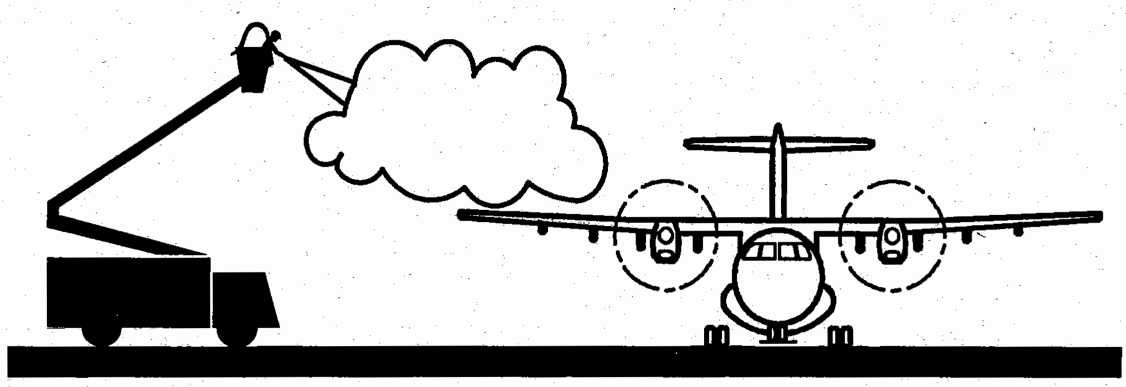
TP 13129E

Examination of the Role of Fluid Freeze Point Buffers



Prepared for

Transportation Development Centre

on behalf of

Civil Aviation

Safety and Security
Transport Canada

by

APS AVIATION INC.

November 1997

Final - Version 3.0

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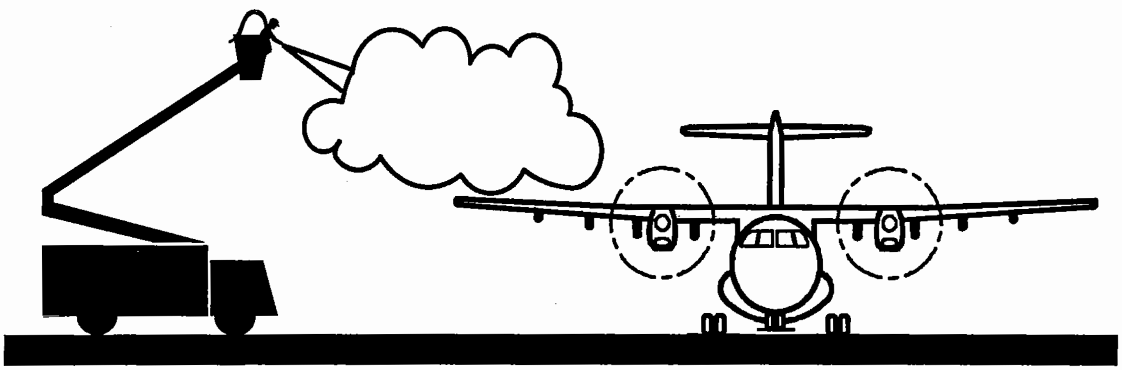

by

Peter Dawson, and
John D'Avirro

APS AVIATION INC.

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Final - Version 3.0

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DOCUMENT ORIGIN AND APPROVAL RECORD

Prepared by:	Peter Dawson, P. Eng. Consultant	Sept 11, 1998 Date
and by:	John D'Aviro Program Manager	Sept 11 98 Date
Reviewed by:	Gilles Bourret, Eng. Director of Programs	Sept 14, 1998 Date
Approved by:	R.V. Potter, Ph.D. Vice-President Programs & QA	Sept 14, 1998. Date

ACKNOWLEDGMENTS

Special thanks are extended to Barry Myers of the Transportation Development Centre for his participation, contribution and guidance provided in the preparation of this document.

Un sommaire français se trouve avant la table des matières.

PREFACE

At the request of the Transportation Development Centre of Transport Canada, APS Aviation Inc. has undertaken a research program to further advance aircraft ground deicing/anti-icing technology. Specific objectives of the APS test program were:

- To complete the substantiation of holdover time tables and evaluate those parameters that may reduce holdover times for currently available and properly qualified SAE deicing and anti-icing fluids (Type I, Type II, Type III and Type IV);

- To collect weather data on winter storms at airports and to assess the precipitation, wind and temperature values that bound the holdover time ranges given in the tables;

- To develop a procedure for the evaluation of fluid dry-out characteristics and to determine the dry-out characteristics of fluids;

- To determine the influence of fluid type, precipitation and wind on location and time to fluid failure initiation, and also failure progression on service aircraft; and

- To review, from an operations standpoint, those factors that contribute to the need for a freeze point buffer and make recommendations for possible revisions.

The research activities of the program conducted on behalf of Transport Canada during the 1996/97 winter season are documented in three separate reports. The titles of these reports are as follows:

- TP 13131E Aircraft Ground De/Anti-icing Fluid Holdover Time Field Testing Program for the 1996/97 Winter;
- TP 13130E Aircraft Full-Scale Test Program for the 1996/97 Winter; and
- TP 13129E Examination of the Role of Fluid Freeze Point Buffers.

This report, TP 13129E addresses the objective to:

- Review, from an operations standpoint, those factors that contribute to the need for a freeze point buffer and make recommendations for possible revisions.

  This objective was met by documenting those factors which contribute to the need for a freeze point buffer and examining their relative values.

Research has been funded by the Civil Aviation Group, Transport Canada, with support from the Federal Aviation Administration. This program of research could not have been accomplished without the participation of many organizations. APS would therefore like to thank the Transportation Development Centre, the Federal Aviation Administration, the National Research Council of Canada, Atmospheric Environment Services, Transport Canada, and the fluid manufacturers for their contributions to, and assistance with the project. Special thanks are extended to Air Canada, AeroMag 2000, American Airlines, Canadian Airlines International, CanAir Cargo, the Department of National Defence, and Inter-Canadien for provision of personnel and facilities, and for their cooperation on the test program. APS would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data leading to the preparation of this document.

Transport Canada / Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No. TP 13129E	2. Project No. 9131 (DC150)	3. Recipient's Catalogue No.
4. Title and Subtitle Examination of the Role of Fluid Freeze Point Buffers		5. Publication Date November 1997
		6. Performing Organization Document No. CM1338.001
7. Author(s) Peter Dawson and John D'Avirro		8. Transport Canada File No. ZCD1455-14
9. Performing Organization Name and Address APS Aviation Inc. 1100 René Lévesque Blvd. West, Suite 1340 Montreal, Quebec H3B 4N4		10. PWGSC File No. XSD-6-01882
		11. PWGSC or Transport Canada Contract No. T8200-6-6553/001-XSD
12. Sponsoring Agency Name and Address Transportation Development Centre (TDC) 800 René Lévesque Blvd. West 6th Floor Montreal, Quebec H3B 1X9		13. Type of Publication and Period Covered Final
		14. Project Officer Barry B. Myers

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

Research reports produced on behalf of Transport Canada for testing during previous winters are available from the Transportation Development Centre. Three reports (including this report) were produced as part of this winter's research program. The subject matter of these reports is provided in the preface.

16. Abstract

SAE Aerospace Recommended Practice ARP4737 provides guidelines for the application of aircraft deicing and anti-icing fluids which include defined temperature limits (fluid freeze point buffers) for each type of fluid.

The freeze point buffers have been established without a clear understanding of the nature and extent of the contributing components and may be excessively conservative, preventing more efficient procedures from being introduced.

The review identified that the buffer addresses two separate factors:

- the capacity of an anti-icing fluid to absorb precipitation over a period of time in cold temperatures without itself freezing; and
- variations in conditions may occur that can place additional demands on the fluid during actual operations performance, risking that the fluid itself may freeze and become a source of contamination or that the holdover time value may be significantly reduced.

The review examined variations in:

- Wind;
- Rate of precipitation;
- Outside air temperature;
- Aircraft skin temperature versus outside air temperature;
- Fluid concentration;
- Spray technique; and
- Fluid temperature.

Temperature buffer values for different operating conditions were recommended.

17. Key Words Glycol, deicing, freeze point buffers	18. Distribution Statement Limited number of copies available from the Transportation Development Centre

19. Security Classification (of this publication)	20. Security Classification (of this page)	21. Declassification (date)	22. No. of Pages	23. Price
Unclassified	Unclassified	—	xiv, 44, apps	—

CDT/TDC 79-005
Rev. 96

Canada

Transports Canada Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada TP 13129E	2. N° de l'étude 9131 (DC150)	3. N° de catalogue du destinataire
4. Titre et sous-titre Examination of the Role of Fluid Freeze Point Buffers		5. Date de la publication Novembre 1997
		6. N° de document de l'organisme exécutant CM1338.001
7. Auteur(s) Peter Dawson et John D'Avirro		8. N° de dossier - Transports Canada ZCD1455-14
9. Nom et adresse de l'organisme exécutant APS Aviation Inc. 1100, boul. René-Lévesque Ouest, Bureau 1340 Montréal (Québec) H3B 4N4		10. N° de dossier - TPSGC XSD-6-01882
		11. N° de contrat - TPSGC ou Transports Canada T8200-6-6553/001-XSD
12. Nom et adresse de l'organisme parrain Centre de développement des transports (CDT) 800, boul. René-Lévesque Ouest 6e étage Montréal (Québec) H3B 1X9		13. Genre de publication et période visée Final
		14. Agent de projet Barry B. Myers

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

Les rapports sur les essais réalisés pour le compte de Transports Canada au cours des hivers passés peuvent être obtenus auprès du Centre de développement des transports. Le programme de recherche de l'hiver 1997-1998 a donné lieu à trois rapports (dont celui-ci). Le contenu de ces rapports est donné dans la préface.

16. Résumé

La pratique aérospatiale recommandée n° 4737 de la SAE, qui énonce des lignes directrices concernant la mise en oeuvre des fluides dégivrants/antigivrage, établit des seuils de température (avec marges de sécurité) applicables à l'utilisation de chaque type de fluide, selon le point de congélation des fluides.

Comme ces valeurs ont été établies sans étude préalable approfondie de la nature et de l'importance des variables en jeu, il se peut que, par trop prudentes, elles empêchent la mise en place de procédures plus efficientes.

Les chercheurs ont constaté que la marge de sécurité joue sur deux plans distincts :

- elle permet au fluide antigivrage d'absorber des précipitations pendant une période donnée, par temps froid, sans geler lui-même;
- elle permet de parer aux fluctuations possibles des conditions d'exploitation pouvant exiger du fluide un niveau de performance en service plus élevé que prévu, dans des circonstances où il risquerait de lui-même geler et devenir une source de contamination, et où sa durée d'efficacité pourrait être sensiblement réduite.

Les chercheurs ont étudié la fluctuation des variables suivantes :

- Vent
- Taux de précipitation
- Température extérieure
- Température du revêtement de l'avion par rapport à la température extérieure
- Concentration du fluide
- Technique d'application du fluide
- Température du fluide

Des marges de sécurité correspondant à différentes conditions d'exploitation ont été recommandées.

17. Mots clés Glycol, dégivrage, marges de sécurité	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

19. Classification de sécurité (de cette publication)	20. Classification de sécurité (de cette page)	21. Déclassification (date)	22. Nombre de pages	23. Prix
Non classifiée	Non classifiée	—	xiv, 44, ann.	—

CDT/TDC 79-005
Rev. 96

Canada

EXECUTIVE SUMMARY

At the request of the Transportation Development Centre of Transport Canada, APS Aviation Inc. undertook a study to review, from an operations standpoint, those factors that contribute to the need for a freeze point buffer, and to make recommendations for possible revisions.

SAE Aerospace Recommended Practice ARP4737 provides guidelines for the application of aircraft deicing and anti-icing fluids. This recommended practice presents fluid holdover time tables for different types of fluids; these include defined temperature limits that must be respected for each type of fluid, as follows:

- SAE Type I fluids: when used either as the single fluid in a one-step operation, or the second fluid in a two-step operation, the freeze point of the fluid mixture must be at least 10°C (18°F) below the ambient temperature; and

- SAE Type II, Type III and Type IV fluids: may have a lower limit of -25°C (-13°F). The application limit may be lower provided that the freeze point of the concentrated fluid is at least 7°C (13°F) below the ambient temperature. (Lowest operational use temperature limits as defined by aerodynamic acceptance tests must also be respected.)

The temperature difference between the fluid's freezing point and the defined lower temperature limit for the fluid's use is referred to as the freeze point temperature buffer.

The freeze point buffers have been established somewhat arbitrarily without a clear understanding of the nature and extent of the components that together contribute to the need for a temperature buffer, and in actual operations may be excessively conservative, preventing more efficient procedures from being introduced.

The review identified that the freeze point buffer addresses two separate factors:

- When used as anti-icing agents, the fluid must provide the capacity to absorb precipitation over a period of time in cold temperatures without itself freezing. Thus the initial freeze point of an anti-icing fluid must be somewhat lower than the outside air temperature; and

- Variations in conditions may occur during actual operations. These variations exert additional demands on the performance of any given fluid. The issues examined here are:

  i) Is there a risk that the fluid itself may freeze and become a source of contamination when applied to the aircraft surface; and

ii) Is there a risk that the holdover time value as provided in the table may be significantly reduced.

iii) Variations or anomalies in any of the following conditions during the deicing operation or during the subsequent aircraft taxi and hold phase, prior to commencing take-off run, can affect fluid performance:

- Wind;
- Rate of precipitation;
- Outside air temperature;
- Aircraft skin temperature versus outside air temperature;
- Fluid concentration:
  - inaccuracies in local mixing procedure, and
  - faulty identification of different fluid mixes;
- Spray technique; and
- Fluid temperature:
  - heat transfer from heated deicing fluid to aircraft skin,
  - effect of evaporation on fluid concentration, and
  - reduced thickness for heated Type IV fluid (due to deicing truck design).

The review provides estimates of the freeze point temperature buffer contribution for some sources of variation in procedures or operating conditions, but concludes that other sources of variation cannot reasonably be protected against through the use of temperature buffers.

The review recommends that temperature buffers be established for different operating conditions as follows:

- Fluids applied before the start of precipitation, to prevent bonding of frozen precipitation to the aircraft surface, 0°C;

- Fluids used to deice aircraft surfaces following termination of precipitation, and for frost removal, 4°C;

- Type I fluids used to protect against frost formation or applied as anti-icing fluids during ongoing precipitation, 10°C; and

- Type II, Type III and Type IV fluids used to protect surfaces against frost formation, 7°C. The 7°C buffer is marginal for use during ongoing precipitation; an increase to 10°C should be considered.

It is further recommended that conditions of deicing following end of precipitation be studied to refine the estimate of buffer requirement.

SOMMAIRE

À la demande du Centre de développement des transports de Transports Canada, APS Aviation Inc. a entrepris une étude visant à revoir, dans une perspective opérationnelle, les facteurs à la base de l'établissement des marges de sécurité, et à formuler des recommandations en vue de révisions possibles.

La pratique aérospatiale recommandée n° 4737 de la SAE énonce des lignes directrices pour l'application des fluides dégivrants/antigivrage. Cette norme présente des tables de durée d'efficacité pour différents types de fluides, lesquelles comportent des seuils de température à respecter pour l'utilisation de chaque type de fluide, soit :

- fluides de type I, selon la SAE : dans le cas où ils constituent le seul fluide appliqué dans une procédure à une seule étape, ou le deuxième fluide d'une procédure comportant deux applications successives, le point de congélation du fluide doit être d'au moins 10 degrés Celsius (18 degrés Farhenheit) inférieur à la température ambiante;

- fluides de type II, de type III et de type IV, selon la SAE : la limite inférieure de température d'utilisation de ces fluides atteint -25°C (-13°F). Cette limite peut être encore plus basse, à condition que le point de congélation du fluide concentré soit d'au moins 7 degrés Celsius (13 degrés Farhenheit) inférieur à la température ambiante. (Les limites inférieures de température définies au terme d'essais aérodynamiques d'acceptation doivent également être respectées.)

L'écart prescrit entre le point de congélation du fluide et la limite inférieure de température correspond à une marge de sécurité.

Ces marges de sécurité ayant été établies de façon quelque peu arbitraire, sans étude préalable approfondie de la nature et de l'importance des variables en jeu, il se peut que, par trop prudentes, elles empêchent la mise en place de procédures plus efficientes.

Les chercheurs ont constaté que la marge de sécurité prémunit contre deux éventualités distinctes :

- Lorsqu'il est utilisé comme agent antigivrage, le fluide doit pouvoir absorber les précipitations pendant une période donnée, par temps froid, sans geler lui-même. La température à laquelle un fluide antigivrage commence à geler (son point de congélation) doit donc être inférieure à la température extérieure.

- La fluctuation possible des conditions d'exploitation peut exiger de tout fluide, quel qu'il soit, un niveau de performance en service plus élevé que prévu. Le cas échéant, les questions suivantes se posent:

  i) Le fluide risque-t-il de geler et devenir une source de contamination, une fois appliqué sur la surface de l'aéronef?

  ii) La durée d'efficacité nominale inscrite dans les tables de durée d'efficacité risque-t-elle d'être sensiblement réduite?

  iii) La fluctuation de l'une ou l'autre des variables ci-après, pouvant parfois entraîner des conditions extrêmes pendant le dégivrage ou les phases subséquentes de circulation et d'attente au sol avant le décollage, peut altérer la performance du fluide :

    - Vent
    - Taux de précipitation
    - Température extérieure
    - Température du revêtement de l'aéronef par rapport à la température extérieure
    - Concentration du fluide :
      - taux de dilution non respecté
      - erreur d'identification des différents types de fluides
    - Technique d'application
    - Température du fluide :
      - transfert de chaleur du fluide de dégivrage chauffé au revêtement de l'aéronef
      - effet de l'évaporation sur la concentration du fluide
      - épaisseur réduite des fluides de type IV chauffés (selon le type de camion de dégivrage utilisé).

L'étude donne une estimation de la protection offerte par les marges de sécurité contre l'effet de certaines variations dans les procédures ou conditions d'exploitation. Elle conclut toutefois qu'il existe d'autres facteurs de variation auxquels ne peuvent raisonnablement parer les marges de sécurité.

Les chercheurs recommandent des marges de sécurité à respecter pour les conditions d'exploitation suivantes :

- Fluides appliqués avant la précipitation, pour empêcher les précipitations gelées d'adhérer à la surface de l'aéronef : 0 degré.

- Fluides utilisés pour dégivrer les surfaces d'un aéronef après la précipitation, et pour enlever le givre : 4 degrés Celsius.

- Fluides de type I utilisés pour prévenir la formation de givre ou appliqués comme agents antigivrage pendant la précipitation : 10 degrés Celsius.

- Fluides de type II, de type III et de type IV utilisés pour protéger les surfaces contre la formation de givre : 7 degrés Celsius. Cette marge de 7 degrés est tout juste suffisante pendant la précipitation; il devrait être envisagé de porter cette marge à 10 degrés Celsius.

Il est en outre recommandé de se pencher sur les conditions de dégivrage une fois que la précipitation a cessé, afin de produire une estimation plus juste de la marge nécessaire.

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1. INTRODUCTION

Society of Automotive Engineers (SAE) Aerospace Recommended Practice ARP4737 (Appendix B) provides guidelines for the application of aircraft deicing and anti-icing fluids. This documentation discusses the concept of fluid holdover time, and defines it as the estimated time that a fluid, applied to provide anti-icing protection, will prevent frost or ice formation and/or snow or slush accumulation on fluid-treated surfaces of an aircraft.

ARP guidelines for holdover times for different types of fluids (SAE Type I, II, III and IV) include definitions of temperature limits that must be respected for each type of fluid, as follows:

- SAE Type I fluids: when used either as the single fluid in a One-Step operation, or as the second fluid in a Two-Step operation, the freeze point of the fluid mixture must be at least 10°C (18°F) below the ambient temperature; and

- SAE Type II, Type III and Type IV fluids: may have a lower limit of -25°C (-13°F). The application limit may be lower provided that the freeze point of the concentrated fluid is at least 7°C (13°F) below the ambient temperature. (Lowest operational use temperature limits as defined by aerodynamic acceptance tests must also be respected.)

The temperature difference between an anti-icing fluid's freezing point and the defined lower temperature limit for fluid application is referred to as the freeze point or temperature buffers.

Freeze point buffers have been established somewhat arbitrarily without a clear understanding of the nature and extent of the components that together contribute to it's requirement. In actual operations the buffers may impose a degree of excessive constraint, preventing more efficient procedures from being introduced. A typical situation would be an overnight snowfall that has terminated prior to morning operations, leaving aircraft with accumulated snow to be removed prior to departure. The requirement for a buffer in this situation when a holdover time is not required may be different than that during active precipitation.

