Transport Canada Transports Canada

Canada

April 2004

Tactile Inspection for Detection of Ice on Aircraft Surfaces

Notes on Current Practice: Update Spring 2004

Transport Canada
Transportation Development Centre

TP 13858E

TP 13858E

TACTILE INSPECTION FOR DETECTION OF ICE ON AIRCRAFT SURFACES

Notes on Current Practice: Update Spring 2004

by

F.W. Eyre
Transportation Development Centre
Transport Canada

April 2004

Notices

This report reflects the views of the author and not necessarily those of Transport Canada.

Transport Canada does not endorse products or manufacturers. Trade or manufacturers' names appear in this report only because they are essential to its objectives.

Un sommaire français se trouve avant la table des matières.

Transport Canada / Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No. TP 13858E	2. Project No. 5005 (DC 142J)	3. Recipient's Catalogue No.
4. Title and Subtitle Tactile Inspection for Detection of Ice on Aircraft Surfaces: Notes on Current Practice: Update Spring 2004		5. Publication Date April 2004 6. Performing Organization Document No.
7. Author(s) F.W. Eyre		8. Transport Canada File No. ZCD2450-B-14
9. Performing Organization Name and Address Transportation Development Centre (TDC) 800 René Lévesque Blvd. West Suite 600 Montreal, Quebec H3B 1X9		10. PWGSC File No. 11. PWGSC or Transport Canada Contract No.
12. Sponsoring Agency Name and Address Transportation Development Centre (TDC) 800 René Lévesque Blvd. West Suite 600 Montreal, Quebec H3B 1X9		13. Type of Publication and Period Covered 14. Project Officer Frank Eyre

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

16. Abstract

Remote sensors are potentially more effective than tactile inspection in consistently and reliably determining whether frozen contamination remains present following aircraft deicing. A preliminary study failed to identify any applicable documentation on tactile inspection performance.

Anecdotal information on the conduct of tactile inspection was therefore sought from deicing operators/personnel and is well documented.

The regulatory environment was reviewed. Development of a test program to compare sensor detection with tactile procedures was considered. Substantial difficulties were associated with quantifying human tactile behaviour in a winter aircraft ground operating environment. The tactile inspection procedure was found to involve more than simply feeling an iced surface. It was concluded that a recorded history of field experience with remote sensors, supported by theoretical characterization of residual ice, needs to be generated.

This update has been prepared to include results of studies conducted since the original report was prepared in March 2002.

17. Key Words Tactile inspection, aircraft, ground icing, contamination sensors, update	18. Distribution Statement Limited number of copies available from the Transportation Development Centre

19. Security Classification (of this publication) Unclassified	20. Security Classification (of this page) Unclassified	21. Declassification (date) —	22. No. of Pages xii, 30, apps	23. Price Shipping/ Handling

Transports Canada | Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. Nº de la publication de Transports Canada TP 13858E	2. Nº de l'étude 5005 (DC 142J)	3. Nº de catalogue du destinataire
4. Titre et sous-titre Tactile Inspection for Detection of Ice on Aircraft Surfaces: Notes on Current Practice: Update Spring 2004		5. Date de la publication Avril 2004
		6. Nº de document de l'organisme exécutant
7. Auteur(s) F.W. Eyre		8. Nº de dossier - Transports Canada ZCD2450-B-14
9. Nom et adresse de l'organisme exécutant Centre de développement des transports (CDT) 800, boul. René-Lévesque Ouest Bureau 600 Montréal (Québec) H3B 1X9		10. Nº de dossier - TPSGC
		11. Nº de contrat - TPSGC ou Transports Canada
12. Nom et adresse de l'organisme parrain Centre de développement des transports (CDT) 800, boul. René-Lévesque Ouest Bureau 600 Montréal (Québec) H3B 1X9		13. Genre de publication et période visée
		14. Agent de projet Frank Eyre

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

16. Résumé

Les capteurs à distance sont potentiellement plus efficaces que l'inspection tactile pour déterminer de façon constante et fiable la présence de contamination solide après le dégivrage d'un aéronef. Une recherche documentaire préliminaire sur la question de l'inspection tactile s'est révélée infructueuse.

Des données anecdotiques sur la procédure d'inspection tactile ont donc été recueillies auprès de responsables de services de dégivrage et de leur personnel. Le rapport fait clairement état de ces données.

Les chercheurs ont passé en revue la réglementation touchant les inspections. Ils ont envisagé l'élaboration d'un programme d'essais pour comparer la détection à l'aide de capteurs et la procédure d'inspection tactile. Il s'est révélé très difficile de quantifier le toucher humain lors d'opérations dans des conditions de givrage au sol. Il s'est avéré, notamment, que la procédure d'inspection tactile ne se limitait pas à palper une surface givrée. Il a été conclu à la nécessité de consigner les données issues de l'expérience de l'utilisation de capteurs à distance en conditions réelles, et corroborées par la caractérisation théorique du givre résiduel.

Cette mise à jour a été effectuée afin d'inclure les résultats d'études menées depuis la rédaction du rapport original datant de mars 2002.

17. Mots clés Inspection tactile, aéronef, givrage au sol, détecteurs de contamination, mise à jour	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

19. Classification de sécurité (de cette publication) Non classifiée	20. Classification de sécurité (de cette page) Non classifiée	21. Déclassification (date) —	22. Nombre de pages xii, 30, ann.	23. Prix Port et manutention

CDT/TDC 79-005
Rev. 96

Canada

Acknowledgements

The major part of the record of experience with tactile inspection given in this report has been provided by Mario Rosa and the staff of AéroMag 2000 inc., Wayne Anaka and the staff of GlobeGround North America, and Joe Ferrandini of Delta Airlines, Inc.

Thanks are also extended to Barry Myers of the Transportation Development Centre for his participation, contribution and guidance in the preparation of this report.

Foreword

Aviation regulations require that, under winter icing conditions, aircraft must be checked prior to takeoff to ensure there is no frost, ice or snow adhering to aircraft critical surfaces. Once an aircraft has been deiced, it is difficult to assess whether all ice has been removed or whether some is still present even under the deicing fluid. As a result, the requirement for a tactile inspection has, for some cases, become part of the deicing operation.

There is little information on the effectiveness of tactile inspection for detection of ice and no applicable research or published material on the topic. There is, however, a wealth of practical experience in the field with those who have long been involved in conducting tactile inspections. As an aid or alternative to tactile inspection, the possible use of remote sensing devices is also being considered.

The original report on tactile inspection for detection of ice on aircraft prior to takeoff was commissioned in 2002 to serve as a reference documenting the regulatory environment, field experience and sensor implications not reported elsewhere. This update has been issued to include newly available material.

Avant-Propos

La réglementation aérienne exige que, dans des conditions givrantes, des inspections soient effectuées avant le décollage, afin de déterminer si du givre, de la glace ou de la neige adhèrent aux surfaces critiques de l’aéronef. Une fois qu’un aéronef a été dégivré, il est difficile d’évaluer si toute la contamination a été enlevée ou s’il en subsiste sous le fluide de dégivrage. C’est ainsi qu’une inspection tactile est devenue obligatoire dans certains types d’opérations de dégivrage.

On dispose de peu de données sur l’efficacité de l’inspection tactile à détecter le givre. Aucun document pertinent, rapport de recherche ou autre, n’a été publié sur la question. Mais les préposés au dégivrage, qui effectuent depuis longtemps des inspections tactiles, possèdent une grande expérience pratique. Le rapport se penche en outre sur l’utilisation possible de capteurs à distance en complément ou en remplacement de l’inspection tactile.

Cette recherche originale sur l’inspection tactile pour la détection de contamination sur un aéronef avant le décollage a été exécutée en 2002, en raison du besoin de disposer d’un document de référence inédit sur le cadre réglementaire, l’expérience acquise sur le terrain et les incidences de l’utilisation de capteurs. Cette mise à jour a été effectuée afin d’inclure le matériel nouvellement disponible.

Executive Summary

Remote sensors have been proposed as an alternative to tactile inspection of aircraft critical surfaces immediately following deicing. Remote sensors are potentially more effective in determining whether there is frozen contamination present following deicing than can be achieved by human tactile inspection.

Despite significant testing, demonstration and limited field use, there has been no dedicated program to compare sensors with human tactile capability and performance in order to substantiate claims made. A review failed to identify any documented post-deicing tactile inspection performance that would provide a reference for comparative evaluation.

These notes document pertinent aviation regulations, available anecdotal information on the conduct of tactile inspection to determine whether there is frozen contamination present on aircraft surfaces following deicing under winter operating conditions, and experience to date with remote sensors in this application. The focus is on inspections conducted in the context of Canadian operations and regulations. This update has been prepared to include results of studies conducted since the original report was prepared in March 2002.

It is postulated that a thin layer of smooth ice, which might remain below the fluid after deicing and which is also below the current 0.5 mm thickness threshold of detection of frozen contamination detection sensors, supported by theoretical characterization of residual ice, would not constitute a hazard.

The difficulties associated with quantifying human tactile behaviour in a winter aircraft ground operating environment and developing a test program to compare sensor detection with tactile performance are considered. It is concluded that a recorded history of field experience with remote sensors, supported by theoretical characterization of residual ice, needs to be generated.

Sommaire

Une proposition a été faite de remplacer l'inspection tactile par des capteurs à distance pour vérifier l'état des surfaces critiques des aéronefs immédiatement après le dégivrage. Les capteurs à distance sont potentiellement plus efficaces que l'inspection tactile, réalisée par un humain, pour déterminer s'il subsiste de la contamination solide sur les surfaces de l'aéronef après le dégivrage.

Les capteurs ont été l'objet de multiples essais et démonstrations, et ils sont utilisés avec restrictions en service réel. Mais aucun programme n'a jamais été conçu expressément pour comparer les capteurs et le toucher humain, de façon à attester les prétendus avantages des capteurs. Une recherche documentaire sur la procédure d'inspection tactile consécutive à une opération de dégivrage s'est révélée vaine. On ne dispose donc d'aucun point de comparaison pour évaluer les capteurs.

Les présentes notes exposent la réglementation aérienne pertinente, résument l'information anecdotique disponible sur la procédure d'inspection tactile servant à déterminer s'il subsiste une contamination solide sur les surfaces de l'aéronef après une opération de dégivrage, et font état de l'expérience acquise à ce jour touchant l'utilisation de capteurs à distance pour détecter la contamination. L'accent est mis sur les inspections menées au Canada en vertu de la réglementation canadienne. Cette mise à jour a été effectuée afin d'inclure les résultats d'études menées depuis la rédaction du rapport original datant de mars 2002.

Les chercheurs ont posé comme postulat que la présence éventuelle d'une mince couche de glace vive sous le fluide de dégivrage, d'une épaisseur inférieure à 0,5 mm, soit le seuil actuel de détection de contamination gelée par les capteurs corroboré par la caractérisation théorique du givre résiduel, ne pose pas de danger.

Le rapport rend compte des difficultés associées à la quantification du toucher humain dans des conditions hivernales d'exploitation d'un aéronef au sol, et à l'élaboration d'un programme d'essais pour comparer la détection par des capteurs et par le toucher. Il conclut à la nécessité de consigner les données issues de l'expérience de l'utilisation de capteurs à distance en conditions réelles, et corroborées par la caractérisation théorique du givre résiduel.

