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A History and Interpretation of Aircraft Icing Intensity Definitions and FAA Rules for Operating in Icing Conditions

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16. Abstract

This report traces the evolution of aircraft icing severity definitions and of the Federal Aviation Administration (FAA) regulations governing flight in icing conditions in order to understand the intent of each and how they relate to each other. There have been several changes in both the definitions and the regulations over time, and part of the problem is that the definitions have not been updated or clarified to account for current regulations. Much confusion has resulted and, in order to improve the situation, new and updated definitions have been recently proposed by a new working group established as part of the 1997 FAA In-Flight Icing Plan.

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EXECUTIVE SUMMARY

Current definitions of trace, light, moderate, and severe icing intensities have come to be criticized because (a) they seem vague and subjective, (b) icing is aircraft-dependent, and therefore it is not known how the intensity reported by one airplane relates to intensities on other airplanes, and (c) the definition for severe icing appears to be incompatible with the rules (Title 14 Code of Federal Regulations (14 CFR 91.527, 14 CFR 125.221, and 14 CFR 135.227) under which flight is permitted in severe icing conditions.

This report traces the evolution of aircraft icing severity definitions and of the Federal Aviation Administration (FAA) regulations governing flight in icing conditions in order to understand the intent of each and how they relate to each other. There have been several changes in both the definitions and the regulations over time, and part of the problem is that the definitions have not been updated or clarified to account for current regulations. Much confusion has resulted and, in order to improve the situation, new and updated definitions have been recently proposed by a new working group established as part of the 1997 FAA In-Flight Icing Plan.

The last part of this report explains the ideas behind reintroducing a measurable aspect to the icing intensity definitions, demonstrating the benefits of quantifying the icing intensities in terms of specific ice accretion rates. These rates are measurable and, with modern-day, computerized ice accretion models, they are easily calculable and therefore forecastable. This scheme actually takes advantage of the individual sensitivity of different airplanes to icing conditions and provides a way to improve icing pilot reports (PIREPS), icing forecasts, and the documentation and evaluation of icing tests. Several examples are given in the appendix to illustrate these applications.

INTRODUCTION

ICING DEFINITION INCONSISTENCIES.

Currently accepted icing intensity definitions are those which appear in the Aeronautical Information Manual (AIM) [1]. These definitions, which are repeated here in table 1, date from the 1960s and were designed for reporting icing conditions in flight.

TABLE 1. AIRFRAME ICING REPORTING TABLE [1]

TRACE	Ice becomes perceptible. The rate of accumulation is slightly greater than the rate of sublimation. It is not hazardous even though deicing/anti-icing equipment is not utilized, unless encountered for an extended period of time—over 1 hour.
LIGHT	The rate of accumulation may create a problem if flight is prolonged in this environment (over 1 hour). Occasional use of deicing/anti-icing equipment removes/prevents accumulation. It does not present a problem if the deicing/anti-icing equipment is used.
MODERATE	The rate of accumulation is such that even short encounters become potentially hazardous and the use of deicing/anti-icing equipment or flight diversion is necessary.
SEVERE	The rate of accumulation is such that deicing/anti-icing equipment fails to reduce or control the hazard. Immediate flight diversion is necessary.

In subsequent years, the definitions have come to be criticized for several reasons:

a. they seem vague and subjective,

b. icing is aircraft dependent and therefore it is not known how the intensity reported by one airplane relates to intensities on other airplanes, and

c. the definition for severe icing appears to be incompatible with the rules (Title 14 Code of Federal Regulations, (14 CFR 91.527, 14 CFR 125.221, and 14 CFR 135.227) [2] under which flight is permitted in severe icing conditions.

THE CRITICISMS IN DETAIL.

Vague and Subjective. It is understood that these definitions (table 1) are intended to be guidelines rather than rigorous rules and, in order to be simple and brief, some vagueness in the wording may have been unavoidable. Nevertheless, if the definitions are pressed for an interpretation, a number of uncertainties arise. For example, the definitions were presumably intended to help pilots estimate the intensity of icing encounters for inflight reporting purposes. But the definitions really only give an explanation or warning of what is expected to happen if flight is continued in a given icing intensity with or without the use of ice protection equipment. In other words, the definitions explain what to expect if the aircraft is flown into icing conditions of known intensity. The definitions do not tell how to decide in flight what the icing intensity actually is, except perhaps by staying in it long enough to see what happens. So,

- *How does a pilot recognize the different icing intensities in flight?* The definitions do not say. They are based on rates of ice accumulation that are unspecified, except possibly as measured by the need for, and the frequency of using any deicing or anti-icing equipment. Otherwise, the definitions only warn that some "problem" or "hazard" will occur sooner or later, depending on the icing intensity and the use and adequacy of any ice protection equipment.

  - In order to find out what icing intensity the airplane is in, must the pilot of an unprotected airplane continue flying until a problem or hazard occurs?

  - How do pilots distinguish between trace and light icing if neither presents a problem or hazard until after an hour of exposure?

  - During flight in light icing conditions, for example, how will the pilot know if the intensity *changes* to trace, or moderate, or severe?

  - If deicing boots are used successfully to keep the ice from accumulating, how does the pilot then distinguish between trace, light, and moderate icing? Is it by how often the boots have to be activated? In that case, what if the boots are automatically cycled at equal intervals?

  - If an airplane is anti-iced with heated wings, how will the pilot ever know what intensity is being encountered?

- What is meant by "problem" or "potentially hazardous" [3]? Is the problem that may result from light icing worse than the hazard that may result from trace icing?

- Are all unprotected aircraft hazardous to fly in trace or light icing for longer than an hour? What hazard will occur? How do I know that my particular airplane will not face a hazard in less than an hour?

- How long is a "short encounter" [3] for my airplane in moderate icing?

- How can icing ever be severe for airplanes that are certificated for flight into icing conditions, if certification means that the ice protection equipment will not be overwhelmed in unrestricted icing conditions?

Icing is Aircraft Dependent.

The Effects on Pilot Reports (PIREPS). Different airplanes will report different icing intensities in the same icing conditions. Pilots must generally look for PIREPS from other airplanes similar to theirs to learn what to expect for their particular airplane. It is also generally accepted that a report of light, moderate, or severe icing from a large (jet) airplane means that the icing intensity will probably be worse for smaller aircraft. On the other hand, no reports of icing or reports of trace icing by a large airplane cannot be used to conclude that there is little or no icing for small airplanes too. This is because large airplanes are generally anti-iced and may not show any visible signs of icing anyway.

This aircraft dependency is a recognized condition, however, and for this reason the PIREPS include the type of airplane that submitted each report. This still leaves uncertainty in the mind of pilots of small aircraft, because it is not known whether light icing reported by a large airplane will mean light, moderate, or severe icing for small aircraft.

The Effects on Icing Forecasts. The icing intensity definitions contain no reference to any atmospheric variables associated with icing. The result is that forecasters are issuing estimates of icing intensity based on various rules of choice or convenience, using terminology that they assume is meaningful to aviators. Aviators are interpreting the terminology according to whatever definitions they believe apply (the U.S. Air Force icing forecasts are said to apply only to certain aircraft models [4]), or according to what they feel the effects of the icing will actually be on their airplane. They may think in terms of the PIREP definitions, or they may also interpret the terms (trace, etc.) rather subjectively, based on their experience or simply on the connotations of the words.

Icing forecasts are also criticized for predicting the same intensity for all aircraft, knowing that any given icing condition will affect different aircraft differently, especially for helicopters as compared to fixed wing aircraft. This failing is largely due to the lack of data on the effects of icing on individual aircraft, and therefore to the lack of any way to tailor the predictions to different aircraft.

Relationship to the Certification and Operating Rules in 14 CFR. There appears to be an inconsistency between the definition of severe and the presumption of flightworthiness for aircraft that are certificated for flight into icing conditions. 14 CFR 135.227(d) permits airplanes to fly into severe icing conditions if they have ice protection equipment that is certificated for icing. However, according to the definitions of (table 1), severe icing is considered to be impenetrable, even for protected airplanes.

One reason for this inconsistency is that the definitions have never been updated to acknowledge the certification and operating rules in the Federal Aviation Regulations (FARs) which consider icing-certificated airplanes to be capable of flying in unrestricted icing conditions.

NTSB Criticisms. In response to all these shortcomings, the National Transportation Safety Board (NTSB) issued several Safety Recommendations in 1981 [5]. One recommendation (A-81-

118) called for re-evaluation and clarification of the rules in 14 CFR 91.527 and 14 CFR 135.227 to ensure that the regulations are compatible with the definition of severe icing. A second recommendation (A-81-115) states that the Federal Aviation Administration (FAA) should evaluate individual aircraft performance in icing conditions in terms of liquid water content (LWC), drop size distribution, and temperature and should establish operational limits and publish this information for pilot use. More recently, as a result of the "Roselawn" accident, the NTSB has recommended that the FAA "Revise existing aircraft icing intensity reporting criteria and other FAA literature by including nomenclature related to specific types and sizes of aircraft."

THE HISTORY OF THE DEFINITIONS AND THE REGULATIONS.

In order to attempt an answer to these questions, it is really necessary to understand the origins and evolution of both the definitions and the FAA regulations regarding icing. One may ask: what definitions were in mind when the regulations were written? The regulations do not define the terms light, moderate, and severe, so it has always been assumed that they refer to the definitions in the AIM. But on the other hand, one may ask: what regulations, if any, were in mind when the definitions were formulated? One also needs to know the intent behind the definitions and the regulations—i.e., what were the framers thinking and what exactly were they trying to accomplish?

A review of the available historical literature has provided considerable insight. Both the definitions and the regulations have evolved through several changes over the past four decades. This evolution is traced in detail in the following two sections.

Basically, the current definitions were first developed for icing-unprotected military airplanes in the 1950s and then modified to accommodate both deicing-equipped and icing-unprotected civil aircraft in the 1960s. The present wording reflects these origins and the stated effects of each intensity level are understandable if applied to icing-unprotected aircraft. Subsequently, FAA regulations have greatly restricted civil, icing-uncertificated aircraft from flying in icing conditions. But the icing intensity definitions have not been updated or clarified to acknowledge the presence of the FAA icing regulations. Much confusion has resulted, as was previously indicated.

ORIGINS AND EVOLUTION OF THE ICING INTENSITY DEFINITIONS

THE ORIGINAL ICING INTENSITY SCALE (1940s).

The words *trace*, *light*, *moderate*, and *severe* (or *heavy*) have been in use for several decades to describe atmospheric icing conditions. The terminology was originally defined in the 1940s by the U.S. Weather Bureau for reporting the amount of ice deposited by frequent icing conditions at the observatory on the summit of Mt. Washington, New Hampshire [6]. For purposes of estimating the amount of ice that may accrete on an airplane flying through similar cloud conditions, the measurements were converted to the rate of accretion on a three-inch (7.5-cm)-diameter (nonrotating) cylinder, at an "aircraft standard" airspeed of 200 miles per hour (174 kt). The resulting icing intensity scale is shown in table 2.

TABLE 2. ORIGINAL ICING INTENSITY SCALE [6]

Rate of Ice Accretion on 3″ diam. cyl. at 200 mph (g/cm^2 per hour)	Weather Bureau Scale of Icing Intensity for Mountain Stations
0.00-1.00	trace
1.01-6.00	light
6.01-12.00	moderate
$>$ 12.00	severe

Direct measurement of ice accretion was a simple way of characterizing clouds for icing conditions. The 3-inch-diameter cylinder served as a standard probe which approximated the leading edge of typical airplane wings and other airframe components where icing is a concern. Thus, the rate of ice accumulation on one of these cylinders could be used to estimate the accumulations on aircraft flying in similar conditions.

The words *trace*, etc., served the dual purpose of allowing measured icing rates to be reported in simple, meaningful terms and at the same time indicating the expected difficulty of flying an aircraft with similar rates of ice accretion. But flight experience began to show that icing rates arbitrarily called moderate in table 2 often seemed to result in pilots having severe difficulty flying the plane.

