RESEARCH ON AIRWORTHINESS REQUIREMENTS OF SUPERCOOLED LARGE DROP ICING PROTECTION FOR AIRCRAFT (§25.1420)

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Abstract

Supercooled large droplets (SLD) are one category icing weather conditions with liquid water diameter more than 100μm which extensively exist worldwide and out of the coverage of Appendix C of 14 CFR Part 25 icing conditions. Moreover, SLD icing conditions are much more rigorous and hazardous for flight than Appendix C. After several years study, Federal Aviation Administration (FAA) and European Aviation Safety Agency (EASA) have issued final rules on SLD icing conditions and corresponding airworthiness requirements in 2015. A few regulations are newly established including §25.1420 and Appendix O which present the SLD icing conditions as well as the general airworthiness requirements of operating in SLD icing conditions for transport category aircraft. This work firstly focuses on the background analysis of the SLD icing conditions (Appendix O) and the general SLD icing requirements (§25.1420), which can help us to understand these requirements. Secondly, the technical definition and explanation of these requirements are presented. Finally, a fully discussion is given on how to comply with these SLD icing protection airworthiness requirements, including how to consider these requirements during aircraft icing protection system (IPS) design, how to verify the compliance of the design with these requirements and which Means of Compliance (MOC) to use. We hope this work can provide some useful information for aircraft designers during their aircraft design practice, as well as for aircraft inspectors from aviation authorities during their certification practice.

1 Introduction

Safety concerns about the adequacy of the icing certification standards were brought to the forefront of public and governmental attention by a 1994 accident in Roselawn, Indiana, involving a Transport Regional ATR 72 series airplane. Full and vast investigations led to the conclusion that freezing drizzle conditions created a ridge of ice on the wing's upper surface aft of the deicing boots and forward of the ailerons. It was further concluded that this ridge of ice contributed to an uncommanded roll of the aircraft [1]. Based on the investigation results, National Transportation Safety Board (NTSB) recommended changes to the icing certification requirements.

After that accident, FAA has paid much attention on SLD icing problems. FAA tasked the Aviation Rulemaking Advisory Committee (ARAC), through its Ice Protection Harmonization Working Group (IPHWG) to study SLD weather conditions and their impacts on airworthiness, and started rulemaking and amending works. Based on ARAC's recommendations, FAA issued a NPRM titled "Airplane and Engine Certification Requirements in Supercooled Large Drop, Mixed Phase, and Ice Crystal Icing Conditions" [2] on June 29, 2010. After a long time of public comments, discussion and modification, FAA finally released SLD icing protection rulemaking results as Amendment Nos. 25-140 and 33-34 "Airplane and Engine Certification Requirements in Supercooled Large Drop, Mixed Phase, and Ice Crystal Icing Conditions" [3] in November 2014. Several months later in March 2015, European Aviation Safety Agency

(EASA) also made the same Amendments to CS 25 (Amendment 16) [4]. In this amendment, 21 sections of 14 CFR/CS 25 are amended or newly established, which refer to performance and handling qualities, component requirements, operating limitation, and SLD icing conditions. Most of the revisions are based on original regulations concerning flight safety requirements of operating in SLD icing conditions. Only a few regulations are newly established including §25.1420 and Appendix O which present the SLD icing conditions as well as the general airworthiness requirements of operating in SLD icing conditions for transport category aircraft.

This work mainly focus on the research of newly established SLD icing conditions and the general SLD icing protection airworthiness requirements (i.e. §25.1420), including SLD icing conditions analysis, technical explanation and compliance discussion of the requirements.

2 SLD icing conditions analysis

Appendix O (14 CFR Part 25) SLD icing conditions is structured two parts like Appendix C of 14 CFR Part 25, one part defining icing conditions and the other defining ice accretions.

SLD icing conditions can be subdivided into two types: maximum drop diameter (D_{max}) between 100 and 500μm called freezing drizzle environment (FZD), and D_{max} >500μm called freezing rain environment (FZR). Each of these two can be further separated into two conditions, one with MVD <40μm, and the other with MVD >40μm. 40μm is selected as the MVD threshold since it represents the maximum MED of 14 CFR Part 25, Appendix C continuous maximum icing conditions (stratiform clouds). All Appendix O conditions have SLD with D_{max} >100μm, while in general, Appendix C stratiform conditions are assumed to have D_{max} <100μm. Hence, Appendix C and Appendix O together account for almost all icing environments associated with supercooled liquid water. As a result, SLD icing conditions are fully analyzed compared Appendix C icing conditions.