An improved understanding of the components of the temperature buffer would assist in validating the need for, and extent of, buffers as they currently exist.

The purpose of this report is to examine, from an operational perspective, the various factors that contribute to the need for a fluid freeze point buffer.

The detailed objectives of this review are provided in the work statement for the 1996/97 winter season test program included as Appendix A.

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2. POTENTIAL IMPACT OF VARIATIONS IN CONDITIONS

In examining the need for freeze point temperature buffers and evaluating the extent of buffering required, it appears that the buffer addresses two separate needs.

The first is related to variations in conditions that may occur during ground operations, and which can place additional demands on fluid performance, and thereby reduce the time to fluid failure.

The second need discussed in the next section, is related to the use of fluid as an anti-icing agent, and pertains to the capacity of the fluid to absorb precipitation over a period of time in cold temperatures without itself freezing. To satisfy this objective, the initial freeze point of the anti-icing fluid must be somewhat lower than outside air temperature.

2.1 Potential Sources of Variations

Freeze point buffers provide a factor of safety against variations in conditions or other anomalies that may occur during actual operations, and which can place additional demands on fluid performance thereby reducing the time to fluid failure.

Variations or anomalies in any of the following conditions during the deicing operation or during the subsequent aircraft taxi and hold phase prior to commencing take-off run, can impact fluid performance:

- Wind;
- Rate of precipitation;
- Outside air temperature;
- Aircraft skin temperature versus outside air temperature (Cold-soaked from flight or from sitting overnight);
- Fluid Concentration:
  - inaccuracies in local mixing procedure, and
  - faulty identification of different fluid mixes.
- Spray Technique; and
- Fluid Temperature:
  - heat transfer from heated deicing fluid to aircraft skin,
  - effect of evaporation on fluid concentration, and
  - reduced thickness for heated Type IV fluid (due truck design).

In reality, since a degree of variability of some of these parameters would have been experienced while fluid testing was being conducted, the resultant holdover time values would inherently incorporate some degree of buffer. In other words, trials experiencing a variable range of conditions could be expected to provide shortened times to failure, which in turn would influence the accepted values for holdover times. Variations that extend beyond those experienced during testing need to be understood.

2.2 Potential Contributors to the Need for Buffer

As Type I fluid offers the least capacity (shortest holdover times) to provide anti-icing protection, it is considered to be the most severe case (most susceptible to variations in conditions) and is the subject of this analysis.

The fact that Type I fluid lends itself to being mixed locally, and to an unlimited range of concentrations, gives greater importance to the role of the freeze point buffer for Type I fluid application.

Fluids that are used only at a limited number of concentrations (e.g. 100%, 75%, 50%) are less frequently exposed to *worst case* conditions and consequently require less severe freeze point buffers. None the less, at the ultimate temperature limit of the fluid, variations in conditions affect all fluids including Type II, Type III and Type IV.

The issues examined here are:

- Is there a risk that the fluid itself may freeze and become a source of contamination when applied to the aircraft surface; and

- Is there a risk that the holdover time value as provided in the table may be significantly reduced.

2.2.1 Potential Contribution of Variations in Wind

Trials conducted outdoors to determine fluid holdover times will have experienced naturally occurring winds of varying degree during the course of testing. In general, winds experienced during testing ranged up to 30 kph, and holdover time values based on data from those tests would, as a consequence, have some amount of wind effect factored in. Procedures for these trials require that the flat plate test panels are oriented into the wind.

In an actual operation, the typical orientation of the aircraft during deicing is nose into the wind, however the subsequent taxi to the departure runway may subject the wing to winds from various directions. A large part of the taxi phase may be down-wind when travelling on a taxi-way parallel to the departure runway. The aircraft taxi speed may increase or decrease the net wind effect on the wing depending on taxiway layout and wind direction. Additionally, jet blast or prop wash from other operating aircraft may contribute to the net result.

Trials to investigate the performance of hot water as a deicing medium have shown that winds have a substantial and detrimental effect on the rate of heat loss from the wing surface. Figure 2.1 illustrates the effect of wind speed on the time interval that the test surface temperature remains above 0°C after having been heated by application of water at 74°C (165°C).

2.2.1.1 Contribution to freeze point buffer

There is insufficient data at this time to assess the contribution of wind to the freeze point buffer.

2.2.2 Variation in Rate of Precipitation

In the determination of fluid holdover times, results of fluid failure tests are grouped within prescribed ranges of precipitation rates. For the purpose of establishing holdover time table values, an upper limit of precipitation rate has been fixed for each type of precipitation.

Examining the snow case as an example, holdover times have been established based on test data for precipitation rates up to 25 g/dm²/hr. The issue then is:

- What is the likelihood of exceeding a precipitation rate of 25 g/dm²/hr during the minimum recommended holdover time for Type I fluid of 6 minutes; and

- In the event that one occurs, will the Type I 10°C buffer support the existing published holdover time values.

The report on Holdover Times for the 1995/96 winter[4] included an examination of rates of snowfall during snowstorms experienced at Dorval airport in 1993/94 and 1994/95. That study concluded that the probability of exceeding the rate of 25 g/dm²/hr in any six-minute period while snow was falling during the snowstorms analysed was about 10%.

Accepting that there is a reasonable possibility that a heavy snowfall may occur over brief periods, will the temperature buffer support the existing holdover time?

As will be seen in Figure 3.4, the additional freeze point buffer offered by the neat fluid over the diluted fluid delivered limited benefits in extended fluid failure times. During heavy precipitation the Type I fluid at either concentration is rapidly diluted and undergoes a rapid rise in fluid freeze point.

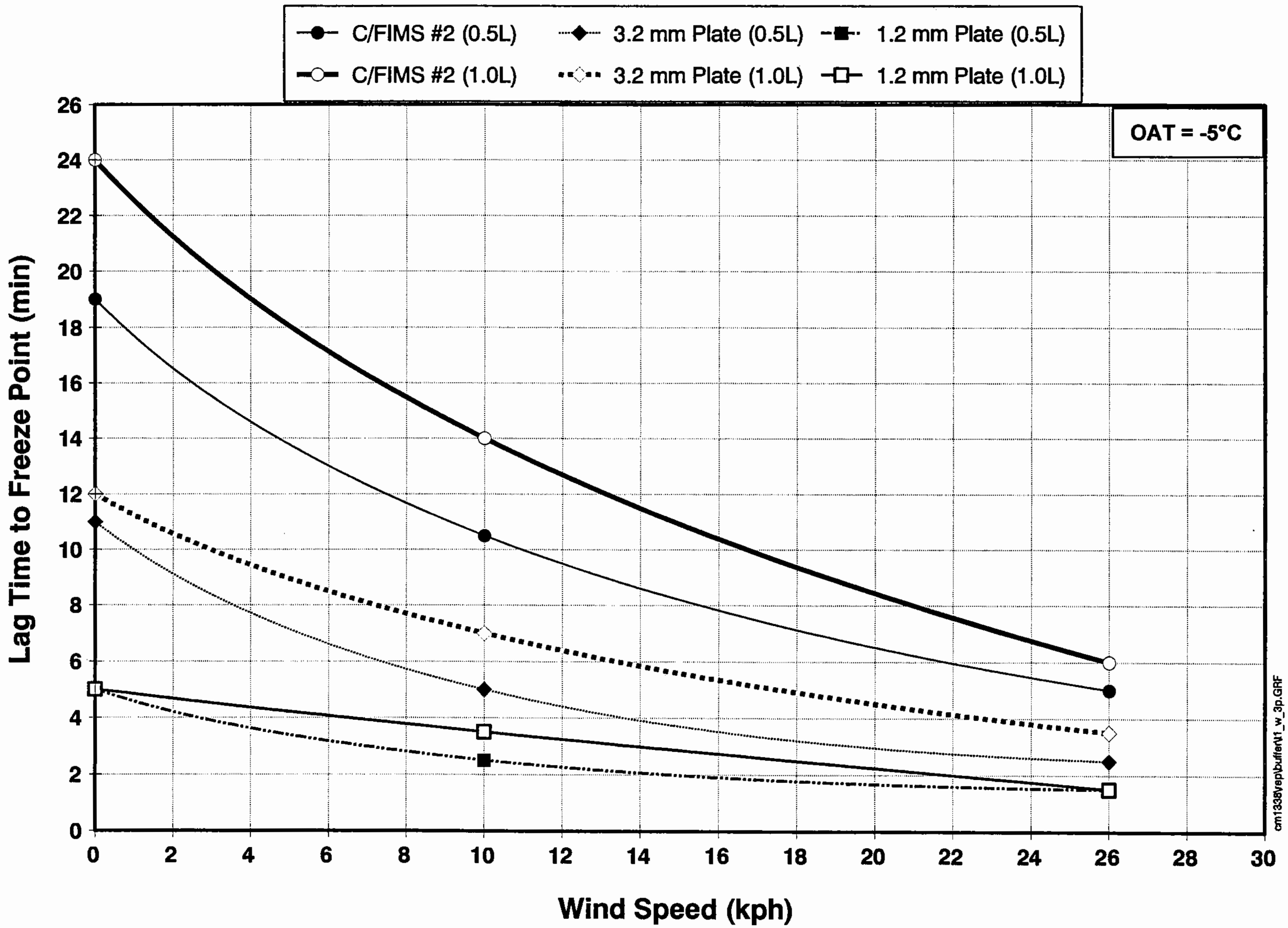
4. D'Avirro, J., *Aircraft Ground De/Anti-icing Fluid Holdover Time Field Testing Program for the 1995-1996 Winter*, APS Aviation Inc., Montreal, December 1996, TP 12896E, 172.

FIGURE 2.1

EFFECT OF WIND SPEED, VOLUME POURED & PLATE THICKNESS ON LAG TIME TO FREEZE POINT

Tests Conducted @ National Research Council Climatic Engineering Facility

APRIL 12, 1995



A theoretical analysis was performed to aid in understanding the influence of different rates of precipitation on fluid freeze point. This analysis calculated the rise in fluid freeze point when subjected to various precipitation rates. A five-minute period was selected as typical of holdover time table values for Type I fluid. Outside air temperature was defined as -5°C. A standard strength fluid was examined as well as a fluid mixed to freeze point -15°C (10°C freeze point buffer). The analysis assumed a film thickness of 0.2 mm (reflecting findings of the fluid thickness study). For each of the rates, the quantity of water falling on a fixed area of the wing during a five-minute period was calculated. This quantity was then added to the initial volume of fluid mix in the same area, and the new concentration and freeze point was calculated neglecting fluid mixture run-off. Results are shown in Table 2.1. Although this analytical model has obvious flaws, it serves to demonstrate the point.

The calculated values for fluid freeze point show that the additional protection offered by the greater freeze point buffer of the full strength fluid diminishes as precipitation rate increases to very heavy rates. This indicates that a small incremental value to freeze point buffer as offered by a more concentrated fluid would offer an insignificant degree of protection against heavy precipitation.

2.2.2.1 Contribution to freeze point buffer

It is unlikely that a small increment of freeze point buffer (such as would be contained within the current freeze point buffer) would offer any appreciable degree of protection against very heavy rates of precipitation. The current advice to pilots and operators that fluids will fail more rapidly in heavy precipitation appears to offer the most realistic protection against fluid failing in less than the published holdover time values. Consequently, the contribution this factor makes to the need for a freeze point buffer is evaluated at zero.

2.2.3 Variations in Outside Air Temperature

The holdover table for Type I fluid has three levels of temperature gradation; above 0°C, 0 to -10°C, and below -10°C. Except for *Freezing Fog*, the holdover time values for each precipitation type are constant for all temperature gradations. Any variation in ambient temperature during an operation, or inaccurate information regarding ambient temperature does not have an influence in estimated value of holdover time.

The risk that the applied fluid may freeze due to temperature variation is a function of: selection of a fluid mix based on the coldest temperature expected during a spray operation, and subsequent failure to recognize that outside air temperatures

TABLE 2.1

FLUID FREEZE POINT INCREASE WITH PRECIPITATION

XL54 (ADF 57/43)

Rate	Concentration After 5 minutes	Freeze Point After 5 minutes
13 g/dm²/hr	62% Water	-23°C
25 g/dm²/hr	71.5% Water	-13°C
75 g/dm²/hr	86.2% Water	-5°C

BUFFER STRENGTH (ADF 30/70) @ -5°C OAT

Rate	Concentration After 5 minutes	Freeze Point After 5 minutes
13 g/dm²/hr	80% Water	-8°C
25 g/dm²/hr	85% Water	-5.5°C
75 g/dm²/hr	92.7% Water	-2°C

Assumptions: - Time = 5 minutes
- Film thickness = 0.2 mm
- OAT = -5°C
- Simplified model used to demonstrate effect of precipitation rate

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have fallen more than expected; errors in temperature forecasts; and, errors in monitoring local temperatures (inaccurate thermometer or reading errors).

A value of 2°C, composed of 1°C for instrument and reading error and 1°C for unrecognized error in forecast would be a reasonable assessment of this risk. More study would be required to refine and confirm this estimate.

2.2.3.1 Contribution to freeze point buffer

An incremental value of 2°C reflects the contribution to freeze point buffer of variation in temperature.

2.2.4 Variation of Aircraft Skin Temperature Relative to Outside Air Temperature

SAE ARP4737 guidelines include a caution that aircraft skin temperatures may differ from outside air temperature. This is generally associated with situations where the aircraft has landed with wing structure and fuel in wing tanks cold-soaked from extended flight in the cold temperatures experienced at altitude. Considerable time may pass before the wing skin temperature warms to outside air temperature.

Wing temperatures experienced in operations were measured and reported in a 1996 report[5]. That study examined wing temperatures at a number of airport locations in North America and Europe, and included a variety of aircraft types. The study found that wing temperatures generally were higher than air temperatures when outside air temperature was below 0°C and lower than outside air temperature when air temperatures were above 0°C. However, cases of cold-soaking do exist at all operational outside air temperature ranges.

The survey report presented wing temperature values in the form of bar charts (see example Figure 2.2). These charts are included in this report and are located in Appendix C. Values for temperature differential between wing skin and outside air, and the calculated standard deviation of survey data are plotted for various ranges of outside air temperature.

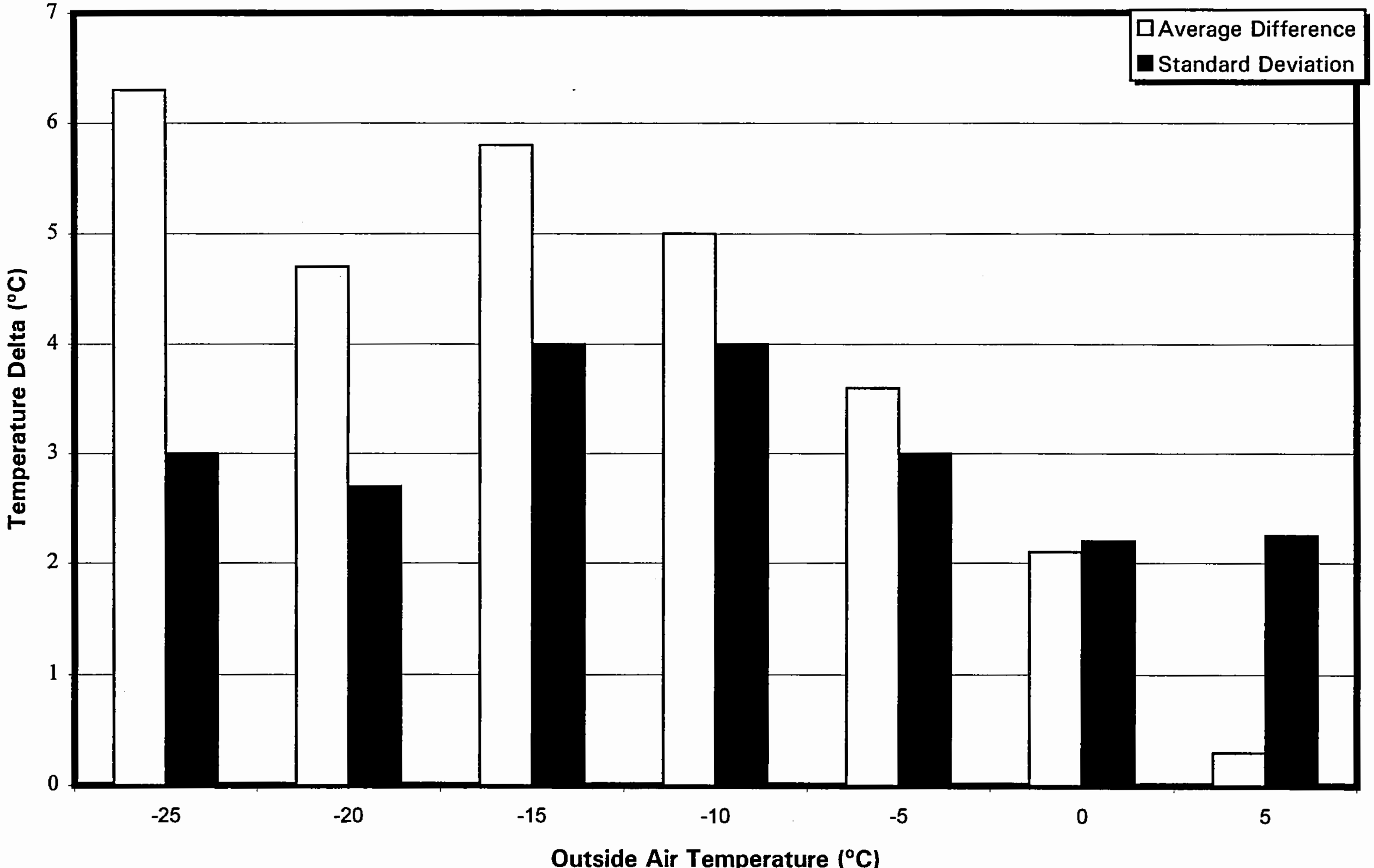
In analysing the data presented in the report, specific charts were selected. For North American surveys, charts were selected which represented the average of all aircraft sampled including results from measurements in Winnipeg (to represent a cold location) and results from tests on the DC-9 aircraft to represent an aircraft with wet wing). For surveys in Europe, charts

5. *Aircraft Ground Operations in Canadian Winter Weather*, Taxi Times, Wing Temperatures and Hot De-icing, Aviation Research Corporation, Montreal, April 1996, TP 12735E, 128.

FIGURE 2.2

WING VERSUS AIR TEMPERATURE DIFFERENTIAL AS FUNCTION OF OUTSIDE AIR TEMPERATURE

(All Aircraft, All Airports)



SOURCE: AVIATION RESEARCH CORPORATION (Reference 6)

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representing the right-hand wing (at arrival), and both the right-hand and left-hand wings (following refuelling) were selected.

An analysis of the temperature data taken from that study is presented in Table 2.2. At the 90th percentile of the samples provided, the maximum drop from outside air temperature to wing temperature is about 4°C at a 98% level of confidence and about 2°C at a 90% level of confidence.

This means that the maximum extent of fluid freeze point buffer needed to protect against a wing being colder than outside air temperature, and unrecognized by the operator, is about four degrees Celsius. This may be an overly conservative estimate as the referenced study measured wing temperature before deicing was performed. In a deicing operation, heated fluid is applied with some amount of heat transferred to the wing, thereby raising wing skin temperature and reducing the required magnitude of the fluid freeze point buffer.

When considering application of a safety factor to guard against this particular risk, it should be noted that a concurrent safety factor for error in outside air temperature is redundant.

2.2.4.1 Contribution of freeze point buffer

An incremental value of 4°C reflects the maximum contribution to freeze point buffer of cold-soaked wings.

2.2.5 Errors in Fluid Concentration

Operators of aircraft deicing installations may need to alter the concentration of deicing fluids. Some fluids may be delivered to the customer in concentrated form and these must be adjusted on site to obtain the desired concentration for the local operation. As well, for economic and environmental reasons, deicing installations may use fluids at different concentrations for different conditions. Fluids may be pre-mixed on site to concentrations suitable for prevailing local conditions and maintained in storage pending occurrence of appropriate temperature and precipitation conditions. Additionally, fluids delivered at standard strength may have errors in concentration.

Fluid manufacturers provide detailed procedures for adjusting fluid concentration, including the advice to always measure the fluid strength (by refractive index) following adjustment to assure that the desired result has been obtained.

