U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: HAZARDS FOLLOWING GROUND DEICING AND GROUND OPERATIONS IN CONDITIONS CONDUCIVE TO AIRCRAFT ICING

Date: 12/17/82
Initiated by: AWS-100

AC No: 20-117
Change:

1. PURPOSE. To emphasize the "Clean Aircraft Concept" following ground operations in conditions conducive to aircraft icing and to provide information to assist in compliance.

2. RELATED FEDERAL AVIATION REGULATIONS (FAR) SECTIONS. Sections 121.629, 91.209, and 135.227.

3. BACKGROUND. Recent accidents involving large transport and small general aviation aircraft indicate that misconceptions exist regarding the effect of slight surface roughness caused by ice accumulations on aircraft performance and flight characteristics and the effectiveness of Freezing Point Depressant (FPD) ground deicing and anti-icing fluids. During development of information contained herein it was recognized that guidance information should be directed to all segments of aviation to include aircraft manufacturers; airline engineering, maintenance, service and operations organizations; aircraft maintenance and service personnel; and aircrews of all aircraft types and categories. Information contained herein therefore is general in nature for basic understanding purposes to facilitate development of standardized procedures and guidance by various segments of the aviation industry. The FAA will assist in development of specific industry standards and will publish additional advisory information as necessary.

4. DISCUSSION.

a. Regulations were established by the Civil Aeronautics Board (CAB) in 1950 prohibiting takeoff of aircraft when frost, snow, or ice is adhering to wings, propellers, or control surfaces of the aircraft. These regulations remain in effect as cited under FAR 121.629, 135.227, and 91.209. The basis of these regulations, which are commonly referred to as the clean aircraft concept, is known degradation of aircraft performance and changes of aircraft flight characteristics when ice formations of any type are present. These effects are wide ranging, unpredictable, and dependent upon individual aircraft design. The magnitude of these changes is dependent upon many variables and is thus unpredictable, but these changes can be significant. Wind tunnel and flight tests indicate that ice, frost, or snow formations on the leading edge and upper surface of a wing, having a thickness and surface roughness similar to medium or coarse sandpaper, can reduce wing lift by as much as 30 percent and increase drag by 40 percent. These changes in lift and drag will significantly increase stall speed, reduce controllability and alter aircraft flight characteristics.

Thicker or rougher ice accumulations in the form of frost, snow, or ice deposits can have increasing effects on lift, drag, stall speed, stability, and control, but the primary influence is surface roughness relative to critical portions of an aerodynamic surface. It is therefore imperative that takeoff not be attempted unless it has been ascertained, as required by regulation, that all critical components of the aircraft are free of adhering snow, frost, or other ice formations.

b. Most transport aircraft used in commercial transportation as well as some other aircraft types are certificated for flight in icing conditions. It is emphasized that to date rotorcraft and most small, general aviation fixed wing aircraft have not been certificated by the FAA for flight in icing conditions. Aircraft so certificated have been designed and demonstrated to have the capability of penetrating supercooled cloud icing conditions in the forward flight regime. This capability is provided either by ice protection equipment installed on critical surfaces (usually the leading edge) or demonstration that ice formed, under supercooled cloud icing conditions, on certain unprotected components will not significantly affect aircraft performance, stability and control. Ice, frost, or snow formed on these surfaces on the ground can have a totally different effect on aircraft flight characteristics than ice formed in flight. Exposure to weather conditions on the ground that are conducive to ice formation can also cause accumulation of frost, snow, or ice on ice protected areas of the aircraft that are designed for inflight use only and that are not designed for use during ground operation. In addition, aircraft are considered airworthy and are certificated by the FAA only after extensive analyses and testing have been accomplished. With the exception of analyses and testing to ascertain the flight characteristics of an aircraft during flight in icing conditions, all analyses and certification testing are conducted with a clean aircraft flying in a clean environment. If ice formations are present, other than those considered in the certification process, the airworthiness of the aircraft may be invalid and no attempt should be made to fly the aircraft until it has been restored to the clean configuration. The ultimate responsibility for this determination rests with the pilot in command of the aircraft.

c. Common practice developed by the North American and European aviation community over many years of operational experience is to deice an aircraft prior to takeoff. Various techniques of ground deicing were also developed. The most modern of these techniques is use of FPD fluids to aid the ground deicing process and to provide a protective film of FPD (anti-icing) to delay formations of frost, snow, or other ice.

d. In scheduled airline operations, where large numbers of aircraft are dispatched, the process of assuring airworthiness must be a team effort where each member of the team has specific duties and responsibilities. In the case of private aircraft operations, all functions may be performed by only one person, the pilot. In all cases, the pilot has the ultimate responsibility of ascertaining that the aircraft is in a condition for safe flight.

e. The only method currently known of positively ascertaining that an aircraft is clean prior to takeoff is by close inspection. Under conditions of precipitation or where moisture can be splashed, blown, or sublimated onto critical surfaces in subfreezing weather, many factors influence whether ice, frost, or snow may accumulate and result in surface roughness.

These variables are described in appendix 3 of this advisory circular (AC) but for convenience are listed as follows:

- Ambient Temperature
- Aircraft Surface Temperature
- Presence of Deicing Fluid
- Deicing Fluid Type
- Deicing Fluid Aqueous Solution (Strength)
- Precipitation Type and Rate
- Deicing Fluid Application Procedure
- Relative Humidity
- Solar Radiation
- Operation in Close Proximity to other Aircraft, Equipment, and Structures
- Operation on Snow, Slush, or Wet Surfaces
- Wind Velocity and Direction
- Aircraft Component Inclination Angle, Contour, and Surface Roughness

f. Aircraft maintenance and operations personnel neither have the capability to quantify the occurrence or the effects of the many variables that can influence whether ice, frost, or snow may form prior to takeoff, the surface roughness of ice formations, nor the effect that surface roughness may have upon aircraft performance and handling characteristics. Therefore, the time that may be considered a safe interval between ground deicing and takeoff cannot be estimated. Calculations of time incorporating the effects of only a few of these variables (e.g., ambient temperature of 20°F, fluid strength of 50 percent, precipitation rate of 1/2 inch/hour, assumed water content of snow of 0.1, and assumed surface film thickness of FPD fluid of 0.1 mm) reveals that aircraft surfaces may remain free of ice formations (onset of FPD fluid crystallization) for approximately 10 minutes. Other variables listed above could reduce this time. Since neither the pilot in command nor ground support staffs have even these limited facts on hand, quantitative judgements of time available between the ground deicing or anti-icing process and takeoff <u>cannot</u> be made.

g. The essence of flight safety following ground operations in conditions conducive to icing is the clean aircraft concept. To understand the need for the clean aircraft concept requires thorough knowledge of: (1) The adverse effects that ice, frost, or snow can have on aircraft performance and handling qualities; (2) the various procedures that are available for aircraft ground deicing and anti-icing: (3) the capabilities and limitations of these procedures; (4) the variables that will influence the effectiveness of these procedures; (5) the critical areas of the particular aircraft; and (6) recognition that final assurance for a safe takeoff rests in pretakeoff inspection. Additional information to assist in development of this understanding and knowledge may be found in the appendices of this AC. The success of the aviation community to date is attributed to many years of experience on the part of many companies where this knowledge has been gained, through experience, and passed on in the form of policy, procedures, quality assurance programs, and training programs.

5. ACCEPTABLE PRACTICES.

a. General. The clean aircraft concept is essential. The FAR makes the clean aircraft concept law. This law exists for flight safety reasons. The FAR states a general requirement but allows operators to comply with the requirement in an appropriate manner, depending upon local circumstances. The clean aircraft concept has been in effect since 1950. Many techniques of complying with the clean aircraft concept have been developed over the years by the aviation industry. Many of these techniques were developed prior to 1950 because of the need recognized by the aviation community. The consensus of the aviation community and the conclusion reached by the FAA is that the only method of assuring flight safety following ground operations in conditions conducive to aircraft icing, is by either close inspection prior to takeoff to ascertain that critical aircraft components are clean (free of ice, frost, or snow formations) or a determination that any formations are not adhering to critical surfaces and will blow off in the early stages of takeoff roll. This consensus is valid regardless of the use of currently available FPD deicing fluids or the use of manual techniques of deicing. FPD fluids commonly used today should not be considered to have anti-icing qualities for a finite period of time because a multitude of variables make it impractical to estimate that time. However, under certain condition FPD fluids are known to be effective in retarding the formation of frost, snow, or ice and in this sense may be considered to have anti-icing qualities (to prevent the formation of ice) for a period of time during ground storage (overnight or during brief layover) thus making the process of deicing (removing ice formations) simpler and in many cases negating further deicing or treatment. It is emphasized, however, that the need for close inspection prior to takeoff remains. The following paragraphs are intended to provide suggested methods of assuring the clean aircraft concept.

(1) Aircraft Deicing and Anti-Icing.

(i) An airplane may be cleaned of ice formations (deiced) by any suitable manual method, by use of water, by use of FPD fluids, or mixtures of FPD fluids and water. To date manufacturers of rotorcraft have not approved use of FPD fluids for application to rotorcraft. Heated water, FPD fluids or aqueous solutions of FPD fluids are more effective in the deicing process. The deicing and anti-icing process may be performed in one stage or multiple stage processes as desired depending upon prevailing conditions, concentration of FPD utilized, facilities available and deicing methods. In any case the freeze point of residual fluids (water, FPD fluids or mixtures) should not be greater than 20°F below ambient or surface temperature whichever is less. Unheated FPD fluids or aqueous solutions are more effective in the anti-icing process than heated fluids.

(ii) In conditions of freezing precipitation or high humidity when aircraft surface temperatures are near or below freezing and when it cannot be determined that snow or other ice crystal accumulations are not adhering and will blow off during initial stages of takeoff, surfaces should be anti-iced to retard the formation of ice prior to takeoff.

(iii) FPD freeze point can be determined using refractive index techniques. FPD fluid manufacturers can suggest or supply suitable equipment.

(iv) Critical surface temperatures under many circumstances are found in the vicinity of integral wing fuel tanks. When fuel temperatures are higher than ambient, critical surface temperatures will occur at other locations. These temperatures can be determined by direct measurement or by estimating fuel temperature. If surface temperature is not measured or estimated then the freeze point of residual fluids should be the lowest possible with available fluids.

(v) In conditions of nonprecipitation an anti-iced aircraft should be closely inspected to assure the freeze point of residual fluids remain 20°F below ambient or surface temperature whichever is lower. This is especially important when relative humidity is high.

(vi) Underwing frost should be removed and, where practical, the surface anti-iced to delay re-formation of frost. See appendix 3 for additional information on this subject.

(2) Preflight Inspection. Preflight inspection should be performed immediately following or during the ground deicing and anti-icing process. Areas to be inspected depend upon the aircraft design and should be identified in an inspection checklist. The inspection checklist should include all items recommended by the aircraft manufacturer and may be supplemented, as necessary, to include special operational considerations, but this checklist should include the following general items:

- Wing leading edges, upper surfaces, and lower surfaces

- Stabilizing device leading edges, upper surfaces, lower surfaces, and side panels

- High lift devices such as leading edge slats and leading or trailing edge flaps

- Wing lift spoilers

- All control surfaces and control balance bays

- Propellers

- Rotor Blades, rotor heads and controls

- Critical rotor system devices such as droop stops

- Engine inlets, particle separators and screens

- Windshields and other transparencies necessary for vasibility

- Antennas

- Fuselage sections forward of stabilizing, control and lifting surfaces, propellers, rotors, or engine air inlets

- Exposed instrumentation devices such as angle-of-attack vanes, pitot-static pressure probes, and static ports

- Fuel tank and fuel cap vents

- Cooling and APU air intakes/inlets/exhausts

- Undercarriage

(3) Once it has been determined through pre-flight inspection that the aircraft is clean and adequately protected, the aircraft should be released for takeoff as soon as possible. This is especially important in conditions of precipitation or high relative humidity.

(4) Pretakeoff Inspection.

(i) Fixed Wing Aircraft

(A) Just prior to taking the active runway for takeoff or just prior to initiating takeoff roll, a visual pretakeoff inspection should be made. The components to be inspected depend upon aircraft design. In some aircraft, the entire wing and portions of the empennage are visible from the cockpit or the cabin. In other aircraft, these surfaces are so remote that only portions of the upper surface of the wings are in view. Undersurfaces of wings and undercarriage are not viewable in any but high-wing type aircraft. A practice in use by some operators is to perform close visual inspection of wing surfaces, leading edges, engine inlets, and other components of the aircraft that are in view either from the cockpit or cabin (whichever provides maximum view). If surfaces have not been treated with FPD fluid, evidence of melting snow and possible freezing is sought. Also evidence of any ice formation that may have been induced by taxi operations is sought. If the aircraft has been treated with FPD fluids, evidence of a glossy smooth and wet surface is sought. If, as a result of these inspections, evidence of ice, snow, or frost formations is observed, the aircraft should be returned to a maintenance area for additional deicing.

