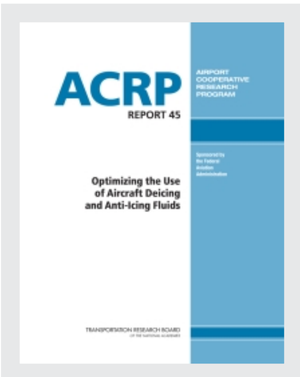

Optimizing the Use of Aircraft Deicing and Anti-Icing Fluids

DETAILS

157 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-15551-9 | DOI 10.17226/14517

AUTHORS

Airport Cooperative Research Program; Transportation Research Board; National Academies of Sciences, Engineering, and Medicine

AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP REPORT 45

Optimizing the Use of Aircraft Deicing and Anti-Icing Fluids

John D'Avirro
Michael Chaput
APS AVIATION INC.
Montreal, QC

Subscriber Categories
Aviation • Maintenance and Preservation • Environment • Operations and Traffic Management

Research sponsored by the Federal Aviation Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2011
www.TRB.org

ACRP REPORT 45

Project 10-01
ISSN 1935-9802
ISBN 978-0-309-15551-9
Library of Congress Control Number 2011924371

Published reports of the

AIRPORT COOPERATIVE RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet at

http://www.national-academies.org/trb/bookstore

Printed in the United States of America

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is one of six major divisions of the National Research Council. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **www.TRB.org**

www.national-academies.org

COOPERATIVE RESEARCH PROGRAMS

CRP STAFF FOR ACRP REPORT 45

Christopher W. Jenks, *Director, Cooperative Research Programs*
Crawford F. Jencks, *Deputy Director, Cooperative Research Programs*
Michael R. Salamone, *ACRP Manager*
Edward T. Harrigan, *Senior Program Officer*
Melanie Adcock, *Senior Program Assistant*
Eileen P. Delaney, *Director of Publications*
Margaret B. Hagood, *Editor*

ACRP PROJECT 10-01 PANEL
Field of Operations

Jorge E. Panteli, *McFarland-Johnson, Inc., Concord, NH* (Chair)
Janell Barrilleaux, *Federal Aviation Administration, Renton, WA*
John A. Lengel, Jr., *Gresham, Smith and Partners, Columbus, OH*
Danuta Leszczynska, *Jackson State University, Jackson, MS*
Alec J. Simpson, *Transport Canada, Ottawa, ON*
Bryan C. Wagoner, *Wayne County (MI) Airport Authority, Detroit, MI*
George Legarreta, *FAA Liaison*
Richard Marchi, *Airports Council International–North America Liaison*
Christine Gerencher, *TRB Liaison*

FOREWORD

By Edward T. Harrigan
Staff Officer
Transportation Research Board

ACRP Report 45: Optimizing the Use of Aircraft Deicing and Anti-Icing Fluids provides practical technical guidance on procedures and technologies to reduce the use of aircraft deicing and anti-icing fluids (ADAF) while maintaining safe aircraft operations across the wide range of winter weather conditions found in the United States and Canada. This guidance is presented as (1) a series of best management practices that are immediately implementable and (2) the detailed findings and recommendations of experiments to evaluate holdover time determination systems, spot deicing for aircraft frost removal, and ADAF dilutions. The report will be of direct interest to airport and airline staff responsible for aircraft deicing and anti-icing operations and the mitigation of their environmental impacts.

Current understanding of the mechanisms of the formation, retention, and removal of ice from critical aircraft surfaces is incomplete, leading to conservative deicing and anti-icing practices that may waste some portion of the ADAF used for this critical function. Further, airports are under regulatory pressure to minimize the quantity of spent ADAF discharged to waterways or sewage treatment plants because the fluids can contribute to aquatic toxicity, excessive chemical and biological oxygen demand, and deterioration of the airport infrastructure. Mitigation of storm water runoff containing ADAF can require the expenditure of sums in excess of $10 million at individual airports.

The objective of ACRP Project 10-01 was to identify procedures and technologies that optimize the use of ADAF, thus reducing their environmental impact while assuring safe aircraft operations in conditions requiring deicing and anti-icing. The project was conducted by APS Aviation, Inc., Montreal, Quebec, Canada.

The project team first reviewed the worldwide literature to identify a wide range of procedures and technologies to optimize ADAF use and then conducted a combination of engineering analyses and laboratory and field experiments to measure and validate the effectiveness of the most promising procedures and technologies selected in consultation with the ACRP project panel.

The report is organized into five chapters. Chapter 1 is a concise summary of the research conducted in the project. Chapter 2 presents the key findings of a literature review to identify technologies and procedures that could potentially optimize ADAF use and reduce environmental impact while maintaining or even enhancing the safety of aircraft operations. In addition, Chapter 2 describes the results of a focus group organized to gain industry insights and feedback on current and future ADAF optimization practices. The focus group looked at 34 potential optimization technologies and procedures, many of which were ultimately deemed to possess technical or operational deficiencies, or to not offer an adequate environmental or operational enhancement, and were thus eliminated from further examination with the concurrence of the ACRP project panel.

Chapter 3 presents the results of field experiments conducted at four airports in the United States and Canada to examine whether a holdover time (HOT) precipitation sensor at a single location can reliably report precipitation conditions for an entire airport. The experiment was carried out by measuring precipitation intensity simultaneously at several sites at an airport during winter weather events. The experimental results indicate that differences in between-site HOTs for snow can be significant to the operation, and that they are a function of distance. Specifically, the differences in HOT generated from different sites begins to impact the operation when the sites are separated by mid-range distances (7,000 to 13,500 ft), and have a definite impact at long separation distances (on the order of 28,000 ft).

Chapter 4 presents the findings of an investigation into the use of spot deicing for frost removal, which is a procedure that involves deicing small frost-contaminated spots on aircraft wings in lieu of deicing the entire wings. A significant number of operators are not familiar with the spot deicing procedure; training, lack of qualified individuals to make assessments, and asymmetrical application are obstacles to its use. As a result of this project, guidance material for spot deicing for frost removal will be incorporated into SAE ARP 4737. A cost-benefit model and presentation aids were prepared to assist operators in assessing the benefits of implementing spot deicing for frost removal in their operations and consequentially encouraging its use.

In Chapter 5, the results of an investigation to assess the use of ADAF dilutions and to ascertain potential savings in the use of glycol for deicing and anti-icing of aircraft are documented. ADAF dilutions are not widely used, although adequate regulations and guidelines for their use exist. Indeed, their use can be shown to be cost beneficial for many operations. A cost-benefit model and presentation aids were developed to give operators the tools they need to assess whether implementing the use of fluid dilutions would be beneficial for their operation.

The final part of the report presents 16 Fact Sheets describing promising technologies and procedures from Chapter 2, singly or in combination, in the form of readily implementable best management practices. The Fact Sheets complement those in ACRP Project 02-02, "Managing Runoff From Aircraft and Airfield Deicing and Anti-Icing Operations," as presented in *ACRP Report 14: Deicing Planning Guidelines and Practices for Stormwater Management Systems*. Each Fact Sheet includes (1) a description of the technology or procedure; (2) implementation considerations; and (3) cost information.

The appendixes from the contractor's final report, computational tools, and presentation media may be downloaded from the ACRP Project 10-01 webpage at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=122.

Note: As part of ACRP Project 02-61, Fact Sheets 45, 55, and 56 were updated and a new one, Fact Sheet 112, was added in September 2016.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

CHAPTER 1

Project Summary

The objective of ACRP Project 10-01, "Optimizing the Use of Aircraft Deicing and Anti-Icing Fluids," was to identify procedures and technologies that optimize the use of aircraft deicing and anti-icing fluids, thus reducing their environmental impact while assuring safe aircraft operations in deicing and anti-icing conditions. The project was intended to produce (1) a description of the application of currently available procedures and technologies to optimize the use of aircraft deicing and anti-icing fluid (ADAF); (2) validation of the effectiveness of promising procedures and technologies; (3) a plan for implementation of these promising procedures and technologies; and (4) recommendations for further study.

