SUBJECT:		**Unusual Ice Protection System design for aeroplane operation above the CS-25 Appendix C Intermittent Maximum icing altitude**
REQUIREMENTS incl. Amdt.	:	**CS 25.1419 @ Amendment 21, CS 25.1093(b) @ amendment 21, CS 25 Appendix C @ Amendment 21**[1]
ASSOCIATED IM/MOC	:	Yes☒ / No ☐
ADVISORY MATERIAL	:	

INTRODUCTORY NOTE:

The following Special Condition has been classified as important and as such was subject to public consultation from 02 July 2019 to 30 September 2019 in accordance with EASA Management Board decision 12/2007 dated 11 September 2007, Article 3 (2.) which states:

"*2. Deviations from the applicable airworthiness codes, environmental protection certification specifications and/or acceptable means of compliance with Part 21, as well as important special conditions and equivalent safety findings, shall be submitted to the panel of experts and be subject to a public consultation of at least 3 weeks, except if they have been previously agreed and published in the Official Publication of the Agency. The final decision shall be published in the Official Publication of the Agency.*"

IDENTIFICATION OF ISSUE:

CS 25.1419 requires applicants seeking certification for flight in icing conditions to demonstrate that the aeroplane is able to safely operate within the CS-25 Appendix C Continuous Maximum (CM) and Intermittent Maximum (IM) icing environment. CS 25.1093(b) requires the engines being able to properly function in icing conditions of Appendix C as well.

Although the intent of CS 25.1419 and CS 25.1093(b) is for the aeroplane to safely operate in supercooled liquid icing conditions, CM and IM icing conditions provided in Appendix C of CS-25 are limited in term of altitude to a maximum of 22000 feet and 31000 feet respectively. However, icing conditions may exist above the current Appendix C IM icing altitude, albeit they are currently not precisely characterised. Although one can postulate that they are less severe in nature compared to Appendix C conditions, owing to the Liquid Water Content (LWC) general trend with temperature, it cannot be completely ruled out that icing conditions above Appendix C IM icing altitude may definitely exist.

Indeed, the Appendix C of CS-25 constitutes an engineering standard to characterise the icing atmosphere. Such envelope has been in use since 1964 to select values of icing-related cloud variables for the design of aeroplane in-flight ice protection systems. As a matter of fact, it was developed based on data from the continental US atmospheric conditions and the available knowledge on aviation environment that existed at that time. In addition, hot-day conditions are not addressed in the current CS 25 Appendix C. Indeed, according to the flight test data showed in FAA technical report ADS-4, Figure 1-21, there is a significant number of icing encounters at altitude between 16000 and 20000 feet occurring at temperature warmer

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[1] This is the CS-25 amendment level applicable to the aeroplane TC (at the time when the final Special Condition text has been published), where the Special Condition first was applicable.

than the current Appendix C (Source Boeing flights). More recently, hot-day icing environment data above Appendix C IM icing altitude were available as a result of survey of flight test campaigns performed in the framework of research activities[2]; finally, AIA/ASD aerospace industry association with a jointly effort to support the development/finalization of this Special Condition reviewed ice detection frequency and IPS activation data above current Appendix C IM altitude from operational flights to provide additional hot-day atmospheric conditions to further characterise the severity of icing encounters above current Appendix C IM icing altitude.

It is acknowledged that the current CS-25 Appendix C provides icing conditions up to a maximum altitude of 31,000 feet for the IM icing conditions, but it is mainly attributed to the “limited” altitude capability of the aeroplanes used during research projects to determine the icing conditions envelope at that time. Nevertheless, it is commonly agreed that below -40°C, air cannot hold any more moisture.

Although CS 25.1419 and CS 25.1093(b) have been often interpreted in the way that the ice protection system (IPS) effectiveness would not be assessed above the Appendix C IM icing altitude, an IPS designed to meet Appendix C icing environment is expected to provide adequate protection for any icing encounter at altitudes above the Appendix C IM envelope.

Decades of safe in-service history of in-flight icing operation with aeroplane whose IPS thermal power was only naturally reduced (phased out) by engine bleed flow availability with altitude (i.e., due to natural reduction of global engine inlet mass flow with altitude) prove the robustness of such IPS design. It will be referred hereafter as “traditional On/Off IPS”. In such a case, and on the basis of the past good in-service experience, it is assumed that an aeroplane equipped with “traditional On/Off IPS” operated in the full flight aeroplane envelope can be certified using the Appendix C envelopes, and that no further assessment is required for the part of the flight envelope which is above the Appendix C IM icing altitude.