(B) The fact that it is impractical for an aircraft crewmember to disembark at the end of a runway and perform pretakeoff inspections, means that the crewmember should perform that inspection from the best vantage point available from within the aircraft. The crewmember may elect to open windows, doors, or hatches to improve the view, but in many aircraft even this is impractical. In the darkness of night the crewmember must rely upon wing and other aircraft illumination lights that may not provide sufficient reflection to make appropriate visual observations. The crewmember may, where practical, call upon the assistance of qualified ground personnel. If under any circumstance, the pilot in command cannot ascertain that the aircraft is clean, takeoff should not be attempted.

(C) Conducting pretakeoff inspection in the manner described relies upon the pilot in command to be knowledgeable of ground deicing procedures, that the ground deicing process was conducted in a thorough and uniform manner, and that critical surfaces or components not in view during pretakeoff inspection will also be clean. The decision to takeoff, following pretakeoff inspection remains the responsibility of the pilot in command.

(ii) Rotorcraft.

(A) Only rotorcraft that have been certificated for flight in icing conditions should be operated in conditions conducive to icing such as freezing fog. To date none have been so certificated by the FAA.

(B) Rotorcraft certificated for flight in falling and blowing snow may operate in such conditions. In this case pretakeoff inspection of rotor systems should be conducted just prior to starting rotors turning. Rotor systems should not be started unless blade surfaces and other critical components are free of ice, frost or adhering snow.

b. Common practices or suggested practices necessary to assure the pilot has every advantage for his judgements:

(1) Establish training programs to continually update pilots on the hazards of winter operations, adverse effects of ice formations on aircraft performance and flight characteristics, proper use of ice protection equipment, ground deicing and anti-icing procedures, and preflight and pretakeoff inspection procedures following ground deicing or anti-icing and operations in conditions conducive to aircraft icing.

(2) Establish training programs for maintenance or other personnel who perform aircraft deicing to assure thorough knowledge of the adverse effects of ice formations on aircraft performance and flight characteristics, critical components and specific ground deicing and anti-icing procedures for each aircraft type, and the use of ground deicing and anti-icing equipment including detection of abnormal operational conditions.

(3) Establish quality assurance programs to assure that FPD fluids being purchased and used are of the proper characteristics, that proper ground deicing and anti-icing procedures are utilized, that all critical areas are inspected, and that all critical components of the aircraft are clean prior to departure.

(4) Perform thorough planning of ground deicing activities to assure that proper supplies and equipment are available for forecast weather conditions and that responsibilities are specifically assigned and understood. This is to include maintenance service contracts.

(5) Monitor weather conditions very closely to assure that planning information remains valid during the ground deicing or anti-icing process and subsequent aircraft operations. FPD fluids, deicing or anti-icing procedures and departure plans should be altered accordingly.

(6) Use FPD concentrations that will delay ice formations for as long a period as possible under the prevailing conditions.

(7) Deice or anti-ice areas that may be viewed by the pilot (from inside the aircraft) first so that during pretakeoff inspection he may have assurance that other areas of the aircraft are clean since areas deiced or anti-iced first will generally freeze first.

(8) Use the two-stage deicing process where ice deposits are first removed, and then all critical components of the aircraft are coated with an appropriate mixture of FPD fluid (anti-icing) to prolong effectiveness.

(9) Assure thorough coordination of the ground deicing and anti-icing process so that final treatments are provided just prior to takeoff.

(10) Use remote sites near the take-off position, where feasible, for deicing or anti-icing to reduce the time between deicing and takeoff or to provide additional FPD fluid to prolong anti-icing effectiveness.

(11) Use multiple aircraft deicing or anti-icing units for faster and more uniform treatment during precipitation.

(12) Use FPD fluids that are approved for use by the aircraft manufacturer. Some fluids may not be compatible with aircraft materials and finishes and some may have characteristics that impair aircraft performance and flight characteristics or cause control surface instabilities.

(13) Do not use substances that are approved for use on pneumatic boots (to improve deicing performance) for other purposes unless such uses are approved by the aircraft manufacturer.

c. Suggested practices for pilots to assure the clean aircraft concept.

(1) Be knowledgeable of the adverse effects of surface roughness on aircraft performance and flight characteristics.

(2) Be knowledgeable of ground deicing and anti-icing practices and procedures being used on your aircraft whether this service is being performed by your own company, a service contractor, or a fixed-base operator.

(3) Do not allow deicing or anti-icing until you are familiar with the ground deicing practices and quality control procedures of the service organization.

(4) Be knowledgeable of critical areas of your aircraft and assure these areas are properly deiced and anti-iced, proper precautions are being taken during the deicing process to avoid damage to aircraft components, and

proper preflight inspections are performed even though this is also the responsibility of other organizations or personnel.

(5) Be knowledgeable of ice protection system function, capabilities, limitations, and operation.

(6) Perform additional preflight inspections related to deicing or anti-icing as necessary or required.

(7) Be aware that no one can accurately determine the time of effectiveness of an FPD deicing or anti-icing treatment because of the many variables that can influence this time.

(8) Be knowledgeable of the variables that can reduce time of effectiveness and their general effects.

(9) Assure that deicing or the anti-icing treatment is performed at the last possible time prior to taxi to the takeoff position.

(10) Do not start engines, propellers, or rotor blades until it has been ascertained that all ice deposits are removed. Ice particles shed from rotating components under centrifugal and aerodynamic forces can be lethal.

(11) Be aware that certain operations may produce recirculation of ice crystals, snow or moisture.

(12) Be aware that operations in close proximity to other aircraft can induce snow, other ice particles, or moisture to be blown onto critical aircraft components, or allow dry snow to melt and refreeze.

(13) Do not takeoff if snow or slush is observed splashing onto critical areas of the aircraft, such as wing leading edges, during taxi.

(14) Always perform pretakeoff inspections just prior to takeoff.

(15) Do not takeoff if positive evidence of a clean aircraft cannot be ascertained.

M. C. BEARD
Director of Airworthiness, AWS-1

APPENDIX 1. RELATED FAA PUBLICATIONS, TRAINING MATERIAL, AND OTHER READING MATERIAL

1. RELATED FAA PUBLICATIONS.

-- Air Carrier Operations Bulletin (ACOB), No. 7-81-1, Aircraft Deicing and Anti-Icing Procedures, dated April 10, 1981, DOT/FAA Order 8430.17, Change 21.

-- ACOB, No. 7-76-9, Aircraft Control and Lifting Surfaces-Cold Weather Operations, October 20, 1976.

-- ACOB, No. 7-76-11, Engine Ice Accumulation - Ground Idle (Formerly Air Carrier Operations Alert, No. 70-9), October 20, 1976.

-- ACOB, No. 7-76-12, Turbojet Aircraft Engine Icing During Prolonged Ground Operations in Icing Conditions (Formerly Air Carrier Operations Alert No. 69-3), October 20, 1976.

-- ACOB, No. 7-76-13, Takeoff Warning Systems During Cold Weather Operations, October 20, 1976.

-- ACOB, No. 7-76-2, Water/Snow Entering Parked Boeing 727 Aircraft Causing Electrical Power Loss, October 20, 1976.

-- ACOB, No. 7-76-1, Winter Operations Under FAR 121 and 127 (Formerly Air Carrier Operations Bulletin No. 68-15), October 20, 1976.

-- Air Carrier Operations Alert (ACOA), No. 67-3, Aircraft Control and Lift Surfaces - Cold Weather Operations.

-- ACOA No. 69-3, Turbojet Aircraft Engine Icing During Prolonged Ground Operations in Icing Conditions.

-- ACOA No. 70-9, Engine Ice Accumulation - Ground Idle.

--Air Carrier Maintenance Bulletin (ACMB) No. 115, Deicing of Aircraft with Engines Operating.

-- ACMB 127, Aircraft Deicer Fluids.

-- ACMB 128, Responsibility for Aircraft Servicing.

-- ACMB 155, Winter Operation of Aircraft.

-- AC 00-6A, Aviation Weather, March 3, 1975.

-- AC 00-45B, Aviation Weather Services, 1979.

-- AC 20-73, Aircraft Ice Protection, April 21, 1971.

-- AC 20-93, Flutter Due to Ice or Foreign Substance On Or In Aircraft Control Surfaces, January 29, 1976.

-- AC 20-113, Pilot Precautions and procedures to be taken in Preventing Aircraft Reciprocating Engine Induction System & Fuel System Icing Problems, Oct. 22, 1981.

-- AC 20-106, Aircraft Inspection for the General Aviation Aircraft Owner, April 1978.

-- AC 61-84A, The Role of Preflight Preparation, December 1, 1980.

-- AC 91-6A, Water, Slush, and Snow on the Runway, May 24, 1978.

-- AC 91-13C, Cold Weather Operation of Aircraft, July 24, 1979.

-- AC 91-51, Airplane Deice and Anti-Ice Systems, September 15, 1977.

-- AC 135-9, FAR Part 135 Icing Limitations, May 30, 1981.

-- AC 121-12, Wet or Slippery Runways, August 17, 1967.

-- AC 150/5380-4, Ramp Operations During Periods of Ice and Snow Accumulations, September 11, 1968.

-- FAA RD-80-50, Engine Inlet Anti-Icing System Evaluation Procedure (Report).

-- ASF 140-75-3, Report of Propulsion Conference and Environmental Workshop.

-- Aircraft Ice Protection, Report of Symposium, April 28-30, 1969.

-- FAA General Aviation News Article "Rime Without Reason."

-- FAA Pamphlet "Weather (Pilot's) How It Is Forecast."

-- FAA Pamphlet "The Weather Decision."

2. <u>TRAINING MATERIAL</u>.

-- AC 61-8D, Instrument Rating, Written Test Guide.

-- AC 61-18B, Air Transport Pilot (Airplane, written test guide).

-- AC 61-21A, Flight Training Handbook.

-- AC 61-23B, Pilots Handbook of Aeronautical Knowledge.

-- AC 61-31B, Gyroplane Pilot Written Test Guide, Private and Commercial.

-- AC 61-70A, Flight Instructor, Instrument Airplane, Written Test Guide.

-- AC 61-71B, Commercial Pilot -- Airplane -- Written Test Guide.

-- AC 61-72B, Flight Instructor -- Airplane -- Written Test Guide.

-- AC 61-73A, Private & Commercial Pilot Rotorcraft Helicopter Written Test Guide.

-- AC 61-74A, Flight Instructor -- Rotorcraft, Helicopter Written Test Guide.

-- AC 61-75A, Flight Instructor -- Glider Written Test Guide.

-- AC 61-81A, Private & Commercial Pilot -- Glider -- Written Test Guide.

-- Exam-O-Gram Number 21, "Flying Into Unfavorable Weather."

-- Exam-O-Gram Number 28, "Factors Affecting Stall Speed."

-- DOD (USN) Film, "Ice Formation On Aircraft."

-- FAA Film, "Some Thoughts on Winter Flying."

-- FAA Slide Presentation, "Fog, Stratus, and Icing."

-- FAA Slide Presentation, "Thunderstorms and Turbulence."

-- DOD Training Circular, Number 1-12, "Cold Weather Flying Sense," January 1978.

3. OTHER RELATED INFORMATION.

-- SAE, AMS 1425A, Deicing/Anti-Icing Fluid, Aircraft, Ethylene Glycol Base.

-- SAE, AIR-1335, Ramp Deicing.

-- FAA Film, "The Cold Front."

-- FAA Film, "The Warm Front."

-- AOPA Article, "The Icing Options," AOPA Pilot, September 1981.

-- Wing Surface Roughness, Cause, and Effect by Ralph E. Brumby, Principal Engineer Aerodynamics published in Issue No. 32 of DC Flight Approach, January 1979.

-- Methods of Prediction of the Influence of Ice on Aircraft Flying Characteristics by M. Ingelman Sundberg, O. K. Trunov, and A. Ivaniko; a joint report from the Swedish-Soviet Working Group on Scientific-Technical Cooperation in the Field of Flight Safety, Report No. JR-1, 1977.

-- Wind Tunnel Investigations of the Hazardous Tail Stall Due to Icing by M. Ingelman-Sunberg and O. K. Trunov; a joint report from the Swedish-Soviet Working Group on Scientific-Technical Cooperation in the Field of Flight Safety, Report No. JR-2, 1979.

-- A Study of Some Methods and Means for Protecting Aircraft Against Ground Icing by O. K. Trunov and T. Aaro; a joint report from the Swedish-Soviet Working Group on Scientific-Technical Cooperation in the Field of Flight Safety, Report No. JR-4, 1980.

-- Roughness Penalties for Flight Simulators, P. Haines and J. K. Luers, University of Dayton Research Institute, Dayton, Ohio, presented to the AIAA 20th Aerospace Sciences Meeting, January 11-14, 1982, Orlando, Florida.

-- 737 Wing Leading Edge Condition published in July-September 1981 issue of Boeing Airliner Magazine.