TABLE 2.2
WING TEMPERATURE VALUES FROM COLD-SOAKED WING SURVEY

Appx	Outside Air Temperature °C		Wing ΔT (°C) (Average) (See Figures in Appendix C)	Wing T (°C)[1] Average	Standard Deviation	Min. Wing Temp.[2] @ 98% Confidence	Min. Wing T - OAT (Mid PT)
	Range	Mid PT					
C1		5	0.2	5.2	2.2	0.1	-4.9
		0	2.1	2.1	2.2	-3.0	-3.0
		-5	3.5	-1.5	3.0	-8.4	-3.4
		-10	5.0	-5.0	4.0	-14.2	-4.2
		-15	5.8	-9.2	4.0	-18.4	-3.4
C2		5	0	5.0	0	-	-
		0	0.4	0.4	0.8	-1.4	-1.4
		-5	2.1	-2.9	1.6	-6.6	-1.6
		-10	3.4	-6.6	1.8	-10.7	-0.7
		-15	4.0	-11.0	2.1	-15.8	-0.8
C3		5	-1.5	3.5	2.0	-1.1	-6.1
		0	2.9	2.9	1.7	-1.0	-1.0
		-5	4.2	-0.8	2.8	-7.2	-2.2
		-10	4.1	-5.9	2.5	-11.7	-1.7
		-15	4.8	-10.2	2.6	-16.2	-1.2
C4	5, 10	7.5	-3.0	4.5	2.2	-0.6	-8.1
	0, 5	2.5	-0.5	2.0	2.0	-2.6	-5.1
	-5, 0	-2.5	2.5	0.0	3.0	-6.9	-4.4
	-10, -5	-7.5	4.0	-3.5	2.2	-8.6	-1.1
	-15, -10	-12.5	7.0	-5.5	2.8	-11.9	0.6
C5	5, 10	7.5	-3.0	4.5	0.6	3.1	-4.4
	0, 5	2.5	-2.5	0.0	0.5	-1.2	-3.7
	-5, 0	-2.5	2.5	0.0	1.5	-3.5	-1.0
	-10, -5	-7.5	4.0	-3.5	3.0	-10.4	-2.9
	-15, -10	-12.5	3.8	-8.7	2.2	-13.8	-1.3

(1) Wing T (Average) = Outside Air Temperature Range Mid-Point + ΔWing T

(2) Minimum Wing T = Wing T (Average) - 2.3 (Standard Deviation)

A safety concern may exist that deicing operations could be conducted using fluid at incorrect concentration as a result of inaccuracies in local mixing procedures, or faulty identification of different fluid mixes in storage tanks or in tanks of deicing vehicles.

Proper training in mixing procedures and the habitual use of fluid strength measuring instruments should protect against making major errors while adjusting fluid concentration. Reading errors by a trained user should not produce an error in fluid freeze point temperature greater than ± two degrees Celsius.

The magnitude(s) of the mixing errors that could result from factors such as untrained personnel, inadequate procedures, or failure to measure final fluid concentrations are potentially very large. A decimal point error in calculating the amount of water to be added to achieve a desired final concentration could result in a freeze point error well beyond the protection afforded by the buffer of 10°C. It is not realistic to attempt to protect for this type of error through the freeze point buffer safety factor.

Similarly, faulty identification of fluid strengths in storage or in truck tanks could cause large fluid freeze point errors that can not be offset by a freeze point buffer.

The pumping systems on some deicing vehicles may be fitted with fluid blenders designed to deliver fluid at concentration specified by the operator. Literature from manufacturers has been seen which claims accuracy in fluid mix proportions of ± 2% (or, for a typical Type I fluid, accuracy in the range of ± 0.5 to 1.5°C).

2.2.5.1 Contribution to freeze point buffer

An incremental value of 2°C reflects the contribution to freeze point buffer of errors in fluid concentration.

2.2.6 Variations in Fluid Application

During the conduct of full-scale aircraft deicing trials, a wide range of operator skills and resultant fluid film thicknesses has been noted. This observation was based wholly on application of Type IV fluids which require a spray technique that promotes build-up of a thick film.

There is no evidence or reported problems to indicate that spray application of Type I fluid is an issue. Consequently Type I fluid does not require a buffer for this potential contributor.

2.2.7 Variations in Fluid Temperature

The standard and recommended procedure for application of Type I deicing fluid includes heating the fluid to not less than 60°C. Reasonable variations in fluid temperature of heated Type I fluid do not appear to contribute to the need for a freeze point buffer.

Application of heated fluid has some inherent benefits associated with it that may decrease the need for a buffer. Trials were conducted during the 1996/97 winter season to evaluate the effects of evaporation of heated Type I fluid when applied to a test surface. Trials included fluids of various strengths, ambient temperatures from 0°C to -13°C, and no precipitation. Test data included percentage of area of the surface left bare and dry at measured elapsed times, and the final freeze point of the fluid remaining on the surface. Figures 2.3 and 2.4 present some results from these trials.

Observations from the trials were:

- A substantial portion of the surface was left bare and dry. The weaker the fluid concentration, the greater was the area left dry. Application of both a heated 2% ADF solution and heated water left the surface virtually dry, except for the bead of fluid retained on the lower edge by surface tension; and

- The final freeze point of fluid left on the surface after 20 minutes was measurably lower than that of the initial fluid at application. This observation applied to the bead of fluid gathered at the surface lower edge, and was even more pronounced for areas where only a thin film of fluid was left on the surface.

The implication of the latter observation is that a natural buffer may be inherent in the use of heated fluid, wherein the concentration of the applied fluid increases after application as a result of evaporation. The practical effectiveness of this buffer enhancement depends on the extent of surface drying.

As noted in Section 1, application of a One-Step deicing fluid (Type I procedures) allows use of a fluid with freeze point above outside air temperature. The results of the foregoing trials on heated Type I fluid indicate that the need to protect the wing from contamination caused by freezing of the One-Step fluid may be less severe than might otherwise be expected.

2.2.7.1 Contribution to freeze point buffer

Variation in temperature of heated Type I fluid does not warrant protection by means of the freeze point buffer.

FIGURE 2.3

PERCENTAGE OF PLATE AREA BARE

HEATED WATER & TYPE I FLUID EVAPORATION TESTS

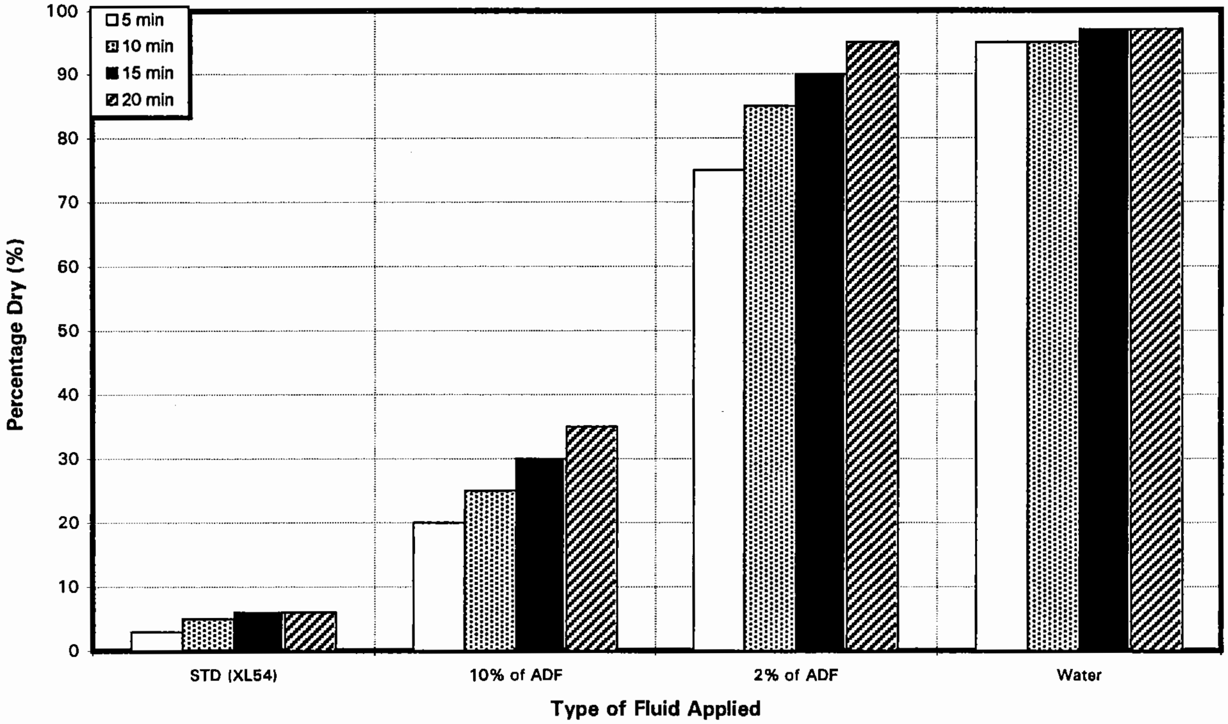
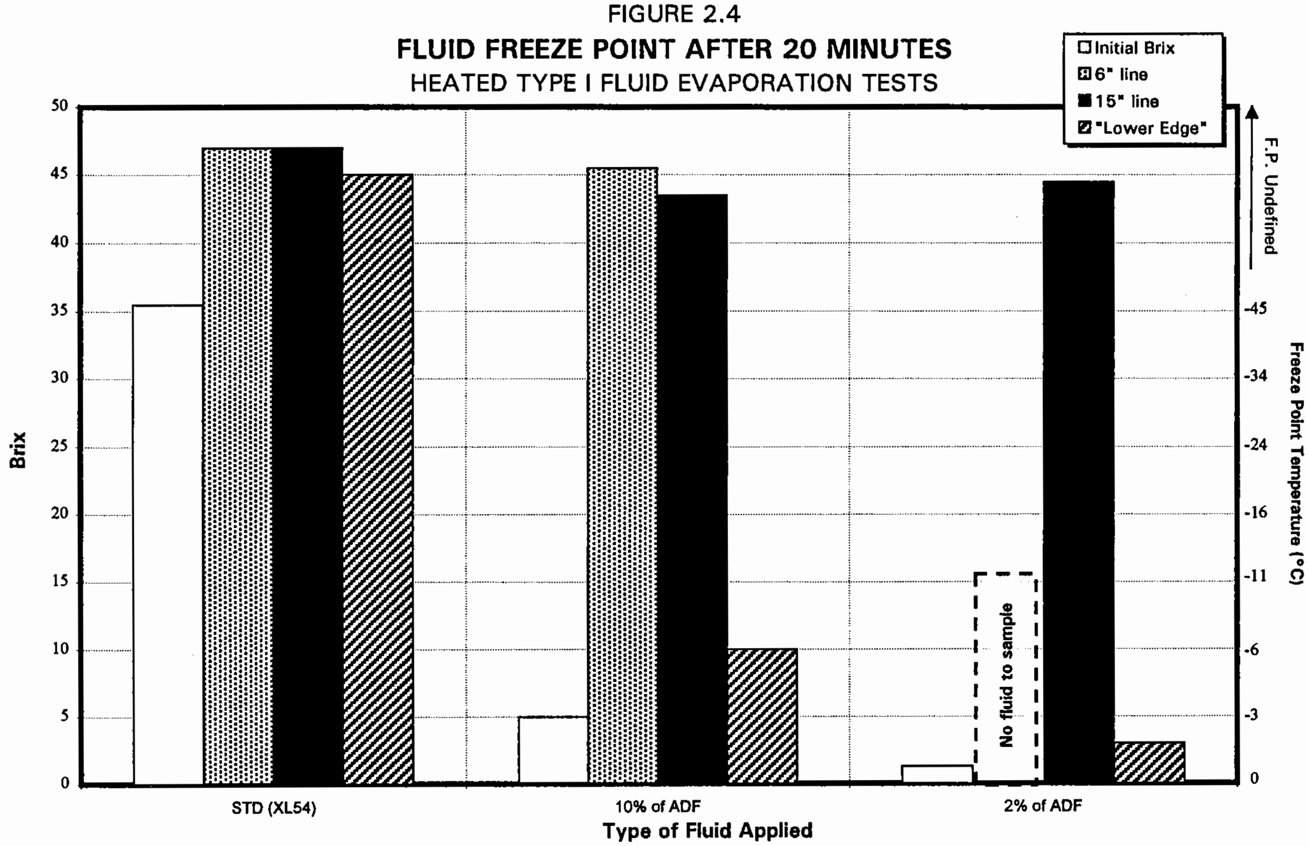


FIGURE 2.4

FLUID FREEZE POINT AFTER 20 MINUTES

HEATED TYPE I FLUID EVAPORATION TESTS



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2.3 Consolidated Requirements for Freeze Point Buffers

A summary of the contributions to the need for a freeze point buffer is presented in Table 2.3. If the contributions are simply added together, a consolidated contribution of 6°C results.

When integrating all elements to determine a consolidated value, the two elements *variations or errors in outside air temperature* and *difference in wing skin temperature from outside air temperature* are considered together. As a single buffer value will provide protection for both elements, only the greater of the two values is considered.

As the variable factors can be considered to be random independent events, they could be combined on the basis of their probability of occurrence, which would yield a considerably lower consolidated value than that produced by addition.

Example:
The probability that a wing will be cold-soaked to 4°C lower than outside air temperature was calculated to be 2%.

The probability of occurrence of an inaccurate fluid mix depressing the fluid freeze point by 2°C might be estimated at 10% probability.

The probability that these two events would occur concurrently would be the product of their individual probabilities, or 0.2% (.02 * .10 = .002). Based on these probabilities, the probability of a condition occurring that would require a full 6°C buffer is 0.2%.

In order to apply this approach, the probability of occurrence of each factor would need to be evaluated, which was beyond the scope of this project.

Buffer contributions are presented in chart form to better understand their implication during different operating conditions.

2.3.1 Fluid Application During Ongoing Precipitation

Figure 2.5 represents buffer values for a fluid at standard concentration during precipitation conditions. The line representing outside air temperature has a range of ±2°C, as well as a -4°C deviation for a cold-soaked wing condition. The line representing fluid freeze point as it rises due to absorbed precipitation, has a buffer range of 2°C to account for mixing errors. The *worst case* occurs where the highest freeze point line crosses the cold-soaked wing temperature line, resulting in the largest reduction to holdover time. Application of the buffer values to protect against variations in conditions reduces the anti-icing

TABLE 2.3

SUMMARY OF CONTRIBUTIONS TO BUFFER

VARIABLE CONDITIONS	CONTRIBUTION TO FP BUFFER (°C)
Wind[1]	0
Precipitation	0
OAT[2]	2
Wing Skin Temperature[2]	4
Fluid Concentration and Mixing	2
Fluid Application Technique	0
Fluid Temperature	0
Consolidated Requirement	6°C

[1] Insufficient information is available to assess this factor.

[2] The larger of the buffer values for the two noted elements provides protection for the smaller. Values are not cumulative.

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FIGURE 2.5

FREEZE POINT BUFFER CONTRIBUTION DURING PRECIPITATION

FULL STRENGTH FLUID

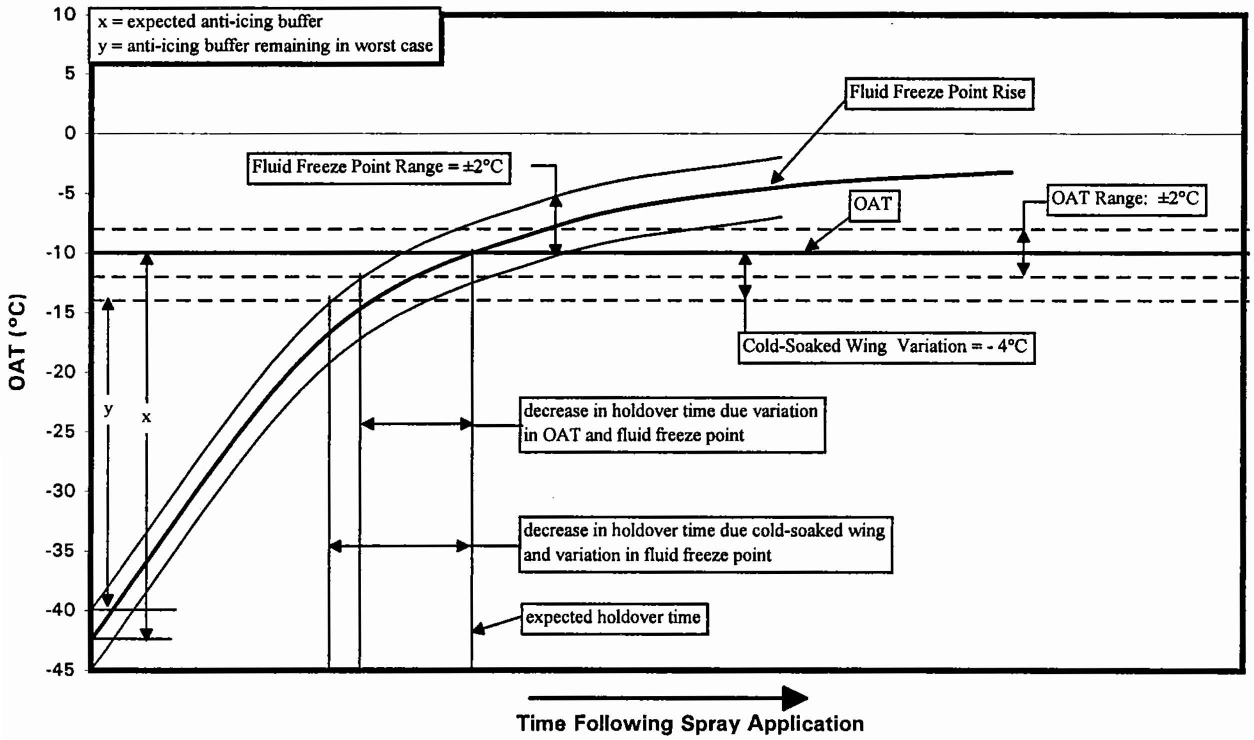
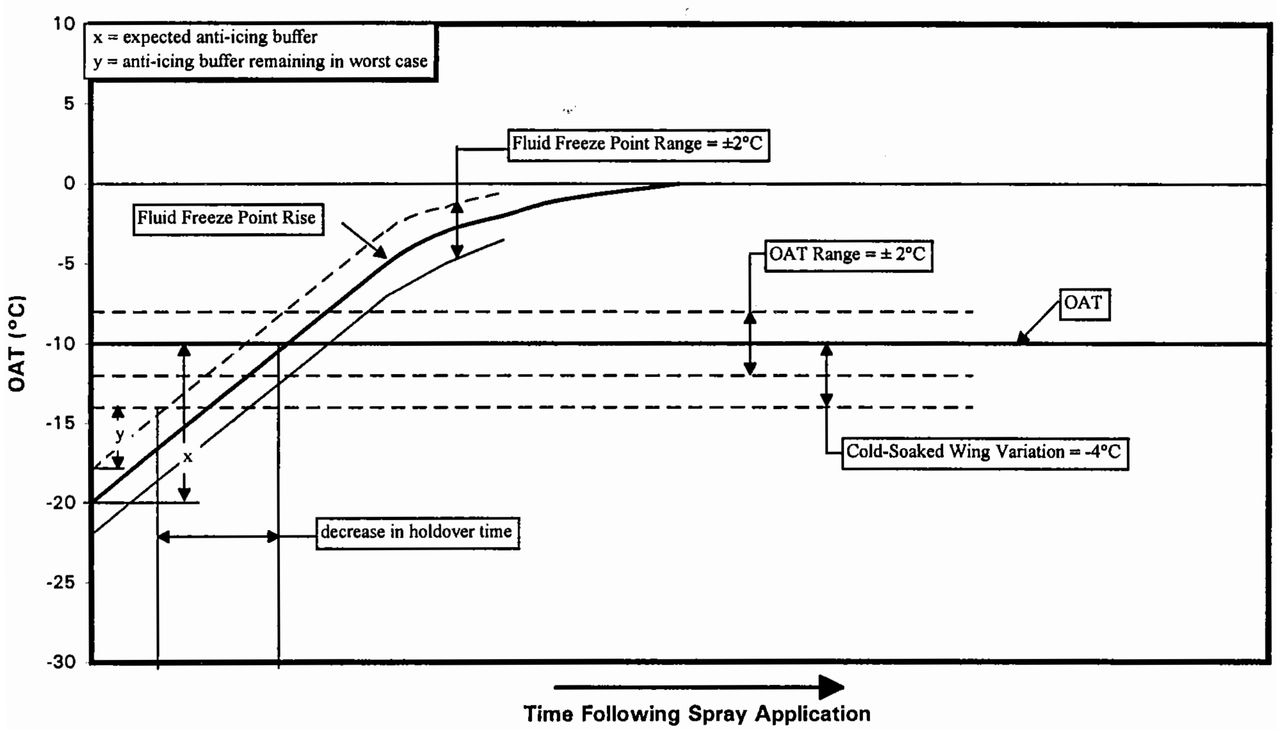


FIGURE 2.6

FREEZE POINT BUFFER CONTRIBUTION DURING PRECIPITATION

FLUID MIXED TO 10°C BUFFER



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buffer from the expected value X to a minimum value Y resulting in reduced holdover times as indicated.