2.1 Icing clouds extend or ranges

Table 1 gives the extend and ranges of four different icing conditions defined in Part 25, Appendix C and Appendix O, from which we can see that all the first 3 icing conditions could possibly appear where it's as low as the sea level, hence when conducting the icing certification, we need to consider the influences of these 3 icing conditions on the flight safety during takeoff, and approach. The altitude ranges of atmosphere that might appear CMI and FZD icing conditions are the same, both 0~22,000ft. While the highest altitude where the FZR conditions possibly happen is 12,000ft. This is due to that the higher the altitude is, the lower the atmospheric temperature is, which is not suitable for generating of the large diameter FZR drops. Lower than 12,000ft altitude is in the climbing range of flight envelope, so we need to pay more attention to the FZR icing conditions during the climbing period.

Table 1 Extend or ranges of different icing conditions

Types of icing conditions	Pressure altitude range (ft, MSL)	Maximum vertical extent (ft)	Horizontal extent (nautical miles)
Appendix O, Freezing Drizzle (FZD)	0 ~ 22,000	12,000	17.4
Appendix O, Freezing Rain (FZR)	0 ~ 12,000	7,000	17.4
Appendix C, Continuous maximum icing (CMI)	0 ~ 22,000	6,500	17.4
Appendix C, Intermittent maximum icing (IMI)	4,000 ~ 22,000	--	2.6

Regarding to the maximum vertical extent of icing clouds, the FZD is the largest; the second largest one is FZR, followed by CMI. Thus it can be seen that, when encountering certain icing condition, there is greater possibility that suffering long time from Appendix O icing conditions than Appendix C, especially when coming across the icing condition of FZD. Therefore, when the airplane comes across the Appendix O icing conditions during climbing, it's very necessary to exit from it. This is the deep reason why the FAA has issued some Airworthiness Directives (ADs) for exit of SLD icing conditions, and considered the requirement of escaping from such weathers in §25.1420.

Horizontal extent of icing clouds is a statistical result based on mass experimental data. For FZD, FZR and CMI icing conditions, this value is 17.4 nautical miles. While, IMI conditions have a smallest extent with only 2.6 nautical miles. So, it's quite difficult to escape in the horizontal extent when encountering the first 3 icing conditions.

