U.S. Department
of Transportation
**Federal Aviation
Administration**

Advisory Circular

Subject: TURBOJET, TURBOPROP, AND TURBOFAN ENGINE INDUCTION SYSTEM ICING AND ICE INGESTION

Date: 2/02/04
Initiated By: AIR-100
AC No: 20-147
Change:

1. PURPOSE. This advisory circular (AC) provides guidance and acceptable methods, but not the only methods, for demonstrating compliance with the applicable engine induction system icing and engine ice ingestion requirements. These requirements are applicable to the Federal Aviation Regulations, parts 23, 25, and 33 of Title 14 of the Code of Federal Regulations (14 CFR parts 23, 25, and 33). The primary purpose of this AC is to reduce inconsistencies and eventual surprises to both engine manufacturers and engine installers, when installing a part 33 certified engine in a part 23 or 25 aircraft. The guidance in this AC is not intended to address turboshaft engine installations, or the rotary wing aircraft they are installed on. Due to the complexity that those aircraft and installations pose for icing, AC 20-73, Aircraft Icing Protection,is considered the primary AC for those installations. Further, this AC is not intended to address mixed phase icing conditions (meaning, mixed water and ice precipitation), although there is a discussion on the subject. While these guidelines are not mandatory, they are historically based and are derived from extensive Federal Aviation Administration (FAA) and industry experience in determining compliance with the relevant regulations. This AC does take precedence over the engine and engine installation icing guidance in AC 20-73. It is important to note that AC 20-73 does contain useful information on the understanding and characterization of the icing environment. Additionally, AC 23-16, Powerplant Guide for Certification of Part 23 Airplanes, does take precedence over the engine installation guidance provided in this AC, as one method of compliance to part 23 regulations.

2. APPLICABILITY.

a. The guidance provided in this document is directed to engine manufacturers, modifiers, foreign regulatory authorities, FAA engine type certification engineers and their designees.

b. This material is neither mandatory nor regulatory in nature and does not constitute a regulation. It describes acceptable means, but not the only means, for demonstrating compliance with the applicable regulations. The FAA will consider other methods of demonstrating compliance that an applicant may elect to present. Terms such as “should,” “shall,” “may,” and “must” are used only in the sense of ensuring applicability of this particular method of compliance when the acceptable method of compliance in this document is used. While these guidelines are not mandatory, they are derived from extensive FAA and industry experience in determining compliance with the relevant regulations. Alternatively, if the FAA becomes aware of circumstances that convince us that following this AC would not result in compliance with the applicable regulations, we will not be bound by the terms of this AC, and we may require additional substantiation as the basis for finding compliance.

c. This material does not change, create any additional, authorize changes in, or permit deviations from existing regulatory requirements.

3. RELATED REGULATIONS.

a. Part 23, Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes, §§ 23.901(d)(2), 23.1093, and 23.1419.

b. Part 25, Airworthiness Standards: Transport Category Airplanes, §§ 25.1093 and 25.1419.

c. Part 33, Airworthiness Standards: Aircraft Engines, §§ 33.68, 33.77(c), 33.77(e), 33.89(b), and § 33.78, Rain and Hail Ingestion.

4. RELATED READING MATERIAL (Latest Revisions).

a. AC 20-73, Aircraft Ice Protection.

b. AC 33-2B, Aircraft Engine Type Certification Handbook.

c. FAA Report No. FAA-RD-77-78, Engineering Summary of Powerplant Icing Technical Data, July 1977.

d. AC 23-16, Powerplant Guide for Certification of Part 23 Airplanes.

5. BACKGROUND.

The induction system icing requirements of parts 33, 23, and 25 are intended to provide protection for anticipated flight into icing conditions with no adverse effect on engine operation or serious loss of power or thrust. Propulsion systems certified under these requirements and operated in accordance with the airplane flight manual, have generally demonstrated safe operation when exposed to natural icing environments. This AC will supersede the engine and induction system icing guidance contained in AC 20-73 and AC 33-2 with regard to turbojet, turboprop and turbofan engine icing and engine installation icing approvals. Bear in mind AC 20-73 does contain additional guidance on turboshaft engines and installations. The suggested test conditions called out in this AC are intended to be standardized engine icing certification test conditions. These standard conditions, in conjunction with any design-specific critical test points, should be used together with any additional conditions that the Administrator determines to be critical. These standard test conditions have been determined, through more than 30 years of certification experience, to provide an adequate and consistent basis for engine icing certification with good service experience. The successful demonstration of the test conditions outlined in this AC is intended to address many potential engine power conditions, aircraft flight conditions, and environmental conditions that could otherwise prove to be costly and difficult to realistically test. Service experience, now in the hundreds of millions of hours, has also shown a long success record when using these test points to cover unknown environmental or operational factors. Finally, one should be aware that in Appendix C of part 25, the environmental threat is considered probable, and therefore likely to occur. In comparison, this occurrence rate is far more probable than the remote threat posed by the rain and hail environmental threat in Appendix B of part 33. Therefore, a direct comparison of guidance between the acceptable test outcomes of the icing certification requirements and the rain and hail certification requirements is not appropriate. Again, it should also be recognized that although Appendix C is the certification standard, it is still possible to have in-service icing conditions that are more severe than the Appendix C conditions. Often, experience has shown that the actual icing environment in nature can be a combination of conditions, such as a continuous maximum cloud followed by a intermittent maximum cloud followed by a continuous maximum cloud, and so on.

6. DEFINITIONS. The following are defined for the purpose of this AC:

a. Auto-recovery systems. Auto-recovery systems typically include auto-relight systems, stall recovery systems, or any other engine system intended to recover the operability of an engine following a flameout, surge, stall, or a combination of these.

b. Freezing fraction. The fraction of impinging water that freezes on impact.

c. Ice formations. Ice formations resulting from the impact of supercooled water droplets on propulsion system surfaces are classified as follows:

(1) Glaze ice. A clear, hard ice, which forms at temperatures close to (but below) freezing, in air with high liquid water content and large droplet sizes. Droplets impacting the surface do not freeze immediately, but run back along the surface until freezing occurs. Glaze ice typically has a non-aerodynamic shape and is more susceptible to aerodynamic forces that result in shedding. Glaze ice typically has both a lower freezing fraction and lower adhesive properties than rime ice. Glaze ice is often a concern for static hardware while rime ice is often a concern for rotating hardware.

(2) Rime ice. A milky, white ice which forms at low temperatures, in air with low liquid water content and small droplet sizes. Rime ice typically forms in an aerodynamic shape, on both rotating and static engine hardware. The freezing fraction is high for rime ice, typically approaching a value of 1.0. Rime ice typically has greater adhesion properties than glaze ice but often a lower density. Adhesion properties increase with lower temperature up to a test point where no additional adhesion is gained with additional lower temperature.

(3) Mixed or intermediate ice. A combination of glaze and rime ice which forms with rime patches slightly aft of the glaze ice portions. This ice forms at temperatures, liquid water content, and droplet sizes between those that produce rime and glaze ice.

d. Ice shed cycles. The time period required to buildup and shed ice on a propulsion system surface for a given power and icing condition. A shed cycle can be identified through visual means (for example, high-speed camera which should view fan and booster or low pressure compressor (LPC) inlet guide vane components), and engine instrumentation (such as, vibration pickups, temperature probes, speed pickups, and so on).

e. Icing condition. A meteorological condition defined by the following parameters:

(1) Liquid Water Content (LWC). Concentration of liquid water in air, typically expressed in grams of water per cubic meter of air.

