AC 91-51A - EFFECT OF ICING ON AIRCRAFT CONTROL AND AIRPLANE DEICE AND ANTI-ICE SYSTEMS

U.S. Department of Transportation
Federal Aviation Administration

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Initiated by: AFS-820

1. PURPOSE. This advisory circular (AC) provides information for pilots regarding the hazards of aircraft icing and the use of airplane deice and anti-ice systems.

2. CANCELLATION. AC 91-51, Airplane Deice and Anti-ice Systems, dated September 15, 1977, is canceled.

3. RELATED READING MATERIAL. The information contained in this AC complements the documents listed below.

a. Current editions of the following AC's may be obtained at no cost by sending a written request to U.S. Department of Transportation, Subsequent Distribution Center, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785:

(1) AC 20-117, Hazards Following Ground Deicing and Ground Operations in Conditions Conducive to Aircraft Icing.

(2) AC 135-16, Ground Deicing and Anti-icing Training and Checking.

(3) AC 135-17, Pilot Guide, Small Aircraft Ground Deicing.

b. Current editions of the publications below may be purchased from: New Orders, Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250-7954.

(1) AC 00-6, Aviation Weather.

(2) AC 00-45, Aviation Weather Services.

(3) AC 61-21, Flight Training Handbook.

(4) AC 61-23, Pilot's Handbook of Aeronautical Knowledge.

4. BACKGROUND. A review of aircraft accident and incident reports indicates that pilots may not be fully aware of the effects of icing on aircraft control. The review also indicates that pilots may be unaware of the limitations of aircraft deice and anti-ice systems and the conditions under which those systems are approved for flight into icing conditions.

5. DISCUSSION. One of the hazards to flight is aircraft icing. Pilots should be aware of the conditions conducive to icing, the types of icing, the effects of icing on aircraft control and performance, and the use and limitations of aircraft deice and anti-ice equipment.

a. It is important that a pilot understand the conditions which are conducive to icing. An understanding of these conditions allows the pilot to evaluate the available weather data and make an educated decision as to whether an intended flight should be made. One of the best sources of available weather data is pilot reports. The Federal Aviation Administration (FAA) encourages all pilots to report their flight conditions when warranted.

(1) For ice to form, there must be moisture present in the air and the air must be cooled to a temperature of 0° C (32° F) or less. Aerodynamic cooling can lower the temperature of an airfoil to 0° C even though the ambient temperature is a few degrees warmer. However, when the temperature reaches -40° C (-40° F) or less, it is generally too cold for ice to form. Ice is identified as clear, rime, or mixed. Rime ice forms if the droplets are small and freeze immediately when contacting the aircraft surface. This type of ice usually forms on areas such as the leading edges of wings or struts. It has a somewhat rough looking appearance and is a milky white color. Clear ice is usually formed from larger water droplets or freezing rain that can spread over a surface. This is the most dangerous type of ice since it is clear, hard to see, and can change the shape of the airfoil. Mixed ice is a mixture of clear ice and rime ice. It has the bad characteristics of both types and can form rapidly. Ice particles become imbedded in clear ice, building a very rough accumulation.

(2) The following table lists the temperatures at which the various types of ice will form.

Table 1: Temperature Ranges for Ice Formation

Outside Air Temperature Range	Icing Type
0°C to -10°C	Clear
-10°C to -15°C	Mixed Clear and Rime
-15°C to -20°C	Rime

b. There are two kinds of icing that are significant to aviation: structural icing and induction icing. Structural icing refers to the accumulation of ice on the exterior of the aircraft; induction icing affects the powerplant operation. Significant structural icing on an aircraft can cause aircraft control and performance problems. The formation of structural icing could create a situation from which the pilot might have difficulty recovering and, in some instances, may not be able to recover at all. To reduce the probability of ice buildup on the unprotected areas of the aircraft, a pilot should maintain at least the minimum airspeed for flight in sustained icing conditions. This airspeed will be listed in the airplane flight manual (AFM).

(1) Structural icing can block the pilot tube and static ports and cause the breakage of antennas on the aircraft. This can cause a pilot to lose or receive erroneous indications from various instruments such as the airspeed indicator and altimeter and can cause a loss of communications and radio navigation capabilities.