Phase I: Promising De/Anti-Icing Source Reduction Practices

Phase I of the project consisted of a literature review of aircraft ground deicing-related technical reports; deicing product manufacturer reports; and regulatory, government and industry documentation, guidance material and standards to assist in the identification of technologies and procedures that could potentially optimize the use of aircraft deicing and anti-icing fluids, thus reducing the environmental impact of operations using these products. In addition, an industry focus group was surveyed for inputs on current practices and optimization strategies. The literature review and focus group survey identified a list of 18 optimization technologies and procedures for potential future study. Using the Binary Analysis Decision Model, the optimization technologies and procedures were subjected to a ranking exercise, based on a series of weighed analytical criteria. The analysis resulted in the recommendation of several de/anti-icing optimization technologies and procedures for evaluation in Phase II. This effort is described in Chapter 2 of this report. Appendixes A through G are available at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=122.

Phase II: Research and Development on Four Selected Topics

Based on its review of the results of Phase I, the ACRP Project 10-01 technical panel selected four topics for further research and development in Phase II:

1. Fact Sheets for De/Anti-Icing Optimization;
2. Holdover Time Variance Across an Airfield;
3. Increased Use of Spot Deicing for Aircraft Frost Removal; and
4. Increased Use of Aircraft De/Anti-Icing Fluid Dilutions.

Fact Sheets for De/Anti-Icing Optimization

Several technologies and procedures identified in Phase I were developed into a set of detailed Fact Sheets for optimizing ADAF use.

The format followed for development of the Fact Sheets was similar to that used in ACRP Project 02-02, "Managing Runoff From Aircraft and Airfield Deicing and Anti-Icing Operations." This enabled inclusion of these Fact Sheets within the overall compendium of Fact Sheets for optimizing ADAF use presented in *ACRP Report 14: Deicing Planning Guidelines and Practices for Stormwater Management Systems.* The fact sheets include a description of the technology or procedure, implementation considerations, and cost information.

The Fact Sheets developed in this project are presented separately from this report.

Holdover Time Variance Across an Airfield

Holdover time determination systems (HOTDS) measure meteorological parameters at airport sites that are then used to calculate expected fluid holdover times, thus facilitating better de/anti-icing fluid selection. Task 2 of Phase II examined if a single location precipitation sensor can reliably report precipitation conditions for the entire airport by measuring precipitation intensity simultaneously at different sites at an airport.

Data were collected over two winter seasons, 2007–08 and 2008–09, at four airports during 15 snowstorms. Data collection site separation distances varied from 4,167 ft to 28,500 ft. Data also were collected during lake-effect snowfall to examine its effect.

Measured precipitation rates produced between-site differences in holdover time (HOT) ranging from zero to greater than 50%. It was concluded that differences in HOT in the order of 20 to 30% are of potential operational interest, and between-site differences greater than 30% are of definite interest.

The longest separation distances showed a considerably higher frequency of occurrence of large between-site differences in HOT. The differences in HOT generated from different sites begin to impact operations when the sites are separated by mid-range distances and have a definite impact at long separation distances.

There is considerable variance in the snow intensity and HOT values derived from test data and from METAR sources.

The results, findings, and conclusions developed in the HOT study are presented in Chapter 3 of this report. Appendices A through C are available through links on http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=122.

Increased Use of Spot Deicing for Aircraft Frost Removal

In Task 3 of Phase II, an investigation was conducted to substantiate the spot deicing for frost removal methodology, a procedure used to deice small frost-contaminated spots on aircraft wings in lieu of deicing the entire wings. The objective was to better understand current practices and regulations for this procedure, quantify its potential benefits, identify potential obstacles to its use, and provide tools for decision makers to determine whether it is suitable for their operation. This effort encompassed (1) a review of current government and industry regulations, guidance material and standards; (2) a survey of airlines and deicing service providers; (3) the generation of a cost-benefit model; and (4) the design and conduct of experimental tests.

A significant number of airport and aircraft operators are still not familiar with this procedure, and training, lack of qualified individuals to make assessments, and asymmetrical application are obstacles to its use. The cost-benefit model and presentation aids prepared in this project give operators tools to assess the benefits of implementing spot deicing for frost removal and consequentially encouraging its use. Guidance material for spot deicing for frost removal based on the results of this project will soon be available in SAE ARP 4737.

The results, findings, and conclusions developed in the spot deicing study are presented in Chapter 4 of this report.

Increased Use of Aircraft De/Anti-Icing Fluid Dilutions

In Task 4 of Phase II the use of ADAF dilutions was assessed to determine the potential for reductions in the use of glycol for deicing and anti-icing aircraft.

The objective was to examine current practices and regulations related to the use of fluid dilutions and to document the opportunities, limitations, obstacles and potential benefits associated with their usage. This encompassed (1) a review of current government and industry regulations, guidance material, and standards related the use of fluid dilutions; (2) a survey of airlines and deicing service providers; and (3) the development of a cost-benefit model.

The study concluded that the majority of users do not employ ADAF dilutions, despite the facts that (1) adequate regulations and guidelines for their use exist and (2) their use can be shown to be cost beneficial for many operations. This lack of use is likely related to a poor understanding that the financial savings to be gained in many cases much outweigh the additional costs of introducing dilute fluids into an operation. A cost-benefit model and presentation aids were developed to give operators the tools they need to assess whether implementing the use of ADAF dilutions would be beneficial for their operation.

The results, findings, and conclusions developed in the study of ADAF dilutions are presented in Chapter 5 of this report.

CHAPTER 2

Promising De/Anti-Icing Source Reduction Practices

Introduction

Aviation regulations prohibit the takeoff of aircraft when snow, ice or frost is adhering to wings, tails, control surfaces, propellers, engine intakes and other critical surfaces of the aircraft. This rule forms the basis of the "Clean Aircraft Concept." To this end, the aviation industry has developed ground de/anti-icing procedures and technologies to maintain the safety of winter flight operations. Aircraft deicing consists of the removal of ice, snow, and frost from aircraft surfaces; anti-icing uses a protective agent to avoid any further accumulation of ice or snow following deicing and prior to takeoff. The technologies most prominently used for aircraft ground de/anti-icing are glycol-based, freeze point depressant fluids.

Aircraft ground de/anti-icing is critical to flight safety because ice accumulation on critical aircraft surfaces can have a detrimental impact on aerodynamic performance and can possibly result in engine loss or damage due to ice ingestion. Aircraft ground de/anti-icing became the subject of concerted industry attention approximately 15 years ago due to the occurrence of several fatal icing-related aircraft accidents. Of particular importance to North American regulators were the crashes that occurred in Dryden, Ontario and La Guardia, New York in 1989 and 1992, respectively. Both accidents resulted in the loss of lives and ultimately stimulated extensive Transport Canada (TC) and FAA involvement in aircraft de/anti-icing research and development.

Despite dramatic improvements in recent years in the quality of aircraft de/anti-icing fluids, fluid delivery equipment, fluid recovery equipment, industry procedures, and ground/flight crew training, the negative aspects of the use of glycol for aircraft ground de/anti-icing are still prominent. These negative aspects include, but are not limited to:

- High costs associated with the use of glycol;
- Environmental concerns (toxicity, biodegradability);
- Aircraft delays and airport throughput issues in deicing events;
- Increase in fuel burn due to live deicing operations;
- Glycol mitigation; and
- Occupational hazards.

The negative aspects of glycol aircraft de/anti-icing fluids and their direct impacts were once dismissed by the industry as the necessary evil to ensure safe winter operations. This situation is changing rapidly, however. Environmental protection agencies and regulators worldwide are exerting increasing pressure on airports and operators to be accountable, and the high costs associated with the use of glycol have made many airlines examine the current way of doing business.

