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

Advisory Circular

Subject: Turbine Engine and Airframe Sensor Icing Compliance

Date: 06/18/2025
Initiated By: AIR-625

AC No: 20-197
Change No: N/A

1. PURPOSE.

This advisory circular (AC) describes an acceptable method for demonstrating compliance with title 14, Code of Federal Regulations (14 CFR) 33.28, 33.68, 33.75, 33.89, and 33.91, concerning mixed phase, ice crystal icing (ICI), and other icing conditions for engine inlet sensors. This AC may also assist applicants for part 25 airplanes in demonstrating compliance with 14 CFR 25.901(c), 25.1093(b), 25.1309, 25.1323, 25.1324, and 25.1325 concerning icing conditions and data obtained from engine inlet sensors on turbine-powered airplanes. This AC addresses temperature probes, combined temperature and pressure probes, and static pressure probes installed in turbine engines. Manufacturers can use this method of compliance to evaluate probe behavior in mixed phase, ICI, and other icing conditions, and assess the resulting impact of engine probe performance on engine and airframe systems. Although the main focus of this AC is on engine inlet probes, the methodology can also be applied to evaluate temperature probes, combined pressure and temperature probes, and static pressure probe behavior regardless of installation location.

2. APPLICABILITY.

2.1 The guidance provided in this AC is for airplane manufacturers, modifiers, foreign regulatory authorities, Federal Aviation Administration (FAA) transport airplane type certification engineers, and FAA designees.

2.2 **This is a guidance document. Its content is not legally binding in its own right and will not be relied upon by the Department as a separate basis for affirmative enforcement action or other administrative penalty. Conformity with the guidance document is voluntary only. Nonconformity will not affect rights and obligations under existing statutes and regulations.**

2.3 The FAA will consider other means of demonstrating compliance that an applicant may elect to present. Terms such as "should," "may," and "must" are used only in the sense of ensuring the applicability of this particular method of compliance when the acceptable method of compliance in this document is used. If the FAA becomes aware of circumstances in which following this AC would not result in compliance with the applicable regulations, the FAA may require additional substantiation or design changes as a basis for finding compliance.

2.4 The material contained in this AC does not change or create any additional regulatory requirement, nor does it authorize changes in, or permit deviations from, existing regulatory requirements.

3. RELATED MATERIAL.

3.1 Title 14, Code of Federal Regulations (CFRs).

The following 14 CFR regulations are related to this AC. You can download the full text of these regulations from the Federal Register website at eCFR.

- Section 33.28, *Engine control systems.*
- Section 33.68, *Induction system icing.*
- Section 33.89, *Operation Test.*
- Section 33.91, *Engine system and component tests.*
- Appendix D to Part 33—*Mixed Phase and Ice Crystal Icing Envelope (Deep Convective Clouds).*
- Section 25.901, *Installation.*
- Section 25.1093, *Induction system icing protection.*
- Section 25.1309, *Equipment, systems, and installations.*
- Section 25.1323, *Airspeed indicating system.*
- Section 25.1324, *Angle of attack system.*
- Section 25.1325, *Static pressure systems.*
- Appendix C to Part 25—(no title) *Part I - Atmospheric Icing Conditions.*
- Appendix O to Part 25—*Supercooled Large Drop Icing Conditions.*
- Appendix C to Part 29—*Icing Certification.*

3.2 FAA Advisory Circulars.

The following ACs are related to the guidance in this AC. The latest version of each AC referenced in this document is available on the FAA website at FAA Advisory Circulars and on the Dynamic Regulatory System.

- AC 20-73A, *Aircraft Ice Protection.*

- AC 20-147A, *Turbojet, Turboprop, Turboshaft, and Turbofan Engine Induction System Icing and Ice Ingestion.*
- AC 25-28, *Compliance of Transport Category Airplanes with Certification Requirements for Flight in Icing Conditions.*

3.3 **FAA Technical Standard Order (TSO) and Report.**

The following TSO and report are related to the guidance in this AC. The latest version of each referenced in this document is available on the FAA website at TSO, Research Reports, and on the Dynamic Regulatory System.

- Technical Standard Order, TSO-C16b, *ELECTRICALLY HEATED PITOT AND PITOT-STATIC TUBES.*
- FAA Report No. DOT/FAA/AR-09/13, *Technical compendium from meetings of the engine harmonization working group.*

3.4 **ASTM International.**

ASTM F3120 / F3120M – 20, *Standard Specification for Ice Protection for General Aviation Aircraft*, is related to the guidance in this AC. Unless otherwise specified, use the latest FAA-accepted revision for guidance. If the document is revised after the publication of this AC, you should verify that the FAA accepts the subsequent revision or update as an acceptable form of guidance. This document can be ordered online at ASTM F3120/F3120M-20.

3.5 **RTCA (formerly Radio Technical Commission for Aeronautics).**

RTCA DO-160G, *Environmental Conditions and Test Procedures for Airborne Equipment*, is related to the guidance in this AC. Unless otherwise specified, use the latest FAA-accepted revision for guidance. If the document is revised after the publication of this AC, you should verify that the FAA accepts the subsequent revision or update as an acceptable form of guidance. This document can be ordered online at RTCA.

3.6 **Society of Automotive Engineers (SAE) International.**

The following SAE documents are related to the guidance in this AC. Unless otherwise specified, use the latest FAA-accepted revision for guidance. If the document is revised after the publication of this AC, you should verify that the FAA accepts the subsequent revision or update as an acceptable form of guidance. The documents are available online at SAE International.

- SAE International 2011-38-0050, *An Analysis of Turbofan Inlet Water and Ice Concentration Effects in Icing Conditions*, SAE Technical Paper, Liao, S., Liu, X., and Feulner, M.
- SAE International 2015-01-2086, *Studies of Cloud Characteristics Related to Jet Engine Ice Crystal Icing Utilizing Infrared Satellite Imagery*, SAE Technical Paper, Grzych, M., Tritz, T., Mason, J., Bravin, M., and Sharpsten, A.