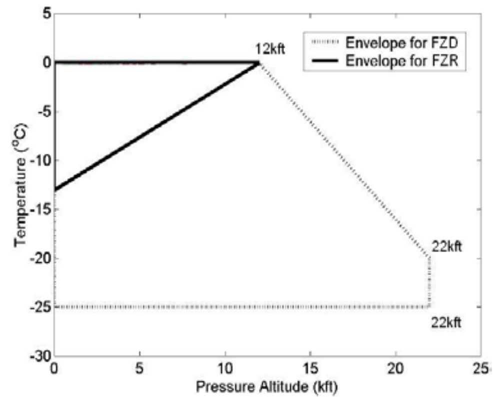

Fig. 1. Altitude-temperature envelopes of FZD and FZR conditions

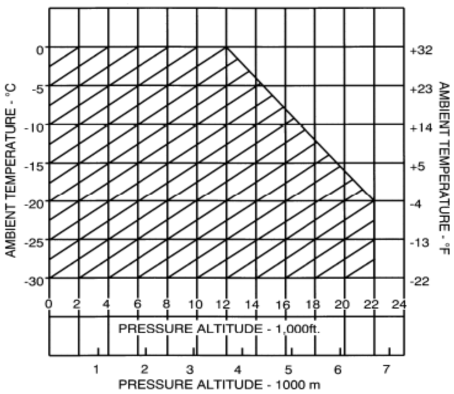

Fig. 2. Altitude-temperature envelopes of CMI conditions

2.2 Altitude-temperature envelopes

Fig. 1 is the comparison of altitude-temperature envelopes of FZR and FZD, and Fig.2 is the altitude-temperature envelope of CMI environment. From the figures we can see, the area of altitude-temperature envelope of FZR only accounts very small part of FZD, and when the altitude become higher, the temperate extent of FZR is becoming smaller, with the possible highest altitude 12,000ft which will happen only when the temperate is 0°C. Thus, we know there is a greater possibility the FZR appears when the altitude is low. Therefore when the airplane is holding at low altitude, it is better to fly over 12,000ft in order to avoid the FZR. The scope and trend of altitude-temperature envelopes are almost the same with each other for FZD and CMI, except that the lowest temperate extent of CMI is 5℃ lower than that of FZD. The highest temperature of FZD and CMI conditions above 12,000ft will become lower and lower as the increase of the altitude. That's because it is lower than 0°C throughout the year at this altitude, and the temperature becomes lower as the increase of the altitude. From the figures we can also see, the area of altitude-temperature envelope of FZR is contained by the area of FZD envelope, while the one of FZD is contained by that of CMI, which can be shown in mathematical expression as follows:

$$\Delta_{FZR} \subset \Delta_{FZD} \subset \Delta_{CMI} \qquad (1)$$

Where Δ presents the area of altitude-temperature envelope.

This suggests that within the Δ_{FZR} there is possibility that all the 3 icing conditions exist; within the scope of (Δ_{FZD} - Δ_{FZR}), the icing conditions of FZD and CMI possibly appear; while within (Δ_{CMI} – Δ_{FZD}), only the CMI conditions will appear.

2.3 Liquid water content (LWC)

From Appendix O we know that the temperature-LWC envelop of FZD environment is much larger than that of FZR environment. FZR can only be formed when the temperate is within 0 ~ -13°C, while FZD can still exist when the temperate is as low as -25°C. The lowest temperature of icing conditions for Appendix C is lower than those: the lowest temperate of CMI is -30°C, while IMI's lowest temperate could be -40°C (see Table 2).

Table 2 Comparison of temperature-LWC envelops of different icing conditions

Types of icing environment	Ambient temperature range (℃)	Maximum LWC at lowest temperature (g/m^3)	Maximum LWC at highest temperature (g/m^3)
Appendix O, FZD	0 ~ -25	0.37	0.53
Appendix O, FZR	0 ~ -13	0.31	0.38
Appendix C, CMI environment	0 ~ -30	0.20	0.80
Appendix C, IMI environment	0 ~ -40	0.25	2.90

Table 2 also provides the maximum LWC at the highest and lowest temperatures under all kinds of icing conditions, from which we can see that, the maximum LWC at 0 ℃, IMI's is the largest, followed by FZD's, and FZR's is the smallest. The maximum LWC is one of the most important parameters for computation of energy requirements during IPS design and validation. The larger LWC is, the larger the liquid water catch rate is under the same conditions, the more energy the IPS will need. The lower the temperature is, the more energy the IPS will need under the same conditions. However, the lower the temperature is, the lower the maximum LWC will be at the same conditions. As a result, during thermal-type IPS design and assessment, we should comprehensive consider all the parameters within the 4 icing conditions' temperature-LWC envelops, and choose the grouped parameters, that would lead to the maximum energy needs, as the input of IPS design.

2.4 Drop diameter distribution

The trajectory and collision limit of the liquid drops are directly related with their diameters. Drop diameter distribution is one of the most important parameters for the computation of drop collision limit, determination of de-/anti-icing areas, and computation of ice shapes, which is worthy to pay attention to. The diameter drops that have the maximum mass portion are shown in Table 3. Comparatively speaking, the icing conditions of FZD, MVD <40μm have the most concentrated droplet diameters with 50% mass portion of 13 ~ 23μm droplets. The concentration of the drops' diameters will quite ease the computation of the drop collision limit and ice accretion shapes.

Table 3 Comparison of temperature-LWC envelops of different icing conditions

Types of icing conditions	Maximum mass portion liquid water diameter range (μm)	Cumulative mass range	Mass portion
FZD, MVD <40μm	13 ~ -23	0.2 ~ 0.7	0.5
FZD, MVD >40μm	160 ~ 250	0.6 ~ 0.8	0.2
FZR, MVD <40μm	80 ~ 200	0.2 ~ 0.54	0.34
FZR, MVD >40μm	500 ~ 800	0.48 ~ 0.7	0.22

3 Analysis of §25.1420 requirements

§25.1420 includes four subsections, and (a), (b), (c) are requirements, while subsection (d) are definitions of terms. Subsection (a) are technical requirements which define the applicability of §25.1420 and gives three different options and corresponding requirements related to safe operating. §25.1420 apply to transport aircraft with either a maximum takeoff weight (MTOW) of less than 60,000 pounds (27,215kg), or reversible flight controls.