(2) Mean effective droplet diameter (MED or MEDD). A characteristic of a given icing cloud where the volume of water associated with droplets larger than the MED is equal to the volume of water associated with droplets smaller than the MED.

(3) Temperature. The total temperature associated with the icing cloud environment. Appendix C temperatures are static ambient temperatures. When a critical test point analysis is conducted, the local total temperatures at the engine inlet should be considered, based on applying the Appendix C static temperatures and assumed flight mach number.

f. Power loss instabilities. Engine operating anomalies such as non-recoverable or repeating surge, stall, rollback, or flameout, can result in engine power or thrust cycling.

g. Scoop factor (concentration factor). The ratio of nacelle inlet highlight area (A_H) to the area of the captured air stream tube (A_C) [scoop factor = A_H/A_C]. The highlight area is defined as the area bounded by the leading edge of the nacelle inlet. Scoop factor potentially concentrates liquid water available for ice formation in the inlet and additionally in the low-pressure compressor or engine core as a function of aircraft forward airspeed and engine power condition. The scoop factor affect depends on the droplet diameter, the simulated airspeed and the engine power level as well as the geometry and size of the engine. For small thrust engines (30 inch diameter and less), MEDD over 15 microns can influence the water concentration while typically, MEDD must be over about 40 microns to become an influence on water concentration for large engines with diameters in excess of 100 inches.

h. Serious loss of power or thrust. Engine operating anomalies such as non-recoverable or repeating surge, stall, rollback or flameout, which can result in noticeable engine power or thrust loss. The FAA (that is, the Engine and Propeller Directorate, the Transport Airplane Directorate, and the Small Airplane Directorate) expects there will not be a noticeable power or thrust loss. This is especially important when considering that icing encounters are considered a frequent event, and multiple encounters for each flight is a reasonable assumption. The word "noticeable", as used above, refers to flight crews tactile feel during the event, or the use of typical engine test instrumentation, or flight deck instrumentation (such as, N_1, N_2, vibes, exhaust gas temp).

i. Steady Operation. During icing testing, the engine should demonstrate steady, reliable, and smooth operation while sitting on test point (during multiple build or shed cycles, if ice is accreting), as well as during throttle transients. The term “steadily” is intended to address both stabilized ice accretions and stabilized engine operation. Ice accretions are considered stabilized when either ice is not forming on any engine parts, or the accreting ice has demonstrated a regular shed cycle when viewed by a video camera or instrumentation indication. Engine operation is considered stabilized when the measured engine parameters are not changing, or a regular, repeatable shed cycle has been demonstrated through the recording of measured engine parameters. The applicant should determine what parameters need to be monitored to determine steady operation of the engine during the icing test. Variations in measured parameters are acceptable during the performance of the ice test, as long as the long-term trend (typically the duration of several shed cycles) is stable and not trending upwards or downwards.

j. Sustained power loss. A permanent reduction in power or thrust at the engine’s primary power set parameter (for example, fan rotor speed, engine pressure ratio). A sustained measurable power loss is considered a “severe power loss” in the context of the icing requirement. Power or thrust losses that are not sustained are temporary in nature and may be related to the effects of ingesting super-cooled water or ice particles, or possibly the effects of ice accumulation or ice shedding. The engine’s momentary response during shedding may be from the thermodynamic engine response to the ice ingestion.

k. Water impingement rate. The rate (gm/Sq. m/min) at which a portion of the surface area of a solid object is impacted by the water droplets in a moving air stream.

7. DISCUSSION. The induction system icing requirements of §§ 23.1093, 25.1093, and 33.68 are intended to provide protection for flight into icing conditions with no adverse effect on engine operation or sustained loss of power. An icing encounter, including a prolonged encounter, should not be of consequence to the crew, and should not invalidate the engine's compliance with other part 33 requirements (for example, §§ 33.15, 33.19, 33.63, 33.65, 33.75, 33.77, 33.83, 33.89(b), and the like). The engine should have sufficient durability to operate through prolonged or repeated environmental encounters, such as icing, without special operational or maintenance interventions. Operational procedures to assist ice shedding, such as throttle manipulation, should not be relied on, or be required to comply with parts 23, 25, and 33 in-flight icing requirements. It is acceptable to provide engine throttle manipulation (for example, power run-ups to shed ice) instructions to shed accumulated ice during ground operations. These instructions will be used as a recommendation for in-service ground operation, although they would be mandatory if they were utilized during the ground icing compliance demonstration of §§ 33.68(b), 23.1093(b)(2), and 25.1093(b)(2). The applicant should provide instrumentation and video or photographic coverage to supplement test results under §§ 33.68, 23.1093, and 25.1093. The applicant should determine the parameters, which may include both visual and instrumented indications that need to be monitored. The demonstration should include stable build or shed cycles (that is, steady operation) with either no ice buildup or no additional ice buildup on the engine or inlet. Normal engine control system responses during the ice accumulation process (for example, isochronous control response to accreting ice) are considered acceptable as long as there are no power losses. At the conclusion of the test point, during the acceleration to takeoff power, the measured parameters should demonstrate a smooth and steady acceleration characteristic, unless the applicant can provide an acceptable justification for a performance change while on test point (for example, thermodynamic engine response to shed ice ingestion is acceptable). Close coordination is necessary by all parties to ensure that test plans are in reasonable bounds for the anticipated use of the airplane. (You will find background information on for guidance on low engine speed compliance testing if you refer to attachment A of this AC.) The body of this AC is arranged in three sections corresponding to the applicable parts (§§ 33.68 and 33.89(b); 33.77; and 23.1093 and 25.1093).

a. Mixed Phase or Glaciated Icing Conditions. Mixed phase icing conditions occur when supercooled liquid water droplets and ice particles coexist in a cloud, often around the outskirts of a thunderhead cloud formation. Service experience generally indicates that turbine engines are not susceptible to mixed phase or glaciated icing conditions, with the possible exception of two known potentially vulnerable engine design features. These two design features are (1) pronounced inlet bends (such as particle-separator inlets), or inlet flow reversals, where inlet flow can stagnate and accumulate ice, and (2) high solidity dual row front stage compressor stators that can be susceptible to non-aerodynamic ice buildup on the stator air foils resulting in core airflow blockage. These two design features should either be avoided or carefully scrutinized by analysis and testing to assure their non-susceptibility to mixed phase or glaciated icing conditions. Additionally, there have been cases of icing encounters in mixed phase icing conditions where ice detectors have not detected ice formation. Ice detection systems should be evaluated for these conditions.

b. Auto-recovery systems. The use of auto-recovery systems is acceptable for certain engine certification testing. The FAA supports the use of auto-recovery systems, or other protective engine systems or devices, while in service, and allows the use of auto-recovery systems during ice slab ingestion certification testing as defined in § 33.77. Generally, compliance with §§ 33.68 and 33.77 requires a demonstration that no flameout, sustained power loss, surge or stall, or rundown is evident. Although ignition systems have generally been found to be reliable for auto-relight use after certain ice ingestion or accretion induced flameouts (§ 33.77), the auto-relight system should not be relied on during typical icing encounters (§ 33.68). Auto-recovery systems are regarded as only back-up devices, and should not be routinely needed. An example where the use of an auto recovery systems may be acceptable would be rare ice ingestion events resulting from severe (that is, significantly outside Appendix C) icing conditions. In addition, auto recovery systems are not considered the primary protection for continued safe engine operation during normal ice sheds or accumulations while operating in typical icing conditions. Details will be provided later in this AC about the use of auto-recovery systems when demonstrating compliance to §§ 33.68 and 33.77.