- SAE International 2015-01-2146, *Ice Crystal Ingestion In a Turbofan Engine*, SAE Technical Paper, Feulner, M., Liao, S., Rose, B., and Liu, X.
- SAE AS5562, *Ice and Rain Minimum Qualification Standards for Pitot and Pitot-static Probes*.

3.7 **Aerospace Industries Association (AIA).**

Aerospace Industries Association/Engine Icing Working Group, *AIA/EIWG Subcommittee on Engine Probe Icing: A Process for Evaluating the Performance of Temperature Probes, Combined Temperature and Pressure Probes, and Static Pressure Probes in Icing Conditions*, is related to the guidance in this AC. Unless otherwise specified, use the latest FAA-accepted revision for guidance. If the document is revised after the publication of this AC, you should verify that the FAA accepts the subsequent revision or update as an acceptable form of guidance. This document can be ordered online at AIA.

4. DEFINITION OF KEY TERMS.

For the purposes of this AC, the following definitions apply.

- Ice Water Content (IWC). The amount of frozen water mass per unit volume contained in the icing environment.
- Liquid Water Content (LWC). The amount of liquid water mass per unit volume contained in the icing environment.
- Total Water Content (TWC). The amount of water mass per unit volume contained in the icing environment. In ice crystal conditions, TWC refers to the amount of water mass per unit volume contained in the ice crystals. In mixed conditions, TWC includes the water mass contained in both the liquid and frozen phases.

5. BACKGROUND.

5.1 The FAA is aware of more than two dozen examples of ice crystals blocking turbine engine inlet heated probes on turbine engine-powered airplanes. These events are discussed in the AIA/EIWG report listed in paragraph 3.7 of this AC. These ice blockages have resulted in uncommanded engine power rollbacks, lack of throttle response, and out-of-range probe data flightcrew warnings.

5.2 Some airplane manufacturers have eliminated airframe probes and instead use the turbine engine probe data for airframe systems, such as total or static air temperature. Using engine probe data for different airframe systems requires applicants to put greater emphasis on ensuring that probes continue to function throughout the various icing conditions to support the airplane-level system safety analysis and overall aircraft safety. Eliminating the airframe probes also removes the ability of the electronic engine control system to use airframe probe signals to validate data from engine probes. Without the use of airframe probes, data from the engine probes is substantially more critical throughout the operating envelope of the aircraft.

5.3 Some engine manufacturers use heated inlet probes to prevent ice from accreting on or in the probe, while others use unheated inlet probes.

5.3.1 Heated Inlet Probes.

Heated inlet probes can effectively prevent ice from accreting on the probe while in supercooled droplet-icing conditions typically found at low to mid-altitudes. Heated inlet probes, however, can still be susceptible to ice accretion from ICI conditions. These conditions are typically found at high altitudes but can also exist at lower altitudes. When using heated inlet probes, manufacturers should consider the reliability of the heat source when evaluating inlet probe-related loss of thrust control under § 33.28(d)(1) during icing encounters.

5.3.2 Unheated Inlet Probes.

Unheated inlet probes are less susceptible to ICI conditions but may be more vulnerable to lower and mid-altitude supercooled droplet-icing conditions. An acceptable method for unheated inlet probes in ICI conditions can be found in AC 20-147A, paragraph 9.s.(3), which allows for a similarity analysis for engines proven safe to operate in mixed-phase or glaciated atmospheric conditions. This similarity approach for engines can be extended to unheated inlet probes so long as the applicant can show that the installation effects are similar.

5.4 Generally, testing of heated and unheated inlet probes installed in the engine during certification testing has been a successful method of evaluating the engine inlet probe in supercooled droplet icing conditions. This method is effective as long as the critical point analysis includes an assessment of the critical conditions for the probe.

5.5 Applicants have redesigned certain heated inlet temperature probes to reduce the potential for ice crystal blockage but not eliminate it. Engine manufacturers have incorporated Full Authority Digital Engine Control logic to detect and annunciate the obstruction and utilize an alternative temperature signal to preclude thrust anomalies.

5.6 Although the need for reliable and accurate airspeed, temperature, and pressure data is addressed by §§ 33.28, 33.68, 33.89, 33.91, 25.901(c), 25.1093(b), 25.1303(b), and 25.1309, there is no airworthiness standard that requires applicant showings for engine probes separate from the engine control system. Historically, testing of engine inlet probes occurs during the engine's § 33.68 induction icing system compliance testing, which demonstrates continuous operation throughout the supercooled water droplet icing environment described in appendix C to part 25. Turbine engine inlet probes are also typically subjected to RTCA DO-160 standards and test procedures during § 33.91 testing, but RTCA DO-160G, the latest version as of this writing, does not address the effects of ice crystals or supercooled water droplets on turbine engine inlet probes. FAA TSO-C16b describes the minimum performance standards for heated pitot (total pressure) probes and heated pitot-static (combined total and static pressure) probes. TSO-C16b and SAE AS5562 describe methods to evaluate the performance of such heated probes in icing conditions, including ICI and mixed-phase conditions. This AC describes methods that assess the performance of temperature probes, combined temperature and pressure probes, and static pressure probes in mixed-phase, ICI, and other icing conditions to support design and installation requirements related to engines and airframe systems, including § 33.68(e). If applicable, the aircraft applicant should supplement the TSO-C16b standard with additional data addressing specific installation aspects of the probe and the pass/fail criteria of the aircraft to show compliance with the applicable aircraft regulations.

5.7 The engine manufacturer should document probe assumptions, capabilities, and pass/fail criteria in the engine installation manual according to § 33.5(a)(4) through (6) for later use by the airplane engine installer.

