distribution analysis should be verified for varying flight conditions including climb, cruise, hold, and descent. A temperature evaluation may be necessary to verify the thermal analyses.

(8) Ice Detection Light(s). Ice detection lights should be evaluated during night 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 both in and out of clouds during dry air tests. Use of a hand-held flashlight for ice detection is not acceptable.

b. Dry Air Tests with Artificial Ice Shapes. Where ice buildups are predictable and are known to contribute significantly to performance loss and handling quality degradation, artificial ice shapes should be developed and flight tested. Shapes may be developed from analyses or from icing tunnel tests. These analyses and tunnel tests should be conservative and should address the conditions associated with the icing envelope of part 25, appendix C, that are critical to the airplane's performance and handling qualities in critical phases of the airplane operational envelope, including climb, cruise, descent, holding pattern, approach, and landing. See subparagraph d.

Tests should be conducted to allow a controlled examination of the effects of ice buildups to these critical shapes in conjunction with associated operating losses, such as, bleed air heat systems, inertial separator doors, and electrical loads. They should establish performance degradations for stall speed or minimum control speed and for engine power or thrust loss. Handling qualities should be investigated to determine that an acceptable level of safety exists. The results of these tests may be used in preparing operating restrictions or limitations for the AFM.

c. Icing Flight Tests. Flight tests in icing conditions, both natural and simulated, are used to verify the function of the ice protection system installed on the airplane. They are also used to confirm the analyses used in developing the various components and to confirm the conclusions reached in flight tests conducted with artificial ice shapes.

(1) Instrumentation. Sufficient instrumentation should be planned to allow documentation of important airplane, system and component parameters, and icing conditions encountered. The following parameters should be considered:

(i) Altitude, airspeed, and engine power.

(ii) Static air, engine component, electrical generation equipment, surface, interlaminate, and any other key temperatures which could be affected by ice protection equipment, by ice accumulation, or are necessary for validation of analyses.

(iii) Liquid water content can be measured using a hot-wire anemometer based instrument, calibrated drum, or other equivalent means.

(iv) Median volumetric droplet diameter can be approximately determined by using a drop snatcher to expose a gelatin oil or soot slide and then measuring the resultant impact craters, or by use of more sophisticated equipment such as the forward scattering spectrometer system.

(2) Simulated Icing. Flight tests in a simulated icing environment represent one way to predict the ice protection capabilities of individual ice protection equipment. These tests are especially useful for validating ice protection components having small exposed surfaces, such as heated pitot tubes, antennas, air inlets including engine induction air inlets, empennage, and other surfaces having small leading edge radii and windshields. Small components are more sensitive to the higher accumulation rates associated with high liquid water content and large droplet size -- conditions which are easily simulated and not frequently encountered in natural icing flight tests.

A simulated icing exposure may be obtained by the use of onboard spray nozzles forward of the component under examination or by flying the test airplane in the cloud generated by an icing tanker. It is difficult to obtain small droplet sizes with current spray nozzles; therefore, these methods have been found to produce larger ice buildups and different ice shapes than those observed in natural icing conditions within the icing envelope of part 25, appendix C. With consideration of the tanker droplet sizes and the outside air temperature, simulated icing tests may provide total substantiation of small components. For those components where small droplet sizes are critical, simulated icing tests are not a satisfactory sole means of compliance.

(3) Natural Icing. Flight tests in natural icing conditions are necessary to demonstrate the acceptability of the airplane and ice protection system for flight in icing conditions. AC 20-73 (paragraphs 25f and 25g(1)) provides additional information that would be useful when establishing a natural icing flight test program. In the case of certification based on similarity to a previously approved airplane, natural icing flight tests may be required. For other installations, at least one exposure to icing conditions within the part 25, appendix C, Continuous Maximum envelope should be obtained. The exposure should be sufficiently stabilized to obtain valid data. It is often difficult to obtain temperature stabilization in brief exposures. Additional exposures may be required to allow extrapolation to the envelope critical conditions by analysis. Test data obtained during these exposures may be used to validate the analytical methods used and the results of any preceding simulated icing tests.

