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16. Abstract The design and validation of adequate aircraft ice protection has evolved into a specialized and technically complex area where many engineering disciplines are involved; namely, aeronautical, electrical, mechanical, electronics, chemical simulations, mathematical modeling, airframe/engine systems design, atmospheric physics, and meteorology. Research advances in any one discipline have a direct effect on updating the procedural technology used in the design and validation of ice protection configurations, equipment, and systems. Periodically the Federal Aviation Administration (FAA) provides documentation to assist regulatory certification teams and industry design engineers in standardizing testing and validating procedures. Examples of such documentation are "Engineering Summary of Airframe Icing Technical Data," FAA Report No. ADS-4 dated December 1968, and "Engineering Summary of Powerplant Icing Technical Data," FAA Report No. RD-77-76 dated July 1977. Although most of the information contained in these reports is still valid, some is outdated, and more usable information is now available through recent research and experience. Therefore, this work was directed towards developing an updated and more comprehensive combined version of Report ADS-4 and RD-77-76 that includes reference material on ground and airborne icing facilities, simulation procedures, and analytical techniques. This document represents all types and classes of aircraft and is intended as a working tool for the designer and analyst of ice protection systems.					
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SYMBOLS AND ABBREVIATIONS

<u>Symbol</u>	<u>Description</u>
AC	Advisory Circular
AGL	Above Ground Level
ATR	Air Transport Rating
°C	Degrees Celsius
CAR	Civil Air Regulation
DOT	Department of Transportation
°F	Degrees Fahrenheit
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
IFR	Instrument Flight Rules
LWC	Liquid Water Content
m	Meters
MVD	Median Volumetric Diameter
OAT	Outside Air Temperature
SFAR	Special Federal Aviation Regulation
STC	Supplemental Type Certificate
TC	Type Certificate
VFR	Visual Flight Rules

GLOSSARY

liquid water content (LWC) - The total mass of water contained in all the liquid cloud droplets within a unit volume of cloud. Units of LWC are usually grams of water per cubic meter of air (g/m^3).

median volume diameter (MVD) - The droplet diameter which divides the total water volume present in the droplet distribution in half; i.e., half the water volume will be in larger drops and half the volume in smaller drops. The value is obtained by actual drop size measurements.

micron (μm) - One millionth of a meter.

VI.1.0 U.S. CIVIL AVIATION REGULATIONS

VI.1.1 INTRODUCTION

The purpose of this section is to provide a review of U.S. Civil Aviation Regulations, i.e., Federal Aviation Regulations (FARs) relating to aircraft and engine certification for operations in known icing conditions. The applicable regulations are FAR Part 23 (reference 1-1), SFAR 23 (reference 1-10), and FAR part 25 (reference 1-2) for normal, small commuter, and transport category airplanes, respectively. (Large aircraft are defined as having takeoff gross weights in excess of 12,500 pounds.) FAR Parts 27 (reference 1-3) and 29 (reference 1-4) apply to normal (weight less than 6,000 pounds) and transport category rotorcraft, respectively; and FAR Part 33 (reference 1-5) applies to aircraft engines.

To be approved for flight into known icing conditions, an aircraft must be equipped with ice protection systems which are designed to provide protection when the aircraft is exposed to the icing conditions likely to be encountered in service, which is further quantified by reference to the FARs. There are two types of regulatory references to ice protection; one provided by the aircraft type design certification rules set forth in Federal Aviation Regulations Parts 23, 25, 27, 29, 33, and SFAR 23, and the other provided by the operating rules of Federal Aviation Regulations Parts 91, 121, and 135 (references 1-6 through 1-8).

Aircraft and engine type design certification, concerning ice protection, is accomplished by meeting the requirements of the appropriate FAR sections delineated below:

FAR Part 23

23.929
23.975
23.1093
23.1095
23.1097
23.1099
23.1101
23.1105
23.1309
23.1325
23.1416
23.1419
23.1559b
23.1583h

SFAR 23.34

FAR Part 25

25.929

25.975

25.1093

25.1105

25.1309

25.1323

25.1325

25.1403

25.1416

25.1419

Appendix C

FAR Part 27

27.1093

27.1419

27.1525

27.1583

FAR Part 29

29.1093

29.1101

29.1157

29.1419

29.1525

29.1583

Appendix C

FAR Part 33

33.66

33.68

33.77

In addition, there are two related Special Federal Aviation Regulations (SFARs). These are:

SFAR 29-4 (reference 1-11)

SFAR 41 (reference 1-12)

Along with SFAR 23, SFAR 41 pertains to certification of FAR Part 23 (reference 1-1) airplanes and SFAR 29-4 pertains to operation of helicopters in IFR conditions. SFAR 41 and SFAR 29-4 do not address aircraft icing requirements and therefore will not be discussed in the applicable FAR sections. The effectiveness of these SFARs is very limited and production of aircraft certified under their rules will cease in 1991.

The above rules give the minimum requirements for the design of aircraft and aircraft systems for safe flight into known icing conditions and define the meteorological parameters upon which these requirements are based. Compliance with the FARs normally requires a combination of analyses and testing because testing rarely can be performed at critical design points. Tests of the ice protection system must be conducted or similarity analyses must be performed to demonstrate that the airplane is capable of operating safely in continuous maximum and intermittent maximum icing conditions as defined in Appendix C of FAR Part 25 (reference 1-2) or Appendix C of FAR Part 29 (reference 1-4). A different baseline of icing conditions has been reported by Masters (reference 1-13) for altitudes below 10,000 feet (3048 m). Applicants, i.e., rotorcraft and certain small airplanes, may elect to seek certification for these altitude limited criteria; however these criteria should be treated as guidance since they are not regulatory.

The operating rules and aircraft ice protection systems required for flight into known or forecast icing conditions are given in the following:

FAR Part 91 (reference 1-6)

91.209

91.31

FAR Part 121 (reference 1-7)

121.341

121.342

121.629

FAR Part 135 (reference 1-8)

135.227

Appendix A, Paragraph No. 34

These rules require that no pilot fly under IFR into known or forecast icing conditions; or under VFR into known light or moderate icing conditions; unless the aircraft has functioning ice protection systems protecting each propeller, windshield, wing, stabilizing or control surface, and each airspeed, altimeter, rate of climb, or flight attitude system. Except for an airplane that is equipped with ice protection systems that meet the requirements in Section 34 of Special Federal Aviation Regulations (SFAR) No. 23, or those for transport category airplane type certification, no pilot may fly an airplane into known or forecast severe icing conditions.

Current regulations state that any equipment intended for de-icing or anti-icing must be shown to comply with the pertinent FARs before the FAA considers it to perform its intended function. In addition, unless operations at night in known or forecast icing conditions are prohibited by an operating limitation, a means must be provided for illuminating or otherwise determining the formation of ice on parts of the wings that are critical from the standpoint of ice accumulation (reference 1-2).

VI.1.2 FEDERAL AVIATION REGULATIONS (FARs)

1.2.1 FAR Part 23 (Normal Category Airplanes)

1.2.1.1 Introduction

The first small non-turbine powered airplanes were approved for flight into known icing conditions under CAR Part 3 (reference 1-14). However, some FAA guidance material was also suggested which added the following criteria:

- a. Conduct suitable tests under simulated icing conditions, or
- b. Make a rational analysis of the equipment based on similar types of equipment already known to fulfill its intended function.

The following areas were suggested by the FAA to require ice protection:

- a. Airspeed, altimeter, and rate of climb systems
- b. Propeller surfaces
- c. Flight surfaces
- d. Cockpit visibility, during approach and landing
- e. External radio masts or antennas

From these early requirements, icing certification has evolved more specific requirements which have been integrated into Part 23 (reference 1-1). Actually, the intent has not changed significantly, as can be seen by reviewing appropriate sections of references 1-1 and 1-14. The requirements listed in this Handbook reflect the current requirements. Further guidance on certification of small airplanes is found in references 1-15 and 1-16. The ice protection systems must be shown to meet these requirements under the conditions specified in Appendix C of FAR Part 25 (reference 1-2).

1.2.1.2 Airplanes Weighing Less than 12,500 Pounds (5680kg)

The specific paragraphs of FAR Part 23 (reference 1-1) pertaining to icing certification are listed in Section 1.1. Compliance procedures essential in meeting these regulations are discussed in Chapter V. However, there are many other considerations which the FAA has developed as background to these specific requirements. The following paragraphs discuss some of these considerations which form the overall basis for certification.

The principal ice protection requirements are stated in FAR paragraphs 23.1583, 23.929, 23.975, 23.1093, 23.1095, and 23.1419. These paragraphs describe the requirements for airplane flight manual, propeller, fuel vents, induction system, analysis, and tests, respectively, that are necessary for icing certification. In general, compliance can be established when there is reasonable assurance that while operating in the specified icing environment: (1) the engine(s) will not flame out or experience significant power losses or damage; (2) the handling qualities, performance, visibility, and systems operations do not deteriorate unacceptably; (3) external protrusions are not overstressed from ice

accumulation (e.g., antennas) that could endanger the aircraft or cause navigation and communication loss; and (4) inlet scoop blockage (e.g., oil cooler inlet) is not excessive.

Assessment of performance loss should include the drag and weight of the ice accumulated on the airfoil surfaces as well as electrical or other load demands of the ice protection system. It is understood, however, that the ice protected airplane may experience reduced performance and altered handling qualities (although not deteriorated unacceptably) due to ice accretions, even though the ice protection systems have been found to adequately remove or prevent ice build-up while the airplane is operating in icing conditions. The criteria for acceptable performance is based on showing that the airplane does not have any features or characteristics that will prevent it from safe operations when flying in icing conditions.

Compliance with FAR 23.1309 is a requirement for all systems, which covers the affect of a system on other systems and a hazard evaluation of the ice protection systems. Also, since many of the ice protection systems use electrical power for control or electro-thermal heat, compliance with FAR 23.1351 and 23.1357 is required. FAR 23.1351 is a general requirement on the electrical systems and equipment necessary for certification and FAR 23.1357 is a requirement for the provision of circuit protective devices for the airplane electrical system. FAR 23.1559(b) is a requirement for placarding which is employed to delineate airplane operational limitations (including operations in icing conditions) if the required systems are not installed. Another requirement for compliance is FAR 23.1583(h) which necessitates a statement relating to flight into known icing and listing any limitations in the airplane flight manual.

Windshield

In addition to the principal requirements discussed above, the windshield must comply with FAR 23.773 and 23.775(d). FAR 23.773 requires a thorough evaluation of the pilot's view. Both day and night flight evaluations are necessary to assure adequate visibility through the windshield when the ice protection system is both on and off. One item to consider with an electrically heated windshield is the fuzziness or "starring" effect which may reduce visibility. FAR Part 23 does not require that a defogging system be installed. However, if such a system is installed, it has to be evaluated for its effectiveness in maintaining adequate visibility through the windshield. If observation of wing ice accumulation or ice protection system operation is necessary, the cockpit side window must provide adequate visibility for this function. In some cases, a means of defogging the side window may be necessary.

Consideration should be made for other components such as the magnetic direction indicator. The high power required for an electrically heated windshield may cause magnetic deviations of more than 25 degrees. If a deviation of more than 10 degrees occurs, then a placard per FAR 23.1327 and 23.1547(e) is required.

Propeller

The propeller ice protection requirements are stated in FAR 23.929. Propellers must be protected against the accumulation of ice to enable satisfactory functioning without appreciable power loss in icing conditions. Unsymmetrical ice shedding from a propeller should not cause excessive vibration. In addition, care must be taken to avoid propeller damage from shed ice for a pusher (rear-mounted) engine airplane configuration.

Engine Induction Systems

Engine installation certification requirements for operation in icing conditions are stated in FAR paragraphs 23.1093, 23.1095, 23.1097, 23.1099, and 23.1105. These requirements specify the protection necessary for engine induction systems and carburetor de-icing. For certification the final proof of compliance is, of course, flight tests in natural or simulated icing conditions. The principal concerns are that the engine neither sustain damage nor experience inlet blockage that would result in appreciable power loss. On reciprocating engines, attention should be given to insuring that inlet air ducts are not restricted or blocked by ice accumulations. On turbopropeller engines, care should be taken to ensure that any movable induction air doors do not freeze in place so as to restrict operation. In addition, the inlet lip should be protected from ice accumulation that might shed into the engine and cause damage or serious power loss.

Fuel Vents

Fuel vents must comply with the requirements stated in FAR 23.975. Specifically, FAR 23.975(a)(1) requires fuel vents to be located and constructed to minimize the possibility of being obstructed by ice.

Static Pressure System

In addition to the general requirements listed in Section 1.2.1.2, the static pressure system must comply with FAR 23.1325(b)(3). Static port design or location should be such that the correlation between air pressure in the static system and true ambient pressure is not adversely altered when flying in icing conditions. An anti-icing means or an alternate static source may be used for compliance.

Airfoil Leading Edge Surfaces

The principal requirements for protection of airfoil leading edge surfaces were listed in Section 1.2.1.2. Additional requirements are stated for pneumatic boot de-icer systems in FAR 23.1416. The first step in achieving compliance is to evaluate each leading edge surface and determine if ice protection is actually necessary. There are cases where analysis or testing has demonstrated that some of these surfaces may not require ice protection. Unprotected surfaces are discussed further in Chapter I. The leading edges of lifting or control surfaces such as wings and horizontal stabilizers usually require ice protection.

Pitot Probe

The general requirements for protection of pitot probes were listed in Section 1.2.1.2. Since the airspeed system requires static pressure, the requirements of FAR 23.1325(b)(3) apply. In addition, a pitot probe should be protected against blockage from ice accumulations. This is usually achieved with an electro-thermal heating system.

Air Scoops

Ice protection of air scoop inlet lips or ducts may be required where blockage could affect system operation. Specific examples would be the cooling air requirements that are contained in FAR Paragraphs 23.1041 and 23.1061.

Stall Warning

The stall warning system must comply with the requirements of FAR Part 23.207. Ice protection of the stall warning sensor or transducer may not be necessary if substantiated by analyses. Where ice protection is necessary, FAR Parts 23.1301 and 23.1309 apply. The analysis usually involves the determination of the electrical heat required to prevent icing. In some cases, a successful installation on another aircraft approved for flight into known icing conditions could support and ease the verification process with a properly documented similarity analysis.

Antennas

Ice protection usually is not provided for antennas except to insure that ice shed from the antenna will not damage an essential part of the airplane or that an antenna structural failure, due to ice loading, will not result in a loss of communication or navigation capability. A certain amount of structural integrity must be included in the antenna design unless it adequately selfsheds. The design should include consideration of an exposure to FAR 25, Appendix C icing conditions.

1.2.1.3 Airplanes Weighing More Than 12,500 Pounds (5680 kg)

If the original certification for a Part 23 aircraft was prior to October 17, 1979, the applicant may, with some restrictions, apply for an amended or supplemental type certificate in the normal category for a reciprocating or turbopropeller powered multiengine airplane with a takeoff gross weight greater than 12,500 pounds (5680 kg). This amended or supplemental type certificate is granted under SFAR 41 (reference 1-12). Approval of airplanes certified to this criteria ends in 1991.

1.2.1.4 Special Federal Aviation requirements (SFARs)

The regulations for icing certification of SFAR 23 (reference 1-10) aircraft are similar to the current FAR Part 23 (reference 1-1) regulations. If certification for flight in icing conditions is desired, analyses and tests must demonstrate that the airplane is capable of operating safely in continuous maximum and intermittent maximum icing conditions as described in FAR Part 25, Appendix C (reference 1-2). In addition, SFAR 23.48 requires that there must be a means to indicate to appropriate flight crew members the functioning of the powerplant ice protection system (reference 1-10). The ice protection indicator could show, for example, that the engine anti-icing bleed air valve is open or that the inertial separator vanes are positioned in the ice protection mode. In some cases, the inlet lip could be heated continuously with engine exhaust and no indicator is required. In this case, it would have to be shown that there is no valve to fail and that a duct failure is not probable.

1.2.2 FAR Part 25 (Transport Category Airplanes)

1.2.2.1 Introduction

Transport Category Airplanes were first certified for flight into known icing conditions under CAR Part 4b (reference 1-17). Since that time, the FAA has issued much guidance material and rewritten the regulations. Currently, the ice protection requirements for commercial transports are specified in FAR Part 25 (reference 1-2). Demonstration of ice protection system compliance for unrestricted flight in icing conditions normally involves several paragraphs in FAR Part 25. These were enumerated in Section 1.1.

The requirements for demonstrating ice protection system compliance are contained in FAR Part 25, paragraphs 25.1093, 25.1309, 25.1416, and 25.1419. The specific compliance procedure will be influenced by the aircraft operating characteristics and the type of ice protection system used. In general, compliance can be established when there is reasonable assurance that while operating in the specified icing environment: (1) the engine(s) will not flame out or experience significant power losses or damage; (2) external protrusions are not overstressed from ice accumulations (e.g., antennas) that could endanger the aircraft or cause communication loss; (3) the handling qualities, performance,

visibility and systems operations are not deteriorated unacceptably; and (4) inlet scoop blockage (e.g., oil cooler inlet) is not excessive.

Assessment of aircraft performance during flight in icing conditions must account for the effects of the ice protection systems on electrical/mechanical or other engine load demands, accumulated ice on unprotected surfaces, and any residual ice on protected surfaces. It must be realized that the ice protected airplane may experience somewhat reduced performance and possibly altered handling qualities in severe icing conditions, even though ice protection systems have been proven to adequately remove or prevent ice accumulation while the airplane is operated in other less critical icing conditions.

This summarizes the general requirements of FAR paragraphs 25.1093 and 25.1419. Some requirements, such as FAR 25.1419(a), are straightforward. The following paragraph addresses additional general requirements. Specific requirements are outlined in subsequent paragraphs.

Compliance with FAR 25.1309 is a requirement for all systems which covers the affect of a system on other systems and a hazard evaluation of the ice protection systems. Also, since many of the ice protection systems use electrical power for control or electro-thermal heat, compliance with FAR 25.1351 and 25.1357 are required for electrically powered systems. FAR 25.1351 is a general requirement on the electrical systems and equipment and FAR 25.1357 is a requirement for the provision of circuit protective devices for the airplane electrical system. For certification the entire system, including both operating and monitoring functions, must meet FAR Paragraph 25.1309. This requires that the probability of a failure condition is expected to remain within limits which are related to the consequence of the failure condition. Icing flight approval of prior certified systems may comply with the intent of this paragraph by means of properly documented similarity.