6. GUIDANCE.

6.1 Probe Icing Method of Compliance.

6.1.1 This AC provides a structured method of compliance for engine and aircraft manufacturers to show how turbine engine inlet probes perform in icing conditions to support compliance with § 33.68 and other referenced regulations. This AC also describes a process applicants can use to target their analysis and develop tailored test points to show compliance with the requirements related to probe icing. Consider this method for any temperature or pressure probe that provides data to the engine control system or airframe systems, whether installed in the engine or on the airframe.

6.1.2 Figure 1-1 illustrates the structured method of the compliance process. A detailed explanation of each step follows. The numbered blocks in figure 1-1 are consistent with the sub-paragraphs of section 6.2.

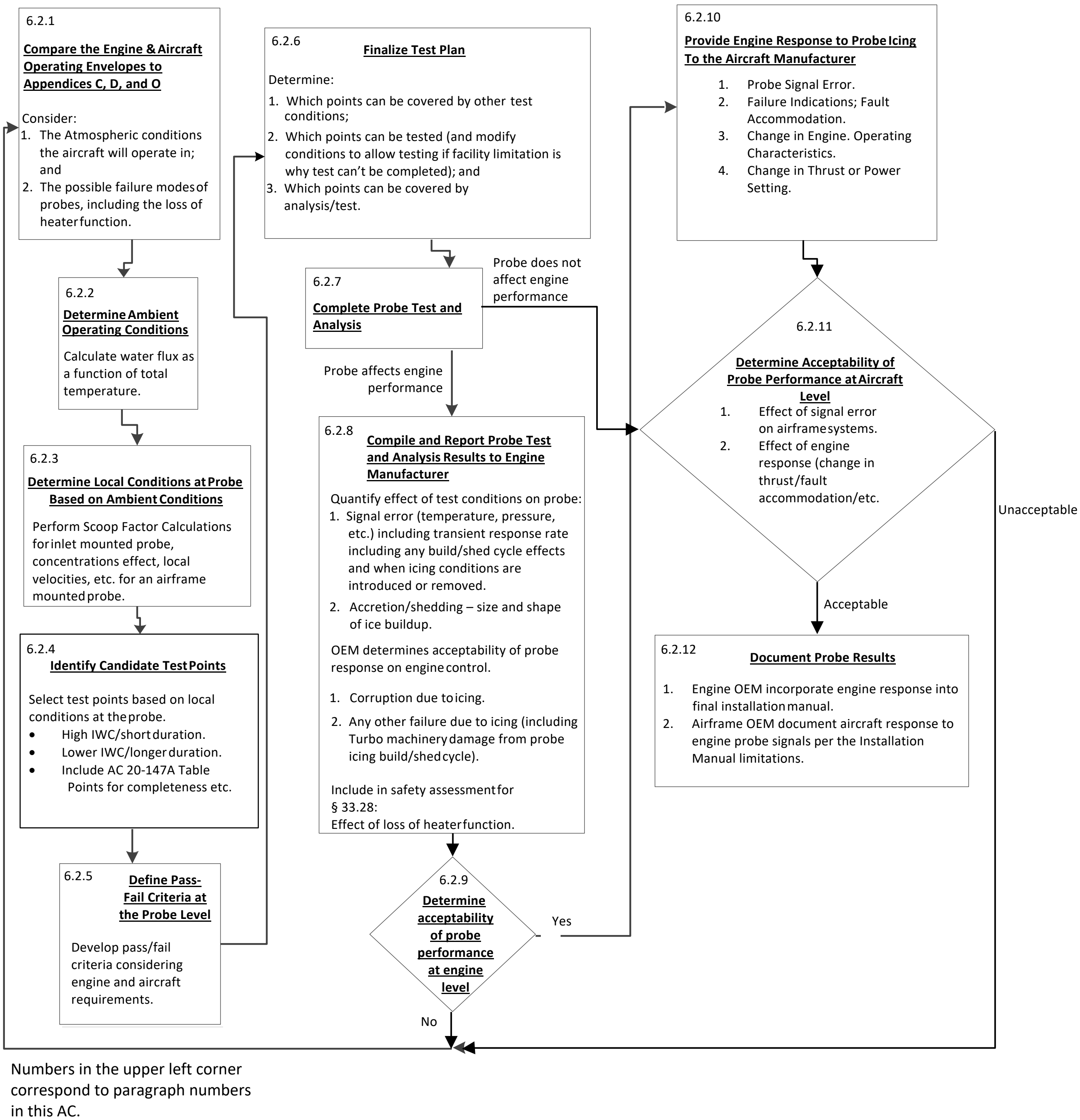

Figure 1-1. Process Flow Chart

6.2 Method of Compliance.

6.2.1 <u>Compare engine and aircraft operating envelopes to appendix D to part 33 and appendices C and O to part 25</u>. The initial step requires defining the engine and aircraft operating envelopes (altitude, airspeed, temperature) relative to the environmental icing conditions considered for certification. Compare appendix C to part 25 and appendix D to part 33 environmental icing envelopes with the applicable airworthiness standards for the aircraft to determine the applicability of those envelopes. As required, evaluate appendix O to part 25 icing envelope to support the engine and/or aircraft certification.

6.2.1.1 Appendices C and O to part 25 and appendix D to part 33 apply to turbine engines except for turboshaft engines. The icing conditions depicted in appendix O to part 25 and appendix D to part 33 do not apply to turboshaft engines or their installations. Under § 33.68(b), turboshaft engines need only comply with the icing conditions depicted in appendix C to part 29.