-- 737 Wing Leading Edge Condition - Part II, published in the October-December 1981 issue of Boeing Airliner Magazine.

-- Mirabel Deicing Project 1978-1979, Airports and Construction Services Directorate, Airport Facilities Branch, Transport Canada, Air, Report No. TR 2159, May 1979.

-- Cold Weather Operations, Frank J. Billand, published in the October-December 1982 issue of Boeing Airliner Magazine.

-- Recommendations for DE-ICING/ANTI-ICING of Aircraft on Ground, Association of European Airlines, October 1982.

-- Air Dynamic Effects of Deicing/Anti-icing Fluids, Service Letter, Boeing Commerical Airplane Company, December 2, 1982.

-- Ground Deicing and Anti-icing of Aircraft, Douglas Service, September/October 1982.

APPENDIX 2. METHODS OF ESTIMATING FREEZING POINT DEPRESSANT (FPD) FLUID EFFECTIVENESS.

1. GENERAL. Many variables can influence the time of the effectiveness of freezing point depressant (FPD) fluids, as discussed in appendix 3 of this advisory circular (AC), that make it impractical, if not impossible, to estimate that time following deicing or anti-icing processes. However, during efforts to ascertain whether or not accurate estimates could be made, mathematical relationships were developed to allow estimates to be made using only a few known or assumed parameters. This appendix contains the rationale for these mathematical relationships only for the purpose of providing the basis of estimates presented in the body and appendix 3 of this AC. It is emphasized that the mathematical relationships derived herein are an oversimplification of the problem. Extreme caution is emphasized that these relationships not be used for estimating time available between deicing and takeoff or as a substitute for the clean aircraft concept or pretakeoff inspections.

2. RATIONALE. To estimate the time of effectiveness of FPD fluids in conditions of precipitation, several parameters must be known or assumed. To simplify this rationalization, figure 2-1 depicts a segment of a surface containing a film of FPD fluid of a certain depth (δ_f), and of a certain mixture M_1 (% by weight of FPD in water). This fluid will freeze (begin to crystallize) at a given fluid temperature (t_f) when its mixture (M_2) reaches the freeze point (onset of crystallization). That is to say that at a given t_f an additional amount of water must be mixed with the FPD fluid to further dilute the mixture to M_2. Precipitation in the form of snow, sleet, hail, freezing rain or drizzle or any other source of water such as dew, frost, spraying, and/or splashing can dilute the FPD mixture. If the rate of addition of water is known (R_w) the time to reach M_2 can be estimated.

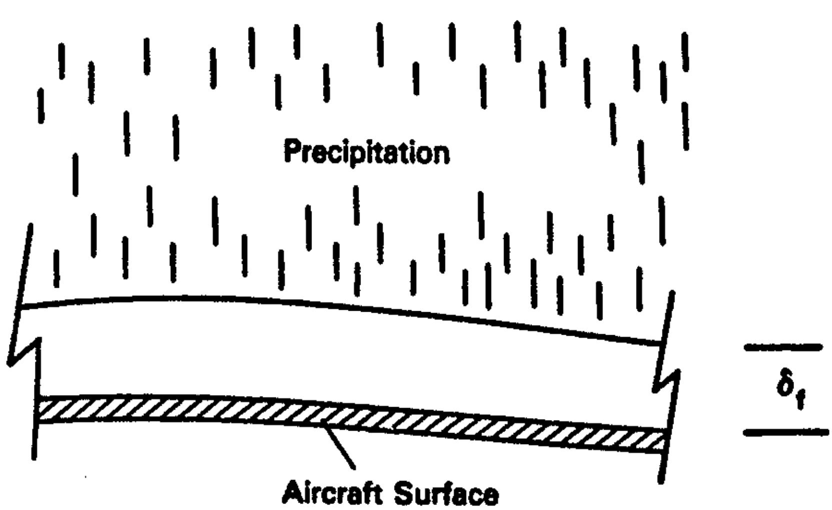

FIGURE 2-1

To further simplify this rationalization, figure 2-2 depicts schematically the relationships of the various parameters.

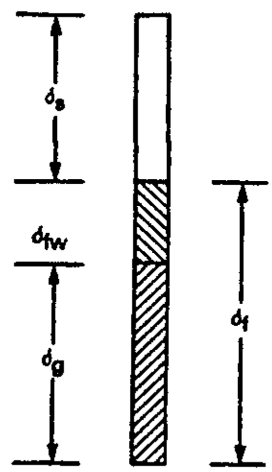

FIGURE 2-2

where:

δ_f = Original fluid film thickness

δ_g = Quantity of FDP fluid (glycol) in the FPD/water mixture

δ_{fw} = Quantity of water in the original FPD/water mixture

δ_s = The quantity of water needed to further dilute the mixture

M_1 and M_2 can then be calculated as follows:

M_1 = Is the percentage of FPD in the mixture

$$= \frac{\delta_g}{\delta_f}$$

$$M_2 = \frac{\delta_g}{\delta_f + \delta_s} = \frac{\delta_g}{\delta_{f_w} + \delta_g + \delta_s}$$

a. From this relationship the amount of water needed to be added to the FPD fluid mixture can be determined since:

$$d_s = \frac{d_g}{M_2} - d_f$$

$$d_g = d_f M_1$$

$$d_s = \frac{d_g}{M_2} - d_f = \frac{d_f M_1}{M_2} - d_f = d_f\left(\frac{M_1}{M_2} - 1\right)$$

b. If a rate of addition of water (R_W) is known, the time (T) required to add the amount of water can be estimated:

$$T = \frac{d_s}{Rw} = \frac{d_f}{Rw}\left(\frac{M_1}{M_2} - 1\right)$$

c. For example calculation assume:

d_f = 0.1 mm

R_s = 1.0 in/hour

R_W = .1 R_s = 0.1 in/hour

M_1 = 90% ethylene glycol

t_a = +20°F

d. Under these assumptions M_2 can be determined by referring to the phase diagram (figure 3-1, appendix 3) and at 20°F it can be seen that the mixture of ethylene glycol that will begin to freeze at 20°F is 16%. Therefore, M_2 = 0.16 and under the above assumptions, time can be estimated as follows:

$$T = \frac{0.1\ \text{mm}}{0.1\ \text{in/hr}} \left(\frac{0.9}{0.16} - 1\right)\left(\frac{\text{in}}{25.4\ \text{mm}}\right)\left(\frac{60\ \text{min}}{\text{hr}}\right)$$

$$= 2.36 \left(\frac{0.1}{0.1}\right)\left(\frac{0.9}{0.16} - 1\right) = 10.91\ \text{min}$$

APPENDIX 3. GENERAL INFORMATION RELATING TO GROUND AND FLIGHT OPERATIONS IN CONDITIONS CONDUCIVE TO AIRCRAFT ICING.

1. INTRODUCTION. This advisory circular (AC) deals with the hazards following ground deicing and ground operations in conditions conducive to aircraft icing. This appendix provides general information necessary for the overall understanding of these hazards and includes causes and effects of ice formations (induced on the ground or in flight) as well as ground related issues such as: methods of ground deicing, capabilities and limitations of freezing point depressant (FPD) ground deicing fluids, and discussions of variables that can influence the effectiveness of ground deicing fluids.

2. CONDITIONS CONDUCIVE TO AIRCRAFT ICING.

a. Aircraft on the ground or in flight are susceptible to accumulation of ice formations under various atmospheric and operational conditions. Aircraft in-flight can encounter a variety of atmospheric conditions that will individually or in combination produce ice formations on various components of the aircraft. These conditions include:

(1) Supercooled Clouds. Clouds containing water droplets (below 32°F) that have remained in the liquid state. Supercooled water droplets will freeze upon impact with another object. Water droplets can remain in the liquid state at ambient temperatures as low as -40°F. The rate of ice accretion on an aircraft component is dependent upon many factors such as droplet size cloud liquid water content, ambient temperature, and component size, shape, and velocity.

(2) Ice Crystal Clouds. Clouds existing usually at very cold temperatures where moisture has frozen to the solid or crystal state.

(3) Mixed Conditions. Clouds at ambient temperatures below 32°F containing a mixture of ice crystals and supercooled water droplets.

(4) Freezing Rain and Drizzle. Precipitation existing within clouds or below clouds at ambient temperatures below 32°F where rain droplets remain in the supercooled liquid state.

(5) Frozen precipitation such as snow, sleet, or hail.

b. Aircraft on the ground, during ground storage or ground operations, are susceptible to many of the conditions that can be encountered in flight in addition to conditions peculiar to ground operations. These include:

(1) Supercooled ground fog and ice clouds.

(2) Operation on ramps, taxiways, and runways containing moisture, slush, or snow.

(3) Blown snow from snow drifts, other aircraft, buildings, or other ground structures.

(4) Snow blown by ambient winds, other aircraft or ground support equipment.

(5) Recirculated snow made airborne by engine, propeller, or rotor wash. Operation of jet engines in reverse thrust, reverse pitch propellers, and helicopter rotor blades are common causes of snow recirculation.

(6) Conditions of high relative humidity that may produce frost formations on aircraft surfaces having a temperature at or below the frost point. Frost accumulations are common during overnight ground storage and after landing where aircraft surface temperatures remain cold following descent from higher altitudes. This is a common occurrence on lower wing surfaces in the vicinity of fuel cells. Frost formations can also occur on upper wing surfaces in contact with cold fuel.

3. THE EFFECTS OF ICE, SNOW, AND FROST FORMATIONS ON AIRCRAFT PERFORMANCE AND FLIGHT CHARACTERISTICS

a. General During flight operations ice will form on leading edges of various components, within forward facing air intakes (e.g., engine inlets) and frontal areas of the airframe. During ground storage or operations, ice will form on other portions of aircraft components such as upper surfaces of wings, fuselages, engine nacelles, horizontal stabilizer surfaces, and control surfaces. The effects that inflight or ground accreted ice formations will have on aircraft performance and flight characteristics are many, are varied and are highly dependent upon aircraft design, ice surface roughness, ice shape, and areas covered. These effects will generally be reflected in the form of decreased thrust, decreased lift, increased drag, increased stall speed, trim changes, and altered stall characteristics and handling qualities. Slight weight increases will also occur, however, the effect of weight increase (with the exception of heavy snow and freezing rain deposits during ground operations) is usually insignificant in comparision to aerodynamic degradation.

b. Aircraft Certification for Flight in Icing Conditions.

(1) Most commercial transport aircraft and many other aircraft types are designed for safe flight in most atmospheric icing conditions that can be encountered in conventional flight; i.e., from takeoff to landing. They are not certificated for takeoff or flight with ice formed as a result of ground storage or operations. Such formations must be removed and the aircraft sustained in a clean configuration prior to initiation of takeoff and throughout the takeoff roll. Although several helicopters are now in the initial phases of icing certification, no commercial helicopters are currently certificated for flight in icing conditions. Only a small number of helicopters have been certificated for flight in falling or blowing snow. Before an aircraft is certificated to fly in atmospheric conditions conducive to icing, that capability must be demonstrated to the FAA. This is accomplished through extensive analyses and flight testing. If an aircraft is not so certificated, it should not be intentionally flown in atmospheric icing conditions. Aircraft that are certificated for flight in icing conditions are equipped with ice protection systems to reduce the adverse effects of ice formations, either by preventing the formation of ice (anti-icing) or by periodically removing ice (deicing). Some components of some aircraft certificated for flight in icing conditions do

not require ice protection equipment. Aircraft so certificated have been demonstrated to be capable of safe flight with ice of certain shapes adhering to critical areas. Aircraft certificated for flight in icing conditions are capable of sustained operations in supercooled cloud conditions. Their engines and engine inlets are capable of operation without serious performance degradation in supercooled clouds. Some aircraft may have limited capability for flight in freezing rain and drizzle, in mixed conditions or pure ice crystal clouds, however, ice protection systems are certificated only for operation under the supercooled cloud conditions noted in paragraph 2a(1) above. Small aircraft are generally less tolerant to freezing rain conditions than large aircraft.

(2) Many aircraft in service today (generally small aircraft) have ice protection equipment installed, but are not certificated for flight in icing conditions. Aircraft of this type have only been demonstrated to show the equipment is nonhazardous for flight in nonicing conditions with the equipment installed. Aircrews should be aware of these limitations and be cautious because this type of equipment may not provide safe flight during icing encounters.