(2) The most hazardous aspect of structural icing is its aerodynamic effects. Ice can alter the shape of an airfoil. This can cause control problems, change the angle of attack at which the aircraft stalls, and cause the aircraft to stall at a significantly higher airspeed. Ice can reduce the amount of lift that an airfoil will produce and increase drag several fold. Additionally, ice can partially block or limit control surfaces which will limit or make control movements ineffective. Also, if the extra weight caused by ice accumulation is too great, the aircraft may not be able to become airborne and, if in flight, the aircraft may not be able to maintain altitude. For this reason, Title 14 of the Code of Federal Regulations (14 CFR) prohibits takeoff when snow, ice, or frost is adhering to wings, propellers, or control surfaces of an aircraft. This clean aircraft concept is essential to safe flight operations.

(3) Another hazard of structural icing is the possible uncommanded and uncontrolled roll phenomenon referred to as roll upset that is associated with severe in-flight icing. Pilots flying airplanes certificated for flight in known icing conditions should be aware that severe icing is a condition that is outside of the airplane's certification icing envelope. Roll upset may be caused by airflow separation (aerodynamic stall) inducing self-deflection of the ailerons and loss of or degraded roll handling characteristics. This phenomena can result from severe icing conditions without the usual symptoms of ice accumulation or a perceived aerodynamic stall.

(4) The term "severe icing" is associated with the rapid growth rate of visible ice shapes most often produced in conditions of high liquid water content and combinations of other environmental and flight conditions. Severe icing is often accompanied by aerodynamic performance degradation such as high drag, aerodynamic buffet, and premature stall.

(5) In addition, ice associated with freezing rain or freezing drizzle can accumulate on and beyond the limits of an ice protection system. This kind of ice may not produce the familiar performance degradation; however, it may be potentially hazardous. Freezing rain and freezing

drizzle contain droplets larger than the criteria specified by certification requirements. Temperatures near freezing can produce severe icing.

(6) Another hazard structural icing is the sailplane (empennage) stall. Sharp-edged surfaces are more susceptible to collecting ice than large blunt surfaces. For this reason, the sailplane may begin accumulating ice before the wings and can accumulate ice faster. Because the pilot cannot readily see the sailplane, the pilot may be unaware of the situation until the stall occurs. There have been reports of ice on the sailplane without any visible ice on the wing. This can occur if the sailplane has not or cannot be deiced.

(7) A sailplane stall occurs when, as with the wing, the critical angle of attack is exceeded. Since the horizontal stabilizer counters the natural nose down tendency caused by the center of lift of the main wing, the airplane will react by pitching down, sometimes uncontrollably, when the sailplane is stalled. Application of flaps can aggravate or initiate the stall. The pilot should use caution when applying flaps during an approach if there is the possibility of icing on the sailplane.

(8) Perhaps the most important characteristic of a sailplane stall is the relatively high airspeed at the onset and, if it occurs, the suddenness and magnitude of the nose down pitch. A stall is more likely to occur when the flaps are approaching the fully extended position, after nose down pitch and airspeed changes following flap extension, or during flight through wind gusts.

c. Small aircraft engines commonly employ a carburetor fuel system or a pressure fuel injection system to supply fuel for combustion. Both types of induction systems hold the potential for icing which can cause engine failure.

(1) The pilot should be aware that carburetor icing can occur at temperatures between -7° C (20° F) and +21° C (70° F) when there is visible moisture or high humidity. This can occur in the carburetor because vaporization of fuel, combined with the expansion of air as it flows through the carburetor, causes sudden cooling, sometimes by a significant amount within a fraction of a second. Carburetor ice can be detected by a drop in rpm in fixed pitch propeller airplanes and a drop in manifold pressure in constant speed propeller airplanes. In both types, usually there will be a roughness in engine operation. Some airplanes are equipped with carburetor heat for use in both prevention and removal of ice. The pilot should consult the AFM or the pilot's operating handbook for the proper use of carburetor heat.