As we know, ice accretion influences to the aircraft performance and handling qualities are much more rigorous for small aircraft than for large ones. Based on review and analysis of large data of aircraft icing accidents and incidents, FAA finds that airplanes with a MTOW of 60,000 pounds or greater have not experienced accidents or incidents associated with flight in SLD. FAA also recognizes that design features such as control surface size and wing chord length are important parameters, which can affect the sensitivity of a wing to SLD icing conditions. Control surfaces with big size could make the wing less sensitive to SLD icing conditions, and big size control surfaces need large control force which usually provided by hydraulic or electric actuators. Hydraulic or electric actuators are used in irreversible flight control systems. That's why FAA defines the aforementioned application limitations of §25.1420.

60,000 pounds (27,215kg) MTOW can be easily reached for transport aircraft since we know that A320-100's MTOW is 77,000kg, and the maximum MTOW of ATR-72 series' is 23,000kg (ATR72-600). According to §25.1420(d), reversible flight controls mainly refer to mechanical flight control systems, and flight controls in which all of the force necessary to move the pitch, roll, or yaw control surfaces is provided by hydraulic or electric actuators, are not reversible flight controls. Because, the force or motion cannot be transmitted directly back to the flight deck controls. So, hydraulic or electric flight control systems are irreversible flight controls which are very popular in modern transport aircraft. As a result, §25.1420 may only apply to small transport aircraft with mechanical flight controls.

The three options §25.1420(a)(1), (a)(2), (a)(3) are grouped by aircraft' acclimatization extends to the SLD icing conditions defined in Appendix O. So, the three options can be concluded as non-acclimatization, partial acclimatization, and full acclimatization. Partial acclimatization means the aircraft can safely fly in some light SLD icing conditions. §25.1420 requires that aircraft of non-acclimatization and partial acclimatization can detect the SLD conditions which are out of their acclimatization range and can safely exit those conditions, which means the aircraft must have means for detecting that the aircraft is operating in Appendix O icing conditions or exceeding the chosen partial SLD conditions, and give immediate alert to flight crews. Following the detection and alert, the aircraft must be capable of operating safely while exiting all icing conditions (including SLD) until landing.

§25.1420(b) are provides the requirements of demonstration compliance with subsection (a), which requires both analysis and one test, or more as found necessary, to establish that the ice protection for the various components of the airplane is adequate. The words "as found necessary" would be applied in the same way as they are applied in §25.1419(b). Then, 5 methods including two types of laboratory tests and three types of flight tests are provided. The definitions and differences of Simulated Icing Test and Simulated Ice Shape could be found in §25.1420(d)(2) and (d)(3). These methods are very commonly used while validating the compliance of §25.1419.

§25.1420(c) extends the requirements of §25.1419(e), (f), (g), and (h) [5] to include activation and operation of airframe ice protection systems (IPS) in Appendix O icing conditions for which the aircraft is certified. §25.1420(c) doesn't apply to aircraft certified to §25.1420(a)(1) because §25.1420(a)(1) only requires a method to identify and safely exit all appendix O conditions.

4 Discussion of Acceptable Means of Compliance (MC) for §25.1420

§25.1420 require that the airplane operate safely in SLD icing conditions defined in Appendix O, 14 CFR Part 25. Then, the compliance verification methods and techniques should be developed for certification of flight in SLD icing conditions. Table 4 presents the general recommended Means of Compliance (MC) for §25.1420, which could be given some suggestions and references for small transport aircraft certification. Since §25.1420(a) are technical requirements and §25.1420(b) are compliance requirements for §25.1420(a), the compliance verification of §25.1420(a), (b) should be considered together.