c. Use of Cloud Extent Factors for § 33.68. In Appendix C, a cloud extent is the distance vertically (vertical extent) or horizontally (horizontal extent) that a cloud extends. Vertical extent is normally measured in feet while horizontal extent is measured in nautical miles. The cloud extent factor is a dimensionless number, which relates the length of a cloud to an average

LWC across the cloud. These relationships described within Appendix C should be used in the critical point analysis (CPA) for assessing the probability of occurrence of icing conditions during various aircraft mission and performance analyses. These factors are applicable to airframe flight profiles where the straight-line flight portion of the evaluations may use the cloud extent factor included in Appendix C, in Figures 3 and 6 as applicable. However, engines and induction systems being evaluated under § 33.68 have historically not been limited to or evaluated against a specific aircraft flight profile when considering icing environments. Instead, under § 33.68, they are evaluated for unlimited operation in icing. It is emphasized that the criteria in Appendix C represent those icing conditions that could result from encounters with supercooled clouds. Other conditions that may contribute to aircraft engine icing conditions not currently included in Appendix C, and not currently required to be addressed under § 33.68 are, for example, freezing precipitation (that is, rain, drizzle, sleet, hail, and snow), ice crystals, and mixed conditions (meaning, mixture of supercooled water droplets and ice crystals). Rulemaking is currently being considered for these conditions. To account for the differences described above, multiple clouds should be assumed, with an extent factor equal to 1.0, as actual cloud extent is not a consideration for engine operations, particularly in an aircraft hold pattern. This approach will assure unlimited engine and induction system operation within the atmospheric conditions defined by Appendix C, and as experience indicates, in actual icing environments that include Appendix C in its entirety. The cloud horizontal extent factor was not intended to be used to limit the severity of exposure to icing conditions, where it is reasonable to assume the aircraft will be required to operate in that condition (for example, the holding pattern which may require repeated passes through a severe icing environment, or continuously remain in that severe environment). As a general rule, engines and induction systems should be shown to operate continuously in icing without regard to time in icing conditions. The only exception to this would be for low engine power conditions where sustained level flight is not possible. Even then, a conservative approach must be used where multiple horizontal and vertical cloud extents in series are assumed.

d. Low Engine Speed Compliance Testing in Continuous Maximum Clouds. During § 33.68 compliance test demonstrations, when demonstrating engine speeds (N1) below minimum for sustaining level flight (meaning, below “light-hold” N1), and in continuous maximum icing conditions, the test duration should be no less than 10 minutes and do not need to continue beyond 30 minutes. It may be terminated in-between 10 and 30 minutes, if and when stabilized operation in icing is shown. These low N1 test duration’s are based on multiple appendix C clouds in series while in descent. At engine powers that can sustain flight, all compliance test conditions must be run indefinitely, until stabilized operation in icing is demonstrated. Stabilized operation is the same as “steady operation”, and is defined in this AC. These test duration criteria should be applied to all icing demonstration test points that are within, or close to the continuous maximum conditions of Appendix C. At the end of each test point, the engine should be accelerated to maximum power to shed any residual ice, and then it can be shutdown. (You will find background information for low engine speed compliance testing if you refer to attachment A of this AC.)

e. Low Engine Speed Compliance Testing in Intermittent Maximum Clouds. For § 33.68 compliance test demonstrations defined in Appendix C, intermittent maximum icing conditions, the test duration should be 10 minutes. Indefinite operation is not required when operating at these low N1's, so the test can be terminated and the engine accelerated to takeoff power after the

10-minute demonstration period. This 10-minute test duration can be applied to all engine power conditions up to, but not including light hold power. These low N1 test durations are based on multiple Appendix C clouds in series while in descent. At engine powers that can sustain level flight, all compliance test conditions should be run until stabilized operation is demonstrated, which may be well beyond 10 minutes. Stabilized operation is the same as "steady operation" and is defined in this AC. (You will find background information on low engine speed compliance testing if you refer to attachment A of this AC.) These criteria should be applied to all icing demonstration test points that are within or close to the intermittent maximum conditions of Appendix C. At the end of each test point, the engine should be accelerated to maximum power to shed any residual ice and then it can be shut down.

SECTION 1. INDUCTION SYSTEM ICING (§§ 33.68 and 33.89(b))

8. CRITICAL POINT ANALYSIS (CPA). Compliance with the requirements of § 33.68 includes identifying, through analysis, the critical operating test points for icing within the declared operating envelope of the engine. The CPA should include a range of possible combinations of icing conditions. This range should relate to Appendix C of part 25, aircraft speed range, and engine powers as defined by the engine manufacturer, and prolonged operation in icing (for example, in-flight hold pattern), or repeat icing encounters. The CPA should be validated by empirical test data. This analysis should consider both critical ice accumulation conditions (that is, rime ice and glaze ice), environmental and engine operational effects on accumulation, accretion locations, as well as the most critical engine operating conditions for ice shed and ingestion. Some manufacturers have included within their CPA, a best practice of including conditions that may be outside of Appendix C, that have been identified through service difficulty of other engine models. Often the CPA is supplemented with development test data (for example, wet and dry testing with thermocouple components). The methodology used to calculate ice accretions should account for freezing fraction and pertinent aerodynamic effects. For example, water ingestion into fan inlet and core inlet, water impingement rates for critical surfaces, forward aircraft air speed effects, engine configuration effects such as inter-compressor bleed, and altitude effects such as bypass ratio effects. This should be in conjunction with an energy balance of critical engine surfaces, for example, latent heat and heat of fusion effects, metal-to-ice heat transfer effects, and ice insulating effects. For anti-iced parts, the critical test point should be determined from energy balance calculations of required heat loads encompassing the range of possible combinations of icing condition and engine power. In instances of low freezing fraction in glaze ice conditions, additional complexities arise from assessing the effects of non-aerodynamic ice formations and their shedding. Federal Aviation Administration (FAA) Report No. FAA-RD-77-78, Engineering Summary of Powerplant Icing Technical Data, provides additional guidance on performing a critical test point icing analysis.

a. Test versus Analysis. To approach the problem of reducing a matrix of potentially hundreds of test points to a few appropriately chosen test points, a certification process was developed over 30-years ago where a number of standard AC table test points (shown in tables 1 and 2 of this AC) have been demonstrated through full engine test which is then augmented by a CPA. The CPA was not meant to replace testing, or eliminate or replace the standard table test points, but instead to provide a means to predict other critical test points and test them in addition to the standard AC table test points. The FAA maintains this view of the CPA complementing the standard AC table test points provides an adequate methodology to cover all icing conditions.

