Notice of Proposed Amendment 2015-07

Use of comparative analysis when showing compliance with SLD icing specifications

RMT.0572 — 12.6.2015

EXECUTIVE SUMMARY

Rulemaking task RMT.0058 aims to develop new CS-25 certification specifications for flight in icing conditions which were introduced through Amendment 16 of CS-25. A new Appendix O environmental standard representing Supercooled Large Drop (SLD) icing conditions has been created. These SLD icing conditions are therefore part of the certification specifications related to the ice protection of the aeroplane systems and equipment, powerplant and Auxiliary Power Unit (APU), as well as specifications related to aeroplane performance and handling qualities.

This Notice of Proposed Amendment (NPA) addresses a need identified by the Agency during the development of rulemaking task RMT.0058, i.e. to have the possibility of taking credit from previously certified large aeroplane type designs having proven to safely operate in SLD icing conditions.

The specific objective is to introduce an acceptable means of compliance which may be used by applicants in order to show compliance with the certification specifications related to SLD icing conditions. To this end, this NPA proposes changes to CS-25 Book 1 and Book 2 to enable the use of a means of compliance based on comparative analysis when showing compliance with SLD-related specifications.

The proposed changes are expected to maintain safety while increasing cost-effectiveness and facilitating the certification process.

Applicability		Process map	
Affected regulations and decisions:	ED Decision 2003/2/RM Certification specifications, including airworthiness codes and acceptable means of compliance, for large aeroplanes ('CS-25')	Concept Paper:	No
		Terms of Reference:	28.1.2013
		Rulemaking group:	Yes
		RIA type:	Light
Affected stakeholders:	Large aeroplane manufacturers	Technical consultation during NPA drafting:	No
		Duration of NPA consultation:	3 months
Driver/origin:	New CS-25 provisions for flight in icing conditions introduced through Amendment 16 Request from industry	Review group:	Yes
		Focussed consultation:	No
		Publication date of the Opinion:	N/A
		Publication date of the Decision:	2016/Q2
Reference:	NPA 2011-03; CRD 2011-03; NPA 2012-22; CRD 2012-22		

Table of contents

1. Procedural information

1.1. The rule development procedure

The European Aviation Safety Agency (hereinafter referred to as the 'Agency') developed this Notice of Proposed Amendment (NPA) in line with Regulation (EC) No 216/2008[1] (hereinafter referred to as the 'Basic Regulation') and the Rulemaking Procedure[2].

This rulemaking activity is included in the Agency's Revised 2014–2017 Rulemaking Programme under RMT.0572.

The text of this NPA has been developed by the Agency based on the input of the Rulemaking Group RMT.0572. It is hereby submitted for consultation of all interested parties[3].

The process map on the title page contains the major milestones of this rulemaking activity to date and provides an outlook of the timescale of the next steps.

1.2. The structure of this NPA and related documents

Chapter 1 of this NPA contains the procedural information related to this task. Chapter 2 (Explanatory Note) explains the core technical content. Chapter 3 contains the proposed text for the new requirements. Chapter 4 contains the Regulatory Impact Assessment showing which options were considered and what impacts were identified, thereby providing the detailed justification for this NPA.

1.3. How to comment on this NPA

Please submit your comments using the automated **Comment-Response Tool (CRT)** available at **http://hub.easa.europa.eu/crt/**[4].

The deadline for submission of comments is **14 September 2015.**

1.4. The next steps in the procedure

Following the closing of the NPA public consultation period, the Agency will review all comments, and a Review Group meeting will be organised.

The outcome of the NPA public consultation will be reflected in the respective Comment-Response Document (CRD).

The Agency will publish the CRD concurrently with the Decision amending CS-25.

---

[1] Regulation (EC) No 216/2008 of the European Parliament and of the Council of 20 February 2008 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency, and repealing Council Directive 91/670/EEC, Regulation (EC) No 1592/2002 and Directive 2004/36/EC (OJ L 79, 19.3.2008, p. 1).

[2] The Agency is bound to follow a structured rulemaking process as required by Article 52(1) of the Basic Regulation. Such process has been adopted by the Agency's Management Board and is referred to as the 'Rulemaking Procedure'. See Management Board Decision concerning the procedure to be applied by the Agency for the issuing of Opinions, Certification Specifications and Guidance Material (Rulemaking Procedure), EASA MB Decision No 01-2012 of 13 March 2012.

[3] In accordance with Article 52 of the Basic Regulation and Articles 5(3) and 6 of the Rulemaking Procedure.

[4] In case of technical problems, please contact the CRT webmaster (crt@easa.europa.eu).

2. Explanatory Note

2.1. *Overview of the issues to be addressed*

Within the frame of rulemaking task RMT.0058, new certification specifications (CS) and acceptable means of compliance (AMC) have been created for certification of large aeroplanes for flight in icing conditions. These new provisions, introduced through Amendment 16 of CS-25, include the introduction of Supercooled Large Drop (SLD) icing conditions in various paragraphs of Book 1.

Some provisions have been included in AMC 25.1420 so that the applicant may use and take credit for similarity to a previous type design having proven to safely operate in SLD icing conditions. However, the details of the method and the acceptance criteria to be used when conducting a comparative analysis are not provided; therefore, the Agency decided to create a new rulemaking task to further develop the application of comparative analysis.

For more detailed analysis of the issues addressed by this proposal, please refer to the RIA Section 4.1. 'Issues to be addressed'.

2.2. *Objectives*

The overall objectives of the EASA system are defined in Article 2 of the Basic Regulation. This proposal will contribute to the achievement of the overall objectives by addressing the issues outlined in Chapter 2 of this NPA.

The specific objective of this proposal is to introduce an acceptable means of compliance based on comparative analysis when showing compliance with SLD-related specifications.

2.3. *Summary of the Regulatory Impact Assessment (RIA)*

Option 1 (see Section 4.3) is recommended, i.e. amend CS-25 to introduce an acceptable means of compliance based on comparative analysis when showing compliance with SLD-related specifications. This would provide a benefit in terms of safety level harmonisation, and would facilitate the certification process for both the applicants and the Agency when eligible to the comparative analysis, with an overall economic benefit. It would also meet the request made by several large aeroplane manufacturers within the frame of the development of the new icing certification specifications (RMT.0058).

2.4. *Overview of the proposed amendments*

Changes to CS-25 Book 1 and Book 2 are proposed in order to enable the use of a means of compliance based on comparative analysis when showing compliance with SLD-related specifications.

This section provides the background and the methodology used to develop the proposed changes.

2.4.1. Definitions

2.4.1.1 Key definitions

Similarity analysis

— The direct comparison of a new or derivative aeroplane model to models already certified for operation in the icing environment of Appendix C and/or Appendix O. Similarity can be established for aircraft, system and/or components.

— Key elements:

- Similar design features
- Similar performance and functionality

Comparative analysis

— The use of analyses to show that an aircraft is comparable to models that have previously been certified for operation in the icing environment of Appendix C with a proven safe operating history in supercooled liquid water icing conditions, but that may not have already been certified for operation in the icing environment of Appendix O.

— Key elements:

- The new model is certifiable for Appendix C icing conditions
- Aircraft models previously certified for Appendix C icing conditions are used to establish a reference fleet
- The new model has similar design features and/or margins for key parameters relative to the reference fleet
- The reference fleet has a safe fleet history in supercooled liquid water icing conditions

Events

For the purposes of this document, the word 'event' means 'accident and/or serious incident' as defined in ICAO Annex 13, Chapter 1.

Reference fleet

The fleet of previously certified aeroplanes used to establish safe fleet history in order to enable the use of comparative analysis as a means of compliance.

Certification ice shapes/ice shape data

Ice shapes or ice shape data used to show compliance with certification specifications for flight in icing conditions. As used in this document, these are the ice shapes or data used to represent the critical ice shapes with the intent that they convey the ice that represents the most adverse effect on performance and flight characteristics. The data which is used to represent these shapes may be comprised of flight test data (artificial or natural ice), wind tunnel data, analytical data, or combinations of the above as allowed during previous certification efforts.

Key parameters

Parameters that can be shown to have contributed to the safe operation in icing conditions of the reference fleet. These parameters should be defined and provided by the applicant for each of the topics addressed in comparative analysis. They should be agreed with the Agency.

2.4.1.2 Additional definitions

Anti-icing

The prevention of ice accumulation on a protected surface.

CPR

The Changed Product Rule (CPR) is the process used to determine the applicable certification specifications for an aircraft as determined under Subpart D of Annex I ('Part 21') to Commission Regulation (EU) Regulation No 748/2012[5] as amended by Commission Regulation (EU) Regulation No 69/2014[6] (please see 21.A.101).

De-icing

The periodic shedding or removal of ice accretions from a surface by destroying the bond between the ice and the protected surface.

Freezing drizzle

Liquid precipitation in the form of water drops with diameters between 50 and 500 µm that fall in liquid form, but freeze upon impact with the ground or exposed objects.

Freezing rain

Precipitation near the ground or aloft in the form of liquid water drops which have diameters >0.5 mm (500 µm) that fall in liquid form, but freeze upon impact with the ground or exposed objects.

Ice accretion

A growth, build-up, or formation of ice on an aircraft surface.

Impingement limits

The farthest aft location on a body on which water droplets impact. This applies to both the upper or lower surface for a body such as an airfoil. This distance can be measured either as the x distance from the leading edge or as the surface distance from the stagnation point (attachment line).

---

[5] Commission Regulation (EU) No 748/2012 of 3 August 2012 laying down implementing rules for the airworthiness and environmental certification of aircraft and related products, parts and appliances, as well as for the certification of design and production organisations (OJ L 224, 21.8.2012, p. 1).

[6] Commission Regulation (EU) No 69/2014 of 27 January 2014 amending Regulation (EU) No 748/2012 laying down implementing rules for the airworthiness and environmental certification of aircraft and related products, parts and appliances, as well as for the certification of design and production organisations (OJ L 23, 28.1.2014, p. 12).

Liquid Water Content (LWC)

The total mass of water contained in liquid drops within a unit volume or mass of cloud or precipitation, usually given in units of grams of water per cubic metre or kilogram of dry air (g/m3, g/kg).

MoC

Means of Compliance

Residual ice

Ice remaining immediately after an actuation cycle of a de-icing type of ice protection system.

Runback ice

Ice formed from the freezing or refreezing of water leaving an area on an aircraft surface that is above freezing and flowing downwind to an area that is sufficiently cooled for freezing to take place. This ice type is frequently associated as an unwanted product of thermal anti-icing or de-icing systems.

Supercooled Large Drop (SLD)

Supercooled liquid water drop with diameter >50 µm; this includes freezing rain and freezing drizzle.

Supercooled liquid water

Liquid water at a temperature below the freezing point.

2.4.2. *Comparative analysis as a means of compliance — Explanatory note*

This paragraph provides the rationale and explanation of the development of comparative analysis as a MoC for certification against the CS-25 certification specifications addressing Supercooled Large Drop (SLD) icing conditions as represented in Appendix O. The Agency acknowledges that there are a significant number of aeroplane models that have an exemplary record of safe operation in all icing conditions, which inherently include SLD icing conditions. The proposed use of comparative analysis as MoC provides an analytical certification path for new aeroplane models and derivatives by allowing the applicant to substantiate that a new or derivative model will have at least the same level of safety in all supercooled liquid water icing conditions that previous models have achieved.

For derivative models, the applicable certification specifications are determined through application of the CPR. Rather than demonstrating compliance with the certification specifications in effect at the date of application, an applicant may demonstrate compliance with an earlier amendment of the certification specifications when meeting one of the conditions provided in paragraph 21.A.101(b). After application of the CPR, if the derivative model must comply with an amendment that includes the SLD-related requirements of the certification specifications, compliance by comparative analysis may be used.

To use a comparative analysis as a MoC for a new or derivative aeroplane model, four main elements should be established:

1. A reference fleet with an adequately safe history in icing conditions;

2. Accepted analysis of aeroplane features and/or margins that are deemed to contribute to the safe reference fleet history;
3. Comparison showing that the new or derivative aeroplane model shares the comparable design features and/or margins with the reference fleet; and
4. Compliance of the new or derivative aeroplane model with the applicable CS-25 certification specifications relative to flight in the icing conditions defined by Appendix C.

The AMC material will provide guidance for showing compliance by using comparative analysis. It includes specific discussion of:

— ice protection systems;

— unprotected components;

— ice or icing conditions detection;

— ice accretion and ice shedding sources;

— aeroplane performance and handling characteristics;

— aeroplane flight manual information; and

— additional considerations — augmenting comparative analysis.

To ensure consistency, proposed changes to Book 1 and Book 2 to CS-25 are included in this NPA.

2.4.2.1 Definition of 'adequately safe fleet history'

2.4.2.1.1 Objective

The objective is to define the number of flights that the reference fleet must have accumulated without any accidents or serious incidents whilst operating in the supercooled liquid water icing conditions represented in CS-25 Appendix C and Appendix O, to allow the reference fleet history to be used in a demonstration of compliance with the SLD specifications by comparative analysis.

Most aircraft accidents associated with SLD icing are caused by a chain of events in which the aircraft design is only one factor. When considering fleet history, these accidents have also typically resulted from crew reaction and response during times of high workload. Additionally, when reviewing the service history of the aircraft that have had accidents or serious incidents with SLD icing conditions listed as a contributing factor, it was noted that all of the models had precursor events in icing conditions which were not described as SLD.