(2) Fuel injection systems are less susceptible to icing than the carburetor system. Ice, which can partially or totally block the air from entering the engine, forms on the air intake of the engine. The usual indication of icing in a fuel injection system is the same as in a carburetor system. An alternate air source located inside the engine cowling is used to provide air to the engine to continue

combustion. Usually, this source is operated automatically and has a manual backup system that can be used if the automatic system malfunctions.

d. Ice detection is very important in dealing with icing in a timely manner. A careful preflight of the aircraft should be conducted to ensure that all ice or frost is removed before takeoff. This is especially true in larger aircraft where ice is difficult to see in some locations. Also, it is more difficult to detect ice during flight on such areas as the tail, which may be impossible to see. At night, aircraft can be equipped with ice detection lights which will assist in detecting ice. Being familiar with the airplane's performance and flight characteristics will also help in recognizing the possibility of ice. Ice buildup will require more power to maintain cruise airspeed. Ice on the sailplanc can cause diminished nose up pitch control and heavy elevator forces, and the aircraft may buffet if flaps are applied. Ice on the rudder or ailerons can cause control oscillations or vibrations.

e. When operating in icing conditions on the ground or in flight, a pilot must have knowledge of aircraft deicing and anti-icing procedures. Deicing is a procedure in which frost, ice, or snow is removed from the aircraft in order to provide clean surfaces. Anti-icing is a process that provides some protection against the formation of frost or ice for a limited period of time. There are various methods and systems which are used for deicing and anti-icing. A pilot must be knowledgeable regarding the systems and the procedures to be used on the specific aircraft before operating in icing conditions.

(1) There are numerous methods which are capable of removing ice from an aircraft surface. One method is pneumatic boots. This system is commonly used on smaller aircraft and usually provides ice removal for the wing and tail section by inflating a rubber boot. Ice can also be removed by a heat system or by a chemical fluid. Deicing the propeller is usually done by electrical heat, but it can also be done with a chemical fluid.

(2) Anti-icing can be accomplished by using chemical fluid or a heat source. Anti-ice systems are activated before entering icing conditions to help prevent the ice from adhering to the surface. These methods provide protection for the wings, tail, propeller, windshield, and other sections of the aircraft that need protection.

Table 2: Icing Intensity, Accumulation, and Pilot Action

Intensity	Airframe Accumulation	Pilot Action
Trace	Ice becomes perceptible. Rate of accumulation of ice is slightly greater than	Unless encountered for one hour or more, deicing/anti-icing equipment and/or

	the rate of loss due to sublimation.	heading or altitude change not required.
Light	The rate of accumulation may create a problem if flight in this environment for one hour.	Deicing/anti-icing required occasionally to remove/prevent accumulation or heading or altitude change required.
Moderate	The rate of accumulation is such that even short encounters become potentially hazardous.	Deicing/anti-icing required or heading or altitude change required.
Severe	The rate of accumulation is such that deicing/anti-icing equipment fails to reduce or control the hazard.	Immediate heading or altitude change required.

f. For an airplane to be approved for flight into icing conditions, the airplane must be equipped with systems which will adequately protect various components. There are two regulatory references to ice protection: the application to airplane type certification in 14 CFR parts 23 and 25 and the operating rules contained in 14 CFR parts 91 and 135.

(1) With regard to ice protection, airplane type certification is currently accomplished by meeting either the requirements of § 23.1419 or § 25.1419. These rules require an analysis to establish the adequacy of the ice protection system for the various components of the airplane based on the operational needs of that particular aircraft. In addition, tests of the ice protection system must be conducted to demonstrate that the airplane is capable of operating safely in the continuous maximum and intermittent maximum icing conditions, as described in part 25, appendix C. The type certificate data sheet (TCDS) gives the certification basis for the airplane and lists the regulations with which the airplane has demonstrated compliance. Therefore, when an airplane complies with one of the regulations which refers to part 25, appendix C, the icing certification is indicated on the TCDS and in the AFM. The AFM lists the equipment required to be installed and operable. The AFM or other approved material will also show recommended procedures for the use of the equipment.