Table of Contents

1. Introduction 1

2. Objectives 2

3. The Regulatory Environment 3
- 3.1 General 3
- 3.2 Canadian Regulations 4
- 3.3 U.S. Regulations 5
- 3.4 Joint Aviation Authorities Regulations 5

4. Information Gathering 6
- 4.1 Controlled Testing of Tactile Performance 6
- 4.2 Tactile Sensory Perception 6
- 4.3 Solicited Data 7

5. Tactile Inspection 8
- 5.1 Required Tactile Inspections 8
  - 5.1.1 Aircraft Without Leading Edge Devices 8
  - 5.1.2 Aircraft With Rear-Mounted Engines 8
  - 5.1.3 Airframe Manufacturers' Requirements 8
- 5.2 Procedures Following Deicing 8
- 5.3 Procedures for Cold Soak Ice Detection 9
- 5.4 Checker Performance 10
- 5.5 Secondary (Visual) Indications of Residual Contamination 10
  - 5.5.1 During Deicing 10
  - 5.5.2 Following Deicing 11
- 5.6 Limitations of Tactile Inspection 12
  - 5.6.1 Human Factors 12
  - 5.6.2 Time Constraints 12
  - 5.6.3 Physical Limitations 12
- 5.7 Effectiveness of Tactile Inspection Following Deicing 13

6. Threshold of Ice Detection Issues 14
- 6.1 Characteristics of "Residual Ice" Following Deicing 14
- 6.2 Theoretical Considerations 15
  - 6.2.1 The Deicing Operation 15
  - 6.2.2 Residual Ice 16

7. Some Effects of Contamination on Aircraft Performance 17
- 7.1 Frost, Adhering Snow and Ice with a Rough Surface 17
- 7.2 Thin Ice 17
- 7.3 Precautions If Sensors Are Used for Residual Ice Detection 17

8. Sensors as Post-deicing Inspection Devices ... 18
8.1 Regulatory Considerations ... 18
8.2 Ground Ice Detection Sensor Types ... 18
8.3 Thresholds for Sensor Use Following Deicing ... 19
8.4 Detection of Ice Due to Cold Soaking ... 19
8.5 Experience by Delta Airlines ... 19
8.6 Generalized Use of Remote Sensors as an Alternative to Tactile Inspection – Experience at Toronto's LBPIA ... 21

9. Discussion ... 23
9.1 Tactile Procedures and Experience ... 23
9.1.1 Effectiveness of Tactile Inspection ... 23
9.1.2 Difficulties with Quantitative Determination of Tactile Capabilities. 23
9.1.3 Threshold Thickness Levels for Tactile Detection of Ice ... 24
9.2 Thresholds for Tactile Detection of Ice on Wings ... 24
9.3 Remote Sensors as an Alternative to Tactile Inspection ... 25
9.3.1 Application of Remote Sensors ... 25
9.3.2 Threshold Requirements for Remote Sensors ... 25
9.3.3 History of Experience ... 26

10. Conclusions ... 27
10.1 Effectiveness of Tactile Inspection ... 27
10.2 Tactile Ice Detection Thresholds ... 27
10.3 Sensors as an Assistance or Alternative to Tactile Inspection ... 27

References ... 29

Appendices

A Canadian Aviation Regulations 602.11: Aircraft Icing
B Canadian Aviation Regulations 622.11: Ground Icing Operations

Glossary and Terminology

Glossary

AS	Aerospace Standard (SAE)
CAR	Canadian Aviation Regulation
CDF	Central Deicing Facility
EuroCAE	European Organization for Civil Aviation Equipment
FAA	Federal Aviation Administration (U.S.)
FAR	Federal Aviation Regulation
FBO	Fixed Base Operator
FOD	Foreign Object Damage
JAA	Joint Aviation Authorities (European)
LBPIA	Lester B. Pearson International Airport, Toronto
OEM	Original Equipment Manufacturer
RVSI	Robotic Vision Systems, Inc.
SAE	SAE International (formerly Society of Automotive Engineers)
SAS	Scandinavian Airlines System
SDI	SDI Aviation (trade name of Superior Deicers Inc.)

Terminology

The term “inspection” is used in this report to define the verification that the pertinent de/anti-icing procedure has achieved (or, not achieved) its intended function (i.e., that there is no residual ice following deicing in the present case). Canadian regulations use the term “inspection”, which must be conducted in accordance with the inspection procedures of the operator’s approved deicing plan. U.S. (FAA) regulations refer to conduct of a “check”, which must be conducted in accordance with the certificate holder’s program. The person conducting the inspection (in Canada) or the check (in the U.S.) may perform a dedicated function or may be a qualified member of the deicing team. The term “checker” has been adopted to simplify the text.

The term “operator” is, in general, used to refer to the aircraft operator (i.e., the airline), or the aircraft operator’s designated agent, which may be the local FBO (fixed base operator) at certain airports.

The term “contamination” refers specifically to contamination of an aircraft wing by ice that may be in the form of clear ice, rough ice, adhering snow, frost, or ice crystals in a deicing or anti-icing fluid in the form of slush. Contaminants other than frozen water are not considered.

1. INTRODUCTION

Tactile inspection in this document refers to determination by direct touch of the fingers or hand of a checker as to whether there is ice on the (aerodynamically) critical surfaces of an aircraft. The checker in this case may be a qualified technician performing aircraft deicing, a dedicated inspector, or a qualified third party.

The surfaces most commonly subject to tactile inspection are the leading edges of aircraft wings and areas on the upper surfaces of an aircraft's wings. The wing leading edges must be kept free from contamination since the presence of even small amounts of contamination on the leading edge can have a serious negative effect on aerodynamic performance. This is particularly true for aircraft without wing leading edge devices (slats). For some aircraft the presence of cold fuel in the fuel tanks can lead to development of ice on the wing upper surface while on the aircraft is on the ground, even under otherwise clear conditions. In the case of such aircraft with rear-mounted engines (e.g., Douglas MD80), the primary danger of ice formation on the wing upper surface is ice ingestion into the engines during takeoff, also referred to as a form of Foreign Object Damage (FOD).

Under most circumstances the presence of ice on a wing is determined visually. In some particular cases visual detection of the presence of ice, and in particular smooth, clear ice, is very difficult. Tactile detection of ice is recognized as being more reliable on its own merits [1] and provides an alternative or a supplementary check to visual inspection. Tactile inspections are therefore required in particular cases following deicing or on aircraft where formation of ice due to "cold soaking" may be a problem.

Tactile inspections are relatively slow and limited to the reach of the operator, therefore retarding traffic movement, particularly at centralized deicing facilities.

The possibility now exists to consider remote frozen contamination sensing devices to either assist human operator-performed tactile inspection immediately following deicing, or replace the human operator altogether. Sensors are potentially faster than human operators, have a greater field of view, and are able to record the condition of the aircraft. They have design threshold capabilities expressed as minimum thickness and area of frozen contamination to be detected at some specified distance.

To provide a reference comparison for sensors, it was anticipated that a threshold level could be established for human touch detection of ice that might remain after deicing (referred to as "residual ice"). This residual ice has been subjected to hot deicing fluid and will, in general, be below deicing fluid at the time of inspection.

Preliminary investigation revealed a lack of documented reference information on the subject of tactile inspection of aircraft following deicing. This report provides reference information not previously published.

2. OBJECTIVES

- Document common tactile procedures and experience to provide a benchmark for possible sensor support to, or substitution of tactile inspection.

- Review the thresholds for human tactile detection of the presence of ice on an aircraft wing, with emphasis on the condition of the wing immediately following deicing.

- Comment on the application of remote sensors as an assistance or alternative to tactile inspection.

3. THE REGULATORY ENVIRONMENT

3.1 General

Canadian Aviation Regulation (CAR) 602.11 and U.S. Federal Aviation Regulation (FAR) 121.629 require that, under winter icing conditions, the aircraft must be inspected to ensure that there is no frost, ice or snow adhering to aircraft critical surfaces prior to takeoff.

Two types of inspections are called for by Canadian Aviation Standard (CAS) 622.11 ¶7.1 to meet the regulatory requirements – the Critical Surface Inspection and the Pre-take-off Contamination Inspection.

- The Critical Surface Inspection must take place immediately after final application of the fluid when the aircraft is de/anti-iced (¶7.1.2);
- The Pre-take-off Contamination Inspection is required when the holdover time has been exceeded (¶7.1.3).

Unless specifically approved the operator's pre-takeoff contamination inspection program must include a tactile inspection for all aircraft without leading edge devices, such as the DC9-10 and the F-28. In practice, approved programs normally call for these mandatory tactile inspections to be conducted immediately following deicing.

The FARs are similar to the Canadian regulations except in that the pre-takeoff contamination inspection is mandatory at all times.

European Joint Aviation Authorities (JAA) regulation JAR-OPS 1.345 imposes similar requirements to the FARs and CARs, though it is less specific.

In addition to regulatory requirements, some airframe manufacturers also provide for tactile inspection in the operations manual. Inspection for detection of "cold-soak" ice above fuel tanks is covered in such a case.

Subject to the regulations and the operator's approved deicing plan, the tactile inspection may be conducted immediately following deicing on the deicing pad or at the end of runway immediately prior to takeoff (the Pre-take-off Contamination Inspection).[1]

The regulations do not specify how the tactile inspections are to be conducted; responsibility for the deicing plan rests with the operator. The detail methods used by airlines and other service providers to conduct tactile inspections vary and, in most cases, are not documented. The SAE Aerospace Recommended Practice *Aircraft Deicing/Anti-icing Methods with Fluids*, ARP 4737, includes a section on inspection but does not make reference to tactile inspection procedures.

[1] This is further expanded in Section 4.2 of this report.

3.2 Canadian Regulations

The focus of this report is in the context of the Canadian regulations. Canadian regulations (and JAA regulations) refer to "inspection" of the pertinent surfaces whereas FARs refer to "checks". In this report, the term "inspection" is used.

The most common applications of the tactile method of inspection are:

- for verification of the removal of all adhering frozen contamination on the leading edges of hard-wing aircraft following deicing; and
- for verification of the absence of ice on the wings of aircraft where ice formation due to cold-soaking could give rise to catastrophic FOD of rear-mounted engines.

In both these cases the ice may be difficult to see and visual inspection is unreliable.

CAR 602.11 (see Appendix A) requires that operators have a deicing program that includes an inspection program, in accordance with the Operating and Flight Rules Standards.

The Operating and Flight Rules Standards, given in CAR 622.11 (see Appendix B) state that two types of inspections meet the requirements – "the Critical Surface Inspection and the Pre-take-off Contamination Inspection."

Section 7.1 continues: "Under icing conditions, the Critical Surface Inspection is mandatory; however, depending on the requirements of the operator's Program, the Pre-take-off Contamination Inspection may not be required. In its section on inspection procedures, the operator's manual must describe the techniques to be used in contamination recognition and the conduct of the two types of inspection."

Section 7.1.1 requires that the operator's contamination recognition method be specified, and states that this *may* include tactile inspection.

Section 7.1.1.2 further qualifies this: "Tactile inspection, under certain circumstances, may be the only way of confirming that the critical surfaces of an aircraft are not contaminated. This physical inspection shall be carried out by a qualified person and must include the leading edge and upper surface of the wings."

Section 7.1.1.4 provides for the use of sensors.

Section 7.1.2, which refers to Critical Surface Inspection, states that "this inspection is mandatory whenever ground icing conditions exist, and if the aircraft is deiced/anti-iced, must take place immediately after final application of the fluid. After the inspection, an inspection report must be made to the pilot-in-command by a qualified person." Note that "inspection" here does not explicitly require a tactile inspection.

Section 7.1.3, which refers to Pre-take-off Contamination Inspection, stipulates that "unless other procedures have been specifically approved, a tactile external inspection must be conducted on all aircraft without leading edge devices, such as the DC9-10 and the F-28, and on any other aircraft as designated by the Director, Air Carrier."

It should be noted that in practice the tactile inspection in approved programs is normally done immediately after deicing when a two-step procedure is performed.

3.3 U.S. Regulations

The pertinent U.S. regulations are covered by FAR Part 121, which addresses Operating Requirements: Domestic, Flag, and Supplemental Operations. Section 121.629 deals with Operation in Icing Conditions.