As a result of accumulated experience from pilot reports, it was proposed in 1951 that for aviation usage the descriptive terms in Table 2 be changed to *light*, *moderate*, *heavy*, and *very severe*, [6]. It does not appear that the changes were permanently adopted, however, because the original terms and associations are still in general use today.

For meteorologists trying to provide information on existing or forecasted icing conditions aloft, the ice accretion scale is of little use. In-cloud measurements like these are not available for assessing current conditions, and estimates of icing rates elsewhere could only be made with difficulty using statistics from Mt. Washington for similar cloud and weather situations. Alternate scales had to be used where ice accretion rates were replaced by equivalent amounts of supercooled cloud water concentration, commonly termed liquid water content (LWC). This is a variable that could be roughly estimated for different cloud types and weather situations. This alternate intensity scale is given in table 3.

TABLE 3. ALTERNATE ICING INTENSITY SCALE FOR FORECASTERS [6]

Supercooled Water Content (g/m^3)	Intensity
0-0.1	trace
0.1-0.6	light
0.6-1.2	moderate
$>$1.2	severe (or heavy)

THE U.S. AIR FORCE VERSION (1956).

By 1956 [7] the preferred reference probe had changed from the 3-inch cylinder to a "small" probe, which was apparently represented by a ½-inch-diameter hollow cylinder. No documentation has been found on the thinking behind this change, but perhaps it was reasoned that wiper blades or other nearby small protrusions were more easily viewed and monitored by the pilots than the wing leading edges.

Table 4 published the relationship between the liquid water content (which forecasters could try to estimate) and the resulting ice accretion rate on these small probes. This table was evidently prepared by the U.S. Air Force for its own use, but it is obviously based on table 3. Notice that table 4 modifies the liquid water content categories of table 3, with the second category being split into two smaller intervals. The intensity terms have been reassigned too, with both *heavy* and *severe* icing being used separately for the two highest intensities.

For the first time, the effects that pilots generally associated with the different icing terms were included in column two of table 4. This table tied together all the various aspects of each icing intensity level—the terminology used to describe it, the effects that the pilot would notice, the liquid water content that the meteorologists would attempt to forecast, and the amount of ice that would actually be measured (or collected) on a specific probe, if one were available.

TABLE 4. ICING SEVERITY SCALES USED BY THE U.S. AIR FORCE IN 1956 [7]

Descriptive Terminology	Aircraft Performance Criteria	Liquid Water Content (g/m^3)	Ice Collection Rates on Small Probes	
			Inches per 10 miles	Miles per ½ inch
Trace	Barely perceptible ice formations on unheated aircraft components	0 to 0.125	0 to 0.09	56 or more
Light	Evasive action unnecessary. (No perceptible effects on performance).	0.125 to 0.25	0.09 to 0.18	28 to 56
Moderate	Evasive action desirable. (Noticeable effects on performance.)	0.25 to 0.60	0.18 to 0.36	14 to 28
Heavy	Eventual, evasive action necessary. (Aircraft is unable to cope with icing situation and extended operation is not possible.)	0.60 to 1.0	0.36 to 0.72	7 to 14
Severe	Immediate evasive action is required. (Aircraft uses climb power to hold altitude, and continued operation is limited to a few minutes.	1.0 or more	0.72 or more	0 to 7

Although the descriptive effects on performance could be used by the pilots of any aircraft, the specific relationship between them and the stated liquid water contents in this table were said to be for "typical fighter aircraft" [7]. It is not clear how these relationships were established (no documentation has been found so far). The stated connection between the terminology, the effects, and the liquid water content allowed the forecaster and the pilot to use the same terminology (trace, light, moderate, etc.) unambiguously, at least for a particular class of aircraft. From a numerical estimate of liquid water content the meteorologist could issue a forecast of trace, light, etc. icing and the pilots (of the fighter aircraft) would know what to expect. Conversely, when these pilots reported trace, light, etc. icing, the forecaster could translate that back to a range of liquid water content. This was helpful in judging the accuracy of the forecasts.

It is important to remember that these fighter aircraft were probably not (and still are not) protected against ice accumulation on the wings and tailplane. Thus the listed effects on performance were real and noticeable and served as a basis for avoidance or evasive action.

THE NATIONAL COORDINATING COMMITTEE FOR AVIATION METEOROLOGY (NCCAM) VERSION (1964).

The relationship between terminology and inflight effects as postulated in table 4 apparently became popular with pilots in general. By 1964 a national coordinating committee (with representatives from the U.S. Air Force, Army, Navy, Coast Guard, Weather Bureau, FAA, and NASA) agreed on a similar, but revised table for use by both civil and military aviators in general. This is shown in table 5.

There are several important things to notice in table 5.

- It was still considered important to tie the definitions to some measurable standard—in this case it was still a small probe of some kind, but apparently the relationship to liquid water content was dropped. Nevertheless, the information in the third and fourth columns caused these to be sometimes called "operational definitions." The table 5 shown here is actually a second-hand version, the original documents of the committee have not been found.

- The table now seems to accommodate both unprotected and ice-protected airplanes. The "Effects on Aircraft" column still describes what would happen to an airplane without ice protection. As in the 1956 Air Force version, no mention of deicing is made at all in this column, except in the heavy category to emphasize the futility of trying to cope with those icing conditions. But the "Pilot Response" column tells the pilot what to do *if* the aircraft has deicing equipment.

- A judgement has now been made that even *with* deicing equipment, airplanes generally cannot control heavy icing conditions. The basis for this judgement is not known. Perhaps it was meant to convey the idea that even if deicers could continue to remove ice from the protected parts of the wing and tail, the ice buildup on other (unprotected) parts of the plane would be great enough to cause a dangerous situation.

- The "Pilot Response" column does not explicitly mention *anti-iced* (heated wing) airplanes. Either it was assumed that (large) heated-wing airplanes were exempt from icing concerns or else deicing equipment was meant to be a generic term for *all* ice protection equipment.

TABLE 5. ICING DEFINITIONS ADOPTED BY THE NCCAM IN 1964 [8 AND 9]

Definition	Accumulation Rate on a Small Probe	Effects on Aircraft	Pilot Response
Trace	1/2-inch in 80 miles	The presence of ice on the airframe is perceptible, but rate of accretion is nearly balanced by rate of sublimation. Therefore, this is not a hazard unless encountered for an extended period of time.	The use of deicing equipment is unnecessary.
Light	1/2-inch in 40 miles	The rate of accretion is sufficient to create a hazard if flight is prolonged in these conditions, but is insufficient to make diversionary action necessary.	Occasional use of deicing equipment may be necessary.
Moderate	1/2-inch in 20 miles	On the airframe, the rate of accretion is excessive, making even short encounters under these conditions hazardous.	Immediate diversion is necessary, or use of deicing equipment is mandatory.
Heavy	1/2-inch in 10 miles	Under these conditions, deicing equipment fails to reduce or control the hazard.	Immediate exit from the icing condition is mandatory.

Note: This version was based on table 4 but the *severe* category was eliminated and the representative ice accumulation rates were replaced by an average value from the last column of table 4.

THE FEDERAL SUBCOMMITTEE ON METEOROLOGICAL SERVICES[1] VERSION (1968).

This successor committee to the NCCAM made some final modifications and recommendations in 1968. These are given below in table 6 and are tailored specifically as guidelines for reporting inflight icing conditions. They combine and refine the wording in the *Effects* and *Response* columns of table 5, and they make the exposure times a bit more specific by adopting one hour as the threshold of concern for trace and light icing conditions.

[1] Today, this interagency committee is part of the Office of the Federal Coordinator for Meteorology (OFCM) in the U.S. Department of Commerce.

TABLE 6. AIRFRAME ICING REPORTING TABLE ADOPTED IN 1968 [9, 10]

TRACE	Ice becomes perceptible. The rate of accumulation is slightly greater than the rate of sublimation. It is not hazardous even though deicing/anti-icing equipment is not utilized, unless encountered for an extended period of time—over 1 hour.
LIGHT	The rate of accumulation may create a problem if flight is prolonged in this environment (over 1 hour). Occasional use of deicing/anti-icing equipment removes/prevents accumulation. It does not present a problem if the deicing/anti-icing equipment is used.
MODERATE	The rate of accumulation is such that even short encounters become potentially hazardous and the use of deicing/anti-icing equipment or flight diversion is necessary.
SEVERE	The rate of accumulation is such that deicing/anti-icing equipment fails to reduce or control the hazard. Immediate flight diversion is necessary.

There are several things to notice about this latest version.

- These definitions required no special measuring equipment, were readily understandable, and were directly related to the seriousness of the effects of icing on any particular aircraft. It is said [10] that these definitions were recommended for use in all Federal Aviation Administration (FAA), Department of Commerce (DoC), and Department of Defense (DoD) handbooks, manuals, and publications. Indeed, these definitions are still in use today [1].

- The effects of the accumulations still describe what would happen on an *unprotected* aircraft, or on a protected aircraft when the ice protection is not used. The use of deicing or anti-icing equipment is expected to control at least light icing, if not moderate icing too.

- The connection to a standard reference probe has been lost. These were obviously not considered necessary or even available for routine reporting of inflight icing conditions. The definitions have evolved *away* from a measurable reference standard to a qualitative set of guidelines based on effects that the pilots can perceive. This has the advantage that the above definitions can be used by the pilot of *any* aircraft and not just for a specific type of airplane. But it means that there is no definable set of icing conditions that constitutes light, moderate, or severe icing. Intensities are now simply relative to the effects on the individual aircraft. It also means that a pilot report from a particular aircraft model has direct meaning only for that model or similar aircraft. No method is given for translating icing effects to different aircraft.

HOW THE METEOROLOGISTS COPED.

In 1969, a year after the pilot reporting definitions were issued, the U.S. Air Force updated and published its major handbook for forecasting icing conditions [4]. Here (page 1-2, paragraph 3b) the problem is discussed in regards to the definitions in table 6. It states:

> "Although the table is intended for use primarily in the reporting of icing encountered by pilots, the AWS, for standardization purposes, will now use the same definitions in issuing forecasts."

And then,

> "Convention has been to designate icing intensity in terms of its operational effect upon the reciprocating-engine, straight-wing transport aircraft as the standard. For example, the terminology (see table 6) applies to the C-54 and C-118 aircraft under "normal" loading and "normal" cruise conditions, and implies the meteorological explanations, based on liquid water content of the cloud, as given in paragraph 29. *Caution must be observed not to state operational effects of icing on other types of aircraft.*" (Italics are theirs).

It is further explained on page 5-4, paragraph 29c,

> "The (icing) intensities forecast by the subjective rules used in this manual imply these liquid water contents," table 3, "and not the actual operational effect upon the aircraft."

There was apparent concern about converting to general purpose definitions when, to the Air Force, the definitions really applied to only two specific airplane models. In addition, the loss of a correlation to LWC left no other way to forecast the new intensity levels. The compromise was to acknowledge the definitions imposed by the Federal Coordinating Committee in table 6 but to point out that the Air Force forecasts would still have to be based on the liquid water assignments in table 3. In addition, the Air Force was careful to point out that these LWC-based forecasts were still thought to be valid only for C-54 and C-118 airplanes.

THE IMPACT ON INSTRUMENT MANUFACTURERS.

The present icing intensity definitions (table 6) contain *nothing* that can be calculated or measured. Therefore, for engineering and forecasting purposes, they are practically useless. If one wished to market an icing rate meter to indicate trace, light, moderate, and severe icing conditions during flight, it would be impossible to do so with these definitions.