2.4.2.1.2 Methodology

Safe in-service experience is defined in terms of flights accrued by a fleet without an accident or serious incident while operating in supercooled liquid water icing conditions aloft. Based upon the following definitions, a fleet that has accrued the defined number of flights will have encountered sufficient SLD icing conditions to provide a high level of confidence that the aircraft can operate safely in SLD conditions.

To determine the number of flights required to provide this level of confidence, two approaches are used. A check is also made by computing the number of sufficiently long SLD encounters a fleet would have accrued after the defined number of flights. The process therefore consists of the following three steps:

1. Computation of the number of flights required based on the probability of a heavy SLD icing encounter;
2. Review of the in-service record of aircraft that have experienced serious in-service incidents or accidents to determine the number of flights accrued by the fleets prior to serious icing incidents and accidents; and
3. Final Check: determination of the number of 5-minute, 10-minute, 15-minute and 30-minute SLD exposures a fleet would have encountered, on average, after accruing the specified number of flights.

The second step was used as a ‘common-sense’ check. This was considered necessary to compensate for any uncertainty in the probability of SLD icing conditions and to validate that the number of flights selected would have addressed those models. Whilst the first step could be determined either in terms of the number of flights or flight hours, using the number of flights is a better means of comparing various types and sizes of aircraft which fly different route lengths and spend different proportions of their flight times at altitudes where CS-25 Appendix O icing conditions are encountered. The database of in-service events was originally calculated in terms of flight hours. It was then converted to an equivalent number of flights by dividing by the average flight times of the aircraft. The objective therefore was to check that the required number of flights determined by the two different approaches were of a similar order of magnitude.

The third step was used to add another check of consistency by determining the number and the duration of SLD exposures within the number of flights required to establish the safe fleet history.

2.4.2.1.3 Computation of adequate number of flights based on probability

2.4.2.1.3.1 Introduction

This paragraph describes how the required number of flights was determined based on the probability of a heavy SLD icing encounter. It is first necessary to define an appropriately conservative icing scenario and the associated probability.

It was considered that the scenario must include the severity of the SLD conditions in order to ensure that a fleet of aircraft had encountered sufficiently conservative exposure. To ensure this, the probability computations are based on heavy SLD icing conditions which reduces the probability of the scenario which is conservative because it increases the number of flights that the reference fleet must have accumulated. Therefore, it was necessary to determine the probability of encountering icing in flight (P_{ICING}), the proportion of in-flight icing conditions that are SLD (P_{SLD}) and finally the probability of encountering heavy SLD ($P_{HEAVY\ SLD}$) conditions.

The overall probability of the scenario can be computed from:

$$P_{SCENARIO} = P_{ICING} \times P_{SLD} \times P_{HEAVY\ SLD}$$

And the required number of flights is:

$$\text{Required Fleet Number of Flights} = 1/P_{SCENARIO}$$

The duration of the encounter is not included in this computation; it is considered when computing the number of SLD encounters as described in section 2.4.2.1.5 below.

2.4.2.1.3.2 Probability of SLD icing conditions

Based on the service history of the aeroplane manufacturers represented in the rulemaking group RMT.0572, the probability of encountering supercooled liquid water on any given flight is estimated to be between 5 % and 10 %, with 6% to 7 % per flight being more typical. This is based on manufacturers' test data and airline in-service reports of icing conditions. The required fleet exposure time is inversely proportional to this probability and therefore a lower probability will lead to a longer required fleet exposure. A conservative value of 5 % per flight was therefore used.

Next, the probability of encountering SLD icing conditions aloft at altitudes up to 22 000 feet, whilst in icing conditions, is taken from FAA report DOT/FAA/AR-09/10[7]. The report concludes that the probability of SLD in any region of the North America during the winter season is between 0.5 % and 5% (P from 0.005 to 0.05). On page 25 of the referenced report, the ratio of SLD icing to normal icing conditions is stated as 17 % (P of 0.17)[8]. The report also states, however, that because the intent of the testing conducted to gather that data was to fly in SLD conditions, the ratio of SLD icing to non-SLD icing found during the research flight tests could be as much as ten times higher than typically found in icing conditions of all types. This is consistent with the factor of 10 shown in the range of SLD probability of 0.05 to 0.005. Therefore, a conservative probability for SLD conditions of 0.017 was used for this analysis.

Hence, P_{ICING} = <u>0.05</u> per flight

And, P_{SLD} = <u>0.017</u>

2.4.2.1.3.3 Probability of heavy SLD icing conditions

The final term in the SLD scenario probability equation is the probability of SLD conditions being heavy. Again, based on the data of DOT/FAA/AR-09/10, 99 % and 99.9 % exceedance probabilities were presented for Appendix O icing conditions. Figures 37 through 40 of the referenced report show that the 99 % exceedance limits of Appendix O are consistent with the Newton definition of heavy icing conditions (refer to DOT/FAA/AR-09/10 section 3.22). Indeed, Appendix O is based on 99 % exceedance limits. The 99.9 % Liquid Water Content (LWC) analysis contained in this report has significant confidence limits, and there were no SLD observations that exceeded the upper confidence limit of the 99.9 % LWC envelopes. Therefore, to provide an additional element of conservatism, a probability of exceeding Appendix O icing conditions was defined as 0.001.

Hence, $P_{HEAVY\ SLD}$ = <u>0.001</u>

---

7 http://www.tc.faa.gov/its/worldpac/techrpt/ar0910.pdf

8 0.17 = (2,444 observations with an average static temperature ≤0 °C, an average LWC >0.005 g m^{-3}, an ice crystal concentration <1 L^{-1}, an assessment of either liquid or mixed-phase, and drops >100 µm in diameter)/(14,199 observations (29 % of in-flight) where supercooled liquid water was assessed to exist)

2.4.2.1.3.4 Explanations relative to the choice of criteria associated with a number of flights

Because aeroplanes of different size and design fly different missions, the amount of time during a typical flight that the aeroplane is within icing altitude limits, particularly for SLD icing conditions, cannot be compared directly. Therefore, it is more appropriate to compare only the number of flights, since almost all flights by all aeroplane types spend an hour or less for the take-off, climb, descent, approach and landing phases, within the altitude envelope of SLD icing conditions. This eliminates consideration of flight hours in cruise, for example, that were completely clear of any icing conditions.

Hence, the resulting fleet history associated with $P_{SCENARIO}$ will be defined in terms of total flights by the reference aeroplane fleet.

2.4.2.1.3.5 Overall probability of the defined SLD icing scenario

The overall probability of the defined SLD icing scenario is obtained by multiplying the individual probabilities:

$$P_{scenario} = P_{ICING} \times P_{SLD} \times P_{HEAVYSLD}$$

$$P_{scenario} = 0.05 \text{ per flight} \times 0.017 \times 0.001 = 8.5 \times 10^{-7} \text{ per flight.}$$

The number of flights required to demonstrate a safe fleet service history is determined by taking the inverse of the probability of the SLD icing scenario.

$$\text{Required Fleet Number of Flights} = 1/P_{SCENARIO}$$

$$= 1 / 8.5 \times 10^{-7}$$

$$= 1{,}200{,}000 \text{ flights}$$

Based on this method, a fleet history of 1.2 million flights would be required. To validate the order of magnitude and the method, this value was checked against the service history of aircraft which have experienced accidents or serious incidents with SLD listed as a contributing factor.

2.4.2.1.4 Review of in-service experience

To provide a common-sense check of the probability computations, the RMT.0572 Rulemaking Group reviewed the accident and incident history of aircraft that have experienced events in SLD conditions. To identify aircraft that have experienced such events, all of the supercooled liquid water icing incidents and accidents recorded in the National Transportation Safety Board (NTSB), Australian Transport Safety Bureau (ATSB), Transport Canada (Civil Aviation Daily Occurrence Report System (CADORS)), FAA (Accident/Incident Data Systems (AIDS)), and NASA accident and incident databases were reviewed. The Ice Protection Harmonization Working Group (IPHWG) Task 2 Working Group Report[9] was also taken into account as it includes a compilation of relevant icing incidents and accidents between 1940 and 2002.

From this review, the following transport category regional turbo-propeller aircraft were identified as having experienced serious incidents and/or accidents due to SLD conditions:

— ATR 42/72; and

[9] Report available on www.regulations.gov, in the docket FAA-2010-0636

— Embraer Brasilia (EMB 120).

The review of these databases also showed that other aeroplane types experienced icing-related events. Cessna 560 aircraft suffered accidents while operating in icing conditions in 1995 and 2005, and a Saab 340 experienced an in-flight icing incident in 2006. In these cases, however, there was no consensus on whether SLD icing conditions were a cause of the events. Therefore, those aeroplane types are not shown in tables 1 and 2 below. Nevertheless, a check of the in-service history of the Cessna 560 and Saab 340 aircraft was performed to ensure that the selected threshold would cover those aircraft types. The flight hours that these aircraft fleets had accrued prior to a supercooled liquid water icing accident or incident (not limited to SLD) were determined, converted to an equivalent number of flights, and compared to the proposed acceptable fleet history to determine whether the accidents and/or serious incidents occurred before the fleet achieved the threshold computed by the probability method.

Table 1: Summary of fleets' in-service history in terms of Flight Hours (FH)

Aircraft Fleet	FH Before Serious Icing Incident	FH Before Icing Accident	FH Before Suspected SLD-Related Accident/Incident
ATR 42/72	N/A	150,000 Note 1	3,900,000
Embraer Brasilia	450,000	2,500,000 Note 2	2,500,000

Note 1: ATR 42 Lake Como, Italy, non-SLD icing accident, 1987
Note 2: Pine Bluff, Arkansas, SLD accident, 1993 (pilot error identified as main cause)

The results of the database search, shown in **Error! Reference source not found.**, indicate that the ccidents and serious icing incidents experienced by the ATR42/72 and Embraer Brasilia occurred prior to each fleet accruing 2.5 million flying hours; yet, the first icing-related incidents occurred within 0.5 million flight hours. Suspected SLD events occurred after 2.5 million and 3.9 million flying hours. To convert from flight hours to the number of flights, the flight hours accumulated prior to the incidents or accidents were divided by the average flight time for each aeroplane type. An analysis of the in-service data showed that the average flight time for the Embraer aircraft is 50 minutes. Other turboprops of this type and size range also have an average flight time of approximately 50 minutes. The ATR average flight time is assumed to be of a similar order of magnitude. Using this average flight time yields the data in

Table 2.

Table 2: Summary of fleets' in-service histories in terms of number of flights

Aircraft Fleet	Flights Before Serious Icing Incident	Flights Before Icing Accident	Flights Before Suspected SLD-Related Accident/Incident
ATR 42/72	N/A	180,000	4,680,000
Embraer Brasilia	540,000	3,000,000	3,000,000

Table 2 shows that the first recorded icing incident occurred for the Embraer after 540 000 flights. The first icing accident for the ATR occurred after 180 000 flights with the first SLD related accident or incident at nearly 4.7 million flights.

Using the in-service history of these aircraft indicates that 600 000 flights would be sufficient to reveal any aeroplane, system, or procedural deficiencies that would occur due to icing conditions, even those less severe than SLD. Comparing this value against the number of flights determined using the probability method validates that using 1.2 million flights as the fleet history requirement captures the models listed in table 2.

2.4.2.1.5 Number of SLD encounters during a typical 1.2-million-flight service history

The probability computation does not include an assessment of the duration or number of SLD encounters. To address this issue, Dr Stewart Cober (Environment Canada) and Dr James Riley (FAA) developed a means to determine how many heavy SLD exposures of a given duration a fleet of aircraft would have, on average, experienced during a given number of flights. The detailed description of the methodology and the associated calculations are included in Appendix 1 to this NPA.

The methodology allows calculation of the number of encounters of heavy SLD for various durations. To determine an adequate duration to be considered, the accident reports for the ATR and EMB 120 were reviewed to assess how long the aircraft had been flying in icing conditions prior to loss of control. It was not possible to determine the icing exposure duration for the EMB 120 accident, but for the ATR Roselawn accident the NTSB report indicates that the aircraft had been flying in icing conditions for between approximately six to twenty-four minutes.

However, most of the SLD events studied by the IPHWG were of relatively short duration of around five to ten minutes.

Therefore to cover the range of encounter durations associated with the in-service events, the numbers of 5-, 10-, 15- and 30-minute SLD encounters a fleet would have typically experienced during 1.2 million flights have been computed.

The results are:

— 76 encounters of 5-minute duration, or;

— 29 encounters of 10-minute duration, or;

— 12 encounters of 15-minute duration, or;

— 3 encounters of 30-minute duration.

2.4.2.1.6 Conclusions

For aircraft types known to have experienced problems in SLD icing conditions, the data of paragraph 2.4.2.1.4 indicates that serious in-service incidents in supercooled liquid icing conditions have occurred after those aircraft fleets had accumulated 540 000 flights. It is appropriate to consider the first icing incidents as noted in paragraph 2.4.2.1.1 since the fleet history requirement states that the fleet must not have experienced any accidents or serious incidents in any supercooled liquid water icing conditions aloft. These incidents would have preceded any of the SLD-related events which occurred later in the service history.

Meteorological data based on DOT/FAA/AR-09/10 indicates that heavy SLD icing conditions can reasonably be expected to be encountered within 1.2 million flights of an aeroplane fleet. Using the analysis of Dr. Cober (Appendix 1 to this NPA), this would translate into approximately 12 encounters in heavy SLD conditions of 15-minute duration or 3 encounters of 30-minute duration and substantially more 5 and 10-minute encounters (see paragraph 2.4.2.1.5 above). Furthermore, many other light and moderate SLD icing conditions would be encountered.