Requirements for procedures and responsibilities related to de/anti-icing and subsequent checks are defined in §121.629 ¶ (c) (4). Unlike the Canadian regulations, there is no specific requirement in the FARs for tactile inspections and no specific provision for the use of sensors. However, Federal Aviation Administration (FAA) Advisory Circular AC 120-60, which provides a means (though not the only means) for obtaining approval of a Ground Deicing and Anti-icing Program and for ensuring compliance with FAR Section 121.629, notes that following aircraft de/anti-icing a tactile check is the only known method to verify whether the critical surfaces are uncontaminated unless an airplane is equipped with wing clear-ice detectors. AC 120-60 also calls for a tactile check of selected portions of the wing leading edges and upper wing surfaces of hard-wing aircraft with aft fuselage-mounted turbine-powered engines.

3.4 Joint Aviation Authorities Regulations

The pertinent JAA regulation, JAR-OPS 1.345, requires that "an operator shall establish ground de/anti-icing procedures" and further that "a Commander shall not commence take-off unless the external surfaces are clear of any deposit which might adversely affect the performance and or controllability of the aeroplane except as permitted in the Aeroplane Flight Manual."

There are no specific requirements for tactile inspection, nor is the issue of sensor use addressed.

4. INFORMATION GATHERING

Limited literature, Internet, and telephone surveys yielded no documented information pertinent to the tactile detection of ice on an aluminum (or other metal) surface. Discussions with specialists in the field of human tactile response confirmed the absence of study or documentation in this particular area. Conversely, a wealth of information is available on the subject of tactile perception in general. For example in a study conducted by the Life Support System Section of the Japanese Aeromedical Laboratory [2], an evaluation of performance of manual tasks during exposure to severe cold (–25ºC or –13ºF) while wearing standard cold protective clothing showed diminished manual dexterity; however, neither the temperature at which manual dexterity started to diminish nor the threshold of detection ability are reported.

4.1 Controlled Testing of Tactile Inspection Performance

In the absence of existing directly applicable data, the possibility of conducting a controlled laboratory test program to obtain quantifiable data on human performance in tactile detection of ice under deicing fluid on an aluminum surface in simulated winter conditions was considered. The difference between tactile capability to detect contamination and actual performance by checkers should be noted. Thus, while a checker may be capable of detecting a certain threshold level of contamination, in normal conduct of work he or she may or may not do so. It is the performance level of checkers during normal work that is of interest in the present case, not the limits of human tactile capability.

After review it was concluded that such a program was not practical at the time of writing because of the large number of variables and because of budgetary limitations. The variables to be considered include such factors as training, previous experience, sense of responsibility, and time since work shift began, all of which are difficult to quantify. In addition there are the fundamental variables such as ice thickness, fluid thickness, surface temperature, ambient temperature, etc. The tests would also have to be developed so as to simulate the work environment.

4.2 Tactile Sensory Perception

As with the tactile determination of any surface condition, the ability to detect residual ice on a wing following deicing may be characterized by one or more of the following perceptions:

- a difference in the surface friction of ice compared to the wing metal;
- a difference in the surface profile (e.g., changes in "waviness", roughness, or other);
- an apparent difference in the surface temperature of ice as compared to the wing metal surface; and
- possibly, an incremental step at the edge of an area of ice.

In this latter case it might possible to estimate the local ice thickness. Some checkers report using a fingernail to confirm (or negate) the presence of ice when direct feel of the wing surface suggested that ice might be present. In such cases the ice thickness might be compared to some reference such as the thickness of a piece of paper.

After discussions with deicing personnel who have conducted tactile inspection, it was concluded that they could provide a useful source of reference information in the absence of extensive laboratory/controlled testing.

4.3 Solicited Data

Selected FBOs (fixed base operators) were contacted. These operators had many years experience and were highly cooperative.

5. TACTILE INSPECTION

Substantive information on field experience contained in this section has been provided by AéroMag 2000, GlobeGround North America, Delta Airlines, Inc. and others.

5.1 Required Tactile Inspections

5.1.1 Aircraft without Wing Leading Edge Devices

Roughness due to adhering frozen contamination in general and especially frost can significantly affect the lift and handling characteristics of an aircraft. Hard-wing aircraft in particular are sensitive to such contamination on the wing's leading edge. It is in this context that the CARs and Original Equipment Manufacturer's (OEM) operations manuals require tactile inspection of critical wing surfaces on all hard-wing aircraft during the Pre-take-off Contamination Inspection.

5.1.2 Aircraft with Rear-Mounted Engines

The pertinent problem for aircraft with rear-mounted engines is the risk of engine damage due to ice shed from the wings. In this case there is no damage potential from thin frost or thin 1.9 mm (0.075 in.) residual ice following deicing. However, ice buildup as a result of a cold-soaked wing condition on an aircraft with integral wing fuel tanks ("wet wings") – possible on aircraft such as the Douglas MD-80 – can be significant and may also be difficult to see; therefore, tactile inspections are required. Regardless of thickness (i.e., no matter how thin), if frost or ice is present it must be removed in compliance with the regulations.

5.1.3 Airframe Manufacturers' Requirements

In addition to requirements specified by the regulations, the OEM's operations manual may require additional tactile inspections.

5.2 Procedures Following Deicing

It is common practice to conduct the inspection immediately following deicing in cases where a tactile inspection is required. This action is written into the operator's procedures and submitted for regulatory approval. The regulations covering the Critical Surface Inspection do not directly stipulate a tactile inspection after deicing (CAR 622.11 ¶. 7.1.2), whereas the Pre-take-off Contamination Inspection does require tactile inspection for aircraft without leading edge devices (CAR 622.11 ¶. 7.1.3). However, in practice tactile inspection at the end of the runway is not commonly performed.

As a guide to the impact of tactile inspection on operations, it has been observed that tactile inspections following deicing are required on 5 to 10 percent of all aircraft passing through the centralized deicing facilities at Pierre Elliott Trudeau International Airport (PETIA) in Montreal and Lester B. Pearson International Airport (LBPIA) in Toronto. This translates to the order of 500 to 1000 or more aircraft at each centre. Of these aircraft some ¼ to ½ percent require re-deicing as a result of the tactile inspection (i.e., perhaps five aircraft per winter at each airport). At PETIA, aircraft that are not required to have a tactile inspection following deicing are usually given one as an additional safety precaution.

The wing's leading edge can, in many cases, be reached from the ground (e.g., the Bombardier CL-65 Regional Jet). Immediately following deicing the checker leaves the truck, proceeds to the wing tip, then walks along in front of the leading edge with a hand on the wing surface. The skin contact with the wing surface may be the tips of the fingers or the palm of the hand, depending on the checker. A waving motion of the hand, which is commonly done, extends the area inspected to a width across the wing chord of 0.5 m or more. In other cases the inspection must be done from the deicing truck basket or from a ladder. The area to be checked must conform to the approved inspection plan, though this area is not always specified.

In some cases checkers have reported running a fingernail along the wing surface. A very thin layer of ice can be detected in this manner. Verbal reports refer to thickness as low as 0.05 mm (0.002 in.), though this is not known to have been verified. When there is a suspected ice patch, the fingernail technique is a reported to be a very good inspection method.

In the case of the CL-65, one operator's procedure specifically calls for physically scratching the wing's upper surface with the fingers at three mid-chord locations, using multiple tests in each area to determine whether clear ice due to cold soaking has formed. This is done in the ambient temperature range between –3ºC and +10ºC (26ºF to 50ºF), and for all departures at ambient temperatures between +10ºC and +14ºC (50ºF to 57ºF). If the scratch tactile inspection detects the presence of ice, the aircraft must be deiced and a second scratch tactile inspection performed immediately following deicing.

5.3 Procedures for "Cold-Soak" Ice Detection

On aircraft such as the MD-80, the surface to be inspected is not readily accessible by hand from the ground. In this case some operators have coated an appropriate wing area with a roughened surface similar to that on an anti-slip walkway. A rod, typically 3 m (9.8 ft.) long, is then extended by the deicer from the basket. A variation used by SAS involves a longer hooked rod so that this method of inspection can be done from the ground. A smooth surface indicates presence of ice; a rough surface means no ice. The method is adequate, although ice with a profile height lower than the bare surface roughened height may remain undetected. Full effectiveness may also be compromised by the use of gloves by the checker.

In cases where a rod has been used to check for ice on the "cold corner" (i.e., the point on the wing surface where fuel in the tank first comes in contact with the inside of the wing upper surface) and no artificial roughness has been added, a thin layer of ice may remain undetected. However, if there is also a visual inspection, marks in the ice made by the rod can be seen. Given that the primary objective in this case is to avoid engine damage, the presence of a thin layer of ice, less than 1.9 mm (0.075 in.) is not serious. Accordingly, use of an ice detection sensor developed by Goodrich Corporation has been approved for use on MD80, MD90 and B717 aircraft. This sensor is located at the cold corner and has a threshold of 0.5 mm (0.02 in.)

5.4 Checker Performance

Responses from deicing operators confirm the complexity of defining a tactile inspection procedure based on checker capability. The actual inspection involves not only the required "touch" and "feel" components but, subject to the experience of the checker, also secondary sensory inputs as a result of visual changes to the fluid appearance. These secondary inputs in turn are subject to lighting conditions, fluid type and possibly other factors.

- With respect to checker sensitivity to friction, there is a difference in the "feel" of ice compared to that of metal. If the surface is smooth when doing the tactile inspection, it means that ice is present. If the checker feels the texture of the aircraft skin and/or the rivets, the aircraft is clean.
- With respect to checker sensitivity to surface profile, contamination on the wings can be detected by an experienced checker based on the surface "waviness" or roughness.
- With respect to checker sensitivity to apparent surface temperature differences, it has been observed that the ice has different heat transfer characteristics to the hand than those of the aircraft metal surface. The checker "feels" this difference and reports the effect as different temperatures (a common comparable experience is the perception that an exposed wood surface is warmer than an ice surface, even though the two are at the same temperature).

Factors that might adversely affect checker performance have been accommodated in the procedures adopted by experienced operations. Reduced checker sensitivity caused by tiredness and/or continued exposure to cold ambient temperatures is reported to be virtually eliminated by carefully scheduling assignments and by providing rest facilities.

Usually, when a large aircraft is deiced, two trucks are located at the back of the aircraft, one on each side, and two at the front, again one for each wing. The tactile inspection is normally done from the trucks at the front of the aircraft.

During a busy operation, the chief coordinator will go from deicing bay to deicing bay to do additional tactile and visual inspections as deemed necessary.

5.5 Secondary (Visual) Indications of Residual Contamination

Although tactile inspection is addressed separately from visual inspection, in practice visual observations and tactile inspections are effectively combined.

5.5.1 During Deicing

In the case of deicing with Vestergaard Elephant ß deicing trucks, where the fluid application boom has a long reach and a spotlight is placed relatively close to the surface being treated, the quality of visual inspection (at night or during the day in the absence of sunlight) can be upgraded to reduce dependency on tactile inspection. It has been reported by some operators that when the spotlight is directed over the wings and exposes a shining surface, this indicates that there is ice on the wings. If no shine is visible when the spotlight is directed over the wings, there is no ice.

The technique was reported to work well, though it is still difficult at times to detect ice below deicing fluid. Tactile inspection over a large part of the wing is not practical since the surface cannot be reached conveniently. Use of lights is beneficial in that the "quality"of visual inspection of such areas is improved.

For the case of residual ice below some Type I fluids following deicing, one operator has reported detecting such ice on the wing by observing tiny bubbles that are evenly spread across the wings during fluid application. If residual ice is present, the bubbles can be spotted around it but not on it. A deviation or a slight wave on the fluid surface can also indicate the presence of residual ice. It should be noted that not all operators agree with this procedure.

It has been observed that when an aircraft is sprayed and ice is present, the fluid runs smoothly over the wings. A further visual indication that ice is present occurs when the glycol infiltrates between the ice and the skin of the wing. A darker colour appears, indicating that ice is still present. This latter condition is quite common because the heat of the deicing fluid conducts through the metal and causes early melting of the ice from the underside.