6.2.1.2 At the aircraft level under § 25.1093(b)(3), the icing conditions depicted in appendix O to part 25 do not apply to turbine engine induction systems on part 25 airplanes with a maximum takeoff weight equal to or greater than 60,000 pounds. Section 25.1093(b)(1) requires that turbine engine induction systems on part 25 airplanes with a maximum takeoff weight equal to or greater than 60,000 pounds comply with the icing conditions depicted in appendix C to part 25, appendix D to part 33, and in falling and blowing snow within the limitations established for the airplane for such operation. Section 23.2415(b) requires that the powerplant installation design prevent any accumulation of ice or snow that adversely affects powerplant operation in those icing conditions for which certification is requested. Guidance for part 23 airplanes is available in ASTM F3120 / F3120M.

6.2.1.3 The applicant should account for exposure to extended operations (ETOPS) if proposed as part of the engine or airplane certification basis. The applicant should confirm there is no impact to the probe operation during a maximum length diversion since probes tend to react to ICI in significantly less than one-hour exposures, the minimum threshold diversion time for ETOPS. If the applicant finds there is an impact to probe operation during a maximum length diversion, then the applicant should account for the effect when showing compliance to § K25.1.3(a) of appendix K to part 25.

6.2.1.4 To support engine and airframe safety analysis, identify and consider the proposed probe's possible failure modes and the failure effects at this stage. For example, if the probe is heated, identify failure modes and their effects of the heater element in the appropriate safety analysis. It is unnecessary to demonstrate these failure modes as part of the test program; however, an applicant should explain the probe failure modes and failure effects to ensure the impact of probe failure is known.

6.2.1.5 Early in development, determine the fidelity of the data provided from the probe. That way, the airframe and engine manufacturers can determine what systems the probe is acceptable for (i.e., systems with catastrophic safety effects will require a more reliable probe or multiple data sources, whereas systems with only minor safety effects may be able to utilize data from a less reliable probe).

6.2.1.6 Figure D1 in appendix D to part 33 shows the temperature-altitude envelope for ICI. The envelope covers altitudes up to approximately 48,000 feet and temperatures down to -60°C, based on atmospheric and airline operation data available at publication. More recent data shows that ICI can occur at higher altitudes and lower temperatures than in figure D1. For that reason, if an airplane manufacturer expects the airplane envelope to extend above the envelope shown in figure D1, they should consider evaluating that part of the envelope for ICI vulnerability.

6.2.2 Determine ambient operating conditions. Appendices C and O to part 25 and appendix D to part 33 describe ambient or free stream concentrations of liquid water and ice crystals. Use these concentrations and the aircraft operating speeds to calculate water flux as a function of total temperature. For glaciated conditions, the highest water flux cases tend to be the most severe. In contrast, the highest water flux cases are not necessarily the severest cases for super-cooled liquid water or mixed phase conditions. Other parameters to consider when selecting critical points include the local concentration factor at the probe, highest total cooling load, minimum predicted surface temperature, maximum water-to-air mass flux ratio, etc.

6.2.2.1 Within the mixed phase and ice crystal envelope described in appendix D to part 33, TWC in g/m3 is based upon the adiabatic lapse defined by the convective rise of 90% relative humidity air from sea level to higher altitudes. The TWC is scaled by a factor of 0.65 to a standard cloud length of 17.4 nautical miles (nm). In-service experience shows that several temperature and pressure probe icing events in glaciated conditions have occurred outside appendix D to part 33 envelope altitude and outside air temperature limits. Events have occurred in conditions outside of those considered by appendix D to part 33, encompassing International Standard Atmosphere (ISA) +30°C conditions and down to a minimum temperature of -70°C. Events have also happened outside appendix D to part 33 envelope down to ISA -5°C conditions above 25,000 ft and down to a minimum temperature of -70ºC. Therefore, if the applicable aircraft envelope extends beyond the appendix D to part 33 envelope, the applicant should consider evaluating the icing environment corresponding to the portion of the aircraft operating envelope that lies outside appendix D to part 33, such as that described in SAE AS5562.

6.2.2.2 In addition, data suggest that the standard cloud of 17.4 nm and the associated scaled TWC values described in appendix D to part 33 may not provide an appropriately conservative set of conditions for air data probe testing. Service data experience suggests that peak ice-crystal concentration values (not average values) are critical to probe ice freeze over or blockage. The ‘max’ or ‘peak’ TWC values occur at shorter distances than shown in figure D3 of appendix D to part 33. The applicant should use the max or peak TWC values instead of the ‘17.4 nm’ values provided by appendix D to part 33 if the peak TWC values are higher. These ‘max’ or ‘peak’ adiabatic values are depicted in FAA Report No. DOT/FAA/AR-09/13 and correspond to the ‘17.4 nm’ values multiplied by a factor of 1.538 (1/0.65). See the discussion on mixed-phase values in paragraph 6.2.4.9 of this AC.

6.2.3 Determine local conditions at the probe based on ambient conditions. Based on the ambient operating conditions determined in paragraph 6.2.2, define the local conditions at the probe. Probes are typically mounted a sufficient distance from the mounting surface (e.g., the fuselage skin or engine inlet) to accurately sense the freestream parameter of interest (total temperature, total pressure, etc.). However, when flying through particles such as supercooled water droplets, ice crystals, or rain, there can be a concentration effect near the mounting surface. This concentration effect is primarily due to inertia and drag effects, but large particles that bounce, splash, or break up yet remain in proximity to the mounting surface can also affect the results. This effect is highly installation-dependent and can vary significantly depending on probe location and probe design.

6.2.3.1 Determining local conditions involves reviewing the probe's installed position (e.g., in the engine inlet or on the airframe) and determining local flow velocities and concentration effects for airframe-mounted probes or scoop factor effects for inlet-mounted probes.

6.2.3.2 AC 20-73A, appendix I, presents some methods used to calculate drop impingement and water catch at the location of interest for supercooled liquid water cases.