Table 4 Recommended Means of Compliance (MC) for §25.1420

Requir-ements	MC	Explanations
a(1), (b)	MC1: design description	Ice detection and warning system, ice protection system (IPS) design description, including system construction and function drawings. Describe that ice detection and warning system can timely detect the encountered of SLD icing conditions and warn the flight crew to exit

		immediately, and IPS can ensure the aircraft to safely exit all icing conditions.
	MC2: computation & analysis	● Analysis and determine of icing protection area and component for safely operating in Appendix C conditions and exiting all icing conditions; ● Failure Analysis: Applying the system safety principles of § 25.1309 in determining the need for system requirements to address potential hazards from operating in Appendix C icing environment and exiting all icing environment; ● Computation of critical ice shapes formed while operating in Appendix C icing environment and exiting all icing environment; ● IPS energy needs calculation and analysis, ice detector location reasonability analysis.
	MC4: laboratory test	Following tests may be needed to get ice shapes and their aerodynamic influence, and to determine the critical ice shapes: ● Wind tunnel tests ((b)(1), (2))：with simulated ice shape; ● Icing wind tunnel tests ((b)(1)、(2))：including ice accretions tests in SLD conditions, ice detection system effectiveness tests.
	MC6: flight test	● Dry air flight tests: clean configuration flight tests (to verify that IPS energy needs and protected surfaces’ temperature are satisfied); flight test with simulated ice shapes ((b)(4)) (to verify the influence of different ice shapes to performance and handling qualities); ● Simulated icing flight tests ((b)(3)): to verify the effectiveness of IPS and ice detection system; ● Natural icing flight tests ((b)(5)): to verify the effectiveness of ice detection and warning system, and IPS can ensure the aircraft safely exiting all icing conditions. Natural icing flight tests are generally not mandatory requirement since these conditions are difficult to find.
a(2), (b)	MC1: design description	● Definition of the selected portion SLD icing conditions by the parameters of D_{max}、LWC、MVD, etc.; ● Ice detection and warning system, ice protection system (IPS) design description, including system construction and function drawings. Describe that ice detection and warning system can timely detect the exceeding of the selected SLD icing conditions and warn the flight crew to exit immediately, and IPS can ensure the aircraft to safely exit all icing conditions.
	MC2: computation & analysis	● Analysis and determine of icing protection area and component for safely operating in the selected Appendix O conditions and exiting all icing conditions; ● Failure Analysis: Applying the system safety principles of § 25.1309 in determining the need for system requirements to address potential hazards from operating in the selected icing conditions and exiting all icing conditions; ● Computation of critical ice shapes formed while operating in the selected icing conditions and exiting all icing conditions; ● IPS energy needs calculation and analysis, ice detector location reasonability analysis.
	MC4: laboratory test	Following tests may be needed to get ice shapes and their aerodynamic influence, and to determine the critical ice shapes: ● Wind tunnel tests ((b)(1), (2))：with simulated ice shape; Icing wind tunnel tests ((b)(1)、(2))：including ice accretions tests in SLD conditions, ice detection system effectiveness tests.
	MC6: flight test	● Dry air flight tests: clean configuration flight tests (to verify that IPS energy needs and protected surfaces’ temperature are satisfied); flight test with simulated ice shapes ((b)(4)) (to verify the influence of different ice shapes to performance and handling qualities); ● Simulated icing flight tests ((b)(3)): to verify the effectiveness of IPS and ice detection system; ● Natural icing flight tests ((b)(5)): to verify the effectiveness of ice detection and warning system, and IPS can ensure the aircraft safely exiting all icing conditions. Natural icing flight tests are generally not mandatory requirement since these conditions are difficult to find.
a(3), (b)	MC1: design description	Ice detection and warning system, ice protection system (IPS) design description, including system construction and function drawings. Describe that ice detection and warning system and IPS can ensure the aircraft safely operating all SLD icing conditions.
	MC2: computation & analysis	● Analysis and determine of icing protection area and component for safely operating in all icing conditions; ● Failure Analysis: Applying the system safety principles of § 25.1309 in determining the need for system requirements to address potential hazards from operating in all icing conditions; ● Computation of critical ice shapes formed while operating in all icing conditions; ● IPS energy needs calculation and analysis.
	MC4: laboratory test	Following tests may be needed to get ice shapes and their aerodynamic influence, and to determine the critical ice shapes: ● Wind tunnel tests ((b)(1), (2))：with simulated ice shape;