Nevertheless, at least one manufacturer has produced an icing rate meter that is calibrated in terms of LWC *and* icing intensity [10]. But in order to do this, the manufacturer *had* to go back and base the calibration on a measurable LWC-to-intensity relationship like in table 3 or 4. In fact, the referenced manufacturer apparently chose to arbitrarily define its own new intensity scale where trace = 0 to 0.25 g/m^3, light = 0.25 to 0.5 g/m^3, moderate = 0.5 to 1 g/m^3, and heavy = 1 to 2 g/m^3. This scale is based solely on LWC and not on any correlation with effects of icing on the aircraft. So there is no demonstrable connection between these intensities and those with the same name in table 6. As a result of these difficulties, the manufacturer has recently decided to replace the words *trace*, *light*, *moderate*, and *heavy*, with simply the words level 1, level 2 etc. on the readout dial of their icing rate meter.

The forecasting and manufacturing concerns described here clearly illustrate a major shortcoming of unquantifiable definitions such as those in table 6. Engineering applications are forced to ignore these and turn instead to other definitions that are measurable.

EVOLUTION OF THE OFFICIAL RULES FOR OPERATING IN ICING CONDITIONS

THE ORIGINAL OPERATING LIMITATIONS, 14 CFR 135.85 (1966).

While the evolution in icing intensity terminology was taking place, mostly outside the FAA, a parallel effort was underway within the FAA to establish some suitable requirements for ice protection equipment and regulations for operating in icing conditions. The latter first appear in the Federal Aviation Regulation (FARs) in 1966, as shown in the version of 14 CFR 135.85[2], for air taxi operators and commercial operators of small aircraft (30 seats or less).

§ 135.85 Icing conditions: Operating limitations.

(a) No pilot may take off an aircraft that has—

(1) Frost, snow, or ice adhering to any rotor blade, propeller, windshield, or powerplant installation, or to an airspeed, altimeter, rate of climb, or flight attitude instrument system;

(2) Snow or ice adhering to the wings, or stabilizing or control surfaces; or

(3) Any frost adhering to the wings, or stabilizing or control surfaces, unless that frost has been polished to make it smooth.

(b) No pilot may fly—

(1) Under IFR into known or forecast light or moderate icing conditions; or

(2) Under VFR into known light or moderate icing conditions; unless the aircraft has functioning deicing and anti-icing equipment protecting each rotor blade, propeller, windshield, wing, stabilizing or control surface, and each airspeed, altimeter, rate of climb or flight attitude instrument system.

(c) No pilot may fly an aircraft into known or forecast heavy icing conditions.

There are several things to notice about the wording.

- With exceptions, flight was prohibited into forecasted and/or known, light or moderate icing conditions. There was a complete prohibition against flight into heavy icing conditions, with no exceptions.

- The exceptions given in paragraph (b) do not mention icing certification as a means of exception, probably because no ice certification rules for Part 23 airplanes were in effect at that time. The only requirement in 1966 was that the airplane have functioning ice protection equipment for certain listed components.

[2] 14 CFR 135.85 as it appeared as of January 1, 1966.

- The location of the wording for the exceptions in paragraph (b)(2) became a persistent source of confusion. Were the exceptions intended only for VFR and not for IFR? If so, why is there a semicolon in (b)(2)? The semicolon at the same relative position in both (b)(1) and (b)(2) can be interpreted to mean that the words before the semicolons are stand-alone statements of equal weight. In that case, the exceptions named after the semicolon in (b)(2) would apply equally to both IFR and VFR. Otherwise, the rule prohibits IFR flights in icing conditions altogether!

- Nowhere in the rule are *light*, *moderate*, or *heavy* icing defined, but by 1966 the NCCAM definitions (table 5) had been out for one or two years and presumably those were the definitions the FAA had in mind.

AMENDMENT 135-12 (1969).

On December 3, 1969, the FAA published Amendment 135-12 in the Federal Register (34 FR 19130). This Amendment exempted icing-certificated airplanes from the prohibition against flying in light, moderate, and heavy icing conditions. The amended part of 135.85 is shown below. Note that the previous exemptions were still in effect for airplanes having functioning (but unproven) ice protection equipment for certain listed components. But the confusion was still there. Could these airplanes (without icing certification) fly under IFR in light and moderate icing conditions? This Amendment was to become effective on April 1, 1970.

- Amendment 135-12 -

§ 135.85 [Amended]

28. By amending § 135.85(b)(2) by striking out the word "and" immediately following the words "functioning deicing" and inserting the word "or" in place thereof and by adding new paragraphs (d) and (e) to read as follows:

(d) Paragraphs (b) and (c) of this section do not apply—

(1) To reciprocating engine powered airplanes that have ice protection provisions that comply with § 25.1419 (a) through (c) of this chapter, in effect after March 31, 1970;

(2) To turbine engine powered airplanes that have ice protection provisions that comply with §§ 25.1093(b) and 25.1419 (a) through (c) of this chapter, in effect after March 31, 1970; or

(3) To airplanes certificated in accordance with section 34 of Appendix A of this part or section 34 of Special FAR No. 23 of this chapter.

(e) If current weather reports and briefing information relied upon by the pilot in command indicate that the forecast icing condition that would otherwise prohibit the flight will not be encountered during the flight because of changed weather conditions since the forecast, the restrictions in paragraphs (b) and (c) of this section based on forecast conditions do not apply.

- Explanation -

Limitations for operations in icing conditions. Section 135.85(d)(3) has been changed from the notice to include airplanes certificated in accordance with Special Federal Aviation Regulation No. 23 in the list of airplanes in paragraph (d) of that section.

Some comments contended that proposed paragraph (e) of § 135.85 would allow a pilot to ignore forecast icing conditions; other comments recommended deleting the prohibitions against flying into forecast icing conditions. The amendment is intended to allow for changing weather conditions that obsolete a forecast before the next forecast is issued. The proposal as adopted herein has been revised for purposes of clarification.

These amendments are based on a notice of proposed rule making issued as Notice 69-4 and published in the FEDERAL REGISTER on January 30, 1969 (34 F.R. 1443).

FEDERAL REGISTER, VOL. 34, NO. 231—WEDNESDAY, DECEMBER 3, 1969

AMENDMENT 135-13 (1969).

Apparently, some operators complained that their airplane(s) were already certificated for flight in icing but that Amendment 135-12 would not allow them to fly in icing conditions until four months later in April—after the icing season was practically over. The FAA responded immediately with Amendment 135-13 which allowed the new exemptions to go into effect on December 24, 1969. It also revised the wording again to nearly the form that it has today. The explanations and the complete, reworded version of 135.85 follow.

[Docket No. 8041; Amdt. 135-13]

PART 135—AIR TAXI OPERATORS AND COMMERCIAL OPERATORS OF SMALL AIRCRAFT

Operation in Icing Conditions

The purpose of this amendment to Part 135 of the Federal Aviation Regulations is: (1) To relax § 135.85 by allowing airplanes that are certificated to operate in icing conditions to operate without complying with the limitations against flying into icing conditions in paragraphs (b) and (c) of that section; (2) to provide this relief immediately; and (3) to clarify § 135.85. In addition, this amendment revokes the amendment to § 135.85 contained in Amendment No. 135-12 and published in the FEDERAL REGISTER on December 3, 1969 (34 F.R. 19130).

Amendment No. 135-12 was based on a notice of proposed rule making which was issued as Notice No. 69-4 and published in the FEDERAL REGISTER on January 30, 1969 (34 F.R. 1443). Amendment No. 135-12 contains a revision to § 135.85 that allows airplanes certificated in accordance with certain ice protection airworthiness standards to be operated without complying with paragraphs (b) and (c) of § 135.85. However, Amendment No. 135-12 does not become effective until April 1, 1970.

It has now come to the attention of the FAA that some small airplanes have already complied, or will comply before April 1, 1970, with the airworthiness standards for ice protection. In view of these circumstances, and since the substance of the proposal is relaxatory, it is considered appropriate to make the amendment to that section effective prior to April 1, 1970.

The proposal to amend § 135.85 in Notice 69-4 is changed by clarifying the references to ice protection provisions of the airplane airworthiness regulations. As amended herein, the rule permits operation of an airplane in light, moderate, or heavy icing conditions if it has ice protection provisions that meet the appropriate requirements for airplanes certificated with ice protection provisions. If certification with ice protection provisions is desired, it must be shown, among other things, that the airplane is able to safely operate in continuous maximum and intermittent maximum icing conditions determined as specified in the appropriate airworthiness certification regulations. (See CAR 4b.640; section 34 of SFAR No. 23; and § 25.1419 of FAR Part 25, which contain requirements for airplanes certificated with ice protection provisions.)

It will also be noted that paragraph (b) has been revised to make it clear that both deicing and anti-icing equipment are not required for each surface or system, by changing the word "and" to "or" immediately following the word "deicing."

Since this amendment is relaxatory in nature, I find that good cause exists for making it effective on less than 30 days notice.

In consideration of the foregoing:

1. The amendment to § 135.85 of Part 135 of the Federal Aviation Regulations contained in Amendment No. 135-12 and published in the FEDERAL REGISTER on December 3, 1969 (34 F.R. 19130), is hereby revoked, effective December 24, 1969; and

2. Section 135.85 is amended effective December 24, 1969, as follows:

FEDERAL REGISTER, VOL. 34, NO. 249—WEDNESDAY, DECEMBER 31, 1969

- Amendment 135-13 -

§ 135.85 Icing conditions: operating limitations.

(a) No pilot may take off an aircraft that has—

(1) Frost, snow, or ice adhering to any rotor blade, propeller, windshield, or power plant installation, or to an airspeed, altimeter, rate of climb, or flight attitude instrument system;

(2) Snow or ice adhering to the wings, or stabilizing or control surfaces; or

(3) Any frost adhering to the wings, or stabilizing or control surfaces, unless that frost has been polished to make it smooth.

(b) Except for an airplane that has ice protection provisions that meet the requirements in section 34 of Special Federal Aviation Regulation No. 23, or those for transport category airplane type certification, no pilot may fly—

(1) Under IFR into known or forecast light or moderate icing conditions; or

(2) Under VFR into known light or moderate icing conditions;

unless the aircraft has functioning deicing or anti-icing equipment protecting each rotor blade, propeller, windshield, wing, stabilizing or control surface, and each airspeed, altimeter, rate of climb, or flight attitude instrument system.

(c) Except for an airplane that has ice protection provisions that meet the requirements in section 34 of Special Federal Aviation Regulation No. 23, or those for transport category airplane type certification, no pilot may fly an aircraft into known or forecast heavy icing conditions.

(d) If current weather reports and briefing information relied upon by the pilot in command indicate that the forecast icing condition that would otherwise prohibit the flight will not be encountered during the flight because of changed weather conditions since the forecast, the restrictions in paragraphs (b) and (c) of this section based on forecast conditions do not apply.

(Sec. 313(a), 601(c), Federal Aviation Act of 1958, 49 U.S.C. 1354(a), 1421; sec. 6(c), Department of Transportation Act, 49 U.S.C. 1655(c))

Issued in Washington, D.C., on December 24, 1969.

J. H. SHAFFER,
Administrator.

[F.R. Doc. 69-15468; Filed, Dec. 30, 1969; 8:49 a.m.]

FEDERAL REGISTER, VOL. 34, NO. 249—WEDNESDAY, DECEMBER 31, 1969

Subsequently, the same rules were added as part of 14 CFR 91.209 (now 14 CFR 91.527) in 1973 and as part of 14 CFR 125.221 in 1980.

The "unless" clause has been purposely disassociated from the VFR clause in (b)(2), but the wording was still ambiguous. It resulted in a series of memoranda between the FAA's regional certification offices, the Engineering & Mechanical Division, Flight Standards, and the General Counsel Office from 1970 to 1975. These reveal that there was "considerable concern in industry as to the legal interpretation of this rule because of the wide variation in cost of either meeting or not meeting (the) requirements" [11]. Even among FAA engineering and operations personnel there was divided opinion on whether the rule required icing certification or just functioning ice protection equipment to fly IFR into icing conditions [12]. The sentiment in the FAA Engineering & Manufacturing Division was leaning toward requiring icing certification for IFR flights in icing conditions. Otherwise, the rule could be seen as "encouraging icing flight with unproven equipment and providing a means to circumvent the airworthiness rules" [12].