While the probability analyses presented in this document are considered to be conservative and are validated through a common-sense check against aeroplane models with known SLD incidents, a fleet history criterion of two million flights is recommended. This recommendation adds conservatism to account for the uncertainty in the statistics. In addition, this value also captures the events of the other aircraft models (Cessna 560 and Saab 340) which are not listed in Tables 1 and 2 but have been considered in other reports. Note that two million flights equates to approximately five 30-minute SLD encounters.

2.4.2.2 Compliance with CS-25 Certification Specifications relative to flight in the icing conditions defined by Appendix C

The new or derivative aeroplane model should comply with the CS-25 certification specifications relative to the Appendix C icing conditions. Comparative analysis is an acceptable MoC only for the CS-25 certification specifications relative to the Appendix O icing conditions.

2.4.2.3 Analysis of aeroplane design features or margins that are deemed to contribute to the safe fleet history

Upon establishment of the reference fleet that has demonstrated safe operation in all supercooled liquid water icing conditions aloft, a collection of design features and/or margins, deemed to contribute to that history, can be identified. Demonstrating that the new or derivative aeroplane model maintains comparable design features and/or margins, along with flight-in icing compliance using the icing conditions defined in CS-25 Appendix C, will provide confidence that the new or derivative aeroplane model is safe in all supercooled liquid water icing conditions. These include the SLD icing conditions represented in Appendix O.

The key parameters which will be used to show compliance via comparative analysis will have to be identified, and agreed to with the Agency. Examples are included in Appendix 2 to this NPA in order to help clarify the identification and use of key parameters in comparative analysis.

The current CS-25 specifications envisage conventional aeroplane designs. Electronic Flight Control Systems (EFCS) with design features like flight envelope protection functions are not fully addressed by the current CS-25 certification specifications. Nevertheless, aeroplane types with such features have been certified for many years using Special Conditions.

Therefore, the reference fleet for comparative analysis may include aeroplanes that feature EFCS or other design features that are not fully addressed by the current CS-25. However, these design features may contribute to the safe fleet history and therefore they should be eligible to be included in the comparative analysis.

The material described in paragraph (e)5.7 (Aeroplane Performance and Handling Characteristics) of the proposed amendment to AMC 25.1420 is intended to be used for conventional aeroplane designs envisaged in the existing CS-25 text and also for aeroplane designs with EFCS that provide flight envelope protection functions.

2.4.2.4 Additional considerations — Augmenting comparative analysis

At the time of this rulemaking task, the SLD tools required to design and certify new or derivative aeroplane model are not adequately mature. For example, little data and few analysis and test tools are available for use in predicting the ice accretions associated with flight in all SLD icing conditions as represented in Appendix O. However, various organisations are working towards generating more information on SLD ice accretions and improving the associated tools. In the future, this additional information can be expected to lead to improved knowledge leading to alternative types of analyses.

The comparative analysis may be used in combination with new methodologies (test or analysis) at the applicant's discretion in order to establish a comparison between the new or derivative model and the reference fleet. The use of any new methodologies should be agreed by the Agency. The applicant may then substantiate that the new or derivative model has comparable key parameters using the new methodologies.

2.4.3. Proposed amendments to CS-25 Book 1 and Book 2

BOOK 1:

CS 25.1420 Supercooled large drop icing conditions:

It is proposed to create a new sub-pragraph (c) which provides for the possibility to use a comparative analysis as a means of compliance, as an alternative to what is required in sub-paragraph (b). The existing sub-paragraph (c) is renamed sub-paragraph (d).

BOOK 2:

AMC 25.21(g) Performance and Handling Characteristics in Icing Conditions

References to the comparative analysis (provided in AMC 25.1420(e)) as a potential means of compliance have been added in several paragraphs of the AMC.

When comparative analysis is used, the AFM information may be based on the reference fleet AFM(s) or operating manual(s) content.

AMC 25.629 Aeroelastic stability requirements

At the end of the sub-paragraph dealing with ice accumulation, a reference to the comparative analysis of AMC 25.1420(e) as a potential means of compliance is created.

AMC 25.773(b)(1)(ii) Pilot compartment view in icing conditions

A reference to the comparative analysis of AMC 25.1420(e) as a potential means of compliance is created.

AMC 25.773(b)(4) Pilot compartment non-openable windows

A reference to the comparative analysis of AMC 25.1420(e) as a potential means of compliance is created in paragraph 1. Ice and heavy rain.

AMC 25.929(a) Propeller De-icing

A reference to the comparative analysis of AMC 25.1420(e) as a potential means of compliance is created in paragraph 1. Analysis.

AMC 25.1093(b) Powerplant Icing

References to the comparative analysis of AMC 25.1420(e) as a potential means of compliance are created in paragraphs (a) Compliance with CS 25.1093(b)(1) and (b) Compliance with CS 25.1093(b)(2).

AMC 25.1324 Flight instrument external probes

A reference to the comparative analysis of AMC 25.1420(e) as a potential means of compliance is created in paragraph 11. Supercooled Large Drop Liquid Conditions.

AMC No 1 to CS 25.1329 Flight Guidance System

A reference to the comparative analysis of AMC 25.1420(e) as a potential means of compliance is created in paragraph 10.1. Normal Performance (bullet 'Icing').

AMC 25.1403 Wing icing detection lights

A reference to the comparative analysis of AMC 25.1420(e) as a potential means of compliance is created at the end of the introductory paragraph.

AMC 25.1420 Supercooled large drop icing conditions

A new sub-paragraph (e) Comparative analysis, is created to introduce this alternative means of compliance. Different elements must be established in order to be able to use this means of compliance, i.e. a reference fleet with adequately safe history in icing conditions, an analysis of aeroplane features and/or margins contributing to the reference fleet safe history, an analysis showing comparable design features and/or margins between the new or derivative aeroplane model and the reference fleet, and the compliance of the new or derivative aeroplane with certification specifications relative to Appendix C icing conditions.

Additionally, the reference to a comparative analysis is added at various parts of the text in AMC 25.1420.

3. Proposed amendments

The text of the amendment is arranged to show deleted text, new or amended text as shown below:

(a) deleted text is marked with ~~strike through~~;

(b) new or amended text is highlighted in grey;

(c) an ellipsis (…) indicates that the remaining text is unchanged in front of or following the reflected amendment.

3.1. Draft Certification Specifications — CS-25 (Draft EASA Decision)

BOOK 1

SUBPART F – EQUIPMENT

1. Amend CS 25.1420 as follows:

CS 25.1420 Supercooled large drop icing conditions

(see AMC 25.1420)

(a) If certification for flight in icing conditions is sought, in addition to the requirements of CS 25.1419, the aeroplane must be capable of operating in accordance with sub-paragraphs (a)(1), (a)(2), or (a)(3) of this paragraph.

(1) Operating safely after encountering the icing conditions defined in Appendix O:

(i) The aeroplane must have a means to detect that it is operating in Appendix O icing conditions; and

(ii) Following detection of Appendix O icing conditions, the aeroplane must be capable of operating safely while exiting all icing conditions.

(2) Operating safely in a portion of the icing conditions defined in Appendix O as selected by the applicant.

(i) The aeroplane must have a means to detect that it is operating in conditions that exceed the selected portion of Appendix O icing conditions; and

(ii) Following detection, the aeroplane must be capable of operating safely while exiting all icing conditions.

(3) Operating safely in the icing conditions defined in Appendix O.

(b) To establish that the aeroplane can operate safely as required in sub-paragraph (a) of this paragraph, an applicant must show through analysis that the ice protection for the various components of the aeroplane is adequate, taking into account the various aeroplane operational configurations. To verify the analysis, one, or more as found necessary, of the following methods must be used:

(1) Laboratory dry air or simulated icing tests, or a combination of both, of the components or models of the components.

(2) Laboratory dry air or simulated icing tests, or a combination of both, of models of the aeroplane.

(3) Flight tests of the aeroplane or its components in simulated icing conditions, measured as necessary to support the analysis.

(4) Flight tests of the aeroplane with simulated ice shapes.

(5) Flight tests of the aeroplane in natural icing conditions, measured as necessary to support the analysis.

(c) If applicable, a comparative analysis may be used as an alternative to CS 25.1420(b) to establish that the aeroplane can operate safely as required in CS 25.1420(a). In this case, tests may not be required (see AMC 25.1420, paragraph (e)).

~~(c)~~ (d) For an aeroplane certified in accordance with sub-paragraph (a)(2) or (a)(3) of this paragraph, the requirements of CS 25.1419 (e), (f), (g), and (h) must be met for the icing conditions defined in Appendix O in which the aeroplane is certified to operate.

BOOK 2

AMC – SUBPART B

2. Amend AMC 25.21(g) as follows:

AMC 25.21(g)

Performance and Handling Characteristics in Icing Conditions

(…)

1 *Purpose*.

(…)

1.4 Section 5 describes acceptable methods and procedures that an applicant may use to show that an aeroplane meets these requirements. Depending on the design features of a specific aeroplane as discussed in Appendix 3 of this AMC, its similarity to other types or models, and the service history of those types or models, some judgement will often be necessary for determining that any particular method or procedure is adequate for showing compliance with a particular requirement. AMC 25.1420, paragraph (e) provides guidance for comparative analysis as an acceptable means of compliance to meet these requirements.

(…)

4 *Requirements and Guidance*.

(…)

4.4.6 Certification experience has also shown that runback ice may be critical for propellers, and propeller analyses do not always account for it. Therefore, runback ice on the propeller should be addressed. Research has shown that ice accretions on propellers, and resulting thrust decrement, may be larger in Appendix O (supercooled large drop) icing conditions than in Appendix C icing conditions for some designs. This may be accomplished through aeroplane performance checks in natural icing conditions, icing tanker tests, icing wind tunnel tests, aerodynamic analysis,or the use of an assumed (conservative) loss in propeller efficiency. Testing should include a range of outside air temperatures, including warmer (near freezing) temperatures that could result in runback icing. For the Appendix O icing conditions, the applicant may use a comparative analysis. AMC 25.1420 paragraph (e) provides guidance for comparative analysis.

(…)

4.8.2.2 Normal operating procedures provided in the AFM should reflect the procedures used to certify the aeroplane for flight in icing conditions. This includes configurations, speeds, ice protection system operation, power plant and systems operation, for take-off, climb, cruise, descent, holding, go-around, and landing. For aeroplanes not certified for flight in all of the supercooled large drop atmospheric icing conditions defined in Appendix O to CS-25, procedures should be provided for safely exiting all icing conditions if the aeroplane encounters Appendix O icing conditions that exceed the icing conditions the aeroplane is certified for. Information to be provided in the AFM may be based on that which is provided in the reference fleet AFM(s), or other operating manual(s) furnished by the TC holder, when comparative analysis is used as the means of compliance.

(…)

5 *Acceptable Means of Compliance - General*.

(…)

5.1.5 Appropriate means for showing compliance include the actions and items listed in Table 1 below. These are explained in more detail in the following sections of this AMC.

TABLE 1: Means for Showing Compliance

Flight Testing	Flight testing in dry air using artificial ice shapes or with ice shapes created in natural icing conditions.
Wind Tunnel Testing and Analysis	An analysis of results from wind tunnel tests with artificial or actual ice shapes.
Engineering Simulator Testing and Analysis	An analysis of results from engineering simulator tests.
Engineering Analysis	An analysis which may include the results from any of the other means of compliance as well as the use of engineering judgment.
Ancestor Aeroplane Analysis	An analysis of results from a closely related ancestor aeroplane.

Comparative analysis for showing compliance in SLD icing conditions	An analysis which substantiates that a new or derivative aeroplane model has at least the same level of safety in all supercooled liquid water icing conditions that a reference fleet has achieved. Guidance is provided in AMC 25.1420 paragraph (e). The use of a comparative analysis is only an option for showing compliance with CS-25 specifications relative to Appendix O icing conditions; it is not an option for showing compliance with CS-25 specifications relative to Appendix C icing conditions.

(…)

5.6 *Ancestor Aeroplane Analysis*.

5.6.1 To help substantiate acceptable performance and handling characteristics, the applicant may use an analysis of an ancestor aeroplane that includes the effect of the ice accretions as defined in Part II of Appendix C and Appendix O to CS-25. This analysis should consider the similarity of the configuration, operating envelope, performance and handling characteristics, and ice protection system of the ancestor aeroplane to the one being certified.

5.6.2 The analysis may include flight test data, dry air wind tunnel test data, icing tunnel test data, engineering simulator analysis, service history, and engineering judgement.

5.7 *Comparative Analysis*.

For showing compliance with the CS-25 certification specifications relative to SLD icing conditions represented in Appendix O, the applicant may use a comparative analysis. AMC 25.1420, paragraph (e) provides guidance for comparative analysis.

(…)

Appendix 1 - Airframe Ice Accretion

A1.1 *General*.

(…)

f. The applicant should determine the most critical ice accretion in terms of handling characteristics and performance for each flight phase. Parameters to be considered include:

- flight conditions (for example, aeroplane configuration, speed, angle-of-attack, altitude) and
- atmospheric icing conditions for which certification is desired (for example, temperature, liquid water content (LWC), mean effective drop diameter (MED), drop median volume diameter (MVD)).

If comparative analysis (refer to AMC 25.1420 paragraph (e)) is used as the means of compliance with the CS-25 certification specifications relative to the Appendix O icing conditions, the most critical ice accretions determined for Appendix C icing conditions are acceptable.