On the other hand, some aeroplane may incorporate IPS design features able to implement a “per-design” reduction/cut-off of the engine bleed usage for anti-icing above the current Appendix C IM icing altitude in order to optimise engine performance, to reduce the fuel consumption and the impact on the environment. The bleed ‘optimisation’ logic could be implemented at engine or aeroplane level.

This has led to IPS design with an active “*optimisation*” (or modulation) of anti-icing bleed flow schedule with altitude; this feature eventually results into a more or less rapid phasing out of anti-icing thermal power particularly between the Appendix C IM icing altitude and the maximum aeroplane operational ceiling. In some aeroplane, in some extreme operational conditions, bleed air usage for anti-icing purpose is even inhibited above a certain altitude since it can lead to serious engine operability issues (such as engine surge, roll-back...).

Compared with the here-above referred “traditional On/Off” IPS design where the limitation of thermal power is only (mainly) determined by the air bleed availability from the engine with altitude without performing any further air bleed optimisation, these latter designs represent globally a novel or unusual design when compared to the existing flying fleet.

This Special Condition only addresses optimized/modulated or even inhibited IPS above the altitude of Appendix C IM icing envelope. For optimised IPS below 31kft, the text of this CRI should be revised and the

[2] HAIC-HIWC flight campaigns; although the project was focused on ice crystal icing characterization, some data on existence of mixed conditions were collected in hot-day atmospheric conditions.

icing conditions between 22kft and 31kft, to be considered for certification, should be discussed between Industry and Authorities.

At altitudes above the Appendix C IM icing envelope, and particularly at low ambient temperatures, such modulated IPS may be unable to maintain the protected surface at temperature below which, unacceptable amount of ice might accrete on the protected surface.

This Special Condition primarily addresses aeroplane thermal IPS supplied by engine bleed air flow. Nevertheless, it can potentially apply to any other IPS concept, when such IPS envisages similar design features aimed at optimising the anti-icing function.

In order to address such unusual IPS design and to ensure that the aeroplane is able to safely operate in icing conditions in the entire aeroplane flight envelope, according to the Annex I (Part 21) of Commission Regulation (EU) No 748/2012, as last amended, Subpart B, 21.B.75(a)(1), the Special Condition in this paper is raised since "*..the product has novel or unusual design features relative to the design practices on which the applicable certification specifications are based*".

This Special Condition requires the demonstration of safe operation in icing conditions in the aeroplane entire flight envelope when these conditions may still exist.

The special condition is complemented by means of compliance (MOC).

Annex 1 of the associated MOC provides a high altitude icing scenario above the Appendix C IM icing altitude (in lieu of an extension of the Appendix C IM conditions at altitude above 31000 feet). This scenario was based on exploitation of flying fleet database from major aeroplane manufacturers, while the aeroplane types were operated on commercial routes.

Considering the comments received in the period of the public consultation, the several follow-up meetings with AIA/ASD group representatives, their final position letter[3] received on 22.02.2022, which includes the here-above referred icing scenario above the Intermittent Maximum icing altitude, the following Special Condition is defined, together with the associated MOC.

[3] "High Altitude Supercooled Liquid Water Icing Conditions - Results of Analysis of In-service Data, Proposed High Altitude Supercooled Liquid Water Icing Requirements and Recommendations for Future Activities."

Special Condition SC-F25.1419-01 on Unusual Ice Protection System design for aeroplane operation above the CS-25 Appendix C IM icing altitude.

1. Applicability

This Special Condition is applicable to CS-25 aeroplanes with optimized/modulated or inhibited IPS above the altitude of Appendix C IM icing envelope.

This Special Condition primarily addresses aeroplanes thermal IPS supplied by engine bleed air flow. Nevertheless, it can potentially apply to any other IPS concept, when such IPS envisages similar design features aimed at optimising the anti-icing function.

2. Special condition

In addition to CS 25.1419, CS 25.1093(b), CS-25 Appendix C, the actual design shall comply with the following special detailed technical specifications.