The ice protection requirements of FAR Part 25 defines two meteorological icing condition regimes: continuous and intermittent maximum (as defined in Chapter I). The conditions for these requirements are plotted in figures 1-1 through 1-3 (Continuous) and figures 1-4 through 1-5 (Intermittent). Additional data for altitudes below 10,000 feet (3048 m) has recently been published by Masters (reference 1-13) and may be applied to Part 27 and 29 rotorcraft. This new characterization compared with the current FAR Part 25 Appendix C (reference 1-2) is shown in figures 1-7 and 1-8 for continuous maximum and intermittent maximum respectively.

The foregoing comments summarize the general requirements for FAR Part 25 icing certification. Specific requirements are outlined in the following paragraphs.

1.2.2.2 Windshield

In addition to the general requirements listed in Section 1.2.2.1, the windshield must comply with FAR paragraphs 25.773 and 25.775. FAR 25.773 requires a thorough evaluation of the pilot's view. Both day and night flight evaluations are necessary to assure adequate visibility through the windshield when the ice protection system is both on and off. One item to consider with an electrically heated windshield is the fuzziness or "starring" effect which may reduce visibility when

power is turned on. Also, the defogging system needs to be evaluated for its effectiveness in automatically maintaining adequate visibility through the windshield and compliance with FAR 25.773(a)(1). When observation of wing ice accumulation or ice protection system operation is necessary (see Section 1.2.2.7), the cockpit side window must provide adequate visibility for this function.

Consideration should be made for other components such as the magnetic direction indicator. The high power required for an electrically heated windshield could cause a magnetic deviation of more than 10 degrees. If this does occur, then a placard per FAR 25.1327 and FAR 25.1547 is required.

1.2.2.3 Propeller

The requirements for propeller ice protection are shown in FAR 25.929 (reference 1-2). If a combustible fluid is used for propeller de-icing, then Paragraphs 25.1181 through 25.1185 and 25.1189 may apply. These relate to power plant fire protection. These are in addition to the general requirements shown in Section 1.2.2.1. Although not directly associated with ice protection, propeller exposure to ice shedding should be considered. In some cases, ice shedding from other aircraft surfaces should be considered. In the case of a pusher (rear mounted) engine configuration, consideration should be given to ice shed into the propeller by the wing ice protection system or residual ice which could accumulate and break off. Companies building pusher airplanes have been required to investigate the areas of the airplane forward of the propeller to determine that ice shed will not impact and damage the propeller. Currently, the FAA is handling these cases by special condition.

1.2.2.4 Engine Inlet

The requirements for engine inlet certification for operation in icing conditions are stated in FAR 25.1093. The primary concerns are airflow blockage that would reduce engine performance and engine damage due to ingestion of ice (reference 1-18). The first concern is also addressed in Section 1.2.5 (Engines). The FAA also requires that areas of the airplane be investigated to determine if ice will accumulate on them and shed into the engine; such areas be protected to prevent ice accumulation and shedding. This requirement is stated in FAR Paragraph 25.1091(e).

1.2.2.5 Fuel Vents

Fuel vents must comply with the general requirements listed in Section 1.2.2.1. There are additional requirements which apply to the airplane which require compliance even though icing certification is not an issue. For example, FAR paragraph 25.975 requires fuel vents to be located and constructed to minimize the possibility of being obstructed by ice. Icing certification necessitates the demonstration that no fuel vent blockage occurs during flight into natural icing conditions.

1.2.2.6 Static Pressure System

In addition to the general requirements of Section 1.2.2.1, static pressure systems must comply with FAR paragraph 25.1325 (reference 1-2). FAR 25.1325 requires that static port design or location should be such that the correlation between air pressure in the static system and true ambient pressure is not adversely altered when flying in icing conditions. Compliance with FAR 25.1325 is included in the certification basis for older airplanes seeking icing approval. Heated static ports are usually necessary to show compliance.

1.2.2.7 Airfoil Leading Edge Surfaces

Primarily, compliance to the requirements discussed in Section 1.2.2.1 are necessary. Additional requirements are defined for pneumatic boot systems in FAR 25.1416. Compliance with FAR Paragraph 25.1416(c) has generally been interpreted to require the ability of the crew to observe the wing boot and if night operation is requested, a light for illuminating the wing boot is required. The first step in compliance to the requirements is to evaluate each leading edge surface and determine if ice protection is actually necessary. There are cases where analyses or testing has demonstrated that some of these surfaces may not require ice protection. Unprotected surfaces are discussed further in Chapter I.

1.2.2.8 Pitot Probe

In addition to the general requirements shown in Section 1.2.2.1, compliance with FAR Paragraph 25.1323(e) is required even though icing approval is not requested. This requires a heated pitot or equivalent means of preventing malfunction due to icing. This requirement is always included in the certification basis for older airplanes seeking icing approval. Compliance with FAR Paragraph 25.1326, "Pitot Heat Indicating Systems," is also required.

1.2.2.9 Air Scoops

There are no additional special requirements for air scoops. There are considerations which must be made for some air scoops where blockage could affect the operation of a particular system. Specific installations such as powerplant induction systems, inlet ducts, and induction system screens are covered by FAR paragraphs 25.1091, 25.1093, 25.1103, and 25.1105.

1.2.2.10 Stall Warning

The stall warning system must comply with the requirements of FAR Part 25.207. Ice protection of the stall warning sensor or transducer may not be necessary if substantiated by analyses. Where ice protection is necessary, FAR Parts 25.1301 and 25.1309 apply. The analyses usually involves the determination of the electrical heat required to prevent icing. In some cases, a successful installation on another aircraft approved for flight into known icing conditions could support and ease the verification process with a properly documented similarity analysis.

1.2.2.11 Antennas

Ice protection is usually not provided for antennas except to insure that ice shed from the antenna will not damage an essential part of the airplane or that an antenna structural failure, due to ice loading, will not result in a loss of communication or navigation capability. A certain amount of structural integrity must be included in the antenna design unless they adequately self-shed. The design should include consideration of an exposure to FAR 25 (Appendix C) icing conditions.

1.2.3 FAR Part 27 (Normal Category Rotorcraft)

Few helicopter operators have shown interest in qualifying small or normal (gross weight less than 6,000 pounds) category rotorcraft for operation in icing conditions. Designing a full ice protection system and demonstrating compliance will be a costly and time consuming exercise. FAR Part 27 (reference 1-3) contains three paragraphs that make reference to icing. FAA Advisory Circular 29-2 (reference 1-20) also contains three paragraphs that are helpful in showing compliance to Part 27 requirements pertaining to flight in icing conditions. The applicable FAR paragraphs are presented in Section 1.1. The information contained in FAA Advisory Circular 29-2 is reviewed in Chapter VII.

Only slight differences exist between requirements of FAR Part 27 (reference 1-3) and FAR Part 29 (reference 1-4) (see Paragraph 27.1093). Safe operation (Paragraph 27.1419) in the icing envelope of FAR Part 29 Appendix C is required. These icing envelopes are the same as presented in FAR Part 25 (reference 1-2) Appendix C. At the time these envelopes were derived, it was assumed that all airplanes would operate to at least 22,000 feet (6700 m). For present state-of-the-art rotorcraft, this assumption is not entirely valid. Hence, an altitude limited icing envelope, based on the same data used to derive the FAR Part 25 Appendix C envelope, is presented in FAA Advisory Circular 29-2 (reference 1-20) as an alternate to the full icing envelope. In addition, the recent work by Masters (reference 1-13) recommends a new characterization for altitudes below 10,000 feet (3048 m). However, neither of these latter characterizations are regulatory but are offered as options, selectable by the applicant.

1.2.4 FAR Part 29 (Transport Category Rotorcraft)

Many helicopter operators have shown interest in qualifying transport category rotorcraft for operation in icing. Transport category rotorcraft manufacturers have conducted rotor icing trials, but most of these efforts have not been completed. Designing a full ice protection system and demonstrating compliance has been a costly and time consuming exercise. FAR Part 29 (reference 1-4) and FAA Advisory Circular 29-2 (reference 1-20) each contain three paragraphs that make reference to icing (FAR 29.877 has been superceded by FAR 29.1419 although the FAA Advisory Circular retains the older paragraph references). The applicable FAA paragraphs are presented in Section 1.1. The information contained in FAA Advisory Circular 29-2 is discussed in detail in Chapter VII.

The icing envelopes for Transport Category helicopters is contained in FAR Part 29 Appendix C. These are identical to those of FAR Part 25 Appendix and are presented in figures 1-1 through 1-6. These icing envelopes have served as a satisfactory design criteria for fixed wing operations in icing conditions for over two decades. The envelopes extend to 22,000 feet (6700 m) with possible extensions to 30,000 feet (9140 m) and does not present icing severity as a function of altitude. At the time the envelopes were derived, it was assumed that all transport category airplanes would operate to at least 22,000 feet. For present state of the art rotorcraft, this assumption is not valid. Thus an altitude limited icing envelope, based on the same data used to derive the FAR part 25 (reference 1-2) Appendix C envelope, is presented in FAA AC 29-2 as an alternate to the full icing envelope. These envelopes are reproduced and presented as figures 1-9 through 1-12. In addition, recent work by Masters (reference 1-13) recommends a new characterization for altitudes below 10,000 feet (3048 m). These envelopes, as compared to FAR Part 25 Appendix C, are presented in figures 1-7 through 1-8. Neither of these latter envelopes are regulatory but are offered as options.

1.2.5 FAR Part 33 (Engines)

In order to become certified for flight by the Federal Aviation Administration, aircraft engines must demonstrate (by test, analysis or similarity) that they are capable of operating successfully in icing conditions (reference 1-5). In addition, the gas turbine engine must be capable of withstanding the foreign object ingestion test of FAR 33.77 without failure or hazard. The engine should be designed and demonstrated to be capable of ingestion of the most severe ice accumulation that could occur for the particular installation. The pertinent paragraphs of FAR Part 33 are listed in Section 1.1.

FAR paragraph 33.66 specifies that if bleed air from the engine is used for engine anti-icing and can be controlled, provision must be made for a means to indicate to the flight crew that the engine ice protection system is operating.

FAR 33.68 specifies the icing requirements for engine induction systems. The FAR Part 25 appendix C icing conditions apply and were discussed in Chapter I and are presented in figures 1-1 through 1-6 (reference 1-1). FAR 33.68(a) requires that the engine must operate throughout its flight power range without the accumulation of ice on engine components that would adversely affect engine operation or that would cause a serious loss of power or thrust in continuous maximum and intermittent maximum icing conditions. FAR 33.68(b) requires that the engine must be able to idle for 30 minutes on the ground with available air bleed for ice protection at its critical condition without adverse effect in a specified atmospheric condition, followed by a momentary operation at takeoff power or thrust.

The non-specific nature of FAR 33.68(a) allows each engine manufacturer to work out a set of mutually agreeable compliance tests with the Federal Aviation Administration pertaining to his specific engine in his specific test facility (reference 1-21).

FAR 33.77 states the foreign object ingestion requirements for engines. Paragraph 33.77(c) states that ingestion of water, ice, or hail, under prescribed conditions, may not cause a sustained loss of power or thrust or require the engine to be shut down. The ice ingestion requirement is presented in table 1-1. Paragraph 33.77(d) states that if the engine incorporates a protection device (e.g., a screen) in the engine inlet, then the ingestion requirement is waived if the ice cannot pass through the protective device, the protective device will withstand the impact of the ice, and if the ice stopped by the protective device does not obstruct the flow of induction air into the engine with a resultant loss of power or thrust greater than those values specified in FAR paragraph 33.77. Experience has shown that ice can build up on the back side of such screens with the potential of engine damage should the ice shed from the screen.

In general, ice protection systems on engines intended for installation in helicopters are subject to the same standards as for fixed wing aircraft engines. Some interesting helicopter icing phenomena which apply in a secondary manner to the engine are reported in reference 1-21 (FAA-RD-77-76, page 6-7).

VI.1.3 REFERENCES

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- 1-2 "Airworthiness Standards: Transport Category Airplanes," Federal Aviation Regulations, FAR Part 25, U.S. Department of Transportation, Federal Aviation Administration, Washington, D.C., 1986.
- 1-3 "Airworthiness Standards: Normal Category Rotorcraft," Federal Aviation Regulations, FAR Part 27, U.S.Department of Transportation, Federal Aviation Administration, Washington, D.C., 1986.
- 1-4 "Airworthiness Standards: Transport Category Rotorcraft," Federal Aviation Regulations, FAR Part 29, U.S.Department of Transportation, Federal Aviation Administration, Washington, D.C., 1986.
- 1-5 "Airworthiness Standards: Aircraft Engines," Federal Aviation Regulations, FAR Part 33, U.S.Department of Transportation, Federal Aviation Administration, Washington, D.C., 1986.
- 1-6 "General Operating and Flight Rules," Federal Aviation Regulations, FAR Part 91, U.S.Department of Transportation, Federal Aviation Administration, Washington, D.C., 1986.
- 1-7 "Certification and Operations: Domestic, Flag, and Supplemental Air Carriers and Commercial Operators of Large Aircraft," Federal Aviation Regulations, FAR Part 121, U.S.Department of Transportation, Federal Aviation Administration, Washington, D.C., 1986.
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- 1-17 "Airplane Airworthiness Transport Categories," Civil Air Regulation, CARPart 4b, Federal Aviation Agency, Washington, D.C., 1962.
- 1-18 Bowden, et al., "Engineering Summary of Airframe Icing Technical Data," FAA Technical Report ADS-4, General Dynamics/Convair, San Diego, California, 1964.
- 1-19 "Certification of Normal Category Rotorcraft," U.S.Department of Transportation, Federal Aviation Administration, AC 27-1, August 29, 1985.
- 1-20 "Certification of Transport Category Rotorcraft," U.S.Department of Transportation, Federal Aviation Administration, AC 29-2, May 20, 1983.
- 1-21 Pfeifer, G.D., et al., "Engineerind Summary of Powerplant Icing Technical Data," FAA Report No.FAA-RD-77-76, July 1977.
- 1-22 Jones, A.K. and Lewis, William, "Recommended Values of Meteorological Factors to be Considered in the Design of Aircraft Ice-prevention Equipment," NACA TN 1855, March 1949.
- 1-23 Hacker, P.T. and Dorsch, R.G., "A Summary of Meteorological Conditions Associated With Aircraft Icing and a Proposed Method of Selecting Design Criteria for Ice-Protection Equipment," NACA TN 2569, 1951.
- 1-24 Bergrun, Norman R. and Lewis, William, "A Probability Analysis of the Meteorological Factors Conducive to Aircraft Icing in the United States," NACA TN 2738, 1952.

TABLE 1-1. ICE INGESTION REQUIREMENTS FOR TURBINE ENGINES (REFEFENCE 1-5)

Foreign Object	Test Quantity	Speed of Foreign Object	Engine Operation	Ingestion
Ice	Maximum accumulation on a typical inlet cowl and engine face resulting from a 2-minute delay in actuating anti-icing system, or a slab of ice which is comparable in weight or thickness for that size engine.	Sucked in	Maximum cruise	To simulate a continuous maximum icing encounter at 25°F.

NOTE: The term "inlet area" as used in this section means the engine inlet projected area at the front face of the engine. It includes the projected area of any spinner or bullet nose that is provided.

Pressure altitude range, S.L. to 22,000 Ft.
Maximum vertical extent 6,500 Ft.
Horizontal extent, standard distance of 17.4 nmi

Source: (Reference 1-22)
Class III-M continuous maximum

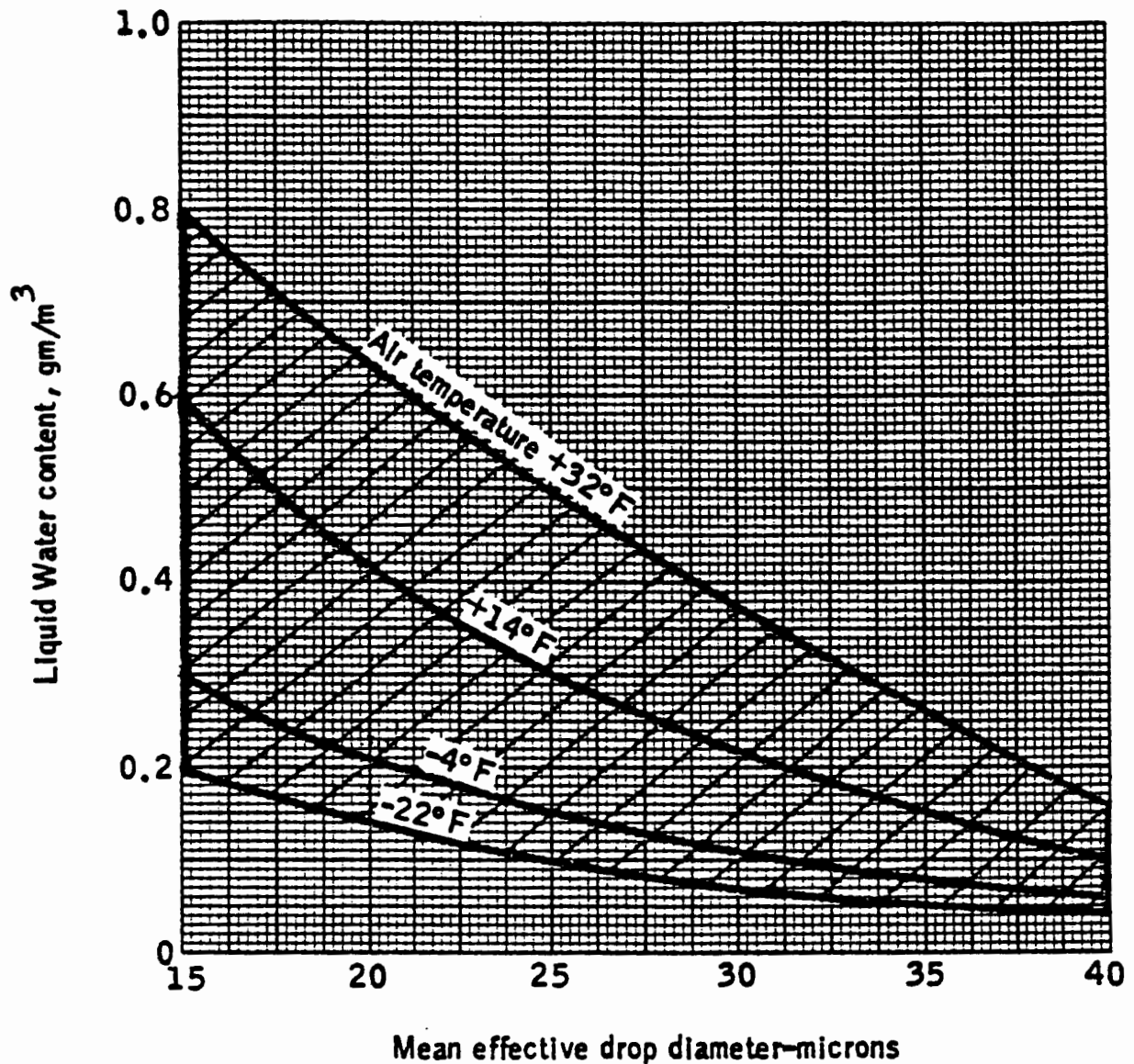


FIGURE 1-1. FAR PART 25 (APPENDIX C) CONTINUOUS MAXIMUM ATMOSPHERIC ICING CONDITIONS (STRATIFORM CLOUDS) - MEAN EFFECTIVE DROPLET DIAMETER VS. LIQUID WATER CONTENT (REFERENCE 1-2)