An indication that the wing is clear of ice occurs when glycol deviates while being sprayed, hits rivets, and/or fills the holes of the rivets.

Black strips used by some airlines on their wings to facilitate the pilot's visual inspection can create a problem for deicing operators because the black surface tends to shine. Experienced operators then double-check.

5.5.2 Following Deicing

During the tactile inspection the operator also performs a visual inspection. The significance in this instance is that the operator's eyes are of the order of one metre from the area of tactile concern. The area of sight, of course, extends well outside the area touched.
A particular problem exists in the case of deicing following freezing rain or during freezing drizzle, particularly at night. There is anecdotal evidence from some operators that at times it can be impossible to discriminate visually between areas that have been deiced and areas of precipitation accumulation that have inadvertently not been deiced. In such cases tactile inspection is currently the only way to determine the surface condition (it should, however, be noted that not all operators agree that visual differentiation between freezing drizzle buildup and applied deicing fluid is impossible).

5.6 Limitations of Tactile Inspection

5.6.1 Human Factors

The principal limitations of the ability of an operator to conduct an effective tactile inspection are caused by poor training, lack of motivation, or both. These may be manifested as a cursory inspection with significant sections of the area of concern (e.g., the wing's leading edge) left untouched, or in an extreme case, a feigned "touch" to avoid the unpleasantness of cold, wet hands, which would then make the insides of the operator's gloves wet!

A related issue is the discomfort of personnel performing tactile inspections. This issue has been addressed by a number of researchers. No studies have been identified that address the particular case of tactile inspection of aircraft, but at least one study [3] addresses the implications of tactile inspection of material surfaces, including aluminum, at temperatures of –10ºC, 0ºC, and +10ºC (14ºF, 32ºF, and 50ºF, respectively). The conditions for skin freezing were quantified and, as would be expected, freezing when in contact with an aluminum surface is much more rapid than when the hands are exposed to air at the same temperature. In a study conducted by the Life Support System Section of the Japanese Aeromedical Laboratory [2], an evaluation of performance of manual tasks during exposure to a temperature of –25ºC (–13ºF) while wearing standard cold protective clothing showed not only diminished manual dexterity, but also an increased risk of both hypothermia and accidents for those who work at night. This latter observation is, of course, not restricted to the conduct of tactile inspection.

5.6.2 Time Constraints

A second set of limitations is imposed by time constraints. Careful tactile inspection is slow in the context of ground operations during winter precipitation. In the case of Type I fluid used for deicing and also as an anti-icing fluid, the Holdover Time (HOT) commences at the start of anti-icing. Typical Type I HOTs are less than 15 minutes and may sometimes be no more than three to five minutes, and this includes time to complete deicing and taxi to the assigned departure runway. In the case of Type II or Type IV fluid used for anti-icing, only three minutes are available for tactile inspection between Type I deicing fluid application and the subsequent anti-icing fluid application. In cases where the area to be inspected is the wing's leading edge and the leading edge can be reached from the ground (such as the Bombardier CL65 Regional Jet) the time requirement is not a major concern. However, in cases where the area of interest cannot conveniently be reached from the ground and the inspection must be made by a deicer who is in an enclosed-cab deicing truck, the time requirement can be significant.

5.6.3 Physical Limitations

The inability of the operator to reach the entire wing area for a tactile inspection on many aircraft can also pose a problem. Obviously there are areas on the wing that cannot be reached during normal deicing operations by the operator, even with the aid of a ladder or from the truck basket.

5.7 Effectiveness of Tactile Inspection Following Deicing

Detection of ice by tactile inspection is generally recognized as an effective inspection method; however, analysis of the efficiency of the process under controlled conditions has only received limited attention [4].

Records are frequently not kept by operators to establish how often residual ice is detected by a tactile inspection. In major operations, estimates of “several” cases per winter where residual ice is identified by tactile inspection translate to less than ½ percent of the pertinent aircraft requiring re-deicing.

6. THRESHOLD OF ICE DETECTION ISSUES

In order to quantify the effectiveness of tactile inspection it necessary to determine the threshold level at which ice on a wing following deicing can be detected by a human operator. Ideally, if a sensor were to be used as a substitute it would have at least the same level of sensitivity, or better.

Unfortunately, the tactile inspection is based on the "feel" of the surface subject to inspection, expressed as surface friction, surface profile and apparent temperature differences – none of these characteristics has been investigated for the application under study. By contrast the threshold capabilities of sensors for post-deicing ice detection are characterized by ice thickness and area.

6.1 Characteristics of "Residual Ice" Following Deicing

There has been no systematic study to obtain quantitative data that characterizes residual ice – i.e., ice that remains after deicing and that has not been detected visually. In general the quality of deicing operations and quality of visual inspection is such that cases of residual ice rarely arise. Thus there are few cases to be studied. When cases do occur, re-deicing is required. Quantitative measurements and recording of residual ice location, area, thickness and surface profile are not practical in normal airline operation due to the delays involved. Conduct of truly representative controlled testing is very difficult since not only must the appropriate human factors be addressed, but also the physical equipment, environment and fluid application conditions must be simulated. Thus only limited information is available.

Sample anecdotal data, obtained from experienced deicing crews, has been recorded:

- The most common condition when ice remains after deicing and passes visually undetected is during freezing rain.
- The areas where the fluid jet from the deicing nozzle strikes the wing surface directly will be free from residual ice.
- Passing a bare hand quickly over the wing surface may only give an indication that ice might be present. A check using a fingernail, for example, may be needed.
- In the event that deicing did not remove all the ice, and this ice was not detected visually, residual ice may be present at more than one location. This presents an added difficulty to ensure that all residual ice has been located.
- There are no patterns as to where on the wing residual ice will occur. It should be noted that most requirements for tactile inspection address the leading edge, and accordingly, this is where most cases of residual ice are identified and reported.
- Residual ice tends to occur locally at locations where there are surface irregularities such as wing surface panel-to-panel joints, or surface undulations due to riveting. The ice tends to "smooth" out these irregularities.
- The surface of the residual ice is always smooth and tapers to a feather-edge, typifying a minor modification of the surface profile rather than a surface discontinuity or roughness. This is attributed to the presence and flow of the hot deicing fluid during the deicing operation.

There is no “typical” residual ice area or thickness. However, an area of 150 mm x 75 mm (6 in. x 3 in.) is a reasonable guideline. Thickness may be more than ½ mm, but this is a “best estimate”.

6.2 Theoretical Considerations

6.2.1 The Deicing Operation

The deicing operation removes adhering frozen contamination (ice) from the wing surface by a combination of heat in the glycol-based deicing fluid and mechanical force due to the applied spray pressure. Recommended procedures [5] call for application of the heated fluid as close to the surface as possible to minimize heat loss. At the spray application nozzle, the fluid temperature is typically of the order of 60°C (140°F).

Fluid flow rate and impact pressure at the aircraft surface depend on the equipment available and nozzle setting, with each specific application adapted to the circumstances – ice removal, accumulated dry snow removal, accumulated wet snow removal, etc. A typical ice removal flow rate would be of the order of 227 L/min (60 gpm).

The heat in the fluid melts frost and light deposits of slush snow and/or ice. Heavier accumulations require the heat to break the bond between the frozen deposits and the aircraft surface. The hydraulic force of the spray flushes off the residue. The presence of glycol is predominantly to prevent re-freezing of the diluted deicing fluid for a period of time depending on aircraft skin temperature, outside air temperature (OAT), fluid used, initial fluid mixture strength, and weather.

A review of the thermal properties of water, ice, air, and aluminum helps explain the physical behaviour of the ice removal process.

Table 1. Thermal Characteristics of Sample Material[2]

Material	**Thermal Conductivity** *(Btu/hr/sq.ft/°F/ft)*	**Specific heat** *(Btu/lb/°F)*
Water	0.343	1.00
Ice	1.26	0.48
Air	0.014	0.24
Aluminum	130	0.23

Latent heat of fusion of ice: 144 Btu/lb

As can be seen from the data given in Table 1, the thermal conductivity of aluminum is very much higher than that of water or ice. Thus the heat conducts through the aluminum wing surface and melts the ice from below more rapidly than the direct heat application from the fluid on the upper surface of the ice.

[2] Theodore Baumeister and Lionel S. Marks, eds. *Standard Handbook for Mechanical Engineers*. 7th ed. Toronto: McGraw-Hill, 1967.

This explains why, in the case of a wing covered with a layer of ice, deicers find it necessary to first "bore" a hole through the ice with the hot fluid jet in order to accelerate the deicing operation.

It can also be seen that a considerable heat input is required to melt ice due to the relatively high latent heat of fusion: a temperature drop of 1 kg of water from 60°C to 0°C (60 kcal) would not be sufficient to melt 1 kg of ice (80 kcal required). This effect is even more pronounced for the heat transfer from aluminum, where the specific heat of aluminum is less than one quarter that of water.

6.2.2 Residual Ice

As the heat conducts through the aluminum below an ice layer, the temperature rise in the aluminum will decrease with distance from the edge of the ice. Some ice will remain as residual ice if the combination of heat input to the ice from the fluid above and the heat transmitted via the aluminum from below is insufficient to melt all the ice.

In the event that a thin layer of residual ice remains after deicing, undetected visually but present when a tactile inspection is conducted, then the following conditions pertain:

- The surface area of rough ice is greater than that of a comparable layer of smooth ice. This results in a higher heat flux from the fluid to the ice, with the highest local heat transfer occurring at the roughness "peaks". As a result, the peaks melt more rapidly than the "lower" areas and the initially rough surface becomes smooth. This is consistent with anecdotal observations.
- The aircraft surface and fluid on the ice will all be $0^{o}C$ below $0^{o}C$ by the time a tactile inspection is conducted (otherwise the ice would melt). It would appear at first consideration that at the edge of the residual ice patch there might be an area of water between the ice and the aluminum. However, the cold aluminum would conduct the heat away from the water and cause local re-freezing.
- It is possible that heat in the aluminum skin is transferred into the aluminum structure below the skin instead of being transferred to the ice.
- At the edge of the residual ice patch the mechanism of heat input would create a "feather edge".

Proof of the foregoing propositions requires a rigorous theoretical analysis. This is a complex issue since the deicing application varies from case to case, the heat transfer coefficients between the materials involved are not easily defined, and the conditions during ice removal are time dependent. A practical approach might be to postulate a typical case and then conduct a sensitivity analysis involving the principal variables.

7. SOME EFFECTS OF CONTAMINATION ON AIRCRAFT PERFORMANCE

7.1 Frost, Adhering Snow, and Ice with a Rough Surface

The addition of roughness to an airfoil surface directly influences the airflow boundary layer, which translates into a change in local airfoil – and possibly wing – aerodynamic characteristics.

It has been shown [6, 7] that roughness, such as frost, with a profile height of only 0.3 mm (0.0118 in.) on a 3 m (118 in.) chord hard wing can reduce the maximum achievable lift of the wing significantly. “Roughness” in an aerodynamic context is not restricted to frost-type distributions; a single sharp step at the leading edge of an ice patch can have an effect similar to that of distributed roughness. The lift curve slope at low angles of attack, however, is largely unaffected. Thus, during normal operation, the pilot may be completely unaware of the potential hazard. In the case of an engine-out at takeoff in a crosswind, however, where one wing may be at a relatively high angle of attack, the result of such apparently minor contamination could be a catastrophic loss of roll control.

7.2 “Thin”, Smooth Ice

A thin layer of smooth ice on a wing at any location creates a small change in the local surface profile with little or no effect on the airfoil characteristics. Wind tunnel tests have been conducted with a commuter aircraft wing section performing simulated takeoff runs through rotation in light freezing rain. After 14 minutes’ exposure to precipitation on the unprotected surfaces, there was virtually no change in the airfoil aerodynamic performance [8]. “Thin” in this context can be quantified. For example, characterization of a typical airfoil section includes the ratio of maximum thickness to chord. A 10 percent maximum thickness for a 3 m (118 in.) chord wing section is 0.3 m (11.8 in.). Imposing 1 mm (0.04 in.) of ice smoothly blended to the surface at the mid-chord station increases the thickness from 10 to 10.03 percent – a negligible change. It has been observed [9] that thin ice accumulations caused by freezing drizzle or freezing rain are smooth. Rough surfaces develop on thicker accumulations and can be seen. Detection by sensor of this condition is readily achievable. Care must be taken not to apply observations pertinent to smooth ice to surfaces with even a small amount of rough ice present.