An official interpretation was issued by the FAA's General Counsel Office (AGC-20) in a three-page memorandum to Flight Standards on January 9, 1975. It concluded that the original intent of the "unless" clause was not to exclude IFR operations, and that therefore "...under currently effective 135.85(b), an aircraft operated under either VFR or IFR must be equipped with the deicing or anti-icing equipment specified in the ("unless" clause)..." [13].

THE PART 135 REGULATORY REVIEW (1975-77).

Due to dissatisfaction with 14 CFR 135, both within and outside the FAA, a Regulatory Review Program was started in 1975. As a result, a Notice of Proposed Rule Making (NPRM) was issued in the Federal Register on August 29, 1977. This NPRM contained another proposed revision to 135.85, including renumbering it as 135.187. The explanation of the proposed changes follows.

§ 135.187 Icing conditions: operating limitations

This section, currently § 138.85, would be redesignated as § 135.187 and revised to make paragraphs (b) and (c) applicable to aircraft rather than airplanes, to delete the intensity conditions "light," "moderate," and "severe" as currently applied in the section, and to define the degree of ice protection required for flight under both VFR and IFR.

Paragraph (b) would be amended to prohibit takeoff for flight under VFR, or the continuation of flight under VFR, into known or forecast icing conditions unless the aircraft has installed functioning deicing or anti-icing equipment protecting each rotor blade, propeller, windshield, wing, stabilizing or control surface, and each airspeed, altimeter rate of climb, or flight altitude instrument system. The FAA believes it unnecessary to specify limiting icing conditions such as "light" or "moderate" for VFR flight operations if functioning deicing or anti-icing equipment is installed to protect the components of the aircraft on which ice accretion or formation would adversely affect its safety. Normally, there is ample opportunity to terminate VFR operations if icing of an intensity that would pose a hazard to the aircraft is reported, forecast, or encountered in flight.

Paragraph (c), as revised, would prohibit takeoff for flight under IFR, or the continuation of flight under IFR, into known or forecast icing conditions without regard to the intensity of the icing conditions unless the aircraft has installed functioning de-icing or anti-icing equipment which meets the certification requirements of Section 34 of SFAR No. 23, or Part 23 effective November 19, 1973, or the certification standards for transport category aircraft concerning ice protection. Under these certification requirements, it must be shown, among other things, that the aircraft is able to safely operate in maximum continuous and intermittent maximum icing conditions determined as specified in the appropriate airworthiness certification regulations. The FAA believes these standards have proven adequate operational use under Part 121 and should be made applicable to Part 135.

FEDERAL REGISTER, VOL. 42, NO. 167—MONDAY, AUGUST 29, 1977

The explanation clarifies the exceptions as the FAA then intended, including the desire to strengthen the IFR requirements. VFR flights could takeoff and continue in unspecified icing conditions as long as the aircraft had functioning (but not necessarily icing-certificated) ice protection equipment. But IFR flights could not even takeoff into forecast or known icing conditions unless the aircraft had functioning *and icing-certificated* ice protection equipment. With such equipment, the aircraft could fly in any icing conditions without regard to the intensity. (Notice that the proposed elimination of icing intensity terms from the regulations would disassociate them from the definitions (table 5 or 6) thereby avoiding any need to interpret the definitions or wrestle with any ambiguities or future changes in them.)

The proposed new wording for 135.187 follows. The revised language nicely clarifies the intent of the rule and removes all of the previous ambiguity.

PROPOSED RULES

§ 135.187 Icing conditions: operating limitations.

(a) No pilot may take off an aircraft that has: (1) Frost, snow, or ice adhering to any windshield or powerplant installation; or to an airspeed, altimeter, rate of climb or flight attitude instrument system;

(2) Snow or ice adhering to the wings, or stabilizing or control surfaces, or rotor, or propellers of the aircraft; or

(3) Any frost adhering to the wings, or rotors, or propellers of the aircraft; or rotors or propellers of the aircraft, unless the wings, or stabilizing or control surfaces, or rotors or propellers have been smoothed to prevent the disruption by the frost of airflow over such surfaces;

(b) No pilot may take off an aircraft, for flight under VFR, or continue to operate an aircraft in flight under VFR, into known or forecast icing conditions unless the aircraft has installed functioning de-icing or anti-icing equipment protecting each rotor blade, propeller, windshield, wing, stabilizing or control surface, and each airspeed, altimeter, rate of climb, or flight attitude instrument system.

(c) No pilot may take off an aircraft, for flight under IFR, or continue to operate an aircraft in flight under IFR, into known or forecast icing conditions unless the aircraft has installed functioning de-icing or anti-icing equipment which meets the certification requirements of Section 34 of Special Federal Aviation Regulation No. 23, or Part 23 effective November 19, 1973, or those for transport category aircraft type certification as applicable to that aircraft.

(d) If current weather reports and briefing information relied upon by the pilot in command indicate the forecast icing condition that would otherwise prohibit the flight will not be encountered during the flight because of changed weather conditions since the forecast, the restrictions in paragraphs (b) and (c) of this section based on forecast conditions do not apply.

FEDERAL REGISTER, VOL. 42, NO. 167—MONDAY, AUGUST 29, 1977

The FAA received many objections to the requirement for icing certification as a condition for flying IFR into icing conditions, as proposed in 135.187. As a result, that version was withdrawn and, with minor rewording, the original 135.85 version was reinstated as 135.227. The objections and the reasons for withdrawing the rule follow.

§ 135.227 *Icing conditions: Operating limitations. (Proposed § 135.187.)*

Many commenters object to prohibiting IFR flights into known or forecast light or moderate icing conditions with present deicing or anti-icing equipment that is not certificated under Part 23. They stated that the expense of meeting Part 23 is unjustified and would impose an undue economic burden. One commenter suggests a "grandfather" clause for present aircraft. Other commenters believe IFR flight to VFR-on-top should be allowed under known or forecast light or moderate icing conditions. One commenter states the proposed rule is extremely restrictive for helicopters because there is no approved anti-icing or deicing equipment for main and tail rotor blades.

Based on these comments and after further deliberation, the FAA concludes the proposed rule is unworkable without major changes. Because of their magnitude, the proposed rule is withdrawn at this time and current § 135.85 is adopted as § 135.229. The reference to SFAR No. 23 in §§ 135.227 (b) and (c) is changed to the identical provision in section 34 of Appendix A.

FEDERAL REGISTER, VOL. 43, NO. 196—TUESDAY, OCTOBER 10, 1978

The reinstated rule (now numbered 135.227) as it appeared in 1978, is given below. Notice that the old ambiguity is back again for airplanes which are not certificated for icing but which have functioning ice protection equipment. Are they permitted to fly in light and moderate icing under both IFR and VFR, or only under VFR? If IFR flight into icing is still not permitted, then the objectors to the previously proposed 135.187 version have not gained anything by going back to this old rule.

Internally, the FAA's General Counsel had previously ruled in 1975 that both IFR and VFR flight in icing required only the functioning ice protection equipment called for in the "unless" clause.

But apparently no public guidance had been issued in the expectation that 135.187, proposed in late 1977, would eliminate the problem and provide all the clarification that was needed.

RULES AND REGULATIONS

§ 135.227 Icing conditions: operating limitations.

(a) No pilot may take off an aircraft that has—

(1) Frost, snow, or ice adhering to any rotor blade, propeller, windshield, or powerplant installation, or to an airspeed, altimeter, rate of climb, or flight attitude instrument system;

(2) Snow or ice adhering to the wings or stabilizing or control surfaces; or

(3) Any frost adhering to the wings, or stabilizing or control surfaces, unless that frost has been polished to make it smooth.

(b) Except for an airplane that has ice protection provisions that meet § 34 of Appendix A, or those for transport category airplane type certification, no pilot may fly—

(1) Under IFR into known or forecast light or moderate icing conditions; or

(2) Under VFR into known light or moderate icing conditions; unless the aircraft has functioning deicing or anti-icing equipment protecting each rotor blade, propeller, windshield, wing, stabilizing or control surface, and each airspeed, altimeter, rate of climb, or flight attitude instrument system.

(c) Except for an airplane that has ice protection provisions that meet § 34 of Appendix A, or those for transport category airplane type certification, no pilot may fly an aircraft into known or forecast severe icing conditions.

(d) If current weather reports and briefing information relied upon by the pilot in command indicate that the forecast icing condition that would otherwise prohibit the flight will not be encountered during the flight because of changed weather conditions since the forecast, the restrictions in paragraphs (b) and (c) of this section based on forecast conditions do not apply.

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ADVISORY CIRCULAR 135-9 (1981).

After 135.187 failed acceptance in 1978 and the original version of the rule was reinstated as 135.227, the FAA again had to overcome the confusion and to clarify FAA policy. The result was an Advisory Circular (AC 135-9) titled "FAR Part 135 Icing Limitations," issued in May of 1981. The focus of this four-page Advisory Circular was stated to be "*aircraft that are not certificated for operations into icing conditions.*" It explained that yet another development had now affected the interpretation.

In 1973, new ice certification rules[3] for small airplanes became effective in 14 CFR 23. The new rule required that if icing certification was desired, then the airplane must be shown capable of operating in icing conditions represented by Appendix C of 14 CFR 25. This was a more stringent requirement than the previous policy under CAR-3 and CAR-4b.

Rather than re-certificate to meet the new, stricter icing certification standards, some manufacturers continued to produce airplanes with ice protection equipment authorized under type certificates issued before 1973. For those airplanes, however, placards were installed prohibiting flight in icing conditions. (This placarding must have resulted from FAA policy, although no rule requiring a placard against flight in icing conditions seems to appear explicitly in the FARs anywhere.) Thus, of many airplanes of the same make and model with identical ice protection equipment, some were placarded because they were built after 1973 while airplanes built before 1973 were not placarded.

To help clarify the operating rules for this situation, FAA Flight Standards Offices were informed after 14 CFR 135.227 became effective in December 1978, that there had been no change in policy on the applicability of 14 CFR 135.227. That is, airplanes could be operated in forecasted or known light or moderate icing under VFR or IFR if the airplane was equipped with functioning ice protection systems as required in 14 CFR 135.227, *unless the airplane was prohibited by operating limitations from operating in icing conditions.*

Advisory Circular 135-9 goes on to interpret further as follows:

> "a. Aircraft equipped with functioning equipment meeting Section 135.227(b) and <u>not</u> placarded restricting operations in icing conditions may fly under IFR or VFR rules in known or forecast light or moderate icing and continue flight in actual icing conditions.
>
> b. Aircraft equipped with functioning equipment meeting Part 135.227(b) and a placard <u>prohibiting</u> operation in icing conditions may depart on a flight when light or moderate icing is forecast or reported to exist for the intended route to be flown. However, continued flight in actual icing conditions is not permitted since such flight does not comply with the placard or the operating limitation in the aircraft flight manual.
>
> c. Airplanes that have the ice protection provisions that meet section 34 of Appendix A of Part 135, that are type certificated with the ice protection provisions of part 23, or those for transport category airplane type certification may be flown into known or forecast icing."

[3] Amendment No. 23-14, (38 FR 31824, Nov. 19, 1973).

In effect, paragraph b (along with the policy of placarding uncertificated airplanes against flying in icing conditions) achieved the prohibition that the FAA wanted in the proposed 135.187 in 1977. Paragraph a is a "grandfather" concession to pre-1973 airplanes.

As far as the operating rules are concerned, it makes no difference whether the icing intensity is light or moderate. Either you are permitted to fly in it, or you are not. Any intensity level above trace serves notice for unprotected or placarded aircraft to keep out. Intense icing warns all but icing-certificated aircraft to keep out.