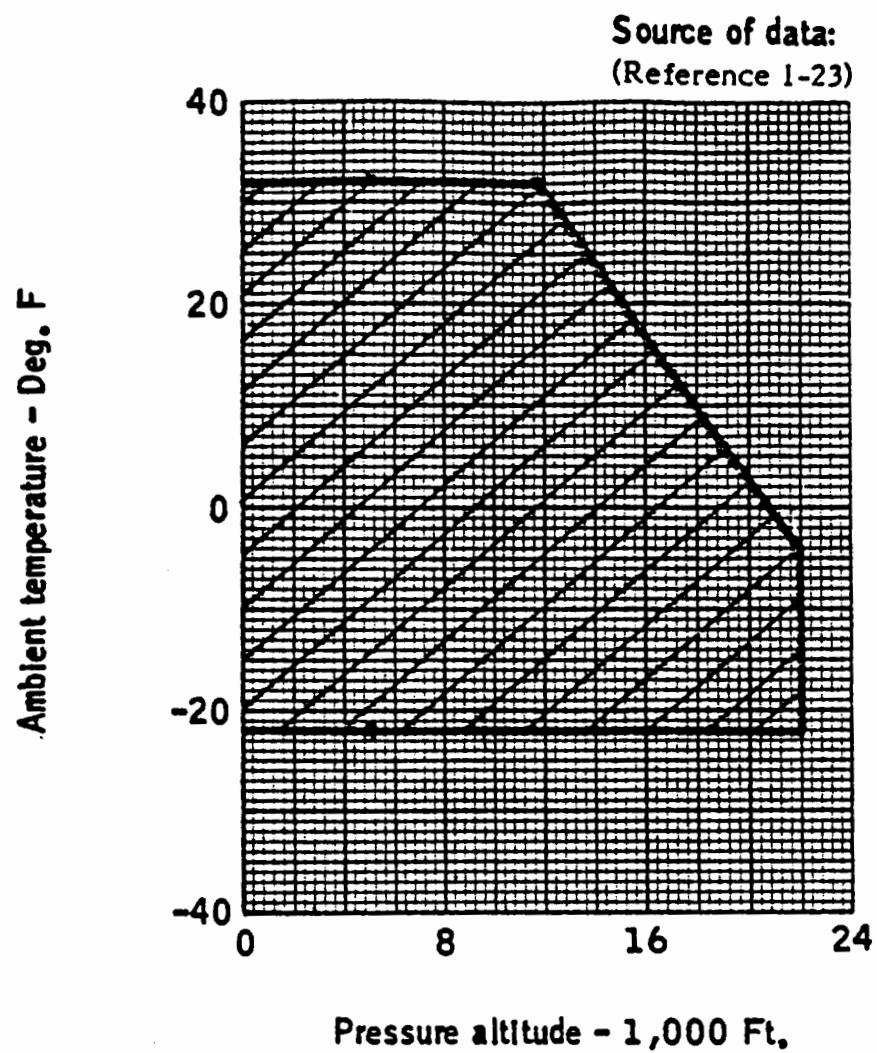


FIGURE 1-2. FAR PART 25 (APPENDIX C) CONTINUOUS MAXIMUM ATMOSPHERIC ICING CONDITIONS (STRATIFORM CLOUDS) - PRESSURE ALTITUDE VS. AMBIENT TEMPERATURE (REFERENCE 1-2)

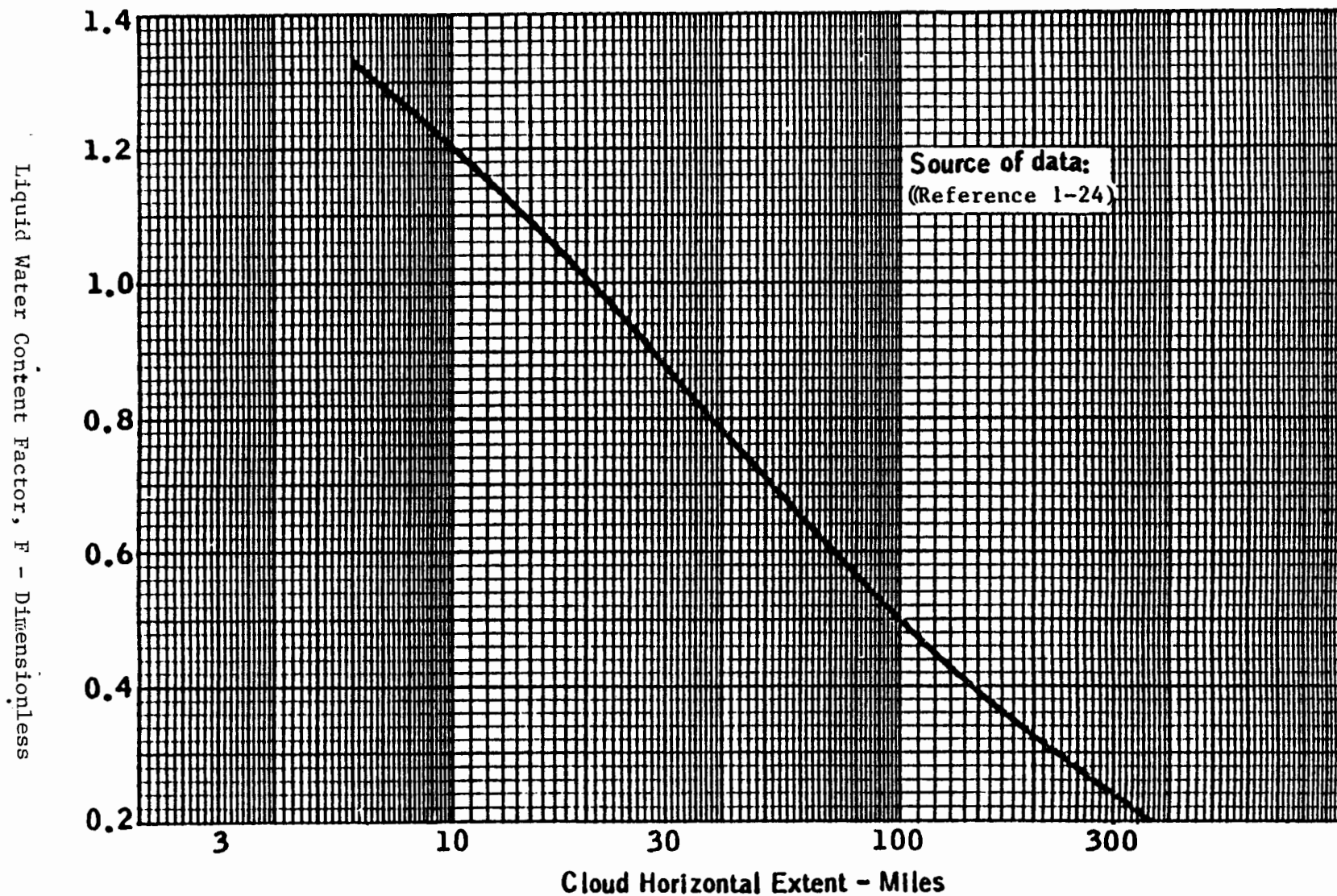


FIGURE 1-3. FAR PART 25 (APPENDIX C) CONTINUOUS MAXIMUM ATMOSPHERIC ICING CONDITIONS (STRATIFORM CLOUDS) - CLOUD HORIZONTAL EXTENT VS. LIQUID WATER CONTENT FACTOR (REFERENCE 1-2)

Pressure altitude range
4,000 to 22,000 Ft.

Horizontal extent, standard
distance of 2.6 Nautical miles

Source of data:
(Reference 1-22)

Note: Dashed lines
indicate possible
extent of limits

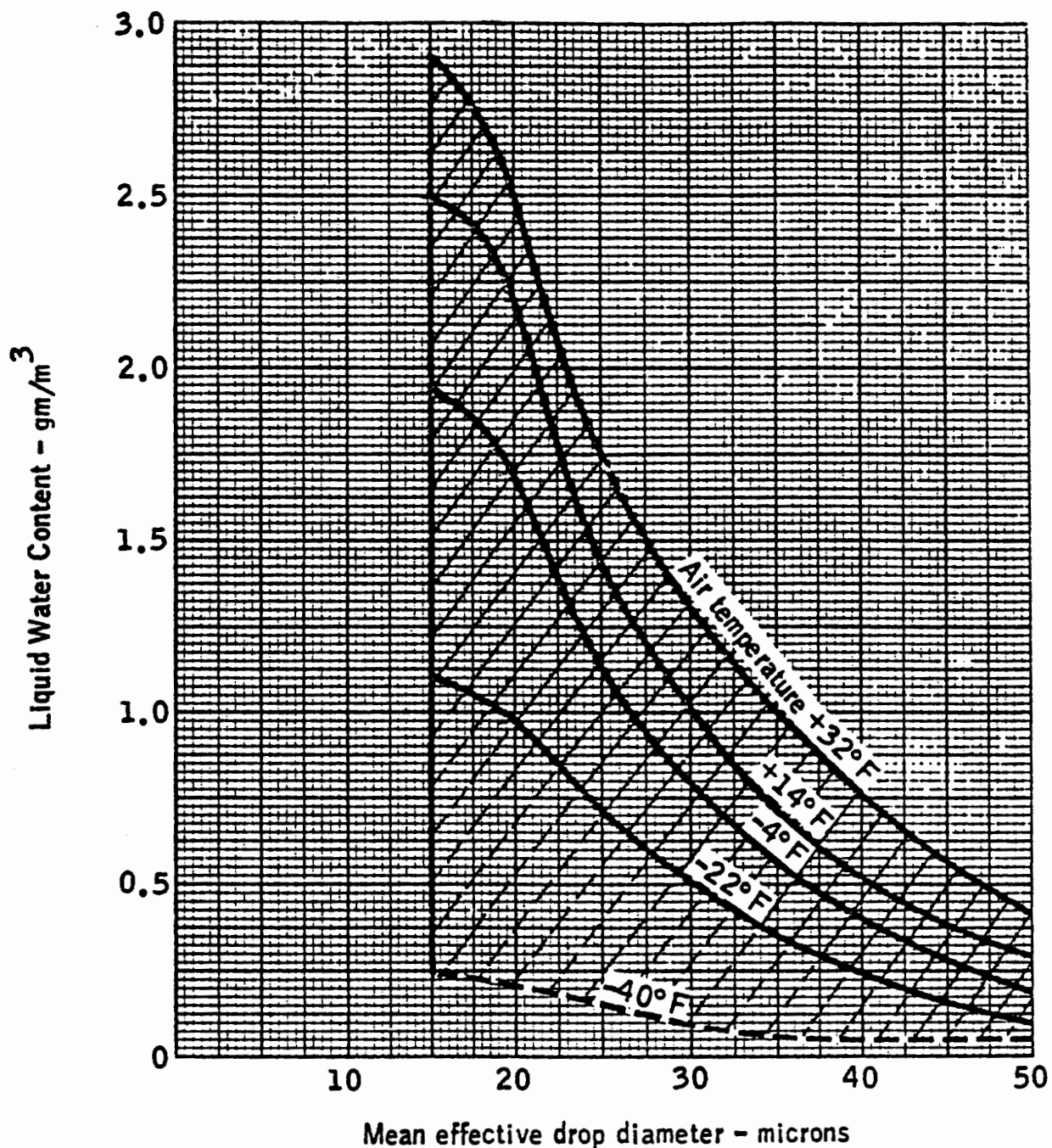


FIGURE 1-4. FAR PART 25 (APPENDIX C) INTERMITTENT MAXIMUM ATMOSPHERIC ICING CONDITIONS (CUMULIFORM CLOUDS) - MEAN EFFECTIVE DROPLET DIAMETER VS. LIQUID WATER CONTENT (REFERENCE 1-2)

Source of data:
(Reference 1-23)

Note: Dashed lines
indicate possible
extent of limits

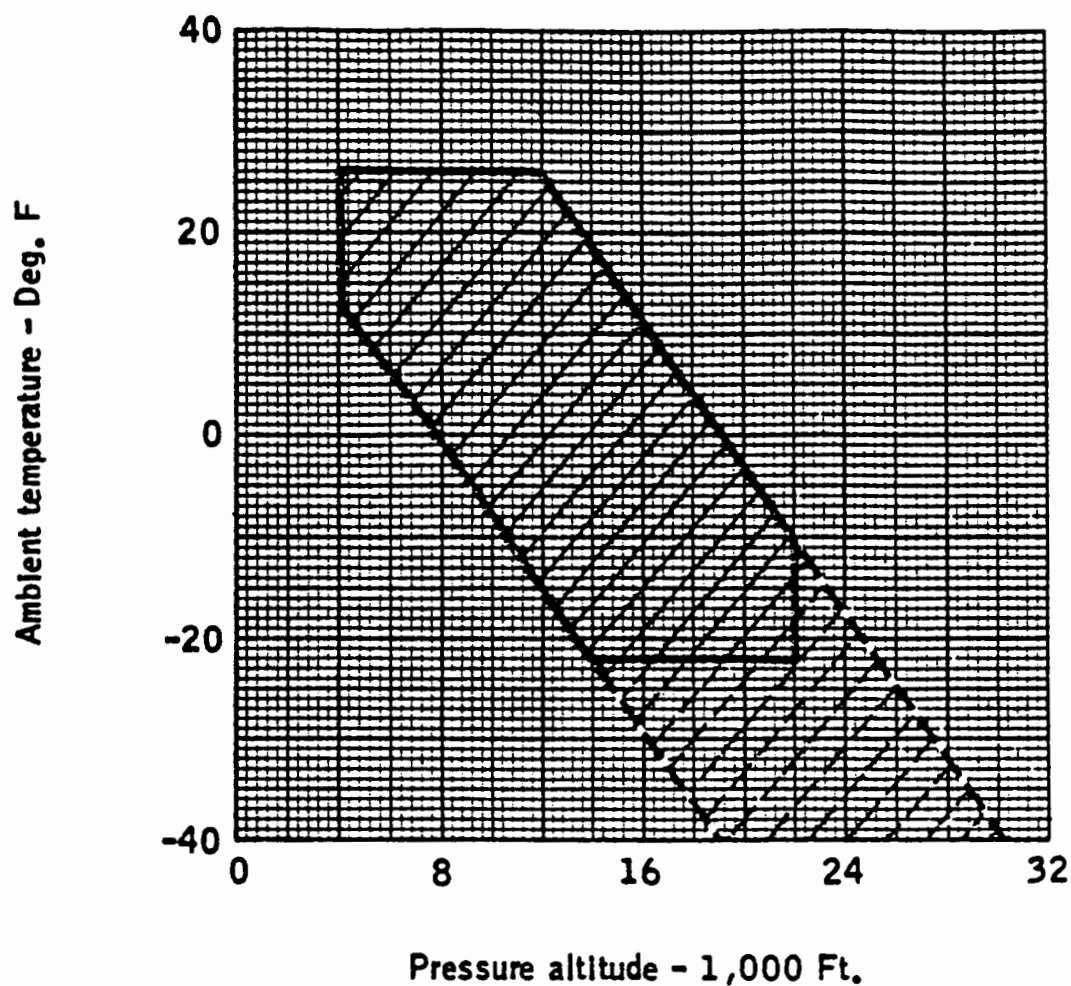


FIGURE 1-5. FAR PART 25 (APPENDIX C) INTERMITTENT MAXIMUM ATMOSPHERIC ICING CONDITIONS (CUMULIFORM CLOUDS) - PRESSURE ALTITUDE VS. AMBIENT TEMPERATURE (REFERENCE 1-2)