Past experience has shown that flight testing in natural intermittent maximum icing conditions may be hazardous due to accompanying severe turbulence and possible hail encounters which may extensively damage the test airplane. Hazardous flight testing such as this may be avoided, provided that design analyses show the critical ice protection design points (heat loads, critical shapes, accumulation, and accumulation rates, etc.), do not occur under these conditions; and, sufficient ground or flight test data exists to verify the analysis.

During natural icing flight tests, ice accumulation on unprotected areas should be observed, where possible, and sufficient data taken to allow correlation with dry air tests using artificial ice shapes. Handling qualities should be subjectively reviewed and determined to be in general correlation with those found in the dry air testing. Performance decrements observed during natural icing flight tests should be compared to the decrements observed during flight tests with artificial ice shapes. In addition, flying qualities and performance should be qualitatively evaluated with the ice accumulations existing just prior to operation of deice (as opposed to anti-ice) components. For anti-ice components, tests should be conducted which simulate inadvertent icing encounters in which the pilot may not recognize that the airplane is about to enter an icing condition and the anti-ice component may not be activated until actual ice buildup is noticed. One minute of flight in icing conditions, after detection of ice buildup and before activation of anti-icing equipment, has been used in these tests. Handling qualities should remain acceptable to the test pilot and performance decrements should not prevent continued safe operation of the airplane.

All systems and components of the basic airplane should continue to function as intended when operating in an icing environment. Some considerations are:

(i) Engine and equipment (such as generator under maximum ice protection load) cooling should be monitored during icing tests and be found acceptable for this operation.

(ii) Engine alternate induction air sources should remain functional in an icing environment.

(iii) Fuel system venting should not be affected by ice accumulation.

(iv) Retractable landing gear should be available for landing following an icing encounter. Gear retraction should not result in an unsafe indication because of ice accretion.

(v) Ice shedding from components of the airplane should cause no more than cosmetic damage to other parts of the airplane, including aft-mounted engines and propellers.

(vi) With residual ice accumulations on the airplane, adequate stall warning (aerodynamic or artificial) should be provided.

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

(viii) Ice detection lights should be evaluated in natural icing conditions to verify that they illuminate ice buildup areas and that they are adequate under the conditions encountered.

(ix) 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 airplane'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 the landing configuration.

d. Performance and Handling Qualities. Airplane performance and handling qualities are degraded by ice accumulations in various ways depending upon type, shape, size, and location of these accumulations. Because of these variations in degradation, it is difficult to establish a standard method of demonstrating such degradations. However, certain minimum tests, as suggested below, should be used to demonstrate that the airplane does not have unsafe features or characteristics that prevent it from operating safely in the part 25, appendix C, icing envelope. If numerous unprotected areas exist, the weight and center of gravity effects of the ice formations should also be evaluated.

(1) Performance. For normal, utility, and acrobatic category airplanes, performance losses are normally demonstrated in icing conditions only for the all engines operating condition. However, for commuter category airplanes, which have takeoff and landing weight limitations based on one engine inoperative climb performance, testing for one engine inoperative performance loss is appropriate. Climb performance losses should be established either by flight tests or by a conservative analysis acceptable to the FAA certifying office. Artificial ice shapes used for performance evaluation should be those critical shapes as found under the conditions in the icing envelope of part 25, appendix C, and the critical operating conditions under which such performance is expected. The following performance loss determinations are normally considered minimum:

(i) Section 23.65, Climb: All Engines Operating. Climb performance losses due to ice formation for the configuration defined in § 23.65 are normally not appropriate since the airplane should not depart with residual ice on the airplane. However, takeoff climb performance should be determined considering any losses associated with operating anti-ice/deice equipment since that equipment could be utilized for takeoff into an icing environment.

(ii) Section 23.67(e)(2) and (3), Climb: One Engine Inoperative. Climb performance losses should consider related power extractions, additional icing drag, and any required changes to operational climb speeds for at least the following:

(A) Climb with one engine inoperative in the en route configuration; and

(B) Climb with one engine inoperative in the approach configuration.