6.2.3.3 For ICI conditions, there is currently no standardized method for calculating ice crystal trajectories or the effects of ice crystals bouncing or breaking up. Both ice crystal events significantly affect the local concentration levels.

6.2.3.4 Preliminary research indicates the ice crystal concentration can be significantly higher than ambient conditions (see SAE Technical Papers 2011-38-0050 and 2015-01-2146), so conservative assumptions should be made at the probe regarding local IWC for ICI conditions using state-of-the-art analytical tools. Document the assumptions regarding concentration factors and provide a rationale for those assumptions.

6.2.3.5 Static testing of an engine inlet probe outside of the engine inlet system may not replicate the same build and shed behavior due to variations in airflow and vibration levels. An integrated inlet/engine test can produce different results due to changes in vibration and local airflow, which may affect shedding behavior differently than when tested in isolation within an icing tunnel.

6.2.4 Identify candidate test points. Based on the local conditions at the probe, identify candidate test points, including peak and cyclic conditions. Test a range of temperatures representative of the icing envelopes for the probes.

6.2.4.1 The probe design should be analyzed to determine whether the probe is more susceptible to higher TWC for short durations, to lower TWC for longer durations, or to cyclic conditions, such as those defined in Test Condition 3 of § 33.68, Table 1 (14 CFR part 33, Amendment 34). As noted in paragraph 6.2.2 of this AC, the maximum ambient TWC should account for peak TWC conditions corresponding to the values of appendix D to part 33, multiplied by 1.538.

6.2.4.2 In addition to the peak adiabatic TWC conditions discussed in paragraph 6.2.2.2 of this AC, test points with reduced ambient TWC and extended duration should be included. Testing at different TWC provides evidence that the installed probe will work throughout the operating envelope and not just at the maximum level. Scale back the peak concentration to a standard (17.4 nm) cloud by dividing the peak TWC values by 1.538. Testing at a concentration of one-half of the peak value is appropriate. From appendix D to part 33, figure D3, the scale factor for the standard cloud is 1, and the scale factor for one-half of the peak value is ½*1.538 = 0.769. Based on appendix D to part 33, figure D3, this scale factor corresponds to a horizontal extent of approximately 215 nm. A review of in-service engine ICI events, as documented in SAE paper 2015-01-2086, shows that the 99th percentile horizontal extent length for events where engine damage occurred is 354 nm (657 km). Most engine events occur within horizontal extents of less than 215 nm (400 km) in length. Since probes typically respond to ICI faster than engines, it is reasonable to reduce the maximum horizontal extent for a probe to 215 nm and use a TWC corresponding to one-half the peak value.

6.2.4.3 Consider the time duration of each test point. In general, 2 minutes is sufficient to evaluate the probe’s behavior when demonstrating compliance with appendix D to part 33. However, for cases where ice builds up on external probe surfaces, extend the test point duration as required to quantify the size of ice that may accrete and thoroughly evaluate any build/shed cycles. For the reduced concentration points, run the tests for a sufficient time to traverse a 17.4 nm or 215 nm cloud as appropriate to the test condition. For a typical transport airplane at cruising airspeed, traversing a 17.4 nm cloud takes about 2 to 3 minutes. For these cases, the conditions completed with the peak TWC for 2 minutes is a more severe test than 2 to 3 minutes at a reduced TWC. Therefore, you can eliminate the lower TWC case from consideration. For a typical transport airplane at cruising airspeed, a 215 nm cloud takes approximately 25 minutes to traverse.

6.2.4.4 For liquid water icing testing of engine-mounted components, test or analysis points should be identified according to the conditions in table 1 of § 33.68. This testing requires 10-minute duration glaze ice and rime ice tests at various power settings (airflows) as well as 45-minute glaze and rime ice holding conditions.

6.2.4.5 For airframe-mounted probes in liquid water icing conditions, identify test or analysis points per the conditions stated in tables 1-1 and 1-2 of this AC. Table 1-1 requires steady-state 15-minute durations representing continuous maximum cloud concentrations and 5-minute durations representing intermittent maximum cloud concentrations. Table 1-2 requires cyclical tests at the liquid water conditions at either of the repetitions per section 6.2.4.5.1 or 6.2.4.5.2 of this AC.

6.2.4.5.1 For 15.1 nm in the conditions of table 1-2, column (a), under column LWC (g/m^3), appropriate to the temperature, followed by 2.7 nm in the conditions of table 2, column (b), under column LWC (g/m^3), appropriate to the temperature, for a duration of 30 minutes.

6.2.4.5.2 For 3.2 nm in the conditions of table 1-2, column (a), under column LWC (g/m^3), appropriate to the temperature, followed by 2.7 nm in the conditions of table 1-2, column (b), under column LWC (g/m^3), appropriate to the temperature, for a duration of 10 minutes.

Table 1-1. Stabilized Icing Conditions for airframe mounted probes in liquid water icing conditions

Test number	Static Air Temperature (°C)	Altitude Range (ft)	LWC (g/m^3)	Duration (min)	MVD (µm)
SL1	-20	0-22,000	0.22 to 0.3	15	15 to 20
SL2	-30	0-22,000	0.14 to 0.2	15	15 to 20
SL3	-20	4,000-31,000	1.7 to 1.9	5	15 to 20
SL4	-30	4,000-31,000	1 to 1.1	5	15 to 20

Table 1-2. Cycling Icing Conditions for airframe mounted probes in liquid water icing conditions

Test number	Static Air Temperature (°C)	Altitude (ft)	LWC (g/m^3)		MVD (μm)
			(a)	(b)	
SL5	-10	17,000	0.6	2.2	20
SL6	-20	20,000	0.3	1.7	20
SL7	-30	25,000	0.2	1.0	20

6.2.4.6 For both engine-mounted and airframe-mounted probes, in addition to the tests or analysis defined in paragraphs 6.2.4.1 through 6.2.4.5 of this AC, perform a critical point analysis based on appendix C to part 25 requirements to determine if there are additional critical points within the operating envelope. The critical points, which the engine is tested against to show compliance with § 33.68, may or may not be critical points for the probe. For example, high airflow conditions like maximum continuous power may be more critical for an inlet-mounted probe than for the entire engine. Therefore, it is important to determine the critical conditions for the probe as part of this step and not rely solely on the § 33.68 points for demonstrating the proper operation of the probe. The points defined in § 33.68 and tables 1-1 and 1-2 of this AC represent conditions at the engine inlet for the installation. For a component (probe) test, the appropriate concentration factor must be determined so that the local conditions at the probe match installed conditions.