If an ice protection system (IPS) implements control logic that reduces, cuts-off, or even inhibits the power/energy supplied to any protected surfaces with increasing altitude in icing conditions above the Appendix C IM icing altitude, the aeroplane must be able to safely operate in icing conditions encountered at any altitude within the operational flight envelope, or an AFM limitation shall be introduced to prohibit operations in icing conditions at altitudes above a certified icing envelope.

The applicant has to follow one of the following options:

(1) The aeroplane is capable to safely operate in icing conditions above Appendix C IM envelope at any altitude within its flight envelope where icing conditions may exist; then the certified icing envelope is the aeroplane flight envelope, and no AFM limitation is required.

(2) The aeroplane is not capable to safely operate in icing conditions above the Appendix C IM icing altitude~~s~~; an AFM limitation is introduced to prevent aeroplane operation in icing conditions above the Appendix C IM icing altitude.

(3) The aeroplane is capable to safely operate in icing conditions up to a certain altitude between the Appendix C IM icing maximum altitude and its operational ceiling; an AFM limitation is introduced to prevent aeroplane operation in icing conditions above the demonstrated altitude and up to its ceiling.

Associated Means of Compliance.

An aeroplane IPS is considered optimised/modulated wherever an '*optimization*' logic is implemented at engine or aeroplane level. When an aeroplane is operated with such IPS logic, it may not be able to demonstrate safe operation in icing conditions above Appendix C IM altitude, at any altitude within its flight envelope where icing conditions may exist. In such a case the applicant should define the certified icing envelope where the aeroplane operation in icing conditions is unrestricted.

The applicant has 3 options as described in the Special Conditions text.

An applicant may demonstrate safe flight operation of an aeroplane with an optimised IPS design above Appendix C IM icing altitude through two compliance strategies, i.e.:

a) based on comparative analysis with previously certified IPS designs with safe flight-in-icing in-service experience, or

b) based on direct demonstration.

Below some guidance material for options a) and b).

Compliance Strategy/Option a)): Comparative Analysis

For a new aeroplane with an "optimised" IPS design having in Appendix C icing conditions comparable handling qualities and performance margins to a previous certified aeroplane, the applicant may demonstrate compliance with the Special Condition by means of a comparative analysis between the proposed "optimised" IPS above Appendix C IM icing altitude and a previously approved design, supported by safe flight-in-icing in-service history in the entire certified aeroplane operating envelope.
The analysis should demonstrate that the new IPS provides comparable performance as the reference one within the respective aeroplane operational envelopes. The applicant might claim that although the IPS thermal flow is optimised above Appendix C IM altitude, it remains comparable in term of ice protection to former IPS design in the reference fleet. Both aeroplane operational envelopes and the kind of operation of the IPS should be comparable.

Compliance Strategy/Option a)): Direct Demonstration

Applicants may seek for direct demonstration to validate that the aeroplane, while operated with an optimised/modulated or even inhibited IPS above the Appendix C IM icing altitude, is still safe. For the evaluation of safe operation, the applicant should assess the degradation of performance and handling qualities created by the potential ice accretion on the aeroplane unprotected and protected parts. Furthermore, the applicant should assess the impact of the sudden release of ice accretions from aeroplane surfaces on the engines and essential equipment[4]. An icing scenario for flight above Appendix C IM icing altitude is provided in the Annex 1.