(iii) Section 23.77, Balked Landing. For normal, utility, and acrobatic category airplanes, the airplane with ice accumulations and all icing systems operational (e.g., bleed air systems) should meet the all engine minimum climb requirements on a 32°F day at sea level as is required on the non-iced (icing systems off) airplane under § 23.77(a) at sea level on a standard day. For commuter category airplanes, climb performance losses should be measured and the maximum weight adjusted, if required.

(iv) Section 23.75, Landing. The landing performance should be calculated or measured considering the effects of critical ice accumulations upon landing. Minimum speeds, landing configuration, and landing distance (based on increased stall speeds) degradation should be established.

(2) Handling Qualities. Handling qualities evaluation should include actual flight investigation of at least the following with the artificial ice shapes:

(i) Stall characteristics and speeds.

(ii) Trim.

(iii) Lateral directional stability/control.

(iv) Longitudinal stability/control.

(v) V_{MC}.

(vi) Landing approach speeds, maneuvering characteristics, and landing characteristics.

(vii) Appropriate high speed characteristics up to $V_{MO}/M_{MO}/V_{NE}$.

e. Ice Shedding. Ice shed from forward airplane structure may damage or erode engine or powerplant components, lifting, stabilizing, and flight control surface leading edges. Fan and compressor blades, impeller vanes, inlet screens and ducts, as well as propellers (metal and non-metallic) are examples of powerplant components subject to damage from ice impingement. Control surfaces such as elevators, ailerons, flaps, and spoilers are also subject to damage with special attention given to damage of thin metallic, non-metallic or composite constructed surfaces. Trajectory and impingement analysis cannot adequately predict such damage. Unpredicted ice shedding paths from forward areas such as radomes and forward wings (canards) have been found to negate the results of this analysis. For this reason, flight tests should be conducted to supplement analysis. Video or motion pictures are excellent for documenting ice shedding trajectories and impingements while still photography may be used to document the extent of damage.

f. Pneumatic Deicer Boots. For effective ice removal, conventional pneumatic deicer boot systems require a measurable ice accumulation (usually one-half inch or more) prior to activation. Time system activation is highly dependent on visual cues to the crew of this ice accumulation. Most airplane flight manuals specify a minimum ice accumulation thickness prior to each manual activation of the deicer boot system. Also, a maximum ice accumulation that the boot is capable of breaking and removing is usually provided. These systems should be flight tested in simulated or natural icing conditions to verify that the crew can detect and recognize the ice accumulation specified for the proper operation of the installed boot system. The following test criteria have been accepted for previous flight test programs:

(1) The pilot or a crew member should be provided a means to detect from his crew position under both day and night operation the accumulation level the applicant has specified for activation of the boot system for proper ice removal.

(2) The applicant should show that an ice accumulation margin exists which allows for errors in crew recognition of the ice accumulation level.

g. Emergency and Abnormal Operating Conditions. Flight investigations should be conducted to verify that after pilot recognition of emergency and abnormal operating conditions, the airplane handling qualities have not deteriorated to the extent that the AFM procedures for the condition are ineffective. These demonstrations should be conducted with anticipated residual ice accumulation on normally protected surfaces.

11. Placarding and Airplane Flight Manual (AFM). The guidance provided by this AC is oriented towards airplanes for which the certification basis requires an AFM.

a. Placarding. Any placarding necessary for the safe operation of the airplane in an icing environment must be provided in accordance with § 23.1541. Examples of such placards are:

(1) Kinds of operation approved, e.g., Flight in Icing Conditions Approved if Ice Protection Equipment is Installed and Operational."

(2) Equipment limits, e.g., "Operation of Windshield Anti-Ice May Cause Compass Deviation in Excess of 10^{o}."

(3) Speed restrictions, e.g., "Maximum Speed for Boot Operation - 175 KIAS."

(4) Fluid filler-inlets for fluid freezing point depressants should bear a placard showing approved fluid type and quantity.

b. Airplane Flight Manual (AFM). The AFM should provide the pilot with the information needed to operate the ice protection system. Information should include:

(1) Operating Limitations Section. Suggested areas to be addressed are:

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

(ii) Speed limitations (if any) for deicing boot operation for airplanes equipped with boots.