6.2.4.7 For unheated probes in liquid water environments, evaluate the impact of ice accumulation and shedding on altitude. Consider analysis and testing at altitude. Heated probes may be tested in liquid water conditions in a non-pressure controlled (sea level or ambient conditions) wind tunnel if that would be more conservative than testing at higher altitudes

6.2.4.8 If a probe has more than one operating mode (e.g., a de-icing cycle), verify the proper operation in all operating modes.

6.2.4.9 For mixed-phase and ice crystal conditions, select test/analysis points with the TWC based on a 10 nm cloud. The TWC for a 10 nm cloud corresponds to the ‘17.4 nm’ values multiplied by a factor of 1.05, as shown in figure D3 in appendix D of part 33.

6.2.4.9.1 Appendix D to part 33 describes the liquid water portion of mixed-phase conditions as ≤1.0 g/m^3 for clouds of less than 50 nm extents for temperatures above -20°C and zero for temperatures below -20°C.

6.2.4.9.2 SAE AS5562 assumes the LWC is per appendix C to part 25 intermittent maximum cloud, and the remainder of the TWC is ice crystals.

6.2.4.9.3 When performing mixed phase condition tests, use the LWC described in appendix C to part 25 for an intermittent maximum cloud with a mean effective drop diameter of 20 microns. The ice crystal concentration is the TWC determined in paragraph 6.2.4.9 of this AC minus the LWC described in appendix C to part 25 for an intermittent maximum cloud. Using these test conditions is consistent with SAE AS5562 and conservatively simulates mixed-phase conditions in colder conditions.

6.2.4.10 Consider the time duration for mixed-phase icing test points. For the maximum TWC in mixed-phase conditions, test conditions lasting 2 minutes are appropriate, as this is sufficient time for an air data probe to reach a steady state and stabilized condition. In addition, flight testing in well-developed, large-diameter mesoscale convective systems completed as part of the FAA and European Union Aviation Safety Agency Industry High-Altitude Ice Crystals/High Ice-Water Content (HAIC/HIWC) flight test campaigns showed a low frequency of mixed-phase regions.

6.2.4.10.1 During the HAIC/HIWC flight tests, -10°C mixed phase regions accounted for less than about 5% of the total in-cloud distance traversed, and maximum average distances across mixed phase zones were about 8 nm. The frequency of mixed-phase zones decreased with decreasing temperature. Well-developed storm cells can produce large amounts of falling and recirculating ice that tend to glaciate any new updraft, thus resulting in lower LWCs and smaller regions of mixed-phase conditions. For smaller or still developing cells with less glaciation and less circulation, regions of mixed-phase conditions with higher LWC could exist for longer times. While traversing the storm, these areas of mixed-phase conditions are still likely to exist as separate regions within the storm, resulting in alternating between mixed-phase and fully glaciated conditions.

6.2.4.10.2 For engine-mounted probes, a conservative approach to represent these smaller or fresh convective cells is to perform a cyclic test alternating between mixed phase and fully glaciated conditions. In addition to the test conditions for maximum TWC conditions for two minutes, test points should include cycling between mixed phase and fully glaciated conditions. For these cyclic conditions, set the TWC to a value scaled by the distance factor associated with the horizontal extent traversed in 12 minutes (3 cycles) at the aircraft operating speed. This lower TWC is justifiable as the HAIC/HIWC flight test results indicate that extended regions of liquid water seem less likely in high IWC conditions. Therefore, lower IWC and the resulting lower TWC values are necessary to sustain mixed-phase conditions without transitioning to fully glaciated conditions. Because the HAIC/HIWC flight tests did not evaluate mixed phase conditions in developing storm cells, a conservative estimate of LWC should be used. To define a conservative test, assume LWC equal to appendix C to part 25 Intermittent Maximum value for the test conditions.

As discussed below, other engine or airframe level mitigation may be necessary to ensure acceptable aircraft operation, depending on the test results in these conservative conditions. Each cycle should alternate between 2 minutes in mixed-phase conditions and 2 minutes in fully glaciated conditions. To simulate an engine flying through a developing storm system or holding in such conditions, continue the cycles until the probe operates for a maximum of 3 cycles (12 minutes).

6.2.4.10.3 For heated probes, account for conditions with the heater turned off. The purpose is to address an inadvertent icing encounter where the heater is not turned on immediately or a transient power interruption. For example, some engine anti-ice systems link to nacelle anti-ice, requiring the pilot to activate the system. The timing should be coordinated with the engine and airframe manufacturers to define appropriate conditions. Paragraph 6.2.1.4 discusses the evaluation of failure modes.

6.2.5 Define test pass-fail criteria at the probe level. Considering engine and aircraft-level requirements, define the pass/fail criteria for the candidate test points determined in paragraph 6.2.4. Pass/fail criteria should consider a system-level analysis developed by the probe, engine, and airframe manufacturers.