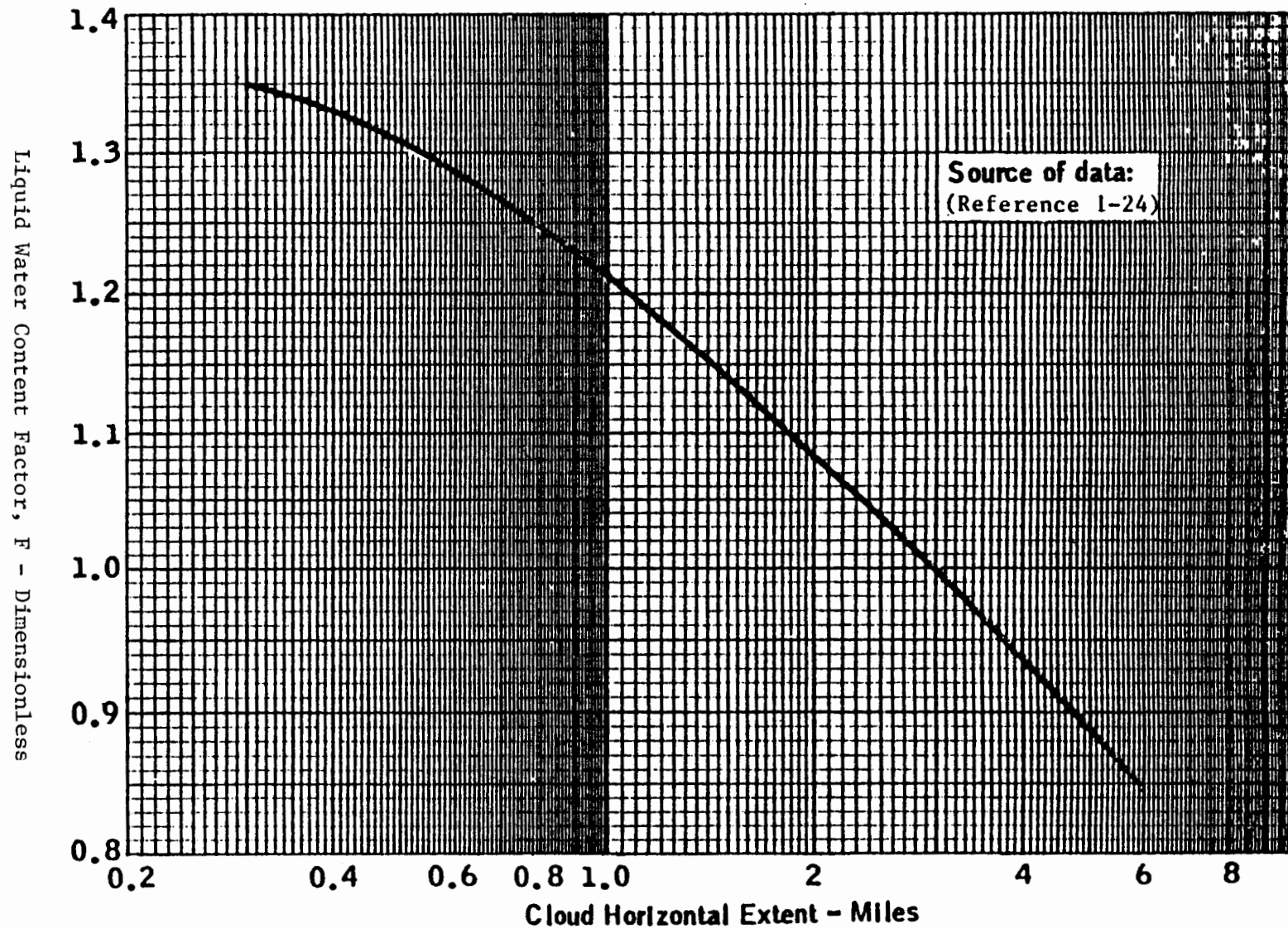


FIGURE 1-6. FAR PART 25 (APPENDIX C) INTERMITTENT MAXIMUM ATMOSPHERIC ICING CONDITIONS (CUMULIFORM CLOUDS) - CLOUD HORIZONTAL EXTENT VS. LIQUID WATER CONTENT FACTOR (REFERENCE 1-2)

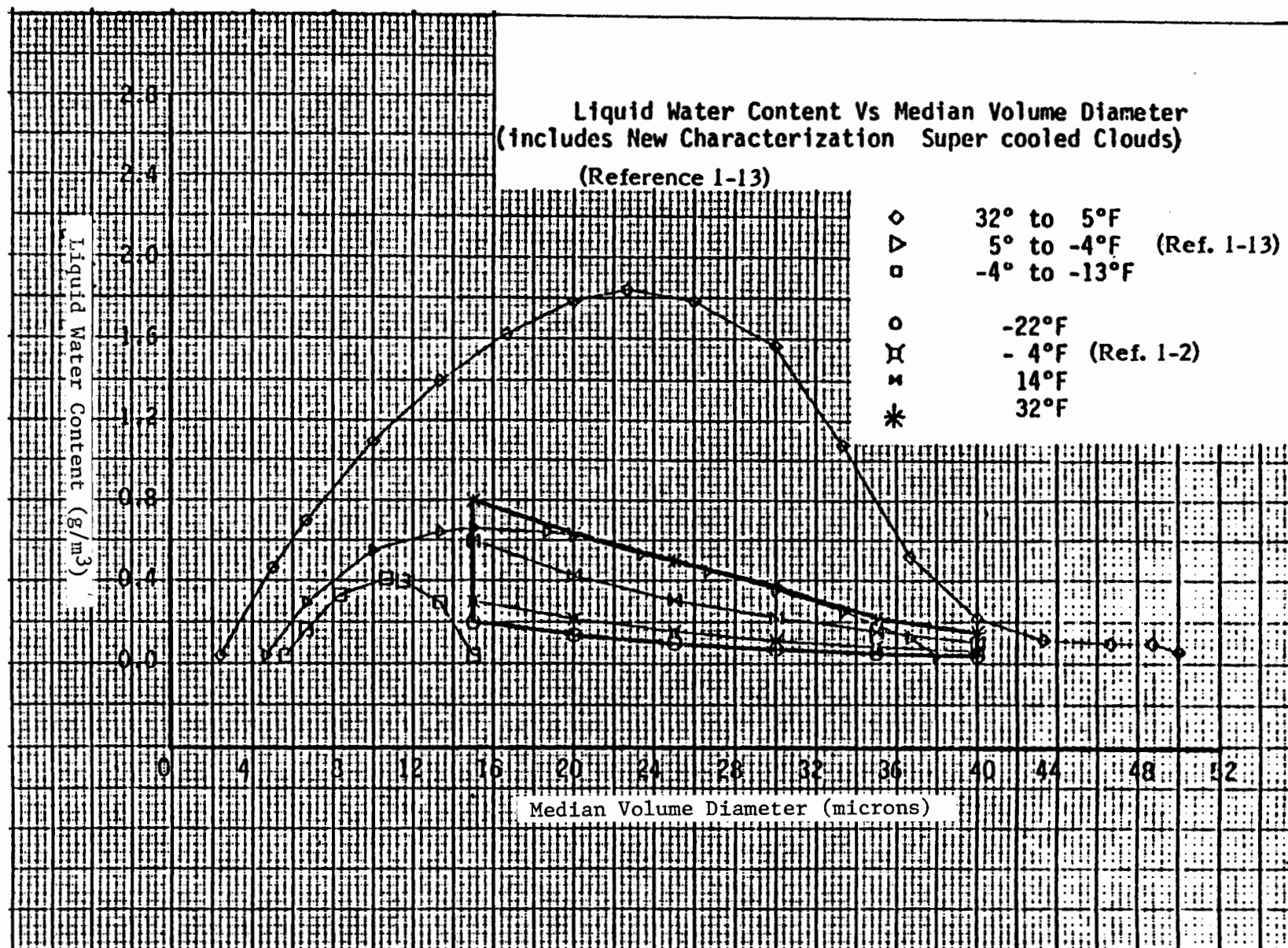


FIGURE 1-7. COMPARISON OF BASELINE ICING CONDITIONS (STRATIFORM CLOUDS)

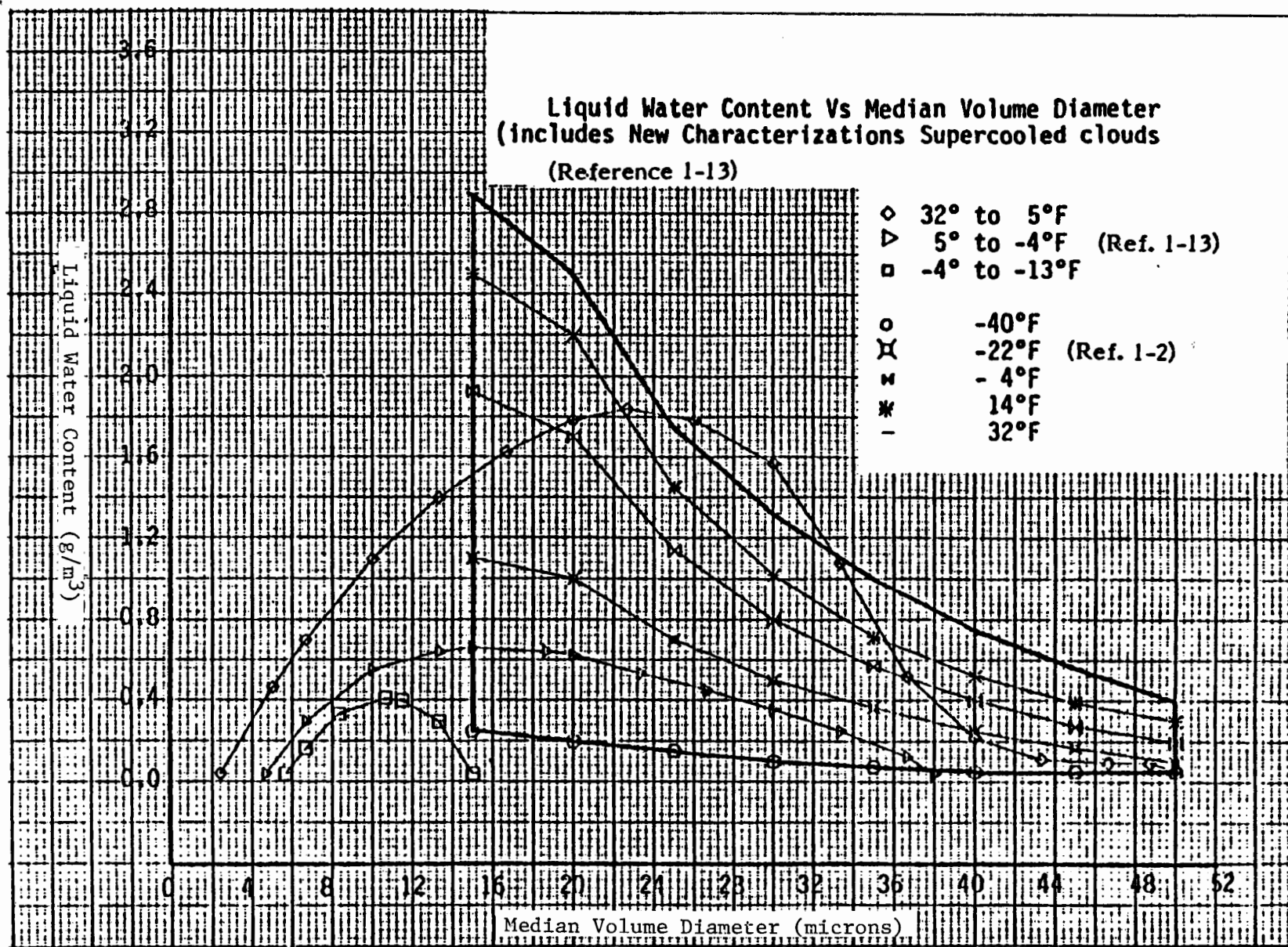


FIGURE 1-8. COMPARISON OF BASELINE ICING CONDITIONS (CUMULIFORM CLOUDS)

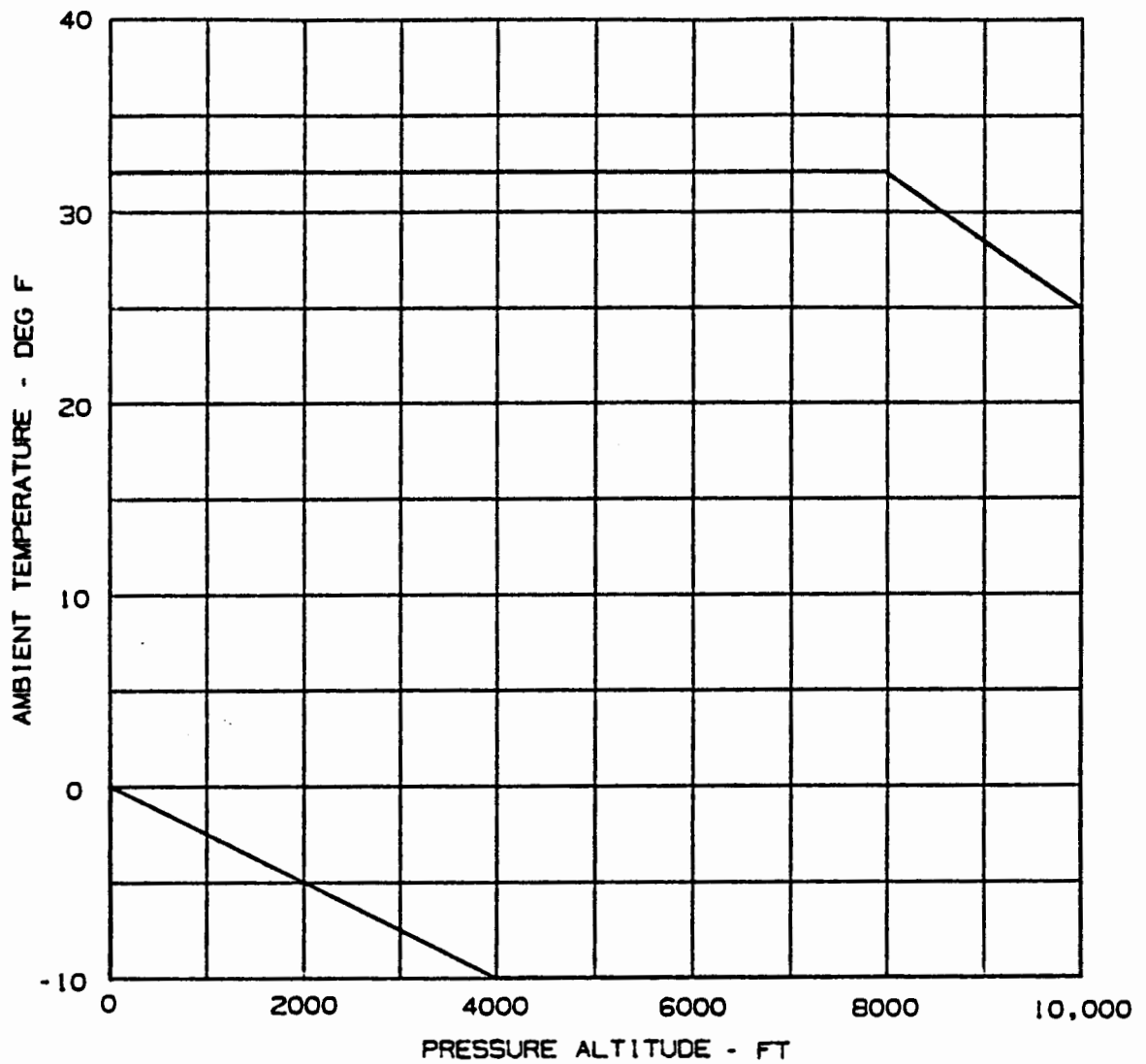


FIGURE 1-9. CONTINUOUS ICING TEMPERATURE VS ALTITUDE LIMITS (REFERENCE 1-20)