(3) Many aircraft in service today (generally large aircraft) are permitted by maintenance manuals to be dispatched for flight with slight amounts of frost adhering to fuel tank areas of wing undersurfaces. Maintenance manuals of such aircraft specify limits of frost thickness (generally between 1/8" and 3/8") depending upon the aircraft characteristics. It is emphasized that this practice is based upon operational experience only and no FAA certification or other test data has verified the accuracy of these limits. Operational experience as well as research experiments indicate that underwing frost formations do not generally influence aircraft performance and flight characteristics as severely as leading edge and upper wing frost; however, some wing designs may be more sensitive to underwing frost than others.

c. Effects of Ice Formations

(1) Wind tunnel and flight testing conducted in the past under research, development, and certification efforts, as well as operational experience, have shown that ice formations on various aircraft components can have very significant and sometimes devastating effects on aircraft equipment operation, aircraft performance, and flight characteristics. Components of an aircraft normally affected by ice formations are highly dependent upon aircraft design, however, they generally fall in the following categories: lifting devices; stabilizing devices; control surfaces; engine inlets; engines; propellers; rotor blades; anti-torque devices; windshields and other transparent structures; cooling air inlets; fuselage sections; antennas; undercarriage devices; fuel cap vents; and fuel tank vents.

(2) The effects of ice formations on some of these components and the contribution to degradation of aircraft performance and flight characteristics are itemized in the following list:

(i) Slight surface roughness can have significant effects on stall speed and power required to achieve or to sustain flight.

(ii) Surface roughness on the afterbody of a wing can have an effect approximately equal to the effect of similar surface roughness on the leading edge on some airfoils. Leading edge surface roughness is more significant on most airfoils.

(iii) Increased surface roughness, due to ice formation, on wing leading edges and afterbodies will produce additional drag and further reduce lift.

(iv) Due to increased stall speed, maneuvers should be more gentle and airspeed margin during approach should be increased.

(v) Stall angle-of-attack will decrease and in some aircraft stall will occur prior to activation of stall warning devices.

(vi) Stall characteristics will change and, depending upon aircraft design, the nature of ice formations can cause either violent stall or a slower progression of stall. In some aircraft pitch-up tendencies may be greater and roll-off tendencies can be exaggerated.

(vii) Controllability may be reduced requiring more stick deflection for maneuvers or stall recovery.

(viii) Power available may be reduced due to ice formations on propellers or jet engine inlets.

(ix) Ice or excessive quantities of FPD fluid have been known to cause control surface flutter.

(x) Trim effectiveness can deteriorate with the accumulation of ice on unprotected surfaces.

(xi) Power failures may occur due to carburetor icing or ingestion of ice particles into jet engines or clogging of fuel tank vents and fuel caps.

(xii) Severe vibrations may occur due to asymmetric shedding of ice from propellers or rotor blades. Helicopter autorotation capability can be significantly changed or lost.

(xiii) Control surfaces such as ailerons, elevators, and wing spoilers can freeze in place if water deposits, snow, and FPD fluids are not properly cleaned or drained from critical areas.

(xiv) Wing flaps may be damaged if retracted with ice formations adhering to critical areas.

(xv) Landing gear mechanisms may be damaged or frozen in place if not properly cleared of ice formations.

(xvi) Forward visibility may be lost or significantly reduced if windshield anti-icing systems are not available or are not properly utilized.

(xvii) Radio, radar, and other communication and navigation antennas may be damaged or efficiency reduced due to ice formations.

(xviii) Ventilation, air conditioning, and other air inlets can be blocked or flow restricted.

(xiv) Ice dislodged from fuselage sections, antennas and other components forward of engine inlets and other critical components can produce damage.

(xx) Ice formations, under certain conditions, may not have noticeable effects on aircraft performance and flight characteristics, however, these effects may become quite apparent in the event of engine failure or other emergencies.

(xxi) Flight, engine, and other instruments are subject to error if ice formations exist on external probes, in pressure lines, or on areas forward of or adjacent to external probes. Operational experience indicates that typical sources of error are icing of pitot-static probes used for airspeed, altitude, and engine pressure ratio measurements.

(xxii) Automatic systems that utilize external signal sources such as AFCS, auto-pilots, autothrottle speed command systems, or stability augmentation systems may be adversely affected by ice formations on or in the vicinity of external sensors.

(xxiii) Residual moisture on door and cargo hatch seals may freeze under certain conditions causing leaks or seal damage.

4. METHODS OF DEICING OR CLEANING ICE FROM AIRCRAFT SURFACES.

a. Ground deicing procedures have been under development, practically speaking, since the time of the invention of the aircraft. Early methods employed the use of hangars to avoid exposure to the elements or use of wing covers and covers for other critical components such as windshields, engine air intakes, pitot probes, etc. But these devices were useful only to lessen the extent of work required to remove frost, snow, or other ice formations from the aircraft. Various devices such as brooms, brushes, ropes, squeegees, fire hoses, or other devices were used to remove dry snow accumulations but caution had to be exercised to preclude damage to aircraft skins and other critical components. Common sense prevailed. Many of these manual methods are still used today for both small and large aircraft. As larger aircraft were introduced and the numbers of air carrier fleets and scheduled flights increased, more expeditious and less costly procedures were developed. Thus, freezing point depressant (FPD) fluids were introduced to prevent or retard the formation of frost during overnight storage, to assist in melting and removal of frost, snow, or other ice formations such as would develop as a result of freezing rain or drizzle or for assisting in the removal of ice or frost formations accumulated during a previous flight.

b. Various methods of applying FPD fluids were utilized, such as mopping the fluid on the surface requiring treatment from a bucket, use of hand pumps attached to a supply tank and spreading the solution with a mop, brush or other suitable devices to, in time, melt the ice to the extent that it could be removed by using manual means.

c. These manual methods of deicing provided a capability, in clear weather, to clean an aircraft adequately to allow a safe takeoff and flight. In inclement, cold weather conditions, however, the only alternative was to place the aircraft in a protected area such as a hangar to perform the cleaning process by whatever means were available. In freezing precipitation conditions, takeoff had to be initiated almost immediately following removal from the protected area. Common practice developed was to clean the aircraft in the hangar and provide a protective coating of FPD fluid (anti-icing) to protect the aircraft from ice or snow accumulation prior to takeoff.

d. Many of these techniques remain in use today, depending upon the local facilities and services that exist. However, most modern airports have traffic conditions and limitations of hangar space that, for the most part, preclude indoor ground deicing. These airports usually have one or more fixed base operators who have the equipment, capability, and experience to clean the aircraft and provide brief protection to allow safe takeoff to be performed. Many airlines have prepositioned ground deicing equipment for ramp deicing at major airports where icing conditions are prevalent in the United States, Canada, and European countries. Several manufacturers of various types of aircraft ground deicing equipment exist today to meet the ground support equipment demands of the aviation community. These ground support equipments vary in types from simple trailers hauling a 55 gallon drum of FPD fluid with a wobble pump and mop to exotic equipment capable of heating and dispensing large quantities of water and deicing fluid and capable of elevating deicing personnel to heights necessary to have access to any area of the largest of today's aircraft. This technology exists and it is believed that any demand for aircraft ground deicing can be readily met by the ground support equipment industry.

e. Although modern and sophisticated ground support equipment exists, cost considerations sometimes dictate combination of ice removal methods. For example, heavy accumulations of snow may be more cost effectively removed using brooms, brushes, ropes, fire hoses, and other techniques followed by final cleaning with aqueous solutions of FPD fluid. Again, common sense, experience, and planning prevail to make the aircraft ground deicing process a cost effective and safe operation. With the rising cost of petroleum products, the primary base of most commonly used aircraft deicing fluids, the expense of FPD fluid deicing has become a very significant parameter in the final decision process. An answer to this problem has been developed in recent years employing use of very hot water. Some manufacturers of such equipment have conducted extensive testing and evaluation to develop and perfect the procedures, precautions, and recommended aqueous FPD fluid mixtures necessary for cost effective, but safe, deicing. However, an understanding of the equipment, the characteristics, and limitations regarding use of FPD fluids is essential to assure safe winter operations.

5. CHARACTERISTICS OF FREEZING POINT DEPRESSANT (FPD) AIRCRAFT GROUND DEICING FLUIDS.

a. Deicing fluid manufactured in accordance with MIL-A-8243C is by specification 3 parts ethylene glycol and 1 part propylene glycol mixed with small quantities of water, corrosion inhibitors and wetting agents to allow smooth, even coverage of a surface. MIL-A-8243C fluid is specified in two types. Type I, used by the U.S. Air Force contains the ingredients described above while Type II, used by the U.S. Navy contains a small amount of additive to inhibit a chemical reaction between ethylene glycol and silver oxide. This additive is used to preclude a possible fire hazard relating to electrical relays and switches that incorporate silver oxide electrical contacts.

b. All known commercially available FPD fluids for aircraft deicing use are of the ethylene glycol or propylene glycol family. The exact formulae of various manufacturers' fluids are proprietary. It is very important to understand that some commercially available FPD fluids contain either ethylene glycol or derivatives of ethylene glycol such as diethylene glycol with small quantities of additives and water; that various FPD manufacturers, upon request, will premix aqueous solutions of FPD for specific customer reasons; and that before using a solution of FPD it is imperative that the ingredients be checked by close examination of the stock number and by a quality control examination to ascertain that the fluid supply conforms to the need. FPD fluid manufacturers can supply methodology and suggest equipment needed for quality control examinations.

c. FPD fluids in use today have characteristics that are best defined by a phase diagram or freeze chart as illustrated in figure 3-1. It is emphasized that this diagram is not representative of any commercially available FPD fluids. FPD fluid manufacturers can furnish phase diagrams for their product. This diagram illustrates the variation of the freezing point of various mixtures with water. FPD fluids are very soluble in water. The addition of glycol to water will lower the freezing point of the water mixture. The freeze point of glycol or a glycol/water mixture is not a sharp point as is the case with water alone. The freeze point of glycol or a glycol water mixture can be said to occur when crystals begin to form. As the temperature is lowered, glycol or water begins to crystallize and the mixture will assume a slushy consistency. As cooling proceeds the mixture will thicken and may no longer flow and eventually if cooled to very low temperatures can solidify to a hard granular solid.

d. It can be seen from figure 3-1 that minimum freeze point (onset of crystallization) occurs when the mixture consists of approximately 60 percent glycol and 40 percent water. This is commonly referred to as the eutectic point. It can also be seen that beyond the eutectic point the freezing temperature of ethylene glycol is higher. This means that pure ethylene glycol will freeze (onset of crystallization) at warmer temperatures than aqueous solutions of ethylene glycol. Propylene glycol does not exhibit this characteristic as shown in figure 3-1. For this reason, all currently available commercial and military deicing fluids contain small quantities of water. Military deicing fluids contain propylene glycol. This facilitates outside storage at cold temperatures. Generally, sufficient water is added to allow the

PHASE DIAGRAM OF AQUEOUS GLYCOL SOLUTIONS

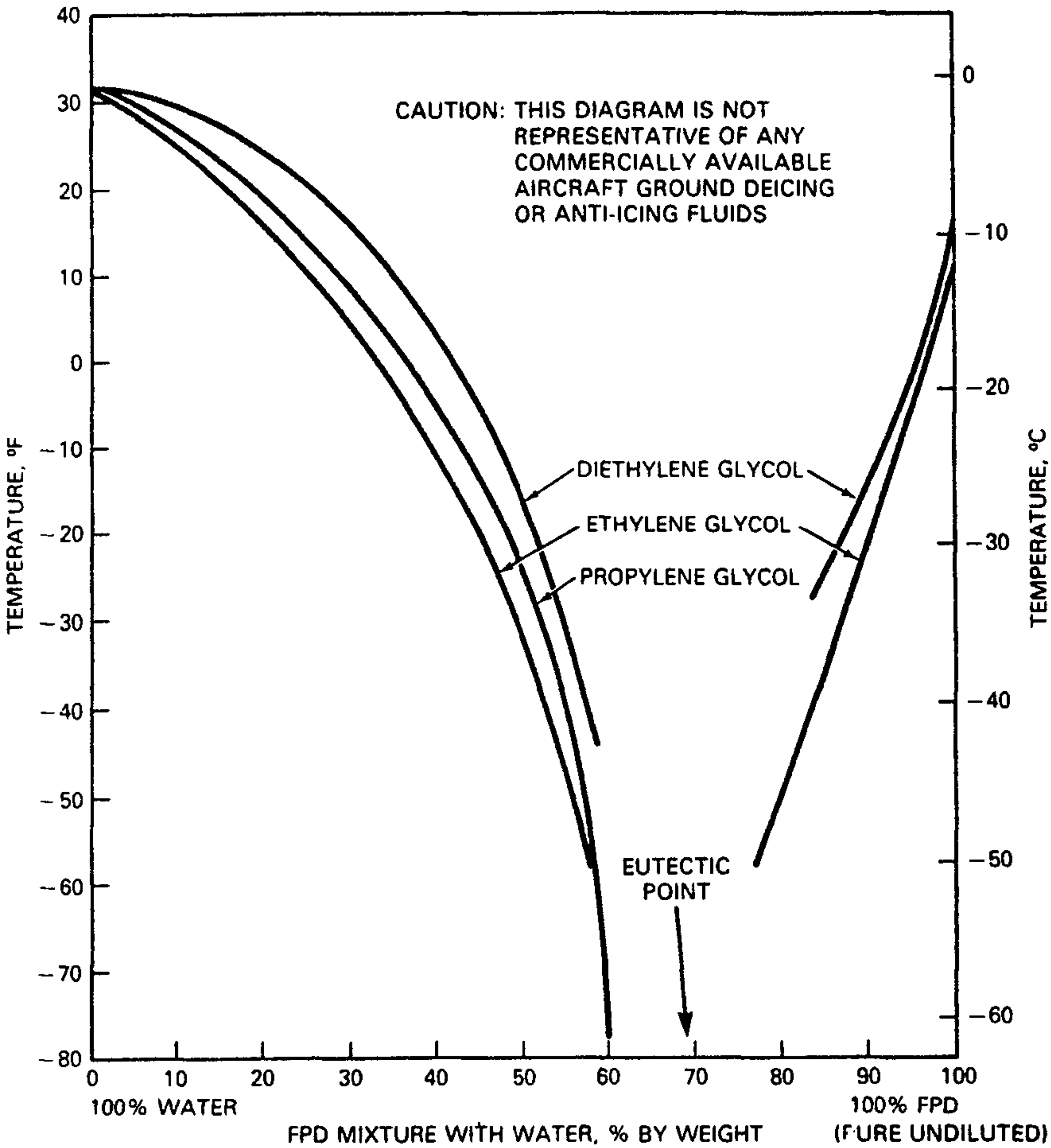

FIGURE 3-1

freeze point to be not greater than -25°F. However, it is very important for the user of the fluid to know the specific characteristics of the fluid being used.