Objective

The objective of ACRP Project 10-01 was to identify procedures and technologies that optimize the use of ADAFs, thus reducing their environmental impact while assuring safe aircraft operations in deicing and anti-icing conditions. The project produced (1) a description of the application of currently available procedures and technologies to optimize ADAF use; (2) the results of an experiment to validate the effectiveness of several promising procedures and technologies; (3) a plan for implementation of these promising procedures and technologies; and (4) recommendations for further study.

Organization

ACRP Project 10-01 was performed in two phases. Phase I has three work elements:

1. A thorough literature review and information collection on current aircraft ground de/anti-icing optimization procedures and technologies.
2. An analysis of data developed in work element #1 to identify specific procedures and technologies for further evaluation in Phase II of ACRP Project 10-01.

3. Preparation of an interim report summarizing the results of Task 1, a comprehensive discussion of each of the procedures and technologies recommended for further evaluation, and an outline of an experimental plan.

Phase II has these work elements:

1. Design of the experimental plan to validate the feasibility and effectiveness of procedures and technologies approved by ACRP in Phase I and conduct of the experiments.
2. Identification of additional opportunities for further research.
3. Preparation of this final report summarizing the results and recommendations of the research.

Research Approach

This section describes the approach and methodologies employed in Phase I.

Literature Review and Data Examination

APS performed a literature review to identify technologies and procedures that could potentially optimize the use of aircraft de/anti-icing fluids and, thus, reduce environmental impact while maintaining or even enhancing the safety of aircraft operations in de/anti-icing conditions. The literature review consisted of:

- Aircraft ground deicing technical reports, produced on behalf of the Transportation Development Centre (TDC) of TC, the FAA, and aviation industry product manufacturers;
- Regulatory, government and industry documentation, guidance material, and standards; and
- Aircraft ground deicing patents.

Aircraft Ground Deicing Technical Reports

Thirty-seven aircraft ground deicing technical reports were reviewed. In the initial step, the reports were grouped into these areas of interest to facilitate the presentation of report review findings:

- Deicing Procedures—Fluid Freeze Point Buffer Requirements;
- Aircraft Anti-Icing Fluid Characteristics;
- Ice Detection Sensors;
- Alternative Deicing Approaches:
  - Hot Water;
  - Forced Air Systems;
  - Warm Fuel;
  - Mobile Infrared System; and
  - Tempered Steam.
- Aircraft De/Anti-Icing Fluid Research;
- Aircraft De/Anti-Icing Fluid Testing;
- Application of Holdover Time Guidelines;
- Holdover Time Determination Systems;
- Aerodynamic Penalties of Clean or Partially Expended De/Anti-icing Fluid; and
- Aircraft Ground Deicing Exploratory Research.

Subsequent to the classification exercise, a thorough review of each technical report was performed to examine and identify potential technologies and procedures for use in de/anti-icing optimization. Particular attention was paid to identify potential quick hits—optimization technologies and procedures that are ready to implement now or that are already in use, but could be improved upon readily.

For each technical report reviewed, the optimization technology or procedure was listed along with a list of the positive and negative attributes of the optimization technology or procedure and general comments from the review. A summary of the review of each of the 37 technical reports is provided in Appendix A.

A complete listing of all literature reviewed is given at the end of this chapter.

Regulatory, Government and Industry Documentation, Guidance Material, and Standards

Twenty-two regulatory, government, and industry documents were reviewed. The preponderance of these documents were from the FAA, and addressed many of the activities associated with aircraft icing to include ground icing, ground deicing programs, in-flight icing, aircraft ice protection and use of infrared deicing facilities. Similar ground deicing documents were reviewed from TC and from the Association of European Airlines (AEA). One document from the U.S. Environmental Protection Agency (EPA), entitled *Preliminary Data Summary—Airport Deicing Operations (Revised)*, was reviewed. Other documents reviewed were those used by foreign air carriers and included documentation from the Joint Aviation Authorities (JAA), International Organization for Standardization (ISO), International Civil Aviation Organization (ICAO) and New Zealand Civil Aviation Authority. Also, the Society of Automotive Engineers (SAE) document Aerospace Recommended Practice (ARP) 4737, *Aircraft Deicing/Anti-icing Methods with Fluids,* which serves as the industry standard for methodologies on aircraft deicing, was reviewed. In the Bibliography of Chapter 2, the regulatory, government and industry documentation, guidance material, and standards reviewed were grouped in the following manner:

- U.S. Federal Aviation Administration (FAA);
- U.S. Environmental Protection Agency (EPA);

- Transport Canada (TC);
- Society of Automotive Engineers (SAE);
- Association of European Airlines (AEA); and
- Other.

A summary of the document was prepared, including an assessment of the positive and negative aspects of the documentation. A summary of the review of each of the 22 regulatory, government and industry documents has been provided in Appendix B.

In addition to performing a general review, each document was assigned a rating relative to current aircraft ground deicing practices. The ratings varied from high to very low. Those documents that were updated in a timely manner (usually yearly or whenever significant changes in ground deicing practices or requirements occurred) were assigned a high rating, whereas those documents that were seriously outdated or were not specifically directed at ground deicing issues, were assigned ratings from medium to very low, depending upon the relevance of their information content. The document ratings appear in Appendix C.

Aircraft Ground Deicing Patents

A general review of aircraft ground deicing-related patents was performed to identify potential deicing optimization technologies and procedures for future study. Patent-related information was gathered from two Internet websites:

- http://www.freepatentsonline.com; and
- http://www.braindex.com/patent_pdf/.

A search for aircraft ground deicing-related patents produced over 400 U.S. patents and applications. An abstract of each of the 400 patents was reviewed, and 52 hard-copy versions of the patents (in Adobe Acrobat PDF) were downloaded for more extensive review. An abstract of each of the 52 patents reviewed in detail is provided in Appendix D.

Most of the patents reviewed applied to de/anti-icing fluid formulation, de/anti-icing vehicle configuration, ice detection sensors, deicing sprayers, onboard deicing systems, and non-glycol deicing technologies. Only a few potential technologies and procedures were identified for further examination from the patent review. These included the use of non-glycol de/anti-icing fluid formulations and the use of laser technology for deicing aircraft.

Focus Group Survey

A focus group was organized to gain industry insights and feedback on current and future aircraft de/anti-icing fluid optimization practices. The methodology employed to assemble the focus group and conduct the survey are summarized herein. A copy of the survey, list of survey respondents, and detailed survey results are provided in Appendixes E, F, and G respectively.

Focus Group

The focus group was assembled from two sources: key contacts in the aviation industry and ACRP Project 10-01 panel members.

Industry contacts were selected for inclusion in the focus group based on their knowledge, experience, and decision-making authority related to aircraft ground operations in winter conditions, specifically de/anti-icing fluid usage. A concerted effort was made to include individuals representing various interests in the industry including: de/anti-icing fluid manufacturers, deicing equipment manufacturers, air carriers (of various sizes), airframe manufacturers, deicing service providers, airport authorities and regulators. While most individuals selected were based in North America, several Europeans were also included in the focus group.

ACRP Project 10-01 panel members were included in the focus group to allow panel members to share their experience and knowledge.

Survey

A survey was developed to gather information from the focus group. A copy of the survey is included in Appendix E.

Survey Administration and Response

The survey was provided to the focus group via email and the responses organized in a database.

In total, the survey was sent to 37 individuals, including 24 industry contacts and 13 ACRP Project 10-01 panel members. Nineteen individuals submitted completed surveys, and one individual provided general comments. The overall response rate was 54% (20 of 37).

The response rates by inclusion source and interest group are shown in Tables 1 and 2, respectively. At least one response was received from each interest group. A complete list of focus group members who completed the survey is included in Appendix F.

Survey Results

The detailed survey results are provided in Appendix G. The application of survey results is discussed in the following section.

Binary Decision Analysis Model

The *Binary Decision Analysis Model* was used in the determination of which technologies and procedures should be

Table 1. Survey response rate by inclusion source.