7.3 Precautions If Sensors Are Used for Residual Ice Detection

As has been observed in Section 6.2.2, residual ice below the fluid will have a smooth surface. A limitation applies to this general observation if sensors are to be used for contamination detection: the entire wing must be deiced. This is very important in conditions where even low levels of frost may be present.

8. SENSORS AS POST-DEICING INSPECTION DEVICES

8.1 Regulatory Considerations

Provision is made in the Canadian regulations for the use of Ground Ice Detection Sensors (GIDS) for post-deicing inspection (and any other inspection to be conducted as part of the de/anti-icing program). According to CAR 622.11, s. 7.1.1.4:

> "Sensors that provide information directly to the pilot-in-command may be used to determine whether critical surfaces are contaminated or not. The installation and use of sensors must meet applicable Transport Canada airworthiness and operational requirements. The procedures for use of sensors must be detailed in the operator's Program."

U.S. FAA regulations have no such specific reference, but indirectly provide for their use. FAR § 121.629 (c)(2)(ii) requires that the certificate holder's approved program specifically cover "aircraft deicing/anti-icing procedures, including inspection and check procedures and responsibilities". Thus, certificate holders (operators) may propose use of sensors for post-deicing inspection procedures as part of their ground deicing/anti-icing program.

8.2 Ground Ice Detection Sensor Types

GIDS may be designated as On-Board or Ground-Based. On-board GIDS include two sub-categories: In-Situ GIDS that make a direct measurement on a monitored surface and Remote GIDS that make a remote measurement of a monitored surface. Ground-Based GIDS embraces only the Remote GIDS sub-category.

- **Post-deicing Inspection**

Visual inspection under most circumstances is effective and it rarely happens that a crew does not remove all the ice during a deicing operation. However when there is residual ice present it may be located anywhere on the wing. Since it is not practical to locate In-situ (point detection sensors) GIDS in the wings to detect a random distribution of ice, only Remote GIDS are presently identified as suitable for post-deicing inspection. Although remote GIDS could be aircraft mounted, to date only ground-based sensors have been considered. These would typically have a field of view sufficient to cover a significant portion of the wing and be hand held or truck-mounted to facilitate inspection of the whole wing.

- **Cold-Soak Ice Detection**

If cold-soak ice develops it will always be present on the cold corner. For this reason both point sensor GIDS and Remote GIDS are potentially practical for this application.

8.3 Thresholds for Sensor Use Following Deicing

SAE Aerospace Standard AS5116 and EuroCAE Standard ED 104 set sensor equipment qualification threshold requirements at 0.5 mm (0.020 in.) thickness over an area of 315 cm^2 (49 sq. in.), and set extensive laboratory test requirements to establish the capability of the sensor to detect frozen contamination under a wide range of conditions. These conditions include provision for detection of residual ice below a deicing fluid. The threshold values and the tests for detection of frozen contamination establish equipment capability; they do not necessarily establish a safe takeoff condition.

Training and motivation of deicing crews are important issues in this context to ensure that the entire wing surface has been deiced, since frost profile heights below typical sensor thresholds could cause severe aerodynamic penalties.

Use of sensors for detection of ice forms, including frost prior to deicing, is outside the scope of this report. In practice, frost formation does not occur in isolated cases. Buildings, vehicles, and other aircraft are also subject to frost formation; therefore, the need for specific inspections is usually quite evident. If it were necessary for a sensor to be used for light frost detection, the threshold would have to be adjusted downward significantly from the equipment standard of 0.5mm.

8.4 Detection of Ice Due to Cold Soaking

In the case of ice (frost) buildup due to cold soaking on aircraft with rear-mounted engines, the potential problem is engine damage due to ice shedding at takeoff. The wing aerodynamic penalty due to a thin layer of ice buildup at the mid-chord section on transport category airplanes is minor, and ice less than 1.9 mm (0.075 in.) is not considered a FOD hazard. An ice detection sensor developed by Goodrich Corporation [10] has been approved for use by the FAA for installation on MD80, MD90 and B717 aircraft, with a threshold of 0.5 mm (0.020 in.). While even lower ice thickness thresholds are possible it was judged that detecting lower levels would result in nuisance warnings.

The Goodrich point detection sensor system, designated “Primary Wing Ice Detection System” (PIDS) has a sensor detection head area of the order of 3 cm^2 (0.5 sq. in.) located at the cold corner and was approved for use by the FAA in 1995. The display is in the cockpit to advise the pilot of an “unsafe” condition if the threshold level of ice accumulation is exceeded.

8.5 Experience by Delta Airlines

The only recorded field service experience with remote sensors as an alternative to tactile inspection has been with Delta Air Lines, Inc. This application was limited to specific aircraft on a specific route – Boeing 727 aircraft operating on the Boston-New York-Washington shuttle route – and a requirement for visual inspection was retained. Delta’s procedures for deicing were approved with a provision to use remote sensors as secondary devices as an alternative to a tactile inspection for the MD-80 and MD-90 series aircraft; however, this application has now been discontinued.

Following an incident at Nashville International Airport, an Advisory Circular was issued requiring a tactile check of the escape path area on the wings of Delta's fleet of Boeing 727 aircraft. Remote sensors were proposed as a more effective alternative. Tests were conducted in the field at Boston's Logan International Airport during the winter of 1994-95 using the RVSI ID-1H Hand-Held Ice Detector. The wing surface walkways were repainted with aluminized paint and textured with crushed walnut shells. To facilitate the testing, Robotic Vision Systems, Inc. (RVSI) purchased a Trump (now FMC Corporation) D40D deicing truck, and three RVSI employees attended the Delta deicing training classes to become qualified deicers. The ID-1H sensor was mounted on the Trump D40D truck. During the winter season the RVSI crew deiced many aircraft and conducted numerous tests, gaining valuable experience on how best to operate the ID-1H equipment.

FAA approval was then addressed. Water was poured from a cup onto selected locations of the leading edge and on the walkways and allowed to freeze. Sensor images were taken and compared to visual and tactile inspections on the ice patterns formed, and showed that clear ice detected by the ID-1H could not be detected visually. The presence of ice was confirmed by touching the area with hand and fingernail. The test was repeated three times, with the final test conducted in falling snow to confirm the capability of the sensor to detect ice on the wing under precipitation conditions. The issue of ice thickness was not addressed (the ID-1H was set at 0.25 mm or 0.010 in.). FAA representatives witnessed the tests.

A second set of tests was conducted in the walk-in cold chamber at the FAA facilities in Atlantic City, New Jersey. Ice formed in machined plates at –23ºC (–10ºF) ambient temperature was identified by the sensor down to 0.25 mm (0.010 in.), the thinnest sample tested.

The use of sensors, identical to the unit tested, was subsequently approved as an alternative to tactile inspection for Delta's 14 Boeing 727 aircraft operating on the Boston-New York-Washington shuttle route, though a requirement for visual inspection was retained. The use of the sensors on these aircraft by Delta was discontinued after the winter of 2000-01 because of reassignment of the aircraft.

The MD-80 and MD-90 series aircraft have a wet wing and are prone to clear ice buildup when subjected to cold-soaking conditions. In such a case, a tactile inspection on the wing area ahead of the engines is mandatory to eliminate the risk of FOD. Sensors have a history of operation for this specific application at Boston's Logan International, New York's La Guardia, Cincinnati/Northern Kentucky International, and other airports for over three years. Experience has been gained over several thousand ice-detection operations. This has included not only checking for clear ice above the fuel tank on an otherwise clean wing, but also checking for residual ice after deicing especially on the leading edge. Use of sensors during ongoing precipitation has been limited. While the sensors are known to have some operational limitations, users learned how to apply the sensors and were generally satisfied with their performance. It was found that the thickness threshold, which was initially set at 0.25 mm (0.010 in.), had to be increased to 0.5 mm (0.020 in.) because of the over-sensitivity of the sensors. In total, several thousand inspections were conducted using remote sensors over several winter seasons. Issues related to training, maintenance, and procedures were also addressed. Although records have been made, they are not available in a database matrix format covering all variables and detail quantitative analyses have not been performed.

A particular problem encountered by the RVSI ID-1H sensors used by Delta related to the difficulty of sensor differentiation between ice/slush (not acceptable for safe takeoff) and foam (acceptable for safe takeoff) following deicing. Deicing fluids from a number of manufacturers tend to generate foam. During the winter of 2000-01 Union Carbide (now Dow Chemical), producer of one such fluid, UCAR XL54, modified its formula to reduce or eliminate foam formation. End-of-winter (2000-01) season trials at Toronto's Central Deicing Facility (CDF) were positive. Subsequent field use has demonstrated that foam formation has been significantly reduced but not completely eliminated.

Sensor manufacturers have also addressed the foam problem and new units are claimed to have improved discrimination.

In general, Delta reported that sensors proved to be as effective as human operators, were easy to use, and are much faster than conventional tactile inspection.

8.6 Generalized Use of Remote Sensors as an Alternative to Tactile Inspection – Experience at Toronto's LBPIA

As reported in section 8.5, remote sensors were first used as an alternative to tactile inspection by Delta Airlines. However, the approval by the FAA was restrictive: no general application was granted, and although the sensors used had been subject to significant field and laboratory testing, they were not approved for use against any recognized standard.

Use of remote sensors has been of interest to the CDF at Toronto's LBPIA since the winter of 1996-97 in order to reduce delays due to requirements to conduct time-consuming tactile inspections. The interest expressed was to have a general approval for use of sensors granted by Transport Canada against a defined standard. This implied that a formal request for approval would have to come from the equipment manufacturer, and that a threshold for residual ice detection would have to be established.

Cox and Co. supplied a sensor, based on infrared technology with an external light module, for mounting on an SDI open-basket deicing truck for initial testing during the winter of 1996-97. Tests were discontinued following an accident with the truck. Two new units were supplied for further testing during the winters of 1997-98 and 1998-99, mounted on SDI enclosed-cab trucks.

Goodrich Corporation supplied an Ice Hawk[3] sensor, based on laser technology with integral light emitting source, to the Toronto LBPIA CDF for demonstration and testing in the winter of 1998-99. The Ice Hawk sensor benefited from experience in service with Delta Airlines where it was used as a hand-held unit. In the Toronto tests the unit supplied was also mounted on an SDI truck.

In parallel with these field tests, separate manufacturer-sponsored laboratory tests were conducted in National Research Council Canada's Climatic Engineering Facility in Ottawa to establish the performance of the sensors in accordance with the requirements of SAE Standard AS 5116 Minimum Operational Performance Specification for Ground Ice detection

[3] Originally the ID-1H Hand-Held Ice Detector owned by RVSI

Systems. These tests, conducted with a selection of deicing and anti-icing fluids under a wide range of controlled temperature and precipitation conditions, showed that both sensors had the potential to perform the required function as an alternative to tactile inspection.

Results of the field tests were encouraging and Hudson General Aviation Services Inc. (now GlobeGround North America Inc.), operator of the CDF, acquired six Cox units and six Goodrich units for evaluation during the winter of 1999-2000. Three of the Cox units and five of the Goodrich units were mounted on Vestergaard Elephant β trucks with displays in the cabs. One unit from each supplier was installed on a dedicated inspection pick-up truck. After accumulation of significant service experience, evaluation began during the winter of 2002-03.