(2) The operating rules contained in §§ 91.527 and 135.227 also permit flight into specified icing conditions provided that the aircraft has functioning deice and/or anti-ice equipment protecting specified areas of the aircraft. There are aircraft with partial installations of deicing and/or anti-icing equipment that do not meet the certification or the operating regulatory requirements for flight into icing conditions. Those installations are approved because it has been demonstrated that the equipment does not adversely affect the aircraft's structure, systems, flight characteristics, or performance. In such cases, the ARM or other approved material must explain the appropriate

operating procedures for the partial deicing and/or anti-icing equipment and contain a clear statement that the aircraft is not approved for flight into known icing conditions.

(3) It is important for pilots to understand that an airplane equipped with some types of deice and/ or anti-ice systems may not be approved for flight into known icing conditions. To be approved for such flight, the airplane must be specifically certificated to operate in known icing conditions.

(4) Also, it is important to remember that the certification standards provide protection for the majority of atmospheric conditions encountered, but not for freezing rain or freezing drizzle or for conditions with a mixture of supercooled droplets and snow or ice particles. Some airfoils are degraded by even a thin accumulation of ice aft of the deicing boots which can occur in freezing rain or freezing drizzle.

6. SUMMARY. It is extremely important that pilots understand the dangers of aircraft icing. Even if an airplane is equipped and certificated to operate in known icing conditions, there are limitations. Flight into known or potential icing situations without thorough knowledge of icing and its effects and appropriate training and experience in use of deice and anti-ice systems should be avoided. It is important to know both the pilot's and the airplane's limitations. Pilots should become familiar with the types of weather associated with and conducive to icing and understand how to detect ice forming on the airplane. Pilots should know the adverse effects of icing on aircraft systems, control, and performance. They should also know how to respond to the situation if accidentally caught in icing conditions. A knowledgeable pilot is better prepared to make timely decisions and promptly recognize the factors that can contribute to aircraft icing accidents.

7. ADVISORY MATERIAL. The procedures and techniques discussed in this AC are advisory in nature. They are general guidance and should not be construed as required operating practices. This AC also contains numerous references to compliance with 14 CFR. The regulations themselves are not advisory, and compliance is required. Applicable operating limitations and procedures contained in manufacturers' FAA-approved flight manuals and other approved documents take precedence over the information contained in this AC. For specific guidance, pilots should consult the appropriate FAA approved flight manual.

/s/
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APPENDIX 1. ROLL UPSET

This appendix is a summary of the cues that a pilot should recognize and corrective actions that can be taken if the aircraft encounters an uncommanded or uncontrolled roll upset due to severe in-flight icing. It is based on the FAA's investigation of airplane accidents and incidents during or after flight in freezing rain or freezing drizzle conditions causing severe in-flight icing. The term "supercooled large droplets" (SLD) includes freezing rain or freezing drizzle.

The most effective means to identify severe icing are cues that can be seen, felt, or heard. The general information provided in this appendix is intended to assist pilots in identifying inadvertent encounters with SLD conditions. The suggestions below are not intended to be used to prolong flight in conditions which may be hazardous. Because of the broad range of environmental conditions, limited data available, and various airplane configurations, pilots must use the manufacturer's airplane flight manual (AFM) for specific guidance on individual types of aircraft.

> **Warning: This document describes two types of upset: roll upset and sailplane stall (pitch upset). The procedures for recovery from one are nearly opposite those for recovery from the other. Application of the incorrect procedure during an event can seriously compound the event. Correct identification and application of the proper procedure is imperative.**

DETECTING SLD

Cues:

1. Ice visible on the upper or lower surface of the wing aft of the active part of the deicing boots. It may be helpful to look for irregular or jagged lines or pieces of ice that are self-shedding. All areas to be observed need adequate illumination for night operation.

2. The aft limit of ice accumulation on the propeller spinner. Nonheated propeller spinners are useful devices for sorting droplets by size. SLD icing will extend beyond normal ice limits.

3. Granular dispersed ice crystals or total translucent or opaque coverage of the unheated portions of the front or side windows. This may be accompanied by other ice patterns on the windows such as ridges. These patterns may occur within a few seconds to one-half minute after exposure to SLD conditions.

4. Unusually extensive coverage of ice, visible ice fingers, or ice feathers on parts of the airframe not normally covered by ice.

