

Aerodynamic Design Considerations for Flight in Icing Conditions



**SAE Aircraft & Engine Icing International Conference & Exhibition
September 2007**

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Background

- **Commercial air traffic have increased significantly over the past 40 years to meet the demands of ever increasing number of both air travelers and complex air routes covering every corner of the globe.**
- **The Flight Test Harmonization Working Group (FTHWG), with representatives from FAA, JAA, Transport Canada and the industry, was formed to review the FAR/JAR requirements and propose new and harmonized requirements relevant to A/C handling and performance during flight in icing conditions.**
- **The following provides an overview of the proposed new rules and how they would affect future A/C aerodynamic design approach for flight in icing conditions.**

Past Certification Requirements

- **The only FAR/JAR 25 reference to performance and handling criteria for flight in icing conditions is contained in:**

- “25.1419 Ice Protection

If certification with ice protection provisions is desired, the airplane must be able to safely operate in the continuous maximum and intermittent maximum icing conditions of Appendix C. ...”

- Part 25 Appendix C: defines atmospheric conditions for maximum continuous and maximum intermittent icing: altitude/ temperature envelope, liquid water content, mean effective drop diameter, horizontal cloud extent / liquid water content factor.

- **Issues identified with past requirements:**

- The interpretations of “safely operate” were contained in various guidance/advisory material, special conditions and in some cases specialists agreements documented in minutes of meetings.
- “Level Playing Field” was not maintained when addressing performance degradation in icing conditions.
- The definition of ice accretion varied between different authorities.
- The scope of certification flight testing, in dry air and in natural icing, also varied between different authorities.

Recent Changes

- **Revised Part 25 subpart B requirements**
 - Relevant A/C handling characteristics requirements clearly identified with:
 - Ice accretions on unprotected aerodynamic surfaces
 - Inter-cycle, transient or residual ice on protected surfaces with ice protection systems normally operating.
 - Ice accretions prior to normal system operation
 - Ice accretion on protected surfaces after ice protection systems failures.
 - Ice accretion effects on A/C performance were accounted for when flight in icing conditions including take-off phase
- **Revised Part 25 Appendix C**
 - Introduction of different ice shapes for different phases of flight.
- **New Advisory material (AC)**
 - Sandpaper ice must be considered to address tailplane stall and elevator overbalance issues
 - Roughness added to artificial ice shapes
 - Flight testing with artificial ice shapes and in natural icing clearly defined.

Future Changes

- **Introduction of new Part 25 A/C flight characteristics requirements:**
 - When flight in Appendix X freezing rain or freezing drizzle icing conditions, outside those defined in Appendix C, airplanes must be capable of either:
 - Detecting and safely exiting Appendix X conditions, or
 - Unrestricted operation in Appendix X icing conditions
- **Introduction of new Part 25 Appendix X**
 - Defines relevant atmospheric conditions for freezing rain and freezing drizzle.
- **Introduction of new Advisory Material (AC)**
 - Possible ice accretion behind protected wing leading edges (ridge ice) must be considered to address wing stall and aileron overbalance issues

Aerodynamic Design Considerations

- **Early design considerations for flight in icing condition will not only improve A/C performance and handling capabilities but will also reduce certification schedule & costs risks.**
- **Relevant FAR 25 performance and handling icing requirements are considered throughout all design phases. Some of the topics relevant to aerodynamic design activities are discussed in this presentation:**
 - Wing Design & sizing
 - Empennage design & sizing
 - Airplane stall characteristics
 - Airplane handling characteristics
 - Airplane performance
 - Means of ice detection
 - Effect of de-icing fluids

Design Considerations, Wing Design

- **Wing sizing & wing aerodynamic design is no longer solely based on clean (non-contaminated) wing leading edges:**
 - Type of wing leading edge (hard Vs. slatted), leading edge contours and wing twist will consider effects of ice accretion prior to normal system operation on A/C stall warning, stall onset and stall characteristics.
 - Type of wing ice protection system and coverage extent will consider effects of inter-cycle, transient or residual ice on A/C stall characteristics, stall speeds and climb gradient capabilities.
 - Ice protection system bleed requirements during T/O will consider effects of T/O ice on A/C stall characteristics, stall speeds and climb gradient capabilities
 - Size and type of aileron control (Powered or manual) will consider effects of inter-cycle, transient or residual ice on aileron aerodynamic hinge moment characteristics
 - Wing aerodynamic design will also consider effects of anti-icing/de-icing fluids on wing lift capabilities during take-off

Design Considerations, Horizontal Tail Sizing

- **Horizontal tail sizing is no longer solely based on clean (non-contaminated) leading edges:**
 - Tail sizing to meet A/C loadability & center of gravity range requirements considers ice accretions on tail leading edges
 - Moveable Horizontal stabilizer travel limits requirements considers ice accretions on tail leading edges
 - Requirements for tail ice protection system will consider effects of sandpaper ice and holding ice accretion on tailplane stall during low “g” maneuvers and when trimming at center of gravity limits.
 - Type of elevator control (Powered or manual) and requirements for tail ice protection system will consider effects of sandpaper ice and holding ice accretion on elevator hinge moment characteristics