Basically, unprotected or placarded Part 23 aircraft are prohibited by 14 CFR 135.227 from flying IFR and VFR into forecasted and/or known icing conditions, so the distinction between icing intensity levels is theoretically of little importance to them. Icing-certificated aircraft are permitted by 14 CFR 135.227 to fly into any icing conditions, so the distinctions are mainly of interest for flight planning and avoidance or for reporting (PIREP) purposes. The same may be said for unplacarded but functionally protected aircraft, except that they need to worry about severe icing conditions. Unprotected military aircraft can still probably benefit from the distinction between icing intensity levels in the same way that they were used in table 4.

The rules (14 CFR 135.227 and similar) would seem to be more clearly expressed if they were written in wording similar to paragraphs 7a, b, and c of Advisory Circular 135-9.

CURRENT STATUS

As a result of the current wording and interpretation of the operating regulations as explained above, the relationship between the icing intensity definitions and the operating rules may be summarized as in table 7. Or, another way of looking at it is presented in table 8.

TABLE 7. CURRENT RELATIONSHIP BETWEEN ICING INTENSITY DEFINITIONS AND OPERATIONAL RULES

Term	Effects[1] on an Unprotected Aircraft	Implied Remedy (Pilot Response)		
		Placarded[2] or Unprotected Aircraft	Unplacarded[2] Aircraft With Functional Protection[4]	Aircraft Certificated[3] for Flight in Icing
Trace	Not hazardous for up to an hour	None required—unless icing worsens or lasts more than an hour	None required—unless icing worsens or lasts more than an hour	None required—unless icing worsens or lasts more than an hour
Light	May create a problem after an hour's exposure	Divert from known icing conditions	Use anti-icing or deicing equipment	Use anti-icing or deicing equipment
Moderate	Potentially hazardous even for short encounters	Divert from known icing conditions	Use anti-icing or deicing equipment	Use anti-icing or deicing equipment
Severe	Hazardous	Immediate diversion	Immediate diversion	Use anti-icing or deicing equipment[5]

[1] Readily noticeable performance effects include a loss of airspeed and the need to add power.

[2] Placarded here means that the aircraft has a stated limitation against operating in icing conditions.

[3] Certificated here means an aircraft that has been certificated for flight into icing conditions per Section 34 of Appendix A of 14 CFR 135, or per paragraph 1419 of 14 CFR 23, 25, 27, or 29.

[4] Functional protection means that the aircraft has operable ice protection, as required in 14 CFR 135.227(b)(2), but it is not certificated as in footnote 4.

[5] Certification for flight into icing conditions (see footnote 4) implies that the ice protection system has been designed to handle 99% of all icing encounters [page 3 of reference 14]. This means that the icing certificated airplane should be able to fly in any icing conditions (possibly excluding freezing rain or freezing drizzle) with only rare or occasional diversion being prudent or necessary.

TABLE 8. ICING CONDITIONS IN WHICH FLIGHT IS PERMITTED ACCORDING TO 1999 REGULATIONS (REF.: 14 CFR 91.527, 121.341, 125.221, 135.227)

Ice Protection Equipment	IFR				VFR			
	Known		Forecast		Known		Forecast	
	Light	Moderate	Light	Moderate	Light	Moderate	Light	Moderate
Unprotected, or not functioning	1		1				2	2
Functioning* on all required components	2	2	2	2	2	2	2	2
Certificated for flight in Icing Conditions	(Can fly in all icing conditions, including severe)							

Notes: 1 = Part 91 aircraft only (Subpart F—Large and Turbine Multi Engine Aircraft)
2 = Parts 91, 121, 125, and 135 aircraft
* = but neither certificated for, nor placarded against flight in icing conditions

RECENT PROPOSALS FOR REDEFINING ICING INTENSITIES

THE NATIONAL AIRCRAFT ICING TECHNOLOGY PLAN.

As a result of the NTSB recommendations in 1981 [5], the Subcommittee on Aviation Services at the Office of the Federal Coordinator for Meteorological Services (OFCM) began meetings to develop a plan to improve icing forecasts. The Subcommittee, at their meeting on December 9, 1982 [15], also introduced a proposal for changing the definition of severe icing as follows:

> Severe Icing – "The rate of accumulation is the maximum that deicing/anti-icing equipment can control. Prolonged flight in these conditions is not recommended."
>
> Extreme Icing – "The rate of accumulation exceeds the ability of the deicing/anti-icing equipment to control the hazard. Flights should not be planned into these conditions or if encountered, immediate diversion is required."

Evidently, no formal action was taken on this particular proposal, but the question was left open and incorporated into the major product developed by the Subcommittee—the *National Aircraft Icing Technology Plan* [16] published in 1986. Among other things, the Plan called for establishing an objective definition of icing severity.

NEW PROPOSALS FOR ICING INTENSITY DEFINITIONS.

BASED ON LWC. A major deficiency in ongoing attempts to improve the forecasting of aircraft icing conditions aloft has been the inability to come up with a practical measure of icing severity based on LWC alone. Recent attempts have proposed linking some intensity scale to measured or forecasted values of supercooled liquid water content (SLWC) in icing clouds [17, 18]. But the problem of trying to account for the different response of individual aircraft to the same SLWC was not solved.

BASED ON RATE OF ICE ACCRETION. A more recent proposal [19] explores a simple and practical way to overcome the latter problem of individual aircraft response. The idea is to interpret the existing definitions (table 6) of icing severity (trace, light, moderate, and severe) in terms of how long it takes ice to build up to a certain small thickness, such as 1/4 or 1/2 inch, on an airfoil (wing or tailplane, for example) during flight in icing conditions. According to the proposal, if an hour or more is required to accumulate 1/4-inch of ice, then this will be considered to represent *trace* icing. Light, moderate, and *intense* icing will mean that 15-60 minutes, 5-15 minutes, and less than 5 minutes, respectively, are required to accumulate 1/4 inch. *Severe* is replaced by the term *intense* in this scale which is based solely on rates of accretion and makes no judgement as to the effects of the various rates on the individual aircraft. *Severe* can still be used to describe those rates for which a particular aircraft is unable to cope. Any of these rates of accretion could be severe for one airfoil but not for others. This nicely separates the yet to be determined effects from the basic measurable and calculable quantity—the rate of accretion on a clean airfoil (or other component of interest).

For a given SLWC, cloud dropsize distribution, and outside air temperature (OAT), different airfoil sections will have different accretion rates depending on their individual geometry, airspeed, altitude, and angle of attack. But available, computerized ice accretion codes such as LEWICE [20] can nowadays easily account for all these variables. These computer models can easily calculate how long it should take for a certain small amount of ice to accumulate on a given airfoil for any specified combination of atmospheric and flight variables.

This scheme has a number of advantages:

a. It simplifies the forecasting chore by requiring forecasters to issue only SLWC and OAT ranges, not icing intensities themselves. Individual pilots would know from a simple lookup table or graph what intensity is to be expected for their aircraft for the forecasted OAT and SLWC range and for their particular airspeed and altitude.

b. It provides practical and measurable definitions of icing intensity for possible use with FAA rules for operating in icing conditions (14 CFR 91.527 and 135.227) where light, moderate, and severe icing are called out but not defined.

c. It permits unambiguous icing pilot reports (PIREPS). It would be universally understood that a report of moderate icing, for example, means that icing conditions are enough to cause 1/4 inch of ice buildup on the wing (or tailplane) of the reporting airplane every 5 to 15 minutes, according to the proposed definition. Ideally, the rate of buildup would be monitored by typical onboard icing rate meters calibrated to indicate the rate of buildup on the wing or tail section itself for that particular airplane. This means that anti-iced airplanes can still report icing intensities in accordance with this scheme even though ice may never build up on the leading edges of the wing or tail. They simply report what the ice detector indicates *would* be building up if there were no anti-icing on that airplane. In the absence of an icing rate meter, pilots will have to estimate the rate of ice buildup. In the old days, pilots of booted airplanes could gauge the icing intensity by how often they had to manually inflate the boots. If it was once every 5 to 15 minutes, that would fit the proposed definition of moderate icing. Today's FAA policy calls for cycling the boots automatically starting with the first sign of icing conditions. In this case, pilots may have to rely on the observed rate of ice accretion on the windshield wipers or on some other surrogate component.

d. It provides practical and measurable definitions of icing intensity for gauging the significance of test and certification flights in natural or artificial icing conditions. Depending on the rate of ice accretion, the test can be reported unambiguously as a trace, light, moderate, or intense icing exposure and everybody would know what that means.

e. The definitions are flexible, if necessary or desirable. For example, if icing conditions corresponding to a buildup rate of 1/4 inch every five minutes or less is considered insignificant for some large, thick-winged airplane, then the intensity thresholds could be changed to some other rate, like 1/2 inch every five minutes. This may be more in line with what intense icing conditions are thought to be for that airplane. As long as it was generally known that intense means 1/2-inch or more every five minutes for that airplane, PIREPS from it would still be interpretable.

A copy of the original paper for this proposal is included in the appendix, for the interested reader.

BASED ON THE EFFECTS ON THE AIRCRAFT. An FAA-sponsored working group on icing terminology was formed in 1998 to review the definitions of all icing terms used in aviation and to recommend new or modified definitions where suitable. This was in response to Task 1-B of the 1997 FAA Inflight Aircraft Icing Plan [21]. It was proposed in that working group that the pilot report (PIREP) format be modified to include an item called a level-of-effect, based on the effects the reportable icing encounter had on the reporting aircraft. This four-level scheme (see table 9) nicely supplies a type of severity scale which is independent of, but complements the rate-of-accretion intensity scale. That is, for each aircraft model, each level-of-effect (or severity) category may result from one or more of the intensity categories, but the correlation does not have to be known ahead of time. In fact, such correlations may naturally become apparent over time as PIREPS accumulate for each type of aircraft. As of this writing, all of these new proposals are awaiting public comment.

TABLE 9. EFFECT ON AIRCRAFT

Aircraft Effect (AE)	Speed (See Note 1)	Power (See Note 2)	Climb (See Note 3)	Control (See Note 4)	Vibration (See Note 5)
Level 1	Less than 10 knots loss	Less than 10% increase required	No effect or less than 10% loss	No effect	No effect
Level 2	10-19 knots loss	10%-19% increase required	10%-19% loss rate of climb	No effect	No effect
Level 3	20-39 knots loss	20%-39% increase required	20% or more loss rate of climb	Unusually slow or sensitive response from control input	Controls may have slight vibration
Level 4	40 or more knot loss	Not able to maintain speed	Not able to climb	Little or no response to control input	May have intense buffet and/or vibration

Notes:

1. SPEED: Loss of speed due to aircraft icing. This is based on the indicated airspeed which was being maintained prior to encountering ice on aircraft and before applying additional power to maintain original airspeed.

2. POWER: Additional power required to maintain aircraft speed/performance that was being maintained before encountering icing on aircraft. Refers to primary power setting parameter, i.e., torque, rpm, or manifold pressure.

3. CLIMB: Estimated decay in rate of climb (ROC) due to aircraft icing, example 10% loss in ROC, 20% loss in ROC, or not able to climb at normal climb speed with maximum climb power applied.

4. CONTROL: Effect of icing to aircraft control inputs.

   Levels 1 and 2. No noticeable effect on response to control input.
   Level 3. Aircraft is slow to respond to control input. Aircraft may feel sluggish or very sensitive in one or more axes.
   Level 4. Little or no response to control input. Controls may feel unusually heavy or unusually light.

5. VIBRATION/BUFFET: May be felt as a general airframe buffet or sensed through the flight controls. It is not intended to refer to unusual propeller vibration (for airplanes so equipped) in icing conditions.

Although this information is intended to be used for aircraft with approved ice protection systems, this procedure should also be used to report aircraft effects on icing encounters with all aircraft.