6.2.5.1 The probe remaining free of ice is not necessarily the only pass criteria. Applicants should develop acceptance criteria upon consideration of the criticality of the probe and the air data it provides to the engine or the airframe, or both. One simplified acceptance criterion is for the engine and airframe systems that utilize the data from the probe to continue to operate within an acceptable range in icing conditions. In all expected operating conditions, the probe should perform its original intended function; for example, measuring air temperature with some reasonable accuracy, rather than measuring probe heater temperature. The probe manufacturer can typically only quantify the effect at the probe level (e.g., the probe output/accuracy is ±x° when exposed to a specific condition). The engine manufacturer should translate that probe effect into the resulting system impact at the engine level (e.g., ±x° of measured temperature error equates to ±y thrust or some impact on engine operability). The airframe manufacturer needs to know the probe level effect (e.g., ±x° measured temperature error) and the installation level effect on airframe systems that use data from the probe along with the engine effect and the impact the engine effect has at the aircraft level.

6.2.5.2 The applicant should evaluate potential ice shedding from the probe as part of the pass/fail criteria to ensure no damage to downstream components occurs from ice shedding.

6.2.5.3 Applicants should also account for different atmospheric conditions and the possible failure modes of the probe when developing acceptance criteria. Some failure modes include:

- In ICI conditions, a temperature probe may clog with partially melted crystals, driving it to read 0°C (the temperature of the slush) continuously.
- Smaller errors for some short periods.
- Fluctuations in the probe output with ice build and shed cycles.
- Pressure probes may clog with ice, resulting in a fixed or unchanging signal without normal signal noise.
- Damage to downstream components as a result of ice shedding.

6.2.6 Finalize test plan. Applicants should complete an analysis of the test points identified in paragraph 6.2.4. Evaluate the points to determine which points are covered by other conditions or covered by analysis supported by other test conditions. Also, evaluate the points to determine if the proposed test facility can perform the specific test conditions. When a test facility limitation precludes a particular test condition, an applicant may use the scaling methods of SAE AS5562, sections 3.3.2 through 3.3.4, to vary temperature, airspeed, and water flux to achieve defined equivalent test conditions. If a significant number of test points require modification in this manner, consider an alternate test facility capable of testing more of the proposed envelope to minimize the number of candidate points not directly tested.

6.2.6.1 As noted in SAE AS5562, section 3.3.1, there is no acceptable method to scale the altitude for ICI conditions at this time. Therefore, test ICI conditions at the most critical altitude corresponding to one of the candidate test points determined from paragraph 6.2.4 of this AC. Test facilities capable of testing probes in ICI conditions at altitude are available. It may be possible to change the probe design such that any untested points are no longer critical. Alternatively, it may be possible to impose limitations on the probe's operating envelope. However, this may require engine or aircraft level design changes or limitations. Identify and communicate any limitations on the probe installation to the engine and aircraft manufacturers so those manufacturers can adhere to the limitations as installed.

6.2.6.2 As stated in paragraph 6.2.4.10.3, you should account for the engine and aircraft level effects of loss of the heater function as appropriate. Address the loss of the heater function either in a test matrix or by analysis. This activity documents the effect on the probe with the heater inoperative in the worst-case icing conditions.

6.2.7 Complete probe test and analysis. Complete testing of all conditions identified in paragraph 6.2.6 in a facility capable of meeting the test conditions. The configuration of the test article should match the intended installation, including orientation, as closely as possible, and the probe itself should match the type design configuration, except as necessary to install instrumentation or other test equipment. Meet the following criteria for each test condition.

6.2.7.1 SAE AS5562 test criteria. The following test characteristics should be consistent with the requirements defined by SAE AS5562:

- Probe Mounting Location.
- Probe Mount Heating Requirements.
- Installation Heat Sink Effects.
- Probe Power for Electrically Heated Probes.
- Tunnel Blockage.
- Data Collection Sample Rate.
- Electrically Heated Probe Test Unit Selection.

6.2.7.2 Non-electrically heated probes. For heated probes using some method other than an electrical heater, set the heat source to the minimum allowable value expected for the installation. For example, test a probe that is heated using bleed air with the bleed air supply at the minimum expected regulation pressure and temperature. Provide the specific air supply conditions tested to the installer to support installation approval. It is essential to characterize this air supply fully, including in-line pressure drop, piping clearances, local heat transfer characteristics, and any control orifices in the supply line or sensor. Perform probe qualification tests on a unit having the lowest acceptable performance on a production article as defined by the acceptance test procedure.

6.2.7.3 Angle of attack (AOA). Account for the effect of AOA in the intended installation. Conduct a critical point analysis as specified in paragraph 6.2.3.1 to determine the local probe AOA for each test case. Establish a clear relationship between the aircraft or engine AOA and the local probe AOA. Consider the impact of various flight attitudes within the approved flight envelope on the probe AOA. Specific flight conditions, such as side slipping, can influence local probe conditions due to flow interference from wings or other aircraft features.

6.2.7.4 Test particle size distribution. The particle size median mass dimension for the test conditions must match that defined by appendix D to part 33 (50-200 microns equivalent spherical size) unless justified that a different size will not significantly affect the test.

6.2.7.5 Test duration for steady state ice crystal icing tests. Run tests at the peak TWC values for 2 minutes and run tests completed at one-half of the peak TWC value run for the encounter time calculated from the horizontal extent and the airspeed.

6.2.7.6 Test duration for mixed-phase tests. Run tests conducted at the maximum TWC values for 2 minutes. Run the tests conducted at the reduced TWC values as cyclic tests. Each cycle should alternate between 2 minutes in mixed-phase conditions and 2 minutes in fully glaciated conditions. Continue the cycles until the probe operates for a maximum of 3 cycles (12 minutes).

6.2.7.7 Test duration for airframe mounted probes in liquid water icing conditions. Identify test/analysis points per the conditions stated in tables 1-1 and 1-2 of this AC. This testing requires 15-minute durations per continuous maximum cloud concentrations, 5-minute duration per intermittent maximum cloud concentrations (table 1-1), and either a 30-minute or 10-minute duration cyclical liquid water concentrations (table 1-2).