The FAA recognizes an improvement in the fidelity of analysis tools that are available today. However, based on experience with the various applicants, the FAA believes that the CPA is best utilized as a method to predict the critical icing conditions for a given design, and then use these conditions in conjunction with the standardized AC table test points for certification compliance test purposes. It should be noted that FAA concurrence with a type certificate holders generic CPA method does not automatically constitute FAA acceptance of the resulting critical icing test points for future certification projects. The content of an icing certification program for any given certification project will be evaluated on a case-by-case basis. Some engine manufacturers have had difficulty in consistently achieving the agreed on test points that are necessary for compliance demonstration, due to facility or weather limitations. This difficulty is based on test facility limitations that can be expensive and often impractical to overcome. To directly address this repeated shortfall, the FAA has identified several national and international icing resources for accomplishing § 33.68 compliance testing. These resources include the Air Force's McKinley Climatic Lab (Florida), the Air Force's AEDC (Tennessee), and the Canadian government's NRC (Toronto), to name a few. There are additional test facilities that are suited for component or model testing.

b. Elements of CPA. The CPA should address, at minimum, the following icing issues:

(1) Ice shed damage. Ice accretion on engine surfaces (for example, blades, vanes, sensors) may eventually shed. The shed ice can subsequently cause engine damage if it impacts an engine surface with sufficient mass and velocity.

(2) Fan module. Acoustic panels, fan rub strips, and fan blade tips are susceptible to ice shed from inlet sensor(s), spinner, and fan blade root. The effects of ice density, hardness, and adhesion strength should be assessed to realistic flight conditions. The ice shed cycle for rotating surfaces, such as fan blades, is strongly influenced by rotor speed and the adhesive strength of the ice to the surface. The adhesive strength of ice generally increases with decreasing surface temperature. The ice thickness and rotor speed at the time of the shed defines the impact threat. In determining the critical conditions for fan module damage, surface temperature, exposure time, and rotor speed are important considerations in addition to more typical parameters, such as icing condition and scoop factor In particular, extended operation in a holding condition in very cold continuous maximum icing conditions will maximize the adhesion of ice on rotating fan components.

(3) Compressor damage. A common damage scenario in turbofan engines, is the accretion of glaze (non-aerodynamic) ice formations on static components (for example, sensors, vanes, and bleed ducts upstream of the compressor) which when it sheds, results in damage. This type of damage generally occurs on the first blade set in the high-pressure compressor (intermediate pressure compressor for three spool engines). Establishing the critical conditions for these glaze ice accretions requires careful consideration as they occur at specific limited conditions of low freezing fractions over a range of local mach numbers and air densities. The critical conditions may not occur during any of the power settings recommended by this AC (that is, flight-idle, 50-

percent and 75-percent of maximum continuous takeoff or 100-percent maximum continuous, whichever is applicable). Any engine damage that results from ice testing should be evaluated against the possibility of multiple occurrences, since icing is a common environmental condition.

(4) Engine operability and compressor rematch. Ice shed from upstream components may enter the core compressor. The presence of ice or water from melted ice in the gas path may cause the engine to assume new operating conditions (that is, engine component cycle rematch). The engine should be capable of accelerating from minimum flight-idle and ground idle to takeoff power, at any icing condition, without power loss, or instability (surge or stall). Ice sheds should not result in flameout, rollback, or surge. Any anomalous engine behavior should be raised to the cognizant Aircraft Certification Office (ACO) for evaluation and if found acceptable, should be documented in the engine's installation manual. The applicant should consider as part of the CPA both engine accelerations and decelerations relative to operability challenges. Critical test point testing should demonstrate those conditions where minimum operability margin is expected.

(5) Core and Booster ice blockage. Ice accretion on internal engine vanes due to the presence of glaze ice accretions may affect flow capacity and rematch of the engine cycle and should be considered in the CPA. At engine powers that can sustain flight, ice accretion should be reconciled through a demonstration of several ice build shed cycles to demonstrate no adverse operating effects of either the ice builds or sheds.

(6) Sensor fouling. Ice accretion and blockage of control sensors can result in erroneous engine pressure and temperature measurements. A power loss or power loss instability could result if these measurements are used by the engine control systems control law to establish power or thrust ratings, or to schedule other systems required to operate the engine (for example, variable stator vanes). Critical sensors should be designed to operate without accreting ice sufficient to cause an erroneous measurement that would result in an unacceptable operating characteristic. Additionally, ice accretion on upstream sensors can shed and cause engine damage to downstream rotating hardware.

9. TEST POINT(S) SELECTION. The icing test points selected must address the Appendix C icing envelope. Typically, the test points include those described in this AC (see table 1 and table 2 test points of this AC), and any additional test points identified as part of the CPA. The applicant should consider pertinent service experience as well as the anticipated use of the aircraft when selecting critical icing test points. The following should be considered when constructing an icing test matrix:

a. Section 33.68(a) Acceptable Means of Compliance. The engine should be capable of operating acceptably under the meteorological conditions of Appendix C over the engine-operating envelope, as described in § 33.68(a), and under conditions of ground fog (§ 33.68(b)). Experience has indicated that testing to the conditions specified in the following tables have been a successful means of showing compliance, if used in conjunction with the critical conditions determined in the CPA.

Table 1

Icing Conditions for Engine Certification Testing

Icing Condition	1 (glaze ice)	2 (rime ice)	3 (§ 33.68(b)) (ground fog icing)
Liquid Water Content, gr/meter^3	2 (minimum)	1 (minimum)	0.3 (minimum)
Inlet Temperature, °F (Total Temperature)	23 (+/- 2 F)	-4 (+/- 4 F)	15 - 30
Mean effective water droplet diameter, microns	22 (+/- 3)	15 (+/- 3)	20 (minimum)

Specifically for the icing conditions defined in the table 1.

- Conditions 1 and 2. Operate the engine steadily (see definitions for "steady operation") under icing conditions 1 and 2 for at least 5 minutes at takeoff setting, and at least 10 minutes each at 75-percent of maximum continuous power (M.C.), 50-percent of M.C., and at a flight-idle setting, then accelerate to takeoff. If ice is still building up at the end of 10 minutes, continue running until the engine demonstrates stabilized operation (meaning, stabilized building and shedding is demonstrated or the engine will no longer operate satisfactorily). For test point number 1, the mean effective droplet diameter has been reduced by 3 microns in order to position the test point within the Appendix C envelope, at 23° Fahrenheit and LWC=2. This was done to avert the past discussions on this test point being out of the appendix C envelope.

- Test points 1 and 2 above, are intended to partially cover a widely bounded test matrix of environmental and engine operating conditions to be used when showing compliance with §33.68(a). This test matrix includes power settings from idle to takeoff during exposure to conditions typical of high altitude where rime ice formations occur, as well as conditions typical of low altitude where glaze ice formations often occur. Icing conditions 1 and 2 are normally run for a minimum of 5 minutes when at takeoff power. All other power settings below takeoff should be run for a minimum of 10 minutes, or longer if the natural ice shed cycle is not established. Also, engines that employ an inlet de-ice system that may have some unheated inlet surfaces may need to be run longer.

- Condition 3. Operate steadily at ground idle setting for at least 30 minutes under icing condition 3 followed by acceleration to takeoff setting. Since a broad temperature range is provided, the applicant should identify the most critical temperature, as determined by the CPA, and target that range. If ice is still building at 30 minutes, continue running until the engine demonstrates stabilized operation (that is, stabilized building and shedding is demonstrated or the engine will no longer operate satisfactorily). For large bypass fan engines, shedding at this low speed from static surfaces is not likely at 30 minutes and beyond. For these engines, this test generally establishes the maximum allowable time between engine run-up to shed ice. Typically, the AFM specifies about ½ this time (15 minutes) between run-ups. The engine should be shown to operate continuously (including run-ups, if necessary) at the ground icing condition, as might well occur at an airport where aircraft can be held on the ground several hours in bad weather awaiting takeoff. Periodic run-ups are acceptable as part of this demonstration.