This chart is to be used for pilot reporting of icing effects ONLY and NOT to be used as a guide for operating in icing conditions.

The effect on an aircraft is to be reported as Level 1, 2, 3, or 4. The level reported is to be based on the worst of the five factors.

These effects refer to conditions after operating the airframe ice protection system for airplanes so equipped and with autopilot disengaged. If the aircraft is not equipped and icing is encountered, report effects based on the same chart.

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AIAA-98-0094
A Workable, Aircraft-Specific Icing Severity Scheme

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36th Aerospace Sciences Meeting & Exhibit
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A WORKABLE, AIRCRAFT-SPECIFIC ICING SEVERITY SCHEME

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Abstract

This paper explores the idea of defining icing intensities (trace, light, moderate, and severe) quantitatively in terms of the time required for a specific depth (say ¼ inch (6 mm)) of ice to accumulate on an individual airfoil during exposure to icing conditions. For example, trace icing could correspond to conditions where 60 minutes or more is required to accumulate ¼ inch on the leading edge of any particular wing or tailplane. Light, moderate, and severe icing could mean that 15-60 minutes, 5-15 minutes, and less than 5 minutes, respectively, are required to accumulate ¼ inch. Available, computerized ice accretion models (such as LEWICE) can then be used to easily determine how much time is required for ¼ inch of ice to accrete on the leading edge of an airfoil during exposure to a given liquid water concentration (LWC), median volume dropsize diameter (MVD), and outside air temperature (OAT) at a given airspeed, altitude, and angle of attack. In this way the icing intensity for a given airfoil in a given icing condition is unambiguous, readily calculable, and measurable. This scheme offers a universal rule which is applicable to all airplanes while providing a simple but meaningful way to account for the individual sensitivities of different aircraft. Example results are shown for computed icing intensities on a dozen real airplanes of all sizes. The potential benefits for icing forecasts, pilot icing reports (PIREPS), and for documenting icing flight test conditions are pointed out.

Introduction

A major stumbling block in ongoing attempts to improve the forecasting of aircraft icing conditions aloft has been the inability to come up with a practical measure of icing severity. Recent attempts have proposed linking some intensity scale to measured or forecasted values of supercooled liquid water content (SLWC) in icing clouds.[1,2] But the problem of trying to account for the different response of individual aircraft to the same SLWC has not been solved.

This paper explores a simple and practical way to overcome the latter problem of individual aircraft response. The idea is to interpret the existing definitions[3] of icing severity (trace, light, moderate, and severe) in terms of how long it takes ice to build up to a certain small depth, such as ¼ or ½ inch, on an airfoil (wing or tailplane, for example) during flight in icing conditions. For illustrative purposes, if an hour or more is required to accumulate ¼ inch of ice, then this will be considered to represent "trace" icing. Light, moderate, and severe icing will mean that 15-60 minutes, 5-15 minutes, and less than 5 minutes, respectively, are required to accumulate ¼ inch. "Severe" icing for one airfoil may not be severe for some other airfoil under the same conditions, but in this scheme the difference is definable and calculable.

For a given SLWC, cloud dropsize distribution, and OAT, different airfoil sections will have different accretion rates depending on their individual geometry, airspeed, altitude, and angle of attack. But available, computerized ice accretion models such as LEWICE[4] can nowadays easily account for all these variables. These computer models can easily calculate how long it should take for a certain small amount of ice to accumulate on a given airfoil for any specified combination of atmospheric and flight variables.

In this work, the rate of ice accretion on individual airfoils has been computed using LEWICE version 1.6 for personal computers. Most applications of computerized ice accretion models to date have been for trying to predict the shapes of rather large, and often irregular, ice accretions. There has been considerable concern over how well these large shapes agree with what would occur in actual flight or in icing wind tunnels. The present application has the benefit of only requiring the models to generate small (¼ inch) ice accretions on clean airfoils. This is a simple application, so there should be less concern about the adequacy of the models.

Computing Icing Intensity Thresholds for Individual Airplanes

Ice accretion models require the user to input values for a number of parameters used in the computations. These include a value for SLWC, air temperature, altitude, and dropsize for the environmental variables. Other user inputs include the coordinates for the airfoil section, the chord length, the selected angle of attack, and the airspeed. The computer simulation can then be run until ¼ inch of ice has accumulated. The simulated time for this to occur depends on all the variables mentioned above. For a given set of input variables, if a simulated time of between 15 and 60 minutes is required to deposit ¼ inch of ice on the airfoil, then according to the proposed intensity scale, that combination of environmental and flight variables represents light icing for that airfoil.

For realism, wing section coordinates for actual airplanes were used in this study. The particulars were obtained from various annual editions of *Janes*[5] for a dozen or so different airplanes (Table 1). Actual section coordinates were obtained either from a standard reference[6] or from sources on the *Internet*[7]. Wing sections near the wing tip were chosen because that is where the wing is thinnest and is therefore where the droplet collection efficiency is the greatest. (Tail sections are even thinner and perhaps any eventual protocol for computing icing intensities this way should consider tail sections as well as wingtip sections.)

For consistency, all airplanes were assumed to be at 10,000 ft above sea level (ASL) at an OAT of -10°C. Icing clouds were assumed to be uniform with a MVD of 15 μm*. Each aircraft was assigned its typical cruise speed for that altitude. The wing angle of attack (AOA) was arbitrarily set to zero or else determined from representative lift curves[6], the required lift coefficient being computed for both fully loaded and minimally loaded airplanes. Table 1 lists the various combinations. Airspeeds were generally kept below 250 kt, as required by Federal Aviation Administration regulations[8] (FAR 91.117) for flight below 10,000 ft. It was found that for airspeeds greater than about 250 kt the effects of kinetic heating began to prevent complete freezing of the impinging water. This is the well-known "Ludlam limit" effect.[9] LEWICE reveals this condition with anomalous or null ice buildups as the time steps proceed. This is another aspect that can be realistically taken into account with the present procedure.

Figure 1 illustrates typical shapes of ¼-inch ice accretions computed for the near wingtip of an old Douglas DC-6A (C-118A) (NACA 23012 wing section) for two different SLWC values. The ice depth is measured at the thickest part of the deposit along the shortest line to the airfoil.

Based on the LEWICE results for these small ice accretions, wherever the freezing fraction is near unity, the rate dD/dT of ice buildup is linear in time and proportional to the product of LWC, ß, and TAS, where ß is the maximum value of the local droplet collection efficiency, TAS is the true airspeed, and dD is the increase in ice thickness in time interval dT. In equation form this is

$$dD/dT \propto (LWC)(\beta)(TAS)$$

or

$$dD/dT = (A)(LWC)(\beta)(TAS) \qquad (1)$$

where A is an empirical constant of proportionality. Equation 1 appears to apply to wherever on the leading edge the ice is building up the fastest. For small values of water catch rate, it applies to the stagnation region where rime ice shapes develop as in figure 1a. For larger water catch rates where the freezing fraction drops below unity along the original stagnation line, it applies to the largest developing "horn" (figure 1b) as long as the freezing fraction remains near unity there. In the latter case the region between the developing horns builds up more slowly, presumably due to loss of water by runback to the horns.

The value of A for a given airfoil can be computed from equation 1 after LEWICE is run for a few minutes of simulated exposure time (dT) at a low LWC (eg., 0.1 g/m^3) and for the TAS and angle of attack (AOA) of interest to get the output values of dD and ß. The collection efficiency, ß, is routinely computed by LEWICE and is an output parameter available to the user. Computed values of ß and A for various airplanes are shown in figures 2 and 3. For example, for the Beechcraft *Queen Air* wing (NACA 23012 near the tip) at AOA = 0° and TAS = 195 kt, the values of ß and A are 0.48 and 0.00118 (inch/min per (g/m^3)(ß)(kt)), respectively.

* Statistics compiled by the author from 10,000 nmi of measurements in stratiform icing conditions reveals that about 75% of all MVD's are within ±5 μm of 15 μm in stratiform clouds.

Once the constants A and $ß$ are known for a particular TAS and AOA, then equation 1 can be used to compute the exposure time dT required to accumulate ¼ inch (6.3 mm) of ice for various values of LWC. Alternatively, one can compute the LWC required to produce ¼ inch of ice in the threshold times (dT=5, 15, and 60 minutes) proposed here for the different icing intensity levels (severe, moderate, and light, respectively). This is really the goal of the present study. For the previous *Queen Air* example, a LWC of 0.45 g/m^3 will produce ¼-inch ice accumulation in 5 minutes. That is, 0.45 g/m^3 is the onset of "severe" icing for the *Queen Air* at 195 kt and AOA = 0° in a cloud with an average MVD of 15 μm.

Figure 4 shows the LWC's computed this way for the onset of severe icing at the wing tip region of all the airplanes for the AOA's and airspeeds used in this study so far.

It can be seen from figure 4 that the DeHavilland *Twin Otter* (DH-6) wing appears to be the most resistant to ice accumulation because it requires the largest LWC's for ¼ inch of ice to build up in 5 minutes. This also means that at any given value of LWC, the DH-6 will build up ice more slowly than the other airplanes in this sample, for representative flight speeds. This is due to both a relatively low collection efficiency ($ß$ = 0.2) and the low airspeed (150 kt) for the DH-6. This combination in equation 1 requires a proportionately larger LWC to produce a dD/dT of ¼ inch in 5 minutes.

On the other hand, the Beech 1900D wing appears to be the most sensitive among the limited sample shown here. This is due to a faster airspeed (270 kt) and a larger value of $ß$ (0.55). This larger $ß$ is due to both a thinner wing and the faster airspeed.

For comparison purposes, these figures also show the results for a 3-inch (75-mm) cylinder and a ¼-inch (6.35-mm) cylinder. The latter, having the smallest cross section of all, has the largest $ß$ (0.91) and the greatest accretion rate for any airspeed.

A Universal Curve.

A beneficial result of this study is that the constant of proportionality A in equation 1 does not change much from one airfoil to another, including the cylinders. This is shown in figure 3. That is, A really is nearly a universal constant since it is nearly independent of the airfoil, AOA, and TAS. For present purposes, an average value of about 0.00116 for A could be used to represent nearly all airplanes in the sample. This means that equation 1 is a universal equation, approximately fitting all airplanes at once. Equation 1 can also be written

$$LWC = \frac{dD/dT}{A}\,\frac{1}{(TAS)(ß)} = \frac{const}{(TAS)(ß)} \quad (2)$$

where dD = ¼ inch, dT = 5 minutes, and A = 0.00116. Thus, if threshold values of LWC_{Severe} (from figure 4) are plotted against the product (TAS)($ß$) for each case, all the individual airplane thresholds in figure 4 should fall along the same *universal* curve represented by equation 2. This is shown in figure 5.

This result means that the LWC threshold for a given icing intensity depends only on the product (TAS)($ß$) for any airplane! One merely has to know the value of $ß$ (or the product (TAS)($ß$)) for the airspeed of interest. This can be computed and tabulated or graphed ahead of time for the flight envelope of individual airplane models. The user (pilot, dispatcher, forecaster, etc.) then needs only to use this universal curve to read off the value of LWC that will be the threshold for severe icing for this combination of TAS and $ß$. Analogous curves can be constructed for light and moderate icing thresholds.

Advantages of This New Scheme

There are a number of advantages to defining icing intensities in terms of ice accretion rates.

(a) It simplifies the forecasting chore by requiring forecasters to issue only SLWC and OAT ranges, not icing intensities themselves. Individual pilots would know from a simple table (like the one below) or the universal curves, what severity was implied for their aircraft by the forecasted OAT and SLWC range and for their particular airspeed. (This procedure would also seem to reduce any legal liability for forecasters by relieving them from forecasting severities directly.)