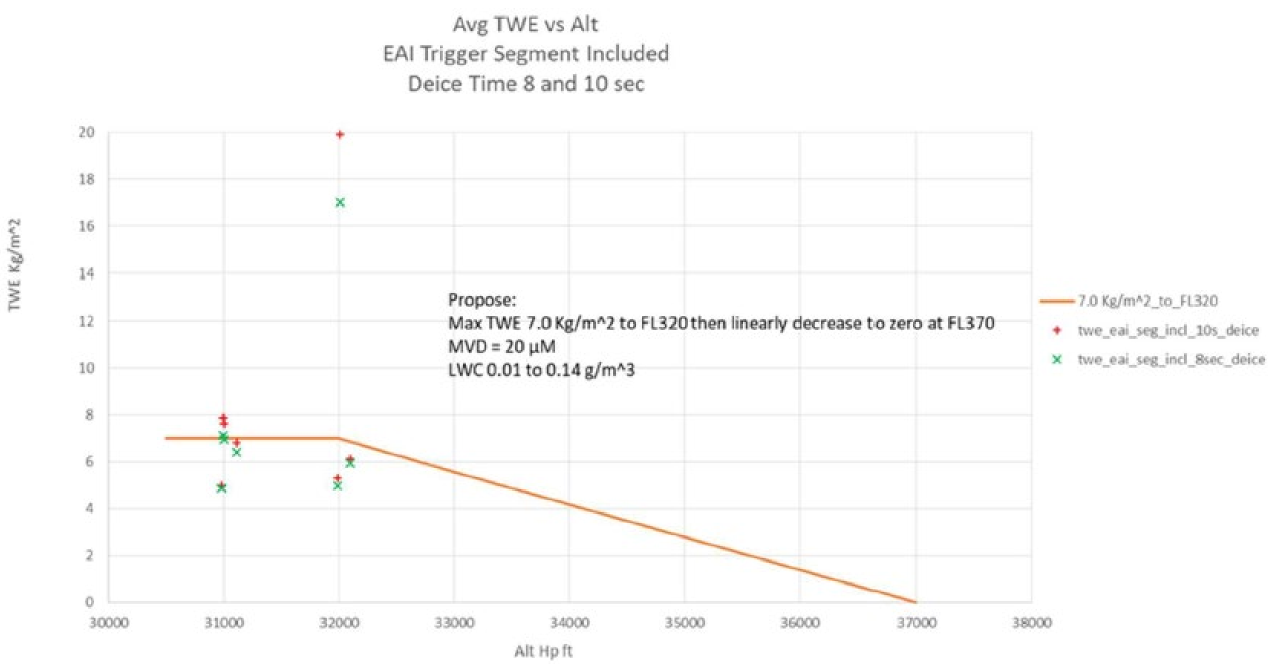
[4] *Essential* is a definition/attribute of a system equipment that contributes to hazardous or catastrophic failure conditions.

Annex 1: Interim icing scenario above CS-25 Appendix C IM icing envelope

The AIA-ASD industry group proposed an interim icing scenario for flight above FL300. The scenario is based on Total Water Exposure (TWE), which is a measure of Liquid Water Content (LWC) multiplied by the distance travelled.

The interim scenario proposes a constant TWE of 7.0 kg/m^2 above the CS 25 Appendix C Intermittent Maximum extension up to FL320, then linearly decrease the TWE to 0 kg/m^2 at FL370, with MVD 20 µm and SAT ISA+16°C. A range of LWC between 0.01-0.14 g/m^3 should be considered for criticality. The distance factor is already accounted for in the range of LWC values, so no further distance factor should be applied.

A visual representation of this scenario definition is provided below and includes the 7 analyzable WAI occurrences from the Boeing data that were >FL300:



These data are analytical approximations and include uncertainties.

Each point is referred to as an "average". The LWC and TWE for each point were calculated two ways, one assuming the icing ceased immediately after the last detector cycle, and the other assuming ice continued to accrete during the persist time but just shy of triggering a subsequent cycle. The average of those two then becomes the resulting "average LWC (or TWE)." The uncertainty contribution due to this is ~ + 20% for LWC, and ~ + 0.5 kg/m^2 for TWE.

Additional uncertainty is due to the assumed time required for the detector to deice itself and then begin re-accreting ice (referred to subsequently as “deice time”). This is believed to be between 6 and 10+ seconds. The results shown are for 8 and 10 seconds of deice time. As deice time increases, so does the calculated LWC and TWE. The proposed “max LWC” of 0.14 g/m^3 is based on 10 seconds. It is believed that 10 seconds is conservative. Transonic tunnel testing such as at the ice detector supplier could significantly reduce this uncertainty.

The proposed 7 kg/m^2 TWE up to FL320 is chosen to fit well with all points except the high outlier of ~19 kg/m^2 at FL320. That point is proposed to be omitted since it is a single occurrence across the over 950,000 flights surveyed. In addition, the average TWE across all seven points and including that outlier is 8.4 kg/m^2 using a 10 second deice time and reduces to 7.6 kg/m^2 using 8 seconds. If that outlier is omitted, the averages are 5.3 kg/m^2 and 4.9 kg/m^2, respectively.

Note: In earlier discussions across industry and with the regulators, the initial EAI trigger for these WAI points was omitted. The data presented here and the proposed scenario now include those segments. The effect of this was to increase the TWE values by slightly more than 1 kg/m^2 each.