water or resultant ice shapes (rivulets or thin layers), but some codes may be able to estimate the mass of the runback ice. Thus runback ice should be determined experimentally, or the mass determined by computer codes with assumptions about runback extent and thickness similar to those used successfully with prior models.

The applicant should consider potential hazards resulting from the shedding of runback ice.

6. Power Sources

The applicant should evaluate the power sources in the IPS design (e.g. electrical, bleed air, or pneumatic sources). An electrical load analysis or test should be conducted on each power source to determine that it is adequate to operate the IPS as well as to supply all other essential electrical loads for the aeroplane throughout the aeroplane flight envelope. The effect of an IPS component failure on availability of power to other essential loads should be evaluated in accordance with CS 25.1309. All power sources affecting engines or engine IPS for multiengine aeroplanes must comply with the engine isolation requirements of CS 25.903(b).

7. Artificial ice shapes and roughness

AMC 25.21(g) contains guidance on icing exposure during various phases of flight that should be considered when determining artificial ice shapes and surface roughness. The shape and surface roughness of the ice should be developed and substantiated with acceptable methods. When developing critical ice shapes, the applicant should consider ice accretions that will form during all phases of flight and those that will occur before activation and proper functioning of the ice protection system.

If applicable, runback, residual, and inter-cycle ice accretions should also be considered.

The applicant should substantiate the drop diameter (mean effective, median volume), liquid water content, and temperature that will cause formation of an ice shape critical to the aeroplane's performance and handling qualities.

Ice roughness used should be based on icing tunnel, natural icing, or tanker testing, or the guidance in AMC 25.21(g), Appendix 2.

8. Similarity Analysis

(i) For certification based on similarity to other type-certificated aeroplanes previously approved for flight in icing conditions, the applicant should specify the aeroplane model and the component to which the reference of similarity applies. The applicant should show specific similarities in the areas of physical, functional, thermodynamic, ice protection system, and aerodynamic characteristics as well as in environmental exposure. The applicant should conduct analysis to show that component installation, operation, and effect on the aeroplane's performance and handling are equivalent to that of the same or similar component in the previously approved configuration.

(ii) A demonstration of similarity requires an evaluation of both system and installation differences. Differences should be evaluated for their effect on IPS functionality and on safe flight in icing. If there is uncertainty about the effects of the differences, the applicant should conduct additional tests and/or analysis as necessary and appropriate to resolve the open issues.

(iii) CS 25.1419(b) requires flight testing in measured natural icing conditions. Flight test data from previous certification programs may be used to show compliance with CS 25.1419(b) if the applicant can show that the data is applicable to the aeroplane in question. If there is uncertainty about the similarity analysis, the applicant should conduct flight tests in measured natural icing conditions for compliance with CS 25.1419(b).

Note: The applicant must possess all the data to substantiate compliance with applicable specifications, including data from past certifications upon which the similarity analysis is based.

(b) CS 25.1419(b) Testing

The aeroplane should be shown to comply with certification specifications when all IPS are installed and functioning when operating normally and under certain failure conditions. This can normally be accomplished by performing tests in natural or simulated icing conditions to either validate analysis or to test those conditions found to be most critical to basic aeroplane aerodynamics, IPS design, and powerplant functions. All IPS equipment should perform their intended functions throughout the entire operating envelope.

The primary purposes of flight testing are to:

— Determine that the IPS is acceptably effective and performs its intended functions during flight as predicted by analysis or ground testing,

— Evaluate any degradation in performance and flying qualities,

— Verify the adequacy of flightcrew procedures as well as limitations for the use of the IPS in normal, abnormal, and emergency conditions,

— Confirm that the powerplant installation as a whole (engine, propeller, inlet, anti-ice system, etc.) performs satisfactorily in icing conditions, and

— Validate the ice accretion size, location, texture and other general characteristics.