Sample Icing Intensity Table
for a Lockheed P-3 at 200 kt

Icing Intensity Threshold (outer wing)	Required LWC (g/m^3)
Light	0.07
Moderate	0.28
Severe	0.83

(b) It permits unambiguous pilot icing reports (PIREPS). It would be universally understood that a report of moderate icing, for example, means that icing conditions are enough to cause ¼ inch of ice buildup on the wing (or tailplane) of the reporting airplane every 5 to 15 minutes, according to the proposed definition.

The universal curves are useful here too. An icing intensity reported by one airplane can now be related to the icing intensity to be expected for another, different airplane. For example, if a *Queen Air* is reporting severe icing conditions, then figure 5 shows that these icing conditions may not be severe for other airplanes above the *Queen Air* on the curve, depending on the actual (but probably unknown) value of LWC. On the other hand, it is certain that these icing conditions will also be severe for all other airplanes below the *Queen Air* on the curve.

Ideally, the rate of buildup would be monitored by typical onboard icing rate meters calibrated to indicate the rate of buildup on the wing or tail section itself for that particular airplane. This means that anti-iced airplanes can still report icing intensities in accordance with this scheme even though ice may never build up on the leading edges of the wing or tail. They simply report what the ice detector indicates *would* be building up if there were no anti-icing on that airplane. In the absence of an icing rate meter, pilots of booted airplanes can gauge the icing intensity by how often they have to inflate the deicing boots. If it is once every 5 to 15 minutes, that would fit the proposed definition of moderate icing.

(c) It provides practical and measurable definitions of icing intensity for gauging the significance of test and certification flights in natural or artificial icing conditions. Depending on the rate of ice accretion, the test can be reported unambiguously as a trace, light, moderate, or severe icing exposure.

(d) It provides practical and measurable definitions of icing intensity for possible use with FAA rules for operating in icing conditions (FAR 91.527, FAR 135.227) where light, moderate, and severe icing are called out but not defined.

Acknowledgement

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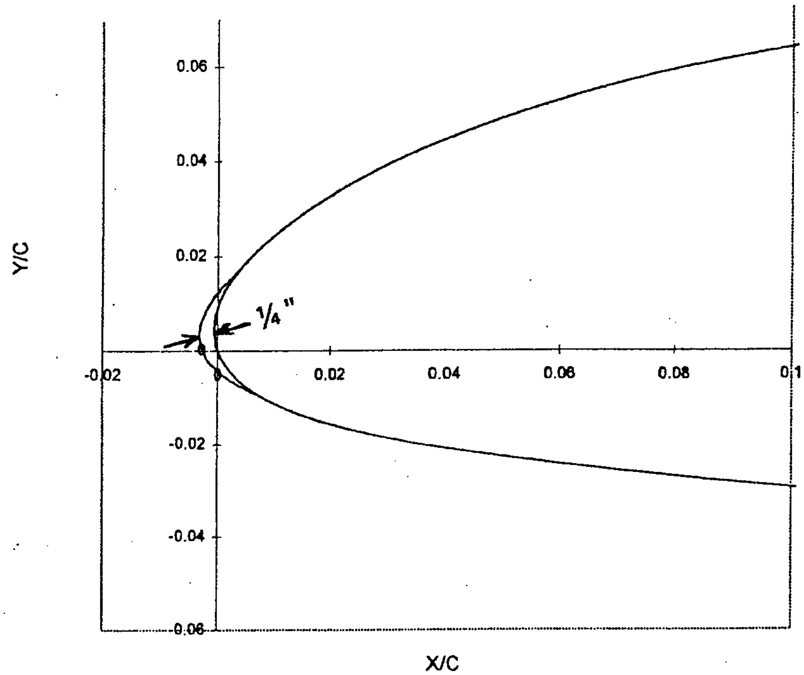
Table 1. Airplanes, Airfoils, and Related Parameters for Which ¼-Inch Ice Accretion Rates Have Been Computed

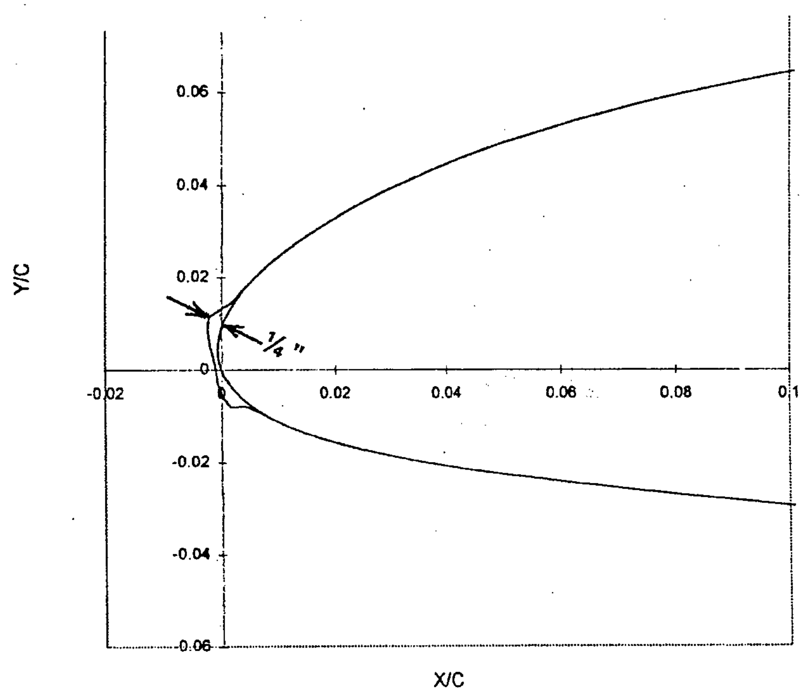
Airplane	Airfoil	Chord (m)	TAS (kt)	AOA (deg)
¼" cylinder	¼" cylinder	0.00635	250	0
¼" cylinder	¼" cylinder	0.00635	200	0
¼" cylinder	¼" cylinder	0.00635	150	0
3-inch cylinder	3-inch dia. cylinde	0.0762	174	0
ATR-72	ATR-72	1.6	250	0
ATR-72	ATR-72	1.6	250	3.3
ATR-72	ATR-72	1.6	200	6.1
ATR-72 @ 5k Ft	ATR-72	1.6	200	4.9
Beech 1900D	NACA-23012	0.91	271	0
Beech 1900D	NACA-23012	0.91	200	2.9
Beech Queen Air	NACA-23012	1.07	195	0
Beech Queen Air	NACA-23012	1.07	150	3
Beech-QA vert tail	NACA-0009	0.7	195	0
Boeing 737-300	B-737	2.6	250	6.5
C-130H	NACA-64A412	4.16	250	3.4
C-130H	NACA-64A412	4.16	200	4.8
Cessna T-37B	NACA-2412	1.7	250	0
Cessna-208	NACA-23012	1.22	181	0
Cessna-337	NACA-2410	1.22	126	4.2
Cessna-337 vert tail	NACA-0009	0.54	126	0
Cessna-500	NACA-23012	1.3	250	0
Convair-640	NACA-23015	1.4	250	1.3
Convair-640	NACA-23015	1.4	200	3.5
DH-6	Tw.Otter	1.98	150	0
DH-6	Tw.Otter	1.98	150	2.4
DH-6	Tw.Otter	1.98	150	4.7
Douglas C-118A	NACA-23013	2.4	250	1.5
Douglas C-118A	NACA-23012	2.4	200	3.4
EMB-120	NACA-23012	1.4	261	0
EMB-120	NACA-23012	1.4	200	3.3
EMB-120 horz tail	NACA-64A008	1.2	250	-0.7
EMB-120 horz tail	NACA-64A008	1.2	200	0.5
P-3 Orion	NACA-0012(mod)	2.31	250	2.1
P-3 Orion	NACA-0012(mod)	2.31	200	5.6

a



After 26 Minutes in 0.1 g/m^3 Supercooled Liquid Water Content

b



After 6 Minutes in 0.5 g/m^3 Supercooled Liquid Water Content

Figure 1. Representative ¼-inch Ice Accretions and Thickness Measuring Convention.

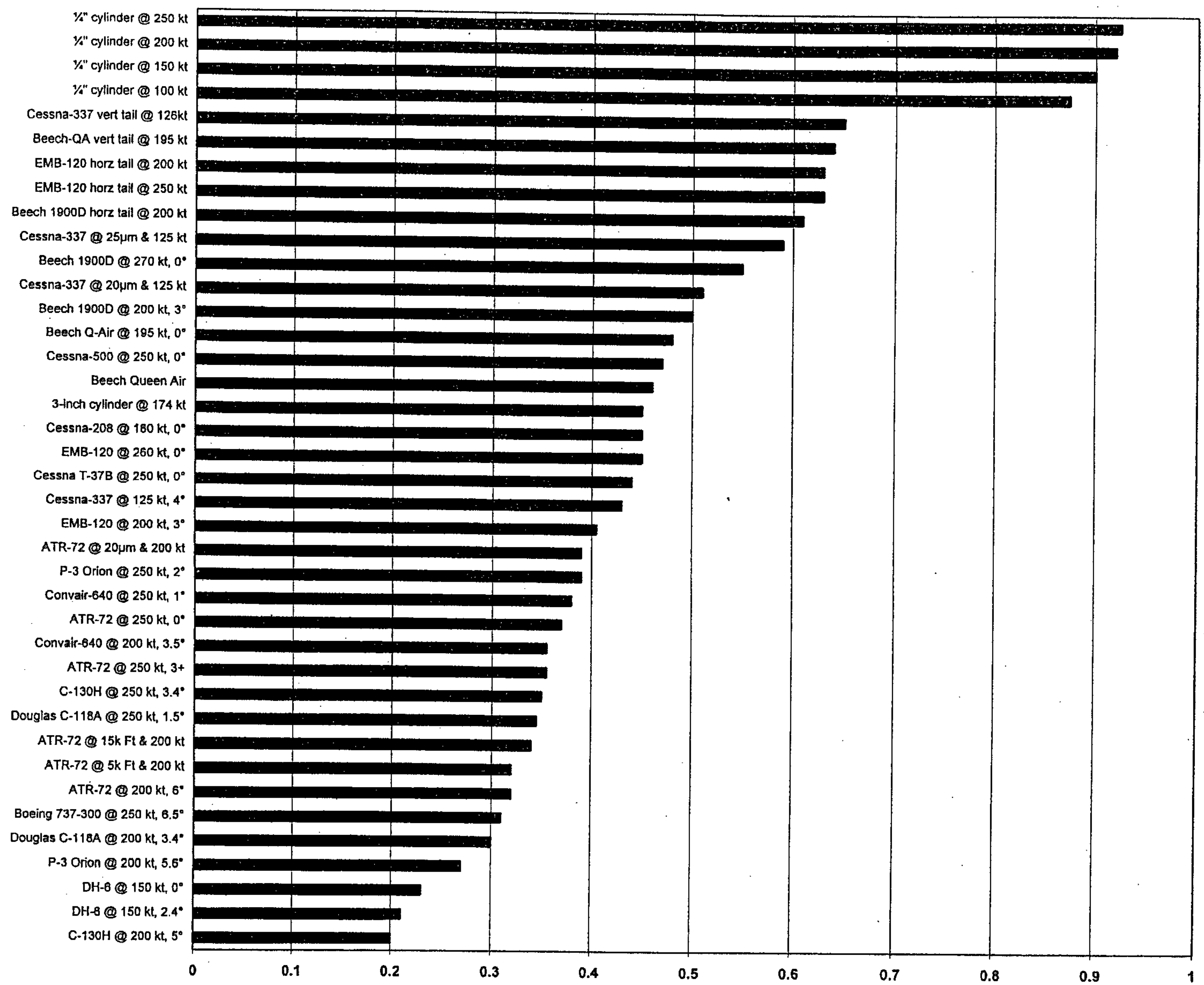


Fig. 2. Maximum Local Collection Efficiency (ß) for 15-μm Diameter Droplets on Various Airfoils (for Conditions Given in Table 1).