Figure 2.6 represents a fluid mixed to the 10°C buffer. In the *worst case*, the buffer (Y) available for anti-icing (precipitation absorption) protection is decreased to a value of 4°C by the need for a 6°C buffer to protect against variations in conditions.

Type II and Type IV fluids used for anti-icing protection are normally applied in the standard pre-mix as delivered by the fluid manufacturer. In these cases, protection against errors in mixing is not required, leaving a total required buffer value of 4°C. In the *worst case*, the remaining available anti-icing buffer could be reduced to 3°C.

2.3.2 Fluid Application Following Termination of Precipitation

Figure 2.7 presents the same buffer contribution values during a condition of no precipitation. Here the fluid freeze point does not increase from its initial value as no precipitation is being absorbed. The temperature gap between the upper range of fluid freeze point and the cold-soaked wing temperature value offers no productive benefit.

In a case where the aircraft has accumulated snow, frost or other contamination while parked overnight, the risk of encountering a cold-soaked wing can be discounted and its buffer (4°) replaced by the buffer for variations in outside air temperature (2°). The consolidated buffer value in this case is 4°C.

2.3.3 Fluid Application Before Start of Precipitation

A protective film of fluid may be applied prior to start of precipitation. (Type II or Type IV fluids provide the best results in this application.) This method of use is represented in Figure 2.8.

In the case of overnight frost, a film of fluid may provide sufficient protection to avoid the need for frost removal prior to the following morning operation. In this circumstance the fluid film experiences little dilution from water content in the frost deposits. Consequently the freeze point of the fluid film does not rise to the value of outside air temperature and the film does not experience failure. Application of freeze point buffers are required only to protect against the applied fluid freezing due to variations in expected outside air temperature and errors in fluid concentration and mixing. As this case generally applies to aircraft parked overnight, protection against cold-soaked wing conditions is not necessary. The consolidated buffer value is 4°C.

FIGURE 2.7

FREEZE POINT BUFFER CONTRIBUTION IN NON-PRECIPITATION CONDITIONS

FLUID MIXED TO 10°C BUFFER

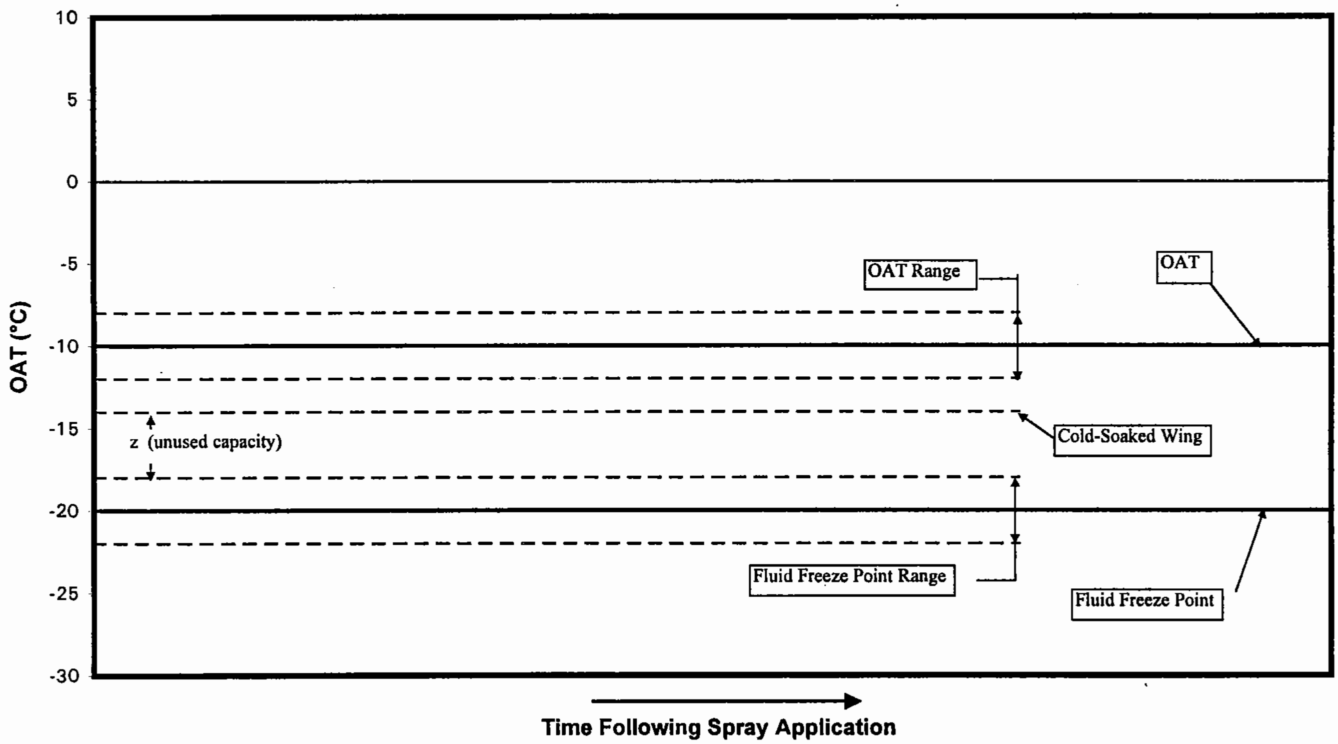
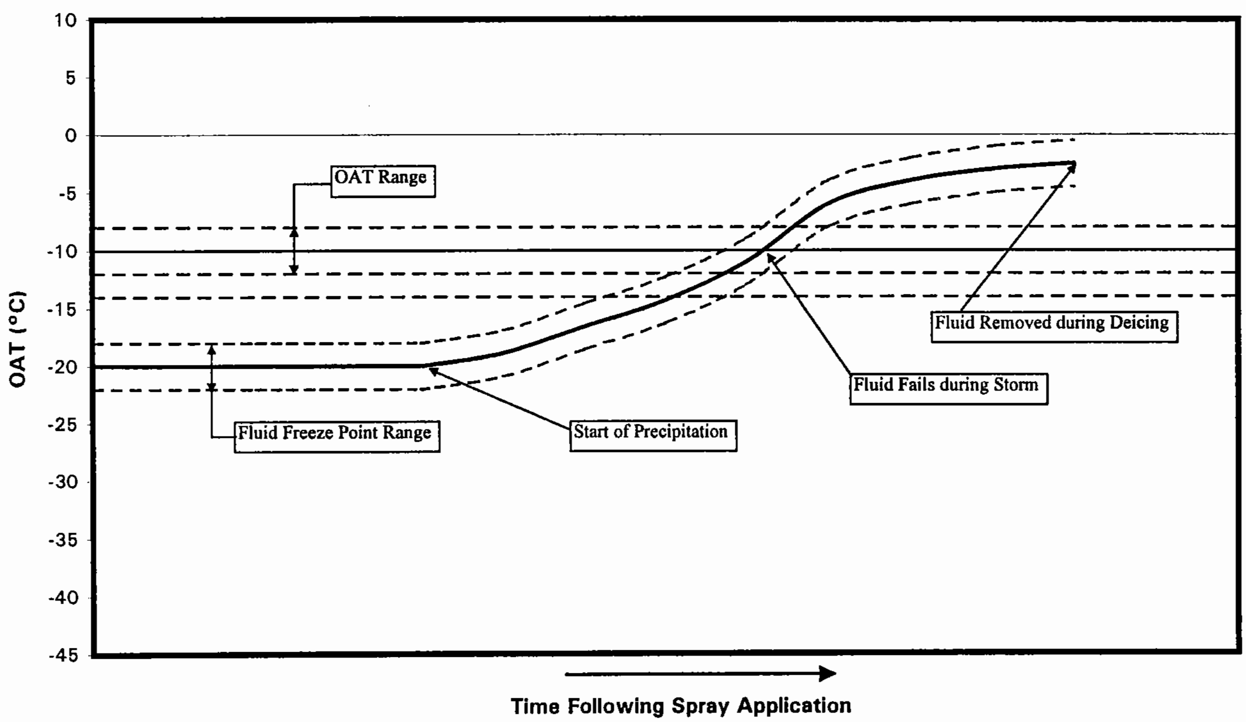


FIGURE 2.8

FREEZE POINT BUFFER CONTRIBUTION -APPLICATION PRIOR TO START OF PRECIPITATION

FLUID MIXED TO 10°C BUFFER



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When precipitation is forecast, application of a protective film of fluid will minimize adherence to the aircraft surface and facilitate subsequent deicing.

This is especially useful to prevent bonding in the case of freezing precipitation. In this circumstance, the fluid is expected to fail (and be subsequently deiced) and neither the freeze point buffer nor the anti-icing buffer is required. The applied fluid must be removed by deicing prior to the next departure.

2.4 Summary of Temperature Buffers

Table 2.4 presents a consolidation of temperature buffer applications during different conditions. The consolidated values for freeze point buffer estimates are listed, along with the remaining available buffer for anti-icing protection based on current SAE ARP4737 temperature limits. Note that the consolidated values are the result of addition of contributions of each factor, and that probability of occurrence is not considered.

This presentation assumes that freeze point buffer values are required for Type II, Type III and Type IV fluids as well as for Type I. As noted earlier, when any fluid is applied at its extreme temperature limit, variations in conditions need to be addressed.

For all fluid types, deicing following end of precipitation or for frost removal requires a 4°C freeze point buffer with no buffer required for anti-icing protection.

Application for frost protection requires a freeze point buffer value of 4°C.

Application of fluid for ongoing precipitation requires a freeze point buffer of 6°C. Remaining values for anti-icing buffers are shown, based on current ARP4737 temperature limits for fluid application.

Application of Type II, Type III or Type IV fluids prior to start of precipitation to prevent bonding to the aircraft surface has no need for temperature buffers as the fluid is expected to fail in any case.

Commuter aircraft may form a special case if it can be safely assumed that they do not experience cold-soaked wings (due to their mode of operation). In that event, the 4°C buffer for cold-soaked wings would disappear, to be replaced by a 2°C buffer for variations in outside air temperature.

TABLE 2.4

TEMPERATURE BUFFERS FOR DIFFERENT CONDITIONS

		OPERATIONAL CONDITION					
Fluid Type	Buffer Requirement	Deicing following Termination of Precipitation or Removal of Frost (°C)	Protection against Frost (°C)	Anti-Icing Protection applied before start of Precipitation (°C)	During Precipitation		
					Two Step Procedure		One Step Procedure (°C)
					First Step Fluid (°C)	Second Step Fluid (°C)	
	Total Buffer Requirement	4	10	0	N/A	10	10
I	Variations in Conditions	4	4	N/R	N/A	6	6
	Remaining Buffer Available for Anti-Icing Protection	N/R	6	N/R	N/A	4	4
II	Total Buffer Requirement	4	7	0	N/A	7	7
III, IV	Variations in Conditions	4	4	N/R	N/A	4	4
	Remaining Buffer Available for Anti-Icing Protection	N/R	3	N/R	N/A	3	3

N/R - Not required
N/A - Not applicable

<u>Note</u>: In conditions requiring anti-icing protection (frost and precipitation), the values shown for anti-icing buffer are the result of applying the full current SAE buffer as the 'requirement'.

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3. ANTI-ICING CAPACITY OF FLUIDS

The second need for temperature buffers is related to the use of fluids as an anti-icing agent, and pertains to the capacity of the fluid to absorb precipitation over a period of time in cold temperatures without itself freezing. To satisfy this objective, the initial freeze point of the anti-icing fluid must be somewhat lower than outside air temperature.

3.1 Capacity of an Anti-icing Fluid to Provide a Holdover Time

3.1.1 Anti-icing Fluid

All anti-icing fluids in operational use are subjected to a series of rigorous tests to determine fluid performance in various temperature and precipitation conditions, measured by the capacity of each fluid to deliver holdover time. As well, the aerodynamic shear properties and dry-out characteristics of the fluids are examined to ensure that they meet approved specifications.

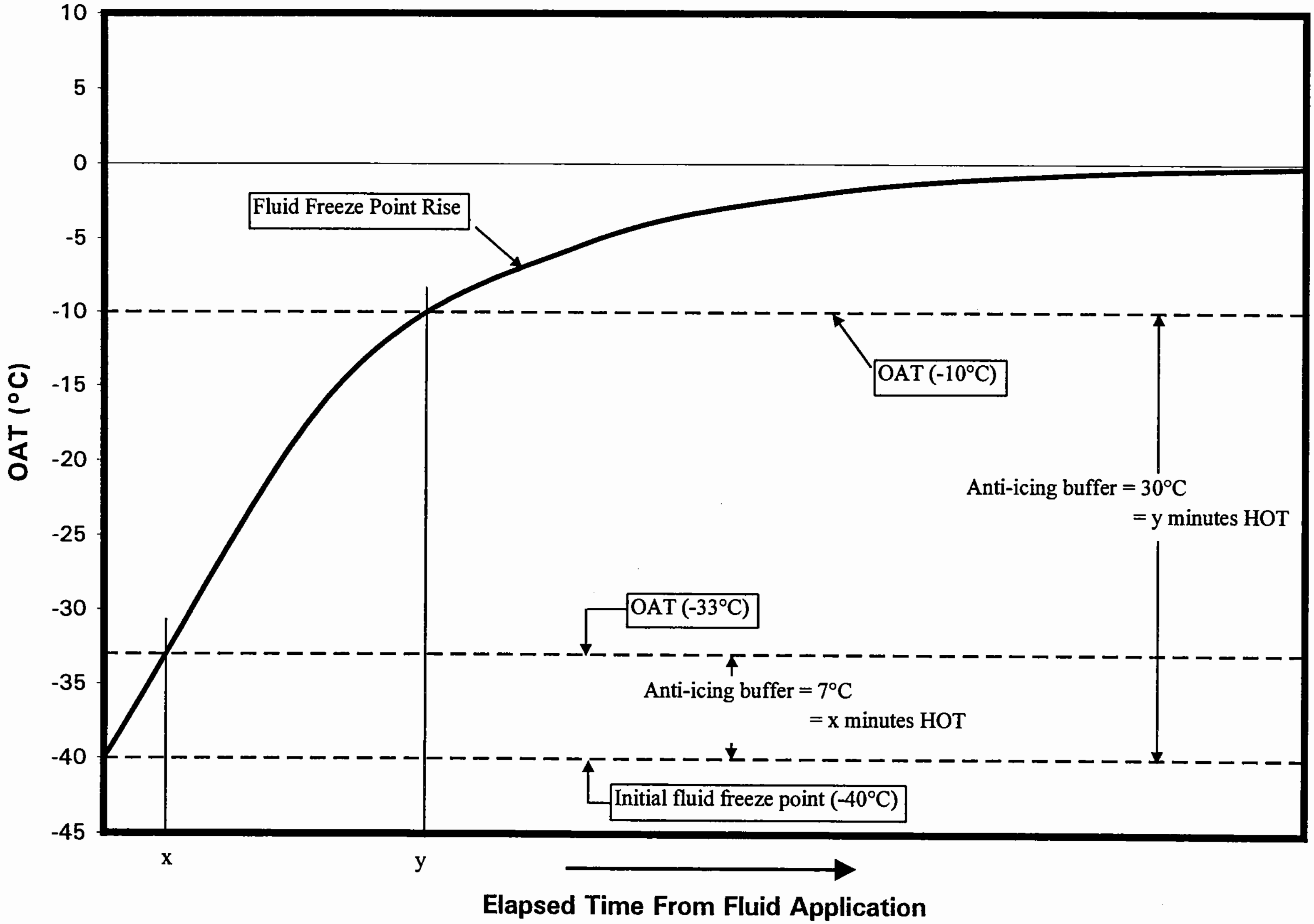
The means by which these fluids provide holdover time is through absorption of precipitation into the mass of fluid remaining on the exposed surface, while maintaining a fluid freeze point below outside air temperature. Design of the newer fluids of the Type II, Type III and Type IV classes has addressed and enhanced the capacity of the fluid to absorb water from precipitation through improving the ability of the fluid to remain on the protected surface rather than running off. The properties of the fluid allow the spray operator to build-up a thick film of fluid on the surface to be protected.

3.1.2 Anti-icing Capacity

Figure 3.1 provides a graphical representation of the relationship between the time from fluid application, outside air temperature and fluid freeze point in precipitation conditions. The curved line represents the freeze point of the fluid as it progressively rises from its initial freeze point (in this case, -40°C) while absorbing water from precipitation.

For the fluid in the case represented, a condition in which the outside air temperature was also -40°C and precipitation was occurring would result in fluid failure commencing very quickly, as the fluid freeze point would immediately start to rise above outside air temperature.

FIGURE 3.1
FLUID FREEZE POINT RISE DUE TO ABSORBED PRECIPITATION



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A condition in which the outside air temperature was -33°C (the lowest allowable temperature based on the 7°C freeze point buffer) and precipitation was occurring would result in fluid failure commencing at the point shown, yielding a holdover time of value X.

In a different condition of outside air temperature at -10°C with precipitation, the same fluid would have a capacity to absorb water prior to freezing as indicated, yielding a different holdover time of value Y.

A period of protection before visual indications of failure will appear can be delivered by an anti-icing fluid only if it is applied at a fluid concentration having a freeze point somewhat below outside air temperature. In other words, a fluid freeze point elevation buffer (referred to hereafter an anti-icing buffer) is required in order for anti-icing fluids to perform their function of delivering a holdover time.

3.2 Temperature Limits Applied to Type I Fluids

Whereas the temperature buffer stipulated in SAE ARP4737 (Appendix B) for Type II, Type III and Type IV fluids (as stated) applies to fluid application for the purpose of providing anti-icing protection, the intent for the Type I fluid buffer is less clear. In the Two-Step Procedure, the Type I fluid used as the second step for anti-icing is required to include a 10°C (18°F) buffer, indicating that the buffer is at least partially directed toward anti-icing protection. In a One-Step Procedure the single fluid applied must provide anti-icing protection in addition to removing contamination, and again, at least some of the 10°C (18°F) buffer requirement must exist to satisfy the anti-icing protection function. This is illustrated in Figure 3.2.

Because Type I fluid is heated before application as a deicing fluid, some amount of heat can be expected to be transferred to the wing surface. This heat supplements the anti-icing protection offered by the fluid as long as the wing surface temperature remains above the freeze point of the fluid. Figure 3.3 illustrates the influence that a heated wing may have on the prolongation of the elapsed time to fluid failure. The effect on holdover time may be either positive or neutral depending on whether the wing skin temperature curve crosses the fluid freeze point curve after or before the fluid freeze point equals outside air temperature. In some conditions Type I fluid may be applied as an unheated anti-icing fluid to a clean cold surface (as in the case to prevent adherence of frost).

A study in Winter 1994/95 of the use of hot water for deicing [1] examined the extent of heat transfer to the wing, and documented the time lag for the heated wing surface to cool to ambient air temperature and to fluid (water) freeze point. An appreciable time lag was noted which varied substantially with wind and outside air temperature variations. Results of three trials were:

Outside Air Temperature °C	Wind kph	Lag Time to 0°C minutes
- 3	6	17
- 9	7	3.5
-13	28	0.5

A separate study examining fluid thickness on aircraft wings [2] determined that Type I fluid thins rapidly to a very thin film (about 0.2 mm) in about 4 to 6 minutes. That study concluded that the extended holdover times experienced with Type I fluid in actual operations must be attributable at least in part to heat

1. Dawson, P., D'Avirro, J., *Hot Water De-icing Trials for the 1994-1995 Winter*, APS Aviation Inc., Montreal, December 1995, TP 12653E, 48.

2. Dawson, P., D'Avirro, J., *Evaluation of Fluid Thickness to Locate Representative Surfaces*, APS Aviation Inc., Montreal, October 1996, TP 12900E, 109.