AMC – SUBPART D

3. Amend AMC 25.629 as follows:

AMC 25.629

Aeroelastic stability requirements

(…)

5.1.4.5. <u>*Ice Accumulation*</u>. Aeroelastic stability analyses should use the mass distributions derived from ice accumulation up to and including those that can accrete in the applicable icing conditions in Appendices C and O to CS-25. This includes any accretions that could develop on control surfaces. The analyses need not consider the aerodynamic effects of ice shapes. For aeroplanes approved for operation in icing conditions, all of the CS-25 Appendix C icing conditions and the Appendix O icing conditions for which certification is sought are applicable. For aeroplanes not approved for operation in icing conditions, all of the Appendix C and O icing conditions are applicable since the inadvertent encounter discussed in paragraph 3.2.3 of this AMC can occur in any icing condition. For all aeroplanes, the ice accumulation determination should take into account the ability to detect the ice and, if appropriate, the time required to leave the icing condition.

For showing compliance with the CS-25 specifications relative to SLD icing conditions represented by Appendix O, the applicant may use a comparative analysis. AMC 25.1420 paragraph (e) provides guidance for comparative analysis.

(…)

4. Amend AMC 25.773(b)(1)(ii) as follows:

AMC 25.773(b)(1)(ii)

Pilot compartment view in icing conditions

CS 25.773(b)(1)(ii) requires that the aeroplane have a means of maintaining a clear portion of windshield in the icing conditions defined in Appendix C and in certain Appendix O icing conditions (corresponding to the CS 25.1420 certification option selected).

The effectiveness of all cockpit windows and windshield ice and precipitation protective systems should be established within relevant icing environment. Sufficient tests, including flight test in natural or simulated Appendix C icing conditions, should be performed to validate the performance prediction done by analysis.

When thermal ice protection systems are used (e.g. electrical heating system), a thermal analysis should be conducted to substantiate the selected nominal heated capacity. Past certification experience has shown that a nominal heating capacity of 70 W/dm2 provide adequate protection in icing conditions; such value, if selected, should anyway be substantiated by the thermal analysis. The applicant should conduct dry air flight tests to verify the thermal analysis. Measurements of both the inner and outer surface temperature of the protected windshield area may be needed to verify the thermal analysis. The thermal analysis should show that the windshield surface temperature is sufficient to maintain anti-icing capability without causing structural damage to the windshield.

When anti-icing fluid systems are used, tests shall be performed to demonstrate that the fluid does not become opaque at low temperatures. The AFM should include information advising the flight crew how long it will take to deplete the amount of fluid remaining in the reservoir.

An evaluation of visibility, including distortion effects through the protected area, should be made for both day and night operations. In addition, the size and location of the protected area should be reviewed to confirm that it provides adequate visibility for the flight crew, especially during the approach and landing phases of flight.

For showing compliance with the CS-25 certification specifications relative to SLD icing conditions represented in Appendix O, the applicant may use a comparative analysis. AMC 25.1420 paragraph (e) provides guidance for comparative analysis.

5. Amend AMC 25.773(b)(4) as follows:

AMC 25.773(b)(4)

Pilot compartment non openable windows

Total loss of external visibility is considered catastrophic. A sufficient field of view must exist to allow the pilot to safely operate the aeroplane during all operations, including taxi.

This field of view must remain clear in all operating conditions. Precipitation conditions such as outside ice, heavy rain, severe hail, as well as encounter with birds and insects must be considered.

This AMC material applies to conventional, multiple pane window systems, i.e. those which are composed of a main windshield and separate side panels assembled with structural posts. In the event a one piece 'uni-body wraparound' windshield is proposed, the applicant must meet the intent of the applicable rules, even though there are no separate side windows.

<u>1. Ice and heavy rain</u>

Unless system failures leading to loss of a sufficient field of view for safe operation are shown to be extremely improbable, the following provides acceptable means to show compliance with CS 25.773(b)(4):

- Each main windshield should be equipped with an independent protection system. The systems should be designed so that no malfunction or failure of one system will adversely affect the other.
- For each forward side window it should be shown that any ice accumulations (Appendix C icing conditions and any applicable Appendix O icing conditions) will not degrade visibility, or the applicant should provide individual window ice protection system capability.
- The icing accretion limits should be determined by analysis and verified by test. The extent of icing of side windows should be verified during natural or simulated icing flight tests with window ice protection systems unpowered. A limited number of test points, sufficient to validate the analysis, are required within Appendix C or Appendix O.
- For the demonstration of compliance under Appendix O icing conditions, the applicant may use a comparative analysis. AMC 25.1420 paragraph (e) provides guidance for comparative analysis.

<u>2. Hail, birds and insects</u>

It should be shown by flight tests that exceptional pilot skill is not required to land the aeroplane using the normal aeroplane instruments and the view provided through the main or side windows having the degree of impairment to vision resulting from the encounter of severe hail, birds or insects. Appropriate test data should substantiate the estimated damage or contamination to the main or forward side windows during such an encounter.

It is unlikely that hail damage can be avoided. Rather than avoidance, the approach to ensure vision assuming hail strike has been to use damage assessment criteria contained in the ASTM International "Standard Test Method for Hail Impact Resistance of Aerospace Transparent Enclosures," ANSI/ASTM F 320-10 or equivalent. For the test set up to determine hail damage or windshield resistance to hail, reference can be made to ANSI/ASTM F 320-10, and "Global Climatic Data for Developing Military Products " MIL HDBK 310 (dated 23 June 1997).

For each impacted window, ANSI/ASTM 320-10 is used to characterize a damage pattern on a limited area of the window. For test purpose, the simulated damage patterns should be applied to the full impacted window surfaces in order to simulate in a conservative manner the visibility degradation through the windows.

The applicant should propose and substantiate the aircraft conditions when hail strike occurs. In the absence of such substantiation, the conservative assumptions will be to consider the maximum aircraft nominal speed combined with the hailstone falling speed.

When the damages are such that there is no remaining visibility through the windshield after hail encounter, or when the ice protection system is no longer operating after the hail encounter, a typical test configuration would be to block visibility out of the forward main windows for the pilot flying, and use simulated damage (if any) and ice accretions (if applicable) on the side window(s).

When conducting flight tests, adequate forward vision should be maintained for a safety pilot while providing appropriate forward view degradation for the test pilot.

Means of compliance to address birds and insects should be proposed by the applicant. The Agency is not aware of any in-service occurrence involving a total loss of visibility through the windshield after birds or insects encounter.

(…)

AMC – SUBPART E

6. Amend AMC 25.929(a) as follows:

AMC 25.929(a)

Propeller De-icing

1. Analysis.

The applicant should perform an analysis that:

(1) substantiates ice protection coverage in relation to chord length and span.

(2) substantiates the ice protection system power density.

(3) consider the effect of intercycle ice accretions and potential for propeller efficiency degradation for all flight phases.

(4) assess the different propeller Ice Protection System failure modes which are not extremely improbable and leading to the:

(i) highest propeller performance level degradation, and

(ii) highest propeller vibration levels taking also into account possible ice shedding.

(5) assess the impact of ice released by the propeller on the vibration levels, the adjacent components (if any) and the aircraft structure, both for normal operation and in the different propeller de-icing system failure modes.

Similarity to prior designs with successful service histories in icing may be used to show compliance. A demonstration of similarity requires an evaluation of both system and installation differences. The applicant should show specific similarities in the areas of physical, functional, thermodynamic, pneumatic, and aerodynamic characteristics as well as in environmental exposure. The analysis should show that propeller installation, operation, and effect on the aeroplane's performance and handling are equivalent to that of the same or similar propeller in the previously approved configuration. 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.

For showing compliance with the CS-25 certification specifications relative to SLD icing conditions represented in Appendix O, the applicant may use a comparative analysis. AMC 25.1420 paragraph (e) provides guidance for comparative analysis.

(…)

7. Amend AMC 25.1093(b) as follows:

AMC 25.1093(b)

Powerplant Icing

(…)

(a) Compliance with CS 25.1093(b)(1)

(…)

2. Testing

(…)

3. Comparative Analysis.

For showing compliance with the CS-25 certification specifications relative to SLD icing conditions represented in Appendix O, the applicant may use a comparative analysis. AMC 25.1420 paragraph (e) provides guidance for comparative analysis.

(b) Compliance with CS 25.1093(b)(2)

(…)

2. Ground taxi exposure to Appendix O conditions.

The service experience indicates that engine fan damage events exist from exposure to SLD during ground taxi operations. For this reason, an additional condition of a 30-minute, idle power/thrust exposure to SLD on the ground must be addressed. Applicants should include the terminal falling velocity of SLD (for example, freezing rain, freezing drizzle) in their trajectory assessment, relative to the protected sections of the air intake. The 100 micron minimum mean effective diameter (MED) is selected as a reasonable achievable condition, given current technology. To certify by analysis the applicant should evaluate the Appendix O drop sizes up to a maximum of 3 000 microns particle size to find a critical condition. For showing compliance with the CS-25 certification specifications relative to SLD icing conditions represented in Appendix O, the applicant may use a comparative analysis. AMC 25.1420 paragraph (e) provides guidance for comparative analysis.

(…)

AMC – SUBPART F

8. Amend AMC 25.1324 as follows:

AMC 25.1324

Flight instrument external probes

(…)

11. Supercooled Large Drop Liquid Conditions

Based on the design of the probe, the drop size may not be a significant factor to consider as compared to the other parameters and in particular the Liquid Water Content (LWC). The SLD LWC defined in Appendix O (between 0.18 and 0.44 g/m3) are largely covered by the Appendix C continuous maximum

LWC (between 0.2 and 0.8 g/m3) and the Appendix C intermittent maximum LWC (between 0.25 and 2.9 g/m3).

Testing SLD conditions may not be necessary if it can be shown that the Supercooled Liquid Conditions of Appendix C are more critical. If some doubt exists, the applicant shall propose a set of critical test points to cover adequately the Icing Environment defined in the Appendix O.

For showing compliance with the CS-25 certification specifications relative to SLD icing conditions represented in Appendix O, the applicant may use a comparative analysis. AMC 25.1420 paragraph (e) provides guidance for comparative analysis.

(…)

9. Amend AMC No 1 to CS 25.1329 as follows:

AMC No 1 to CS 25.1329

Flight Guidance System

(…)

10.1 Normal Performance

The FGS should provide guidance or control, as appropriate, for the intended function of the active mode(s) in a safe and predictable manner within the aeroplane's normal flight envelope.

The FGS should be designed to operate in all aeroplane configurations for its intended use within the aeroplane's normal flight envelope to provide acceptable performance for the following types of environmental conditions:

- Winds (light and moderate)
- Wind gradients (light and moderate)

NOTE: In the context of this AMC, "wind gradient" is considered a variation in wind velocity as a function of altitude, position, or time.

- Gusts (light and moderate)
- Turbulence (light and moderate)
- Icing - all icing conditions covered by Appendix C to CS-25 and applicable icing conditions covered by Appendix O to CS-25, with the exception of "asymmetric icing" discussed under "Rare Normal Conditions" in Section 10.2 below. For showing compliance with the CS-25 certification specifications relative to SLD icing conditions represented in Appendix O, the applicant may use a comparative analysis. AMC 25.1420 paragraph (e) provides guidance for comparative analysis.

NOTE: Representative levels of the environmental effects should be established consistent with the aeroplane's intended operation.

(…)

10. Amend AMC 25.1403 as follows:

AMC 25.1403

Wing icing detection lights

Unless operations at night in icing conditions are prohibited by an operating limitation, CS 25.1403 requires that a means be provided, during flight at night, to illuminate or otherwise determine ice formation on parts of the wings that are critical from the standpoint of ice accumulations~~.~~ resulting from Appendix C and Appendix O icing conditions. For showing compliance with the CS-25 certification specifications relative to SLD icing conditions represented in Appendix O, the applicant may use a comparative analysis. AMC 25.1420 paragraph (e) provides guidance for comparative analysis.

(…)

11. Amend AMC 25.1420 as follows:

AMC 25.1420

Supercooled large drop icing conditions

(…)

(d) CS 25.1420 (b)

1. Analysis

AMC 25.1419(a) applies and in addition, the following should be considered specifically for compliance with CS 25.1420(b):

1.1 Analysis of areas and components to be protected.

In assessing the areas and components to be protected, unless comparative analysis is used as the means of compliance, considerations should be given on the fact that areas that do not accrete ice in Appendix C conditions may accrete ice in the Appendix O conditions.

1.2 Failure analysis

Applying the system safety principles of CS 25.1309 is helpful in determining the need for system requirements to address potential hazards from an Appendix O icing environment. The following addresses application of the CS 25.1309 principles to Appendix O conditions and may be used for showing compliance with CS 25.1309. Alternatively, a comparative analysis, if applicable, may be used as defined in paragraph (e) of this AMC.

1.2.1 Hazard classification

Assessing a hazard classification for compliance with CS 25.1309 is typically a process combining quantitative and qualitative factors based on the assessment of the failure conditions and the associated severity of the effects. If the design is new and novel and has little similarity to previous designs, a hazard classification based on past experience may not be appropriate. If the design is derivative in nature, the assessment can consider the icing event history of similarly designed aeroplanes and, if applicable, the icing event history of all conventional design aeroplanes. The applicant should consider specific effects of supercooled large drop icing when assessing similarity to previous designs.

1.2.2 Qualitative Analysis

The following qualitative analysis may be used to determine the hazard classification for an unannunciated encounter with Appendix O icing conditions. The analysis can be applied to aeroplanes shown to be similar to previous designs with respect to Appendix O icing effects, and to which the icing event history of all conventional design aeroplanes is applicable.