Limitations to use of the Cox[4] equipment were revealed during the years of testing, upgrading and subsequent initial evaluation, particularly with respect to operation in transient lighting conditions. These issues were addressed during 2003, and a further upgraded design was returned for testing during the winter of 2003-04. Service use with the Ice Hawk sensors confirmed an effective range of ~ 20 m (60 ft.) and difficulties distinguishing between foam and ice.

Users have suggested changes to the visual display for both sensors.

All of these concerns can be dealt with through training or equipment modification: sensor positioning and viewing of the surface to be inspected can be oriented so as to avoid problem lighting and distance; ice and foam can be differentiated visually by a trained observer; the visual display can be redesigned.

An important observation of the laboratory and field tests was the practical limitation on ice detection thickness threshold setting. Early use of the Goodrich sensor by Delta Airlines had shown that a very low threshold setting (0.2 mm or 0.008 in.) caused an unacceptable level of “false positive” displays; a setting of 0.5 mm (0.02 in.) was found to be viable. The continued testing and evaluation of both Goodrich and Cox sensors confirmed these earlier observations. While a setting of 0.4 mm (0.016 in.) might be considered, this would require still further testing.

Limited trials were also anticipated during the winter of 2001-02 at the Radiant Aviation Services, Inc. infrared deicing facility in Newark, New Jersey. To date these trials have not been conducted. An essential element for these trials is the need for detailed records.

[4] Ownership of the Cox design reverted to MD Robotics in early 2003

9. DISCUSSION

9.1 Tactile Procedures and Experience

9.1.1 Effectiveness of Tactile Inspection

Regulations and standards do not specify how a tactile inspection should be conducted; furthermore, many approved procedures do not describe the method to be used.

There is no way of knowing how many, if any, aircraft are dispatched with undetected residual ice on the wings following deicing and tactile inspection. The nature of the inspection process in effect starts with deicer personnel looking to see if they have removed all ice while deicing, and performing possible touch-ups. There is then a final visual check, followed by the tactile inspection, which is combined with secondary visual observations at close range to ensure that aircraft are "clean" at dispatch. Some ¼ to ½ percent of aircraft subject to tactile inspection have been observed to require re-deicing at major centers.

Experience of deicing operators has shown that deicing procedures including tactile inspection are generally effective. Although there is no appropriate quantitative data available, it appears that it is extremely rare that an aircraft is dispatched with ice present on surfaces that have been subject to tactile inspection.

Occasionally, tactile inspection reveals residual ice contamination that passed undetected by visual inspection, and by deduction, it is evident that there is a likelihood that, in a small number of cases, residual ice exists in areas of a wing that were not subject to tactile inspection.

9.1.2 Difficulties with Quantitative Determination of Tactile Capabilities

Direct measurement of tactile capabilities and performance is not realistic. The quality of deicing at facilities where the capability for detailed controlled monitoring exists is such that normally there is no residual ice contamination. In the few cases where there is residual ice contamination after deicing, airline and facility scheduling prohibits the delays that controlled measurements would impose.

A test program to determine the quantitative capability of tactile inspection involves significant difficulties. The variables associated with tactile inspection to be addressed include such factors as training, previous experience, sense of responsibility, and time since work shift began, all of which are difficult to quantify. In addition, there are the physical variables such as edge-of-ice thickness, fluid thickness, surface temperature, ambient temperature, etc., all of which are time dependent to some extent. Any planned tests would also have to be developed so as to simulate the work environment, and to differentiate between the checker's capability and actual performance.

9.1.3 Significance of Tactile Experience for Inspection in General

Since tactile inspection reveals residual ice following deicing that was not detected visually, it seems reasonable to assume that aircraft subject to visual inspection only (i.e., not subject to tactile inspection) are being dispatched with undetected residual ice present on the wings, presumably at the same rate at which visually undetected ice occurs on “tactile-inspected” aircraft – of the order of ¼ to ½ percent of deiced aircraft. At the rate of 10,000 deicing operations per year at Montreal’s PETIA and more at Toronto’s LBPIA, this translates to a significant number of dispatches. At airports without centralized facilities, the situation would depend on the operator’s aircraft fleet composition.

9.2 Thresholds for Tactile Detection of Ice on Wings

Detecting residual ice on a wing following deicing is characterized by a difference in the surface friction of ice compared to the wing metal, a difference in the surface profile, and an apparent difference in the surface temperature of ice as compared with the wing metal surface.

The surface of the residual ice has been reported as “always smooth and tapering to a feather edge”, typifying a minor modification of the surface profile rather than a surface discontinuity or roughness. The thickness threshold for tactile detection of residual ice contamination following deicing is not a relevant consideration. Checkers detect the presence of ice by its “feel”.

How tactile ice detection thresholds would be quantified and/or converted to sensor capabilities is an issue that has not been addressed. A superficial theoretical review confirms the anecdotal observations that a residual ice patch below a sensor thickness threshold setting of 0.5 mm (0.02 in.) would be smooth and have edges blending with the wing profile. A more detailed theoretical analysis is warranted.

There are no “typical” residual ice areas or thicknesses. An area of the order of 150 mm x 75 mm (6 in. x 3 in.) appears to be a reasonable guideline. The residual ice depth has been reported anecdotally as “thin” – 0.5 mm (0.020 in.) or less – but this is a “best estimate”.

Some checkers report using a fingernail to confirm (or negate) the presence of ice when direct feel of the wing surface suggested that ice might be present. In such cases the ice thickness might be compared to some reference such as the thickness of a piece of paper. Available data suggests that in some cases for an experienced, motivated checker, this particular thickness threshold is very low. An edge-of-the-ice thickness of the order of 0.05 mm (0.002 in.) can be detected. Factors such as time preclude careful examination of the surface, and thickness measurements have not been recorded. Experienced deicing operators maximize the efficiency of their crews by training, scheduling, and providing facilities so that negative factors affecting checker performance are largely eliminated.

Comments by major operators indicate that, in general, tactile inspection is regarded as a reliable method of determining whether there is ice present on a wing, either as initially untreated ice or as residual ice following deicing. Thresholds of detection of ice by a human operator (i.e., tactile detection) are seen as irrelevant.

9.3 Remote Sensors as an Alternative to Tactile Inspection

9.3.1 Application of Remote Sensors

To be accepted as an alternative to tactile inspection, application of remote sensors for the detection of residual ice must be shown to be equal to, or safer than present tactile inspection. Remote sensors are potentially more effective than tactile inspection in consistently and reliably determining whether there is frozen contamination present following aircraft deicing. They are potentially faster and more reliable than a human operator, have a greater field of view, and are able to record the condition of the aircraft. However, it should be noted that a sensor image display would be that of the distribution of ice above the sensor threshold thickness level and not necessarily the same as the residual ice distribution that might be observed visually.

Compliance with equipment standards (SAE AS5116A/Eurocae ED104) will demonstrate that a sensor is capable of performing the required function. What compliance with SAE AS5116A does not demonstrate is that this performance is superior to tactile inspection.

9.3.2 Threshold Requirements for Remote Sensors

There are no regulatory standards pertinent to the definition of a level of contamination due to residual ice below which the aircraft's aerodynamic performance would not be affected, and which would set sensor detection thresholds for aircraft operational use. SAE Aerospace Standard AS 5116, ¶4.1.1 sets an ice thickness detection threshold at 0.5 mm (0.02 in.) for the purpose of sensor testing. The detection threshold for regulatory approval is not defined.

Although a realistic sensor thickness threshold of the order of 0.4 mm to 0.5 mm (0.016 in. to 0.02 in.) is significantly greater than estimated tactile sensitivity of perhaps 0.05 mm to 0.1 mm (0.002 in. to 0.004 in.) it must be noted that tactile detection of residual ice is based on feel, not thickness.

Since deicing is performed with hot deicing fluid, any undetected residual ice (e.g., ice of less than 0.5 mm or 0.02 in.) below the fluid will be very thin relative to the wing section profile and will have a smooth surface. Such a thin layer of ice on a wing at any location creates only a very small change in the local surface profile with little or no effect on the airfoil characteristics provided that the ice is indeed smooth and that it does not have a "step" at the edges.

With respect to area threshold constraints, it has been observed that "typical" residual ice may extend over an area of 150 mm x 75 mm (6 in. x 3 in.) – 112.5 cm^2 (17.4 sq. in.). This is less than the 315 cm^2 (48.8 sq. in.) set by the standards and must be taken into account in any use of sensors.

A direct comparison of sensor performance with tactile performance is not realistic since the quality of deicing at facilities where the capability for detailed controlled monitoring exists is such that normally there will be no residual ice contamination. In the few cases where there is residual ice contamination after deicing, it is possible that the thickness might be such that it is detected by the tactile inspection but not by a sensor. Such contamination would be smooth and would not present a hazard. Conversely, the sensor may detect contamination in an area not subject to the tactile inspection.

A limitation applies to the use of sensors: if sensors are to be used for contamination detection following deicing, it is essential that the entire wing be deiced. Untreated frost contamination below a sensor threshold height of 0.5 mm may not be acceptable.

9.3.3 History of Experience

In the absence of a reference database, and taking into account the difficulties of conducting meaningful controlled tests in the field, it would seem reasonable that sensors should initially be used for inspecting all aircraft deiced at a selected location having a large number of deicing operations, and the history of experience accumulated to develop confidence. In cases where contamination is detected by either tactile or sensor inspection, as much data as possible should be obtained to characterize the contamination.

Application details and inspection findings of all aircraft deicing events (whether sensors were used, whether tactile inspections were conducted) should be recorded. A “paper trail” should be maintained back to each event so that experience can be credited. After the end of the deicing season it must be possible to go back and review experience relative to weather, prior condition of aircraft (frost, ice, snow, etc.), aircraft, operators, equipment, visual findings, need to re-deice or do significant touch-ups, sensor results (as applicable), or any other comments/factors. It will then be possible to use the detailed documentation to address the critical issues:

- Is safety maintained or even improved?
- Can an operator’s opinions be substantiated?

In developing a historical record of field experience it should be noted that the statistical samples involved in deicing operations where there is residual ice contamination are likely to be a small percentage of the total number of aircraft deiced (the “population”) – less than 1 percent of aircraft subject to tactile inspection following deicing, and probably less than 0.1 percent of all aircraft deiced. A difficulty to be addressed exists: if residual ice is detected, then it should be measured and recorded to provide maximum data; however, this would impose an unacceptable delay to many commercial operations.

As an alternative to compiling a full set of field data records, a theoretical analysis supported by a more limited experience history would be a valid approach to sensor acceptability evaluation.

10 CONCLUSIONS

10.1 Effectiveness of Tactile Inspection

- Deicing procedures are generally effective.
- Tactile inspection is more effective than visual inspection.
- Aircraft found to be clean by visual inspection have been found to have residual ice present when subject to tactile inspection. This implies that aircraft not subject to tactile inspection may be dispatched with undetected residual ice present on the wings.
- Use of a rod to touch a locally roughened wing surface has been used to detect any ice that might cause FOD to rear-mounted engines. In such cases, ice may remain undetected if it is below the roughened dry surface profile peak height.
- The effectiveness of tactile inspection is not known quantitatively:
  - It is not known how many aircraft that are subject to a tactile inspection have residual ice present on the surfaces inspected, and which remains undetected.
  - Residual ice may exist on areas of the wing not subject to tactile inspection.
  - There is a need to re-deice approximately ½ percent of those aircraft subject to tactile inspection.