For all conditions. While at flight-idle engine speed and above, for engines with icing protection systems, stabilize the engine for at least 2 minutes in the icing atmosphere with these protection systems off, prior to turning on the icing protection system. Systems that are automatic and controlled by the full authority digital electronic/engine control (FADEC) do not require the 2-minute delay in ice protection system demonstration. Where the engine's anti-icing system relies on an ice detector to indicate the presence of icing conditions, delay in anti-ice selection is likely following failure of the detector, and so delayed selection testing should still be demonstrated.

- For all conditions. Engine operation in these icing conditions should be reliable, uninterrupted, and without any significant adverse effects, and should include the ability to continue in operation and accelerate and decelerate. Some power reduction is acceptable at idle power settings due to the cycle effects of pumping ice and water, but all other operation should be unaffected.

- The engine must operate "steadily" under the tested icing conditions. The term "steadily" is defined in the definitions section and is intended to address both stabilized ice accretions and stabilized engine operation. Ice accretions are considered stabilized when either ice is not forming on any engine parts, or the accreting ice has demonstrated a regular shed cycle when viewed by a video camera or instrumentation indication, or both. Engine operation is considered stabilized when the measured engine parameters are not changing, or a regular, repeatable shed cycle has been demonstrated through the recording of measured engine parameters.

- At the conclusion of each steady state ice test point, the engine should be accelerated to takeoff power. The throttle motion should be the most critical when considering the ice shed effects on engine operability. In some cases, a quick deceleration before accelerating to takeoff power may be more critical to the ice shed effects on engine operation. The applicant should assess this effect and account for their assessment in their test proposal.

b. Section 33.68(b). Section 33.68(b) provides an icing test point, which represents a typical freezing fog icing encounter during ground operation. The guidance contained in AC 33.2B, with respect to snow ingestion testing, is considered outdated (see paragraph 17 of this AC for additional guidance). The ground-fog icing demonstration should continue for at least 30 minutes or until stabilized operation (see "steady operation" in the definitions section of this AC) is demonstrated. If this stabilized operation cannot be demonstrated then periodic engine speed run-ups should be demonstrated. These run-ups would then become mandatory in icing conditions since they were required to comply with the icing requirements. The effect of ingesting snow during ground-operations can and should be evaluated, but not concurrently with ground fog. Service experience has demonstrated compressor damage (see paragraph 8b(3) of this AC) as a result of exposure to prolonged periods of falling snow during ground operation. Based on review of service events, airports have continued to operate with falling-snow concentrations that result in 0.25 mile or less visibility. The enhancement of freezing fraction in the presence of wet, sticky snow suggests that icing tests conducted with only liquid water require approximately twice that concentration shown in table 1 for condition 3. Utilization of liquid water in-lieu of snow is not recommended, depending on the hardware configuration being tested, ice crystals may be more appropriate. Sections 23.1093(b)(ii) and 25.1093(b)(ii) require that engines must operate satisfactorily in falling and blowing snow throughout the engine power range, within the limitations established for the airplane for such operation.

c. Holding phase. This test, when performed as part of a part 33 demonstration, is intended to be applicable to part 33 engine components. Both the engine (§ 33.68) and aircraft inlet induction system (§§ 23.1093 and 25.1093) should operate safely in an in-flight holding phase without a time limit. The test program for turbofan and turboprop applications should include test points (for example, icing condition and power setting) to address the effects of prolonged exposure in icing conditions typical of in-flight holding patterns. Test point 1 in table 2, below, represents a rime icing condition that is typically encountered on transport category airplanes. Test point 2 in table 2 of this AC represents a mixed rime and glaze icing condition that was originally derived from the JAR-E ice requirements of LWC, temperature and droplet size. The engine and inlet should be capable of prolonged exposure to the conditions specified in table 2. A 45-minute minimum test exposure followed by acceleration to takeoff power will typically demonstrate several ice shed cycles and should normally be sufficient to assess compliance for the engine.

Table 2 - Holding Conditions

Test Point	Total Air Temperature (degrees / Fahrenheit)		Liquid Water Content (g/m^3)	Mean Effective Droplet Diameter
	Turbofan	Turboprop	(minimum)	(microns)
1.	-4 (+/- 4°F)	6 (+/- 2°F)	0.25	15-20
2.	14 (+/- 2°F)	6 (+/- 2°F)	0.30 6 minutes* 1.70 1-minute*	15-20 20 +/-3

NOTE: * alternate between these two conditions for at least 45 minutes

10. TEST SETUP CONSIDERATIONS. The Liquid Water Content (LWC) levels defined in appendix C are intended as ambient icing conditions. Tests may be conducted with a simulated cloud outside of the inlet that is ingested into the engine. Under such a test environment, the LWC within the inlet ducting may be more or less than the engine inlet LWC concentration if the engine were actually installed in an airplane and flying through those icing conditions at actual airspeeds. This inlet concentration effect is dependent on droplet size, engine fan speed, and simulated forward airspeed. Icing tests that provide a simulated icing cloud by direct connection of facility piping to the front flange of the engine, where no inlet air spillage is allowed, may cause test facility effects that could alter the test parameters (for example, LWC and MED). The applicant must provide the FAA with substantiation that the required simulated test conditions adequately simulate an installed engine flying through the Appendix C conditions. This substantiation can be in the form of direct measurement of LWC within the inlet or by acceptable validated analysis of water droplet trajectories for the test setup. In some cases, additional LWC may be needed to address any shortfall in concentration effects due to the test setup (for example, non-uniformity across the engine face).

11. TEST RESULTS AND COMPLIANCE ISSUES. During all icing tests, the engine should operate without the accumulation of ice, which would adversely affect engine operation (for example, flameout, surge, stall, run-down, high vibrations, slow acceleration or lack of throttle response) or cause a sustained loss of power or thrust. Additionally, the applicant should accurately monitor icing test point conditions either through video surveillance or instrumentation and provide the means to identify the source of ice damage, especially in those instances where test apparatus may shed ice (for example, icing nozzles, special test instrumentation).

a. Sustained loss of power or thrust and power loss instabilities. There should be no sustained power loss while operating at approved ratings in icing conditions. Temporary steady state power losses below the engine power and thrust ratings selected in accordance with § 33.8 can be accepted if it is proven that there is sufficient margin against any power loss instability, such as rollback, surge, stall, high vibes or flameout. Although usually not acceptable, temporary power anomalies that may be found acceptable could include those temporary anomalies caused by pumping or processing of ice debris through the fan and compressor during the ice shed ingestion process. If temporary power loss or temporary high vibrations are deemed acceptable to the Administrator, they should be documented in the engine installation manual.

b. Mechanical Damage. There should be no engine damage as a result of § 33.68 icing testing. In some circumstances, some limited damage may be accepted. The acceptance of any damage must fully account for the cumulative damage from repeat encounters, provided the applicant satisfies the following criteria:

(1) Continued in-service use. Any resultant damage should be shown to be acceptable for continued in-service use.

(2) Sustained power losses. There should be no resultant sustained power loss;

(3) Temporary power loss. Although not generally acceptable, any resultant temporary steady state power loss, surge or high vibrations, if found acceptable by the Administrator, should be recorded in the installation manual.

(4) Validation basis. Analytical tools used to substantiate the criteria for determining acceptable damage should be shown to have a sufficient validation basis (for example, engine tests, rig tests, service experience) to substantiate the accuracy of results or be shown to yield conservative results.