		● Icing wind tunnel tests ((b)(1)、(2))：including ice accretions tests in SLD conditions.
	MC6: flight test	● Dry air flight tests: clean configuration flight tests (to verify that IPS energy needs and protected surfaces' temperature are satisfied); flight test with simulated ice shapes ((b)(4)) (to verify the influence of different ice shapes to performance and handling qualities); ● Simulated icing flight tests ((b)(3)): to verify the effectiveness of IPS and ice detection system; ● Natural icing flight tests ((b)(5)): to verify IPS can ensure the aircraft safely exiting all icing conditions. Natural icing flight tests are generally not mandatory requirement since these conditions are difficult to find.
(c)	MC1, 4, 6	Compliance verification means and activities are generally the same as that of §25.1419(e), (f), (g), and (h).
(d)	MC0: statement	State that the terms defined here are correctly applied in the aforementioned compliance verification activities.

4.1 §25.1420(a)

4.1.1 §25.1420(a)(1), (a)(2)

When complying with §25.1420(a)(1), a method for detecting that the aircraft is operating in Appendix O icing conditions must be provided. Following detection, the aircraft must be capable of operating safely while exiting all icing conditions until landing.

If the aircraft is certified for safe operation in portions of Appendix O icing conditions, such as freezing drizzle only, or during specific phases of flight (such as taking off and landing, but without holding), §25.1420(a)(2) applies. If this option is chosen, following detection of conditions that exceed the selected portion of Appendix O, the aircraft must be capable of operating safely while exiting all icing conditions until landing. So, complying with §25.21(g) for exiting the restricted Appendix O icing conditions must be shown. Ice shapes to be tested are those representing the critical Appendix O icing conditions during recognition and subsequent exit from those icing conditions. Moreover, in order to comply with §25.1420(a)(1) or (a)(2), substantiated methods of alerting flight crews when Appendix O or exceeding the selected portions of Appendix O icing conditions are encountered are required. It is acceptable to use an ice detection system that detects accretions behind the aircraft protected areas.

Determining whether the selected Appendix O icing conditions boundary has been exceeded can potentially be accomplished using:

(1) Substantiated visual cues. Substantiated visual cues can range from direct observation of ice accretions aft of the aircraft's protected surfaces to observation of ice accretions on reference surfaces. Responding to a visual cue should not require the flight crew to judge the ice to be a specific thickness or size. Examples of potential visual cues are accretions forming on the side windshields, the sides of nacelles, the propeller spinners aft of a reference point, the radomes aft of a reference point, and/or aft of protected surfaces.

(2) An ice detection system. An ice detection system installed for compliance with §25.1420(a) is meant to determine when conditions have reached the boundary of the Appendix O icing conditions in which the aircraft has been demonstrated to operate safely. A drop impingement analysis and/or tests should be accomplished to ensure that the ice detector is properly located to function during the aircraft operational conditions and in Appendix O icing conditions. Analysis may be used to determine that the ice detector is located properly for functioning throughout the drop range of Appendix O icing conditions when validated with methods described in document SAE ARP5903 [6]. Moreover, the system nuisance warnings should be minimized when operating in icing conditions.

(3) An aerodynamic performance monitor. A crew alerting system using pressure probes and signal processors could be developed for quantifying pressure fluctuations in the flow field from contamination over the wing surface. This technology does exist, but full development is necessary before incorporating it into the crew alerting system.

4.1.1 §25.1420(a)(3)

An aircraft certified to §25.1420(a)(3) must be capable of safely operating throughout the conditions described in Appendix O and does not need a means to distinguish Appendix O conditions from Appendix C conditions. However, a means to alert the flight crew that the airplane has encountered icing conditions is still required in accordance with §25.1419. The provisions in §25.1419 which require a method to detect icing conditions and activate the ice protection system are still applicable as required in §25.1420(c). If the aircraft is certified for unrestricted flight in Appendix O conditions, the ice detection method must be substantiated to function throughout Appendix O. In effect, when §25.1420(a)(3) is chosen, the aircraft is certificated for flight in icing without any specific aircraft flight manual (AFM) procedures or limitations to exit icing conditions.