6. CAPABILITIES AND LIMITATIONS OF FREEZING POINT DEPRESSANT (FPD) AIRCRAFT GROUND DEICING FLUIDS.

a. General. The basic philosophy of using FPD fluids for aircraft deicing is to decrease the freezing point of water either in the liquid or crystal (ice) phase. FPD fluids are very soluble in water. However, the rate at which ice will absorb FPD or melt is very slow. If frost, ice, or snow is adhering to a wing surface, that ice formation may be melted by repeated application of proper quantities of FPD fluid. This process can be significantly accelerated by thermal energy of heated fluids. As the ice melts, the FPD mixes with the water thereby diluting the FPD. As dilution occurs, the resulting mixture may begin to run off. If all the ice is not melted, additional application of FPD becomes necessary until the fluid reaches the ice/aircraft surface interface. When all ice has melted, the liquid residue that remains is a mixture of water and FPD. The remaining film could freeze (begin to crystallize) with only a slight temperature decrease. Slight temperature decreases could be induced by many factors such as cold soaked fuel in wing tanks, reduction of solar radiation by cloud obscuration of the sun, ambient temperature cooling, wind effects, temperature depression during development of wing lift and other factors. If the freeze point of the remaining film is found to be insufficient or is unknown, a fresh coat of FPD fluid should be added before the aircraft is released for flight. Practice developed and accepted by the air carrier industry is to assure that the remaining film has a freezing point less than 20°F below ambient temperature. This entire process can be accomplished by any means available; i.e., pouring, mopping, brushing, or spraying. Freeze point of the remaining FPD film can be measured at specific locations on a surface using refractive index techniques.

b. Nonprecipitation Conditions.

(1) The above description is intended to describe the capabilities and limitations of FPD for deicing (getting the aircraft clean), in a very general way. As mentioned earlier there are many other methods of removing ice, frost, or snow deposits. Large quantities of FPD would be necessary to try to melt ice, frost, and snow and the use of this method alone may not be cost effective or timely. This is especially true with regard to snow deposits. The deicing process can possibly be accomplished more cost effectively by combining manual methods to first remove soft snow and then using the FPD fluid to remove any residual ice. In some instances, where the snow is not adhering to surfaces, all snow may be removed by sweeping, brushing, or blowing with cool air (either shop air or other pressurized air sources). Hot air should not be used to attempt to remove dry snow. In clear (nonprecipitation) weather, once proper inspection has been perfomed, no further action may be necessary.

(2) Where modern ground support equipment (GSE) is available, common practice is to use water heated to approximately 180°F and glycol heated to approximately 150°F. Some GSE manufacturers recommend that hot water alone be used to melt and remove snow, frost, or ice formations. This is possible

because of the heat applied, as well as the mechanical force of the stream tending to melt, loosen, and flush ice formations from the aircraft.

(3) Some manufacturers recommend that pure hot water can be used to deice the aircraft at ambient temperatures above +26°F. Below that temperature or if ice formations occur, sufficient FPD mixed with the water is recommended to prevent freezing during the deicing process. In the latter case, as discussed before, the freeze point of the remaining film may be unknown. Once the aircraft is clean (deiced) a final coat of FPD should be added to prevent freezing due to temperature depression by any of the factors mentioned earlier. If hot water alone is used for deicing, all surfaces should be coated with a solution of FPD to assure that the freezing point of remaining films will be no greater than 20°F below ambient or surface temperature whichever is lower.

(4) Other techniques include frequent use of FPD fluids during storage under conditions of precipitation or frost to reduce the workload and time required to prepare an aircraft for flight. Experience has shown that if ice formations are not allowed to adhere to an aircraft surface they are easier to remove. If ice formations can be prevented from forming, only final inspections need to be performed under some conditions. Under other conditions, however, further treatment may be required to assure that the residual film has a freezing point sufficiently low to prevent ice crystals from forming during taxi and takeoff.

c. Conditions of Freezing Precipitation.

(1) General.

(i) The foregoing paragraphs deal primarily with the capabilities and limitations of FPD fluids in clear (nonprecipitation) weather conditions. This paragraph addresses the capabilities and limitations of FPD fluids under weather conditions where ice, frost, or snow may form. FPD fluids have the capability of preventing the formation of frost, ice, or snow for a finite period of time. The time of protection depends upon many factors and is therefore unpredictable. The primary factors that influence this time of protection are ambient temperature, surface temperature, FPD fluid film thickness, FPD mixture strength, and the rate of addition of moisture. These factors are influenced by many other variables such as solar radiation, relative humidity, surface contour, surface inclination angle, surface roughness, wind effects, fluid application procedures, residual moisture on the surface prior to deicing, etc. But to bring the physical process into perspective one must visualize a simple case where only a few of these variables are examined.

(ii) As discussed earlier, once the deicing process is completed, a thin film of deicing fluid remains on the surface and this film contains a mixture of FPD and water. The ratio of water to FPD is unknown and therefore the freezing point is unknown. Assume that a very rich mixture of fluid is uniformly added to the surface in a manner that most moisture is flushed away while realizing that some water will always remain in the solution. Also assume that the fluid film that remains is 80% ethylene glycol. Under these assumptions, the question then becomes "How much water must be added to this remaining film to cause the freeze point of the fluid to reach that of ambient temperature?" To answer this question, test results have shown that when ambient and surface temperature is 20°F the fluid film thickness on a surface sloped at an angle of 15° is at best (the most) 0.10 mm deep. From the freeze chart (figure 3-1) it can be seen that at 20°F a mixture of 16 percent ethylene glycol and 84 percent water will begin to crystalize.

(2) Snow Conditions.

(i) Precipitation rates in snow conditions have been found to contain water in amounts up to 0.7 in/hr. A general rule of thumb, commonly used by meteorologists, is that the depth of snow is about 10 times the depth of melted snow. This rule of thumb, although useful for some purposes, could be misleading, since snow densities vary widely. Very dry snow can have a density of 30:1 (30 inches of snow contains 1 inch of water) and very wet snow can have a density of 5:1. In snow conditions, the primary influence upon FPD life is the rate of addition of water and subsequent dilution of the FPD fluid. If snow is falling at a rate of 1/2 inch per hour and if the water content of this snow is 0.1, then the rate of addition of water to the FPD will be 0.05 in/hr.

(ii) If we assume that as the falling snow contacts the surface film it melts and the resulting water mixes thoroughly with the fluid contained in the film, the strength (glycol to water ratio) of 16 percent will be reached in a specific time. This time can be calculated using rationale and equations given in appendix 2.

(iii) From this assessment we can see that at a snowfall rate of 1/2 inch per hour onto a wing having been coated with a very rich mixture, 100 percent ethylene glycol, at an ambient temperature of 20°F, crystallization may begin in approximately 25 minutes. Figure 3-2 presents the estimated life of deicing fluids as a function of ambient temperature for several snowfall rates. Extreme caution is emphasized that these estimates should not be used to attempt to estimate the time available from deicing or anti-icing to takeoff, as noted clearly on the chart. The reason for this caution is that these estimated times are influenced by many variables, and figure 3-2 takes into account only a few. These variables are emphasized and their effects discussed in paragraph 7 of this appendix.

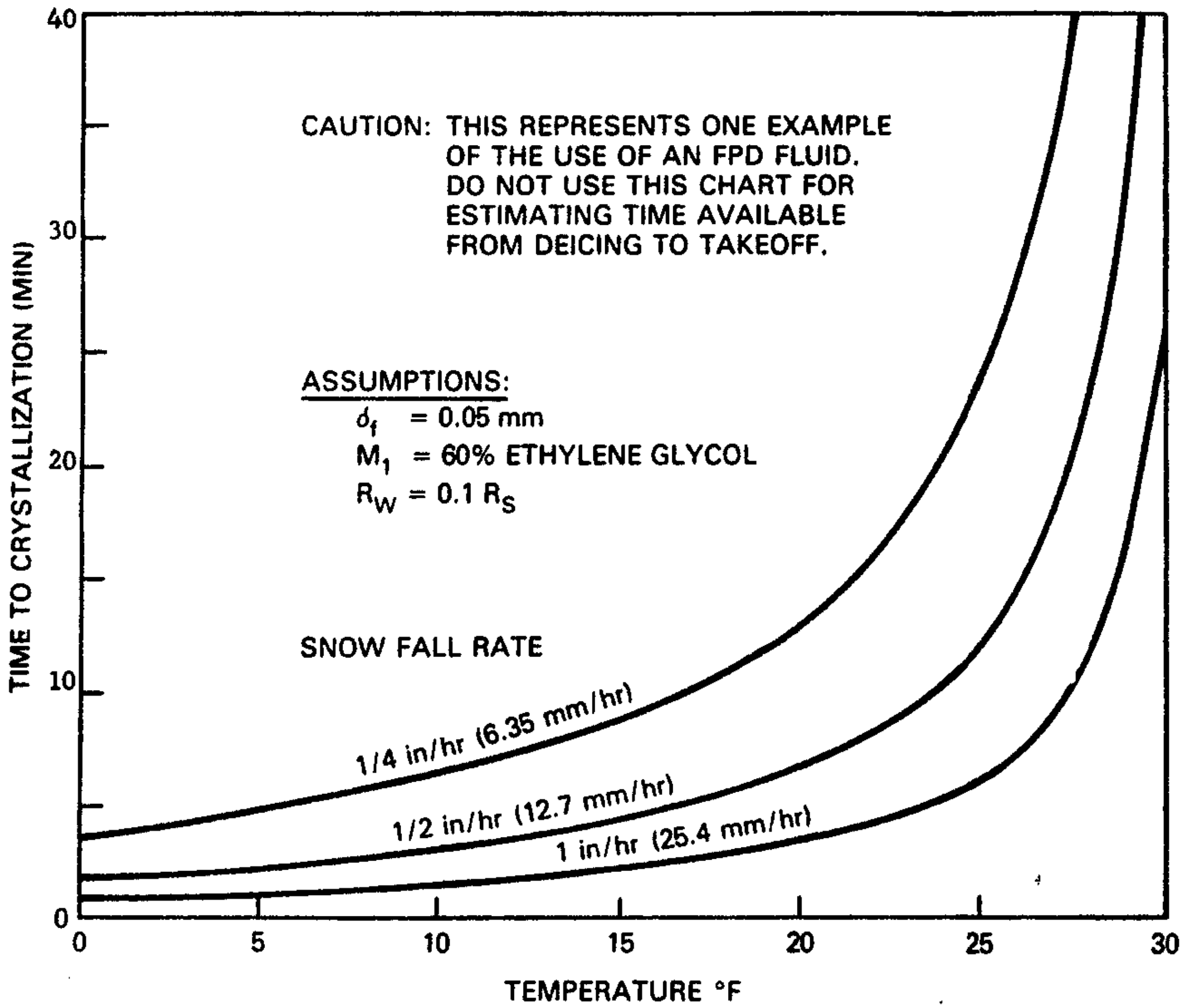

FIGURE 3-2

(iv) It is emphasized that the above rationalization regarding the finite life of FPD fluids is simplified for understanding purposes. Other physical processes occur within an FPD fluid film in the dynamic condition of precipitation or addition of moisture by any means. It is imperative that this process be understood by all associated with winter operations of aircraft.

(v) To assist the understanding of this process, figure 3-3 depicts a surface containing a film of FPD fluid.