(iii) Environmental limitations for equipment operations as applicable; for example, minimum temperature for boot operation or maximum altitude for boot operation.

(iv) A list of all equipment required for flight in icing conditions. Section 23.1583(h) (CAR § 3.778) requires that this list be included in the Kinds of Operation Equipment List (KOEL).

(v) Minimum engine speed if the engine ice protection system does not function properly below this speed.

(vi) A list of required placards.

(vii) For commuter category airplanes, the balked landing climb weight, approach climb weight, and landing weight limitations for flight in icing should be presented. The variation in weight limitations may be presented in the Performance Section of the manual and included as limitations by specific reference in the Limitations Section of the AFM.

(2) Operating Procedures Section.

(i) Section 23.1585(a) requires the pilot be provided with the necessary procedures for safe operation. This should include any preflight action necessary to minimize the potential of en route emergencies associated with the ice protection system. The system components should be described with sufficient clarity and depth that the pilot can understand their function.

(ii) Procedures should be provided to optimize operation of the airplane during penetration of icing conditions, including climb, holding and approach configurations, and speeds.

(iii) Emergency or abnormal procedures including procedures to be followed when ice protection systems fail and/or warning or monitor alerts occur should be provided.

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

(v) For airplanes which cannot supply adequate power for all systems at low engine speeds, load shedding instructions should be provided to the pilot for approach and landing in icing conditions.

(3) Performance Information Section. A brief discussion of the part 25, appendix C, supercooled cloud test environment and a statement that freezing rain and/or mixed conditions have not been tested and may exceed the capabilities of the ice protection system should be provided.

(i) Normal, Utility, and Acrobatic Category Airplanes. For these airplanes, general performance information should be provided to give the pilot knowledge of allowances necessary while operating in ice or with residual ice on airframe, for example:

(A) An accumulation of ______ inch of ice on the leading edges can cause a loss in rate of climb up to _____ FPM, a cruise speed reduction of up to KIAS, as well as a significant buffet and stall speed increase (up to ________ knots). Even after cycling the deicing boots, the ice accumulation remaining on the boots and unprotected areas of the airplane can cause large performance losses. With residual ice from the initial _____ inch accumulation, losses up to FPM in climb, _____ KIAS in cruise, and a stall speed increase of _____ knots can result. With ______ inch of residual accumulation, these losses can double.

(B) Airspeed -- MAINTAIN BETWEEN _______ KIAS AND ______ KIAS with _______ inch or more of ice accumulation.

(C) Prior to a landing approach, cycle the wing and stabilizer deice boots to shed any accumulated ice. Maintain extra airspeed on approach to compensate for the increased stall speed associated with ice on unprotected areas. Use caution when cycling the boots during an approach since boot inflation with no ice accumulation may cause mild pitching and increase stall speeds by ______ knots, may decrease stall warning margin by the same amount, and may cause or increase rolling tendency during stall.

(D) Holding in icing conditions for a period of 45 minutes (or less time if so demonstrated) may result in inadequate handling and control characteristics.

(E) At engine speeds of _____ r.p.m. or lower, the ice protection system may not function properly.

(ii) Commuter Category Airplanes. Data should be provided so that the balked landing climb limited weight and approach climb limited landing weight can be determined. These data should include the effect of drag due to residual ice on protected and unprotected surfaces, power extraction associated with ice protection system operation and any changes in operating speeds due to icing. Also, the effect on landing distance due to revised approach speeds, and/or landing configurations, should be shown.

c. Prior to AFM Requirement. If the airplane was certified prior to the effective date of the requirement for an AFM, then the combination of manuals, markings, and placards should adequately address the placard and AFM subjects previously discussed in this AC.

BARRY D. CLEMENTS
Manager, Small Airplane Directorate
Aircraft Certification Service

APPENDIX 1. APPENDIX TO ADVISORY CIRCULAR

The left column of this appendix provides a simplified checklist of the various influence items which could affect safety of small airplanes while operating in icing conditions. In the right column are suggested considerations for resolving the concerns of each of these influence items. Certain considerations may not be applicable depending on the certification basis of the airplane. (Also, see paragraph 3 of this AC.)