10.2 Tactile Ice Detection Thresholds

- Detection of residual ice by tactile inspection following deicing is predominantly the result of a change in the surface friction, surface profile, and possibly apparent surface temperature differences as the fingers or hands are moved across the wing surface.
- The reliability of detection is dependent on a number of factors such as the checker's exposure to cold, training, fatigue, and/or motivation, which are difficult to quantify.
- There is no thickness threshold for tactile detection of residual ice.
- In some cases where an inspector is uncertain as to whether residual ice is present, a fingernail may be used to scratch on the surface. If ice is present, experienced inspectors can detect very low levels of residual ice, perhaps down to 0.05 mm (0.002 in.) thickness.
- Quantified residual ice tactile detection threshold data are not available. Checkers report that residual ice is typically less than 0.5 mm (0.02 in.) thick with an area of 110 cm^2 (17 sq. in.) – this area may vary considerably.
- Checkers report that residual ice is smooth and blends into the wing surface. This is consistent with simplified theoretical considerations.
- Quantified residual ice tactile detection threshold data is not available. Testing under controlled conditions to establish such data would have to be extensive to address all the variables. Application to sensor capabilities would have to be considered.

10.3 Sensors as an Assistance or Alternative to Tactile Inspection

- Remote sensors are potentially more effective than tactile inspection in consistently and reliably determining whether there is frozen contamination still present following aircraft deicing. They can address the entire wing since they are not restricted by a checker's physiology (i.e., reach). They can record and store information in electronic format for future analysis.

- Since deicing is performed with hot deicing fluid, any residual ice below the fluid will have a smooth surface. A thin layer of smooth ice, below the thickness detection threshold of a sensor that meets present equipment standards, would have virtually no effect on the wing's airfoil characteristics, provided that there are no sharp "steps" at the edge of the ice layer. Sensor settings would have to take into account residual ice area distribution as well as thickness.
- A detailed theoretical model of ice reduction to a thin residual layer due to hot fluid application should be considered as a possible method to establish the residual ice profile form.
- If sensors are to be used for contamination detection, the entire wing area must be deiced.
- Standards have been developed for qualification of sensor equipment. There are no regulatory standards that define a maximum level of contamination consistent with a safe takeoff, or that set sensor detection thresholds for aircraft operational use.
- An intended application of remote sensors must be shown to be equal to, or safer than present tactile inspection.
- There is no comprehensive database for comparative evaluation of sensors to assist or replace tactile inspection, though a limited history of experience has been accumulated.
- Statistically meaningful comparative tests of human tactile and sensor inspection performance under controlled conditions in the field would be difficult to implement.

REFERENCES

1. Lotens, W. A., "Simulation of hand cooling due to touching cold materials", *European Journal of Applied Physiology and Occupational Physiology,* Vol. 65 No. 1, 1992, pp. 59-65.

2. Ozaki H., Nagai Y., and Tochihara Y., "Physiological responses and manual performance in humans following repeated exposure to severe cold at night", *European Journal of Applied Physiology*, Vol. 84 No. 4, 2001, pp. 343-349.

3. Havenith G., van de Linde E.J., and Heus R., "Pain, thermal sensation and cooling rates of hands while touching cold materials", *European Journal of Applied Physiology and Occupational Physiology*, Vol. 65 No. 1, 1992, pp. 43-51.

4. Chen F., Nilsson H., and Holmer I., "Finger cooling by contact with cold aluminum surfaces – Effects of pressure, mass and whole body thermal balance", *European Journal of Applied Physiology and Occupational Physiology*, Vol. 69 No. 1, 1994, pp. 55-60.

5. *Aircraft deicing/anti-icing methods*, Aviation Recommended Practice, ARP 4737, SAE International, Revision F, February 2004.

6 Brumby, R.E., "Wing Surface Roughness: Cause and Effect," *D.C. Flight Approach*, No. 32, Jan. 1979.

7. Tezok, F., and Boyce, F., *Effects of Roughness on Advanced Airfoils: Phase II and Phase III*, Transportation Development Centre, TP 13253E, September 1998.

8. Oleskiw, M.M., and Penna, P.J., *Airfoil-Flap Performance with De/Anti-Icing Fluids and Freezing Precipitation*, Transportation Development Centre, TP 13426E, May 1999.

9. Chaput, M., et al., *Characteristics of Aircraft Anti-Icing Fluids Subjected to Precipitation*, Transportation Development Centre, TP 13317E (draft report), December 1998.

10. Rosenblad, L., *MD-80 Primary Ice Detection System*, Douglas Service, Volume fifty-two, second issue 1997.

Appendix A

Canadian Aviation Regulations, 602.11

Operating and Flight Rules
602.11 Aircraft Icing

(1) In this Section, "critical surfaces" means the wings, control surfaces, rotors, propellers, horizontal stabilizers, vertical stabilizers or any other stabilizing surface of an aircraft and, in the case of an aircraft that has rear-mounted engines, includes the upper surface of its fuselage.

(2) No person shall conduct or attempt to conduct a take-off in an aircraft that has frost, ice or snow adhering to any of its critical surfaces.

(3) Notwithstanding subsection (2), a person may conduct a take-off in an aircraft that has frost adhering to the underside of its wings that is caused by cold-soaked fuel, if the take-off is conducted in accordance with the aircraft manufacturer's instructions for take-off under those conditions.

(4) Where conditions are such that frost, ice or snow may reasonably be expected to adhere to the aircraft, no person shall conduct or attempt to conduct a take-off in an aircraft unless

(a) for aircraft that are not operated under Subpart 5 of Part VII,

(i) the aircraft has been inspected immediately prior to take-off to determine whether any frost, ice or snow is adhering to any of its critical surfaces, or

(ii) the operator has established an aircraft inspection program in accordance with the *Operating and Flight Rules Standards*, and the dispatch and take-off of the aircraft are in accordance with that program; and

(b) for aircraft that are operated under Subpart 5 of Part VII, the operator has established an aircraft inspection program in accordance with the *Operating and Flight Rules Standards*, and the dispatch and take-off of the aircraft are in accordance with that program.

(5) The inspection referred to in subparagraph (4)(a)(i) shall be performed by

(a) the pilot-in command;

(b) a flight crew member of the aircraft who is designated by the pilot-in-command; or

(c) a person, other than a person referred to in paragraph (a) or (b), who

(i) is designated by the operator of the aircraft, and

(ii) has successfully completed an aircraft surface contamination training program pursuant to Subpart 4 of Part VII.

(6) Where, commencing take-off, a crew member of an aircraft observes that there is frost, ice or snow adhering to the wings of the aircraft, the crew member shall immediately report that observation to the pilot-in-command, and the pilot-in-command or a flight crew member designated by the pilot-in-command shall inspect the wings of the aircraft before take-off.

(7) Before an aircraft is deiced or anti-iced, the pilot-in-command of the aircraft shall ensure that the crew members and passengers are informed of the decision to do so.

Appendix B

Canadian Aviation Regulations, 622.11

Operating and Flight Rules Standards
622.11 Ground Icing Operations

Division I - General

1.0 Introduction

In order to operate an aircraft under icing conditions in accordance with the requirements of CAR Section 602.11, an operator must have a program as specified in these standards and the dispatch and take-off of the aircraft shall comply with that program. These Ground Icing Operations Standards specify the program elements, for both operations and training, that shall be addressed in an operator's Ground Icing Operations Program and described in the appropriate operator's manuals. As applied to Canadian operators, these Standards outline a Program's minimum requirements, which may be adapted according to the needs of the individual operator. Foreign operators should use this Standard as a guideline for the development of their Ground Icing Operations Program in Canada.

2.0 Definitions

The following are definitions of important terms used in these Standards

"anti-icing" – is a precautionary procedure that provides protection against the formation of frost or ice and the accumulation of snow on treated surfaces of an aircraft for a period of time.

"contamination" – means any frost, ice or snow that adheres to the critical surfaces of an aircraft.

"critical surfaces" – means the wings, control surfaces, rotors, propellers, upper surface of the fuselage on aircraft that have rear-mounted engines, horizontal stabilizers, vertical stabilizers or any other stabilizing surface of an aircraft.

"critical surface inspection" – is a pre-flight external inspection of critical surfaces conducted by a qualified person as specified in Part VI, subsection 602.11(5), to determine if they are contaminated by frost, ice, or snow. Under ground icing conditions, this inspection is mandatory.

"deicing" – is a procedure by which frost, ice, or snow is removed from the critical surfaces of an aircraft in order to render them free of contamination.

"ground icing conditions" – With due regard to aircraft skin temperature and weather conditions, ground icing conditions exist when frost, ice, or snow is adhering or may adhere to the critical surfaces of an aircraft.

"ground icing operations program" – consists of a set of procedures, guidelines, and processes, documented in manuals, that ensure that an operator's aircraft does not depart with frost, ice, or snow adhering to critical surfaces.

"holdover time" – is the estimated time that an application of deicing/anti-icing fluid is effective in preventing frost, ice, or snow from adhering to treated surfaces. Holdover time is calculated as beginning at the start of the final application of deicing/anti-icing fluid and as expiring when the fluid is no longer effective.

"pre-take-off contamination inspection" – is an inspection conducted by a qualified person, immediately prior to take-off, to determine if an aircraft's critical surfaces are contaminated by frost, ice, or snow. This inspection is mandatory under some circumstances.

3.0 Program Elements

The following elements, which are described in the sections below, will be included in an operator's Ground Icing Operations Program and described in the appropriate manual(s):

- The Operator's Management Plan;
- Aircraft Deicing/Anti-icing Procedures;
- Holdover Timetables;
- Aircraft Inspection and Reporting Procedures; and
- Training and Testing.

4.0 The Operator's Management Plan

According to Canadian regulations, the aircraft operator is responsible for the operational control of an aircraft. In order to properly exercise operational control under ground icing conditions, a Management Plan to ensure proper execution of the operator's approved Ground Icing Operations Program must be developed and implemented.

The Management Plan will identify the management position responsible for the overall Program, identify each subordinate position, and describe those functions and responsibilities needed to properly manage the Program. The Plan must also describe operational responsibilities and procedures, delineate the chain of command, define the relationship between its operations and maintenance groups, and ensure that all parties are informed of their responsibilities with regard to the Program. Although the Program is usually an operations responsibility, it may be shared between operations and maintenance. The Program may be the sole responsibility of operations, but never the sole responsibility of maintenance.

4.1 Operations

(1) The Plan must identify the management position responsible for ensuring that:

> *(a)* all the necessary elements of the Program have been developed, properly integrated, and coordinated;
>
> *(b)* the Program has been disseminated to all personnel who have duties, responsibilities, and functions to perform within the Program;
>
> *(c)* a detailed description of the Program is incorporated in the appropriate operator's manuals;
>
> *(d)* sufficient competent personnel and adequate facilities and equipment are available at each airport where the Program may be applied; and
>
> *(e)* adequate management supervision of the Program is maintained.

(2) The Management Plan must also provide the following information:

(a) at each airport where deicing/anti-icing operations will be conducted, the position that is responsible for deciding when ground deicing/anti-icing operations are to begin and when they are to end must be identified and fully described in a position description;

(b) the functions, duties, and responsibilities of flight crew, aircraft dispatchers, and management personnel must be specified, as well as the instructions and procedures to be followed for the safe dispatch or release of aircraft during ground icing conditions; and

(c) the position responsible for authorizing and coordinating the applicable portions of the Program with Air Traffic Control and airport authorities must be identified and described in a position description.

4.2 Maintenance

Where maintenance shares responsibility for the Program, the Management Plan must identify the position responsible for ensuring that sufficient competent personnel and adequate facilities and equipment are available at each airport where the Program may be applied. The functions, duties, and responsibilities of maintenance personnel must also be specified, as well as the instructions and procedures to be followed for the safe dispatch or release of aircraft during ground icing conditions.

Division II – Procedures

5.0 Aircraft Deicing/Anti-icing Procedures

In a well-organized, clearly identified, separate section of the appropriate manual, the operator's deicing/anti-icing procedures must be described. In particular, the person responsible for a specific procedure must be identified, and procedures particular to a type of aircraft specified. The following minimum information must be covered in the operator's manual:

(a) a detailed description of the weather and aircraft surface conditions under which deicing/anti-icing operations are required and the method whereby the Program is activated; and

(b) a detailed description of the procedures to be followed in the deicing/anti-icing treatment process for each aircraft type. These procedures must be organized so as to minimize deicing/anti-icing fluid application time and must specify the sequence in which critical surfaces are to be treated.