Inclusion Source	Persons in Focus Group	Responses Received	Response Rate
APS Contacts	24	14	58%
ACRP Panel Members	13	6	46%
Total	**37**	**20**	**54%**

recommended for future study. This model, used for ranking of alternatives, is a systematic formalized procedure for solving complex decision problems.

Following the compilation of potential de/anti-icing optimization technologies and procedures, a list of analytical criteria for evaluating the usefulness of the selected technologies and procedures was developed. The *Binary Decision Analysis Model* was then employed to assign a weight to each of the analytical criteria. This process compared each combination of two criteria and determined which of the two was more important. The more important criterion of each pair is then given the value of one, and the other is given a value of zero. At the completion of the exercise, the values are totaled for each criterion, and a percentage is calculated based on the total number of pairs possible. This exercise with seven selected criteria produced 21 pairs for comparison.

An initial, internal weighting of the analytical criteria was made to select technologies and procedures for further research. This selection was later reinforced by criteria weights determined by the focus group as part of the survey described earlier.

Findings and Applications

Aircraft De/Anti-Icing Optimization Technologies and Procedures

The objective of the literature review was to develop a list of potential means for optimizing the use of de/anti-icing fluids, thus reducing environmental impact while maintaining or enhancing aircraft safety. The nature of the potential improvements generally included:

- Procedures that may already be instituted by certain operators, but which would offer value if applied on a wider scale (example: spot deicing for frost);
- Procedures that could be instituted, already having regulatory approval (example: application of dilutions of Type IV fluids versus full strength);
- Procedures that would require regulatory approval (example: reduced fluid freeze-point buffer for first-step deicing fluid and hot water deicing); and
- Application of new technologies (either proven or in development).

Preliminary List of De/Anti-Icing Optimization Technologies and Procedures

The review of technical reports; regulatory, government, and industry documentation; and applicable patents produced the following list of 34 potential de/anti-icing optimization technologies and procedures:

1. Reduction of fluid buffer for deicing-only conditions.
2. Introduction of larger negative freeze-point buffer for first-step deicing fluid, enabling use of hot water for deicing at ambient temperatures lower than 26.6°F (–3°C).

Table 2. Survey response rate by interest group.

Interest Group	Persons in Focus Group	Responses Received	Response Rate
Air Carriers	10	6	60%
Airframe Manufacturers	1	1	100%
Airport Authorities	4	1	25%
Deicing Equipment Manufacturers	1	1	100%
Deicing Service Providers	4	2	50%
Fluid Manufacturers	3	2	67%
Regulators	7	5	71%
Other	7	2	29%
Total	**37**	**20**	**54%**

3. Use of heated Type II and IV fluids as an overspray to support the use of a more dilute first-step deicing fluid.
4. Reduction of fluid buffer for fluids applied before the start of precipitation, to prevent bonding of frozen precipitation to the aircraft surface.
5. Development of means of determining de/anti-icing fluid failure (adherence to surface) as opposed to identifying failure by visual indications.
6. Use of Allied Signal Contaminant/Fluid Integrity Measuring System (C/FIMS) to indicate fluid condition and contamination on aircraft surfaces.
7. Use remote ice detection sensors to scan aircraft critical surfaces just before entering the departure runway.
8. Use of the Intertechnique Ice Detection Evaluation System (IDES) system to detect ice adherence and fluid condition on aircraft surfaces.
9. Use of warmed fuel to protect wings against precipitation and frost contamination.
10. Use of a mobile infrared system to deice aircraft.
11. Use of Type III fluids as a replacement for Type I fluid in one-step de/anti-icing operations.
12. Development and publication of holdover time guidelines for heated Type III fluid.
13. Documentation of guidelines to ensure that adequate quality control checks are conducted on the fluids and on deicing procedures.
14. Implementation and monitoring of quality control checks and operational deicing procedures at airports.
15. Determination of optimum spray equipment and technique to reduce the shearing effect associated with spraying Type II/IV fluid.
16. Implementation of National Center for Atmospheric Research (NCAR) Hotplate at airports to provide pilots with real-time snow intensity information.
17. Development of a simulation model to evaluate wing exposure to wind and snow catch associated with the use of different runways.
18. Reduction of delays at the deicing pad following completion of the anti-icing application through documentation of best practices.
19. Protection of holdover time as opposed to noise abatement when assigning departure runways during deicing events.
20. Protection of holdover time as opposed to noise abatement when assigning departure runways during snowstorm events.
21. Implementation of D-Ice A/S all weather holdover time determination system at airports to provide pilots with deicing decision support.
22. Use of onboard or ground-based lasers to deice aircraft.
23. Use of Tempered Steam as a non-glycol gate deicing or pre-deicing tool.
24. Use of Tempered Steam as an engine deicing tool.
25. Development and implementation of non-glycol or reduced glycol de/anti-icing fluids.
26. Use of ice-phobic or hydrophobic coatings to protect aircraft surfaces from adhering contamination.
27. Use of weather forecasting tools for better identification and planning of deicing-related events.
28. Use of forced air assist for applying de/anti-icing fluids.
29. Use of infrared deicing technology.
30. Use of spray-and-go deicing procedures.
31. Use of threshold deicing procedures.
32. Use of spot deicing for frost.
33. Increased use of anti-icing fluid dilutions.
34. Use of snow/leaf blowers to remove dry contamination.

Elimination of Items with Low Potential for Success

Following the development of the preliminary list of potential de/anti-icing optimization technologies and procedures in the previous section, an analysis was performed to identify those technologies and procedures offering the greatest promise. This evaluation resulted in the elimination of a number of items because of technical, operational, or environmental shortcomings, as described in Table 3.

In addition to the items in Table 3, several items of similar nature were combined under generic titles. For example, Item 6 from the preliminary list, Use of Allied Signal Contaminant/Fluid Integrity System (C/FIMS) to indicate fluid condition and contamination on aircraft surfaces and Item 8, Use of the Intertechnique Ice Detection Evaluation System (IDES) system to detect ice adherence and fluid condition on aircraft surfaces, were combined under the title, Point detection sensors to indicate fluid condition and contamination on aircraft surfaces. This reduced the number of technologies and procedures for further review, as well as eliminated commercial and competitive issues related to technologies of similar nature.

Development of Final List of Technologies and Procedures

Following the activities described in the previous section, the following final list of 18 de/anti-icing optimization technologies and procedures in alphabetical order was developed:

1. **Blowers and/or other mechanical means to remove dry contamination:** leaf blowers, brooms, scrapers, etc., to remove dry contamination prior to de/anti-icing operation (if applicable);
2. **Deicing-only fluid buffer reduction:** “Deicing-only” conditions exist when an aircraft is not exposed to a period of active precipitation (i.e., overnight precipitation that has ceased by the time of departure). The fluid freeze-

Table 3. Elimination of Items from the preliminary list.

#	Item from Preliminary List	Reason for Elimination
3	Use of heated Type II and IV fluids as an overspray to support the use of a more dilute first-step deicing fluid	May require development of additional set of holdover time values for heated fluids
5	Development of means of determining de/anti-icing fluid failure (adhere to surface) as opposed to identifying failure by visual indications	Doesn't offer significant environmental enhancement
9	Use of warmed fuel to protect wings against precipitation and frost contamination	Doesn't offer significant environmental or operational enhancement
12	Development and publication of holdover time guidelines for heated Type III fluid	Doesn't offer significant environmental enhancement
13	Documentation of guidelines to ensure that adequate quality control checks are conducted on the fluids and on deicing procedures	Doesn't offer significant environmental enhancement
14	Implementation and monitoring of quality control checks and operational deicing procedures at airports	Doesn't offer significant environmental enhancement
15	Determination of optimum spray equipment and technique to reduce the shearing effect associated with spraying Type II/IV fluid	Doesn't offer significant environmental enhancement
17	Development of a simulation model to evaluate wing exposure to wind and snow catch associated with the use of different runways	Doesn't offer significant environmental enhancement
18	Reduction of delays at the deicing pad following completion of the anti-icing application through documentation of best practices	Doesn't offer significant environmental enhancement
19	Protection of holdover time as opposed to noise abatement when assigning departure runways during deicing events	Little flexibility is available in the process of assigning runways during deicing conditions
20	Protection of holdover time as opposed to noise abatement when assigning departure runways during snowstorm events	Little chance of success and limited environmental enhancement
22	Use of onboard or ground-based lasers to deice aircraft	Technological and implementation challenges
26	Use of ice-phobic or hydrophobic coatings to protect aircraft surfaces from adhering contamination	Technological and operational challenges

point buffer could be reduced further in these conditions to limit glycol dispensed;