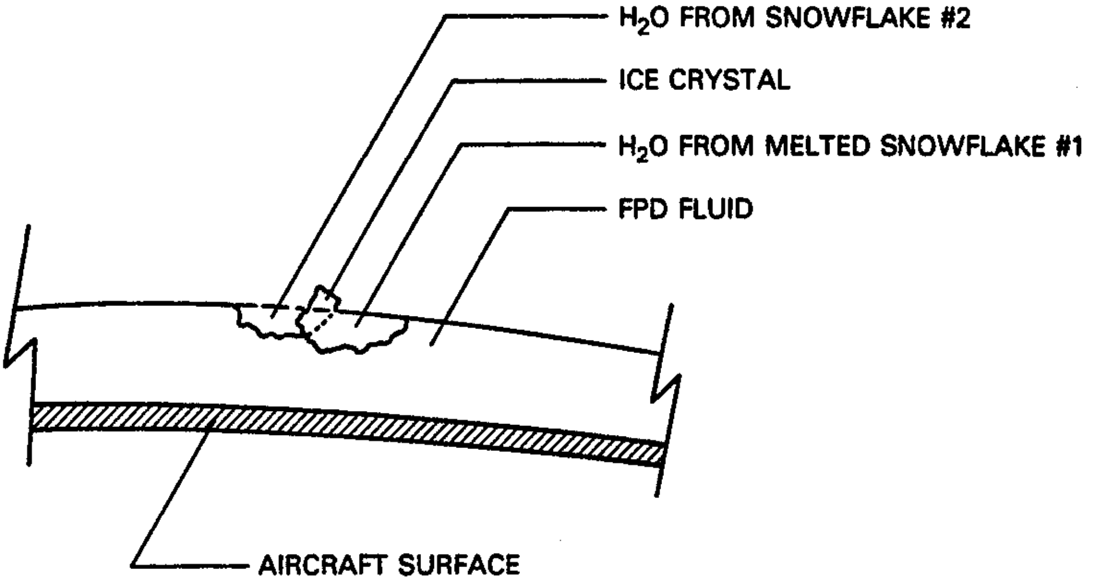

FIGURE 3-3

(vi) As snow contacts the upper surface of this film it melts and the water, begins to mix with the FPD fluid. It is known that glycols are very soluble in water but it is also known that to assure a homogeneous fluid, the mixture must be agitated or stirred. So when a snowflake or other ice crystal, supercooled rain drop, or water in any form contacts the fluid film surface, a finite time is required for the water to mix with the fluid. During this time, the water remains somewhat in pure form or a weak aqueous solution of FPD. If during this process, before the water from a snowflake mixes with the fluid, another snowflake impacts the surface, as depicted in figure 3-3, a portion of the snowflake may not melt immediately but will remain in ice-crystal form. This process has been observed during simulated snow testing. As snow continues to impact the surface, ice crystals can be seen to form on localized areas of the surface of the FPD fluid. Whether or not these ice crystals will bond to the aircraft surface depends upon many factors, such as: fluid film thickness, FPD fluid strength, surface temperature, ambient temperature and temperature of snow, rain, or ice crystals impacting the surface. Another factor is the latent heat of fusion; however, this effect is slight in comparison to heat transfer to ambient air or to massive aircraft structures. As a snowflake impacts the FPD surface and melts, heat is transferred from the fluid to the ice crystal. This reduces the surface temperature and, as precipitation continues, the rate at which snow will melt is reduced.

(vii) If the FPD film is sufficiently thick, these surface ice crystals may initially be localized on or near the surface or be floating on the surface. But as the process continues, water being added will gradually mix with the FPD fluid and, in time, the fluid in the surface film will reach an aqueous solution that will freeze (become slush) at the prevailing temperature and with time become frozen or adhere to the aircraft surface. As the quantity of slush increases, the viscosity of the surface film increases, requiring greater forces to cause the surface slush to be blown off of aircraft surfaces. Once the crystallization process begins, the chances of proper blow-off during takeoff roll are minimal. In addition, once the crystallization process begins, the surface may be expected to be a rough texture which can adversely impair aircraft performance and flight characteristics. It is also very important to understand that many varieties of snow occur in nature and each will result in differing characteristics (surface textures or roughness) during the process of dilution and crystallization of FPD fluid mixtures.

(3) Frost Conditions.

(i) Frost is formed from the sublimation of water vapor onto a surface where the temperature is below freezing. A method of retarding the formation of frost on aircraft surfaces is by applying a film of FPD fluid. As in previous examples, the maximum thickness of fluid that can be expected to be retained is 0.10 mm. A typical heavy frost condition will produce a rate of accumulation of liquid water (in the form of frost) of 0.0008 in/hr or 0.02 mm/hour. Again, we may, as an example, estimate how long the protective film of FPD fluid may last and assess the condition of the fluid as a function of time using rationale and methods contained in appendix 2. The rationale used for snow applies as well for frost since the FPD fluid will absorb the water rather than allow formation of frost, i.e., until the FPD fluid mixture is diluted to its freeze point. Then frost can begin to accumulate. However, it is emphasized that, under frost conditions, moisture will be absorbed by FPD fluids at a faster rate than moisture would be deposited in the form of frost. This is due to the hygroscopic nature of FPD fluids.

(ii) Assume that the ambient temperature is 20°F and the mixture that will begin to freeze at that temperature is 16 percent FPD fluid. In this case, we have assumed that a 50 percent solution of ethylene glycol and water was applied to a clean dry surface prior to the beginning of the dew or frost process. This example would be representative of a heavy frost condition, but it is emphasized that film thickness also is an extreme case. The estimated time of effectiveness for this example is 10.4 hrs. It is emphasized that hygroscopic effects and other variables can significantly reduce this time.

(iii) Figure 3-4 provides the estimated life of FPD fluids for various frost conditions. Extreme caution is emphasized that these estimates should not be used to attempt to estimate time available from deicing or anti-icing to takeoff, as noted clearly on the chart. Many other factors must be considered, such as type of FPD fluid, surfaces to which the fluid is applied, surface temperature, and other variables mentioned earlier. In addition, it is important to realize that when the FPD fluid has been diluted to the freeze point, crystallization has begun. Any slight reduction in surface temperature could result in further crystallization and dangerous surface roughness. After the frost protection process has been utilized, the aircraft surfaces affected should be thoroughly cleaned and inspected to assure that residual diluted fluids will not freeze during takeoff and climbout. This also applies to conditions where ambient temperature has increased since the application of the initial or repeated anti-frost solutions, because surface temperature depression on the upper surface of a wing producing lift can be significant. Temperature depression is a function of wing design, airspeed, and the amount of lift being produced. The aircraft manufacturer can provide specific values of temperature depression for their aircraft. Care should be taken to assure that the residual surface film of FPD has a freeze point no greater than 20°F below ambient temperature whichever is lower.

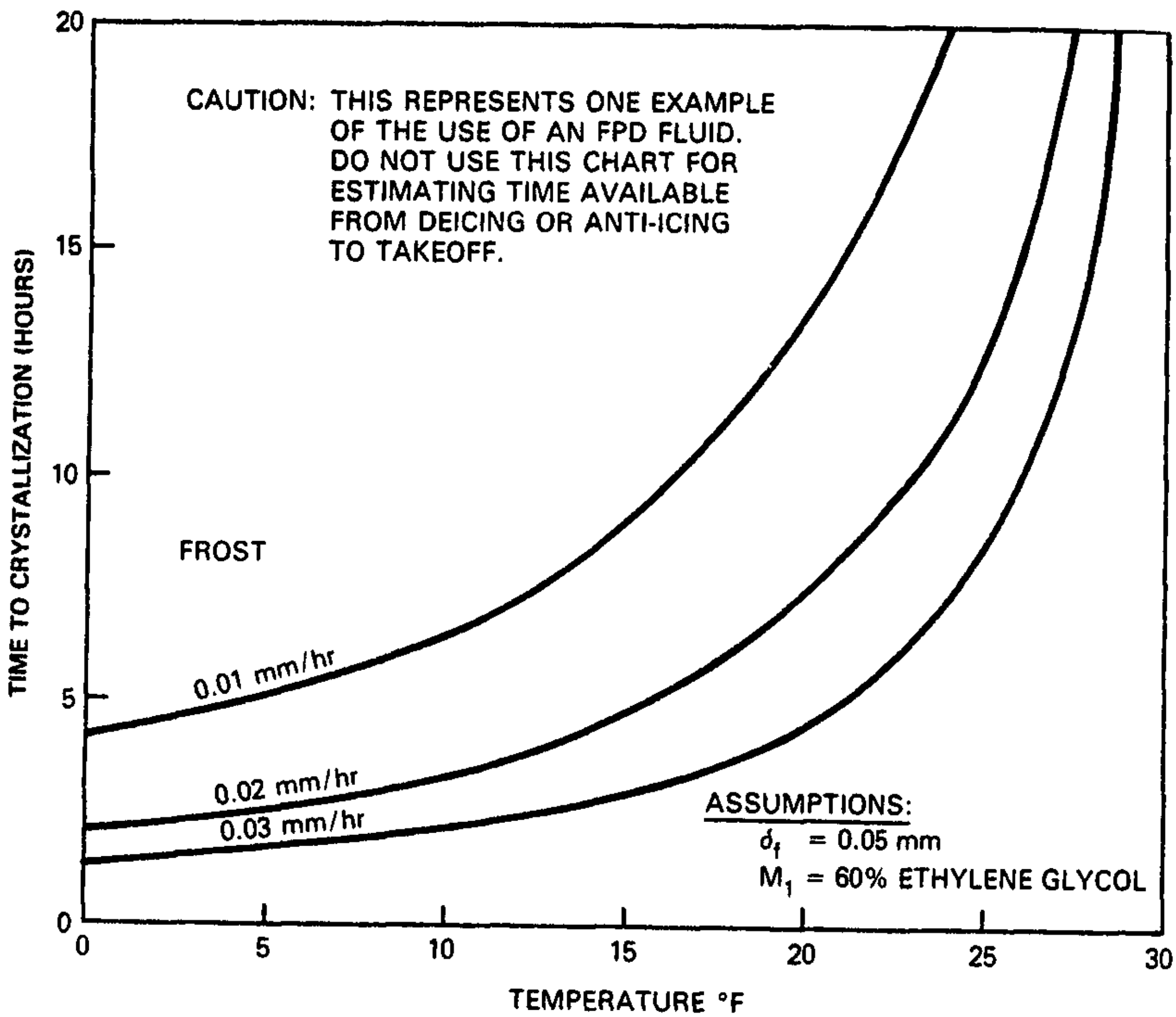

FIGURE 3-4

(4) <u>Freezing Rain and Drizzle Conditions.</u>

(i) Precipitation rates in freezing rain and drizzle conditions have been found to vary from about 0.3 to 5.0 mm per hour or about 0.01 to 0.20 in/hr. These conditions can occur at ambient temperatures between 32°F and approximately 12°F. Freezing rain and drizzle water droplets are in the supercooled liquid state and freeze upon impact with other objects. Because of the large size of freezing rain droplets (400 to 1300 microns) the ice produced is usually glaze ice. When an aircraft surface is coated with a film of FPD fluid, freezing rain and drizzle droplets impacting the fluid film will mix readily with FPD fluid, causing rapid dilution and under certain conditions can wash away the FPD fluid. The effectiveness of FPD fluids to provide protection in freezing rain conditions can be estimated using the techniques contained in appendix 2. Under the most severe freezing rain conditions (5.0 mm/hour or about 0.2 in/hour) crystallization would be expected to begin in less than 11 minutes at 25°F if pure ethylene glycol were used and if FPD fluid film thickness is assumed to be 0.1 mm. Airline operational experience indicates that FPD fluids are short-lived in most freezing rain conditions. In many instances, one side of the aircraft already deiced will begin to refreeze while the other side is being deiced. Figure 3-5 provides estimated FPD fluid life as a function of ambient temperature for several freezing rain precipitation rates. Extreme caution is emphasized that this chart should not be used to attempt to estimate time available from deicing to takeoff.