1.2.2.1 Assumptions

The aeroplane is certificated to either:

a. Detect Appendix O icing conditions and safely exit all icing conditions after detection of Appendix O icing conditions, or

b. Safely operate in a selected portion of Appendix O icing conditions and safely exit all icing conditions after detection of Appendix O icing conditions beyond those for which it is certificated.

The 'unannunciated encounter with Appendix O' refers to Appendix O icing conditions in which the aeroplane has not been shown to operate safely.

The airframe and propulsion ice protection systems have been activated prior to the unannunciated encounter.

1.2.2.2 Service history

The applicant may use service history, design, and installation appraisals to support hazard classifications for CS 25.1309. Service history may be appropriate to support a hazard classification if a new or derivative aeroplane has similar design features to a previously certificated aeroplane. Service history data are limited to the fleet of aeroplane type(s) owned by the applicant.

1.2.2.3 Historical perspective

While definitive statistics are not available, a historical perspective can provide some guidance. Many aeroplanes flying through icing have been exposed to supercooled large drop conditions without the pilot being aware of it. The interval of exposure to the supercooled large drop conditions may have varied from a brief amount of time (such as could occur during a vertical transition through a cloud) to a more sustained exposure (such as during a hold). Severity of the exposure conditions in terms of water content may have varied significantly. Therefore, the hazard from encountering supercooled large drop conditions may be highly variable and dependent on various factors.

1.2.2.4 Icing event history of conventionally designed aeroplanes certificated before the introduction of CS 25.1420

Given the volume of aeroplane operations and the number of reported incidents that did not result in a catastrophe, a factor of around 1 in 100 is a reasonable assumption of probability for a catastrophic event if an aeroplane encounters Appendix O conditions in which it has not been shown capable of safely operating. An applicant may assume that the hazard classification for an unannunciated encounter with Appendix O conditions while the ice protection system is activated is Hazardous in accordance with AMC 25.1309, provided that the following are true:

- The aeroplane is similar to previous designs with respect to Appendix O icing effects, and

- The applicant can show that the icing event history of all conventionally designed aeroplanes is relevant to the aeroplane being considered for certification.

1.2.2.5 Hazard assessment

If an aeroplane is not similar to a previous design, an assessment of the hazard classification may require more analysis or testing. One method of hazard assessment would be to consider effects of ice accumulations similar to those expected for aeroplanes being certified under CS 25.1420. Such ice shapes may be defined from a combination of analysis and icing tanker or icing wind tunnel testing. Aerodynamic effects of such shapes could be evaluated with wind tunnel testing or, potentially, computational fluid dynamics. Hazard classification typically takes place early in a certification program. Therefore, a conservative assessment may be required until sufficient supporting data is available to reduce the hazard classification.

1.2.3 Probability of encountering Appendix O icing conditions

Appendix C was designed to include 99 percent of icing conditions. Therefore, the probability of encountering icing outside of Appendix C drop conditions is on the order of 10^{-2}. The applicant may assume that the average probability for encountering Appendix O icing conditions is 1×10^{-2} per flight hour. This probability should not be reduced based on phase of flight.

1.2.4 Numerical safety analysis.

For the purposes of a numerical safety analysis, the applicant may combine the probability of equipment failure with the probability, defined above, of encountering Appendix O icing conditions. If the applicant can support a hazard level of 'Hazardous' using the above probability (10^{-2}) of encountering the specified supercooled large drop conditions, the probability of an unannunciated failure of the equipment that alerts the flight crew to exit icing conditions should be less than 1×10^{-5}.

1.2.5 Assessment of visual cues.

Typical system safety analysis do not address the probability of crew actions, such as observing a visual cue before performing a specified action. As advised in AMC 25.1309, quantitative assessments of crew errors are not considered feasible. When visual cues are to be the method for detecting Appendix O conditions and determining when to exit them, the applicant should assess the appropriateness and reasonableness of the specific cues. Reasonable tasks are those for which the applicant can take full credit because the tasks can realistically be anticipated to be performed correctly when required. The applicant should assess the task of visually detecting Appendix O conditions to determine if it could be performed when required. The workload for visually detecting icing conditions should be considered in combination with the operational workload during applicable phases of flight. The applicant may assume that the flight crew is already aware that the aeroplane has encountered icing. The assessment of whether the task is appropriate and reasonable is limited to assessing the task of identifying Appendix O accumulations that require exiting from the icing conditions.

1.3 Similarity

On derivative or new aeroplane designs, the applicant may use similarity to previous type designs which have been certified ~~proven safe~~ for operation in SLD icing conditions~~,~~. M~~m~~eanwhile the effects of differences will be substantiated. Natural ice flight testing may not be necessary for a design shown to be similar. ~~At a minimum, the following differences should be addressed:~~

- ~~Aerofoil size, shape, and angle of attack.~~
- ~~Ice Protection System (IPS) design.~~
- ~~Flight phases, operating altitude and airspeed.~~
- ~~Centre of gravity.~~
- ~~Flight control system.~~
- ~~Engine and propeller operation.~~

The guidance provided in AMC 25.1419(a)(8) applies.

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

2. Tests

CS 25.1420 requires two or more means of compliance for approval of flight in icing, except when comparative analysis is used to show compliance. It is common to use a combination of methods in order to adequately represent the conditions and determine resulting degradation effects with sufficient confidence to show compliance.

(…)

(e) CS 25.1420(c) Comparative analysis

For showing compliance with the CS-25 certification specifications relative to SLD icing conditions as represented in Appendix O, the applicant may use a comparative analysis to show similarity of a new or derivative aeroplane model to existing model(s) with features and/or margins which are deemed to have contributed to a safe fleet history in all icing conditions.

When using this comparative analysis as a means of compliance, flight testing in measured natural SLD icing conditions and/or flight testing with simulated ice shapes defined in accordance with Appendix O - Part II may not be required.

1. Definitions

- *Accident:* The definition of the term 'accident' is provided in ICAO Annex 13, Chapter 1.
- *Certification ice shapes/ice shape data:* Ice shapes or ice shape data used to show compliance with certification specifications for flight in icing conditions. As used in this document, these are the ice shapes or data used to represent the critical ice shapes with the intent that they convey the ice that represents the most adverse effect on performance and flight characteristics. The data which is used to represent these shapes may be comprised of flight test data (artificial or natural ice), wind tunnel data, analytical data, or combinations of the above as allowed during previous certification projects.
- *Comparative analysis:*
  – The use of analyses to show that an aeroplane is comparable to models that have previously been certified for operation in the icing environment of Appendix C with a proven safe operating history in supercooled liquid water icing conditions, but that may not have already been certified for operation in the icing environment of Appendix O.

– Key elements:

  - The new model is certifiable for Appendix C icing conditions,
  - Aeroplane models previously certified for Appendix C icing conditions are used to establish a reference fleet,
  - The new model has similar design features and/or margins for key parameters relative to the reference fleet,
  - The reference fleet has a safe fleet history in supercooled liquid water icing conditions.

- *Events:* Within this document the word 'event' means 'accident and/or serious incident' as defined in ICAO Annex 13, Chapter 1.
- *Key parameters:* Parameters that can be shown to have contributed to the safe operation in icing conditions of the reference fleet. These parameters should be defined and provided by the applicant for each of the topics addressed in the comparative analysis. They should be agreed with the Agency.
- *Reference fleet:* The fleet of previously certified aeroplanes used to establish safe fleet history in order to enable the use of comparative analysis as a means of compliance.
- *Serious incident:* The definition of the term 'serious incident' is provided in ICAO Annex 13, Chapter 1.
- *Similarity analysis:*

  – The direct comparison of a new or derivative aeroplane model to models already certified for operation in the icing environment of Appendix C and/or Appendix O. The similarity can be established for the aeroplane, the systems and/or the components.

  – Key elements:

    - Similar design features,
    - Similar performance and functionality.

2. Introduction

This paragraph introduces comparative analysis as a means of compliance with the CS-25 certification specifications addressing SLD icing conditions represented in Appendix O. The Agency acknowledges that there are a significant number of large aeroplane models which have an exemplary record of safe operation in all icing conditions, which inherently include SLD icing conditions. A comparative analysis provides an analytical certification path for new aeroplane models and derivatives by allowing the applicant to substantiate that a new or derivative model will have at least the same level of safety in all supercooled liquid water icing conditions that previous models have achieved.

For derivative models, the applicable certification specifications are determined through the application of the 'Changed Product Rule (CPR)'. Rather than demonstrating compliance with the certification specifications in effect at the date of application, an applicant may demonstrate compliance with an earlier amendment of the certification specifications when meeting one of the conditions provided in Part-21, paragraph 21.A.101(b). After application of the CPR, if the derivative model must comply with an amendment that includes the SLD-related certification specifications, compliance by comparative analysis may be used.

To use a comparative analysis as means of compliance for a new or derivative aeroplane model, four main elements should be established:

1. A reference fleet with an adequately safe history in icing conditions;

2. An analysis of aeroplane design features and/or margins that are deemed to contribute to the safe history of the reference fleet.

3. A comparison showing that the new or derivative aeroplane model shares the comparable design features and/or margins, with the reference fleet.

4. The compliance of the new or derivative aeroplane model with the applicable CS-25 certification specifications relative to flight in the icing conditions defined by Appendix C.

3. Determining Adequately Safe Fleet History

In order to use a comparative analysis, a safe fleet history has to be established for the reference fleet of aeroplane model(s) to be used for comparison.

3.1 Fleet History Composition

The reference fleet should include the previous aeroplane model(s) sharing the design features and/or margins that will be used to substantiate the comparative analysis. The applicant should present to the Agency any known supercooled-liquid-water-icing-related accidents or serious incidents of the reference fleet. The applicant should present an analysis of any such events and explain how the identified root causes were addressed. Unless it can be justified, credit should not be taken for those flights of any aeroplane model that has experienced accidents or serious incidents due to flight in supercooled liquid water icing conditions. If design changes were made to correct deficiencies that contributed to, or caused, the accidents or serious incidents, including those which may have occurred in SLD, credit for flights may be taken only for the fleet of aeroplanes that have the changes incorporated (i.e. post-modification number of flights).

3.2 Use of Fleet History Data Not Owned by the Applicant

The use of fleet history data from the fleets of other certificate holders for Supplemental Type Certificate, new Type Certificate, or Major change to Type Certificate applications may be accepted by the Agency when formal agreements between the applicant and the certificate holder permitting the use of the relevant fleet history are in place. The Agency will determine the acceptability and the applicability of the data.

3.3 Applicability of Fleet History for the Certification Options of CS 25.1420(a)

When compiling data for aeroplane model(s) which will comprise the applicant's reference fleet, operational limitations or restrictions imposed by either the AFM(s) or the operating manuals furnished by the TC holder for the model(s) should be considered. Relevant operational limitations existing for the reference fleet (e.g. AFM or operating manual prohibition against take-off into freezing drizzle or light freezing rain, direction to avoid such conditions in flight, etc.) will limit the certification options available for the use of a comparative analysis.

If the aeroplane model(s) proposed to be included in the applicant's reference fleet has (have) limitations or restrictions applicable to SLD, the certification options for which comparative analysis could be used are limited to CS 25.1420(a)(1) or (a)(2). The applicant should demonstrate within the comparative analysis that the means of ice and/or icing conditions detection for the reference fleet remain valid and are applicable to the new or derivative aeroplane.

3.4 Safe Fleet History Requirements

The reference fleet should have accumulated two million or more flights, in total, with no accidents or serious incidents in supercooled liquid water icing conditions aloft.

4. Compliance with the Applicable CS-25 Certification Specifications Relative to Appendix C Icing Conditions

A comparative analysis is an acceptable means of compliance only with the CS-25 certification specifications relative to Appendix O icing conditions. The use of a comparative analysis is not an option for showing compliance with CS-25 certification specifications relative to Appendix C icing conditions.

5. Conducting Comparative Analysis

If a safe fleet history in icing conditions can be substantiated, and compliance with the CS-25 certification specifications for safe flight in Appendix C icing conditions can be shown, then the reference fleet can be used for comparative analysis.

The substantiation of the reference fleet's design features and/or margins which have contributed to the safe fleet history can be used for a new or derivative model having comparable design features and/or margins, to show compliance with the CS-25 certification specifications relative to flight in SLD icing conditions. When conducting a comparative analysis, the effects of key parameters for individual components or systems should be considered at the aeroplane level. The following aspects should be addressed:

a. Ice protection systems,

b. Unprotected components,

c. Ice or icing conditions detection,

d. Ice accretion and ice shedding sources,

e. Performance and handling characteristics,

f. Aeroplane flight manual information,

g. Additional considerations — Augmenting comparative analysis

5.1 Applicable CS-25 Certification Specifications

The applicable certification specifications relative to SLD icing are listed in Table 1 below. This guidance is applicable to these certification specifications.

Table 1: List of Applicable CS 25 Certification Specifications

Reference	Title
CS 25.21(g)	Performance and Handling Characteristics in Icing Conditions
CS 25.629	Aeroelastic stability requirements
CS 25.773(b)(1)(ii)	Pilot compartment view — icing conditions
CS 25.773(b)(4)	Pilot compartment view — non-openable windows
CS 25.929(a)	Propeller de-icing
CS 25 1093(b)	Powerplant icing — turbine engines
CS 25.1324	Flight instrument external probes
CS 25.1329	Flight Guidance System
CS 25.1403	Wing icing detection lights
CS 25.1420	Supercooled large drop icing conditions
CS 25J1093	Air intake system icing protection

5.2 Ice Protection Systems

The applicant should demonstrate similar levels of protection against the effects of ice accretion at the aeroplane level in the icing conditions of Appendix C. In doing so, the applicant should consider the ice protection system performance, modes of operation and the other factors identified by the applicant that contribute to the overall safety of the aeroplane for flight in the icing conditions of Appendix C. The assessment could include but is not necessarily limited to an analysis of the protection limits relative to supercooled liquid water impingement limits, runback and residual ice, as applicable.