(5) Disposition of Damage. Disposition of damage to any engine or engine component may not be obtainable solely by comparing the damage against the maintenance manual limits. The cumulative damage for repeated encounters should be evaluated.

(6) Communication of results. The Installation and Operating Manuals required by § 33.5 should provide information describing any resultant engine condition observed during engine certification icing tests. The engine manufacturer should provide a process to permit disposition of any potential damage that could occur during natural icing flight tests conducted to demonstrate compliance with §§ 23.1093 or 25.1093, if the installing FAA Aircraft Certification Office finds this acceptable. Also, if periodic engine power run-ups are necessary to minimize damage from icing during the ground icing operation demonstration of § 33.68(b), then this run-up must be documented. Documentation must contain a description of the run-up requirements and the required run-up intervals and it must be contained in the operating manual and airworthiness limitations section of the instructions for continued airworthiness (ICA). Any power loss anomalies due to accumulation, shed, runback and the like, and their effects on performance and operation should be documented in the Installation Manual. Both the engine certifying ACO and the installing ACO should carefully consider any high vibrations induced from ice accretions during ice testing. This too should be documented as described above.

c. Engine systems. It is permissible to use engine systems (that is, automatic, engine initiated ice protection systems) to fulfill § 33.68 requirements provided that its operation is not expected to result in crew action. Examples of engine characteristics that may not be transparent to the flight crew are exhaust gas temp fluctuations, or audible surging. Additionally, any engine system required to show compliance with § 33.68 should meet the following requirements:

(1) System reliability. Demonstrate the capability of the system for reliably sensing the conditions, which enables the function, throughout the operating envelope;

(2) Dispatch. The function should be available for all dispatchable configurations. The system should be configured in its most critical dispatch state for certification icing tests;

(3) Electronic faults. If the system uses electronics, substantiate that the function is not lost due to any single or probable multiple electronic faults;

(4) Other environmental testing. The function should not be affected when the system and any associated electronic systems are exposed to required operating environments, including high intensity radiated fields (HIRF) and lightning; and

(5) Power requirements. For those systems that are powered solely with a dedicated engine alternator (either directly or using another engine system such as full authority digital electronic/engine control (FADEC)), it should be demonstrated that over the operating envelope, that the function (that is, sensing and performance) is provided at the minimum certified rotor speeds. Minimum certified engine speed is the minimum idle rotor speed achievable anywhere in the flight envelope.

d. Auto-recovery systems. Auto-recovery systems should not be needed during § 33.68 testing since these icing conditions are considered to be within the engine's certified operational envelope. The intent of § 33.68 is to certify engines that will be able to perform and operate reliably in the icing conditions described Appendix C. Auto-recovery systems are considered to be back-up devices that are only needed following rare ice ingestion events that result from icing conditions significantly outside Appendix C, and should be communicated to the installing ACO if activation is expected or experienced in these rare occasions. Auto-recovery systems are not the primary protection for continued safe engine operation during normal ice sheds, or accretion while operating in icing conditions described in Appendix C. Therefore, it is acceptable to perform § 33.68 compliance testing with auto-recovery systems enabled, but they should not activate throughout the § 33.68 test sequence. Additionally, continuous ignition should not be selected during § 33.68 compliance testing. To assure non-activation of an enabled auto-recovery system, it may be necessary to display an instrumented signal that monitors auto-recovery system activation. If activation monitoring cannot be accomplished, then disabling of the auto-recovery system may be necessary.

e. Operating instructions. Any operating procedure (for example, ground run-up procedures) required to ensure continued operational compliance with ground icing conditions evaluated under § 33.68(b), or falling and blowing snow conditions which can be evaluated under § 33.89(b) as a precursor to §§ 23.1093(b)(ii), or 25.1093(b)(ii), should be communicated to the installer in the Operating Instructions as a requirement, and should be included in the limitation section of the airplane flight manual. It may be necessary to coordinate with the installer on these procedures to ensure that they can be effectively implemented in-service.

SECTION 2. ICE SLAB INGESTION (§ 33.77)

12. INTENT OF ICE SLAB INGESTION TEST. The intent of the ice slab ingestion test is to demonstrate that the ingestion of an ice slab, which may form after a delayed activation of induction system anti-icing, will not adversely affect engine operation. It is intended that the engine manufacturer will conservatively consider the potential installation effects of the engine induction system. Also, there should be close coordination with the installer to ensure that potential airframe ice accumulation sites that can result in ice ingestion into the engine (for example, inboard section of wing for an aft fuselage mounted engine) are either demonstrated under § 33.77 or addressed under §§ 23.901(d)(2), 23.1093, or 25.1093 (see paragraph 18a(2) of this AC). The induction system manufacturer or installer should assess these accumulations in accordance with §§ 23.901(d)(2), 23.1093, or 25.1093 and provide pertinent test variables to the engine manufacturer for incorporation into a test demonstration in accordance with § 33.77. In the case where an application or product inlet has not been selected at the time of engine certification, the engine manufacturer should provide all pertinent inlet assumptions and test data and results in the engine installation manual for use by the future installer.

13. TEST CONSIDERATIONS. The test demonstration should consider ice slab sizes and trajectories aimed at critical engine locations that are based on the ice accretion and shed characteristics of the induction system that is likely to be installed on the engine. Lacking such specific knowledge, the applicant may select test conditions, which are typical of a condition for a representative installation in-service. The ice slab size, thickness, and density used in § 33.77 compliance demonstration should be assessed for appropriateness against parts 23 and 25 compliance requirements. The reason for this is that part 33 specifically addresses continuous maximum icing conditions, and parts 23 and 25 address all part 25 appendix C conditions and all areas of the airframe that could present an ice slab into the engine inlet. See AC 20-73, AC 23.1419-2B, and AC 25.1419-1 for more guidance on ice shedding. If it is determined that the ice slab size, thickness, and density are appropriate for the engine installation, then the part 33 test results can often be used by the airframe manufacturer to comply with the natural icing flight test requirements which are related to delayed activation of the induction anti-icing system. Historically, slab thickness used in compliance testing for § 33.77 has typically been identified as approximately 0.5" thick, with a few installations identifying approximately 0.33" thick slabs. These thicknesses have typically been sufficient to cover any potential airframe ice slab threats for compliance to parts 25 and 23 compliance. Experience has shown that the method of delivering the ice slab to the face of the engine and the orientation of the slab (for example, the edge of the slab versus the face of the slab) can have a significant effect on the outcome of the test.

Therefore, it is incumbent upon the applicant to determine and test for the most realistic release method. This release method should account for the most critical possible orientation at impact.