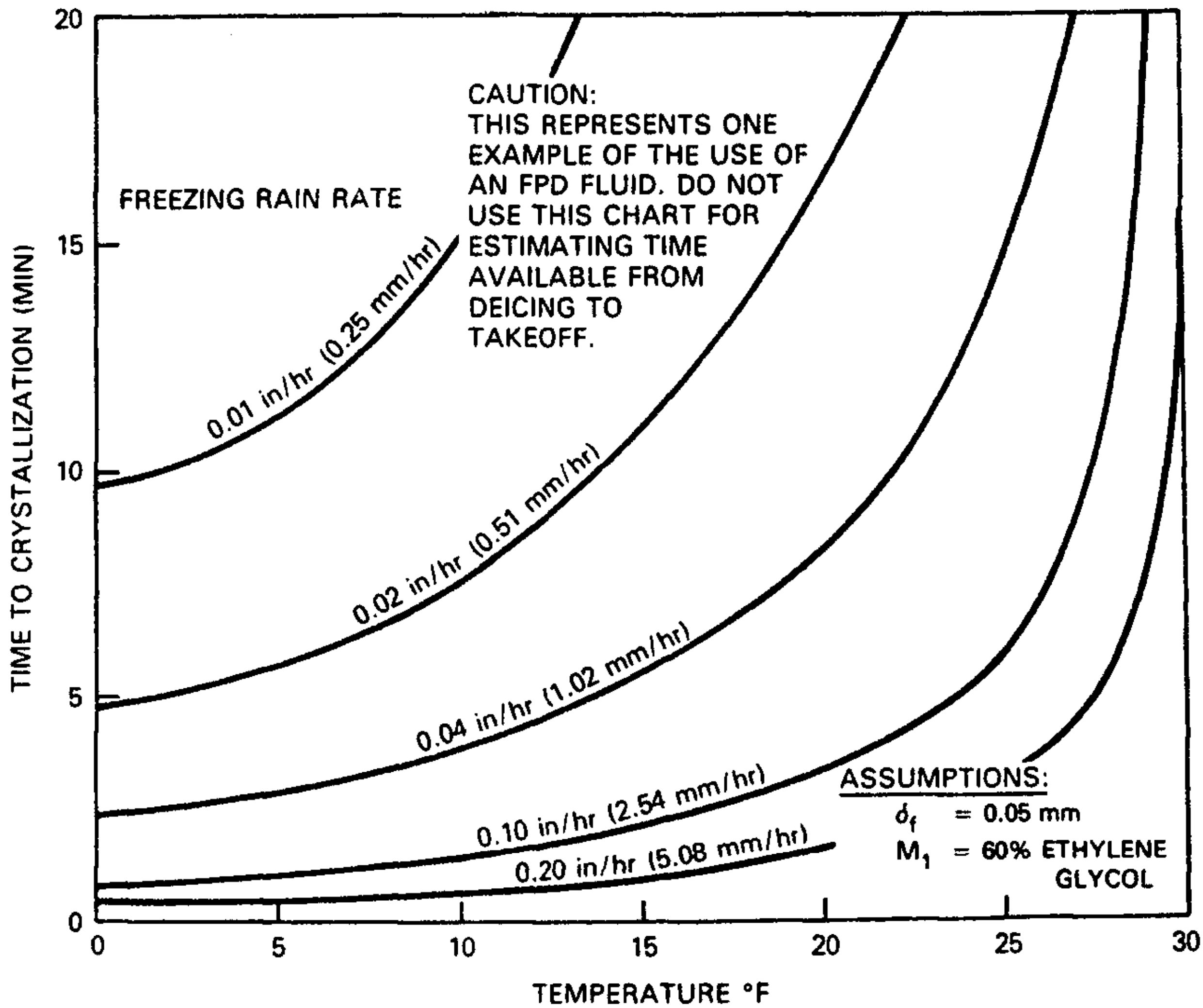

FIGURE 3-5

(ii) It is emphasized that aircraft ice protection systems are designed basically to cope with the supercooled cloud environment (not freezing rain). Supercooled cloud water droplets have a median volumetric diameter (MVD) of 5 to 50 microns. Freezing rain MVD is as great as 1300 microns. Large droplets of freezing rain impact much larger areas of aircraft components and will, in time, exceed the capability of most ice protection equipment. Flight in freezing rain should be avoided where practical.

7. VARIABLES INFLUENCING THE EFFECTIVENESS OF AIRCRAFT GROUND DEICING FLUIDS. Many variables can influence the effectiveness of FPD fluids for deicing and the life of these fluids, especially under conditions where moisture is being added to the fluid. This section is intended to provide a basic understanding of these variables and their influences. Each of these variables is discussed in the following subparagraphs.

a. Chemical Composition of FPD Fluids. FPD fluids intended for use in deicing or anti-icing aircraft are manufactured and distributed by a wide variety of companies either to manufacturer or customer specifications. Each may contain a combination of chemicals that have various freeze characteristics. Although each FPD fluid is manufactured within tolerances contained in the specification, batches may differ and may have significant variations in characteristics.

b. Freezing Characteristics of FPD Fluids. These characteristics were discussed in detail in a previous paragraph of this appendix. It is emphasized here that before a fluid is used on an aircraft, the freeze characteristics should be known by the user. A method of determining this is by thorough understanding of fluid procurement specifications and tolerances and quality control inspections or sampling by either the manufacturer or the user. In addition, FPD fluids are either premixed (diluted with water) by the manufacturer or mixed by the user from bulk supplies. To assure known freezing characteristics, samples of the final mixture should be analyzed.

c. FPD Fluid Strength When Applied.

(i) Fluid strength or the ratio of FPD ingredients, such as ethylene glycol to water, may be known if proper precautions are taken prior to application such as those outlined above. It is important, however, to realize that fluid strength is a very significant factor in deicing properties as well as the time that the FPD fluid may remain effective (anti-icing).

(ii) Figure 3-6 presents estimates of ethylene glycol life as a function of ambient temperature for several commonly used fluid strengths. It can be seen that as fluid strength is increased, the time of effectiveness increases dramatically. This figure is presented for reference purposes only to illustrate the variation of FPD fluid life and should not be used for flight planning purposes. It is also emphasized that pure (100 percent) ethylene glycol fluids should not be used in nonprecipitation conditions, since the freeze point is much higher than fluids diluted with water, as illustrated in figure 3-1. Common practice of the aviation community is never to exceed the eutectic point when using ethylene glycol base fluids.

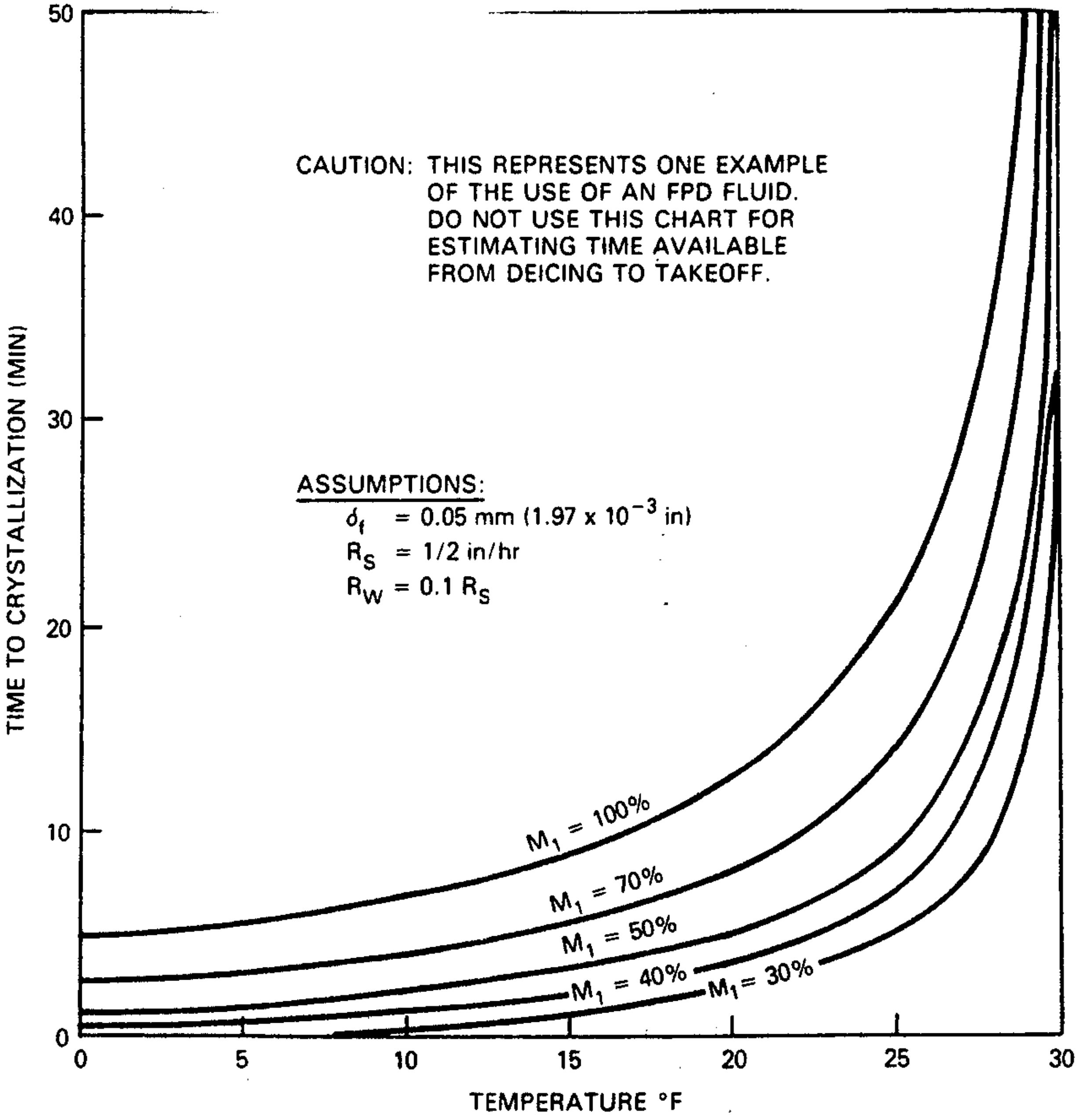

FIGURE 3-6

d. Residual Moisture on the Surface. If a known (quantified strength) FPD fluid is added to a clean dry surface, the residual strength can generally be relied upon to remain at that strength if precipitation is not in process. However, if residual moisture (from any source; e.g., dew, melted ice, precipitation, etc.) is present on the surface, that moisture can be expected to further dilute the FPD fluid being used. This will change the freeze characteristics and influence effectiveness time of the final film of FPD fluid.

e. Fluid Film Thickness. After FPD fluid has been added to an aircraft surface, a thin film of FPD fluid will remain on the surface. This fluid film thickness has been found to vary from 0.002 mm to about 0.100 mm and is influenced by many parameters, but primarily surface and fluid temperature, fluid viscosity, surface contour, surface inclination angle, and surface tension. Film thickness (on a finite area of the surface) influences the effectiveness of the fluid. The effectiveness of the FPD fluid will be different on various parts of the aircraft. Figure 3-7 presents an empirically derived relationship for estimating fluid film thickness as a function of several of these variables. It is emphasized that FPD fluid film thickness can vary significantly in the vicinity of surface discontinuities such as seams, cowling, inspection plates, rivets and screws, etc.

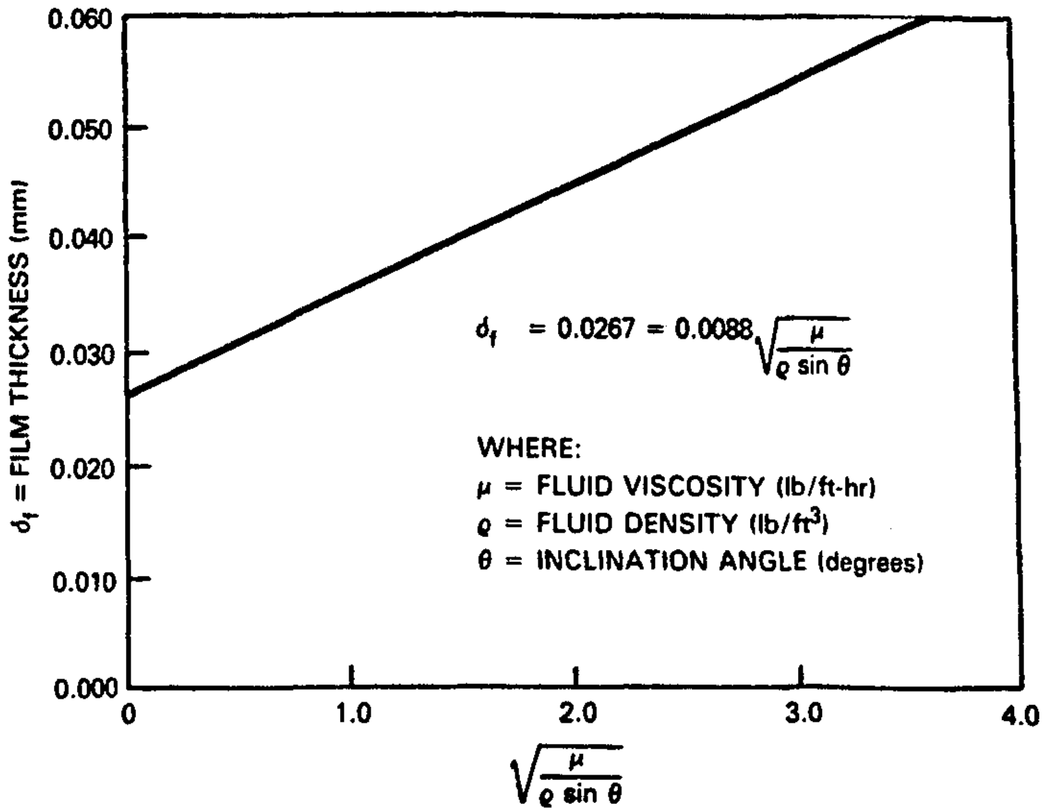

FIGURE 3-7

f. FPD Fluid Application Techniques. Generally, FPD fluids, given time, will seek an equilibrium film thickness regardless of the method of application if the fluid is applied in a uniform manner using sufficient quantities of fluid. All FPD fluids in common use contain wetting agents to aid in this process. If sufficient fluid is not added to the surface, desired film thickness may not be achieved. If the FPD fluid is not uniformly applied, localized areas may be left with less than desired film thickness. In conditions of precipitation, if the rate of FPD application is slow, areas treated first with FPD fluid can have totally different characteristics than areas treated last. In cases where hot water alone is being used for deicing, areas previously oversprayed with FPD fluids can be diluted by water splashed or flowing from other areas being deiced. All of these factors are variables that can influence the effectiveness.

g. Ambient Temperature. A specific mixture of FPD fluid will freeze (begin to crystallize) at a specific ambient temperature. For that specific mixture, the freeze point is accurate and repeatable. Some cockpit installed outside air temperature gages are known to have inaccuracies as great as ±5°C. In addition, the ambient temperature at the ramp, gate, tiedown area, taxiway or runway, may vary significantly from the temperature in the airport tower or from the thermometer on the line shack wall. Ambient temperature may be steady, rising, or falling. Each of these variables, usually unknown to the pilot, can either independently or in combination influence the time of effectiveness of FPD fluids.

h. Aircraft Surface Temperature.