3. **First-step deicing fluid buffer reduction:** Current industry regulations allow for Type I fluid to be sprayed at a –5.4°F (–3°C) buffer (freeze point 5.4°F or 3°C above ambient temperature) when used as a first-step deicing fluid (hot water can also be employed down to 26.6°F). Testing has indicated that this buffer could be further reduced;
4. **Fluids applied before the start of precipitation to prevent bonding:** Pre-treating of aircraft surfaces with de/anti-icing fluid to protect surfaces against the adherence of ice (for example, this procedure would be useful prior to a freezing rain event);
5. **Forced air used to remove contamination:** Forced air has been employed effectively by the industry for several years to blow off dry contamination prior to de/anti-icing;
6. **Implementation of holdover time determination systems:** Airport systems, such as D-Ice A/S Deicing Information System and NCAR Checktime, which measure meteorological parameters at airport sites for use in scientific computations to enhance the accuracy of fluid holdover times, thus facilitating better de/anti-icing fluid selection;

7. **Non-glycol freeze point depressant fluids:** Fluid formulated with freeze point depressants other than propylene, ethylene, and diethylene glycol;
8. **Point detection sensors to indicate fluid condition and contamination on aircraft surfaces:** Ice sensors that are imbedded within aircraft surfaces enabling a determination of aircraft surface condition;
9. **Remote ice detection sensors to scan aircraft critical surfaces before departure runway:** Ice detection systems that are mounted (fixed or mobile) close to the runway threshold, enabling the determination of aircraft surface condition prior to departure;
10. **Spot deicing for frost:** Use of very limited quantities of glycol-based fluids for frost deicing in a controlled application;
11. **Spray-and-go deicing:** De/anti-icing operation conducted near the runway threshold, enabling increased use of Type I deicing fluids as the primary tool and less thickened fluid application;
12. **Tempered steam as a non-glycol gate deicing or predeicing tool:** Tempered steam technology uses moisture-laden air to melt frozen contaminants from aircraft surfaces during gate deicing actions or during pre-deicing events. It has shown great promise in testing to date;
13. **Threshold deicing:** Development and use of remote threshold deicing pads at airports, similar to those built in Munich, Germany. This approach would limit quantities of thickened fluids employed, as the departure point is in close proximity to the application area;
14. **Type III fluids:** Type III is a low viscosity de/anti-icing fluid that could be used in a one-step, heated de/anti-icing operation. Due to its low viscosity, it can be readily collected at the point of spray application and less fluid would be carried by aircraft and deposited over the airfield;
15. **Use of 10°C Type I buffer:** Standard deicing fluid concentrations (typically 50% water/50% glycol) have been employed by the industry, despite the fact that Type I deicing holdover times are based on 18°F (10°C) buffer fluids. Use of proportional blending could easily limit the amounts of glycol dispensed in Type I operations. For the purpose of this report, the metric units (Celsius) will be employed in the title for this item, as this is the common terminology employed within the aviation industry when referring to this procedure;
16. **Use of anti-icing fluid dilutions:** Anti-icing fluids have been used exclusively in 100/00 concentration in North America. Many 75/25 anti-icing fluids have holdover times similar to 100/00 fluids, and many 50/50 fluids have holdover times well in excess of Type I fluids;
17. **Use of infrared deicing technology:** Infrared heat has been employed, with a quantifiable amount of success, by the industry in the past decade (a system is currently operational in New York). Use of this approach could reduce the amounts of glycol dispensed; and
18. **Use of weather forecasting products for deicing process:** Airport meteorological system product, such as NCAR Weather Support for Deicing Decision Making (WSDDM) and SITA Met Office, that would enable better forecasting of oncoming weather and allow for better deicing planning.

Focus Group Survey Inputs on Final List of Technologies and Procedures

In Section 3 of the focus group questionnaire shown in Appendix E, the focus group was asked for input on the usefulness of the final 18 technologies and procedures. Focus group participants were asked to assess the usefulness of the optimization technologies and procedures in one of three categories (not useful, somewhat useful, very useful), assuming that the technologies and procedures were available for use at airports. The focus group assessment of all 18 optimization technologies and procedures was generally very positive; the most that any of the technologies and procedures was deemed to be *not useful* by the focus group was by 32% of respondents. The focus group survey results strongly supported the selection of the 18 technologies and procedures.

The focus group survey results pertaining to the usefulness of the various proposed technologies and procedures are shown in Table 4.

Development of Analytical Criteria

To assist with the analysis of new technologies and procedures for de/anti-icing optimization, APS employed the Binary Decision Analysis Model. The model, used for ranking of alternatives, is an evaluation technique developed by Westinghouse, and was modified by APS. It is a systematic formalized procedure for solving complex decision problems. Consideration will be given to short-term and long-term implementation strategies.

Starting Point in the Development of Analytical Criteria. To evaluate the de/anti-icing optimization technologies and procedures for future use, a series of analytical criteria was required. The development of the list of analytical criteria considered the following:

- Safety enhancement due to the implementation of the optimization technology or procedure;
- Effectiveness of the optimization technology or procedure;
- Reliability of the optimization technology or procedure;
- Capital costs of the optimization technology or procedure;
- Operating costs of the optimization technology or procedure;

Table 4. Focus group results pertaining to usefulness of the selected technologies and procedures.

De/Anti-Icing Optimization Technology and Procedures	Not Useful (%)	Somewhat Useful (%)	Very Useful (%)
1. Blowers and/or other mechanical means to remove dry contamination	5	58	37
2. Deicing-only fluid buffer reduction	11	74	16
3. First-step deicing fluid buffer reduction	28	44	28
4. Fluids applied before the start of precipitation to prevent bonding	6	56	39
5. Forced air used to remove contamination	0	42	58
6. Implementation of holdover time determination systems	5	26	68
7. Non-glycol freeze point depressant fluids	5	58	37
8. Point detection sensors to indicate fluid condition and contamination on aircraft surfaces	17	61	22
9. Remote ice detection sensors to scan aircraft critical surfaces before departure runway	0	58	42
10. Spot deicing for frost	5	26	68
11. Spray-and-go deicing	11	26	63
12. Tempered steam as a non-glycol gate deicing or pre-deicing tool	11	26	63
13. Threshold deicing	5	42	53
14. Type III fluids	32	53	16
15. Use of 10°C Type I buffer	5	53	42
16. Use of anti-icing fluid dilutions	26	42	32
17. Use of infrared deicing technology	32	47	21
18. Use of weather forecasting products for deicing process	0	37	63

- Economic savings to the airport or air carrier due to the optimization technology or procedure;
- Source reduction of glycol due to the optimization technology or procedure;
- Reduction in environmental impact due to the optimization technology or procedure;
- Reduction in environmental costs due to the optimization technology or procedure;
- Effects of technology or procedure on airport infrastructure;
- Adherence to regulatory requirements;
- Reduction in aircraft fuel burn due to the implementation of the optimization technology or procedure;
- Improvement in airport throughput due to the optimization technology or procedure;
- Readiness for implementation of the optimization technology or procedure;
- Ability to combine the optimization technology or procedure with others;
- Effect of the optimization technology or procedure on recycling procedures presently used by airport operators;
- Impact on de/anti-icing fluid holdover time of the optimization technology or procedure; and
- Applicability of the new technologies and procedures to the end user.