14. TEST RESULTS. Section 33.77(c) requires that the ingestion of ice, under the conditions stipulated in § 33.77(e), may not cause a sustained power or thrust loss, or require the engine to be shutdown. The intention of this ice slab test is to account for inadvertent delayed activation of the induction anti-icing system. A nominal 2-minute delay is assumed. The following criteria should be met:

a. Sustained power losses. There should be no resultant sustained power loss. Any fan blade bending or damage should be assessed against potential sustained power loss and the resulting damage should not result in a power loss greater than the ability to assess power level. That is, it should not be outside the capability to measure and assess engine power level.

b. Engine operability. Damage should not adversely affect engine operability (that is, should not cause surge, flameout, nor prevent transient operation).

c. In-service capability. Damage should not result in a failure or a performance loss that would prevent continued safe operation for a conservative flight cycle scenario (for example, within fly back limits or greater if appropriate testing is done to validate a continued period of in-service capability). The period of in-service capability to be demonstrated may vary with installation if the damage is not readily evident to the crew or visible on preflight inspection (for example, tail mounted positions).

d. Other anomalies. Damage should not result in any other anomaly (for example, vibration) that may cause the engine to exceed operating or structural limitations.

e. Auto-recovery systems. If during § 33.77 ice slab ingestion testing, an engine does incur a momentary flameout and auto-relight, then normally the acceptance of that test would be predicated on the inclusion of the auto-relight system as being a required part of the engines type design, and an additional dispatch criteria would be required, where the ignition system must be functional (that is, fully operable) prior to each dispatch. The reason for the additional dispatch criteria is to ensure the ignition system's critical relight function is reliably available during the subsequent flight. The reason for the allowance of auto-recovery systems during § 33.77 certification testing is to account for ice accretion and shedding, as a result of an inadvertent 2-minute delay in actuating the anti-icing system, which is considered to be an abnormal operational result where mild operability effects (for example, momentary flameout and relight) may be accepted.

15. COMMUNICATION OF TEST RESULTS. The installation and operating instructions required by § 33.5 should provide information on the size, thickness, and density of the ice slab ingested, any anomalous behavior such as high vibrations and any affect on the engines ability to operate at the commanded power setting or rating. The icing certification report should include information regarding ice slab orientation and trajectories, slab breakup, impact locations, description of any resultant damage, and any other pertinent data defining the engine's capability or response to the ice ingestion event. Additionally, if the auto-recovery system is required to comply with § 33.77, then the functional state of the recovery system (for example, one igniter inoperative) becomes a limitation that needs to be communicated to the installer to ensure compliance with the delayed activation requirements of §§ 23.1093 or 25.1093.

SECTION 3. INDUCTION SYSTEM ICING PROTECTION (§§ 23.1093 and 25.1093)

16. NATURAL ICING FLIGHT TESTS. Natural icing flight tests are intended to demonstrate that each turbine engine is capable of operating throughout the flight power range of the engine (including idling), without the accumulation of ice on the engine, inlet system components, or airframe components that would have an adverse affect on engine operation or cause a serious loss of power or thrust. Based on multiple engine natural ice damage and operability events experienced on natural icing flight test and in-service airplanes, the FAA requires natural ice encounters for showing compliance with §§ 23.1093(b)(1) or 25.1093(b)(1). However, for airplanes that are not intended to be certificated for flight in icing conditions, the FAA will accept other methods in lieu of natural icing flight tests, such as analysis, ground testing, dry air flight testing, and similarity, to show compliance to § 23.1093(b)(1). Aside from the benefit of validating the engine inlet icing analysis model, there are several other key issues that the natural ice encounter addresses. These evaluations include: (1) The adequacy of the flight crew procedures for operation in icing conditions, (2) acceptability of tactile inputs to the flight crew as the airplane responds to engine fan blade ice shedding during a variety of airplane operating conditions, (3) performance of the engine vibration indication system as well as other engine indication systems and, (4) confirmation that the powerplant installation as a whole (for example, engine, inlet, anti-ice system) performs satisfactorily while in icing conditions.

a. Identification of ice source. A means should be provided to aid in identifying the source of any ice that may be ingested by the engine during the natural icing certification testing. Special attention should be given to non-representative ice accretions on flight test instrumentation probes or other surfaces forward of the engine during prolonged operation in icing conditions.

b. Icing test point monitoring. The applicant should provide sufficient monitoring of the icing test point condition (that is, LWC, droplet diameter, temperature) against the time to ensure that the icing encounter is representative of the appendix C conditions under part 25.

c. Compliance. Compliance with §§ 23.1093 or 25.1093 is required even if flight into icing approval (§§ 23.1419 or 25.1419 compliance) is not obtained. Compliance with the natural ice encounter criteria should be proposed by the applicant and agreed to by the FAA prior to the test. However, typically an adequate test sequence includes three natural fan ice shed cycles at each of the following conditions (with inlet anti-ice turned "on"); descent (flight-idle), holding (power necessary to maintain level flight for a range of anticipated airplane gross weight conditions), and maximum climb, unless a more critical engine power setting exists. These encounters should be conducted at a steady state engine thrust level and although not preferred, sometimes have involved flying through the same icing cloud multiple times (lapping) in order for the fan to accumulate enough ice for a shed cycle to occur. (Caution is emphasized when flying in natural ice conditions.) These fan shed cycles should be due to natural ice accumulation and not induced or forced by throttle excursions or manipulations, or both, during each condition. It has also been allowed for the airplane to exit the icing conditions between each fan shed cycle for the purpose of clearing any other unprotected airplane surfaces from ice. To avoid masking any adverse engine operating conditions during the natural icing encounter, the test engine's ignition system should be selected off during the icing conditions. This may require pulling several airplane circuit breakers to disable the test engine's auto-ignition or recovery system, or both, and caution should be used and all safety precautions exercised. Lastly, based on past experience, it is advisable that the applicants establish and gain concurrence with the FAA for engine damage criteria prior to conducting the natural ice encounter test.

17. FALLING AND BLOWING SNOW. Sections 23.1093(b)(ii) and 25.1093(b)(ii) require that engines must operate satisfactorily in falling and blowing snow throughout the flight power range. The effect of ingesting snow during ground operations can and should be evaluated. Service experience has demonstrated compressor damage (see paragraph 8b(3) of this AC) as a result of exposure to prolonged periods of falling snow during ground operation. Based on review of service events, airports have continued to operate with falling-snow concentrations that result in a 0.25 mile or less visibility. In-flight service experience has also shown that snow can shed from engine or aircraft accumulation sites and cause severe operability affects on turbine engines. Therefore, all engine inlets, including those with plenum chambers, screens, particle-separators, variable geometry, or any other feature, such as an oil cooler, struts or farings, which may provide a potential accumulation site for snow should be evaluated. Also, any airframe accumulation sites upstream of the engine inlet should also be considered.

18. <u>TEST RESULTS</u>. The applicant should carefully consider all evidence of ingestion and damage to the engines and their potential sources. If damage is incurred, the possible test outcomes include:

a. <u>Acceptable damage</u>. The extent of damage is equivalent to or less than that incurred and accepted during engine certification testing.

(1) <u>All systems operating normally</u>. The extent of damage is equivalent or less than that incurred and accepted during the § 33.68 tests.

(2) <u>Delayed activation of induction system anti-icing</u>. If ice ingestion tests under § 33.77 do not adequately represent the particular airframe installation, then the delayed anti-icing system activation test should be considered. (Caution should be used and all safety precautions exercised.) For this condition, the acceptance criteria defined in paragraphs 13 and 14 of this AC, should be used. The airframe manufacturer still must consider all potential ice shedding sites (for example, inboard wing and radome). Similar to the accepted compliance of § 33.77 ice slab ingestion tests (outlined in section 2 of this AC), the use of engine auto-ignition and recovery systems are allowed to show compliance with the delayed activation tests of parts 23 or 25, as long as these automatic systems can not be easily turned off by the flight crew (that is, a flight crew that inadvertently forgets to turn on the engine anti-ice protection is also likely not to have selected any other engine protection features such as continuous ignition, prior to entering the inclement weather). It is important to note the difference in anti-iced inlets versus de-iced inlets. De-iced inlets produce a cyclic shedding of ice from the engine inlet into the engine and typically incorporate, as part of their design, an inlet particle-separator that precludes the ingestion of ice into the core of the engine. It should be recognized that an engine auto-recovery system should not be a compensating design feature utilized to minimize the negative effects of an inadequate particle-separating inlet that is not in full compliance with §§ 23.1093 or 25.1093.

b. <u>Damage from testing in non-representative icing conditions</u>. Damage resulting from icing test conditions which fall significantly outside Appendix C icing envelopes, or when the airplane flight test is conducted in an abnormal manner and results in excessive ice shed damage, may be given additional considerations relative to compliance with the provisions of either §§ 23.1093 or 25.1093, and in some cases may be disregarded. An example of abnormal operation could be flying with one engine at idle while the aircraft is operated in level flight.

c. <u>Unacceptable damage</u>. The icing test conditions was representative of in-service encounters and the resultant airframe or engine ice sheds caused damage that exceeds the criteria established in paragraph 11b of this AC.