6.0 Holdover Timetables

The use of holdover timetables is not mandatory. Holdover timetables, as approved by the Director, Air Carrier, may be used either as guidelines or decision-making criteria in assessing whether it is safe to take off. When holdover timetables are used as decision-making criteria, only high confidence level times shall be used and the procedures to be followed after holdover time has expired must be clearly documented. Where applicable in a Program, an operator's manual will cover the following areas with regard to holdover timetables:

6.1 Responsibilities and Procedures

The operator's Program must define the following:

(a) the operational responsibilities of flight crew, flight watch system personnel, and maintenance and ground personnel;

(b) the procedures to be followed for the use of holdover timetables and the actions to be taken if holdover time is exceeded; and

(c) the procedures to be followed by ground and flight crew for establishing the start of holdover time.

6.2 Use of Holdover Timetables

Holdover timetables provide an estimate of the length of time deicing/anti-icing fluids are effective. Because holdover time is influenced by a number of factors, established times may be adjusted by the pilot-in-command according to the weather or other conditions. Operators' manuals must describe the procedures to be followed for using holdover timetables. When the tables are used as decision-making criteria, the procedures to be followed by the pilot-in-command (PIC) for varying the established values must also be specified.

6.3 Take-off after Holdover Times have been Exceeded

When holdover timetables are used as decision-making criteria, take-off after holdover times have been exceeded can occur only if a pre-take-off contamination inspection is conducted or the aircraft is deiced/anti-iced again. The operator's Program must specify the procedures to be followed when holdover time is exceeded, and these procedures must appear in the appropriate manuals.

7.0 Aircraft Inspection and Reporting

When and where applicable, the operator's Program must document the guidelines and procedures to be followed by flight crew and other personnel for detecting contamination on the critical surfaces of aircraft. Included must be a description of the kinds of inspections permitted by the operator and at what point in the Program they must be conducted. These instructions must be aircraft specific.

The Program shall outline the responsibility of the PIC under CAR Section 602.11 to inform the cabin crew and passengers of the decision to have the aircraft de/anti-iced, when the decision is made. The method by which this information is conveyed may be standardized in the operator's program or left to the discretion of the PIC. It will also be clear that, if the aircraft is de/anti-iced prior to the boarding of passengers, no announcement to that effect is required.

7.1 Inspection Procedures

Two types of inspections, as defined in Section 2.0 of these Standards, meet regulatory requirements. They are the Critical Surface Inspection and the Pre-take-off Contamination Inspection. Under icing conditions, the Critical Surface Inspection is mandatory; however, depending on the requirements of the operator's Program, the Pre-take-off Contamination Inspection may not be required. In its section on inspection procedures, the operator's manual must describe the techniques to be used in contamination recognition and the conduct of the two types of inspection.

7.1.1 Contamination Recognition

Inspection procedures must describe the techniques to be used for detecting frost, ice, and snow and for determining if they are adhering to critical surfaces. These techniques must be specified in the operator's Program and may include the use of holdover timetables, tactile inspection, examination of one or more representative aircraft surfaces, or sensors.

7.1.1.1 Holdover timetables, approved according to the conditions outlined in section 6 of these Standards, may be used to determine, without a tactile or visual Pre-take-off Contamination Inspection, that critical surfaces are not contaminated.

7.1.1.2 Tactile inspection, under certain circumstances, may be the only way of confirming that the critical surfaces of an aircraft are not contaminated. This physical inspection shall be carried out by a qualified person and must include the leading edge and upper surface of the wings.

7.1.1.3 Examination of one or more representative aircraft surfaces may be used for the Pre-take-off Contamination Inspection, which does not require a tactile examination. This technique may be used when the aircraft manufacturer has identified representative aircraft surfaces that can be readily and clearly observed by flight crew during day and night operations and that are suitable for judging whether critical surfaces are contaminated or not.

If no representative aircraft surfaces have been identified by the aircraft manufacturer, an operator may offer one or more representative surfaces for approval by the Regional Manager, Commercial and Business Aviation or Chief, Airline Inspection; such a submission must be accompanied by technical data supporting the use of these surfaces as representative. (amended 2000/09/01; previous version)

7.1.1.4 Sensors that provide information directly to the pilot-in-command may be used to determine whether critical surfaces are contaminated or not. The installation and use of sensors must meet applicable Transport Canada airworthiness and operational requirements. The procedures for use of sensors must be detailed in the operator's Program.

7.1.2 Critical Surface Inspection

This inspection is mandatory whenever ground icing conditions exist, and if the aircraft is deiced/anti-iced, must take place immediately after final application of the fluid. After the inspection, an inspection report must be made to the pilot-in-command by a qualified person.

7.1.3 Pre-take-off Contamination Inspection

The operator's Program must describe the methods to be used in this inspection, which may be conducted from the inside or outside of the aircraft, which may be visual or tactile, and which may use representative aircraft surfaces to judge the extent of contamination. Where only a visual inspection is done, the operator's Program must specify the conditions, such as weather, lighting, and visibility of critical surfaces, under which such an inspection can be conducted. Unless other procedures have been specifically approved, a tactile external inspection must be conducted on all aircraft without leading edge devices, such as the DC9-10 and the F-28, and on any other aircraft as designated by the Director, Air Carrier.

7.2 Inspection Reporting

It is the pilot-in-command's responsibility to ensure that aircraft critical surfaces are not contaminated at take-off. When the pilot-in-command does not conduct the inspection, the delegated person must provide an inspection report in clear language to the pilot-in-command who must indicate that the report is complete and understood. A detailed description of the guidelines and procedures to be followed in communications between the checker and the pilot-in-command, including the use of hand-signals, must be included in the appropriate operator's manual.

For the purposes of these Standards, there are two types of inspection reports, which correspond to the two types of inspections described above.

7.2.1 Critical Surface Inspection Report

This report must be made to the pilot-in-command and, if applicable, state the time at which the last full application of deicing/anti-icing fluid began, the type of fluid used, the ratio of the fluid mixture, and, if the standard documented method was not used, the sequence in which the critical surfaces were deiced/anti-iced. In addition, the report must confirm that all critical surfaces are free of contamination.

7.2.2 Pre-take-off Contamination Inspection Report

This report must be made to the pilot-in-command and, when the standard documented inspection method has not been used, must describe how the inspection was conducted and it must also confirm that all critical surfaces are free of contamination.

Division III – Training

8.0 Training and Testing

An operator's Ground Icing Operations Training Program shall include:

(a) initial and annual recurrent training for all operational and ground/maintenance personnel who have responsibilities within the program; and

(b) testing of crew members and other operations and ground/maintenance personnel who have responsibilities within the program.

8.1 Initial Deicing/Anti-icing Operations

Flight crew and other operations personnel who have responsibilities within the operator's Ground Icing Operations Program shall receive training in at least the following subjects, which are further described below:

• the effects of contamination on critical surfaces;
• aircraft deicing/anti-icing procedures;
• aircraft inspection and reporting procedures; and
• the use of holdover timetables.

8.1.1 Training on the effects of contamination on critical surfaces, including:

(a) the reporting of contamination on arrival to the person responsible for coordinating the deicing/anti-icing of aircraft;

(b) the effects of freezing precipitation, frost (including hoar-frost), freezing fog, snow, rain, and high humidity on cold-soaked critical surfaces and under wings;

(c) the identification, by aircraft type, of critical surfaces and, where applicable, representative aircraft surfaces;

(d) the types, purpose, characteristics and uses of deicing/anti-icing fluids; and

(e) how deicing/anti-icing fluids influence the performance and handling of aircraft, including their effect on rotation speeds, take-off distance, control pressures, stall margins, reduced thrust take-offs, and climb pitch attitudes, where applicable.

8.1.2 Training in aircraft deicing/anti-icing procedures, including:

(a) the safety precautions to be observed during fluid application;

(b) the methods for applying deicing/anti-icing fluid;

(c) the composition and identification of deicing/anti-icing fluids;

(d) remote deicing/anti-icing procedures, including aircraft-specific and location-specific procedures, where applicable; and

(e) the supervisory responsibilities of flight crew with regard to contractor services when the operator does not arrange for the training and qualification of contractor personnel. (See 8.5 Contractor Training)

8.1.3 Training in aircraft inspection procedures, which shall be aircraft specific, when necessary, and which shall include:

(a) identification of the critical surfaces and representative aircraft surfaces to be inspected;

(b) techniques for detecting and recognizing contamination on the aircraft;

(c) the different types of inspection techniques as well as when, where, by whom, and under what conditions (such as lighting and weather) they are to be used; and

(d) the communications procedures to be followed by flight crew when contacting ground personnel, Air Traffic Control, or company station personnel to coordinate aircraft inspections.

8.1.4 Training in the Use of Holdover Timetables, both when Used for Guidance and as Decision-making Criteria

For training in the use of holdover timetables as decision-making criteria, all of the following shall be covered. Only the first four items must be taught when holdover timetables are used for guidance. Training in the use of holdover timetables shall include:

(a) the source of holdover timetable data;

(b) instruction in precipitation category, precipitation intensity, and the relationship of a change in precipitation to holdover time;

(c) the relationship between holdover time and different fluid concentrations for all types of fluid used;

(d) the definition of when holdover time begins and ends;

(e) communications procedures, which covers how to inform flight crew of the type of fluid used, start time of final fluid application, and any requirements for coordination with other agencies; and

(f) the procedures to be followed when holdover time is exceeded, including inspection requirements, alternate means for determining whether surfaces are contaminated, and the requirements governing repeat deicing/anti-icing.

8.2 Recurrent Deicing/Anti-icing Operations Training

Recurrent training must be given on an annual basis and shall include a review of current deicing/anti-icing operations and inspection procedures. This training must highlight changes in procedures and cover the latest available research and development information on ground deicing/anti-icing operations. Prior to the commencement of winter operations, the operator should distribute a ground deicing/anti-icing operations information circular to all affected personnel reviewing procedures and presenting any new information not covered in the annual recurrent training.

8.3 Initial Ground/Maintenance Personnel Training

Ground/maintenance personnel who have responsibilities within the operator's Ground Icing Operations Program shall receive training in at least the following three subjects:

8.3.1 Training on the effects of surface contamination, including:

(a) the items listed in Section 8.1.1 excluding 8.1.1e);

(b) specific information on the effects of contamination on ram-air intakes and instrument pick-up points; and

(c) potential damage to engines by foreign objects.

8.3.2 Training in aircraft deicing/anti-icing procedures, including:

(a) the items listed in Section 8.1.2 excluding 8.1.2e);

(b) a description of and the qualifications required for the operation of various types of equipment;

(c) instruction in the operation of deicing/anti-icing equipment; and

(d) the determination of the start of holdover time.

8.3.3 Training in aircraft inspection procedures, which shall be aircraft specific, when necessary, and which shall include:

(a) the items listed in Section 8.1.3 excluding 8.1.3d); and

(b) the inspection techniques for conducting a Critical Surface Inspection.

8.4 Recurrent Ground/Maintenance Personnel Training

Recurrent training must be given on an annual basis and shall include a review of current deicing/anti-icing operations and inspection procedures. This training must highlight changes in procedures and cover the latest available research and development information on ground deicing/anti-icing operations. Prior to the commencement of winter operations, the operator should distribute a ground deicing/anti-icing operations information circular to all affected personnel reviewing procedures and presenting any new information not covered in the annual recurrent training.

8.5 Contractor Training

An operator who contracts deicing/anti-icing services from another organization is responsible for ensuring that the training program of the contractor and application of deicing/anti-icing operations standards meet the operator’s own Ground Icing Operations Program criteria. Through the operator, the contractor’s procedures and training programs shall be documented.

8.6 Testing

After both initial and recurrent training, the operator’s Program must ensure that all personnel are tested on all information covered in the training program. Records documenting the initial and annual recurrent training of each person must also be maintained.