Influence	Consideration
A. Crew Visibility	1. Conduct evaluations to verify adequate day and night visibility through the protected windshield or the protected windshield segment under dry air and icing conditions.
	2. Evaluate the cabin defogging system's capability to clear side windows for observation of boot ice protection system operation and ice accumulation. If a defogging system is not provided, the windows should be easily cleared by the pilot without adversely increasing pilot workload.
	3. Minimum light transmittance through the protected windshield or protected windshield segment and affected side windows should be 70% as measured perpendicular to the surface with the windshield cleared of ice.
	4. Determine that the temperature gradient produced on heated windshields does not adversely affect pilot vision or windshield structural integrity.
B. Engine Installation and Cooling	1. Conduct flight tests, conduct analyses, or refer to substantiation data to determine that complete engine installation, including propellers, functions without appreciable loss of power. Verify that engine oil and component cooling is adequate at critical design points throughout the operational and icing envelope. If ice is expected to accumulate at the generator during

Influence	Consideration
B. (Continued)	icing encounters, then cooling air inlet generator cooling tests should be performed with the maximum icing load on the electrical system and critical ice shapes installed on the engine and generator cooling air intake.
C. Propeller	1. Provide analysis to establish chordwise and spanwise protection required. Aerodynamic heating due to blade rotation, latent heat of fusion and centrifugal force is important in determining areas requiring protection. Droplet size is the critical parameter for determining chordwise extent of areas requiring ice protection.
	2. Where the propeller ice protection system consumes power from the electrical system, pneumatic system, or bleed air system, a load analysis should be provided showing that the power source capacity is adequate to provide ice protection in addition to all other essential loads.
	3. Where fluid is required for ice protection, a limitation should be placed in the AFM on flight in icing conditions to prevent exhausting the fluid prior to exiting the icing condition. Sufficient margin in fluid capacity should be maintained to allow for alternate airport landing in accordance with operational requirements.
	4. Other specific areas of concern include: (a) The effect of deicer boot installation upon propeller blade and cuff, and hub structural integrity. (b) Surface temperature.

Influence	Consideration
C. (Continued)	(c) Timer or other control system reliability.
	(d) Spinner ice accumulation.
	5. Perform tests to verify that ice sheds from the blades and to demonstrate compliance. During testing, verify that adequate ice protection is provided, propeller performance degradations are not excessive, vibration characteristics are satisfactory and ice being shed is small enough to avoid detrimental damage to other aircraft components. Tests should include examination of the structural integrity of the propeller assembly and associated equipment with ice protection (heater blankets, slip rings, wiring, etc.) installed.
D. Equipment, Systems, Function, and Installation	1. Conduct a study as discussed in paragraph 9e (failure analysis) of this AC to ensure that no probable failure or malfunction of any power source (electrical, fluid, bleed air, pneumatic, etc.) will impair the ability of the remaining source(s) to supply adequate power to systems essential to safe operation during icing flight.
	2. Conduct a power source load analysis to verify proper power requirements are provided.
	3. Verify that power source failure warning is provided to the crew.
	4. Demonstrate that the alternator or generator is protected from detrimental ice accumulation.
	5. Determine if load shedding can be accomplished after a partial failure condition. If applicable, a load shedding sequence should be provided

Influence	Consideration
D. (Continued)	so the pilot may ensure that adequate power is available to the ice protection equipment and other necessary equipment for flight in icing conditions.
E. Circuit and Protective Devices	1. Determine the design incorporates electrical overload protection that opens regardless of operating control position.
	2. Verify the design is such that no protective device is protecting more that one circuit essential to continued safe flight. For example, pitot heat and stall warning transducer heat are considered separate essential circuits and should be provided separate protection. Ice protection monitor and warning circuits should be considered separate from control circuits and each provided individual circuit protection. On airplanes equipped with dual power sources, a DC power distribution system having a single bus and a single circuit breaker protecting the ice protection system are not acceptable.
F. Airfoil Leading Edge Protection System	1. Provide a means to indicate to the crew that the ice protection system is receiving adequate electrical power, bleed air pressure, vacuum, or fluid, etc., as appropriate, and it is functioning normally.
	2. Conduct droplet trajectory and impingement analysis of wing, and horizontal and vertical stabilizers to establish aft limits for ice formation. Areas of concern include adequacy of upper and lower limits of wing and stabilizer protection to allow safe flight in icing conditions.
G. Static Pressure System	1. Each static port design or location should be such that correlation between air pressure in the static system and true ambient pressure is