(1) Aircraft surface (skin) temperature also influences FPD fluid effectiveness time. Surface temperatures can be drastically different from ambient temperatures for many reasons: solar radiation (cloudy day, sunny day, parked in the shade, etc.); temperatures of fuel in fuel cells; the type and location of fuel cells; fuel cold soaked during previous high altitude flight; quantity of fuel in fuel cells; the source of fuel (above or below ground storage); time since refueling; engine operation; APU operation; operation of subsystems or components that generate heat; thickness of the skin, type of skins, and skin materials. These are only a few of the many variables that can influence aircraft surface temperature.

(2) Common practice accepted in the aviation community is that if it can be determined that a small quantity of dry snow is not adhering to aircraft surfaces, it will blow off during the takeoff roll and thereby not affect aircraft flight characteristics. This practice is well proven if one can ascertain that the snow is not adhering to critical surfaces. Dry snow at cold ambient temperatures will not adhere to dry aircraft surfaces if surface temperatures are also very cold and will remain cold during start, taxi, and takeoff. However, operation of engines, or other equipment, refueling, solar radiation and many other factors may warm surface temperatures, causing melting or partial melting of snow and possibly cause freezing prior to takeoff or during the takeoff roll. Simply checking the consistency of snow during pre-flight inspection is not considered adequate. Pretakeoff inspections should also be performed. In addition, during preflight inspection and pretakeoff inspection, caution should be exercised when making this judgment to not rely upon spot checking, especially on areas of hollow structures, such as ailerons, spoilers, etc., since these devices are not normally exposed to certain heat sources. Under certain conditions dry snow could adequately blow off of a dry cold spoiler but not from large fuel tankage areas.

i. Solar Radiation. Solar radiation can significantly influence aircraft surface and FPD fluid temperatures. In conditions of heavy precipitation, solar radiation is usually slight. Generally, solar radiation will warm aircraft surfaces, but, in shadow areas, surface and FPD fluid temperatures will be colder.

j. Wind. Ambient wind blowing over an aircaft surface tends to remove heat from the surface at a more rapid rate than under calm conditions. Evaporation of liquids can cause surface temperatures to actually be lower than ambient. The rate of reduction of surface temperatures and the temperature depression is a function of many variables that make it impractical to estimate, but this factor can influence FPD fluid effectiveness.

k. FPD Fluid Temperature. Elevated FPD fluid temperatures (hot fluid) are commonly used during the aircraft ground deicing process to assist in melting and reducing bond strength of ice formations. Fluid viscosity, however, is reduced with increases of fluid temperature. This can reduce the residual surface film thickness that is an essential parameter in FPD fluid effectiveness. Also, if hot fluids are applied during precipitation conditions (snow or other ice crystal), during the time that elevated fluid temperatures remain, the heat provides a source of latent heat of fusion to melt impacting snow/ice crystals and to mix with and dilute the mixture. This process is favorable in that formation of water crystals in the upper surfaces of the fluid film will be delayed. However, in the presence of wind and other factors, the additional time, if any, cannot be estimated. If hot FPD fluids are not utilized, ice crystals (precipitation) impacting the fluid will melt and mix at a slower rate and the latent heat of fusion demand will depress the surface film temperature. Use of hot or cold FPD fluids is considered acceptable common practice, however, unheated fluids will leave greater amounts of residual film prolonging effectiveness while heated fluids are more effective in the deicing process.

l. Precipitation Rate and Type. Subfreezing precipitation occurs in many forms: supercooled rain (freezing rain or drizzle), snow, sleet, and combinations thereof. Each of these conditions can produce an infinite variety of conditions and resulting characteristics on the surface of an aircraft. Snow has been categorized into 22 varieties, each having different crystalline structure and each containing various amounts of frozen water (density). Each type of precipitation contains droplets or ice crystals having various temperatures which may be equal to or below ambient temperature. These combined effects introduce another set of variables that cannot be quantitatively assessed to determine their influence upon effectiveness of FPD fluids. However, under these conditions surface roughness can vary significantly and in conjunction with other variables, time-to-initiation of freezing (surface roughness) can vary.

m. Operation on Snow, Slush, or Wet Surfaces. Such operations can cause ice, snow or slush to be splashed or blown onto various aircraft surfaces. Jet engine exhaust (in forward or reverse thrust), jet engine inlet vortices, prop or rotor wash, and taxi and takeoff operations can, through recirculation, blowing, or splashing, cause snow, ice particles or water to impact various aircraft surfaces and freeze or adhere to these surfaces or further dilute FPD deicing fluids. These occurrences are somewhat predictable and should be expected during ground operations. The effect of these occurrences is unpredictable. If ice formations are anticipated, the clean aircraft concept must be implemented. These occurrences can also have an influence upon FPD fluid effectiveness.

U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: HAZARDS FOLLOWING GROUND DEICING AND GROUND OPERATIONS IN CONDITIONS CONDUCIVE TO AIRCRAFT ICING

Date: 4/15/83
Initiated by: AWS-100

AC No: 20-117
Change: 1

PURPOSE. This change corrects an error in Figure 3-2, Appendix 3, page 12 of Advisory Circular 20-117. The values of "TIME TO CRYSTALLIZATION (MIN)" should read "10," "20," "30," and "40" rather than "1," "2," "3," and "4."

PAGE CONTROL CHART

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Page 12	12/17/82	Page 12	4/15/83

M. C. BEARD
Director of Airworthiness

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Advisory Circular

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ambient and surface temperature is 20°F the fluid film thickness on a surface sloped at an angle of 15° is at best (the most) 0.10 mm deep. From the freeze chart (figure 3-1) it can be seen that at 20°F a mixture of 16 percent ethylene glycol and 84 percent water will begin to crystalize.

(2) Snow Conditions.

(i) Precipitation rates in snow conditions have been found to contain water in amounts up to 0.7 in/hr. A general rule of thumb, commonly used by meteorologists, is that the depth of snow is about 10 times the depth of melted snow. This rule of thumb, although useful for some purposes, could be misleading, since snow densities vary widely. Very dry snow can have a density of 30:1 (30 inches of snow contains 1 inch of water) and very wet snow can have a density of 5:1. In snow conditions, the primary influence upon FPD life is the rate of addition of water and subsequent dilution of the FPD fluid. If snow is falling at a rate of 1/2 inch per hour and if the water content of this snow is 0.1, then the rate of addition of water to the FPD will be 0.05 in/hr.

(ii) If we assume that as the falling snow contacts the surface film it melts and the resulting water mixes thoroughly with the fluid contained in the film, the strength (glycol to water ratio) of 16 percent will be reached in a specific time. This time can be calculated using rationale and equations given in appendix 2.

(iii) From this assessment we can see that at a snowfall rate of 1/2 inch per hour onto a wing having been coated with a very rich mixture, 100 percent ethylene glycol, at an ambient temperature of 20°F, crystallization may begin in approximately 25 minutes. Figure 3-2 presents the estimated life of deicing fluids as a function of ambient temperature for several snowfall rates. Extreme caution is emphasized that these estimates should not be used to attempt to estimate the time available from deicing or anti-icing to takeoff, as noted clearly on the chart. The reason for this caution is that these estimated times are influenced by many variables, and figure 3-2 takes into account only a few. These variables are emphasized and their effects discussed in paragraph 7 of this appendix.

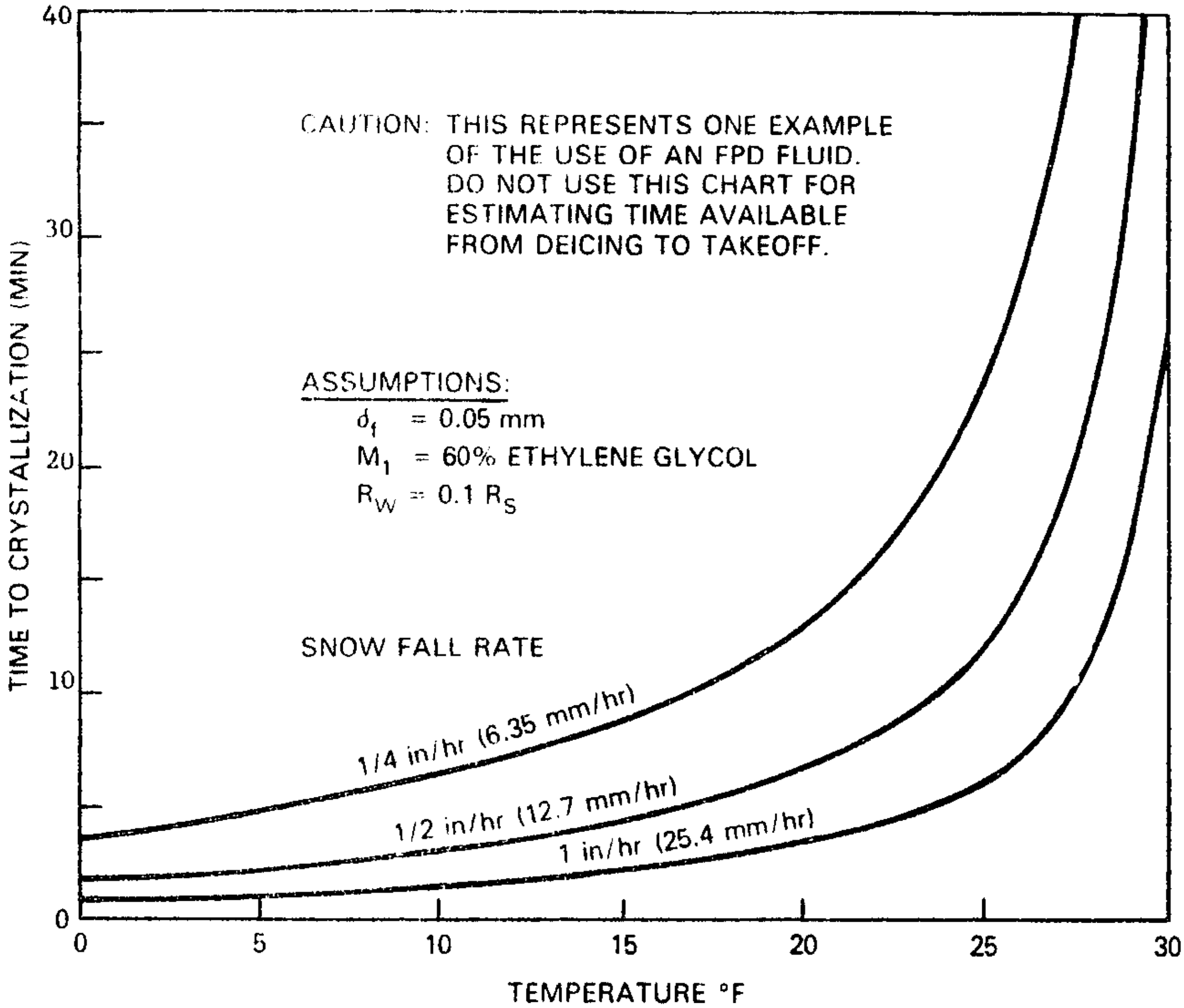

FIGURE 3-2

(iv) It is emphasized that the above rationalization regarding the finite life of FPD fluids is simplified for understanding purposes. Other physical processes occur within an FPD fluid film in the dynamic condition of precipitation or addition of moisture by any means. It is imperative that this process be understood by all associated with winter operations of aircraft.

(v) To assist the understanding of this process, figure 3-3 depicts a surface containing a film of FPD fluid.