Additional Cues Significant at Temperatures near Freezing:

1. Visible rain (consisting of very large water droplets). In reduced visibility conditions, select taxi/ landing lights "On" occasionally. Rain may also be detected by the sound of droplets impacting the aircraft.

2. Droplets splashing or splattering on impact with the windshield. Droplets covered by icing certification envelopes are so small that they are usually below the threshold of detectability. The largest size of the drizzle droplets covered is about the diameter of a 0.5mm pencil lead.

3. Water droplets or rivulets streaming on heated or unheated windows. The droplets or rivulets are an indication of high liquid water content (LWC) of any sized droplet.

4. Weather radar returns showing precipitation. Returns showing precipitation suggest that increased vigilance for all of the cues is warranted. Evaluation of the radar may provide alternative routing possibilities.

PREVENTION/CORRECTION

Before Takeoff:

1. Know the pilot weather reports (PIREP) and the forecast.

2. Know where the potential icing conditions are located in relation to the planned route and which altitudes and directions are likely to be warmer or colder. About 25% of the cases of SLD are found in stratiform clouds colder than 0° C at all levels with a layer of wind shear at the cloud top. There need not be a warm melting layer above.

In-Flight:

1. Maintain awareness of the outside temperature. Know where the freezing level static air temperature (SAT) is located. Be especially alert for severe ice formation at total air temperature (TAT) near 0° C or warmer (when the SAT is 0° C or colder). Many icing events have been reported at these temperatures.

a. SAT is what would be measured from a balloon, and would be the temperatures given in a forecast.

b. TAT is measured by a probe having velocity with respect to the air. Because of heating due to compression upstream of the probe, the total temperature will be warmer than the SAT. The difference is kinetic heating or the so called "ramrise." There is less kinetic heating in saturated air than in dry air because it takes less heat to raise the same unit mass by one degree. TAT and SAT are normally associated with air data systems.

2. Avoid exposure to SLD icing conditions, usually at temperatures warmer than -10° C (+14° F) SAT but possible at temperatures down to -18° C (-1° F) SAT. Be alert for cues and symptoms of SLD at temperatures down to -15° C (+5° F) SAT. Normally, temperature decreases between approximately 1.5° C (2.7° F) for saturated air to 2.75° C (5° F) for dry air with each 1,000 foot increase in altitude. In an inversion, temperature may actually increase with altitude.

Actions When Exposed to SLD Conditions:

1. Disengage the autopilot. Hand-fly the airplane. The autopilot may mask important cues or may self disconnect and present unusual attitudes or control conditions.

2. Advise air traffic control and promptly exit the condition, using control inputs that are as smooth and small as possible.

3. Change heading, altitude, or both to find an area that is warmer than freezing, substantially colder than the current ambient temperature, or clear of clouds. In colder temperatures, there may still be ice that has not completely shed adhering to the airfoil. It may be hazardous to make rapid descents close to the ground to avoid severe icing conditions.

4. When severe icing conditions exist, reporting may assist other crews in maintaining vigilance. Submit a PIREP of the observed icing conditions. It is important not to understate the conditions or effects of the icing observed.

Roll Control Anomaly:

1. Reduce the angle of attack (AOA) by increasing airspeed or extending wing flaps to the first setting if at or below the flaps extend speed (V_{FE}). If in a turn, roll wings level.

2. Set appropriate power and monitor the airspeed/AOA. A controlled descent is a vastly better alternative than an uncontrolled descent.

3. If flaps are extended, do not retract them unless it can be determined that the upper surface of the airfoil is clear of ice because retracting the flaps will increase the AOA at a given airspeed.

4. Verify that wing ice protection is functioning normally and symmetrically by visual observation of the left and right wing. If not, follow manufacturer's instructions.

SUMMARY

Roll upset may occur as a consequence of, or prior to, a wing stall due to anomalous forces that cause the ailerons to deflect or because the ailerons have lost effectiveness. Deflection of ailerons or loss of aileron effectiveness may be caused by ice accumulating in a sensitive area of the wing aft of the deicing boots under unusual conditions associated with SLD and, rarely, normal cloud droplets in a very narrow temperature range near freezing.