Influence	Consideration
G. (Continued)	not altered when flying in icing conditions. Anti-icing devices, alternate source for static pressure, or demonstration by test that port icing doe not occur under any condition are means showing compliance.
	2. Where the port is thermally protected, a thermal evaluation should be conducted to demonstrate that the protection is adequate.
H. Pitot, Static, Angle of Attack, and Stall Warning Sensors	1. Provide analysis (thermal analysis in the case of heated pitot tube and static ports) to establish anti-icing/deicing requirements.
	2. Perform tests to verify analyses and demonstrate compliance. Use these verified analysis to extrapolate to the critical conditions of part 25, appendix C. Several combinations of parameters may be critical test points. For unprotected components, testing may be conducted to demonstrate that airspeed, altitude, and other indications remain within acceptable tolerances under the critical conditions. In some cases, adequate bench and flight testing may already have been accomplished on other airplanes to establish an approval basis by similarity on a specific airplane.
I. Magnetic Direction	1. Designs should minimize magnetic direction indicator (MDI) deviations; however, if MDI deviations greater than 10° exist when operating electrical ice protection equipment, provide placarding. NOTE: If the ice protection system causes greater than a 10° deviation, then § 23.1327 (amendment 23-20) should be applied in lieu of previous requirements.
J. Ice Detection Light(s)	1. Night flight or dark hangar evaluation of light coverage and glare produced by the wing ice detection light(s) should be evaluated.

Influence	Consideration
J. (Continued)	2. A hand-held flashlight is not acceptable as an ice detection light.
	3. The ice detection light(s) should be evaluated in icing conditions to verify that sufficient illumination is provided for the pilot to detect ice accumulation.
K. Antennas and Other Components	1. Conduct structural analysis to establish that critical ice buildups on antennas, masts, and other components attached externally to the airplane do not result in hazards.
	2. Tests in natural icing or with simulated ice shapes may be used to substantiate the structural analysis.
	3. Ice shedding from these components should be evaluated to verify that size and trajectory do not damage other parts of the airplane.
L. Fluid Systems	1. Certain fluids used in ice protection systems are flammable. Components of these systems must meet the flammable fluid protection requirements of § 23.863. No components of these systems may be installed in passenger or crew compartments without the protection required by § 23.853(d) (prior to amendment 23-34) or § 23.853(e) (after amendment 23-34).
	2. Fluid capacity should be established based on the operational capability of the airplane and on the ability to fly to an alternate airport and safely land. Means should be provided to monitor fluid capacity and flow rates as they relate to flight. The method for determining ice protection availability should be provided in the operating procedures of the AFM.

Influence	Consideration
L. (Continued)	3. The Maintenance Manual should list approved fluids; and if pilot and crew members are required to replace fluid, these approved fluids should be listed in the AFM. The fluid filler inlet should bear a placard stating that only approved fluids be used. Approved fluids may be listed on this placard or in the AFM.
	4. The compatibility of the fluid with airframe and engine components should be examined to verify that adverse reactions such as corrosion or contamination do not occur or are prevented through inspection or other measures. For example, if ethylene glycol is a component fluid, then silver and silver-plated electrical switch contacts and terminals should be protected from contamination by the ethylene glycol in order to avoid a fire hazard.
M. Flight Tests	1. The certification rules require analysis and tests to demonstrate that the airplane can safely operate in the icing envelope of part 25, appendix C. Compliance can be determined by similarities to previously approved configurations. If it should be necessary to conduct dry air tests with ice shapes, natural icing tests, or simulated icing tests, the goals and results should be in accordance with the guidance provided in paragraph 11 of this AC.
N. Flight Manual and Placards	1. The AFM and appropriated placards in the airplane should be designed to provide the pilot with sufficient information to safely operate the airplane in an icing environment.

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