6.2.7.8 If the probe data will be used by the engine, proceed to paragraph 6.2.8. If the probe data will be used by the aircraft only, proceed to paragraph 6.2.11.

6.2.8 Compile and report probe test and analysis results to engine manufacturer. Produce the test report. The test and analysis results should quantify the effect of the conditions on the probe. The following topics should be covered, if applicable:

- Signal error (temperature, pressure, etc.), including transient response rate, any build/shed cycle effects, and when icing conditions are introduced or removed.
- Measurement accuracy and any changes upon introduction or removal of icing conditions, and any changes when a probe heater is turned on or off.
- Accretion/shedding - size and shape of ice buildup.
- The frequency of build/shed cycles, impact on signal error, and probe transient response to shedding.

Provide the testing and analysis results to the engine manufacturer so that the acceptability of the probe response can be determined. The engine manufacturer should evaluate the effect on the engine of variations in the probe output signal due to icing and any other failure modes observed during the testing.

6.2.9 Determine acceptability of probe performance at engine level. Based on the testing and analysis results, the engine manufacturer should determine whether the effect of the probe response to the icing conditions meets the requirements of § 33.68. It is important to note, do not change the pass/fail criteria to match the results. Instead, repeat the system analysis step to ensure correctness and ensure the design is reviewed or changed as necessary.

6.2.10 Provide engine response to probe icing to the aircraft manufacturer. The engine manufacturer should document the response of the engine based on the probe response to the icing conditions tested and provide that response to the airframe manufacturer. The engine response evaluation should address:

- Probe Signal error.
- Failure indications/Fault accommodation.

- Changes in engine operating characteristics (surge/stall, flameout, etc.) due to signal error.
- Change in thrust or power setting.
- Change in displayed parameters.

6.2.11 Determine the acceptability of probe performance at the aircraft level. As part of the aircraft certification and compliance demonstration activities, the aircraft manufacturer should review the data provided by the engine manufacturer in paragraph 6.2.10 of this AC to determine the impact on the aircraft. To complete this review, the aircraft manufacturer may need information on the probe location in the engine, etc., from paragraph 6.2.7.1. Based on the testing and analysis results, the aircraft manufacturer should determine whether the effect of the probe response to the icing conditions is acceptable at an aircraft level, as part of the aircraft certification and compliance demonstration activities. If the probe response is not acceptable at the aircraft level, the aircraft manufacturer should review the pass/fail criteria to ensure aircraft-level requirements are clearly defined and repeat the process from paragraph 6.2.1. The revised system analysis may necessitate a review of the candidate test points and/or design changes to the probe or installation, and/or re-evaluation of the aircraft response.

6.2.11.1 Engine probes usually are part of the engine type design and therefore, the engine manufacturer is primarily responsible for evaluating the probe. When the engine utilizes an aircraft probe, the aircraft manufacturer is primarily responsible for assessing whether the probe meets aircraft-level requirements (such as § 25.1323 or 25.1324). Regardless of primary responsibility, however, it is vital that both the aircraft and engine manufacturer communicate requirements and capabilities early and throughout the certification process.

6.2.11.2 When the engine probe is part of the aircraft type design, the aircraft manufacturer will still need information on the engine installation. The aircraft manufacturer should coordinate with the engine manufacturer to determine what installation information is required under § 33.5. The aircraft manufacturer should provide the engine manufacturer with appropriate information to support the engine manufacturer’s design and compliance demonstration.

6.2.11.3 The aircraft manufacturer should also ensure that the engine manufacturer provides the necessary information about the engine probe and engine type design to facilitate demonstrating compliance to relevant aircraft certification requirements, such as §§ 25.901(c), 25.1093(b), 25.1309, 25.1324, and 25.1325.

6.2.11.4 When the aircraft probe is part of the aircraft type design and utilized by the engine manufacturer, the aircraft manufacturer should coordinate with the probe manufacturer and engine manufacturer as necessary. The aircraft manufacturer should refer to AC 25-28 for additional information on certification requirements for flight in icing conditions for aircraft probes.

6.2.12 Document probe results. Complete the final documentation of the probe, engine, and aircraft response to the icing environments, to show compliance with relevant engine and aircraft requirements. The final documentation should include the engine manufacturer incorporating information about the engine response into the engine installation instructions provided under § 33.5. This information should consist of the data provided to the airframe manufacturer in paragraph 6.2.10, a description of the icing environments evaluated, and any other pertinent data from the safety assessments required by §§ 33.28(e) and 33.75(a), describing the probe and engine response. As part of the aircraft certification and compliance demonstration activities, the airframe manufacturer should document the response and compliance with any requirements included in the engine installation instructions as required. Aircraft-level documents that might be affected include the Airplane Flight Manual, the system safety documentation for the aircraft, compliance documents, etc.

7. AC FEEDBACK FORM.

For your convenience, the AC Feedback Form is the last page of this AC. Note any deficiencies found, clarifications needed, or suggested improvements regarding the contents of this AC on the Feedback Form.

DANIEL J. ELGAS

Digitally signed by DANIEL J. ELGAS
Date: 2025.06.18 09:15:35 -04'00'

Daniel J. Elgas
Director, Policy and Standards Division
Aircraft Certification Service

OMB Control Number: 2120-0746
Expiration Date: 12/31/2027

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Subject:____________________ Date: _______________

Mark all appropriate line items:

☐ An error (procedural or typographical) has been noted in paragraph __________ on page _________.

☐ Recommend paragraph ______ on page _____ be changed as follows:

☐ In a future change to this AC, please cover the following subject:
(Briefly describe what you want added.)

☐ Other comments:

☐ I would like to discuss the above. Please contact me using the information below.

Submitted by:___________________________________ Date: ______________________