Pilots can minimize the chance of a roll upset by being sensitive to cues that identify severe icing conditions and promptly exiting the severe icing conditions before control or handling characteristics of the airplane are degraded to a hazardous level.

It is important to review the AFM for aircraft type-specific information. Also, pilots should check any available icing related bulletins from the airplane manufacturer.

APPENDIX 2. SUSPECTED TAILPLANE STALL

This appendix is a summary of the symptoms a pilot should recognize and corrective actions that can be taken if the airplane encounters a sailplane stall. This appendix applies only to airplanes having sailplane pitch control. It is not applicable to aircraft with foreplane (canard) pitch control.

On some airplane designs, if the horizontal sailplane is inadequately cleared of ice, either by anti-ice/deice system failure, failure to operate the system properly, or by ice, snow, or frost left on critical sections of the airfoil, a sailplane stall could occur. Generally, sailplane stall would be encountered immediately after extension of the trailing edge flaps to an intermediate position or, more commonly, after extension from an intermediate position to the full down position. Usually, sailplane stall (or impending stall) can be identified by one or more of the symptoms listed below occurring during or after flap extension. The symptom(s) may occur immediately or after nose down pitch, airspeed changes, or power increases following flap extension.

Warning: This document describes two types of upset: roll upset and sailplane stall (pitch upset). The procedures for recovery from one are nearly opposite those for recovery from the other. Application of the incorrect procedure during an event can seriously compound the event. Correct identification and application of the proper procedure is imperative.

TAILPLANE STALL SYMPTOMS

1. Elevator control pulsing, oscillations, or vibrations*

2. Abnormal nose down trim change*

3. Any other unusual or abnormal pitch anomalies (possibly resulting in pilot induced oscillations)*

4. Reduction or loss of elevator effectiveness*

5. Sudden change in elevator force (control would move nose down if unrestrained)

6. Sudden uncommanded nose down pitch

CORRECTIVE ACTIONS

If any of the above symptoms occur, the pilot should:

1. Immediately retract the flaps to the previous setting and apply appropriate nose up elevator pressure.

2. Increase airspeed appropriately for the reduced flap extension setting.

3. Apply sufficient power for aircraft configuration and conditions. (High engine power settings may adversely impact response to sailplane stall conditions at high airspeed in some aircraft designs. Observe the manufacturer's recommendations regarding power settings.)

4. Make nose down pitch changes slowly, even in gusting conditions, if circumstances allow.

5. If a pneumatic deicing system is used, operate the system several times in an attempt to clear the sailplane of ice.

> **Warning: Once a sailplane stall is encountered, the stall condition tends to worsen with increased airspeed and possibly may worsen with increased power settings at the same flap setting. Airspeed, at any flap setting, in excess of the airplane manufacturer's recommendations for the Bight and environmental conditions, accompanied by uncleared ice contaminating the sailplane, may result in a sailplane stall and uncommanded pitch down from which recovery may not be possible. A sailplane stall may occur at speeds less than V_{FE}.**

SUMMARY

Ice can form on the aircraft's tail at a greater rate than on the wing and can exist on the tail when no ice is visible on the wing. When ice is visible, do not allow ice thickness to exceed the operating limits for deicing system operation or the system may not shed the tail ice. If the control symptoms listed above are detected or ice accumulations on the tail are suspected, land with a lesser flap extension setting and increase airspeed commensurate with the lesser flap setting. Avoid uncoordinated flight (side or forward slips) and, to the extent possible, restrict crosswind landings because of the possible adverse effect on pitch control and the possibility of reduced directional control. Avoid landing with a tailwind component because of the possibility of more abrupt nose down control inputs. Increased landing distances must also be considered because of increased airspeed at reduced flap settings.

> **Warning: Freezing rain, freezing drizzle, and mixed conditions (snow and/or ice particles and liquid droplets) may result in extreme ice buildup on and aft of protected surfaces, possibly exceeding the capability of the ice protection system. Freezing rain, freezing drizzle, mixed conditions, and descent into icing conditions in clouds from above freezing temperatures may result in runback ice forming beyond protected surfaces where it cannot be shed and may seriously degrade airplane performance and control.**