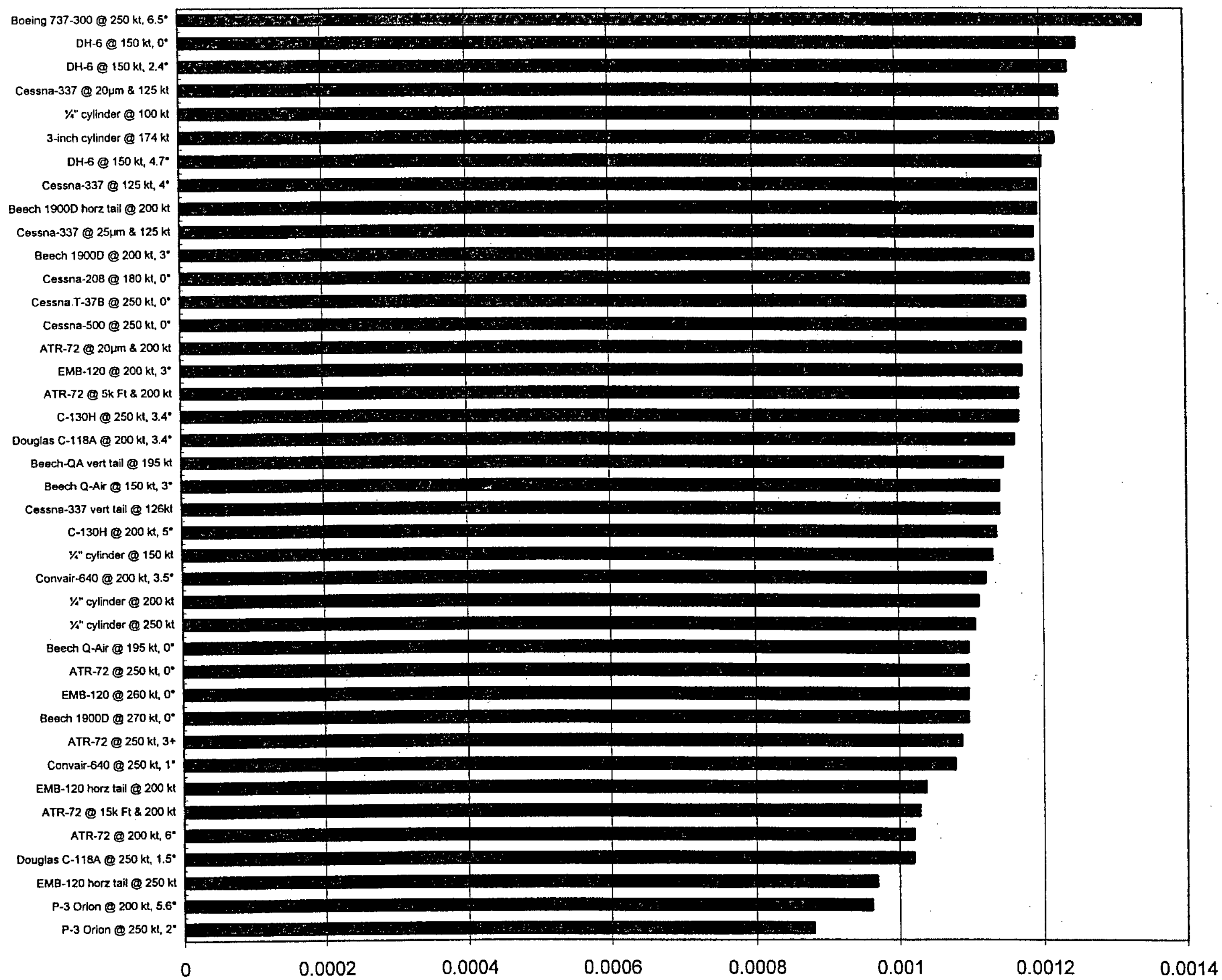


Fig. 3. Value of the Constant of Proportionality (A) in Eq. (1) for Various Airfoils.

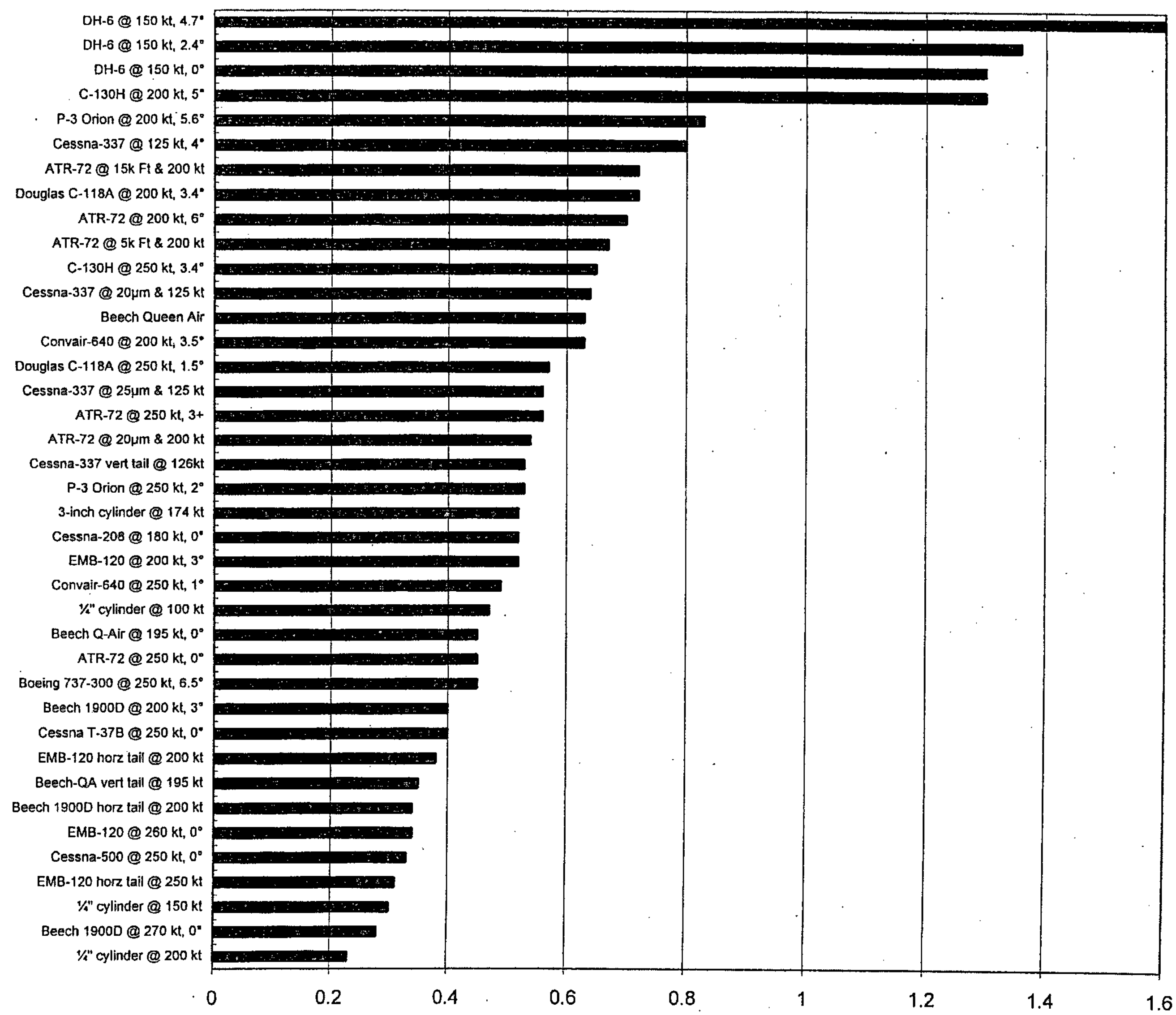


Fig. 4. **LWC (g/m^3) Threshold for Severe Icing: LWC Required to Accrete ¼-inch of Ice in 5 Minutes on Various Airfoils (for Conditions Given in Table 1).**

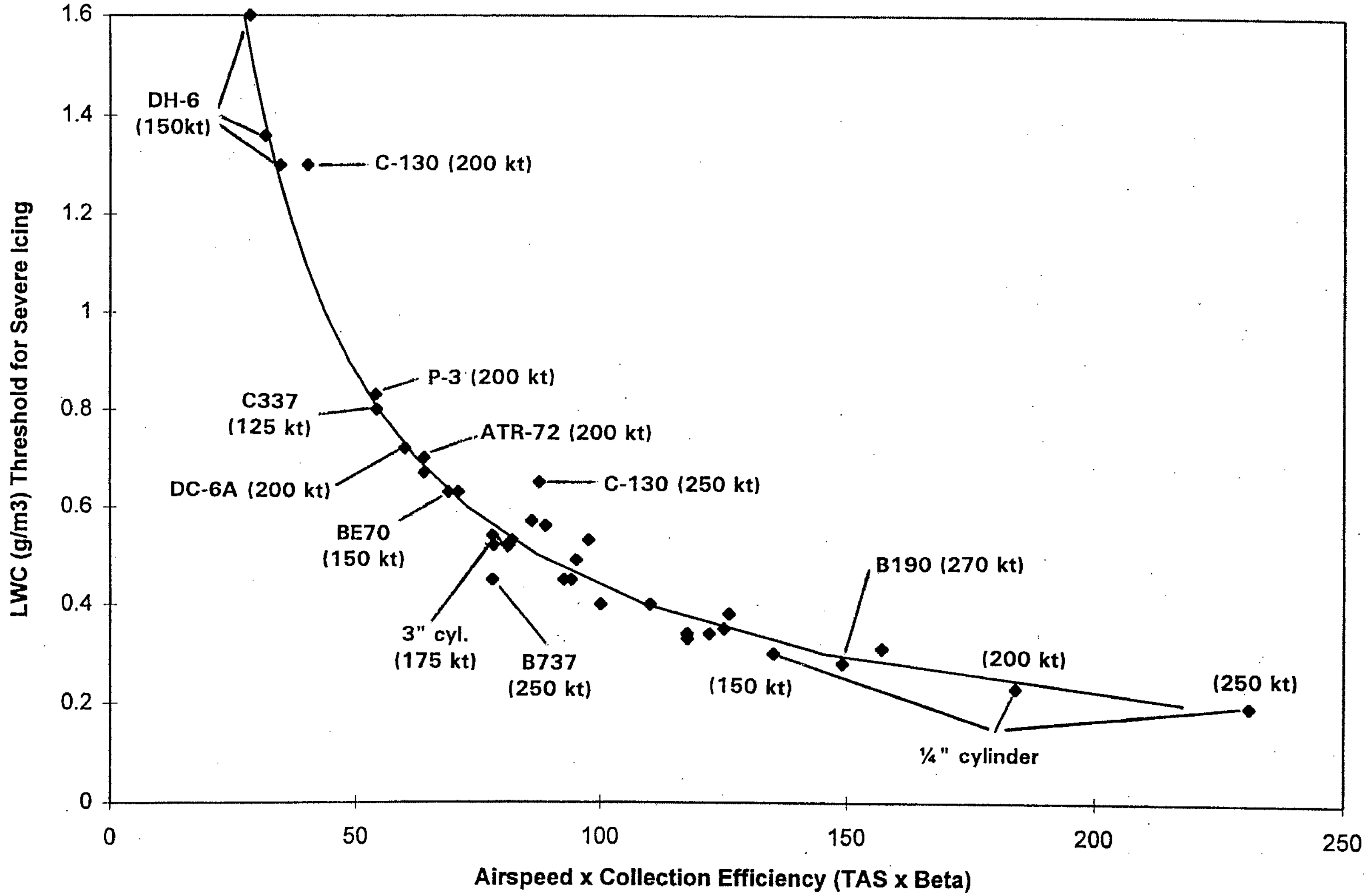


Fig. 5. Universal Curve : Severe Icing Threshold (LWC) for Various Airfoils. (for Conditions Given in Table 1).