5.3 Failure Analysis

The reference fleet will have been certified considering only the supercooled liquid water icing conditions of Appendix C and will have demonstrated an adequate level of safety when flying in both Appendix C and SLD icing conditions. Therefore, if a comparative analysis is used as a means of compliance with the CS-25 certification specifications relative to Appendix O icing conditions, the ice protection system for a new or derivative aeroplane, and the related equipment or components comprising the system, should demonstrate a reliability level consistent with a Functional Hazard Assessment (FHA) as per CS 25.1309(b). The classification and assessment of failure conditions need only consider the effects of Appendix C icing conditions.

5.4 Ice or Icing Conditions Detection

If the new or derivative model being certified has similar ice and/or icing conditions detection means as the reference fleet, including installation and operational considerations (e.g. flight crew procedures), then a comparative analysis may be used to show compliance with Appendix O-related certification specifications.

If the applicant chooses to introduce a new ice and/or icing conditions detection technology and show compliance at the aeroplane level based on a reference fleet with unrestricted operations (CS 25.1420(a)(3)) by comparative analysis, the new ice and/or icing conditions detection technology may require additional analysis, testing, or qualification data to demonstrate the capability to detect supercooled liquid water conditions when exposed to the SLD conditions represented in Appendix O.

If the certification option chosen requires a differentiation between icing conditions (CS 25.1420(a)(1) or (a)(2)), then either the reference fleet should have demonstrated the ability to detect that the aeroplane is operating in conditions that exceed the conditions selected for certification (i.e. for CS 25.1420(a)(1), any Appendix O icing conditions; and for CS 25.1420(a)(2), the icing conditions that are beyond the selected portion of Appendix O), or the ice and/or icing conditions detection means should be substantiated for detection of the applicable Appendix O icing conditions at the aeroplane level.

If the reference fleet has achieved the required number of flights to enable the use of a comparative analysis to show compliance with the CS-25 certification specifications relative to Appendix O, then Appendix C may be used to show compliance with the certification specifications related to ice accretions before the ice protection system has been activated and is performing its intended function (e.g. CS 25.1419(e), CS 25.143(j) and CS 25.207(h)).

5.5 Unprotected Components

For systems that are required to operate in Appendix O icing conditions but do not require ice protection provisions, for example the Autopilot (CS 25.1329), wing illumination lights (CS 25.1403), unprotected ECS intakes (CS 25.1420), etc., a comparative analysis may be used if design features are shown to be similar to those of the reference fleet.

5.6 Ice Accretion and Ice Shedding Sources

If a comparative analysis is used as the means of compliance with the CS-25 certification specifications relative to Appendix O icing conditions, certification ice shapes/ice data determined for Appendix C icing conditions are acceptable without additional Appendix O considerations. The locations where ice accretions may occur on the new or derivative model should be reviewed and compared to those of the reference fleet. The following aspects should be considered:

i. An analysis showing that, in Appendix C icing conditions, the propulsion system and APU installation are such that the geometry and water catch of potential sources of ice shedding are similar to those used to establish the reference fleet history database.

ii. A comparison of the location of, or the methodology for locating, flight instrument external probes to assure that the effect of airframe ice accretion forward of the probes will be comparable for the new or derivative model with that of the reference fleet relative to safe flight in the icing conditions of Appendix C.

iii. For aeroelastic analyses, performance of an analysis showing ice accretion consistency (location and volume), defined using the icing conditions of Appendix C.

5.7 Aeroplane Performance and Handling Characteristics

The comparative analysis should substantiate that the effects of ice accretion and the agreed key parameters of the new or derivative model are comparable to those of the reference fleet. The applicant should substantiate by analysis, test, or a combination of both, that the new or derivative aeroplane will have similar margins to those of the reference fleet for flight in the icing conditions of Appendix C.

The following paragraphs provide guidance on how to achieve the above:

- Aeroplane performance,
- Aeroplane controllability and manoeuvrability,
- Aeroplane trim,
- Aeroplane stability,
- Aeroplane stalls.

5.7.1 Performance

The effects on aeroplane performance of the certification ice shapes/ice shape data determined for flight in the icing conditions of Appendix C for the new or derivative model should be comparable to those of the reference fleet. A comparison of ice accretion effects on lift and drag may be used in this analysis.

If comparable effects to those of the reference fleet cannot be shown, then the applicant should show how margins similar to those of the reference fleet are restored for the new or derivative model by other means that compensate for the effect (e.g. airspeed increase, sizing criteria, or other aeroplane limitations).

5.7.2 Controllability and Manoeuvrability

The effectiveness of the control surfaces and the control forces for the new or derivative model, with the certification ice shapes/ice shape data for flight in the icing conditions of Appendix C, should be comparable to those of the reference fleet. If critical Appendix C ice shapes affect the control surface effectiveness or control forces in a manner which may be different to that of the reference fleet, then the applicant should show how the control effectiveness and forces are restored.

The manoeuvrability associated with the certification ice shapes/ice shape data determined for the icing conditions of Appendix C should be comparable to those of the aeroplanes which comprise the reference fleet. If critical Appendix C ice shapes affect manoeuvrability in a manner which may be different to that of the reference fleet, then the applicant should show how the margins are restored (speed increase, etc.).

5.7.3 Trim

In addition to showing that trim capability for the new or derivative model, with the certification ice shapes/ice shape data for flight in the icing conditions of Appendix C, is comparable to that of the reference fleet, the margins between the required trim in the most critical conditions and the trim capability in Appendix C icing conditions should be comparable to those of the reference fleet.

5.7.4 Stability

The aeroplane stability associated with the certification ice shapes/ice shape data determined for the icing conditions of Appendix C should be comparable to those of the reference fleet. If this cannot be shown, then the applicant should show how similar stability margins are restored (speed increase, sizing criteria, other aircraft limitations, etc).

5.7.5 Stalls

a. Stall warning and protection features

Stall warning, stall protection, and/or airspeed awareness methods, devices, and/or systems as applicable should be shown by comparative analysis to be similar in function or improved relative to those of the reference fleet.b. Stall warning margins

Stall warning margins established with the certification ice shapes/ice shape data associated with flight in the icing conditions of Appendix C should be comparable to those of the reference fleet.

c. Stall characteristics

The stall characteristics demonstrated by the new or derivative model with the certification ice shapes/ice shape data for flight in the icing conditions of Appendix C should be comparable to those of the reference fleet.

d. Aeroplane with Flight Envelope Protection

It should be shown that the new or derivative aeroplane and the reference fleet aeroplane(s) high angle-of-attack protection systems have a comparable ability to accommodate any reduction in stalling angle of attack with the certification ice shapes/ice shape data for flight in the icing conditions of Appendix C relative to the clean aeroplane.

The high angle-of-attack characteristics demonstrated with the certification ice shapes/ice shape data for flight in the icing conditions of Appendix C should be comparable to those of the reference fleet.

5.8 Aeroplane Fight Manual Information

If the certification option chosen for the new or derivative model being certified (CS 25.1420(a)(1), (a)(2), or (a)(3)) is consistent with the operation of the reference fleet, then the information to be provided in the AFM may be based on that provided in the reference fleet AFM(s) or other operating manual(s) furnished by the TC holder.

5.9 Additional Considerations — Augmenting Comparative Analysis

In addition to the use of design features and/or margins, to substantiate a new or derivative design by comparative analysis, the applicant may augment the comparative analysis with other methodologies (e.g. test, analysis or combination thereof). The new methodologies should be agreed with the Agency.

~~(e)~~(f) CS 25.1420~~(c)~~(d)

CS 25.1420~~(c)~~(d) requires that aeroplanes certified in accordance with subparagraph CS 25.1420(a)(2) or (a)(3) comply with the requirements of CS 25.1419 (e), (f), (g), and (h) for the icing conditions defined in Appendix O in which the aeroplane is certified to operate.

Paragraphs (d), (e), (f), and (g) of AMC 25.1419 apply.

4. Regulatory Impact Assessment (RIA)

4.1. Issues to be addressed

Rulemaking task RMT.0058 (refer to NPA 2011-03, NPA 2012-22, and the related CRDs) developed new specifications and acceptable means of compliance for certification of CS-25 large aeroplanes for flight in icing conditions. A new Appendix O environmental standard representing SLD icing conditions was also created. These SLD icing conditions are therefore part of the certification specifications related to ice protection of the aeroplane systems and equipment, powerplant and APU, as well as specifications related to aeroplane performance and handling qualities.

The new CS 25.1420 requires that the aeroplane be able to either safely exit following the detection of any or specifically identified Appendix O icing conditions, or to safely operate without restrictions in the icing environment represented in Appendix O. Specifically, CS 25.1420(a) allows three options:

1. Detect Appendix O conditions and then operate safely while exiting all icing conditions (CS 25.1420(a)(1)); or
2. Safely operate in a selected portion of Appendix O conditions, detect when the aeroplane is operating in conditions that exceed the selected portion, and then operate safely while exiting all icing conditions (CS 25.1420(a)(2)); or
3. Operate safely in all of the Appendix O conditions (CS 25.1420(a)(3)).

To establish that the aeroplane safely operates as per CS 25.1420(a), CS 25.1420(b) requires both analysis and one test, or more as found necessary, to establish that the ice protection for the various components of the aeroplane is adequate.

During the certification process, the applicant would demonstrate compliance using a combination of analyses and test(s). The applicant's Means of Compliance (MoC) would consist of analyses and test(s) agreed by the Agency to be sufficient to demonstrate compliance with the specification. The applicant would propose to use one or more of the tests identified in sub-paragraphs CS 25.1420(b)(1) through (b)(5).

These provisions do not permit taking credit for the similarities of the proposed type of aeroplane compared to previously certified aeroplane(s) that proved by their service experience to be safe for flight in SLD icing conditions.

Nevertheless, it is recognised that many currently certified large aeroplanes have demonstrated, through their service experience, safe operation in these conditions.

During the NPA 2011-03 public consultation period, several large aeroplane manufacturers expressed their wish to have the possibility of taking credit for previous type designs to facilitate their showing of compliance with the proposed rule, and this was also suggested in the NPA 2011-03 Explanatory Note.

For this reason, the Agency created some provisions in the AMC 25.1420 (refer to NPA 2012-22) so that the applicant may use and take credit for similarity to a previous design having proven safe operation in SLD icing conditions. This would facilitate the demonstration of compliance with the specifications and it may eliminate the need for performing testing in natural or simulated SLD conditions. As the details of the method and the acceptance criteria to be used when conducting a comparative analysis are not provided in the AMC material mentioned above, the Agency decided to create a new rulemaking task to prepare a proposal that will further develop a comparative analysis and the conditions for its application as an AMC for CS 25.1420. This proposed AMC will then provide a better assurance to applicants on the conditions required for acceptance of a comparative analysis by the Agency and facilitate the certification process for both Industry and the Agency.

4.1.1. Safety risk assessment

The proposed CS-25 amendment does not involve additional safety risk. The safety risk stemming from SLD icing encounter was considered under rulemaking task RMT.0058. This NPA develops an acceptable means of compliance with the new rules already established and introduced through CS-25 Amendment 16.

4.1.2. Who is affected?

Large aeroplane designers and manufacturers.

4.1.3. How could the issue/problem evolve?

Large aeroplane manufacturers need guidance on how to propose a MoC based on a comparative analysis. If no guidance is published by the Agency, the main risk is to have different approaches and methods developed by the different manufacturers, and a potential lack of harmonisation between the MoCs. This may lead to different level of robustness of the MoCs developed by the manufacturers and approved by the Agency, thus resulting in variable levels of safety of the certified aeroplanes.

4.2. Objectives

The specific objective of this proposal is to introduce an acceptable means of compliance based on comparative analysis when showing compliance with SLD-related specifications.

4.3. Policy options

Table 3: Selected policy options

Option No	*Short title*	**Description**
0		Baseline option : no amendment of CS-25, the issue remains the same as decsribed in 4.1.
1		Amend CS-25 to introduce an acceptable means of comliance based on comparative analysis when showing compliance with SLD related specifications

4.4. Analysis of impacts

4.4.1. Safety impact

Option 0 may lead to different level of robustness of the MoCs developed by the manufacturers and approved by the Agency, hence resulting in variable levels of safety of the aeroplane type certified.

Option 1 does not involve the creation of new requirements to improve safety; however, it would provide a baseline to harmonize the development of a comparative analysis by the manufacturers, thus ensuring harmonised minimum levels of safety.

4.4.2. Environmental impact

None

4.4.3. Social impact

None

4.4.4. Economic impact

Option 1 would facilitate the certification process for large aeroplane manufacturers who are eligible to use a comparative analysis for demonstrating compliance with SLD-icing-related rules. It would provide a better assurance to applicants on the conditions required for acceptance of a comparative analysis by the Agency. This would provide an overall economic benefit.

4.4.5. General aviation and proportionality issues

None

4.4.6. Impact on 'better regulation' and harmonisation

None

4.5. Comparison and conclusion

4.5.1. Comparison of options

Option 1 is the preferred option. It would provide a benefit in terms of safety level harmonisation, would facilitate the certification process for the applicants and the Agency when eligible for the comparative analysis, with an overall economic benefit. It would also meet the request made by several large aeroplane manufacturers.