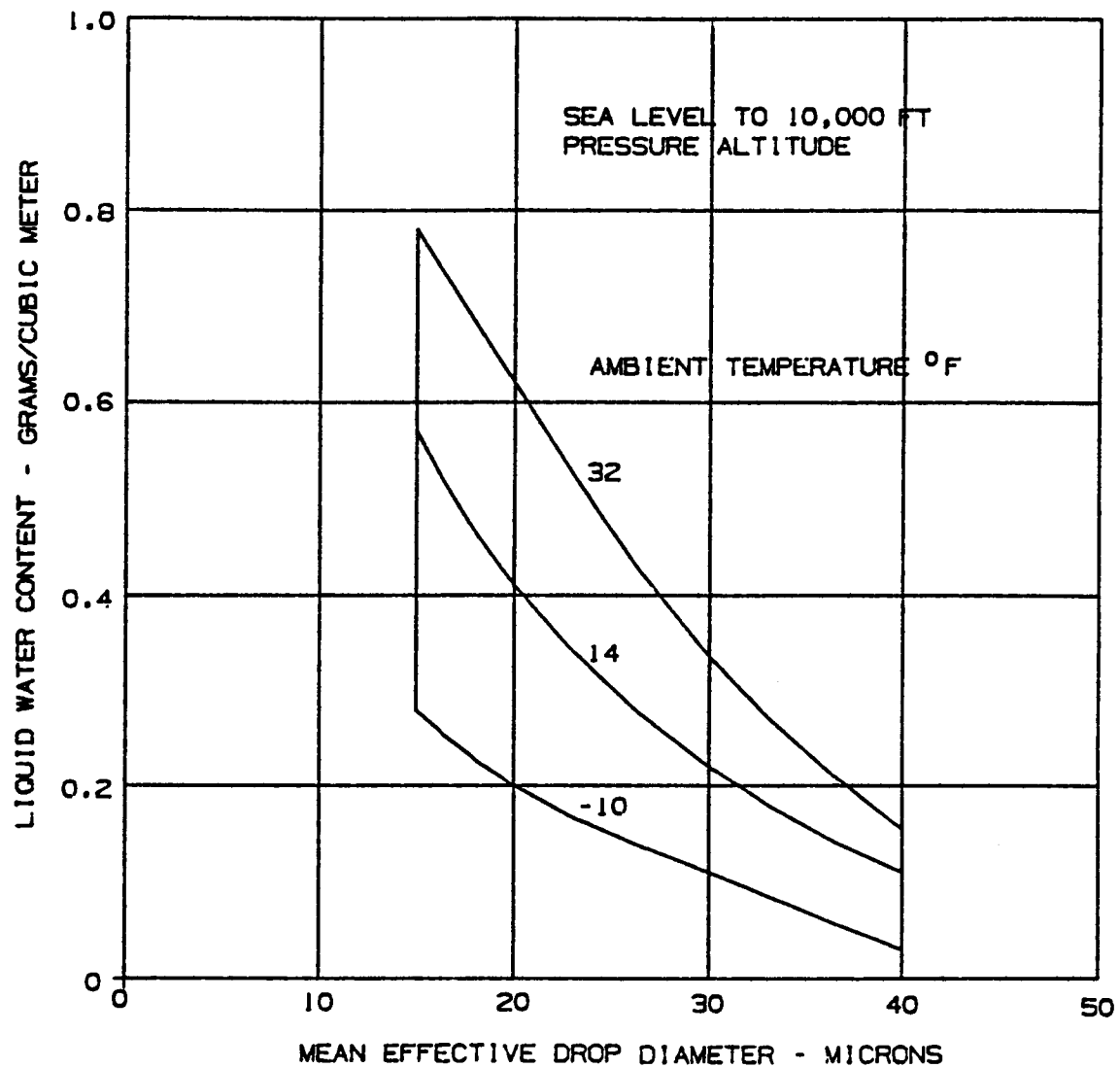
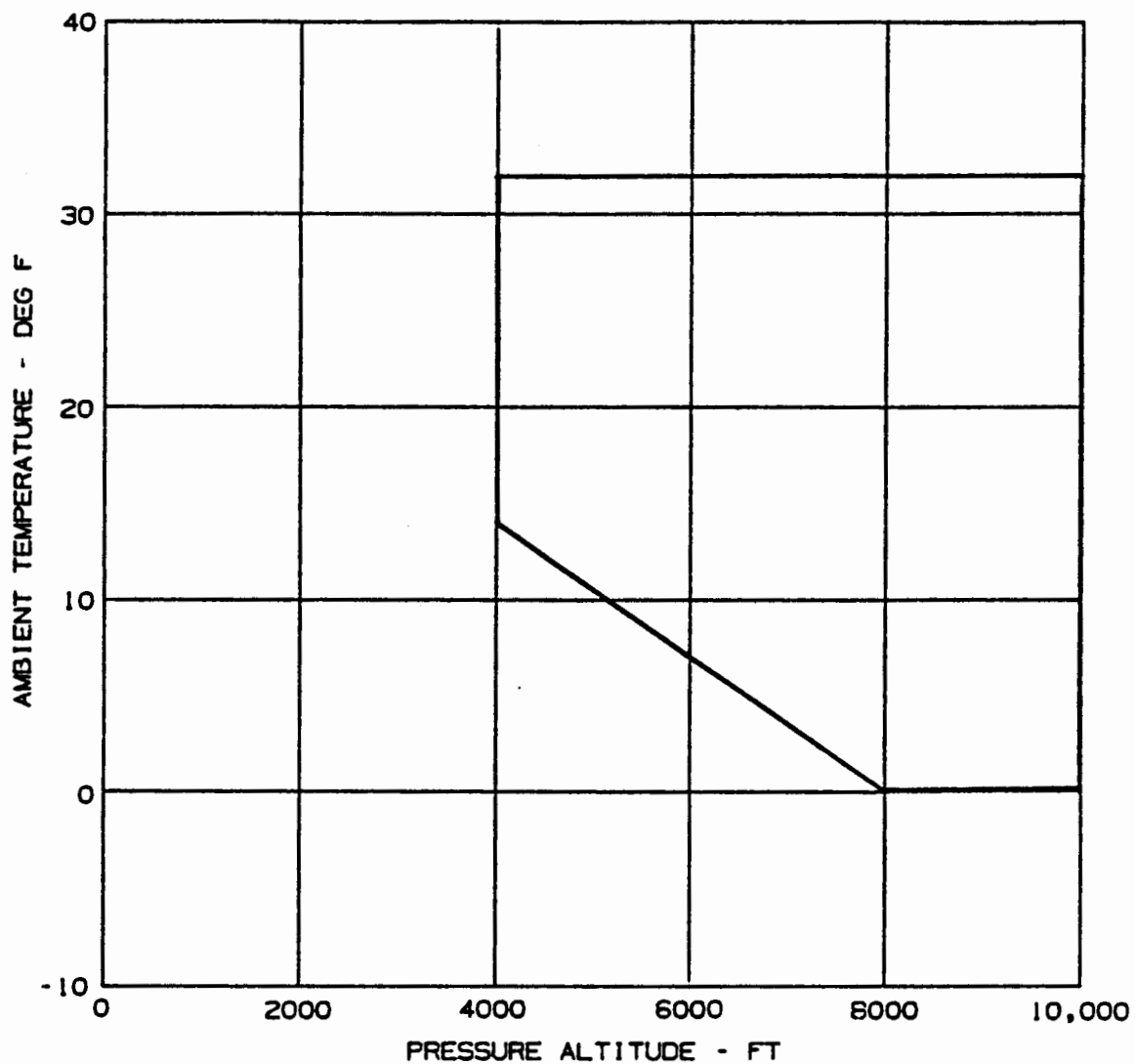


FIGURE 1-10. CONTINUOUS ICING LIQUID WATER CONTENT VS DROP DIAMETER
(REFERENCE 1-20)



**FIGURE 1-11. INTERMITTENT ICING TEMPERATURE VS ALTITUDE LIMITS
(REFERENCE 1-20)**

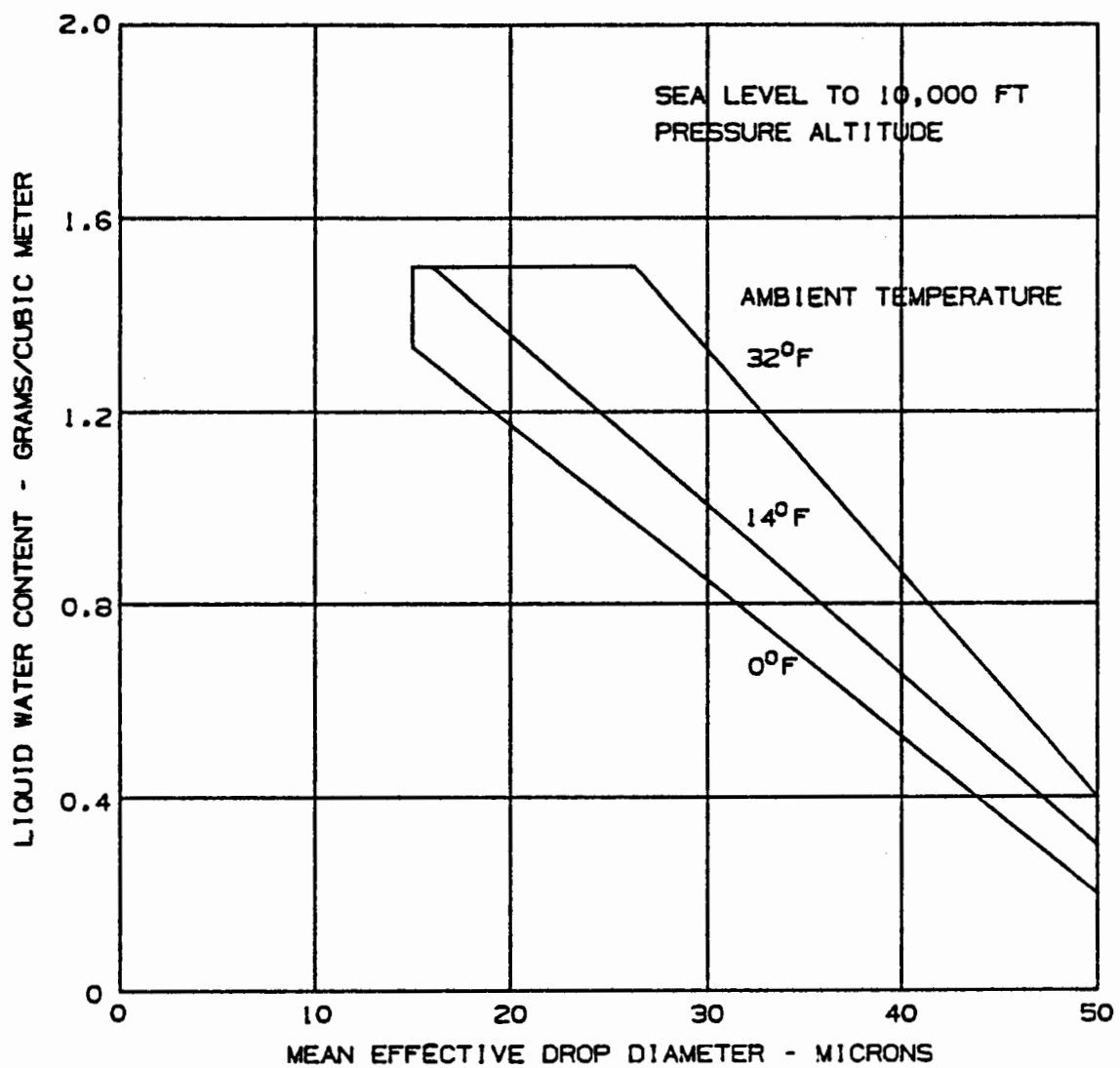


FIGURE 1-12. INTERMITTENT ICING LIQUID WATER CONTENT VS DROP DIAMETER
(REFERENCE 1-20)

CHAPTER VI
SECTION 2.0
U.S. MILITARY SPECIFICATIONS

CHAPTER VI
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SYMBOLS AND ABBREVIATIONS

<u>Symbol</u>	<u>Description</u>
A	Total windshield area, square feet
C	Celsius
cm	Centimeter
F	Fahrenheit
g	Grams
Hg	Mercury
hr	hour
k/hr	Kilometers per hour
lb	Pounds weight
LWC	Liquid Water Content meter
MVD	Median Volume Diameter
μm	Micron (micro meter)
X	Airplane range in hours

GLOSSARY

liquid water content (LWC) - The total mass of water contained in all the liquid cloud droplets within a unit volume of cloud. Units of LWC are usually grams of water per cubic meter of air (g/m^3).

median volume diameter (MVD) - The droplet diameter which divides the total water volume present in the droplet distribution in half; i.e., half the water volume will be in larger drops and half the volume in smaller drops. The value is obtained by actual drop size measurements.

micron (μm) - One millionth of a meter.

VI.2.0 MILITARY SPECIFICATIONS

VI.2.1 INTRODUCTION

Ice protection systems for military aircraft are normally designed to meet Military Specifications. This section presents a summary and discussion of these specifications as they relate to airframe, engines, windshields/canopies, pitot tubes, and ice detectors. Although aircraft originally developed for the military are governed by these specifications, military use of aircraft certified to civilian regulations is common. In the latter case, the military accepts certification to Federal Aviation Regulations of the U.S. Department of Transportation. Recent examples of military purchase or lease and operation of non-military certified aircraft are the C-21A (Gates Learjet Corporation Model 35A aircraft certified to FAR Part 25), the C-12A (Beech Aircraft Company King Air Model 200 aircraft certified to FAR Part 23), and the T-47 (Cessna Aircraft Company Citation Model 552 aircraft certified to FAR Part 25).

Military certification for flight in icing conditions involves considerations similar to that for civilian aircraft of meteorological atmospheric characteristics and ice protection systems. For military aircraft, however, if the operational speed is on the order of 450 knots (830 k/hr) or more (figure 2-1), ice protection is usually not required except for loiter, landing, or takeoff. The design icing conditions for the airframe are 15°F (-9.4°C) or less, liquid water content (LWC) of 0.5 g/m³, and droplet mean volumetric diameter (MVD) of 20 microns. Military specifications are discussed in the following paragraphs for pneumatic boot and heated surface type systems.

VI.2.2 AIRFRAME

The ice protection system is intended to protect the aircraft surfaces against ice accumulation. Portions of the wing and empennage surfaces which are exposed to ice accretion during flight in icing conditions may require protection by an acceptable system. Current specifications cover two types of airfoil surface ice protection systems; namely, pneumatic boots and heated surface type systems as discussed in the following paragraphs.

2.2.1 Pneumatic Boot System

Specification MIL-D-8804A (reference 2-1) covers the general requirements for pneumatic boot de-icing systems for wings, empennage, radome, air inlets, and etc. The system consists of the following components: de-icing boots, air and vacuum sources, valves, pressure regulator, safety valve, oil separator (if required), timer, test connections, and gages. The pneumatic boot de-icing system should be capable of removing accreted ice from all aircraft surfaces under the specified design icing conditions.

System controls should be provided for symmetrical operation of the boots. The predetermined inflation pressure will be regulated to vary not more than ± 0.5 lb/in². The vacuum relief valve will be provided to regulate the vacuum pressure to ± 0.5 inches of Hg of the design value when the engine

is operating at takeoff RPM. Satisfactory operation is required with the aircraft at rest, taxiing, takeoff, in flight, and during landing. The boots, when operating, should not appreciably affect the aircraft stall characteristics.

System ground tests should be conducted with the aircraft at rest using an inflation pressure of 15 to 22 lb/in² and a deflation suction of at least 4 inches of Hg to demonstrate the general operation and safety of the system for flight test. The system should be checked for leaks during these ground tests with a pressure decrease of not more than 5 lb/in² in one minute.

Flight tests are conducted to evaluate the effect of the boot system operation on performance and handling characteristics of the aircraft.

2.2.2 Heated Surface Type Ice Protection (MIL-A-9482) (Reference 2-2)

This specification covers the requirements for airframe thermal ice protection systems, excluding engine air-induction systems and radomes. Some areas to be protected by heated surface type systems are:

- a. Portions of the wings and empennage surfaces which are exposed to ice accumulations during flight under the specified icing conditions.
- b. Antenna masts, hinge fairings, spoilers, dive brakes, struts, and other miscellaneous ice accreting components whose ice protection needs will be decided based on the effect of ice accumulation on the normal functions of the individual component and the associated increase in drag on the aircraft performance.
- c. Transparent areas (see also Section 2.5).
- d. Entrance to each air scoop that must function during icing conditions.
- e. Guide vanes or at abrupt changes in direction of ducts leading from air scoops to permit unrestricted flow in these ducts.

The design conditions for evaporative anti-icing heated surface type systems are an ambient temperature of 15°F (-9.4°C), liquid water content (LWC) of 0.5 g/m³, and a droplet mean volumetric diameter (MVD) of 20 microns. Duration, or horizontal extent, of the icing condition is not specified. These values will be used in the design of evaporative thermal ice protection systems and are similar to the maximum continuous icing conditions specified by the FAA regulations (reference 2-3). If the aircraft design mission requires intermittent operation below 20,000 feet (6100 m) (e.g., low level reconnaissance, attack, or refueling), typical operating conditions should include the high and low speed extremes.

The following procedures are recommended for computing the heat required and available for the heated surface type protection system. The amount and chordwise extent of droplet impingement are determined by droplet trajectory studies (Section 2.3) for the airfoil sections used and corrected for sweep angle. External heat transfer coefficients are based on the transition from laminar to turbulent flow at the aft edge of the impingement area. The impingement area is considered to be

completely wet, while areas aft of the impingement area are considered to be 20 percent wet. Water evaporation is determined from integration of point evaporation rates and will be based on average skin temperatures. Heat requirements are determined at the root, tip, and at an intermediate span section of the wing.

The primary heat source is hot air from compressor bleed, exhaust gas heat exchangers, or combustion heaters. Electrical heating may be used for small areas where it is more convenient or where it induces less penalties to the airplane performance. Detail design includes material specification and precautions. Since aluminum alloy structural members are heated by the ice protection system, allowance must be made for the reduction in allowable stress. If the heating air contains exhaust products, stainless steel or other corrosion resistant material should be used in the construction. Distribution ducts should be insulated to reduce heat losses. All system components should have a minimum life of 500 hours.

Prior to ice protection system installation in an airplane, the manufacturer is normally required to submit to the procuring activity the following:

- a. System design report describing the system with complete data on heat requirements and heat available.
- b. System test report on all items of equipment used in the system to demonstrate compliance with test requirements.
- c. Instrumentation report outlining in detail the proposed instrument installation, methods of calibration, and sufficient description to indicate the location and significance of each item.
- d. Test plan report outlining tests to be conducted, data to be obtained, and the purpose of the tests.
- e. Final report that includes an evaluation and extrapolation of the data to design conditions.

Final approval of the ice protection system is contingent on clear indication of intended function performance and satisfactory submission of the test data. The ground and flight tests specified below is typical of those conducted on an airplane designated by the procuring activity, so as to demonstrate compliance of the ice protection equipment. Whenever possible, the manufacturer is encouraged to conduct the ground tests on ground mock-ups to preclude any damage to the airplane in case of system malfunction and to ensure early detection of deficiencies. Ground tests are conducted to demonstrate control system operation, temperature indication system operation, overheat warning and control operation, general security and safety of the system for flight testing, distribution of available airflow, and freedom from overheating and detrimental effects of differential expansion.

Flight tests in dry air will provide a complete thermal survey to determine the heat available. These tests should be conducted in sufficient detail and accuracy to permit the extrapolation of results to actual icing conditions. Suggested flight conditions are:

1. Normal takeoff and climb to operating altitude.
2. Normal descent and landing.

3. Level flight at speed for maximum endurance, maximum speed, and an intermediate speed approximately half-way between these speeds at 5,000, 10,000, and 20,000 feet (1500, 3050, and 6100 m) altitudes.

Sufficient instrumentation is required to determine the quantity and the temperature of air from each heat source and the quantity and temperature of airflow in all main distribution ducts. Sufficient structural temperatures must be measured to ensure structural overheating does not occur.

VI.2.3 ENGINES (MIL-E-5007) (Reference 2-4)

This specification establishes the performance, operating characteristics, and design features for turbojet and turbofan engines. The engine must operate satisfactorily under icing conditions that are similar to the FAA requirements for continuous and intermittent maximum icing conditions (reference 2-3), with not more than 5 percent total loss in thrust available and not more than 5 percent total increase in specific fuel consumption at all operating conditions above 50 percent maximum continuous power setting. If ice protection is required, the system should prevent ice accumulation on any part of the engine while operating under the specified icing conditions. The engine should be capable of ingesting hail and any ice sheet of 3 x 9 x 0.25 inch (7.6 x 23 x 0.64 cm) which accretes on the engine inlet or duct without flame-out, lengthy power recovery, or critical engine failure.

For a hot air ice protection system, continuous operation of the system throughout the airplane operating envelope should not damage the engine. For electro-thermal ice protection systems, the engine should be capable of simultaneous operation of the ice protection system and all other engine electrical systems.

Environmental icing tests should demonstrate compliance while operating in the specified icing conditions. For this testing, the engine will be operated under the ambient air conditions listed in table 2-1. For each test run the liquid water content (LWC) and droplet size (MVD) will be measured at a distance within 5 feet (1.5 m) of the engine inlet face and still within the inlet duct. During testing, engine thrust, RPM, and vibration will be continuously recorded and high speed photographic coverage of the engine inlet provided. The baseline for determining engine performance loss is established by operating the engine with no air bleed or electrical power extraction for ice protection operation and under the inlet temperature conditions of table 2-1 With ambient air between 80 and 100 percent relative humidity. The thrust/power and specific fuel consumption penalties for ice protection are determined by comparison with engine performance when operating in icing conditions at the same baseline values.