Performance and handling qualities specifications are identified in CS 25.21(g). Flight tests to show compliance with these requirements are addressed in AMC 25.21(g).

1. Dry air flight tests with ice protection equipment operating

The first flight tests conducted to evaluate the aeroplane with the IPS operating are usually dry air flight tests. The initial dry air tests are conducted to:

— Verify that the IPS does not affect flying qualities of the aeroplane in clear air, and

— Obtain a thermal profile of an operating thermal IPS to substantiate its thermal performance.

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

1.1 Thermal ice protection leading edge systems

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

Normally, instruments are installed on system components to measure the anti-icing mass flow rate or energy input (for electrical systems), supply air temperature, and surface temperatures. The dry air test plan generally includes operating conditions such as the climb, holding, and descent phases of a normal flight profile. Since the presence of moisture can affect surface temperatures, tests should be conducted where no visible moisture is present.

Measurements of supply air mass flow rate, energy input, and air temperature allow determination of how much heat is available to the system. The adequacy of the IPS can then be demonstrated by comparing the measured data to the theoretical analysis.

Surface temperatures measured in the dry air, for example, can be useful in extrapolating the maximum possible leading edge surface temperature in-flight, the heat transfer characteristics of the system, and the thermal energy available for the IPS. Supply air temperatures or energy input may also be used to verify that the IPS materials were appropriately chosen for the thermal environment.

1.2 Bleed air systems

Effects of bleed air extraction on engine and aeroplane performance, if any, should be examined and included in the Aeroplane Flight Manual (AFM) performance data. The surface heat distribution analysis should be verified for varying flight conditions including climb, cruise, hold, and descent. Temperature measurements may be necessary to verify the thermal analysis. In accordance with provisions of CS 25.939(a), the maximum bleed air for ice protection should have no detrimental effect on engine operation throughout the engine's power range.

1.3 Pneumatic leading edge boots

Tests should demonstrate a rise and decrease in operating pressures, which results in the effective removal of ice. This pressure rise time, as well as the maximum operating pressure for each boot, should be evaluated throughout the altitude range defined in the relevant icing environment. The appropriate speed and temperature limitation (if any) on boot activation should be included in the AFM. Boot inflation should have no significant effect on aeroplane performance and handling qualities.

1.4 Fluid anti-icing/de-icing systems

Flight testing should include evaluation of fluid flow paths to confirm that adequate and uniform fluid distribution over the protected surfaces is achieved. A means of indicating fluid flow rates, fluid quantity remaining, etc., should be evaluated to determine that the indicators are plainly visible to the pilot and that the indications provided can be effectively read. The AFM should include information advising the flight crew how long it will take to deplete the amount of fluid remaining in the reservoir.

2. Dry air flight tests with predicted artificial ice shapes and roughness

The primary function of dry air flight tests with artificial ice shapes is to demonstrate the ability of the aeroplane to operate safely with an accumulation of critical ice shapes based on exposure to icing conditions. The specific flight tests used to evaluate aeroplane performance and handling qualities are addressed in AMC 25.21(g).

For failure conditions of the IPS that are not extremely improbable, validation testing may be required to demonstrate that the effect on safety of flight (as measured by degradation in flight characteristics) is commensurate with the failure probability. The applicant may use dry air flight tests with predicted critical failed IPS ice shapes, which may include asymmetric ice shapes, to demonstrate acceptable operational safety.

3. Icing flight tests

Flight tests in measured natural icing and tests performed with artificial icing tools, such as icing tankers, are normally used to demonstrate that the IPS performs during flight as predicted by analysis or other testing. Such tests are also used to confirm analysis used in developing the various components, such as ice detectors, and ice shapes. CS 25.1419 requires measured natural icing flight tests within the icing conditions of CS-25, Appendix C. The natural icing flight tests are accomplished to corroborate the general nature of the effects on aeroplane handling characteristics and performance determined with artificial ice shapes (see AMC 25.21(g)), as well as to qualitatively assess the analytically predicted location and general physical characteristics of the ice accretions. If necessary, there should be a means to record ice accumulations to allow the size, location, shape, extent and general nature of the ice to be approximated. Various means can be used to aid this, such as a rod or fence mounted on the aerofoil and black or brightly coloured paint on the aerofoil to increase the contrast between the ice accretion and the aerofoil and aid the determination of the ice shape size.