4.2 §25.1420(b)

Both §25.1419(b) and §25.1420(b) require two or more means of compliance for flight in icing approval. It is common to use a combination of methods listed in Table 4 in order to adequately represent the conditions and determine resulting degradation effects with sufficient confidence to show compliance. From the explanations in Table 4, we can see that MC1, MC2, MC4, MC6 is a step by step process to gradually establish sufficient evidences to comply with the SLD icing requirements. However, if evidence is enough, it doesn't need to choose all of these means to show compliance, and two or more means might be possible.

Detailed guidance on compliance of SLD icing requirements can be found in FAA AC 25-28 [7]. FAA AC 25-25A [8] gives some guidance on how to analysis the ice accretions influence on aircraft performance and handling qualities, which can be used in determination of SLD icing influences, icing protection area and surfaces, as well as critical ice shapes.

4.3 §25.1420(c)

§25.1420(c) requires that aircraft certified in accordance with subparagraph §25.1420(a)(2) or (a)(3) comply with the requirements of §25.1419 (e), (f), (g), and (h) for the icing conditions defined in Appendix O in which the aircraft is certified to operate. Compliance verification means and activities are generally the same as that of §25.1419(e), (f), (g), and (h).

5 Conclusions

This work mainly focuses on the newly established SLD icing conditions and the corresponding general airworthiness requirements to 14 CFR Part 25, including the background analysis of this amendment, SLD icing conditions analysis, technical explanation and compliance discussion of the requirements, and the following conclusions are acquired:

- SLD icing conditions defined in Appendix O and icing conditions defined in Appendix C together account for almost all icing environments.
- FZD, FZR and CMI icing conditions are all possibly encounter on the ground altitude level. Concerning the maximum vertical extent of icing clouds, the FZD is the largest, followed by FZR and CMI.
- For the maximum LWC at 0℃, IMI's is the largest, followed by FZD's, and FZR's is the smallest.
- 60,000 pounds (27,215kg) MTOW can be easily reached for transport aircraft, and reversible flight controls mainly refer to mechanical flight control systems. So, §25.1420 may only apply to small transport aircraft with mechanical flight controls.
- The recommended Means of Compliance (MC) for §25.1420(a), (b) are MC1, 2, 4, 6, and a combination of these methods are commonly used. The recommended MC for §25.1420(c) are the same as that of §25.1419(e), (f), (g), and (h).

We hope this work can help the designers and airworthiness engineers of a new aircraft type to be acquainted with the new SLD regulations amendment and consider these requirements in their aircraft design and airworthiness certification.

Nomenclature

D_{max} Maximum drop size, μm
Δ Area of altitude-temperature envelope

Abbreviations

AC	Advisory Circular
AFM	Airplane flight Manual
CFR	Code of Federal Regulations
CMI	Continuous maximum icing
FAA	Federal Aviation Administration
FZD	Freezing drizzle
FZR	Freezing rain
IMI	Intermittent maximum icing
LWC	Liquid water content
MC	Means of Compliance
MED	Median effective diameter
MTOW	Maximum takeoff weight
MVD	Median volume diameter
MSL	Mean Sea Level
NTSB	National Transportation Safety Board
NPRM	Notice of Proposed Rulemaking
IPS	Ice protection system
SLD	Supercooled large drops

References

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[2] CFR NPRM, Airplane and Engine Certification Requirements in Supercooled Large Drop, Mixed Phase, and Ice Crystal Icing Conditions, *Federal Register*, Volume 75, Number 124, Docket No. FAA-2010-0636, 2010.

[3] FAA Amendment Nos. 25-140 and 33-34, Airplane and Engine Certification Requirements in Supercooled Large Drop, Mixed Phase, and Ice Crystal Icing Conditions, *Federal Register*, Volume 79, p65508-65540, Docket No. FAA-2010-0636, 2014.

[4] EASA CS-25(Amendment 16), Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes, 2015.

[5] FAA Amendment 25-129, IPS activation, *Federal Register*, Volume 74, p38328, Docket No. FAA-2007-27654, August 3, 2009.

[6] SAE ARP5903 Drop Impingement and Ice Accretion Computer Codes, 2003.

[7] FAA AC 25-28, Compliance of Transport Category Airplanes with Certification Requirements for Flight in Icing Conditions, ANM-110, 2014.

[8] FAA AC 25-25A, Performance and Handling Characteristics in Icing Conditions, ANM-110, 2014.

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