Identification of Analytical Criteria. Seven criteria were identified as being important for evaluating the 18 optimization technologies and procedures. The criteria are considered to be mutually exclusive and collectively exhaustive, meaning that all the important parameters needed to make decisions for evaluating new technologies and procedures have been included and that there is no "double counting." The seven criteria are:

1. **Capital Cost:** This criterion is simply the capital costs needed to implement the technology or procedure;
2. **Operating Cost:** This criterion includes the operating costs that would result from the implementation of the technology or procedure, and this would include costs such as heating, maintenance, management/personnel, fluid costs, etc.;
3. **Training:** This criterion considers the need and difficulty to provide training to deicing crews or pilots when implementing the new technology or procedure;
4. **Environmental Impact:** This criterion considers environmental impacts from implementation of the new technology or procedure, mostly from de/anti-icing fluid reductions, but also aircraft fuel burn reductions, and personnel health and safety;
5. **Maturity:** This criterion examines the level of maturity and readiness of the technology or procedure; for example, regulatory approval is considered, as is the sustainability of operations using the new technology or procedure;
6. **Operational Efficiency:** This criterion examines the operational efficiencies that are expected to result from the new technology or procedure; this would include airport throughput, passenger and aircraft delays and/or enhancements; and
7. **Safety:** This criterion examines the level of risk to implement the new technology or procedure. While any new technology would not be considered if it posed a safety concern, certain technologies and procedures have more associated risk than others.

Weighting of Analytical Criteria. In order to assign a weight to each criterion, the focus group participants were asked to compare the criteria to one another using a structured approach, and to determine which of any two criteria was considered more important. This process involved making 21 comparative decisions, as shown in Table 5. The detailed responses from the focus group in this decision process are provided in Appendix G.

For each of the 21 questions, a score of 1 was given to the criterion that had more favorable responses, and a score of 0 was given to the criterion that had less favorable responses. In 15 of the 21 questions, there was a clear decision from the survey participants as to which criterion was more important; the 6 questions that had a closer response result were for the criteria that were of lesser importance. In summary, the criteria weights determined from this decision process are provided in Table 6.

Table 6 shows that a "1" was added to the score for each criterion. This was done to ensure that each criterion selected or considered important was assigned a weight; otherwise the weight of the lowest-ranking criterion would have been zero percent. The results of the focus group survey indicate that Safety is the most important criterion, followed by Operational Efficiency. These results were not unexpected.

The survey participants were asked to provide any additional criteria that they felt should be considered and that had not been included. There were two responses to this question; in both cases the comments provided were already considered within the original criteria.

Evaluation of Optimization Technologies and Procedures

The individual items in the final list of 18 technologies and procedures were next ranked according to their relative importance for each criterion. The most important received the score of 18, progressively reducing to the least important, which received the score of one (1). The total value of each criterion is 171. In some cases, it was impossible to distinguish between certain items, in which case the score for those items was averaged among them, always respecting

Table 5. Focus group comparative decisions on analytical criteria.

Criterion 1		Criterion 2	
Capital cost		**Operating cost**	X
Capital cost		**Environmental impact**	X
Capital cost		**Operational efficiency**	X
Capital cost		**Maturity**	X
Capital cost		**Training**	X
Capital cost		**Safety**	X
Operating cost		**Environmental impact**	X
Operating cost		**Operational efficiency**	X
Operating cost	X	Maturity	
Operating cost	X	Training	
Operating cost		**Safety**	X
Environmental impact		**Operational efficiency**	X
Environmental impact	X	Maturity	
Environmental impact	X	Training	
Environmental impact		**Safety**	X
Operational efficiency	X	Maturity	
Operational efficiency	X	Training	
Operational efficiency		**Safety**	X
Maturity		**Training**	X
Maturity		**Safety**	X
Training		**Safety**	X

the total value in each column of 171. The values in each cell were then converted to percentages based on the total column value of 171.

The evaluation process relative to each of the seven criteria is described in the following sections.

Capital Cost. Ranking against Capital Cost assigns the greatest importance to those items bearing the least capital cost.

In Table 7, Items 1, 4, 7, 10, and 14 were all assessed as having no capital cost associated with them. Consequently they were rated equally, and were ranked at the top of the list. As five items were involved, in total they were assigned the sum of values from 14 to 18, for an average value of 16.

Item 2, *Deicing-only fluid buffer reduction,* Item 3, *First-step deicing fluid buffer reduction,* and Item 15, *Use of 10°C Type I buffer,* all involved blending of Type I fluid according to the ambient temperature. The most effective way to achieve this is through use of an on-board fluid blending system on the deicing vehicle. The capital cost, therefore, is the same for all these cases. As there were three items involved, in total they

Table 6. Focus group criteria weights.

Criteria	Decision Scores	Score+1	Weight %
Capital Cost	0	1	**3.6%**
Operating Cost	3	4	**14.3%**
Environmental Impact	4	5	**17.9%**
Operational Efficiency	5	6	**21.4%**
Maturity	1	2	**7.1%**
Training	2	3	**10.7%**
Safety	6	7	**25.0%**
TOTAL	**21**	**28**	**100%**

Table 7. Ranking of technologies and procedures by capital cost.

Item #	Optimization Technology or Procedure	Capital Cost Rank	Capital Cost %
10	Spot deicing for frost	16.0	9.4%
14	Type III fluids	16.0	9.4%
1	Blowers and/or other mechanical means to remove dry contamination	16.0	9.4%
7	Non-glycol freeze point depressant fluids	16.0	9.4%
4	Fluids applied before the start of precipitation to prevent bonding	16.0	9.4%
15	Use of 10°C Type I buffer	12.0	7.0%
2	Deicing-only fluid buffer reduction	12.0	7.0%
3	First-step deicing fluid buffer reduction	12.0	7.0%
5	Forced air used to remove contamination	10.0	5.8%
16	Use of anti-icing fluid dilutions	9.0	5.3%
11	Spray-and-go deicing	8.0	4.7%
18	Use of weather forecasting products for deicing process	7.0	4.1%
12	Tempered steam as a non-glycol gate deicing or pre-deicing tool	6.0	3.5%
6	Implementation of holdover time determination systems	5.0	2.9%
9	Remote ice detection sensors to scan aircraft critical surfaces before departure runway	4.0	2.3%
13	Threshold deicing	3.0	1.8%
8	Point detection sensors to indicate fluid condition and contamination on aircraft surfaces	2.0	1.2%
17	Use of infrared deicing technology	1.0	0.6%
	TOTAL	171.0	100.0%

were assigned the sum of values from 11 to 13, for an average value of 12.

The following items were viewed as having different levels of capital cost and were ranked accordingly. The required capital costs were:

- Item 5, *Forced air used to remove contamination:* cost to replace deicers or retrofit current deicers with forced air systems;
- Item 16, *Use of Anti-icing fluid dilutions:* cost for fluid blenders and additional fluid tanks for various blends; and
- Item 11, *Spray-and-go deicing:* cost to modify taxiway to enable deicer movement around aircraft and cost to capture spent fluid.

The remaining items all require significant capital investment for the purchase and implementation of the technology or procedure.

Operating Cost. The ranking for Operating Cost is shown in Table 8. The impact on operating costs, in some cases, is expected to be an overall reduction. In other cases, an increase in operating costs would be expected. Ranking against operating cost assigns the greatest importance to those items having the least negative impact. There were no equivalent levels of cost between items, and each approach was given its own ranking.

The operational benefit associated with Item 10, *Spot deicing for frost,* is a reduction in deicing costs (fluid and manpower). An expected reduction in aircraft operating times, which implies important savings in maintenance costs, crew costs, fuel burn, and disrupted passenger costs is claimed in the *Operational Efficiency* criterion.

Item 10, Item 14, and Item 16 all involve a reduction in de/anti-icing fluid costs, with no additional operational expenditure.

Table 8. Ranking of technologies and procedures by operating cost.