Testing will be considered satisfactorily completed when, in the judgement of the procuring service, there was no damage to the engine and performance was maintained within specified limits.

The engine will also be subjected to an ice ingestion test. The type of ice and conditions for ingestion are stated as follows:

- a. One 2 inch (5 cm) diameter hailstone and two 1 inch (2.5 cm) diameter hailstones of 0.8 to 0.9 specific gravity for each 400 square inches (0.26 m²) of inlet area at the engine face at typical takeoff, cruise, and descent power conditions.
- b. Sheet ice in typical sizes, forms, and thicknesses representative of that which would accrete in the inlet duct and/or on the inlet lip in quantities likely to be ingested during takeoff and cruise conditions.

VI.2.4 PROPELLERS (MIL-P-26366A) (Reference 2-5)

This specification covers the standard requirements and tests for aircraft propeller systems. The propeller should have an ice protection system for blades, cuffs, and the spinner. Either electrical, fluid, hot air, compound, or mechanical ice protection system or combination of two or more such systems may be used when approved by the procuring service. The design icing conditions are:

Condition 1

LWC of 1 g/m³

Air temperature of -4°F (-20°C)

MVD of 15 microns

Condition 2

LWC of 2 g/m³

Air temperature of 23°F (-5°C)

MVD of 25 microns

Both conditions are tested at sea level static conditions.

VI.2.5 WINDSHIELDS AND CANOPIES (MIL-T-5842B) (Reference 2-6)

This specification establishes the requirements for systems which protect transparent areas on aircraft surfaces (windshields and canopies) from ice accretion, frost, moisture, and snow. The ice protection system may be designed to function by means of hot air, electrical conductive coatings, liquid spray, infrared radiation, or a suitable method approved by the procuring service. Where applicable, aerodynamic heating may be included in the thermal analysis. The design environment for windshields and canopies is similar to FAR part 25 appendix c.

2.5.1 Windshield Spray Equipment (MIL-S-6625A) (Reference 2-7)

This specification covers a type of spray equipment for the protection from ice formation on aircraft transparencies. This equipment consists of a spray tube, fluid pump, fluid tank, and a control valve. The fluid pump is an electrically driven unit with automatic pressure control. The pump

should have a capacity to supply 2 quarts (1.9 liter) of fluid per square foot/hour for 2/3 of the window area. The fluid storage capacity should be $(0.74 A x/12)$ gallons, where A is the total area of the windshield in square feet, and x is the airplane range in hours with full military load and the pressure in the storage tank is 4 lb/in².

The fluid employed is isopropyl alcohol. The system is expected to function satisfactorily at all temperatures from 120 to -65°F (49 to -54°C) and at all altitudes from sea level to 25,000 feet (7600 m) and not be damaged when exposed to a temperature of 160°F (71°C) for 48 hours.

VI.2.6 ELECTRICALLY HEATED PITOT TUBE (MIL-T-5421B) (Reference 2-8)

This specification covers all types of two-wire electrically heated pitot tubes. Pitot tubes should be tested in an icing wind tunnel at an indicated airspeed of 100 knots (185 k/hr) and an ambient temperature of 5°F ±9°F (-15°C ±5°C). The nose of the pitot tube will be coated with an ice cap approximately 0.25 inch thick (0.64 cm) and then the applicable voltage should be applied. The time required to clear the ice-cap after the voltage is applied should not be more than 2 minutes. The tube is also subjected to a temperature of -5°F for 48 hours after which there should not be any evidence of damage.

VI.2.7 AIR INTAKE DUCT ICE DETECTOR (MIL-D-8181B) (Reference 2-9)

This specification establishes requirements for ice detectors. The ice detector system is designed to

- a. Operate a warning device to indicate to the pilot when dangerous icing conditions are encountered.
- b. Transmit an electrical signal which can be used to actuate the ice protection system.
- c. Sense accumulating ice throughout a temperature range of -65 to 45°F (-54 to 7°C).

VI.2.8 REFERENCES

- 2-1 "De-Icing Systems, Pneumatic Boot, Aircraft, General Specification for,"MIL-D-8804A, 26 September 1958.
- 2-2 "Anti-Icing Equipment for Aircraft, Heated Surface Type, General Specification for," MIL-A-9842(AV), 2 April 1981.
- 2-3 "Airworthiness Standards: Transport Category Airplanes," Federal Aviation Regulations, FAR Part 25, U.S. Department of Transportation, Federal Aviation Administration, Washington, D.C., 1986.
- 2-4 "Engine, Aircraft, Turbojet and Turbofan, General Specification for,"MIL-E-5007D, Amendment 2, 8 October 1982.
- 2-5 "Propeller Systems, Aircraft, General Specification for," MIL-P-26366A, Amendment 2, 22 May 1984.
- 2-6 "Transparent Areas on Aircraft Surfaces (Windshields and Canopies), Rain Removing and Washing Systems for, Defrosting, De-Icing, Defogging, General Specification for," MIL-T-5842B(AS), 29 March 1985.
- 2-7 "Spray Equipment, Aircraft Windshield, Anti-Icing," MIL-S-6625A(ASG), 26 March 1953.
- 2-8 "Tubes, Pitot, Electrically Heated, Aircraft," MIL-T-5421B, Amendment 2, 19 June 1985.
- 2-9 "Detector, Ice, Air Intake Duct, Aircraft Engines and Airframe Systems, General Specification for," MIL-D-8181B(ASG), 15 March 1965.

TABLE 2.1. SEA LEVEL ENGINE ICING CONDITIONS (Reference 2-4)

	Part 1			Part 2
Engine Inlet Total Temp.	-4°F(-20°C)±1°	+15°F(-10°C)±1° (1)	+23°F(-5°C)±1°	+23°F(-5°C)±1°
Velocity	0 to 60 knots	0 to 60 knots	0 to 60 knots	0 to 60 knots
Altitude	0 to 500 ft (0 to 150 m)	0 to 500 ft (0 to 150 m)	0 to 500 ft (0 to 150 m)	0 to 500 ft (0 to 150 m)
Mean Effective Drop Diameter	20 microns	20 microns	20 microns	20 microns
Liquid Water Content (Continuous)	1 g/m ³ ±0.25 g/m ³	2 g/m ³ ±0.25 g/m ³	2 g/m ³ ±0.25 g/m ³	0.4 g/m ³ ±0.1 g/m ³

(1) This condition is deleted for non-fan engines.

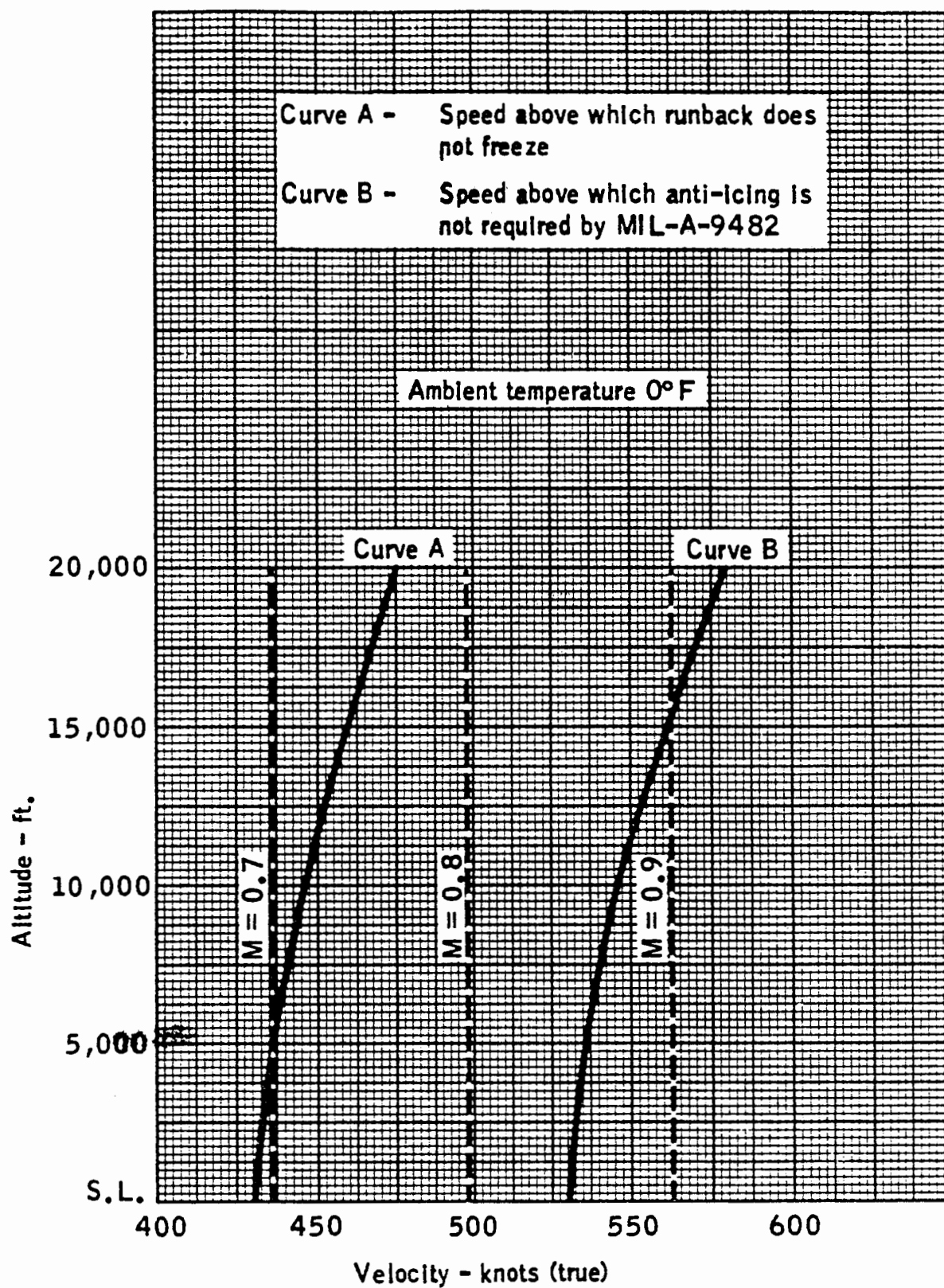


FIGURE 2-1. EFFECT OF SPEED UPON REQUIREMENTS FOR ANTI-ICING (REFERENCE 2-2)

CHAPTER VI
SECTION 3.0
FOREIGN REGULATIONS

CHAPTER VI
CONTENTS
SECTION 3.0 FOREIGN REGULATIONS

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SYMBOLS AND ABBREVIATIONS

<u>Symbol</u>	<u>Description</u>
AC	Advisory Circular
APU	Auxiliary Power Unit
AWO	All Weather Operation
BAA	Bilateral Airworthiness Agreement
BCAR	British Civil Airworthiness Requirement
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
g	Gram
GATT	General Agreement on Tariffs and Trade
JAR	Joint Airworthiness Requirement
LWC	Liquid Water Content
m	Meter
MVD	Median Volumetric Diameter
TSO	Technical Standard Order
μm	Micron (micro meter)
USSR	United Soviet Socialist Republic

GLOSSARY

liquid water content (LWC) - The total mass of water contained in all the liquid cloud droplets within a unit volume of cloud. Units of LWC are usually grams of water per cubic meter of air (g/m^3).

median volume diameter (MVD) - The droplet diameter which divides the total water volume present in the droplet distribution in half; i.e., half the water volume will be in larger drops and half the volume in smaller drops. The value is obtained by actual drop size measurements.

micron (μm) - One millionth of a meter.

VI.3.0 FOREIGN REGULATIONS

VI.3.1 INTRODUCTION

The Federal Aviation Administration has established various agreements with other nations to permit certification of aircraft imported from one nation to another. The general regulations for exporting aircraft and components from the U.S. are given in Federal Aviation Regulations (FAR) Part 21 (reference 3-1), Subpart L (which includes Sections 21.321 through 21.339).

Additional assistance is available in FAA Advisory Circular AC 21-2F (reference 3-2), "Export Airworthiness Approval Procedures," dated August 1987. This contains special requirements that have been submitted to the FAA by 39 foreign governments, indicated by "S" in table 3-1. Samples of export airworthiness forms are included in AC 21-2E. Advisory Circular AC 21-7A (reference 3-3) deals with the certification of aircraft, propellers, and related products being imported into the United States.

Twenty-four nations have agreements with the United States which are known as Bilateral Airworthiness Agreements (BAA). These are "Executive Agreements" concluded at the government-to-government level by exchange of diplomatic notes, with an appropriate State Department official signing for the United States. Advisory Circular 21-18 (reference 3-4), "Bilateral Airworthiness Agreements," contains copies of the BAAs. The BAAs are not considered to be Trade Agreements; rather, they are technical agreements, intended to facilitate the reciprocal acceptance of test results, certificates, or marks of conformity issued by the exporting country. Bilateral Airworthiness Agreements are currently in effect between the United States and the countries indicated by "B" in table 3-1.

A document entitled "Export/Import Airworthiness Certification of Civil Aeronautical Products" (reference 3-5) was issued in 1982 by the FAA Office of Airworthiness. The purpose was to provide assistance in understanding a number of international certification issues. This document discusses the BAAs, their implementation, and their relationship with international conventions and trade agreements to which the United States is signatory, including those under the General Agreement on Tariffs and Trade (GATT).

The addresses of the civil aeronautical authorities in all of these countries are given in AC 21-18 (reference 3-4). Cable addresses and some telephone numbers are also given.

FAA regional offices are assigned responsibility for civil aviation matters in foreign countries as follows:

- | | |
|---|--|
| (a) Canada | FAA Federal Building
John F.Kennedy International Airport
Jamaica, N.Y.11430 |
| (b) Caribbean Area,
South America,
Central America,
Panama, and Canal Zone | FAA, P.O.Box 20636
Atlanta, Georgia 30320 |
| (c) Mexico | FAA, P.O.Box 1660, Ft.Worth, Texas 76101 |
| (d) Area East of
Bangladesh and
India, Including
All Free Nations
South and East of China | FAA, P.O.Box 50109
Honolulu, Hawaii 96850 |
| (e) Europe, Africa,
Middle-East West of
Burma, Iceland, Green-
land, and Bermuda | FAA, Rue de Loi, 15, B-1000
Brussels, Belgium |

In this chapter, certification requirements applying to aircraft icing flight will be summarized. To a great degree, the FAR's have been accepted as the basic standard in most of the world. Many of the regulations described in this section are in the form of variations from the United States Federal Aviation Regulations in Parts 23, 25, 27, 29, or 33 (references 3-6 through 3-10).

VI.3.2 BRITISH CIVIL AIRCRAFT REGULATIONS (BCAR)

The certification of aircraft in Great Britain is the responsibility of the Civil Aviation Authority and its Air Registry Board. The regulations are known as British Civil Airworthiness Requirements (reference 3-11) or BCARs. Copies of BCAR Sections and Amendments are available from:

Civil Aviation Authority
Printing and Publishing Services
Greville House, 37 Gratton Road
Cheltenham, Glos. GL 50 2 BN
England

Inquiries about the technical content of BCARs should be addressed to:

Civil Aviation Authority
Airworthiness Division
Barbazon House
Redhill, Surrey RH 1 1SQ
England

The BCAR's are being replaced by the Joint Airworthiness Requirements (JAR) (see Section 3.3), but much of the JAR are based on sections of BCAR. This process is evolutionary, with JAR Sections replacing BCAR Sections one by one as the JAR sections become established. For aircraft certified under a BCAR Section these regulations will continue to be applied for all derivative models and modifications. For this reason, a short summary of Chapter D1, 4 and 5 (reference 3-11), the main BCAR Sections concerned with icing flight, will be described below. A status listing (as of 1 April 1986) of sections relevant to icing flight certification is shown as follows:

Section	Subject	Latest Revision
A	Certification and Approval Procedures (CAP 460)	1 September 1985
[C	Engines and Propellers (CAP 462), was replaced by JAR-E and JAR-P on 1 January 1984. JAR-P is not yet in final form and Section C, Issue 13, of BCAR is needed for a complete text.]	
[D	Large Aeroplanes, was replaced by JAR-25 on 1 July 1979.]	
G	Rotorcraft (CAP 465)	16 August 1982
K	Light Aeroplanes (CAP 467)	10 April 1974
JAR-25	Large Aeroplanes	17 March 1986
JAR-AWO	All Weather Operations	19 November 1985
JAR-E	Engines	24 January 1986
JAR-P	Propellers	28 August 1981

Procedures for certification of foreign-constructed aircraft are in sections A2 and A4 (reference 3-11 or 3-12).

Chapter D1, 4, and 5 Comments (Applied prior to 1 July, 1979)

The meteorological criteria used for the British Civil Airworthiness Requirements differ from the U.S. FAR's as follows. For continuous maximum icing conditions (reference 3-11, D-1.5.1(a)) the LWC values for 20 micron MVD are the same as the FAR values for 15 microns, which indicates that the British specify only the 20 micron condition to be met while FAA requires the envelope of LWC and MVD shown in FAR Part 25, Appendix C (reference 3-7), and presented here in Chapter I, figure 3-2 (heavy lines). On the other hand, the BCAR assumes a continuous condition "to be encountered for an unlimited distance" while the FAA defines a standard distance as 20 statute miles (17.4 nm) and gives a multiplying factor for LWC greater or less than the 20 mile standard (Chapter I, figure 3-8).

For intermittent icing conditions, the BCAR maximum condition (reference 3-11, D-1.b.1(b)) is identical to that of the FAR Part 25, Appendix C (reference 3-7), if MVD is 20 microns for both. Again, the British use 20 microns only for the required condition while the FAA has a LWC versus MVD envelope (Chapter I, figure 3-3, heavy lines). The definition of intermittent conditions are different. The FAA requires 2.6 nm (4.8 km) of icing condition, presumably followed by clear air, while BCAR defines intermittent as alternating between maximum intermittent and maximum continuous conditions, each of 2.5 nm (4.6 km) extent. This applies up to 30,000 feet altitude (9000 m). Above 30,000 ft (9000 m), 2.5 nm (4.6 km) of maximum intermittent conditions alternate with 20 nm (36 km) of clear air.