4.5.2. Monitoring and ex post evaluation

No specific monitoring is recommended. Nevertheless, the proposed AMC material may be further improved in the future based on the lessons learnt from application to certification projects.

5. References

5.1. Affected regulations

None

5.2. Affected CS, AMC and GM

ED Decision 2003/2/RM of 17 October 2003 on certification specifications, including airworthiness codes and acceptable means of compliance, for large aeroplanes ('CS-25')

5.3. Reference documents

(a) FAA final report DOT/FAA/AR-09/10, Data and Analysis for the Development of an Engineering Standard for Supercooled Large Drop Conditions, dated March 2009.

The report is available here: http://www.tc.faa.gov/its/worldpac/techrpt/ar0910.pdf

(b) Ice Protection Harmonization Working Group (IPHWG) Task 2 Working Group report.

The report is available here: http://regulations.gov

Docket number: FAA-2010-0636.

6. Appendices

Appendix 1: Explanation of the method used to determine the number of SLD encounters experienced by an aircraft fleet during a defined number of flights

Appendix 2: Application of the comparative analysis — Examples

6.1. Appendix 1 — Explanation of the method used to determine the number of SLD encounters experienced by an aircraft fleet during a defined number of flights

The probability computation does not include an assessment of the duration or number of SLD encounters. To address this issue, Dr Stewart Cober (Environment Canada) and Dr James Riley (FAA) developed a means to determine how many heavy SLD exposures of a given duration a fleet of aircraft would have experienced, on average, during a given number of flights.

Dr Cober worked with the SLD data set consisting of 2 444, 30-second (nominally 3-km) SLD observations by the National Research Council Canada's Convair 580 or the NASA Glenn Research Center's De Haviland DHC-6 Twin Otter during several winter weather SLD campaigns. All the 2 444 SLD observations have a 30-second duration. Those for the Convair 580 are approximately 2.9 km and those for the Twin Otter are approximately 2.1 km. Refer to FAA Report AR-09/10, page 23. Note: All of the data are treated as 3-km observations.

Dr Cober took each of the 3-km SLD observations and combined them into exposure lengths that consisted of consecutive or near consecutive 3-km observations. This exposure data set consists of 305 exposures (Figure 1).

The next three figures describe the results.

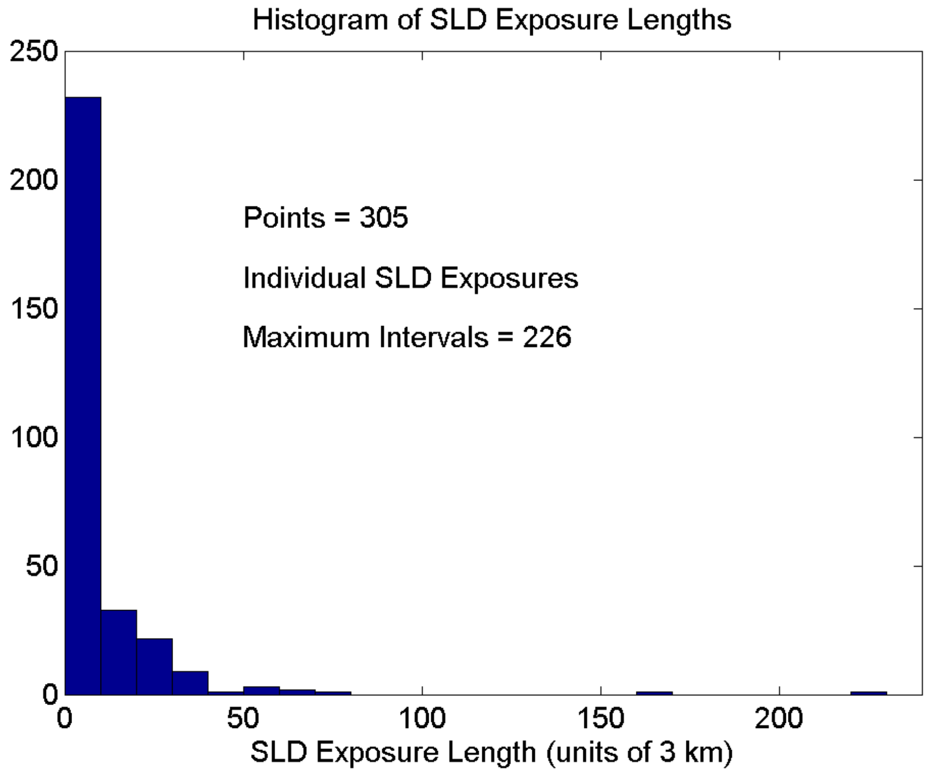

Figure 1 — Histogram of exposure lengths

Figure 1 shows that:

— the 2 444 SLD exposures of 3 km nominal length were combined into 305 SLD exposures of varying length;

— the longest exposure consisted of 226 3-km units, equal to 678 km; and

— the average exposure length was eight 3-km units (2 444/305 = 8), equal to 24 km.

Note: These exposures do not necessarily measure straight-line flight, but rather represent the length over which the aircraft was in an SLD environment.

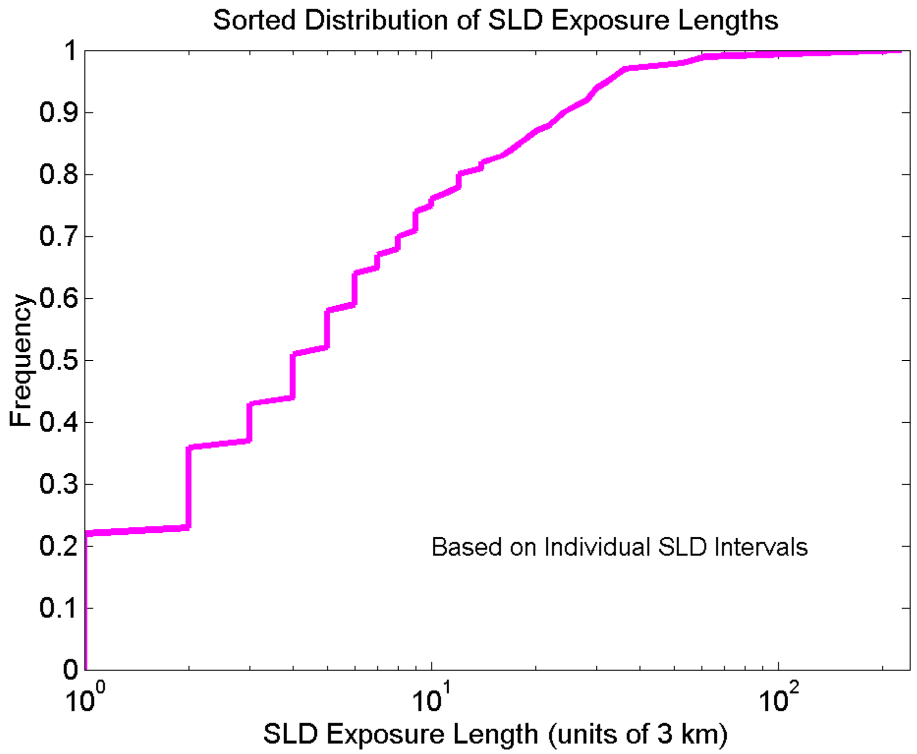

Figure 2 — Cumulative distribution plot of the exposure lengths arranged in ascending order

Figure 2 is designed to show the fraction of the exposures above or below some threshold length.

It shows that:

— approximately 22 % of the exposures are less than or equal to one 3-km units. (In other words, 22 % are isolated units and so cannot be combined with other units to obtain a longer exposure.);

— approximately 13 % of the exposures are equal to two 3-km units, equal to 6 km in length; and

— approximately 72 % of the exposures are less than or equal to ten 3-km units, and so are less than or equal to 30 km in length.

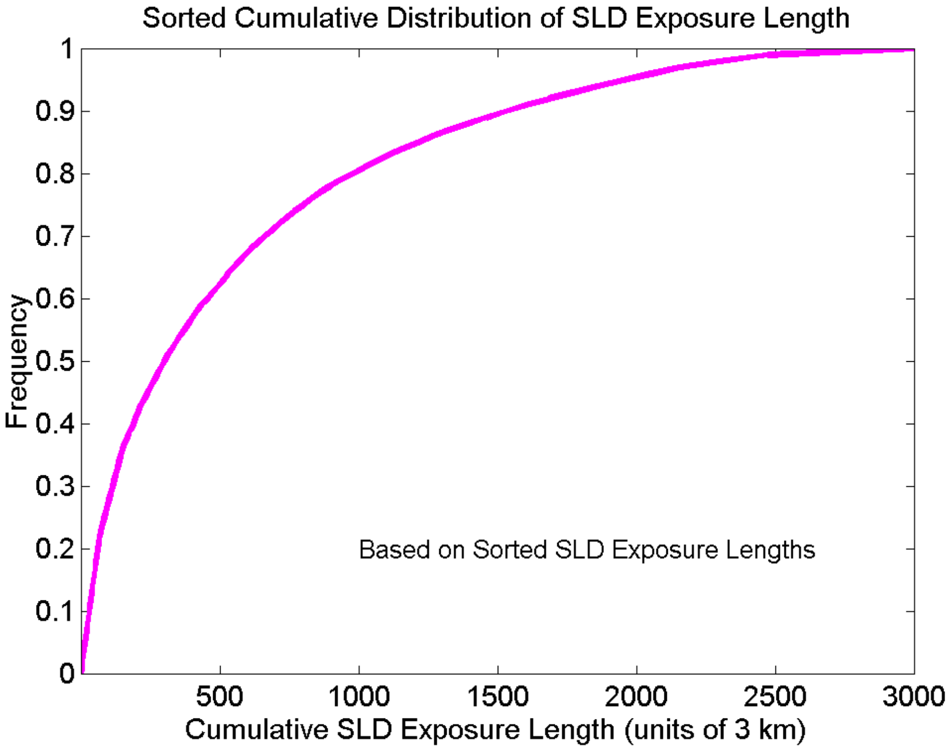

Figure 3 — Cumulative distribution plot of exposure lengths (with exposure lengths arranged in ascending order)

In Figure 3, the frequency on the vertical axis is equal to the proportion of 3-km units (exposures).

Note:

— The lower part of the curve shows that about 55 % of the 3-km units (exposures) account for about 500 3-km units (exposures) (combined exposure length of 1 500 km)

— The upper part of the curve shows that about 25 % of the 3-km units (exposures) account for about 2 000 units (6 000 km) of exposure length.

The total cumulative length (in intervals) is 2 999. This value is close to the 2 444 data points that make up the total SLD data base. There is a difference because some gaps have been included in determining the exposures. For example, if SLD was measured for 4 intervals, followed by 2 intervals with no SLD, and then another 12 intervals with SLD, then this would be considered a single exposure of 18 intervals.

Conclusion based on the three figures:

Even though the majority of the SLD exposures were relatively short in duration, the majority of the time spent in SLD conditions was associated with the smaller number of longer exposures.

Assumptions

(1) It is assumed that exposure lengths less than some minimum time can be ignored. Presumably, it would depend upon how fast the aircraft flies and what exposure time can be encountered without adverse effect on the aircraft. In the example calculations that follow, this is taken to be 5 minutes.

(2) The aircraft travels at 100 m/s.

At this speed, 5 minutes corresponds to 30 km.

Using Figure 2 above, a length scale of 10 intervals or 30 km represents 72 % of the 305 SLD exposures. Using Figure 3, this is only 25 % of the actual time in SLD conditions (750 intervals out of 2 999). Hence, 75 % of the flight distance in SLD conditions will be in exposures that are longer than 30 km.

(3) The figures correctly represent natural conditions.

(4) Any SLD severity can occur at any of these exposure lengths.

Based on the above assumptions, the probability that a significant SLD event will be encountered can be converted into the probability that a significant SLD event will be encountered over a specified period of time (i.e. exposure length). This provides a unit of time in the calculation that can be applied to the number of fleet flight hours required for a number of SLD exposures.

Number of encounters calculation

The methodology described above allows calculation of the number of encounters of heavy SLD for various durations. To determine an adequate duration, the accident reports for the ATR and EMB 120 were reviewed to assess how long the aircraft had been flying in icing conditions prior to loss of control. It was not possible to determine the icing exposure duration for the EMB 120 accident, but for the ATR accident in Roselawn the NTSB report indicates that the aircraft had been flying in icing conditions for between approximately 6 to 24 minutes.

Most of the SLD events studied by the IPHWG were of relatively short duration of around 5 to 10 minutes. Therefore, the number of 5-, 10-, 15- and 30-minute SLD encounters a fleet would have typically experienced during 1.2 million flights has been computed.

To perform this calculation, the number of flights must be converted into a number of flight hours; a mean average duration of 50 minutes below 22 000 ft is retained, (refer to paragraph 2.4.2.1.4 of this NPA). This yields the following total number of flight hours:

1 200 000 x 50/60 = 1 000 000

Considering probabilities determined in paragraph 2.4.2.1.3:

— 5 % of flights encounter icing conditions;

— 1.7 % of the icing conditions are in SLD; and

— 1 % of the SLD are considered heavy.

As explained in paragraph 2.4.2.1.3.3, a probability of exceeding Appendix O icing conditions of 0.1% has been retained to provide an additional element of conservatism to calculate the probability of heavy SLD icing conditions. However, in determining the number of encounters associated with operational conditions, it has been considered that such a conservatism was too severe for this calculation; therefore, as Appendix O is based on 99 % exceedance limits, the 1 % probability of heavy SLD has been selected.