Item #	Optimization Technology or Procedure	Operating Cost Rank	Operating Cost %
10	Spot deicing for frost	18.0	10.5%
16	Use of anti-icing fluid dilutions	17.0	9.9%
14	Type III fluids	16.0	9.4%
15	Use of 10°C Type I buffer	15.0	8.8%
6	Implementation of holdover time determination systems	14.0	8.2%
5	Forced air used to remove contamination	13.0	7.6%
12	Tempered steam as a non-glycol gate deicing or pre-deicing tool	12.0	7.0%
1	Blowers and/or other mechanical means to remove dry contamination	11.0	6.4%
11	Spray-and-go deicing	10.0	5.8%
2	Deicing-only fluid buffer reduction	9.0	5.3%
3	First-step deicing fluid buffer reduction	8.0	4.7%
4	Fluids applied before the start of precipitation to prevent bonding	7.0	4.1%
7	Non-glycol freeze point depressant fluids	6.0	3.5%
9	Remote ice detection sensors to scan aircraft critical surfaces before departure runway	5.0	2.9%
18	Use of weather forecasting products for deicing process	4.0	2.3%
8	Point detection sensors to indicate fluid condition and contamination on aircraft surfaces	3.0	1.8%
17	Use of infrared deicing technology	2.0	1.2%
13	Threshold deicing	1.0	0.6%
	TOTAL	171.0	100.0%

Item 6, *Implementation of holdover time determination systems,* supports better decision making, leading to avoidance of deicing activities when not needed, and use of fluid types more appropriate to the weather condition.

Item 5, *Forced air used to remove contamination,* and Item 12, *Tempered Steam as a non-glycol gate deicing or pre-deicing tool,* are similar in that they can be used to remove most of the contamination before the actual deicing operation, thereby reducing the amount of de/anti-icing fluid expended. Item 1, *Blowers and/or other mechanical means to remove dry contamination,* is similar, but it applies only to smaller amounts of snow and not to other types of contamination.

Item 2, *Deicing-only fluid buffer reduction,* would reduce the amount of glycol expended, as would Item 3, *First-step deicing fluid buffer reduction.* In both cases the reduction in cost is less than simply using a fluid strength equivalent to the 10°C buffer rather than the standard mixes (neat, 75/25, 50/50).

Training. The ranking for Training is shown in Table 9. Ranking against training assigns the greatest value to those items having the least need for training.

In Table 9, Items 4, 7, 14, and 16 were seen to require equivalent levels of training. An average rank value of 16.5 was applied to all four items.

Thereafter, the extent of the training requirement grew according to the increase in complexity of the procedure or technology.

Environmental Impact. The ranking for Environmental Impact is included in Table 10. In most cases, the ranking was based primarily on the reduction in the quantity of glycol expended. In other cases, additional environmental impacts are considered. One such case is Item 10, *Spot deicing for frost,* which can result in a substantial reduction in aircraft fuel burn and its associated impact on the environment.

Table 9. Ranking of technologies and procedures by training.

Item #	Optimization Technology or Procedure	Training Rank	Training %
16	Use of anti-icing fluid dilutions	16.5	9.6%
14	Type III fluids	16.5	9.6%
7	Non-glycol freeze point depressant fluids	16.5	9.6%
4	Fluids applied before the start of precipitation to prevent bonding	16.5	9.6%
10	Spot deicing for frost	14.0	8.2%
13	Threshold deicing	13.0	7.6%
11	Spray-and-go deicing	12.0	7.0%
5	Forced air used to remove contamination	11.0	6.4%
1	Blowers and/or other mechanical means to remove dry contamination	10.0	5.8%
15	Use of 10°C Type I buffer	9.0	5.3%
2	Deicing-only fluid buffer reduction	8.0	4.7%
3	First-step deicing fluid buffer reduction	7.0	4.1%
12	Tempered steam as a non-glycol gate deicing or pre-deicing tool	6.0	3.5%
17	Use of infrared deicing technology	5.0	2.9%
9	Remote ice detection sensors to scan aircraft critical surfaces before departure runway	4.0	2.3%
8	Point detection sensors to indicate fluid condition and contamination on aircraft surfaces	3.0	1.8%
6	Implementation of holdover time determination systems	2.0	1.2%
18	Use of weather forecasting products for deicing process	1.0	0.6%
	TOTAL	171.0	100.0%

Item 13, *Threshold deicing,* and Item 11, *Spray-and-go deicing,* provide an opportunity to reduce the amount of fluid (especially Type IV fluid) sprayed. Additionally, these approaches remove the problem of fluid dripping from aircraft surfaces while taxiing to the departure runway.

Other approaches reduce the quantity of de/anti-icing fluid sprayed by removing contamination prior to proceeding to deicing, or by reducing the glycol content in the fluid by using a lower fluid strength.

Items 8 and 9, which pertain to remote or point ice detection sensors, might actually increase the impact on environment by leading to more returns for repeated deicing.

Maturity. A total of 22 regulatory, government, and industry documents, guidance material, and standards were reviewed by APS personnel during the literature review. These documents were compared to the 18 identified optimization technologies and procedures to determine if the selected optimization technologies and procedures were covered by appropriate guidance or standards material or if additional regulatory, government, or guidance material was required. A subjective rating of "Yes," "No," "N/A" or "Pending" was then assigned to each selected technology or procedure. The results of this comparison are presented in Table 11.

The optimization technologies or procedures with a "Yes" rating are deemed to be currently covered by existing regulatory guidance documents. Those with a "Pending" rating are being addressed by pending regulatory guidance from a regulator, but not by guidance from the FAA, nor have they been addressed in deicing documentation from the SAE at this time. However it appears that most of the technical challenges of the optimization technology or procedure with a "Pending" rating have been met, and regulatory guidance is being considered. Those with a "No" rating have not been addressed by appropriate guidance documents from the regulators or addressed as an acceptable practice by the SAE or the AEA. Typically these "No" rated technologies and procedures are undergoing development or require further evaluations by the authorities before an endorsement is given.

Table 10. Ranking of technologies and procedures by environmental impact.

Item #	Optimization Technology or Procedure	Environmental Impact Rank	Environmental Impact %
10	Spot deicing for frost	18.0	10.5%
13	Threshold deicing	17.0	9.9%
11	Spray-and-go deicing	16.0	9.4%
7	Non-glycol freeze point depressant fluids	15.0	8.8%
12	Tempered steam as a non-glycol gate deicing or pre-deicing tool	14.0	8.2%
5	Forced air used to remove contamination	13.0	7.6%
1	Blowers and/or other mechanical means to remove dry contamination	12.0	7.0%
16	Use of anti-icing fluid dilutions	11.0	6.4%
17	Use of infrared deicing technology	10.0	5.8%
15	Use of 10°C Type I buffer	9.0	5.3%
6	Implementation of holdover time determination systems	8.0	4.7%
2	Deicing-only fluid buffer reduction	7.0	4.1%
14	Type III fluids	6.0	3.5%
3	First-step deicing fluid buffer reduction	5.0	2.9%
4	Fluids applied before the start of precipitation to prevent bonding	4.0	2.3%
18	Use of weather forecasting products for deicing process	3.0	1.8%
9	Remote ice detection sensors to scan aircraft critical surfaces before departure runway	2.0	1.2%
8	Point detection sensors to indicate fluid condition and contamination on aircraft surfaces	1.0	0.6%
	TOTAL	171.0	100.0%

The ranking of technologies and procedures by Maturity is provided in Table 12. When considering *Maturity,* technologies or procedures that are ready for implementation were given the highest-ranking value. Readiness includes availability of the equipment needed to do the job, as well as regulatory approvals. This criterion is important from the perspective of enabling "Quick hit" technologies and procedures.

In the evaluation, six items were assessed as being ready for implementation and were assigned an average ranking value of 15.5, as shown in Table 12.

Item 11, *Spray-and-go deicing,* and Item 13, *Threshold deicing,* were seen as having no deicing regulatory constraints, but needing local approvals and investments.