FIGURE 3.2

TEMPERATURE BUFFERS

TYPE I FLUID

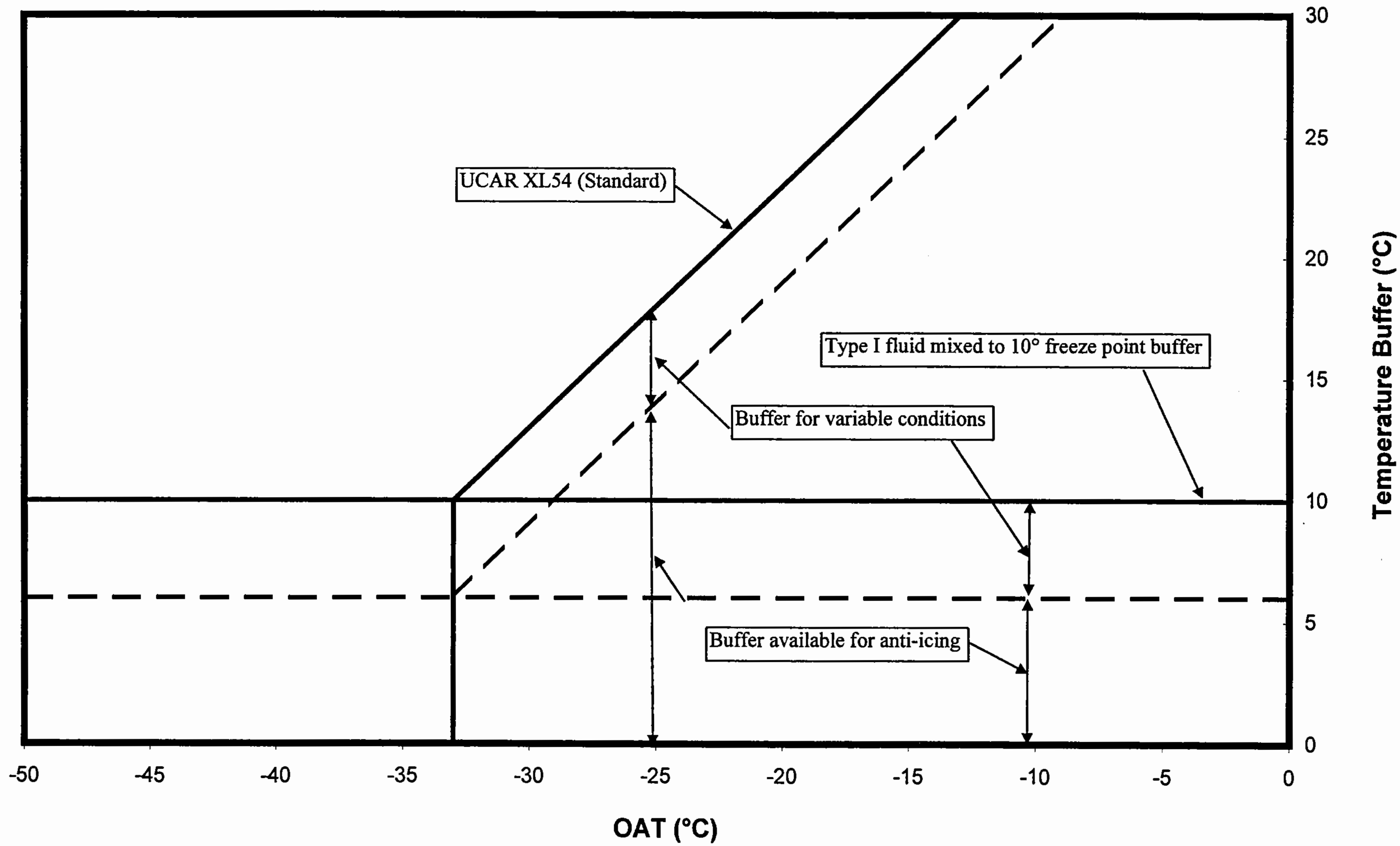

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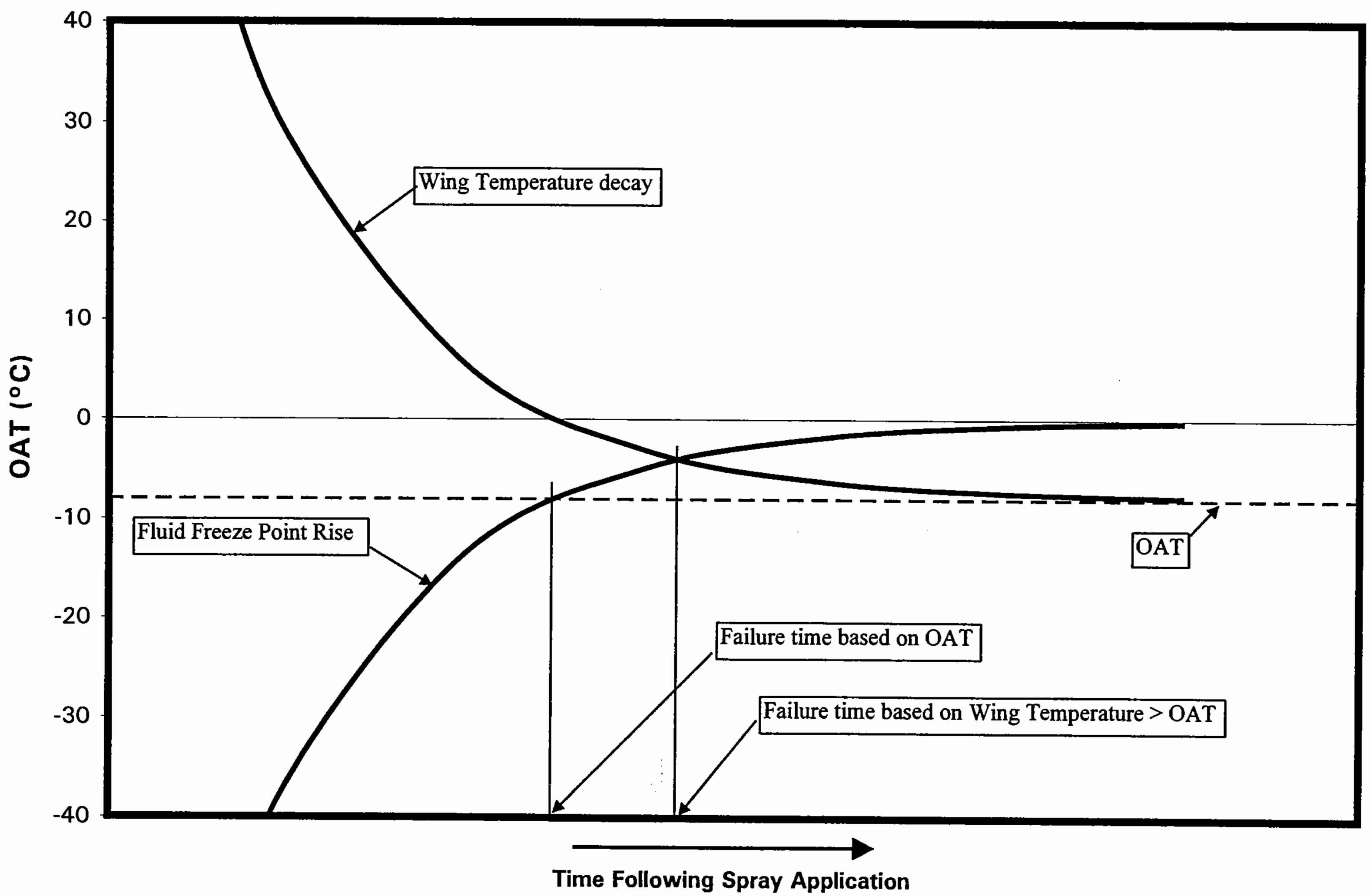
FIGURE 3.3

IMPACT OF HEATED WING SURFACE ON HOT



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transfer from fluid to wing, as the final values for film thickness would not offer the precipitation absorbing capacity required to deliver those holdover times.

It should be noted that the test process for evaluating fluid holdover times[3] respects the freeze point buffer requirements. A study on fluid holdover times conducted during Winter 1994/95 included an examination of the effect on holdover time of Type I fluids diluted to the 10 degree buffer as compared to standard fluid strength as delivered from the manufacturer. Figure 3.4 shows results from those trials. That study concluded that standard strength fluid provided only a slightly better performance than fluid diluted to buffer strength, and offered the explanation that regardless of the initial strength, any precipitation quickly dilutes the fluid on the protected surface thereby raising its freeze point.

This is congruent with the results from the thickness study which showed rapid depletion of the quantity of Type I fluid on the wing during non-precipitation conditions. In any appreciable precipitation condition, the fluid would be exposed to rapid dilution, hastened by even faster run-off and thinning of the protective fluid layer as it is diluted from its initial concentration.

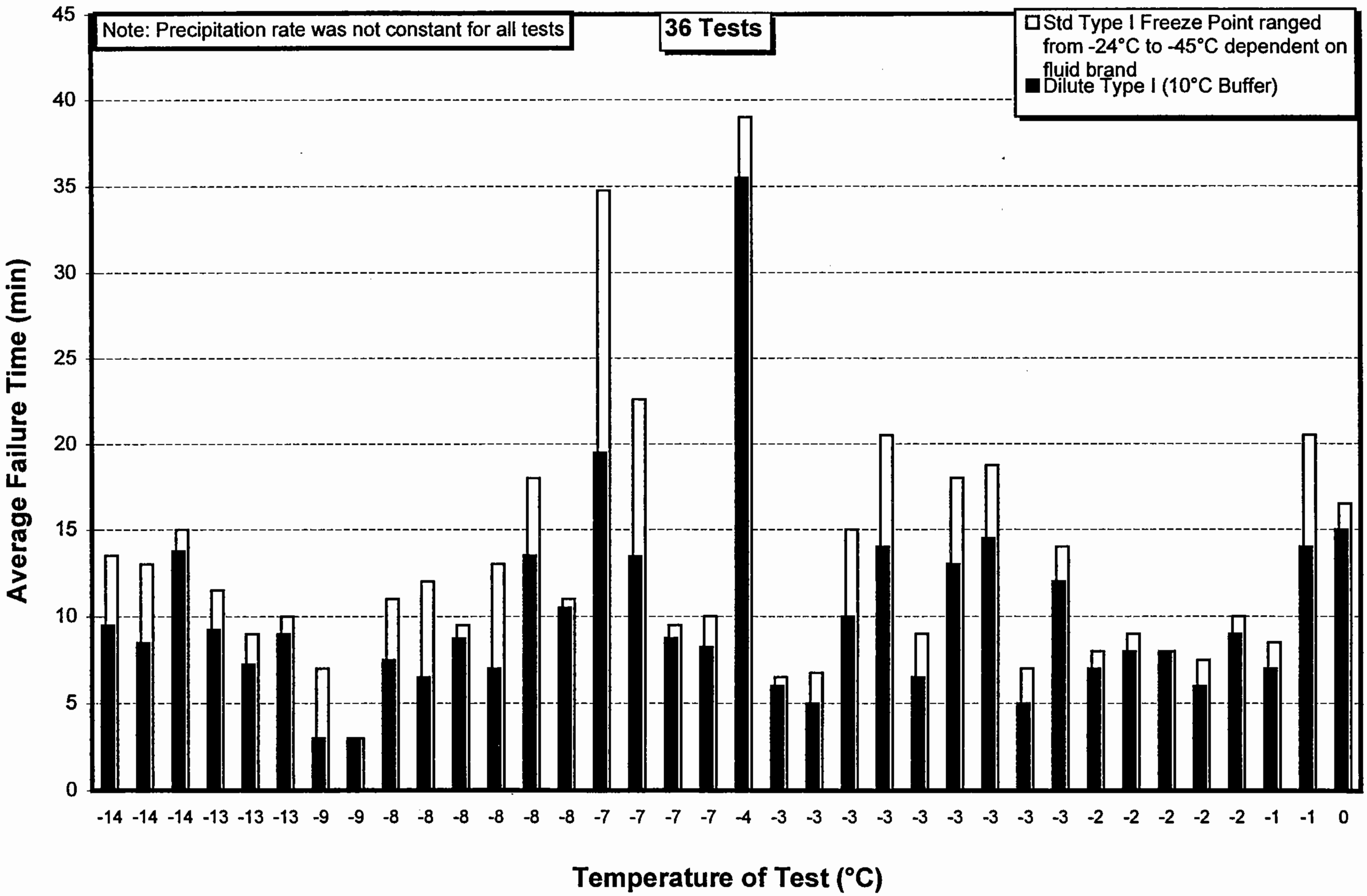
These tests were conducted under natural snow in a variety of temperatures and precipitation rate conditions.

3. D'Avirro, J., Boutanios, Z., *Aircraft Ground De/Anti-icing Fluid Holdover Time Field Testing Program for the 1994-1995 Winter*, APS Aviation Inc., Montreal, December 1995, TP 12654E, 180.

FIGURE 3.4

COMPARISON OF AVERAGE FAILURE TIME BETWEEN STANDARD TYPE I AND DILUTED TYPE I FLUIDS IN NATURAL SNOW CONDITIONS

1994/95



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3.3 Temperature Limits Applied to Non-Newtonian Anti-icing Fluids

3.3.1 Process of Fluid Failure

While the fundamental flight safety requirement (with respect to freezing precipitation) is that there be no contamination adhering to the wing, adhesion of contaminated fluid is not visually identifiable. Instead, fluid failure is identified by the observer according to various accepted descriptions of visual clues relating to the nature of the appearance of fluid on the upper surface of the film layer. As well, visual inspections by the aircraft pilot are limited to the appearance of the upper surface of the fluid.

Different commercial brands of (non-Newtonian) anti-icing fluids exhibit different failure mechanisms one from another, as well as among different temperatures and precipitation rates. In some instances, the upper surface of the fluid may absorb precipitation and encounter local freezing of fluid (and associated visual clues indicating failure) while the underlying layer is still sound. Although the contamination has not adhered to the wing, the fluid would be considered as failed both by the test observer during trials and by the aircraft pilot in an actual operation. Figure 3.5 provides an illustration of this type of failure as well as a fluid experiencing failure uniformly throughout the entire depth of the fluid film.

In the type of failure where freezing has been limited to the upper surface of the fluid, it could be considered that an inherent buffer has been established. In this view, the holdover time based on visual fluid failure indications is seen to be less than the holdover time based on adherence of contamination to the wing surface. However the final test of the fluid is whether or not it flows from the wing and leaves a clean surface during the take-off roll, and there is no assurance that a fluid having an upper surface contaminated to the point that it is visually identifiable will perform this way.

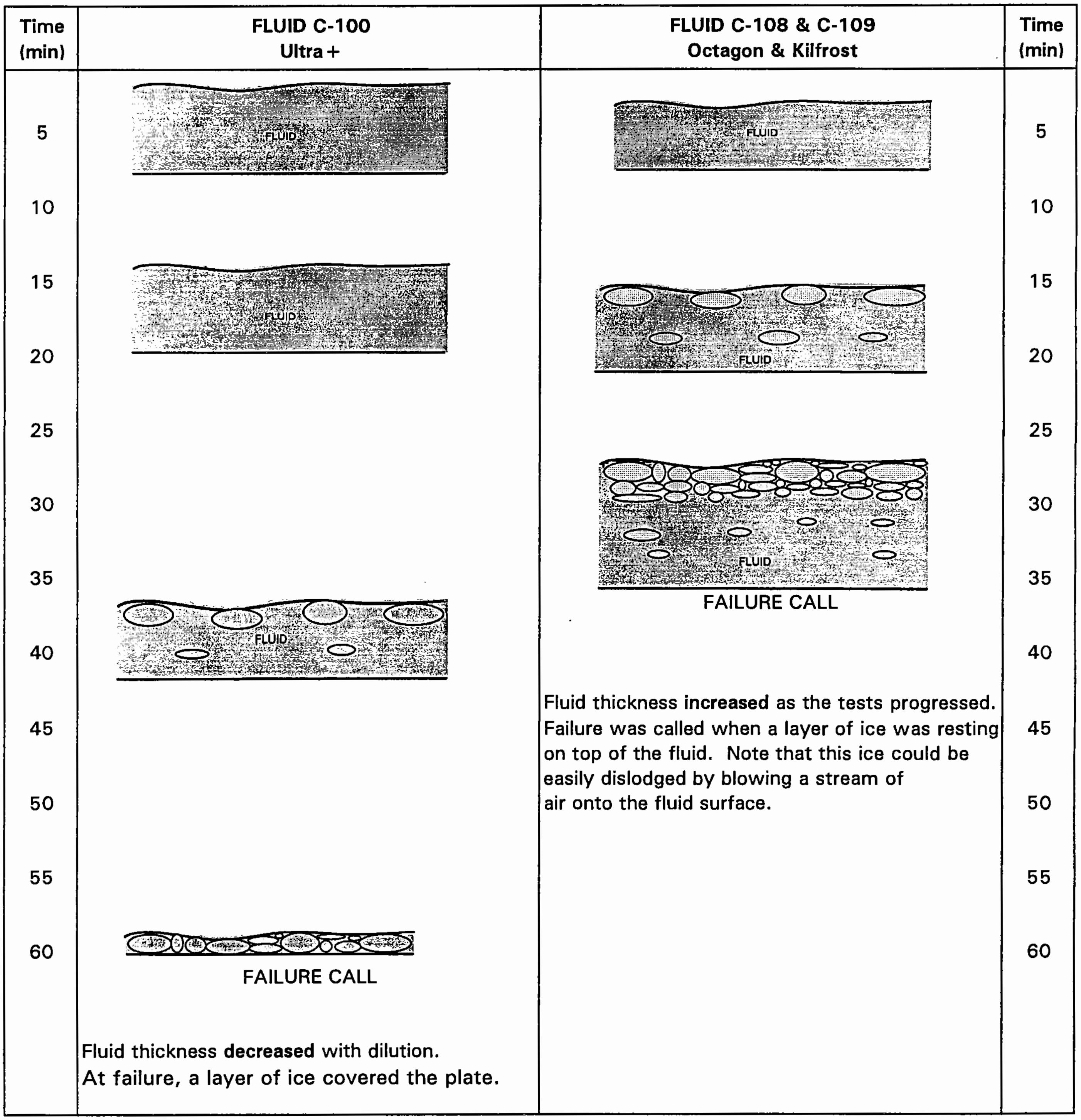
Another mechanism of failure involves a reduction of viscosity of fluid at the exposed upper surface as a result of dilution. This low viscosity fluid progressively bleeds off the upper surface, exposing new uncontaminated fluid to the ongoing precipitation. Eventually the entire fluid film is eroded in this fashion leaving the wing unprotected. Further precipitation now reaches the wing surface, where it freezes.

Other mechanisms of fluid failure may take the form of progressive failure more evenly distributed throughout the depth of the entire layer of protective fluid. In these instances, elapsed time until adherence of contamination to the surface may be more congruent to time of visual indication of failure.

FIGURE 3.5

SCHEMATIC OF FAILURE MECHANISM

FREEZING DRIZZLE (-10°C)



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In each case, the local freeze point of the fluid has been elevated through progressive dilution of fluid as a result of absorption of precipitation. This is so either when failure is localized to the upper layers of fluid or more evenly distributed throughout the entire depth of the fluid film. The time to reach visual indication of failure is dependent up on the time taken for the fluid freeze point on the upper surface to be elevated to the ambient air temperature.

3.3.2 Temperature Limits

Although SAE ARP4737 for Type II, Type III and Type IV fluids refer to a buffer only at temperatures below -25°C, the buffer is generally understood to apply at all temperature ranges.

While the comments in this discussion are directed towards Type IV fluids, similar comments may directed toward Type II and Type III fluids.

Figure 3.6 is a pictorial representation of various temperature limits applied to Type IV fluids in current use. The limits shown for each fluid include the freeze point buffers under discussion, the fluid freeze point, and the aerodynamic shear limit (the lowest temperature at which the fluid will satisfactorily flow-off the wing at take-off speeds). As well, limiting conditions on fluid use imposed by SAE G-12 Holdover Time Subcommittee deliberations are shown.

Examination of limits applied to Ultra+ Type IV neat fluid shows a fluid freeze point (-59°C) considerably below the limit for jet aircraft (-24°C) imposed by aerodynamic shear properties. For this fluid, the freeze point buffer of 7°C has no significance. The actual buffer made available by this fluid to reach its lowest use temperature (-24°C) is 35°C (-59°C-(-24°C)).

In conditions of freezing rain and freezing drizzle, an SAE imposed lower limit of -10°C provides an even greater buffer (49°C).