Thus, the number of flight hours in heavy SLD is:

1 000 000 x 0.05 x 0.017 x 0.01 = 8.5 hours

To determine the number of encounters with duration of 5, 10, 15 and 30 minutes, the exposure length in kilometres is calculated. To convert the duration to kilometres, it is assumed that the aircraft is flying at 100 m/s (which is representative of holding speed).

Hence, a duration of:

— 5 minutes yields 30 km;

— 10 minutes yields 60 km;

— 15 minutes yields 90 km; and

— 30 minutes yields to 180 km.

Based on Figures 4 and 5 below, the proportion of encounters equal to or longer than:

— 30 km is 75 percent; therefore, equal to or longer than 5 minutes;

— 60 km is 57 percent; therefore, equal to or longer than 10 minutes;

— 90 km is 35 percent; therefore, equal to or longer than 15 minutes; and

— 180 km is 17 percent; therefore, equal to or longer than 30 minutes.

To calculate the number of hours of flight in heavy SLD conditions:

— a 5-minute duration is 8.5 x 0.75 = 6.4 hours;

— a 10-minute duration is 8.5 x 0.57 = 4.8 hours;

— a 15-minute duration is 8.5 x 0.35 = 3 hours; and

— a 30-minute duration is 8.5 x 0.17 = 1.4 hours

Hence, the total distances flown in SLD at a speed of 100 m/s are, respectively:

— 2 295 km for a 5-minute duration;

— 1 734 km for a 10-minute duration;

— 1 070 km for a 15-minute duration; and

— 509 km for a 30-minute duration.

Finally, the numbers of exposures, which are the total kilometres flown in SLD divided by the exposure length (in km), are respectively:

— 76 for a 5-minute duration;

— 29 for a 10-minute duration;

— 12 for a 15-minute duration; and

— 3 for a 30-minute duration.

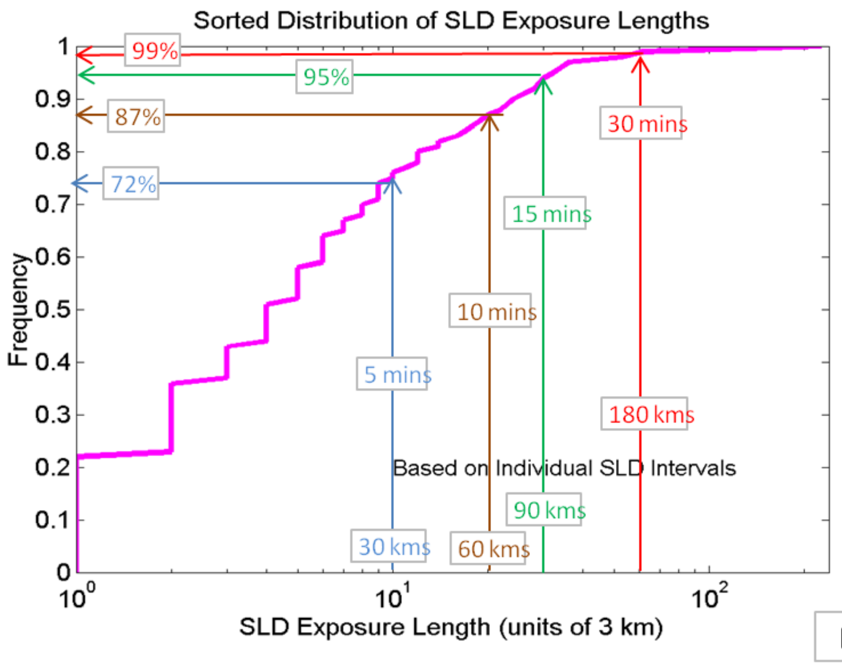

Figure 4

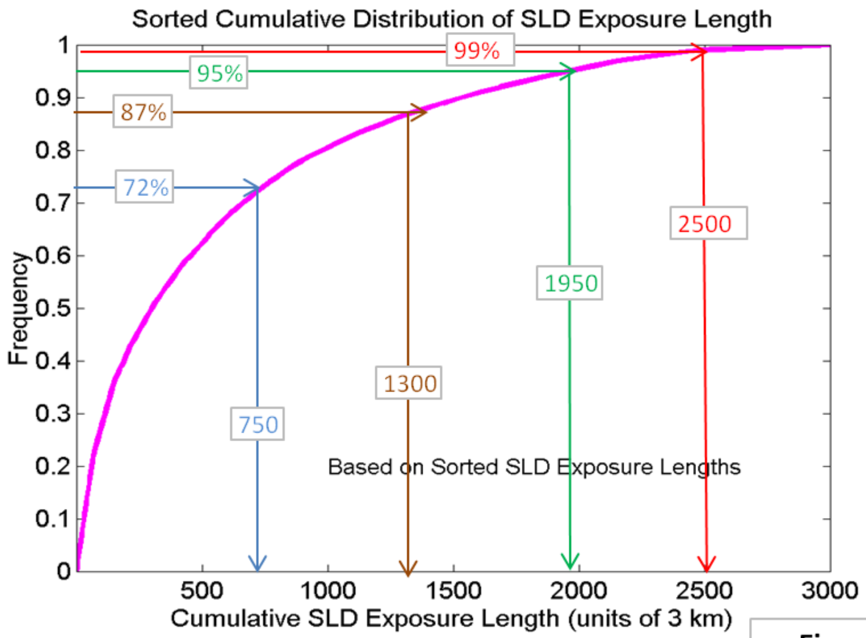

Figure 5

6.2. Appendix 2 — Application of the comparative analysis — Examples

The following examples are provided to illustrate the application of comparative analysis. The examples are provided for guidance only. They do not constitute the only method for utilising comparative analysis and they do not define specific requirements that must be applied by all applicants. The specific application of comparative analysis will differ among applicants as it will depend upon the design and certification approaches the applicants have applied to the reference fleet. The illustrations below are not intended to be exhaustive or prescriptive.

The examples illustrate that geometry or configuration similarities are not the only focus for understanding the application of comparative analysis. When using comparative analysis, the physics and aeroplane design characteristics which govern the margins associated with the identified key parameters are a primary consideration. Aeroplane systems or configurations may not always be equivalent. Nevertheless, the effects of configuration similarities or differences are evaluated to compare aerodynamic and/or other aeroplane margins that affect the overall aeroplane safety, which in turn is directly related to the safe in-service history of flight in icing conditions.

Example 1: Wing ice protection system change

(a) Reference fleet ice protection system: anti-icing system

(b) New product ice protection system: de-icing system

The safe in-service experience of the reference fleet is associated with models that have a wing anti-icing system whose features, efficiency and margins are well known by the applicant.

The reference fleet design results in no ice accretion on the wing leading edges (or if any, some runback ice) during normal operation. Changing from an anti-icing system to a de-icing system will result in intercycle ice accretions on the wing leading edges.

How comparative analysis could be applied?

The applicant has already shown that the existing chordwise extent of wing ice protection is adequate to provide the required safety level in Appendix C icing conditions for anti-icing systems. The safe in-service record shows that these protection limits are also adequate in SLD icing conditions. If the de-icing system on the new model is such that there is no appreciable difference in runback ice (e.g. electro-mechanical), it is reasonable to expect that the applicant can also conservatively predict the effects of intercycle ice and compensate accordingly. The behaviour of the aeroplane with intercycle ice shapes must be demonstrated to meet the certification requirements with the icing conditions of Appendix C.

If the de-icing system on the new model produces runback ice, an analysis comparing the runback ice of the new de-icing system to that of the reference fleet with the anti-icing system in Appendix C icing conditions would be required to show that the system performance and resulting impacts are predictable. This may require specific identified compensating features, like redistributed or additional heat, to be identified. If there are significant differences in the amount of runback ice produced in Appendix C icing conditions by the de-icing system when compared to reference fleet ice shapes/ice data, then an analysis must show that the effects can be accurately or conservatively addressed in SLD. If this cannot be shown, then comparative analysis may not be applicable.

While a de-icing system will result in ice accretion on the protected parts of the wing, comparative analysis could be applied if similar margins are provided through the application of compensating factors as described below. If the applicant decides not to restore similar margins to those of the reference fleet, then comparative analysis will not be applicable.

<u>Key parameters</u>

Manoeuvrability, performance and stall

Intercycle ice on the new aeroplane with the same spanwise ice protection coverage as that of the reference fleet would result in increased lift loss and drag. The applicant should implement compensating features to maintain similar ice effects as those of the reference fleet relative to the overall lift and drag. Compensating features could include but are not limited to:

— increased spanwise extent of protection to address both lift and drag;

— increased wing area to address lift;

— increased aircraft operating speeds to address lift and drag;

— increased slat chords and/or deflection to address lift; and

— increased thrust to address drag and potentially aid manoeuvring capability.

<u>Controllability</u>

Intercycle ice may impact on the controllability of the aeroplane. In order to maintain lateral controllability margins the following compensating features could be applied:

— Increased aileron size;

— Increased spoiler size and/or deflection;

— Addition of an aileron tab or flaperon; and

— If the reference fleet has powered flight controls, then the derivative or new aeroplane would be expected to also have powered flight controls.

The list of above factors is not exhaustive and other compensatory factors could be proposed by the applicant.

<u>Other considerations</u>

Ice shedding

For aeroplanes with aft mounted engines: a demonstration should be performed in the icing conditions of CS-25 Appendix C to show that shedding of intercycle ice from the inboard part of the wing that could enter the engine is addressed.

Aeroelastic analysis

The mass of ice accreted should be computed in Appendix C icing conditions using methods equivalent to those applied to the reference fleet as required.

Example 2: Ice detector technology change

(a) Reference fleet ice detection system: magnetostrictive probe-type ice detector design

(b) New product ice detection system: optical ice detection technology, unrestricted operation in Appendix O

The key parameter in this example is the capability of the ice detection system to detect the icing conditions in which the aeroplane is operating, i.e. Appendix C and/or Appendix O. Other related design parameters which affect ice detection capability are the locations on the aeroplane where ice detectors are installed, and flight deck indications and procedures used by the pilots to react or reconfigure the aeroplane during icing conditions.

The new optical system must be qualified to work in Appendix C icing conditions. If the new optical system is installed in a location determined using the same methodologies to the magnetostrictive probe installations on the reference fleet, or the sensing area is the same, then it can be assumed, by comparative analysis, that the optical probe will be subjected to the same icing conditions exposure as the reference fleet. Since, by definition, Appendix O contains droplet sizes included in Appendix C, the new aeroplane model will have similar ice detection capability as the reference fleet.

Example 3: Change from an ice protected to unprotected horizontal tail plane

(a) Reference fleet: ice protection system on the horizontal tail plane

(b) New product: no ice protection system on the horizontal tail plane

The safe in-service experience of the reference fleet is associated with models that have anti-icing system protection for the horizontal tail plane leading edge.

Changing from a protected to an unprotected horizontal tail plane results in the new model having ice accretions on the horizontal tail plane leading edges while the reference fleet was certified with no ice accretions. Through establishment of the reference fleet, the applicant has already shown that the existing chordwise extent of tail leading edge ice protection is adequate to provide the required safety level in Appendix C icing conditions for anti-icing systems. The safe in-service record shows that these protection limits are also adequate in SLD icing conditions. This implies that the ice protection limits on the tail planes of the reference fleet were adequately determined. Comparative analysis can be used to establish the validity of the methodologies used on the reference fleet to determine the impingement limits and ice shape footprint range and may be used on the new model for similar analysis based on Appendix C icing conditions.

While the ice extent may be understood, the ice shape details in SLD may not be. This may present some challenges for applying comparative analysis without being augmented with other analysis.

In this case, the applicant would have to be able to show that the assumed ice shape for analysing the aerodynamic impact on the tail plane can be conservatively accounted for. Since the impingement limits, and essentially the ice shape footprint range, are known through comparative analysis, other engineering analysis can potentially be used to show that the margins of the new aeroplane are comparable to the reference fleet. This essentially amounts to utilising some of the provisions of 'Additional considerations — Augmenting comparative analysis'. For example, knowing the ice footprint range, a conservative shape may be used to estimate the aerodynamic impact as long as the Agency agrees with the shape and manner in which the aerodynamic impacts are being assessed. Once the aerodynamic impacts are determined, comparative analysis may be used to show that margins similar to the reference fleet have been restored.

If other methods or conservative assumptions cannot be argued as compensating features, comparative analysis likely cannot be applied.

If the methods for determining the impacts of the ice on the aerodynamic performance of the horizontal tail plane are agreed with the Agency, then some of the features that may be used to augment comparative analysis by showing that the new model has similar or improved longitudinal trim and manoeuvrability margins relative to those of the reference fleet are:

— increased horizontal tail plane area;

— increased horizontal tail plane chord;

— modification of the tail plane configuration/profile to reduce sensitivity to ice accretion;

— increased tail arm;

— addition of canards;

— adjusted centre of gravity range;

— resized elevator;

— adjusted elevator deflections; and

— decreased pitch moment due to thrust line.

Example 4: Reduction of chordwise extent of ice protection for the wing, horizontal or vertical tail plane without any other changes to the aeroplane

In this case, the margins between impingement limits and protection limits are changed without any compensating features being added to the aeroplane. Therefore, similar margins in Appendix C icing conditions relative to the reference fleet could not be shown. Consequently, comparative analysis could not be used as means of compliance in this case.