3.1 Instrumentation

The applicant should plan sufficient instrumentation to allow documentation of important aeroplane, system, and component parameters, as well as icing conditions encountered. The following parameters should be considered:

1. Altitude.
2. Airspeed.
3. Engine power level or speed.
4. Propeller speed and pitch, if applicable.
5. Temperatures that could be affected by ice protection equipment or ice accumulation or that are necessary for validation of analysis, such as the temperatures of Static air, Engine components, Electrical generation equipment, Surfaces, Structural components.
6. Liquid water content. This should be measured over the complete water drop size distribution.
7. Median volume drop diameter and drop diameter spectra. When measurement of the icing environment drop diameter is necessary, instrumentation used for measuring drop sizes should be appropriate for the icing environment considered.

3.2 Artificial icing

Flight testing in artificial icing environments, such as behind icing tankers, is one way to predict capabilities of individual elements of the ice protection equipment and to determine local ice shapes.

Since the ice plume has a limited cross-section, testing is usually limited to components, such as heated pitot tubes, antennas, air inlets including engine induction air inlets, empennage, aerofoil sections, and windshields. Calibration and verification of the icing cloud produced by the tanker should be accomplished as necessary for meeting test objectives.

Use of an icing tanker can provide high confidence in local icing effects. But obtaining small drop sizes may be difficult with some spray nozzles. As a result, these methods could produce larger ice build-ups and different ice shapes than those observed in natural Appendix C icing conditions.

Icing tanker techniques can be used in a manner similar to icing tunnel testing with respect to ice shape development. The plume may be of sufficient size that it could be applied to sections of the airframe to examine any potential hinge moment or CLmax (maximum lift coefficient) effects from ice accretions behind protected areas.

This method also has the advantage of being able to combine the effects of thermal systems (such as runback) with direct accretion to simulate resulting ice accumulations.

Atmospheric effects such as humidity and drop residence time (time required to bring the drop to static temperature) should be considered in this type of testing.

3.3 Appendix C natural icing flight testing

CS 25.1419(b) requires measured natural icing flight tests. Flight tests in measured natural icing conditions are intended to verify the ice protection analysis, to check for icing anomalies, and to demonstrate that the IPS and its components function as intended.

The aeroplane should be given sufficient exposure to icing conditions to allow extrapolation to the envelope critical conditions by analysis. Test data obtained during these exposures may be used to validate the analytical methods used and the results of any preceding artificial icing tests.

Flight testing in natural icing conditions should also be used to verify AFM procedures for activation of the IPS, including recognition and delay times associated with IPS activation. Such testing should verify the analytically predicted location and general physical characteristics of the ice accretions. Critical ice accumulations should be observed, where possible, and sufficient data taken to allow correlation with dry air testing. Remotely located cameras either on the test aeroplane or on a chase aeroplane have been used to document ice accumulations on areas that cannot be seen from the test aeroplane's flight deck or cabin.

For an aeroplane with a thermal de-icing system, the applicant should demonstrate the effectiveness of the de-icing operation either in artificial icing conditions or during a natural icing flight test certification program. The tests usually encompass measurements of the surface temperature time history. This time history includes the time at which the system is activated, the time at which the surface reaches an effective temperature, and the time at which the majority of ice is shed from the leading edge. Any residual or intercycle ice accretions should be documented. The data should be recorded in the flight test report.

For anti-icing/de-icing fluid systems, fluid flow paths should be determined when the fluid is mixed with impinging water during system operation.