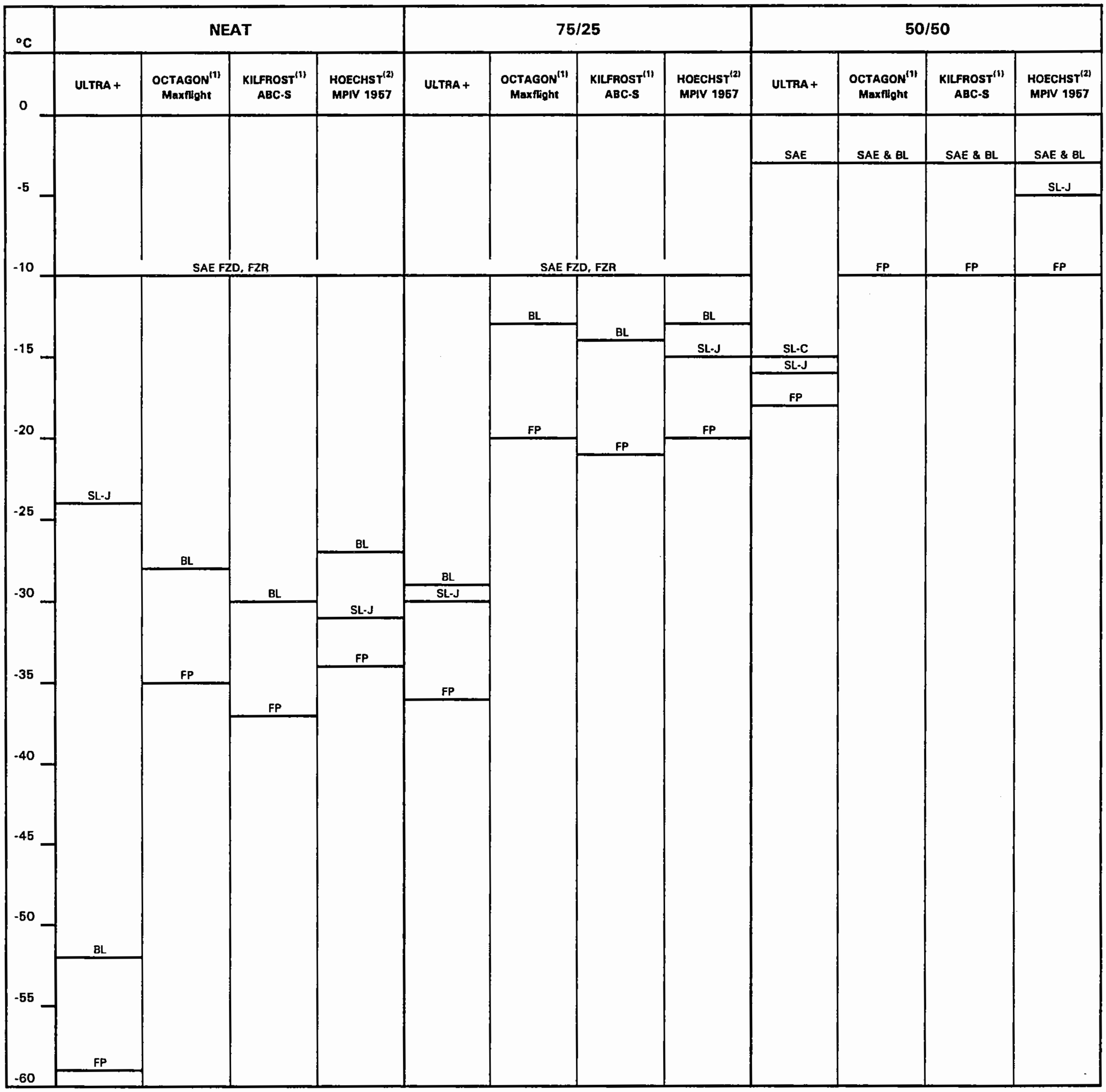
When Ultra$^+$ Type IV fluid is used at 75% concentration, the freeze point is -36°C, the aerodynamic shear limit for jet aircraft is -30°C and the lower limit due to freeze point buffer is -29°C. The minimum buffer for anti-icing is 7°C.

Ultra+ fluid mixed to 50% concentration has a freeze point of -18°C and a freeze point buffer lower limit of -11°C. However, SAE deliberations have established a lower operational use limit of -3°C for all Type IV fluids when mixed to 50/50 strength. This results in this particular fluid having a minimum anti-icing buffer of 15 Celsius degrees.

Ultra+ fluid mixed to a 67% concentration forms the basis for a Type III fluid which can be applied to commuter aircraft. The lower temperature limit of -22°C allowed by the freeze point buffer once again is of no consequence with

FIGURE 3.6

TYPE IV FLUID TEMPERATURE LIMITS



(1) Value of Aerodynamic Shear Limit falls somewhere below buffer limit

(2) Limited Information Available

FP - Freeze Point
BL - Buffer Limit (FP -7°C)
SL - Aerodynamic Shear Limit
SL-J - Aerodynamic Shear Limit - Jet
SL-C - Aerodynamic Shear Limit - Commuter
SAE - Limit imposed by SAE decision

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the limiting factor being the aerodynamic shear limit of -18°C, and a minimum anti-icing buffer of 11 Celsius degrees.

Complete data on aerodynamic shear limits were not available for all Type IV fluid brands, however some comments can be made on the basis of fluid freeze points. Minimum anti-icing buffers at the 100% concentration provided by the remaining fluids is 7°C (equivalent to the required freeze point buffer), compared to the value of 35°C for Ultra+. Other Type IV 50/50 fluids have minimum anti-icing buffers of 7°C compared to 15°C for the Ultra+ 50/50 fluid.

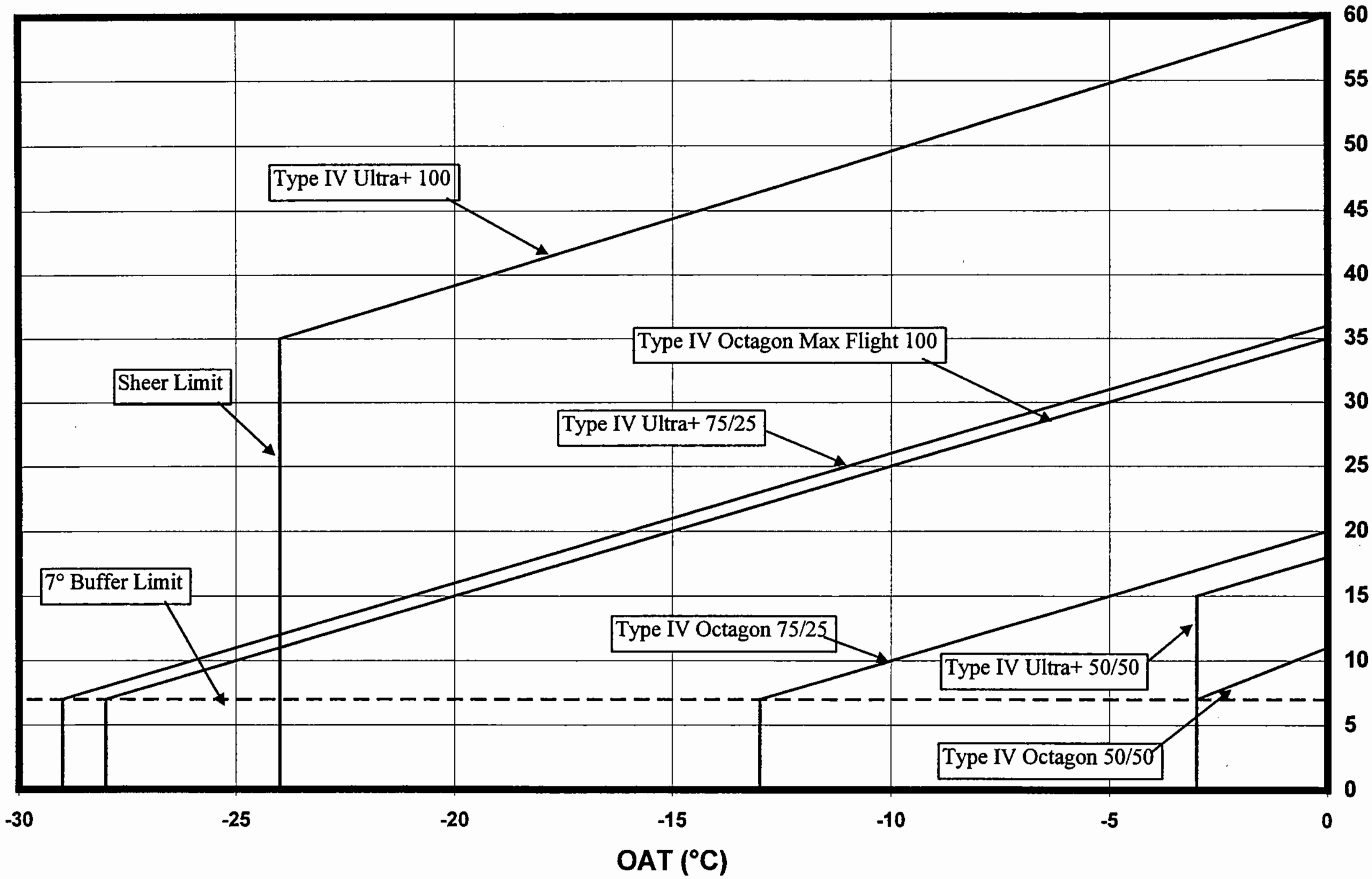
The anti-icing buffer values delivered by two brands of Type IV fluids at various concentrations is illustrated in graphical form in Figure 3.7. It is seen that the real buffer available at outside air temperature values above the minimum temperature limit for each fluid increases rapidly to very substantial values providing ample protection against variations in conditions.

The large difference in anti-icing buffer between the two fluid brands is noteworthy. Referring to the 100% mixes as an example, the Ultra+ fluid has a much larger theoretical capacity for absorption of precipitation than the Octagon Maxflight fluid. This expected advantage did not prove true during fluid failure tests, when the performance of Octagon fluid was observed to be superior to that of the Union Carbide Ultra+ fluid.

FIGURE 3.7

ANTI-ICING BUFFERS

TYPE IV FLUIDS



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3.4 Magnitude of Anti-icing Buffer

While it is apparent that some degree of anti-icing buffer is required in order for the fluid to maintain a freeze point below that of the outside air temperature, the various fluids deliver quite different anti-icing buffer values, and still perform acceptably. The mode or mechanism of fluid failure, the ability of the fluid to allow absorbed precipitation to melt and diffuse into it, the viscosity of the locally diluted fluid at the air/fluid interface, and the volume of fluid (film thickness) applied to the aircraft surface are all factors influencing the fluid anti-icing capacity.

In this report, no attempt is made to evaluate the magnitude of the anti-icing buffer required. Instead, the degree of buffer that remains available for anti-icing protection after identifying the required extent of protection against variations in conditions, is estimated (see Table 2.4).

Values for anti-icing buffers for Union Carbide Ultra+ and Octagon Maxflight Type IV fluids are shown in Table 3.1, formatted for temperature ranges and fluid concentrations similar to the SAE ARP4737 fluid tables.

This presentation points out the marginal nature of the current 7°C buffer for Type II, Type III and Type IV fluids. In the *worst case* condition, when the full 4°C buffer for variations in conditions is absorbed, there remains only a buffer of 3°C for anti-icing protection.

As an example, Octagon Maxflight in a 50/50 mix would have a reduced freeze point of -6°C (10°C freeze point less 4°C buffer for variations). When applied at an outside air temperature of -3°C as is authorized, very little anti-icing protection would be expected. Similarly, the 75/25 fluid freeze point could be reduced to -16°C, matching the lowest outside air temperature authorized.

TABLE 3.1

BUFFER AVAILABLE FOR ANTI-ICING IN WORST CASE CONDITION

OAT (°C)	Fluid Concentration %	Anti-Icing Buffer (°C) UCAR Ultra+	Anti-Icing Buffer (°C) Octagon Maxflight
Above 0	100	≥ 55	≥ 31
	75/25	≥ 32	≥ 16
	50/50	≥ 25	≥ 6
0 to -3	100	52 to 54	28 to 30
	75/25	29 to 31	13 to 15
	50/50	22 to 24	3 to 5
-3 to -14	100	41 to 51	17 to 27
	75/25	18 to 28	2 to 12
-14 to -25	100	30 to 32 LOUT = -23°C	6 to 16
below -25	100		3 to 6 LOUT = -28°C

LOUT = Lowest Operational Use Temperature.

<u>**Example:**</u> Octagon Maxflight 50/50

OAT	= -3°C
Buffer for variations in conditions	= -4°C
Sub Total	-7°C
Fluid freeze point	= -10°C
Buffer available for anti-icing protection	= 3°C

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4. CONCLUSION

This report has examined two aspects of fluid temperature buffers as follows:

- *Fluid Freeze Point Buffer*
  Protects against those additional demands on fluid performance brought to bear by variations in fluid and operating conditions. This includes protection against the fluid itself freezing upon application and becoming the source of contamination; and

- *Anti-icing Buffer*
  Allows the fluid to exercise its capacity to absorb water content from precipitation while still maintaining a fluid freeze point below the temperature of the outside air.

The examination of freeze point buffers has been based on Type I fluid as being the most critical of the existing fluid types, although variations in conditions are important for the other types of fluids when they are applied at their ultimate temperature limits.

Some factors influencing fluid performance were not given values either due to lack of data to enable a valid estimate (variations in wind speed and direction) or because it was believed that the potential extent of impact was too great to be reasonably addressed through provision of a buffer (increased rate of precipitation, use of wrong fluid mix due to tank signage or other inadequacies). With the number of centralized deicing operations on the rise, errors related to inadequate mixture in storage tanks will likely be reduced.

The current advice to pilots and operators, warning of possible early fluid failure during heavy weather and high wind, gives the most realistic form of protection against these factors at this time.

Buffer values required for different operating conditions are estimated. These estimates result from adding the individual factor contributions without regard to their probability of occurrence. The compounded probability of simultaneous occurrence of different factors is expected to be very low.

4.1 Buffer for Deicing Following Termination of Precipitation

The freeze point buffer for fluids used to deice aircraft surfaces following termination of precipitation, including frost removal, has been estimated at 4°C. In this application, there is no need for an anti-icing buffer.

4.2 Buffer for Deicing for Frost Prevention

The freeze point buffer for fluids used to protect against frost formation has been estimated at 4°C. Although only a small amount of water content from frost deposit is absorbed by the fluid film, some degree of anti-icing buffer is needed and is satisfied by current limits.

4.3 Buffer for Fluid Applied Before Start of Precipitation

Fluids applied before the start of precipitation to prevent bonding of freezing precipitation to the aircraft surface are expected to fail, and must be removed prior to the next departure, and thus do not have a need for either a freeze point buffer or an anti-icing buffer.

4.4 Buffer for Fluid Applied During Ongoing Precipitation

The freeze point buffer for fluids applied during ongoing precipitation has been estimated at 6°C. Available anti-icing buffers for the various fluid types in the *worst case* based upon the current SAE ARP4737 limits are:

- Type I = 4°C; and
- Type II, Type III, and Type IV = 3°C.

The available anti-icing buffer for Type II, Type III and Type IV fluids is currently at minimum in order for the fluid to have a freeze point below outside air temperature at time of application, precluding any further reduction in buffer values. The requirement to apply this buffer at all outside air temperatures (rather than only below -25°C) should be clearly stated in the SAE ARP4737.

The available anti-icing buffer of 4°C for Type I fluids does not appear to be excessive in view of the limited holdover times delivered by this fluid, and in view of the fact that Type I fluid lends itself to being mixed locally and to an unlimited range of concentrations, thereby creating a greater potential for exposure to *worst case* conditions.

5. RECOMMENDATIONS

It is recommended that temperature buffers be considered for different operating conditions as follows:

- For fluids applied before the start of precipitation to prevent bonding of frozen precipitation to the aircraft surface, 0°C;
- For fluids used to deice aircraft surfaces following termination of precipitation and for frost removal and protection, 4°C;
- For Type I fluids applied as anti-icing fluids during ongoing precipitation, 10°C; and
- For Type II, Type III and Type IV fluids used to protect against frost formation., 7°C. Clarify in the SAE ARP4737 that buffers for Type II, Type III and Type IV apply at all outside air temperatures.

It is recommended that the condition of deicing following the end of precipitation be studied to refine the buffer estimates, giving consideration to the beneficial impact of the application of heated fluid.

Consolidation of buffer contributions from different sources may be refined (giving a lower result) by applying probability theory. Further study to evaluate probabilities of occurrence of individual sources of error is recommended to enable this approach.

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APPENDIX A

TERMS OF REFERENCE - WORK STATEMENT

TRANSPORTATION DEVELOPMENT CENTRE

WORK STATEMENT

AIRCRAFT AND FLUID HOLDOVER TIME TESTS FOR WINTER 96/97
(Short Title: Winter Tests 96/97)
(November 1996)

1 INTRODUCTION

Following the crash of a F-28 at Dryden in 1989 and the subsequent recommendations of the Commission of Inquiry, the Dryden Commission Implementation Project (DCIP) of Transport Canada was set up. Together with many other regulatory activities an intensive DCIP research program of field testing of deicing and anti-icing fluids was initiated with guidance from the international air transport sector through the SAE G-12 Committee on Aircraft Ground De/Anti-icing. As a result of the work performed to date Transport Canada and the US Federal Aviation Administration (the FAA) have been introducing holdover time regulations and the FAA has requested that the SAE, continue its work on substantiating the existing ISO/AEA/SAE Holdover Time (HOT) tables (DCIP research representing the bulk of the testing).

The times given in HOT Tables were originally established by European Airlines based on assumptions of fluid properties, and anecdotal data. The extensive testing conducted initially by the DCIP R&D Task Group and subsequently by Transport Canada, Transportation Development Centre (TDC), which has taken over the functions of the DCIP, has been to determine the performance of fluids on standard flat plates in order to substantiate the times, or if warranted, to recommend changes.

DCIP has undertaken most of the field research and much other allied research to improve understanding of the fluid HoldOver Times. Most of the HOT table cells been substantiated, however low temperatures have not been adequately explored and further tests are needed.

The development of ULTRA by Union Carbide stimulated all the fluid manufacturers to produce new long lasting anti-icing fluids defined as Type IV. All the Type IV fluids were upgraded in early 1996 and therefore all table conditions need to be re-evaluated and the table revised if necessary. Certain special conditions for which advance planning is particularly difficult such as low temperatures with precipitation, rain or other precipitation on cold soaked surfaces, and precipitation rates as high as 25 $gm/dm^2/hr$ need to be included in the data set. All lead to the need for further research.

Although the Holdover tables are widely used in the industry as guides to operating aircraft in winter precipitation the significance of the range of time values given in each cell of the table is obscure. There is a clear need to improve the understanding of the limiting weather conditions to which these values relate.

An important effort was made in the 94/95 and 95/96 seasons to verify that the flat plate data were representative of aircraft wings. Airlines cooperated with DCIP by making aircraft and ground support staff available at night to facilitate the correlation testing of flat plates with performance of fluids on aircraft. An extension of this testing was to observe patterns of fluid failure on aircraft in order to provide data to assist pilots with visual determination of fluid failure failure, and to provide a data to contamination sensor manufacturers. The few aircraft tests made to validate the flat plate tests were inconclusive and more such tests are needed. Additional tests testing with hot water and with hot air for special deicing conditions were not completed. All these areas are the subjects for the further research that is planned for the 96/97 winter.

2 PROGRAM OBJECTIVE (MCR 16)

Take an active and participatory role to advance aircraft ground de-icing/anti-icing technology. Develop international standards, guidance material for remote and runway-end de-icing facilities, and more reliable methods of predicting de-icing/anti-icing hold-over times.

3 PROGRAM SUB-OBJECTIVES

3.1 Develop reliable holdover time (HOT) guideline material based on test information for a wide range of winter weather operating conditions.

3.2 Substantiate the guideline values in the existing holdover time (HOT) tables for fluids that have been qualified as acceptable on the basis of their impact on aircraft take-off performance.

3.3 Perform tests to establish relationships between laboratory testing and real world experience in protecting aircraft surfaces.

3.4 Support development of improved approaches to protecting aircraft surfaces from winter precipitation.

4 PROJECT OBJECTIVES

4.1 To complete the substantiation of holdover time tables and evaluate those parameters that may reduce holdover times for currently available and properly qualified, SAE deicing and anti-icing fluids (Types I,II,III and IV).

4.2 To collect weather data on winter storms at airports and to assess the precipitation, wind and temperature values that bound the holdover time ranges given in the tables.

4.3 To develop a procedure for evaluating fluid dry out characteristics and to determine the dry-out characteristics of fluids.

4.4 To determine the influence of fluid type, precipitation and wind on location and time to fluid failure initiation, and also failure progression on service aircraft .

5. DETAILED STATEMENT OF WORK

5.1 Planning and Preparation

5.1.1 Program management

The work shall be broken down into the distinct areas of activity consistent with the project objectives.

A detailed workplan, activity schedule, cash flow projection, project management control and documentation procedure shall be developed and delivered to the TDC project officer for approval within one week of effective start date.

5.1.2 Coordination

Prepare, plan, and coordinate with personnel from TDC, airlines, airport authorities, fluid manufacturers, Instrumentation suppliers, and the National research Council of Canada (NRC) with respect to site requirements and test procedures; training of test personnel; conduct of dry-run(s) under no-precipitation conditions; and conduct of tests.

5.1.3 Safety of Personnel and Aircraft

Planning shall include precautions to ensure safety of personnel, and safety (freedom from damage) of aircraft.

A safety officer shall be nominated to prepare an appropriate plan, and monitor its implementation.