Figure 3-1 is a plot of the BCAR LWC versus altitude maximum requirements for continuous and intermittent conditions. Note that the altitude ranges are indicated by the line lengths and that all of these standards are based on a droplet median volume diameter of 20 microns.

For turbine and turboprop engines in ice forming conditions, specific combinations of continuous and intermittent conditions and air temperatures are required.

BCAR (reference 3-11) Chapter D4-2.3.2 covers ice protection systems that are not capable of continuous operation. The maximum operating time is specified to be 30 minutes or 20 percent of the aeroplanes maximum endurance, whichever is the greater.

Visual detection by the crew of a respective section of either the mainplane or the tail-plane leading edge is required in order to check its state in respect to ice buildup (reference BCAR D4-2.1.3). In addition, an ice detector system must be installed and demonstrated unless otherwise agreed by the Board.

VI.3.3 EUROPEAN CIVIL JOINT AIRWORTHINESS REQUIREMENTS (JAR)

3.3.1 Introduction

A common set of regulations have been accepted by ten European Countries:

Belgium
Denmark
Federal Republic of Germany
Finland
France
Italy
Netherlands
Norway
Switzerland
United Kingdom

These are indicated by "J" in table 3-1.

The direction of the JARs (reference 3-13) is performed by the Airworthiness Authorities Steering Committee whose members are representatives of the Civil Airworthiness Authorities of the countries that have signed the "Arrangements Concerning the Development and Acceptance of Joint Airworthiness Requirements." A list of the countries is kept by Direction General de l'Aviation Civile (DGAC) 93, Boulevards du Montparnasse, 75270 Paris, Cedex 06, France.

Copies of the Joint Airworthiness Requirements and Amendments are available from:

Civil Aviation Authority
Printing and Publication Services
Grenville House, 37 Gratton Road
Cheltenham, Glos. GL50 2BN
United Kingdom

Enquiries regarding the contents of the JARs should be addressed to:

The Secretary, Joint Steering Committee
c/o Civil Aviation Authority, Airworthiness Division
Brabazon House, Redhill
Surrey, RH1 1SQ
United Kingdom

The JARs were still in a formative stage as of 1986. Small airplanes are not specifically covered, nor are rotorcraft, reciprocating-engine airplanes, seaplanes, or skiplanes. The degree of conformity and commitment appears to vary among the member nations.

3.3.2 Icing Related Sections - JAR

The outline of the Joint Airworthiness Requirements (reference 3-13) and the national documents on which they are based are:

- JAR-1 Definitions and Abbreviations.
- JAR-22 Sailplanes and Powered Sailplanes - based on the West German LSFM (Lufttuchtigkeitsforderungen fur Segelflugzeuge and Motorsegler).
- JAR-25 Large Airplanes (over 5700 kg [12,500 lbs.]) - based on the U.S. FAA FAR Part 25. (Amendments to FAR Part 25 are automatically accepted into JAR-25 unless a participating national organization calls for discussion within three months of the FAA Amendment effective date.) Sections concerned with icing flight are:
 - JAR 25.929 Propeller De-Icing
 - JAR 25.1093 Induction System De-Icing and Anti-Icing Provisions
 - JAR 25.1416 Pneumatic De-Icer Boot System
 - JAR 25.1419 Ice Protection
- JAR-APU Auxiliary Power Units - Based on U.K. TSO (Technical Service Order) C77a of 20 July, 1981, and partially on U.S. FAR Part 37. Icing related sections are:
 - JAR-APU Section 1-5.2 Air Intake
 - JAR-APU Section 2-1.7 Ice Crystal Conditions, August 1981.
- JAR-E Engines - Based on BCAR Section C, Issue 13, 28 August 1981.
- JAR-P Propellers - Based on BCAR Section C, Issue 13, 28 August 1981.
- JAR-TSO Joint Technical Standard Orders Authorization
- JAR-AWO All Weather operations.

3.3.3 National Variants

In a limited number of cases, one or more participating countries have "National Variants" to the requirements. These are included in the JARs or in the Amendments. The amendments are printed on orange colored paper and are inserted into the JARs.

VI.3.4 OTHER COUNTRY REGULATIONS

3.4.1 Canada

Canadian airplane regulatory material is termed "Airworthiness Standards." These are the same as the U.S. Federal Aviation Administration Regulations with additional requirements based on operational conditions in Canada. The corresponding publications are:

Airplane Type	U.S. FAR	Canadian Airworthiness STD
Normal, Utility, and Arobatic	Part 23	Chapter 523
Category Aeroplanes	(reference 3-6)	(reference 3-14)
Transport Category Aeroplanes	Part 25	Chapter 525
	(reference 3-7)	(reference 3-15)
Normal Category Rotorcraft	Part 27	Chapter 527
	(reference 3-8)	(reference 3-16)
Transport Category Rotorcraft	Part 29	Chapter 529
	(reference 3-9)	(reference 3-17)

The Airworthiness Manual presents in parallel columns the U.S. FAR and the changes for the Canadian regulations. The changes are relatively few and minor. In Chapter 523 (reference 3-14), no differences from FAR 23 involve icing. In Chapter 525 (reference 3-15), the only paragraph which may have an application to some ice protection systems is:

525.1301-1 - Aeroplane Operations After Ground Cold Soak. Substantiation of satisfactory operation of the aeroplane as a total system, by cold weather testing or by documented evidence of satisfactory operation at low temperature, is required after the aeroplane has experienced a prolonged exposure to ground temperatures equal to or less than -35°C (-31°F) unless an alternative minimum ground temperature has been proposed by the applicant and accepted by the Minister.

For Chapters 527 (reference 3-16) and 529 (reference 3-17), the only regulations relating to icing are 527.1301-1 and 529.1301-1. These are the same as 525.1301-1 (above) except for the substitution of the word rotorcraft for the word aeroplane in the places it occurs.

3.4.2 USSR

No formal certification agreements have been made for import/export certification of aircraft between the USSR and the United States. The principle document is the work of O.K. Trunov (reference 3-18) which is often compared to the FAA's document ADS-4.

The design conditions for icing flight listed in (reference 3-18) are as follows:

Air Temperature	LWC	MVD	Altitude
°C	0.9g/m ³	6 μm	500-9000 m(1000-30,000 ft)
-10	0.6	16	500-9000
-20	0.4	16	500-9000
-30	0.3	16	500-9000

These conditions are based on a 99% probability of occurrence. For one percent of flights in icing which exceed the LWC or MVD limits, the aircraft must be able to leave the icing condition. The responsible agency is:

USSR Ministry of Civil Aviation
Technical Science Department
37 Leningradsky Prospekt
Moscow, USSR

VI.3.5 REFERENCES

- 3-1 "Certification Procedures for Products and Parts," Federal Aviation Regulations, FAR Part 21, U.S.Department of Transportation, Federal AviationAdministration, Washington, D.C., 1986.
- 3-2 "Export Airworthiness Approval Procedures," Advisory Circular AC 21-2E, U.S.Department of Transportation, Federal Aviation Administration, Washington, D.C., May 1981 (Scheduled for revision in 1987).
- 3-3 "Certification and Approval of Imported Aircraft," Advisory Circular AC 21-7A, U.S.Department of Transportation, Federal Aviation Administration, Washington, D.C., November 24, 1969 (Scheduled for replacement in 1987).
- 3-4 "Bilateral Airworthiness Agreements," Advisory Circular AC 21-18, U.S.Department of Transportation, Federal Aviation Administration, Washington, D.C., August 20, 1982.
- 3-5 "Export/Import Airworthiness Certification of Civil Aeronautical Products," Document FAA-P-8110-1 U.S.Department of Transportation, Federal Aviation Administration, Washington, D.C., 1982.(This document is obtainable from the Aircraft Engineering Division (AWS-10), office of Airworthiness, FAA, 800 Independence Ave., S.W., Washington, D.C.20591.)

- 3-6 "Airworthiness Standards: Normal Category Airplanes," Federal Aviation Regulations, FAR Part 23, U.S.Department of Transportation, Federal Aviation Administration, Washington, D.C., 1986.
- 3-7 "Airworthiness Standards: Transport Category Airplanes," Federal Aviation Regulations, FAR Part 25, U.S.Department of Transportation, Federal Aviation Administration, Washington, D.C., 1986.
- 3-8 "Airworthiness Standards: Normal Category Rotorcraft," Federal Aviation Regulations, FAR Part 27, U.S.Department of Transportation, Federal Aviation Administration, Washington, D.C., 1986.
- 3-9 "Airworthiness Standards: Transport Category Rotorcraft," Federal Aviation Regulations, FAA Part 29, U.S.Department of Transportation, Federal Aviation Administration, Washington, D.C., 1986.
- 3-10 "Airworthiness Standards: Aircraft Engines," Federal Aviation Regulations, FAR Part 33, U.S.Department of Transportation, Federal Aviation Administration, Washington, D.C., 1986.
- 3-11 "British Civil Aircraft Regulations," Civil Aviation Authority, Printing and Publishing Services, Cheltenham, Glos., England.
- 3-12 "British Civil Aircraft Regulations," Civil Aviation Authority, Printing and Publishing Services, Cheltenham, Glos., England, 1981 Revision.
- 3-13 "Joint Airworthiness Regulations," Civil Aviation Authority, Printing and Publishing Services, Cheltenham, Glos., England.
- 3-14 "Airworthiness Standards, Chapter 523, Normal, Utility, Aerobiotic Category Airplanes," Canadian Airworthiness Regulations, Department of Transportation, Ottawa, Ontario, Canada, K1A 0N8.
- 3-15 "Airworthiness Standards, Chapter 525, Transport Category Airplanes," Canadian Airworthiness Regulations, Department of Transportation, Ottawa, Ontario, Canada, K1A 0N8.
- 3-16 "Airworthiness Standards, Chapter 527, Normal Category Rotorcraft," Canadian Airworthiness Regulations, Department of Transportation, Ottawa, Ontario, Canada, K1A 0N8.
- 3-17 "Airworthiness Standards, Chapter 529, Transport Category Rotorcraft," Canadian Airworthiness Regulations, Department of Transportation, Ottawa, Ontario, Canada, K1A 0N8.
- 3-18 Trunov, O.K., "Icing of Aircraft and Means of Combatting It," 1965.(English language translation from the USAF Foreign Technology Division, FTD-1D(RS)T-1162-79.)

TABLE 3-1. CERTIFICATION CODES AND AGREEMENTS FOR VARIOUS NATIONS

<u>Country</u>	<u>Code</u>
Argentina	S
Australia	S B
Austria	B
Belgium	S B J
Bolivia	S
Botswana	S
Brazil	S B
Canada	S B
Czechoslovakia	B
Denmark	B J
Finland	B J
France	S B J
Germany (FRG)	S B J
Hong Kong	S
India	S
Indonesia	S
Ireland	S
Israel	S B
Italy	S B J
Japan	S B
South Korea	S
Lebanon	S
Malaysia, West	S
Morocco	S
Netherlands	S B J
Netherlands Antilles	S
New Zealand	S B
Norway	B J
Pakistan	S
Panama	S
Philippines	S
Poland	B
Portugal	S
Rhodesia	S
Romania	B

**TABLE 3-1. CERTIFICATION CODES AND AGREEMENTS FOR VARIOUS NATIONS
(CONTINUED)**

<u>Country</u>	<u>Code</u>
Saudi Arabia	S
Singapore	S B
South Africa	S B
Spain	B
Sweden	S B
Switzerland	S B J
Syria	S
Taiwan	S
Tunisia	S
United Kingdom	S B J
Yugoslavia	S
Zambia	S

Explanation:

- J - Covered by the European Joint Airworthiness Requirements (JAR) (reference 3-12).
- B - Has a Bilateral Airworthiness Agreement (BAA) with the U.S.A. as printed in FAA AC 21-18 (reference 3-4).
- S - Has a Special Requirement which is printed in FAA AC 21-2E (reference 3-2).

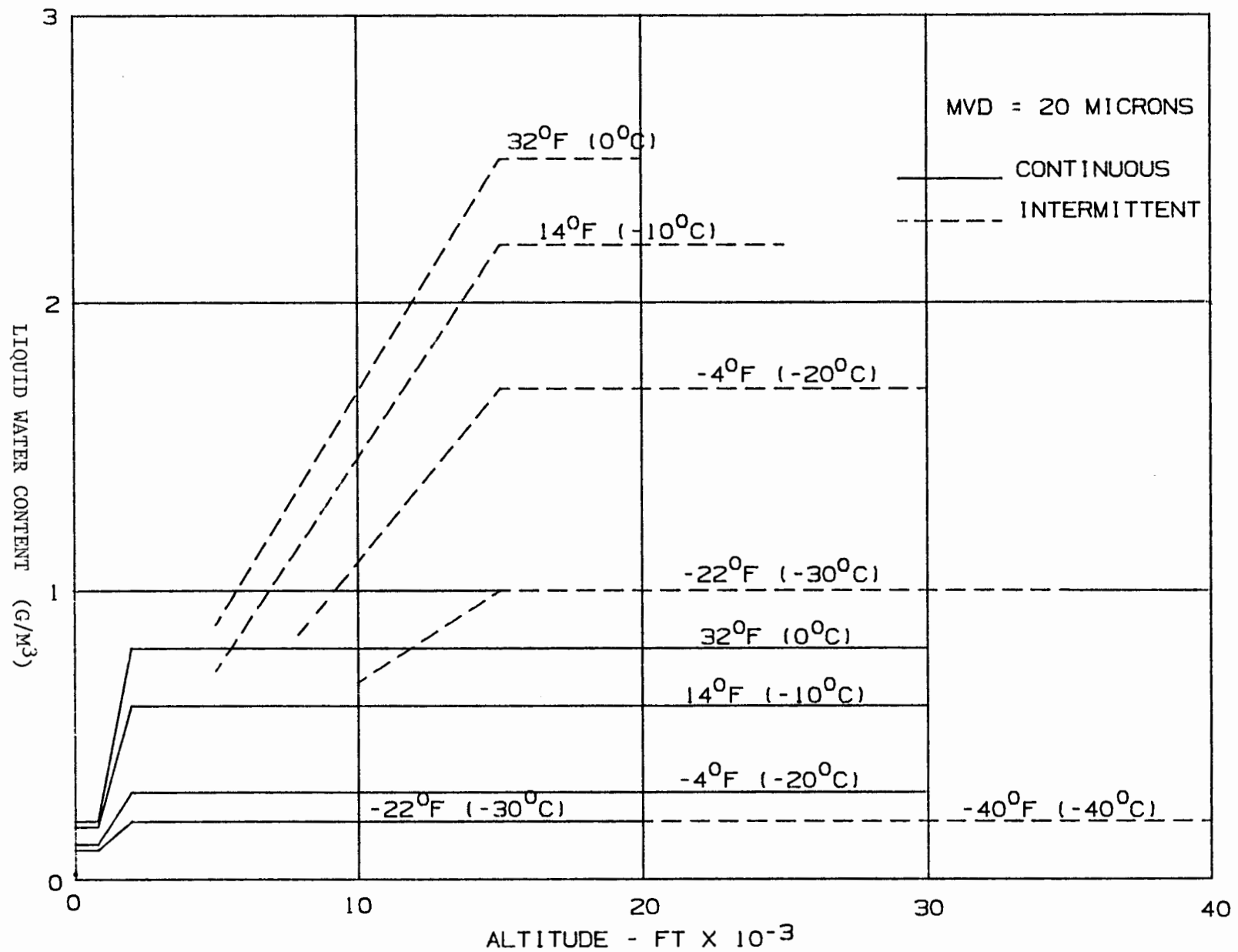


FIGURE 3-1. ICING CONDITIONS SPECIFIED BY BCAR (PRIOR TO 1981)

CHAPTER VII
ADVISORY MATERIAL
SECTION 1.0 - FAA ADVISORY CIRCULARS

CHAPTER VII
SECTION 1.0
FAA ADVISORY CIRCULARS

CHAPTER VII - ADVISORY MATERIAL
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SECTION 1.0 FAA ADVISORY CIRCULARS

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SYMBOLS AND ABBREVIATIONS

<u>Symbols</u>	<u>Description</u>
AC	Advisory Circular
AGL	Above Ground Level
ATR	Air Transport Rating
CAR	Civil Air Regulation
DOT	Department of Transportation
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FMEA	Failure Mode and Effects Analysis
LWC	Liquid Water Content
MVD	Median Volumetric Diameter
OAT	Outside Air Temperature
SFAR	Special Federal Aviation Regulation
STC	Supplemental Type Certificate
TC	Type Certificate

GLOSSARY

light icing - The rate of accumulation that may create a hazard if flight is prolonged in this environment. Occasional use of de-icing/anti-icing equipment removes/prevents accumulation.

liquid water content (LWC) - The total mass of water contained in all the liquid cloud droplets within a unit volume of cloud. Units of LWC are usually grams of water per cubic meter of air (g/m^3).

median volumetric diameter (MVD) - The droplet diameter which divides the total water volume present in the droplet distribution in half, i.e., half the water volume will be in larger drops and half the volume in smaller drops. The value is obtained by actual drop size measurements.

moderate icing - The rate of accumulation is such that even short encounters become potentially hazardous and use of de-icing/anti-icing equipment or diversion from the area and/or altitude is necessary.

Severe icing - The rate of accumulation is such that de-icing/anti-icing fails to reduce or control the hazard requiring immediate diversion from the area and/or altitude.

VII.1.0 FAA ADVISORY CIRCULARS

VII.1.1 INTRODUCTION

The Advisory Circular System is the FAA's primary mechanism for publishing advisory information for the benefit of the aviation community and public. The objective of the system is to provide explanatory and guidance material, in nonregulatory language, which is wholly informational in nature. Its use is neither mandatory nor regulatory. An AC may not be used to add to, interpret, or relieve a duty imposed by a regulation.

The advisory circular numbering system corresponds by subject matter areas to the Subchapter, Part, and Section titles of the FAR's. When the AC is related to many FAR Parts or the relationship is general rather than specific, a FAR Subchapter (general subject area) and part number is used. For example, AC 20-73, "Aircraft Ice Protection," is the 73rd AC dealing with the FAR general subject area of "AIRCRAFT" whose part number is "20." A more specific index number is used when the AC is relevant to a specific FAR Section. For example, AC 23.1419-1, "Certification of Small Airplanes for Flight in Icing Conditions," is the first AC dealing with FAR Part 23 Section 1419 "Ice Protection."