4. Icing wind tunnel tests

Icing wind tunnels provide the ability to simulate natural icing conditions in a controlled environment. Scale models may be used with appropriate scaling corrections, if the scale testing on the component has been validated with full-scale testing or analysis. Hybrid models, with the full-scale leading edge extending beyond the impingement limits, may also be used. The applicant may use these models to estimate impingement limits, examine visual icing cues, and evaluate ice detection devices.

A variety of icing conditions can be simulated, depending on the icing wind tunnel.

Icing wind tunnels have been used to evaluate ice shapes on unprotected areas and on or aft of protected areas, such as inter-cycle, residual, and runback ice. They have also been used to evaluate performance of IPS, such as pneumatic and thermal systems.

For the evaluation of the performance of the IPS, a critical points analysis can be used to identify critical test conditions under which an IPS should be tested in an icing tunnel. In lieu of a critical points analysis the following conditions have been successfully used in the past to simulate the Appendix C conditions:

4.1 Continuous Maximum Condition

Atmospheric Temperature (°C)	Liquid Water Content (g/m³)
0	0.8
-10	0.6
-20	0.3
-30	0.2

The test should be run until steady state conditions are reached. The steady state can be identified by the protected surfaces being completely free of ice or the total ice accretion being contained by repetitive shedding either naturally or enforced by cyclic operation of the IPS. If the steady state cannot be reached, the duration of the run should be limited to 45 minutes.

4.2 Intermittent Maximum Conditions

The encounters considered should include three clouds of 5 km horizontal extent with Intermittent Maximum concentrations as in the following table separated by spaces of clear air of 5 km.

Atmospheric Temperature (°C)	Liquid Water Content (g/m³)
0	2.5
-10	2.2
-20	1.7
-30	1.0

For both the Continuous maximum and Intermittent Conditions, an MVD of 20 µm should be used.

5. Dry air wind tunnel tests

Dry air wind tunnel testing using scaled models and artificial ice shapes has been used to determine if ice protection on particular components (horizontal/vertical plane or wing sections) is required. The scaling, including the effect of the roughness of the ice, should be substantiated using methods found acceptable to the Agency.

(c) CS 25.1419(c) Caution information

CS 25.1419(c) requires that Caution information be provided to alert the flight crew when the IPS is not functioning normally. In this context, Caution information is considered to be a general term referring to an alert rather than referring specifically to a Caution level alert. Crew alerting should be provided for failure conditions of the IPS in accordance with CS 25.1309(c) and

CS 25.1322. It should be assumed that icing conditions exist during the failure event. In accordance with CS 25.1419(c), the decision to provide an alert must not be based on the numerical probability of the failure event. However, the type of alert provided should be based on the failure effects and necessary crew action to be performed in response.

1) Sensor(s) used to identify a failure condition should be evaluated to ensure that they are properly located to obtain accurate data on the failure of the IPS.

2) The indication system should not be designed so that it could give the flight crew a false indication that the system is functioning normally because of a lack of an alert. The applicant should submit data to substantiate that this could not happen. For example, if a pneumatic de-icing system (boots) requires a specific minimum pressure and pressure rise rate to adequately shed ice, an alert should be provided if that minimum pressure and pressure rise rate are not attained. Without an alert, the flight crew may erroneously believe that the boots are operating normally when, in fact, they might not be inflating with sufficient pressure or with a sufficient inflation rate to adequately shed ice. The applicant should also consider the need for an alert about ice forming in the pneumatic system that can result in low pneumatic boot pressures or an inadequate pressure rise rate.

(d) CS 25.1419(e) Ice Detection

1. Compliance with CS 25.1419(e)(1) and (e)(2).

These subparagraphs provide alternatives to CS 25.1419(e)(3) which specifies operation of the IPS based on icing conditions . These alternatives require either a primary ice detection system, or substantiated visual cues and an advisory ice detection system. CS 25.1419(e)(2) requires defined visual cues for recognition of the first sign of ice accretion on a specified surface combined with an advisory ice detection system that alerts the flight crew to activate the airframe ice protection system. The following conditions should be considered when determining compliance with CS 25.1419(e)(2):

— The advisory ice detection system annunciates when icing conditions exist or when the substantiated visual cues are present.