Conduct of tests shall respect OSHA standards, Quebec CSST standards and applicable sections of the Canadian and Quebec labour codes. Where exceptions are taken due to the nature of the work, e.g. emplacement of power and instrumentation cables in the work area, test personnel shall be made aware of potential hazards.

Within the work area, comprising the de-icing pad and access ways, test personnel shall co-ordinate their movements and be made aware of all other operations taking place. Movement of airline equipment - aircraft, tow trucks, de-icing trucks, shall have precedence over test personnel activities.
Care shall be taken to ensure that mobile equipment, such as inspection platforms, lighting stands etc. are not in contact with aircraft surfaces. Potential contact points for such equipment shall be padded.
Movements of visitors and personnel not directly involved in tests at any given time shall be tightly controlled, with safety as the governing criteria.
Obtain 'Airport owners and operators premises and products liability insurance' to indemnify and hold harmless the airport and the operators against any claim arising.

5.2 Substantiation of HoldOver Time Tables

5.2.1 Site preparation.

Set up experimental sites and install sensors as inspection aids to provide consistent plate failure conditions under field and laboratory conditions.

5.2.2 Completion of substantiation of existing Type I and Type II SAE holdover time tables at very low temperatures.

Conduct flat plate tests under conditions of natural snow precipitation to substantiate the existing Type I holdover time table at temperatures below -10°C. Tests shall be conducted at temperatures as low as possible. Tests shall be conducted with at least two different manufacturers fluids, one propylene glycol and one ethylene glycol.
Conduct flat plate tests under conditions of natural snow precipitation to confirm the existing Type II holdover time table at temperatures between -14°C and -25°C, and to substantiate the existing Type II holdover time table at temperatures below -25°C. Tests shall be conducted down to the lowest temperatures experienced in the field consistent with maintenance of a 7°C buffer for each fluid tested. Tests shall be conducted with at least three different manufacturers fluids.
Planning shall be based on conduct of tests at Dorval Airport, Montreal. consideration shall be given to conduct of alternate test sites where the required test conditions may occur more frequently.

5.2.3 Evaluation of HoldOver Time performance of qualified Type III fluids; and Creation of a generic Type III Holdover time table.

Conduct flat plate tests under conditions of natural precipitation and in the laboratory to establish the holdover time performance of qualified Type III fluids.
Create a generic Type III HoldOver Time table in consultation with TDC.

5.2.4 Substantiation of Type IV fluids.

Conduct flat plate tests under conditions of natural precipitation and in the laboratory to substantiate the performance of new Type IV fluids over the full range of Holdover time characteristic conditions. Four new Type IV fluids are presently anticipated.

5.2.5 Review of 'Buffer' Temperatures

Note: The guidelines for holdover times given in the SAE Tables call for the freezing points of fluid mixtures to be at least 10°C (18°F) for Type I, and 7°C (13°F) for Type II below the ambient air temperature.

Review, from an operations standpoint, the components which contribute to these requirements including the effects of imprecise initial fluid mixture strength, discrepancies between nominal ambient temperature and actual temperature at the aircraft, discrepancies between ambient temperature and wing temperature, and possible precipitation accumulation where applicable. An independent reviewer will conduct a separate review of 'Buffer' temperatures oriented towards an evaluation of the properties of de/ant-icing fluids.

Prepare recommendations in cooperation with the independent reviewer and with TDC for possible revisions to the buffer temperatures for frost removal, for aircraft protection at very low temperatures, and to the 'lowest operational use temperature'.

5.2.6 Preparation of HoldOver Time Tables

Prepare draft revised Holdover Time tables for discussion at SAE Holdover Sub-committee meetings. Prepare presentation material for dissemination at SAE G-12 Committee meetings.

5.2.7 Presentation of findings

Participate at the SAE meeting to be held in Pittsburgh in June 1997, and present the results of the HoldOver Test work conducted during the winter season 1996/97.

5.3 Assembly of Weather Data

Assemble weather data from READAC, field measurements, and other data sources taken over several seasons for winter storms at airports for assessment of the precipitation, wind and temperature values that correspond to the limiting values given in the holdover time tables.

Data shall be assembled in a coherent electronic format, for use by others, to establish the combinations of precipitation, wind and temperature values that delimit holdover times.

5.4 Fluid Dry-Out Characteristics

5.4.1 Development of a Potential Test Procedure

Identify a potential procedure for testing the dry out characteristics of fluids using a simulated winter climb-to-altitude environment.

Base the procedure on use of a de-pressurization chamber such as that available at the Centre de Recherche Industriel du Quebec (CRIQ), or equivalent.

The procedure shall take into account action to be taken in the event that pressure and temperature cannot both correspond to a typical aircraft ascent path.

5.4.2 Characteristics of Fluids

Describe the dry-out characteristics of sample qualified Type II fluids to provide a benchmark for comparative evaluation of new fluids.

Determine the dry out characteristics of Type II and Type IV fluids.

Photographic coverage shall be provided where appropriate.

5.4.3 Acceptance Criteria

Review with aircraft operators the effects of contamination (e.g. residual grease, dirt, and ice) in 'aerodynamically quiet areas' on aircraft critical surfaces such as flap tracks, etc. Report on the significance of such contamination as it affects equipment operation, and as it affects maintenance.

Develop a tentative fluid dry-out acceptance criteria in conjunction with TDC.

5.4.4 Review and Coordination Meetings

Participate in review and coordination meetings with TDC and with the Université du Québec à Chicoutimi, Anti-icing Materials International Laboratory (AMIL) where similar work is being undertaken.

5.5 Aircraft Full Scale Tests

5.5.1 Purpose of tests

Conduct full scale aircraft tests:

- to generate data which can be used to assist pilots with visual identification of fluid failure failure;
- to assess a pilot's field of view during adverse conditions of winter precipitation for selected aircraft;

- to assess whether Representative Surfaces can be used to provide a reliable first indication of anti-icing fluid failure;
- to explore the potential application of point detection sensors to warn the Pilot in Command (P.I.C.) of an 'unsafe to take-off condition';
- to obtain failed fluid contamination distributions and profiles which can serve as inputs to a theoretical program designed to assess the effects of such contamination on possible aircraft take-off performance; and
- to compare the performance of de/anti-icing fluids on aircraft surfaces with the performance of de/anti-icing fluids on flat plates.

5.5.2 Test Locations

Conduct tests at Dorval International Airport, Montreal and Pearson International Airport, Toronto using aircraft made available by airlines. Contingency plans shall be made to conduct tests at alternative sites: Ottawa, Uplands Airport; Quebec City, Ancienne Lorette Airport.

5.5.3 Facilities to be Provided

Provide all necessary equipment and facilities for conduct of the tests. Negotiate provision of ancillary equipment and services where possible with the pertinent airlines. Notify TDC of such arrangements. Equipment shall include lighting fixtures as necessary, observation platforms, vehicles, storage facilities, office facilities and personnel rest accommodation. Additional facilities and test equipment, if required, may be requested subject to agreement by all parties involved.

5.5.4 Test Plans

Prepare Test Plans for full-scale aircraft tests to include the following:

a) A detailed statement of work for each of the participants;

b) A specific test plan, for review by all parties, which will include as a minimum:
- Schedule and sequence of activities;
- Detailed list of responsibilities;
- Complete equipment list;
- List of data, measurements and observations to be recorded; and
- Test procedures.

c) A list of test activities including:
- Visual and Instrumented Data Logging;
- Monitoring and recording environmental conditions, including:
    - Air temperature,
    - Wing surface temperature at selected locations,

- Wind velocity and direction, and
- Precipitation type and rate;

- Record of aircraft and plate orientation to the wind; and
- Use of instrumentation to determine the condition of the fluid.

d) Data to be acquired from the tests including:
- Identification of fluid failure criteria;
- Location of first point of fluid failure on the wing, and subsequent failure progression;
- Correlation of fluid failure time to environmental conditions;
- Correlation of fluid failure times on flat plates and aircraft; and
- Behaviour of fluid on the "representative" surface.

Develop a procedure for concurrent comparison testing of fluids under conditions of natural freezing precipitation on flat plates and on aircraft.
Present plans for review and approval by the TDC project officer.
Present the approved program to the airline involved prior to the start of field tests.

5.5.5 Test Scheduling
Schedule tests on the basis of forecast freezing precipitation.
Notify the airline in advance of the desired test set-up, including aircraft orientation with respect to the forecast wind direction, sequence of fluid applications, and any additional services requested.
Confirm that the de-icing equipment used for the tests is equipped with a nozzle suitable for the application of the pertinent fluids. Application of fluids will be by airline personnel.

5.5.6 Personnel and facility preparation
Recruit and train local personnel who will conduct test work.
Secure necessary approvals and passes for personnel and vehicle access for operation on airport airside property.
Provide all equipment and all other instrumentation necessary for conduct of tests and recording of data.
Arrange (with the cooperation of TDC) for deicing equipment and aircraft to be made available for the tests .
Arrange for the provision of fluids for spraying an aircraft. Where possible fluids shall be supplied by the original fluid manufacturer to the operators on a replacement basis either directly or through intermediaries.
Arrange for spray application during the initial tests to be observed by the fluid manufacturer's representative for endorsement.

5.5.7 Aircraft, De-Icing Pads and Crews

Planning shall be based on the following aircraft and facilities:

Aircraft	Airline	Test Locn.	De-Icing Pad	De-Icing Crew
Fokker F-100	American	Dorval	West	American
Canadair RJ	Comair	Dorval	West or East	Delta
Boeing 737	Canadian	Dorval	South or East	Canadian
ATR 42	Cdn. Regl.	Dorval	East	-
D-H DASH-8	Cdn. Regl.	Toronto (or Ottawa)	N/A	-

5.5.8 Dry Runs

Conduct a 'dry run' for test team personnel to ensure familiarity with their requested roles. Dry runs shall be scheduled as early in the winter season as can reasonably be achieved and shall be scheduled at the participating airline's convenience. Operations shall include Type I and Type IV fluid applications and re-orientation of the aircraft.

5.5.9 Full-Scale Tests

Conduct 8 full all-night test sessions.

Note: In general, aircraft will be made available for testing outside regular service hours, i.e. available between 23:00 hrs. and 06:00 hrs. Subject to weather conditions additional test sessions may be requested.

Tests shall be conducted under the following conditions:

Aircraft orientations:	Headwind, Crosswind, Tailwind
Precipitation:	Snow, Freezing drizzle (If possible)
Fluids:	Type I (Predominantly), Type IV
Engine Operations:	Anticipate dry run & full scale tests with engines running for Turbo-prop aircraft.

The following matrix of tests is anticipated:

Aircraft	No. of Tests	A/C Orient's*	Comments
Fokker F-100	1	T, C, H	Dry Run
Fokker F-100	2	T, C, H	Test F-100 & RJ in common if possible
Canadair RJ	2	T, C, H	
Boeing 737	2	T, C, H	
ATR 42	1	T, C, H	Engines running
D-H DASH-8	1	T, C, H	Engines running
Total Tests	8 + 1 dry run		

T = Tail Wind, C = Cross- Wind, H = Head Wind

5.5.10 Priority of Tests

Initial planning for tests shall be based on the matrix of tests covered by items 5.5.7 and 5.5.9, above.

Plans shall be made such that the number of tests with each aircraft and sequence of tests can be easily revised.

5.5.11 Aircraft Orientation and Fluid Application:

Tests shall be conducted in the following sequence: Tail to wind, Cross wind, Head wind.

For tests with Tail to wind and Nose to wind, Type I fluid shall be applied to the port wing, and Type I fluid followed by Type IV fluid shall be applied to the starboard wing in a standard 2-step application procedure. Tests with Type I fluid, only, shall be repeated without change in aircraft orientation until failure of the Type IV fluid.

For cross-wind tests both wings shall be treated with Type I only and observations of fluid behaviour made through to failure of the fluid on both wings.

Under conditions of light precipitation when the expected time to failure of the Type IV fluid is judged to be be 'excessive' the Type IV test shall be aborted, and the aircraft re-orientaion shall proceed for further Type I tests.

Under conditions of heavy precipitation when the expected time to failure of the Type IV fluid is judged to be be 'short', Type IV test(s) shall also be conducted in a cross-wind, with the same fluid application to both wings.

A maximum of three (3) Type I tests and one Type (IV) test are contemplated for each orientation, on a given test night.

5.5.12 Tests with Turbo-Prop Aircraft.

True functional tests with Turbo-prop aircraft; DeHavilland Dash 8 and ATR-42, require that the engines should be running.

Gather available information applicable to the ground operations of these aircraft in regular service. Based on observation and the observations of others, assess the influence of propeller 'wash' on fluid flow-back patterns, and on precipitation behaviour, particularly under cross wind conditions.

Only one test series, each, shall be conducted with these aircraft, and particular consideration shall be given to safety. In the event of conflict between access for data gathering to obtain required test results and safety considerations, safety shall govern.

5.5.13 Test Measurements

Make the following measurements during conduct of each test:

Contaminated thickness histories at points on wings, selected in cooperation with TDC.

Contamination histories at points on wings to be selected in cooperation with TDC.
Location and time of first failure of fluids on wings -
Concurrent measurement of time to failure of fluids on flat plates; plates to be mounted on standard frames and on aircraft wings at agreed locations.
Pattern and history of fluid failure Progression.
Wing temperature distributions.
Amount of fluid applied in each test run, and fluid temperature
Meteorological conditions.

5.5.14 'Clean' Fluid Thickness Measurements

In the event that there is no precipitation at the time of the dry run, or during full scale tests, advantage shall be taken to make measurements of fluid thickness distributions on the wings. These measurements shall be repeated for a number of fluid applications to assess uniformity of fluid application.

5.5.15 Pilot Observations

Contact airlines and arrange for pilots to be present during tests to observe fluid failure and failure progression. Record pilot observations for later correlation with aircraft external observervations.

5.5.16 Remote sensor records

Record the progression of fluid failure on the wing using RVSI and/or SPAR remote contamination detection sensors.

5.5.17 Videotape Records

Make videotape records of tests. Provide professional video tape coverage for at least two overnight test sessions.

5.5.18 Return of equipment

Return any equipment obtained from airlines for use during the tests to its original condition at the end of the test program.

5.5.19 Assembly and analysis of results

Assemble and analyze all results.

5.6 Fluids Physical Properties Measurements

In concert with the testing of fluids on flat plates undertaken in task 5.2 and the testing of fluids on aircraft undertaken in task 5.5, an independent researcher will conduct tests to determine the physical properties of the pertinent fluids.
Participate in a meeting with the researcher, to be called by TDC, to clarify roles and responsibilities and to establish priorities.

One of the flat plates to be used for flat plate measurements of fluid behaviour in all tests shall be fitted with a C/FIMS sensor. Make this plate available to the independent researcher for dedicated tests upon request. Make additional plates available for dedicated tests as requested by TDC.

5.7 Coordination with NRC
TDC will arrange with NRC to make the CEF cold chamber facility available for controlled environment testing as given in "Detailed statement of work". Co-ordinate with NRC for conduct of tests.

5.8 Presentations of test program results

5.8.1 Preliminary Findings
Prepare and present preliminary findings of test programs involving field tests with aircraft to representatives of Transport Canada and the Airlines involved at end of the test season, but no later than May 30 1997.

5.8.2 SAE G-12 Committee
Prepare and present, in conjunction with Transport Canada personnel, winter test program results at the SAE G-12 Committee meeting in Pittsburgh in June 1997.

5.8.3 Test Program Data
All data from tests shall be assembled in electronic format; a backup of all data files will be stored on a dedicated PC and presented to TDC. The data files will be updated on an ongoing basis throughout the test period. Graphic presentation material shall be supplied to facilitate data display.

5.9 Reporting
Reporting shall be in accordance with section 10 "Reporting", below. Separate final reports shall be issued for each area of activity consistent with the project objectives.

6. ROLE OF OTHER PARTIES

Agreements as and when needed will be made by Transport Canada with the following airlines: Air Canada, American Airlines, Comair, Canadian Airlines International Ltd., and Canadian Regional Airlines Ltd. to provide aircraft, equipment and facilities for conduct of tests as outlined in the 'Detailed statement of work'. Direct contact with appropriate personnel of the airlines is encouraged, however TDC shall be advised of all such contacts.

APPENDIX B

EXCERPTS FROM
SAE AEROSPACE RECOMMENDED PRACTICE ARP4737

SAE The Engineering Society For Advancing Mobility Land Sea Air and Space®
INTERNATIONAL®
400 Commonwealth Drive, Warrendale, PA 15096-0001

AEROSPACE RECOMMENDED PRACTICE

Submitted for recognition as an American National Standard

SAE ARP4737 REV. C

Issued 1992-10
Revised Proposed Draft 1997-10-02

Superseding ARP4737B

AIRCRAFT DEICING/ANTI-ICING METHODS WITH FLUIDS

FOREWORD

The purpose of this document is to provide guidelines for the methods and procedures used in performing the maintenance operations and services necessary for proper deicing and anti-icing of aircraft on the ground.

Exposure to weather conditions, on the ground, that are conducive to ice formation, can cause accumulation of frost, snow, slush, or ice on aircraft surfaces and components that can adversely affect aircraft performance, stability, and control and operation of mechanical devices such as control surfaces, sensors, flaps, and landing gear. If frozen deposits 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.

Regulations governing aircraft operations in icing conditions shall be followed. Specific rules for aircraft are set forth in United States Federal Aviation Regulations (FAR), Joint Aviation Regulations (JAR), Canadian Air Regulations, and others. Paraphrased, these rules relate that NO ONE SHOULD DISPATCH OR TAKE OFF AN AIRCRAFT WITH FROZEN DEPOSITS ON COMPONENTS OF THE AIRCRAFT THAT ARE CRITICAL TO SAFE FLIGHT. A critical component is one which could adversely affect the mechanical or aerodynamic function of an aircraft. The intent of these rules is to assure that no one attempts to dispatch or operate an aircraft with frozen deposits that were not approved by the regulatory authorities.

The ultimate responsibility for the determination that the aircraft is clean and meets airworthiness requirements rests with the pilot in command of the aircraft.

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6.3 Limits/Precautions:

6.3.1 Fluid Related Limits:

CAUTION: SAE Type I fluids supplied as concentrates for dilution with water prior to use shall not be used undiluted, unless they meet aerodynamic performance and freezing point buffer requirement (reference AMS 1424). This is due to adverse aerodynamic effects of propylene glycol and diethylene glycol based fluids and the freeze point characteristics of ethylene glycol and diethylene glycol based fluid.

6.3.1.1 Temperature Limits (see appropriate figures): When performing two step deicing/anti-icing, the FP of the fluid used for the first step shall not be more than 3 °C (5 °F) above ambient temperature (refer to 6.3.3.2).

6.3.1.1.1 SAE Type I Fluids: The FP of the SAE Type I fluid mixture used for either one step deicing/anti-icing or as a second step in the two step operation shall be at least 10 °C (18 °F) below the ambient temperature.

6.3.1.1.2 SAE Type II and IV fluids used as deicing/anti-icing agents may have a lower temperature application limit of -25 °C (-13 °F). The application limit may be lower, provided a 7 °C (13 °F) buffer is maintained between the FP of the concentrated fluid and OAT. In no case shall this temperature be lower than the lowest operational use temperature as defined by the aerodynamic acceptance test.

6.3.1.2 Application Limits (see applicable figures): Under no circumstances shall an aircraft that has been anti-iced receive a further coating of anti-icing fluid directly on top of the contaminated film. Should it be necessary for an aircraft to be reprotected prior to the next flight, the external surfaces shall first be deiced with a hot deicing fluid mix before a further application of anti-icing fluid.

6.3.2 Aircraft Related Limits: The application of deicing/anti-icing fluid shall be in accordance with the requirements of the airframe/engine manufacturers.

6.3.3 Procedure Precautions:

6.3.3.1 One Step Deicing/Anti-icing: It is performed with an anti-icing fluid (see 3.2.2). The correct fluid concentration is chosen with regard to desired holdover time, dictated by OAT and weather conditions.

CAUTION: Wing skin temperature may differ and in some cases may be lower than OAT. A stronger mix can be used under the latter conditions

Outside Air Temperature OAT	One-Step Procedure see 6.3.3.1 Deicing/Anti-icing	Two-Step Procedure see 6.3.3.2 First Step: Deicing	Second Step: Anti-icing[1]
-3 °C (27 °F) and above	FP of heated fluid[2] mixture shall be at least 10 °C (18 °F) below OAT	Water heated to 60 °C (140 °F) minimum at the nozzle or a heated mix of fluid and water.	FP of fluid mixture shall be at least 10 °C (18 °F) below actual OAT
Below -3 °C (27 °F)		FP of heated fluid mixture shall not be more than 3 °C (5 °F) above OAT	

NOTE: For heated fluids, a fluid temperature not less than 60° C (140° F) at the nozzle is desirable. Upper temperature limit shall not exceed fluid and aircraft manufacturer's recommendations.