Design Considerations, A/C Stall Characteristics

- **While A/C stall characteristics can be acceptable & certifiable with clean (non-contaminated) wing leading edges, effects of ice accretions with ice protection system normally operating may result in unacceptable stall characteristics:**
 - Significant stall warning (buffeting) onset advance
 - May require artificial stall warning (stick shaker) firing angles to be different when flight in icing conditions
 - May result in A/C performance penalties, when flight in icing conditions, due to increase minimum operation speeds in order to meet minimum maneuvering capabilities requirement
 - Significant stall onset advance and loss in CLmax
 - May require max. angles of attack settings to be different when flight in icing conditions for A/C equipped with stall prevention systems,
 - May require artificial stall warning (stick shaker) firing angles to be different when flight in icing conditions in order to meet minimum stall warning requirements
 - May result in A/C performance penalties due to increase minimum operating speeds in order to meet minimum stall speed factors or minimum maneuvering capabilities requirement
 - For tapered & swept wings, flow separation at stall onset may start more outboard on the wing (compared to clean) resulting in unacceptable stall characteristics due to pitch up or roll-offs

Design Considerations, A/C Stall Characteristics

- **Effects of ice accretion prior to normal system operation (typically thin layer of rough ice) also need to be considered during stall entries**
 - For tapered & swept wings, flow separation at stall onset may start more outboard on the wing (compared to clean) resulting in unacceptable stall characteristics due to pitch up or roll-offs
 - Significant stall onset advance may result in inadequate stall warning margin
- **Ice accretion on horizontal tail leading edges may also result in changes to A/C stall characteristics**
 - Possible reduction in elevator effectiveness during stall entry & recovery
 - For manual elevators, elevator hinge moment characteristics may be adversely affected by ice accretion at high angles of attack near the stall & during recovery

Design Considerations, Airplane handling characteristics

- **Effects of most critical ice accretions on pilot control forces characteristics need to be considered during handling certification maneuvers**
 - Ice accretions on forward facing aerodynamic surfaces may affect basic A/C stability and control surfaces effectiveness.
 - Ice accretions may adversely affect control surfaces hinge moment characteristics especially for A/C equipped with manual controls
- **Effects of most critical ice accretion on A/C buffeting characteristics need to be considered.**
 - Difficult to predict, judged based on past experience.
 - Operating procedures in icing conditions are usually assessed during flight testing.

Design Considerations, Airplane performance

- **Effects of T/O ice accretion need to be considered when establishing aircraft T/O performance capabilities**
 - T/O ice on unprotected surfaces is typically a thin layer of rough ice
 - Ice protection system operation logic requirements during T/O will define T/O ice accretion levels.
 - Ice protection system engine bleed requirements may reduce Max. T/O thrust available.
 - T/O ice may result in Significant stall onset advance, loss in CLmax and A/C performance penalties due to increased stall speeds and minimum operating V2 speeds in order to meet minimum stall speed factors or minimum maneuvering capabilities requirement
 - T/O ice may result in significant increase in A/C drag and reduced A/C first & second segment Climb gradient capabilities

Design Considerations, Airplane performance

- **Effects of holding ice or landing ice need to be considered when establishing aircraft landing Performance**
 - Ice protection system operation logic during holding, approach and landing will define most critical ice accretion
 - Ice protection system engine bleed requirements may be more critical with approach/idle engine power settings.
 - Critical ice may result in Significant stall onset advance, loss in CL_{max} and A/C performance penalties due to increased stall speeds and minimum operating V_{ref} speeds in order to meet minimum stall speed factors or minimum maneuvering capabilities requirement
 - Critical ice may result in significant increase in A/C drag and reduced A/C approach & landing climb gradient capabilities
- **Single engine ceiling capabilities**
 - Critical ice may result in significant increase in A/C drag and reduced A/C single engine ceiling capabilities.

Design Considerations, Means of ice detection

- **Use of ice detectors is the current standard practice in aircraft design and provides reliable means of detection. Airplanes not equipped with ice detectors will need to consider more stringent requirements during low “g” maneuvers and during stall entries**
- **Although handling requirements with ice accretion prior to normal system operation is not intended to penalize aircraft performance capabilities in non-icing conditions, early design decisions on wing design philosophy or means of detection may result in performance penalties in non-icing conditions**
- **Automatic (Vs. manual) ice protection system turn-on primarily reduce pilot workload.**

design Considerations, Effect of de-icing fluids

- **De-icing fluids flow off characteristics not only depend on type of fluid and hold over times, but also depend on A/C take-off speeds and wing aerodynamic design in terms pressure gradients distributions and aerodynamic quiet areas**
- **Effects of residual fluids on wing A/C lift capabilities during T/O rotation, lift-off and climb-out need to be considered**
 - Difficult to predict, judged based on past experience
 - Operating procedures in icing conditions are usually assessed during flight testing.
- **Effects of residual fluids on control surfaces effectiveness need to be considered**
 - Difficult to predict, judged based on past experience
 - Operating procedures in icing conditions are usually assessed during flight testing.

Challenges & Opportunities

- **Development of aerodynamic surfaces “more tolerant” to small amounts of rough ice to minimize possible adverse aerodynamic effects**
- **Development of more energy efficient ice protection systems using alternate and/or new technologies**
- **Development of more capable ice detectors using alternate and/or new technologies**
- **In parallel:**
 - **Improvement of weather forecasting tools and facilities.**
 - **Availability of meteorological data through efficient communication network**
 - **Increased pilot awareness**













Conclusions

- **The new harmonized FAR25 requirements for flight in icing conditions is comprehensive and provide the needed clarifications for future aircraft designs**
- **Early aerodynamic design considerations are required to minimize program cost and schedule risks when developing new aircraft**
- **Development of aerodynamic surfaces “more tolerant” to small amounts of rough ice is a major challenge to the Aerodynamics community.**

THANK YOU

QUESTION?