— The defined visual cues rely on the flight crew's observation of the first sign of ice accretion on the aeroplane and do not depend on the pilot determining the thickness of the accretion.

— The flight crew activates the ice protection system when they observe ice accretion or when the ice detector annunciates ice, whichever occurs first.

1.1 Ice detection system (IDS)

1.1.1 Primary Ice Detection System (PIDS)

A PIDS must either alert the flight crew to operate the IPS using AFM procedures or automatically activate the IPS before an unsafe accumulation of ice on the airframe, engine components, or engine air inlets occurs. The primary ice detection system must perform its intended function for the aeroplane configurations, phases of flight, and within the relevant icing environment.

1.1.2 Advisory Ice Detection System (AIDS)

The AIDS, in conjunction with visual cues, such as visible ice accretion on referenced or monitored surfaces, should advise the flight crew to initiate operation of the IPS using AFM procedures. An AIDS is not the prime means used to determine if the IPS should be activated. When there is an AIDS installed on an aeroplane, the flight crew has primary responsibility for determining when the IPS must be activated; an AIDS that would automatically activate the IPS(s) would not be accepted. Although the flight crew has primary responsibility for determining when the IPS must be activated, if the aeroplane is certificated in accordance with CS 25.1419(e)(2), the AIDS is required (i.e. not optional) and must perform its intended function for the aeroplane configurations, for its phases of flight, and within the relevant icing environment.

1.1.3 Performance and Installation of the ice detection system (IDS)

(i) An IDS should be capable of detecting the presence of icing conditions or actual ice accretion under all atmospheric conditions defined in the relevant icing environment.

It should be demonstrated that the presence of ice crystals mixed with supercooled liquid water does not lead to unacceptable supercooled liquid water ice detection performance degradation, when assessed at aircraft level.

For IDS capable of detecting the presence of ice on a monitored surface, the IDS should always detect when ice is present on the monitored surface whether or not icing conditions are within the relevant icing environment and the IDS should not indicate the presence of ice when no ice is present.

(ii) The applicant should accomplish a drop impingement analysis and/or tests to ensure that the ice detector(s) are properly located. The ice detector should be located on the airframe surface where the sensor is adequately exposed to the icing environment. The applicant should conduct flow field and boundary-layer analysis of candidate installation positions to ensure that the ice detector sensor is not shielded from impinging water drops. The IDS should be shown to operate in the range of conditions defined by the icing environment. Performance of the IDS is affected by the physical installation and can only be verified after installation. It should be shown by analysis and/or flight test that the location(s) of the detection systems sensor(s) is adequate to cover all aeroplane operational configurations, phases of flight, airspeeds, associated angles of attack and sideslip.

A combination of tests and analysis is required to demonstrate performance of the ice detector as installed on the aeroplane. This could include icing tunnel and icing tanker tests to evaluate ice detector performance. The applicant may use drop impingement analysis to determine that the ice detector functions properly over the drop range of the icing environment when validated through natural or artificial icing tests (e.g. tanker, icing tunnel). The applicant should demonstrate that the aeroplane can be safely operated with the ice accretions formed up to the time the ice protection system becomes effective, following activation by the ice detector. The detector and its installation should minimize nuisance warnings.

(iii) Evidences should be provided that the system is qualified under the appropriate standards, and in addition, it should be demonstrated that when installed on the aeroplane the IDS can detect under:

— Light icing conditions (minimum detectability),

— Heavy glaze ice conditions (warm runback), and

— Cold, high-LWC (Liquid Water Content) conditions (thermal load).