CAUTION: Wing skin temperatures may differ and in some cases may be lower than OAT. A stonger mix (more glycol) can be used under the latter conditions.

1 To be applied before first step fluid freezes, typically within 3 min.
2 Clean aircraft may be anti-iced with *unheated* fluid

FIGURE 1 - Guidelines for the Application of SAE Type I Fluid Mixtures (Minimum Concentrations) as a Function of Outside Air Temperature (OAT)

<table>
<tr><th rowspan="2">Outside Air Temperature OAT</th><th rowspan="2">One-Step Procedure see 6.3.3.1 Deicing/Anti-icing</th><th colspan="2">Two-Step Procedure see 6.3.3.2</th></tr>
<tr><th>First Step: Deicing</th><th>Second Step: Anti-icing[1]</th></tr>
<tr><td>-3 °C (27 °F) and above</td><td>50/50 Heated[2] Type II/IV</td><td>Water heated to 60 °C (140 °F) minimum at the nozzle or a heated mix of Type I, II or IV with water.</td><td>50/50 Type II/IV</td></tr>
<tr><td>Below -3 °C (27 °F) to -14 °C (7 °F)</td><td>75/25 Heated[2] Type II/IV</td><td rowspan="2">Heated suitable mix of Type I, II or IV with FP not more than 3 °C (5 °F) above actual OAT.</td><td>75/25 Type II/IV</td></tr>
<tr><td>Below -14° C (7° F) to -25 °C (-13 °F)</td><td>100/0 Heated[2] Type II/IV</td><td>100/0 Type II/IV</td></tr>
<tr><td>Below -25 °C (-13 °F)</td><td colspan="3">SAE Type II/IV fluid may be used below -25 °C (-13 °F) provided that the freezing point of the fluid is at least a 7 °C (13 °F) below OAT and that aerodynamic acceptance criteria are met. Consider the use of SAE Type I when Type II/IV fluid cannot be used (see Figure 1).</td></tr>
</table>

NOTE: For heated fluids, a fluid temperature not less than 60° C (140° F) at the nozzle is desirable. Upper temperature limit shall not exceed fluid and aircraft manufacturer's recommendations.

CAUTION: Wing skin temperatures may differ and in some cases may be lower than OAT. A stronger mix *(more glycol)* can be used under the latter conditions.

1 To be applied before first step fluid freezes, typically within 3 min.
2 Clean aircraft may be anti-iced with *unheated* fluid

CAUTION: An insufficient amount of anti-icing fluid, especially in the second step of a two step procedure may cause *a* substantial loss of holdover time; *particularly when using a Type I fluid mixture for the first step (deicing).*

FIGURE 3 - Guidelines for the Application of SAE Type II and Type IV Fluid Mixtures (Minimum Concentrations) as a Function of Outside Air Temperature (OAT)

concentrations in % V/V

Outside air temperature OAT	One-step procedure see para. 6.3.3.1 Deicing/anti-icing	Two-step Procedure see para. 6.3.3.2	
		First step: Deicing	Second step Anti-icing 1)
-3° C (27° F) and above	100/0 Heated 2 Type III	Water heated to 60°C (140°F) minimum at the nozzle or a heated mix of Type I or III with water	100/0 Type III
Below -3° C (27° F) to -14° C (7° F)	100/0 Heated 2 Type III	**Heated suitable mix of Type I or III with FP not more than 3 °C (5 °F) above actual OAT.**	100/0 Type III
Below -14° C (7° F)	SAE Type III fluid may be used below -14° C (-7° F) provided that the freezing point of the fluid is at least a 7° C (13° F) below OAT and that aerodynamic acceptance criteria are met. Consider the use of SAE Type I when Type III fluid cannot be used (see Figure 1).		

Note: For heated fluids, a fluid temperature not less than 60° C (140° F) at the nozzle is desirable.
Upper temperature limit shall not exceed fluid and aircraft manufacturers recommendations

Caution: Wing skin temperatures may differ and in some cases may be lower than OAT.

Caution: An insufficient amount of anti-icing fluid, especially in the second step of a two step procedure, may cause a substantial loss of holdover time. This is particularly true when using a Type I fluid mixture for the first step(deicing)

1) To be applied before first step fluid freezes, typically within 3 minutes
2) Clean aircraft may be anti-iced with cold fluid.

FIGURE 6 - Guidelines for the Application of SAE Type III Fluid Mixtures as a Function of Outside Air Temperature (OAT)

APPENDIX C

EXCERPTS FROM WING TEMPERATURE SURVEY REFERENCE (5)

FIGURE C.1

TEMPERATURE DIFFERENTIAL AS FUNCTION OF OUTSIDE AIR TEMPERATURE (All Aircraft, All Airports)

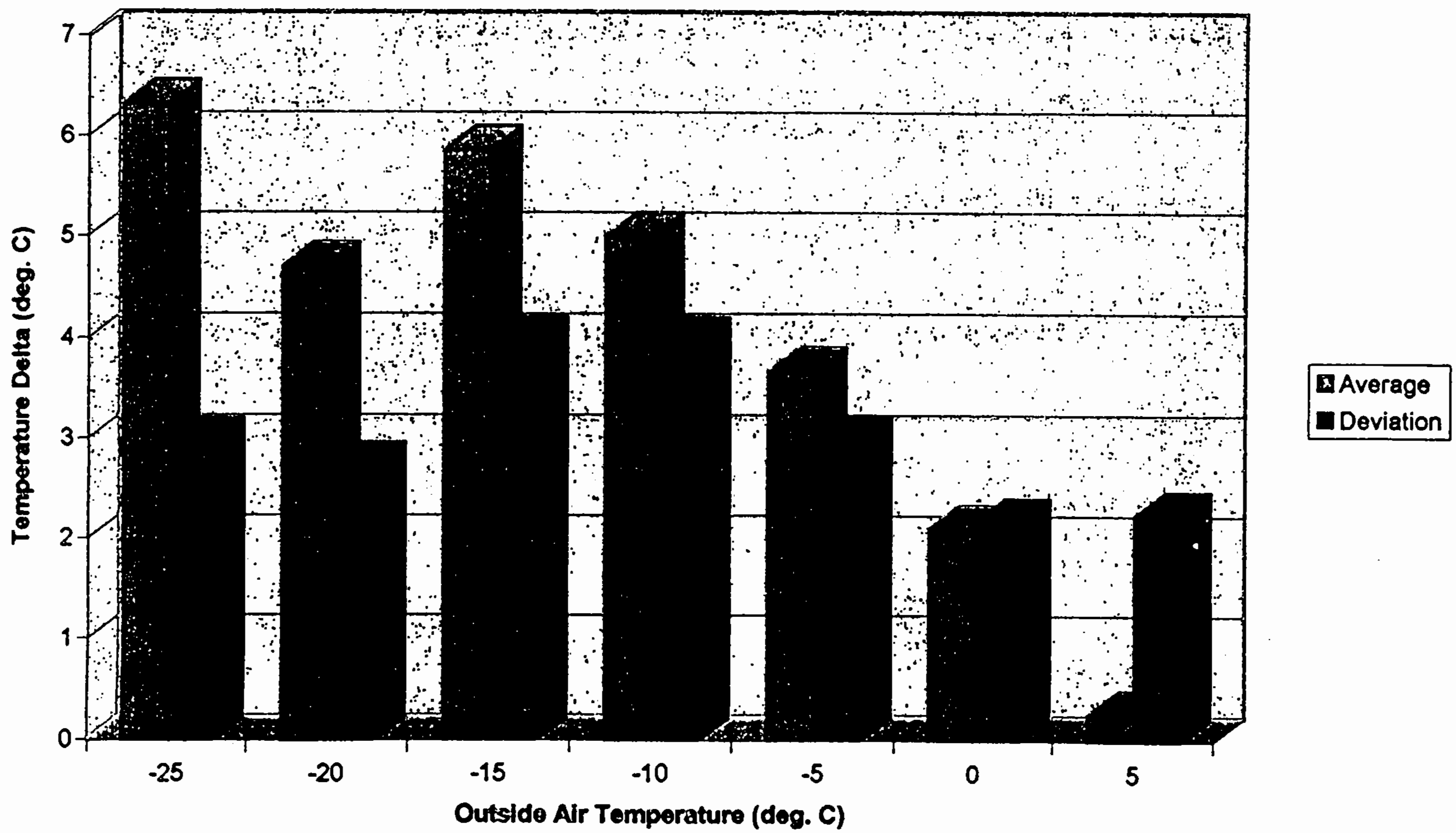

FIGURE C.2

TEMPERATURE DIFFERENTIAL AS FUNCTION OF OUTSIDE AIR TEMPERATURE (All Aircraft, YWG)

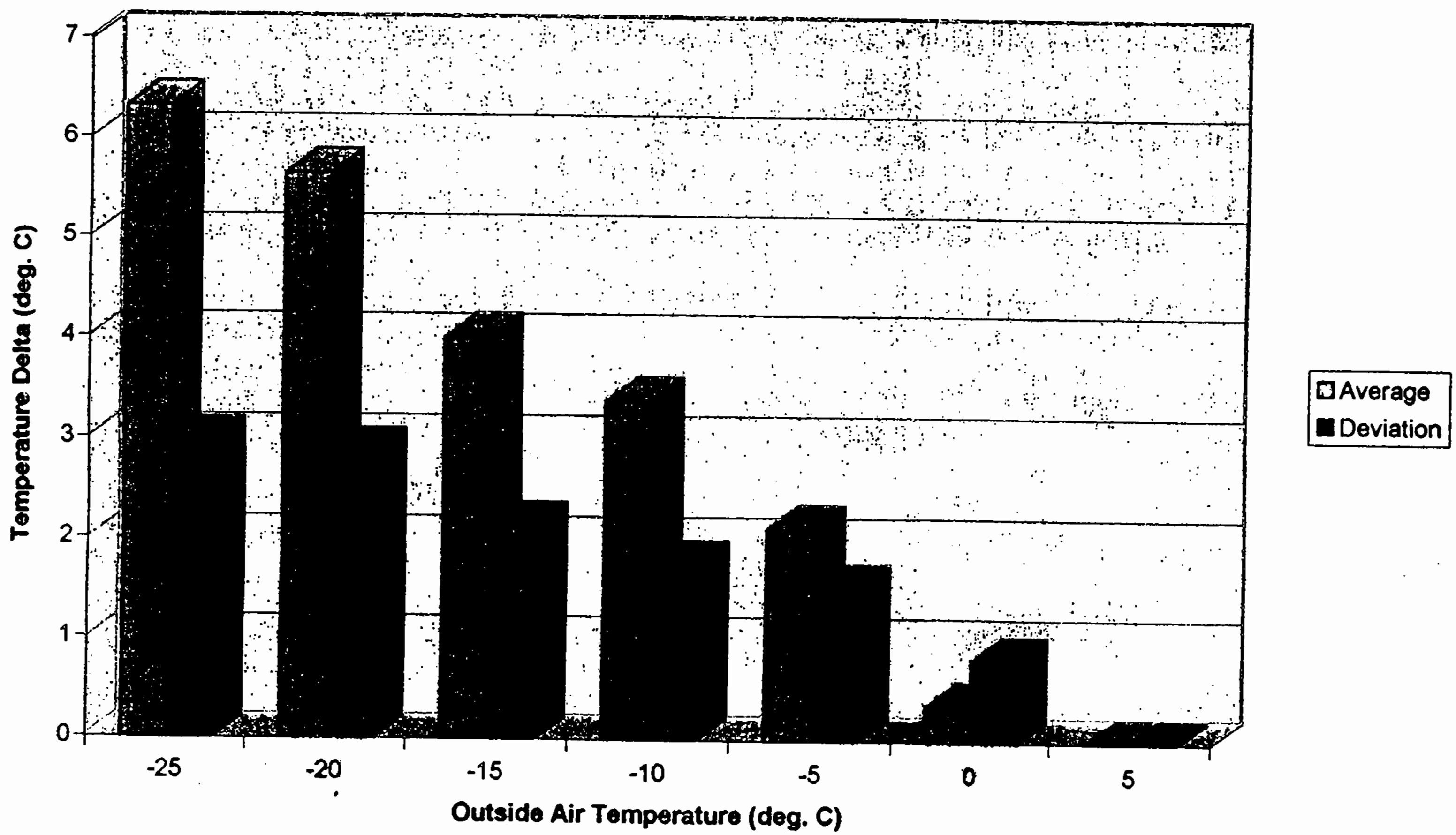

FIGURE C.3

TEMPERATURE DIFFERENTIAL AS FUNCTION OF OUTSIDE AIR TEMPERATURE (DC9, All Airports)

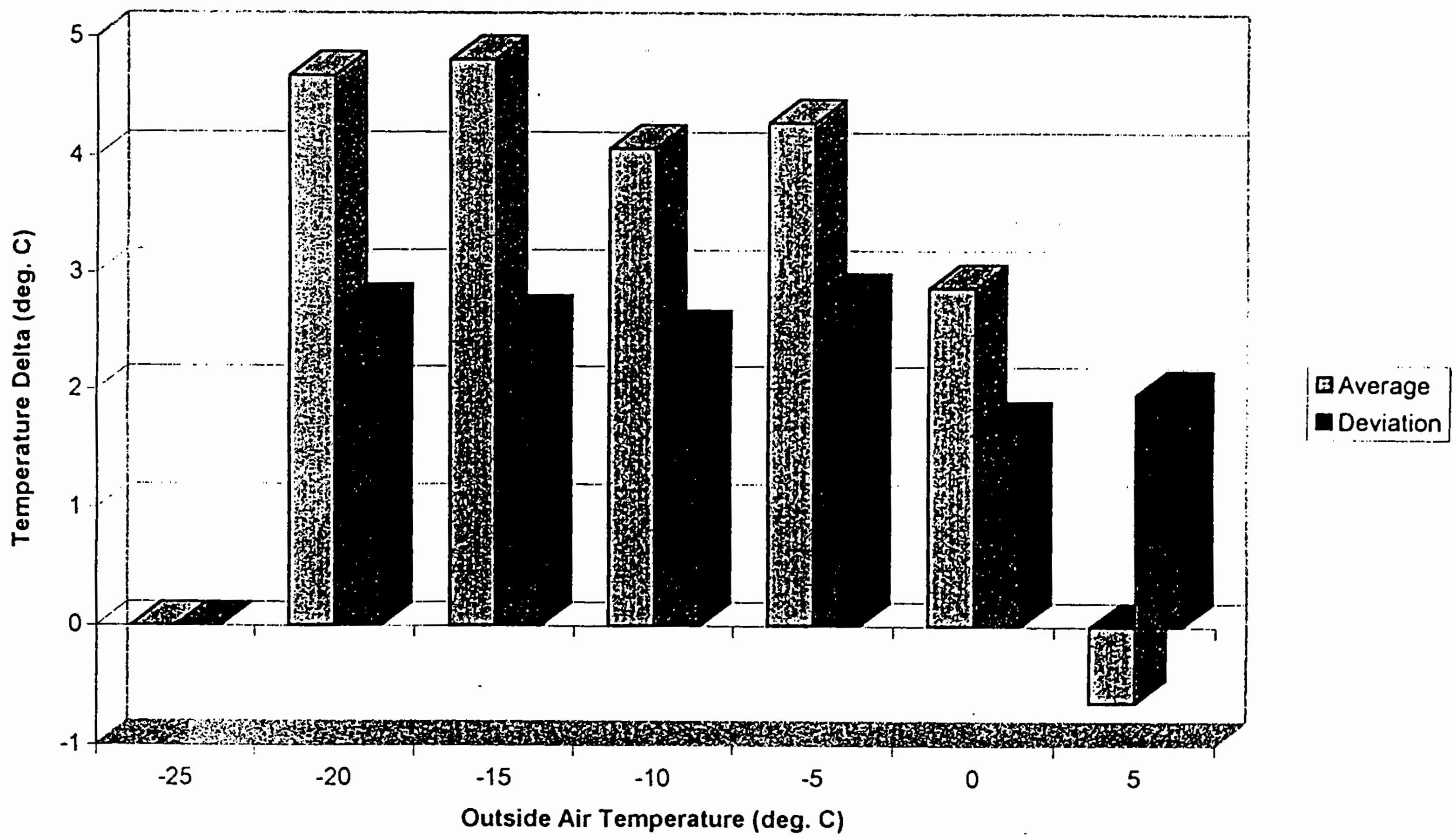

FIGURE C.4

EUROPEAN DATA
TEMPERATURE DIFFERENTIAL AS FUNCTION OF OUTSIDE AIR TEMPERATURE
(R/H Wing. At Arrival)

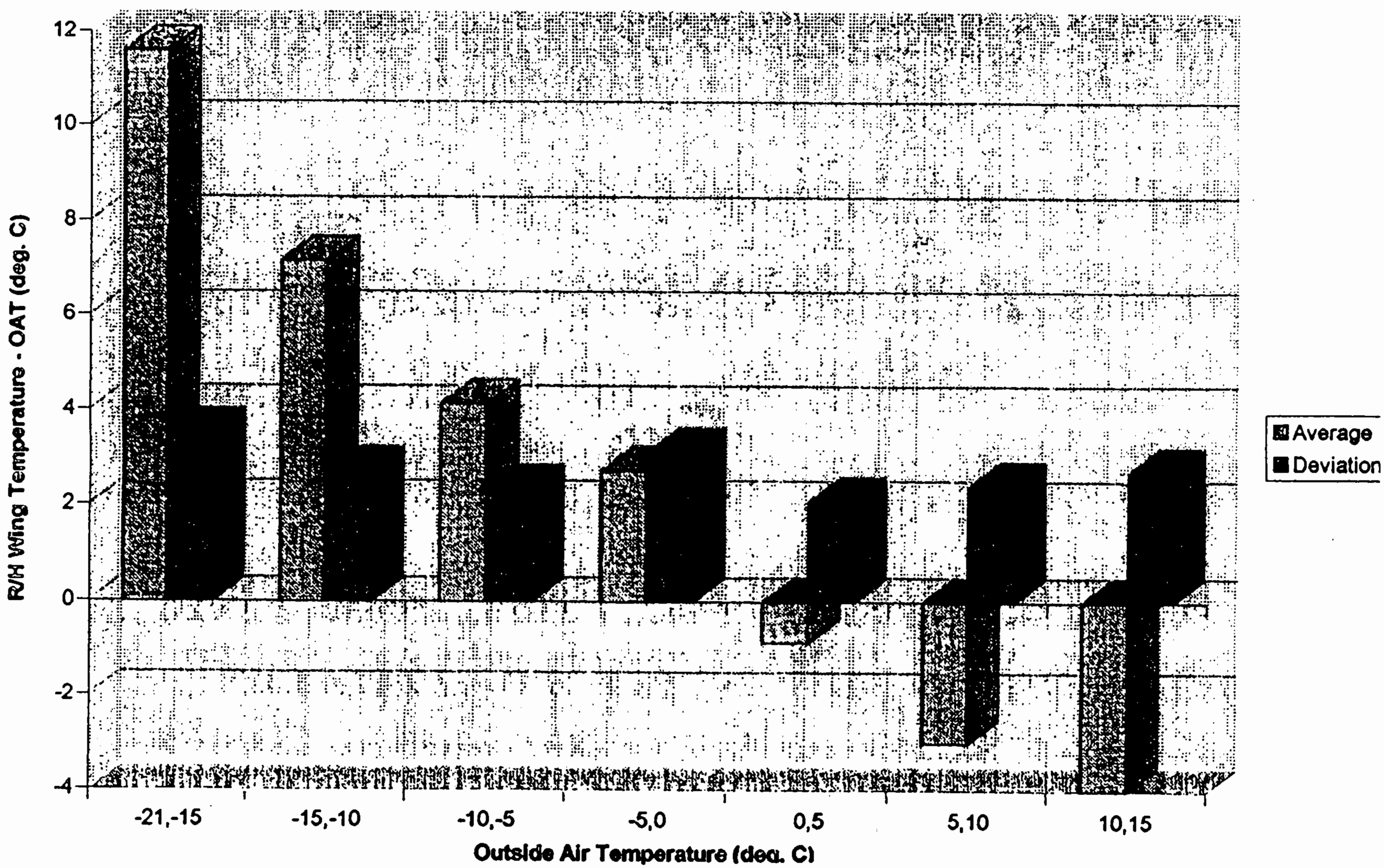

FIGURE C.5

EUROPEAN DATA
TEMPERATURE DIFFERENTIAL AS FUNCTION OF OUTSIDE AIR TEMPERATURE
(Left Wing, Point 2)