Each FAR-related AC makes it clear that methods or procedures described for showing compliance with regulations are not the only ones acceptable to the FAA. In fact, FAR related ACs begin with a statement of purpose which contains the following disclaimer:

"This material is neither mandatory nor regulatory in nature and does not constitute a regulation."

ACs are issued as necessary whenever the FAA determines that a need exists for additional explanation, information, guidance, or warning. They share insights and experiences which can be invaluable, especially to those pursuing aircraft certification, and can vary in length from a few pages to hundreds of pages. Periodically, the FAA issues a checklist of current ACs in a publication which is itself an AC (see Section 1.2). ACs are available from:

Superintendent of Documents
U.S. Government Printing Office
Washington, D.C. 20402

This chapter provides descriptions of those Advisory Circulars which deal most directly with icing flight certification. These descriptions are not summaries of the advisory circular information but are only intended to briefly describe the scope of the circular so that the reader can determine his need for the actual document. ACs which relate to foreign certification are described in Chapter VI, Section 3.0.

VII.1.2 AC 00-2.2: ADVISORY CIRCULAR CHECKLIST

Advisory Circular 00-2.2 (reference 1-1) gives a listing of current FAA Advisory Circulars and the status of certain other FAA publications. It is published on an annual basis in October and each year a numerical value of .1 is added to the decimal numerical designation to indicate the revision.

The full FAR outline is provided and a listing is given of cancelled ACs. The ACs are listed in both numerical and alphabetical order. A bibliography is provided with one-paragraph abstracts of other FAA publications which may be of general interest.

Instructions are given for ordering ACs, only some of which require payment. Sample copies of order and subscription forms are appended, as well as a list of Government Printing Office bookstores.

VII.1.3 AC 00-6A: AVIATION WEATHER

Advisory Circular 00-6A (reference 1-2) provides general educational material on most aspects of aviation weather. Chapter 10 addresses icing for structures as well as for engine induction and instrumentation systems. The weather patterns which are conducive to an icing environment are also discussed thus facilitating an understanding of details provided in the other chapters. Photographs and sketches are provided of ice types and various icing problems - leading edge, inlets, propeller, pitot static ports, etc. (Contains 143 pages.)

VII.1.4 AC 00-45B: AVIATION WEATHER SERVICES

Advisory circular 00-45B (reference 1-3) acts as a supplement to AC 00-6A by providing details on available weather services. Details are provided on the use and interpretation of these services for the novice as well as for ATR pilots. Reports, forecasts, weather maps, and prognostic charts, many of which can be applied directly to flight planning and in flight decisions, are detailed. (Contains 123 pages.)

VII.1.5 AC 20-29B: USE OF AIRCRAFT FUEL ANTI-ICING ADDITIVES

Advisory Circular 20-29B (reference 1-4) provides details on the use of PFA-55MB and MIL-I-27686 additives as a means of FAR 25.997(b) compliance for continuous fuel flow under conditions where ice may occur in turbine aircraft fuel systems. (Contains 5 pages.)

VII.1.6 AC 20-73: AIRCRAFT ICE PROTECTION

Advisory Circular 20-73 (reference 1-5) provides information relating to the substantiation of ice protection systems on airplanes. The ice protection methods discussed are hot air, electric resistance, liquid, and expandable boot systems. Design factors for these systems are briefly presented including:

- a. Sources and terminology for meteorological data with guidance for use.
- b. Operational factors (cruise, climb, holding, etc.) for airplanes, helicopters, and engines, that influence the determination of the most severe design condition. Other factors considered are ice shedding, ice shapes, and the effect of ice collected on unprotected surfaces.
- c. Design analysis approaches for various components of the airplane.
- d. Recommended design practices.
- e. Anti-ice and de-ice system considerations.

Testing methods to support or verify the analyses are outlined as follows:

- a. Natural icing flight tests.
- b. Dry air flight tests.
- c. Flying tanker tests.
- d. Self-contained spray rig tests.
- e. Icing tunnel tests.
- f. Ice shedding tests.
- g. Combination of methods.

Test procedures for each are discussed for components such as airframe surfaces, instruments, engines, engine inlets, and helicopter rotors. Suggestions for finding icing test conditions are given and actual examples of icing encounters cited.

A summary of recommended procedures for type certification is given for airframe and engine manufacturers. An extensive bibliography, arranged by subject but limited to documents published prior to 1971, is included. (Contains 46 pages including appendices.)

VII.1.7 AC 20-93: FLUTTER DUE TO ICE OR FOREIGN SUBSTANCE ON OR IN AIRCRAFT CONTROL SURFACES

Advisory Circular 20-93 (reference 1-6) provides a warning of the hazards of flutter due to ice in, on, or around control surfaces. (Contains 2 pages.)

VII.1.8 AC 20-113: PILOT PRECAUTIONS AND PROCEDURES TO BE TAKEN IN PREVENTING AIRCRAFT RECIPROCATING ENGINE INDUCTION SYSTEM AND FUEL SYSTEM ICING PROBLEMS

Advisory Circular 20-113 (reference 1-7) provides information concerning reciprocating engine induction system icing. The impact of icing is discussed plus types or origin of ice and methods/precautions to take in the prevention of icing. (Contains 6 pages.)

VII.1.9 AC 20-117: HAZARDS FOLLOWING GROUND DE-ICING AND GROUND OPERATIONS IN CONDITIONS CONDUCTIVE TO AIRCRAFT ICING

Advisory Circular 20-117 (reference 1-8) emphasizes the "clean aircraft concept" when ground conditions are conducive to icing. A great deal of information is included concerning freezing point depressant fluids. Fluid applications, including rates, expected results, and caution are addressed. (Contains 37 pages including appendices.)

VII.1.10 AC 23.1419-1: CERTIFICATION OF SMALL AIRPLANES FOR FLIGHT IN ICING CONDITIONS

Advisory Circular 23.1419-1 (reference 1-9) sets forth an acceptable means of demonstrating compliance with ice protection requirements of FAR Part 23 of the Federal Aviation Regulations (reference 1-10). This AC addresses the certification of all small airplanes having a passenger seating capacity, excluding pilots, of nine or less. This material supplements AC 20-73 (reference 1-5) which provides information on substantiation of aircraft ice protection systems.

The guidance provided in AC 23.1419-1 applies to ice protection systems approval for operating in the icing environment defined in FAR Part 25, Appendix C (reference 1-11) and may be applied to new Type Certificates (TCs), Supplemental Type Certificates (STCs), and amendments to existing TCs.

AC 23.1419-1 contains a table which specifies airplane icing certification requirements under CAR Part 3 (reference 1-12) or FAR Part 23 depending upon the date of type certification application. A summary of regulations relating to ice protection is also presented as well as related reading material and a history of icing regulations.

AC 23.1419-1 discusses the planning for certification and a listing of basic information which should be included. A detailed appendix provides a checklist of items which could affect safety in icing flight. Suggested considerations in addressing the safety concerns are also listed.

The analyses which an applicant normally prepares to substantiate his design decisions are outlined for the following:

- a. Areas and components to be protected - thirteen are listed.
- b. The 45 minute hold condition.
- c. Flutter analysis which considers any effect of accumulated ice.
- d. Power sources and power required by the ice protection system and the need to assess the effects of power failures in flight.
- e. Failure analysis such as FMEA (Failure Modes and Effects Analysis).
- f. Similarity analysis if certification is based on type similarity to previously certificated airplanes.
- g. Impingement limit analysis including the establishment of critical conditions and limits of ice accretion.
- h. Induction air system protection.

Flight test planning and performance are discussed in some detail, with each type of ice protection system considered separately. Flight tests in dry air, simulated icing, and natural icing are considered.

The effects of ice accumulations on performance and handling qualities are considered in detail. The required placarding and flight manual instructions and information are discussed with an example. (Contains 25 pages including appendices.)

VII.I.11 AC 25.1309-1: SYSTEM DESIGN ANALYSIS

Advisory Circular 25.1309-1 (reference 1-13) provides guidance material for acceptable means of demonstrating compliance with FAR Part 25. In particular it considers probabilistic terms (as introduced in FAR Amendment 25-23) for airplane equipment systems and installations. There are no specific references made to ice protection systems. However, the principles, definitions, and clarifications given are clearly applicable to ice protection systems.

This AC addresses the need to consider the consequences of faults in separate systems which create hazards to the airplane if simultaneous failures occur. Airplane functions are divided into non-essential, essential, and critical categories. Definitions are given for 22 terms used in the regulations (examples are failure, failure analysis, failure condition, failure effect(s), failure mode, fault). Acceptable failure analysis techniques are given, including quantitative methods using (a) Fault Tree Analysis, (b) Failure Mode and Effects Analysis (FMEA), and (c) Probability Analysis. (Contains 18 pages including appendices.)

VII.1.12 AC 27-1: CERTIFICATION OF NORMAL CATEGORY ROTORCRAFT

Advisory Circular 27-1 (reference 1-14) is a large and detailed guide for certification of normal category rotorcraft. It was issued as part of an effort to achieve national standardization for rotorcraft certification. This AC covers FAA policy on methods of compliance with FAR Part 27 of Subchapter C, Chapter I, Title 14 of Code of the Federal Regulations (reference 1-15). Methods of compliance considered are in the areas of basic design, ground tests, and flight tests.

The FAA intends that additional sections will be added to this AC and sections of the outline have been reserved for such additions. Ice protection is included in two of these reserved sections which are to be added at a later date. These sections are:

Section 30.532 (FAR 27.1093) Induction System Icing Protection

Section 38.692 (FAR 27.1419) Ice Protection

(Page numbers 1 thru 1380.)

VII.1.13 AC 29-2: CERTIFICATION OF TRANSPORT CATEGORY ROTORCRAFT

Advisory Circular 29-2 (reference 1-16) consolidates FAA guidance on the certification of transport category rotorcraft. It is addressed to engineers and test pilots concerned with certification on the behalf of manufacturers, modifiers, and the FAA. It covers FAA policy on methods of compliance with FAR Part 29 (reference 1-17) for basic design, ground tests, and flight tests. The paragraphs are keyed to the FAR Part 29 numbering system. The portion which relates to flight in icing is Section 386 (FAR 29.877), Ice Protection (16 pages).

As of January 1988, no U.S. helicopter has been certified for operation in icing conditions. AC 29-2 discussions generally pertain to the full icing envelopes of FAR Part 29 Appendix C which are replicas of the FAR Part 25 Appendix C envelopes. Certifications with full ice protection systems are envisioned (rotor blades, windshields, engine inlets, stabilizer surfaces, etc.). The AC rejects the concept of limited certification for helicopters where the pilot has no control over the limiting variable such as is done by the U. S. Military and the British. Typically, these permit helicopter flight into known icing conditions where LWC does not exceed 1.0 g/m^3 and OAT is not colder than -4°F (-20°C). This limited certification concept was ruled out by the FAA due to the difficulty in forecasting the severity of icing conditions and the difficulty in relating the effects of fixed wing icing reports to rotorcraft.

However, AC 29-2 does offer a pilot-controllable, altitude-limited, icing design atmosphere based on the same data used to derive the Part 25 Appendix C envelopes but limited to a pressure altitude of 10,000 feet. Separate graphs are provided for continuous (stratiform) and intermittent (cumuliform) conditions. This altitude limitation reduces the severity of LWC and OAT, especially for the intermittent condition. In addition, Change 2 to AC 29-2 offers a second pilot-controllable, altitude limited, icing envelope based on more recent research data (reference 1-18), limited to 10,000 AGL. A single graph is provided that characterizes the icing atmosphere as a combination

of stratiform and low-level cumuliform conditions over icing duration distances. This altitude limitation also reduces the severity of LWC and OAT but broadens the range of MVD cloud droplet sizes to be considered. These altitude limitations can be controlled by the pilot and reflect the practical operational limits of rotorcraft and compatibility of the air traffic control system.

The only ice protection system discussed by this AC is the electrothermal de-icing type since only this system has had significant rotorcraft icing flight experience. Warnings are given regarding transferring icing flight experience from one rotorcraft type to another, or from fixed wing aircraft to helicopters. Even on similar rotorcraft types, ice accumulations and their effects can vary significantly between rotating and non-rotating components.

Suggestions are given for certification planning, analysis, and tests. Compliance demonstration methods are discussed as they apply to large rotorcraft. Instrumentation and data collection methods for this application are discussed. An extensive reference list is included. (Contains 1290 pages.)

VI.1.14 AC 91-13C: COLD WEATHER OPERATION OF AIRCRAFT

Advisory Circular 91-13c (reference 1-19) provides general information on aircraft operation in cold weather. Precautions are noted for use of anti/de-icing equipment, engine operation, and miscellaneous ground conditions. (Contains 9 pages.)

VII.1.15 AC 91-51: AIRFRAME DE-ICING AND ANTI-ICING SYSTEMS

Advisory Circular 91-51 (reference 1-20) provides information for pilots regarding ice protection system approval and results of in-flight testing. A review of accident reports in which in-flight icing was a primary factor indicated that pilots may be unaware of the following:

- a. The difference between airplanes which are approved for flight into icing conditions and those which are not.
- b. Certain effects of in-flight ice accumulation on airplane characteristics and performance.

Pilots are informed of the certification rules in FAR Part 23 and 25 (references 1-10 and 1-11) and are told how to determine the icing certification status. Operating rules from FAR Parts 91 and 135 (references 1-21 and 1-22) are summarized. Pilots are warned that the presence of de-icer boots on an airplane does not insure that it is certified for flight in icing conditions. Some of the physical effects of ice accumulation on an airplane are described and piloting recommendations are listed. (Contains 4 pages.)

VII.1.16 AC 123-39: HAZARDS OF WASTE WATER ICE ACCUMULATION SEPARATION FROM AIRCRAFT IN FLIGHT

This AC emphasizes the potential hazards to life and property due to lavatory fluid and potable water systems ice accumulation and resultant separation from aircraft in flight. (contains 2 pages)

VII.1.17 AC 135-9: FAR PART 135 ICING LIMITATIONS

Advisory Circular 135-9 (reference 1-23) provides information and guidance to commuter air carriers and air taxi operators concerning the requirements of Federal Aviation Regulations (FAR) Part 135, Section 135.227, Icing Conditions: Operating Limitations (reference 1-22). The information in this AC applies to certificate holders using aircraft that are not certificated for operations into icing conditions. Clarification is provided concerning paragraph 135.227, which is similar to the old paragraph 135.85. The historical background is discussed as to why some confusion has existed concerning operations in icing conditions, especially for small to medium type airplanes typical of FAR Part 23 (reference 1-10) and/or SFAR 23 certified aircraft. Operators are also referred to two other Advisory Circulars; namely, AC 00-45B (reference 1-3) and AC 91-51 (reference 1-20). (Contains 4 Pages.)

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CHAPTER VIII
BIBLIOGRAPHY
VIII.1.0 INTRODUCTION

This bibliography has been prepared using the bibliography created by Dr. Ken Korkan of Texas A & M University for the Society of Automotive Engineers (SAE) AC-9C Subcommittee (SAE ATR-4015) on Aircraft Icing Technology. The original bibliography has been reformatted to alphabetize by author within each subject area. Additional references have been incorporated to make the bibliography more complete concerning aircraft icing.

The principal sources for the bibliography area as follows:

- (a) Bibliography of Unclassified National Research Council of Canada Aircraft Icing Reports and Publications.
- (b) K. D. Korkan, "Compendium of Aircraft Anti-ice/Deice/Ice References," private communication, Texas A & M University, College Station, Texas, 1983.
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- (i) National Technical Information Center (NTIS).

The Icing Bibliography was originally created at Texas A & M University using an IBM Personal Computer and word processing software from Micro Pro International Corporation. Modifications and additions to the bibliography have been processed by Gates Learjet Corporation on an IBM 3081 mainframe VIII 1-1 Computer using the Statistical Analysis System (SAS). The final form of the bibliography for the Aircraft Icing Handbook has been processed using word processing software. This bibliography consists of over 2000 references which are subdivided into 23 different categories according to subject and/or title and ordered alphabetically by first author within each subject category.

CHAPTER VIII
SECTION 2.0
METEOROLOGY OF ICING CLOUDS

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CHAPTER VIII
SECTION 3.0
METEOROLOGICAL INSTRUMENTS

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CHAPTER VIII
SECTION 4.0
AIRCRAFT ICE FORMATION

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CHAPTER VIII
SECTION 5.0
PROPELLER ICING

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SECTION 7.0

TURBINE ENGINE AND INLET ICING

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CHAPTER VIII

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WING ICING

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WINDSHIELD ICING

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CHAPTER VIII

SECTION 10.0

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CHAPTER VIII

SECTION 11.0

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CHAPTER VIII
SECTION 12.0

HELICOPTER ROTOR BLADE ICING

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CHAPTER VIII

SECTION 13.0

ENGINE SNOW INGESTION AND SNOW MEASUREMENTS

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CHAPTER VI II

SECTION 14.0

ICE DETECTION AND PROTECTION SYSTEMS

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CHAPTER VIII

SECTION 15.0

DROPLET TRAJECTORIES AND IMPINGEMENT

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CHAPTER VIII
SECTION 16.0
ICE ACCRETION MODELING

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CHAPTER VIII

SECTION 17.0

ICING TEST FACILITIES AND SIMULATION

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CHAPTER VIII

SECTION 18.0

AIRFOIL AND AIRCRAFT PERFORMANCE DEGRADATION

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CHAPTER VIII

SECTION 19.0

ICE ADHESION AND MECHANICAL PROPERTIES

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CHAPTER VIII
SECTION 20.0
HEAT TRANSFER

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CHAPTER VIII
SECTION 21.0
FLUID FLOW DYNAMICS

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CHAPTER VIII

SECTION 22.0

EVAPORATION, SUBLIMATION, AND CRYSTALLIZATION

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CHAPTER VIII

SECTION 23.0

EDUCATION, TRAINING, AND MISCELLANEOUS

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**CHAPTER IX
SUBJECT INDEX**

CHAPTER IX
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