(iv) The maximum detection threshold should be established. The threshold level chosen to activate the ice detection and annunciation system should be guided by the assurance that:

— The aeroplane has adequate controllability and stall warning margins with the ice accretions that exist on the unprotected and protected surfaces prior to normal activation of the IPS(s);

— The amount of ice accreted can be safely eliminated by the IPS(s). It should be demonstrated that when the amount of ice that is accreted on the protected surfaces is shed, no unacceptable damages occur to the airframe or the engines;

— The system will not be overly sensitive, but sensitive enough to readily detect sudden exposure; and

— If the thickness of accreted ice is in excess of the maximum detection threshold on the monitored surface, the IDS should continue to indicate the presence of ice.

(v) If the IDS ice detection logic is inhibited during certain flight phases, handling qualities and performance should be demonstrated, assuming that the ice protection systems are inoperative and the aeroplane is operating in conditions conducive to icing.

(vi) If an accretion-based technology is used for ice detection, and if the IDS cannot detect ice in some condition where ice accretes on critical aircraft surfaces:

— For PIDS, the applicant should either show that the aeroplane can be operated safely with the ice accretions, or the IPS(s) should be forced to operate within the envelope of non-detection of the PIDS.

— For AIDS, if such icing conditions may go undetected by the flight crew (absence of visual cues for these conditions), then the IPS(s) should be forced manually to operate within the envelope of non-detection of the AIDS.

Alternatively, the installation of an icing conditions detector (i.e. one that detects both moisture and temperature), or additional substantiation with the resulting undetected ice accretions, may be required.

(vii) Preferably, the IDS should be turned on automatically at aeroplane power-up, and an alert should be provided if the IDS is turned off.

(viii) If the PIDS has automatic control of the IPS(s), it should be possible to de-select the automatic feature and to revert to an advisory system.

(ix) During the certification exercise, the proper operation of the IDS should be monitored especially by comparison with other icing signs (visual cues, ice accretion probe, etc.). Cloud conditions of the icing encounter should be measured and recorded. When multiple ice detectors are used in an IDS, signals from each ice detector should be recorded during icing tests to verify whether the ice detectors are fully redundant in the whole Appendix C and flight envelope or rather have their own detection threshold to cover the whole Appendix C and flight envelope.

1.1.4 Aeroplane Flight Manual (AFM)

AFM procedures have to be established to cover system malfunction and actions to be taken by the flight crew when alerted by the system. The AFM should at least address the following:

— Pre-flight check, if required, to verify the correct functioning of the IDS,

— Operational use of the IDS and limitations, and

— Appropriate flight crew procedure(s) in case of failure indication(s).

1.1.5 Ice detection system safety considerations

The applicant should accomplish a functional hazard assessment to determine the hazard level associated with failure of the ice detection system (refer to AMC 25.1309).

The probability of encountering the icing conditions defined in Appendix C to CS-25 should be considered to be 1.

The un-annunciated failure of a PIDS is assumed to be a catastrophic failure condition, unless characteristics of the aeroplane in icing conditions without activation of the aircraft IPS(s) are demonstrated to result in a less severe hazard category. When showing compliance to CS 25.1309 and when considering PIDS integrating multiple ice detectors, it should be assumed that the loss of one ice detector leads to the loss of the primary ice detection function, unless it is demonstrated during flight tests that all ice detectors have comparable ice detection performance. After the loss of one ice detector, the applicant may choose to revert to an advisory ice detection system; in this case the applicant should substantiate visual cues and AFM procedures in compliance with CS 25.1419(e)(2).

If visual cues are the primary means of ice detection, the pilots retain responsibility to monitor and detect ice accretions when an AIDS is installed. However, the natural tendency of flight crews to become accustomed to using the AIDS elevates the importance of the detector and increases the need to make flight crews aware of an AIDS failure. Therefore, an un-annunciated failure of the AIDS should be considered as at least a major