19. <u>CONCLUDING REMARKS</u>. Although applicants may conduct representative tests under §§ 33.68, 33.77, 23.1093, and 25.1093, flight test events may still occur which appear inconsistent. In all likelihood, those results would not be inconsistent when judged in light of the scope, intent, and limitations of the certification testing. Only through reliable instrumentation and photographic evidence can the icing test disparities be fully understood. Because of the relatively frequent encounters with icing conditions in conjunction with the potential impact on safety, the FAA takes a conservative approach when accepting icing compliance standards.

David W. Hempe
Manager, Aircraft Engineering Division

ATTACHMENT A

Reference: Policy on low engine speed part 33 compliance testing

The Federal Aviation Administration (FAA), Engine and Propeller Directorate's Standards Staff, ANE-110, has been requested to provide a position relative to test time duration during § 33.68 icing tests at non-flight-sustainable engine speeds. The FAA's position has traditionally been, and continues to remain, that engines are held to a higher standard than aircraft for icing certification and the engines must demonstrate unrestricted and unlimited operation in icing conditions. Therefore, during § 33.68 compliance test demonstration, engines must remain on-point until stable operation has been demonstrated. This has been pointed out as being onerous when operating the engine at non-flight-sustainable engine speeds (meaning, below lightweight hold engine operation). In response to this observation, the FAA has developed criteria that allows for a reasonable test period and termination time for icing testing of non-flight-sustainable engine speeds. It is emphasized that this test time termination criteria is only applicable to icing testing when the engine is operating at non-flight-sustainable engine speeds.

The maximum liquid water content (LWC) severity depicted in Appendix C of part 25 shows that intermittent maximum water content is over three times more severe than the continuous maximum water content. Due to the significant severity differences between intermittent maximum and continuous maximum icing conditions in Appendix C, two separate criteria have been considered.

Appendix C, paragraph (a) - Continuous Maximum Icing Conditions. In an effort to preserve safety of flight in icing conditions, the FAA strives to retain sufficient margin to expected icing conditions when assessing compliance demonstrations. Conservative assessments are applied in several assumptions. The FAA must expect engine designs to exceed the single cloud definitions of appendix C since the encounter of LWC at a stated inlet temperature at any mean effective diameter (MED) is predicted to be a probable event. The expected occurrence rate is too frequent to consider a single cloud extent during §33.68 compliance test demonstrations. With this objective, the FAA has developed a conservative methodology for assessing the worst case (that is, long descent loiter) that can reasonably be expected. The following analysis is intended to approximate a conservative approach to bounding the maximum part 33 low engine speed test time and is not based on expected or representative flight profiles or typical icing conditions.

A typical descent gradient and a rule of thumb for pilots is 3 miles horizontal for 1000-foot vertical descent gradient (15.8:1 gradient). This would work out to about 60-mile descent initiation test point for a 20,000-foot descent. This works out to be about a 3.6-degree nominal descent slope. If we take a conservative 2-degree descent slope, then the descent initiation would start at 120 miles out for a 22,000-foot vertical descent. A total descent altitude of 22,000 above ground level (agl) was used because Appendix C goes from sea level to 22,000 feet, although it is recognized that icing occurs at altitudes greater than 22,000 feet.

In order to convert a 15.8:1 descent gradient into a meaningful descent rate in feet each minute, a horizontal airspeed must be assumed. For this conservative analysis, an average horizontal air speed of 220 knots (250 miles per hour) is assumed. This average airspeed is for the complete descent through all 22,000 feet and assumes periodic head winds and profile variations for all types of fixed wing aircraft. This makes the assumption more conservative for transport category aircraft and less conservative for small lightweight prop aircraft. It is understood that this is a conservative approximation over 10,000 feet agl where speed is not limited.

The result of these inputs is, at 2-degree descent gradient and 220 knots (250 mph) horizontal air speed, you get about a 750-ft descent each minute, from 22,000 feet in 30 minutes. Consequently, it can be justly stated that the engine manufacturers should reasonably test engines at flight-idle up, and to engine speeds that result in non-sustainable flight (that is, less than light hold power) for a total of not more than 30 minutes of appendix C continuous maximum icing conditions, when stabilized operation has not been demonstrated.

Appendix C, paragraph (b) - Intermittent Maximum Icing Conditions. It is widely understood that under part 25, the intermittent maximum icing conditions of Appendix C are more severe than the continuous maximum conditions. Just as the above continuous maximum discussion provides for multiple cloud extents in series, the same philosophy will be applied here for intermittent maximum conditions, to assure robust design demonstrations. This increased severity of an intermittent cloud in conjunction with the reduced horizontal and vertical extents of these clouds necessitates a proportionately reduced maximum compliance test demonstration period. The FAA has a very long and successful historical experience base for compliance test demonstrations in intermittent maximum icing conditions. This historical basis has shown that a 10-minute test period has been sufficient. Additionally the 10-minute period would represent about five to ten sequential intermittent maximum clouds, on an Appendix C horizontal extent basis, depending on speed. This should provide the FAA with sufficient confidence in an engine design when exposed to icing conditions in-service.

Conclusion

In conclusion, during § 33.68 compliance test demonstrations, while demonstrating engine speeds below minimum for sustaining flight (that is, below light hold N1), while in continuous maximum icing conditions, the test duration should be no less than 10 minutes and need not continue beyond 30 minutes, and may be terminated in-between 10 and 30 minutes, if and when stabilized operation in icing is shown. At engine powers that can sustain flight, all compliance test conditions must be run indefinitely, until stabilized operation is demonstrated. These test duration criteria should be applied to all icing demonstration test points that are within or close to the continuous maximum conditions of Appendix C. At the end of each test point the engine should be accelerated to maximum power to shed any residual ice and then it can be shut down.

For § 33.68 compliance test demonstrations of Appendix C intermittent maximum icing conditions, the test duration should be no less than 10 minutes. For compliance demonstrations where engine speeds are below the minimum for sustaining flight (that is, below light hold N1), while in intermittent maximum icing conditions, the test duration should be no less than 10 minutes and need not continue beyond 10 minutes and may be terminated thereafter. There is no requirement for indefinite operation when operating at these low N1's so the test can be terminated and the engine accelerated to takeoff power after the 10-minute demonstration period.

This 10-minute test duration can be applied to all engine power conditions up to, but not including light hold power. At engine powers that can sustain flight, all compliance test conditions must be run indefinitely, until stabilized operation is demonstrated. These criteria should be applied to all icing demonstration test points that are within or close to the intermittent maximum conditions of Appendix C. At the end of each test point the engine should be accelerated to maximum power to shed any residual ice and then it can be shut down.