The use of reduced fluid buffers (Items 2 and 3) will require new regulatory approvals. Item 14, *Type III fluids,* may require investigation as to whether the approach leads to fluid dry-out on aircraft control surface drives. Item 6, *Implementation of holdover time determination systems,* will require regulatory approval, as will the use of ice detectors.

Operational Efficiency. The ranking of technologies and procedures by *Operational Efficiency* is provided in Table 13. Some approaches, such as Item 10, *Spot deicing for frost,* offer additional benefits in the form of reduced delays and aircraft operating times. This leads to important savings in aircraft maintenance and fuel costs, crew costs, and passenger disruption costs.

Item 11, *Spray-and-go deicing,* and Item 13, *Threshold deicing,* should provide greatly improved operational efficiencies. Eliminating the need to deice (Item 6, *Implementation of holdover time determination systems*) or reducing the time to deice (use of forced air, tempered steam and blowers, or mechanical means to reduce the amount of contamination at the deicing stage) will also lead to operational efficiencies.

Safety. The ranking of technologies and procedures by Safety is provided in Table 14. The ranking of items against safety was found to be the most challenging. None of the approaches were perceived to be unsafe, otherwise they would

Table 11. Maturity of technologies and procedures versus guidance material.

Item #	Optimization Technology or Procedure	Rating
1	Blowers & mechanical means to remove dry contamination	Yes
2	Deicing-only fluid buffer reduction	No
3	First-step deicing fluid buffer reduction	No
4	Fluids applied before the start of precipitation to prevent bonding	Yes
5	Forced air to remove contamination	Yes
6	Implementation of holdover time determination systems	Pending
7	Non-glycol freeze point depressant fluids	No
8	Point detection sensors to indicate fluid condition and contamination on aircraft surfaces	No
9	Remote ice detection sensors to scan aircraft critical surfaces before departure runway	No
10	Spot deicing for frost	Yes
11	Spray-and-go deicing	Yes
12	Tempered Steam as a non-glycol gate deicing or pre-deicing tool	Pending
13	Threshold deicing	Yes
14	Type III fluids	Yes
15	Use of 10°C Type I BUFFER	Yes
16	Use of anti-icing fluid dilutions	Yes
17	Use of Infrared deicing technology	Yes
18	Use of weather forecasting products for deicing process	N/A

not have been included in the analysis. A decision process was finally agreed upon wherein each item was first assessed whether it potentially improved safety, was safety neutral, or involved a risk of decreasing the level of safety below the current level (in relation to that item only and while still maintaining a satisfactory level of safety). Six items were identified as potentially improving safety (each given an average score of 15.5), nine were safety neutral (each given an average score of 8), and three were identified as potentially decreasing safety (each given an average score of 2).

Overall Ranking of Optimization Technologies and Procedures

Once the list of optimization technologies and procedures had been ranked for each criterion, the complete matrix of item scores was assembled, as shown in Table 15. The potential items for optimization are sorted by score percentage, with the most promising approaches at the top of the list.

Table 15 is a matrix where each cell presents an overall percentage score. Each cell then has been given a score calculated by multiplying the criterion weights for the approaches within each criterion. This representation allows a direct comparison between various cells, identifying the criterion and the approaches that give the greatest weight.

Sensitivity Analysis

As described in the previous sections, the ranked list of optimization technologies and procedures was developed based upon the focus group weighting of criteria. Prior to requesting inputs from the focus group, an internal exercise was performed to weigh the criteria in a similar fashion to the focus group. A team of experts at the research agency independently developed the criterion weights shown in Table 16.

The weights in Table 16 are slightly different from the weights determined by the focus group. Application of the weights in Table 16 to the technology and procedure

Table 12. Ranking of technologies and procedures by maturity.

Item #	Optimization Technology or Procedure	Maturity Rank	Maturity %
10	Spot deicing for frost	15.5	9.1%
5	Forced air used to remove contamination	15.5	9.1%
16	Use of anti-icing fluid dilutions	15.5	9.1%
15	Use of 10°C Type I buffer	15.5	9.1%
1	Blowers and/or other mechanical means to remove dry contamination	15.5	9.1%
4	Fluids applied before the start of precipitation to prevent bonding	15.5	9.1%
11	Spray-and-go deicing	11.5	6.7%
13	Threshold deicing	11.5	6.7%
2	Deicing-only fluid buffer reduction	10.0	5.8%
14	Type III fluids	9.0	5.3%
17	Use of infrared deicing technology	7.5	4.4%
3	First-step deicing fluid buffer reduction	7.5	4.4%
6	Implementation of holdover time determination systems	6.0	3.5%
18	Use of weather forecasting products for deicing process	5.0	2.9%
12	Tempered steam as a non-glycol gate deicing or pre-deicing tool	4.0	2.3%
7	Non-glycol freeze point depressant fluids	3.0	1.8%
8	Remote ice detection sensors to scan aircraft critical surfaces before departure runway	2.0	1.2%
9	Point detection sensors to indicate fluid condition and contamination on aircraft surfaces	1.0	0.6%
	TOTAL	171.0	100.0%

Table 13. Ranking of technologies and procedures by operational efficiency.

Item #	Optimization Technology or Procedure	Operational Efficiency Rank	Operational Efficiency %
10	Spot deicing for frost	18.0	10.5
11	Spray-and-go deicing	17.0	9.9
13	Threshold deicing	16.0	9.4
6	Implementation of holdover time determination systems	15.0	8.8
12	Tempered steam as a non-glycol gate deicing or pre-deicing tool	14.0	8.2
5	Forced air used to remove contamination	13.0	7.6
1	Blowers and/or other mechanical means to remove dry contamination	12.0	7.0
14	Type III fluids	11.0	6.4
18	Use of weather forecasting products for deicing process	10.0	5.8
4	Fluids applied before the start of precipitation to prevent bonding	9.0	5.3
15	Use of 10°C Type I buffer	8.0	4.7
16	Use of anti-icing fluid dilutions	7.0	4.1
7	Non-glycol freeze point depressant fluids	6.0	3.5
2	Deicing-only fluid buffer reduction	5.0	2.9
3	First-step deicing fluid buffer reduction	4.0	2.3
17	Use of infrared deicing technology	3.0	1.8
8	Remote ice detection sensors to scan aircraft critical surfaces before departure runway	2.0	1.2
9	Point detection sensors to indicate fluid condition and contamination on aircraft surfaces	1.0	0.6
	TOTAL	171.0	100.0%

Table 14. Ranking of technologies and procedures by safety.

Item #	Optimization Technology or Procedure	Safety Rank	Safety %
11	Spray-and-go deicing	15.5	9.1
13	Threshold deicing	15.5	9.1
6	Implementation of holdover time determination systems	15.5	9.1
18	Use of weather forecasting products for deicing process	15.5	9.1
8	Remote ice detection sensors to scan aircraft critical surfaces before departure runway	15.5	9.1
9	Point detection sensors to indicate fluid condition and contamination on aircraft surfaces	15.5	9.1
10	Spot deicing for frost	8.0	4.7
5	Forced air used to remove contamination	8.0	4.7
16	Use of anti-icing fluid dilutions	8.0	4.7
14	Type III fluids	8.0	4.7
12	Tempered steam as a non-glycol gate deicing or pre-deicing tool	8.0	4.7
15	Use of 10°C Type I buffer	8.0	4.7
7	Non-glycol freeze point depressant fluids	8.0	4.7
4	Fluids applied before the start of precipitation to prevent bonding	8.0	4.7
17	Use of infrared deicing technology	8.0	4.7
1	Blowers and/or other mechanical means to remove dry contamination	2.0	1.2
2	Deicing-only fluid buffer reduction	2.0	1.2
3	First-step deicing fluid buffer reduction	2.0	1.2
	TOTAL	171.0	100.0%

Table 15. Overall ranking of technologies and procedures.

#	Optimization Technology or Procedure	Capital Cost Score (%)	Operating Cost Score (%)	Environmental Impact Score (%)	Operational Efficiency Score (%)	Maturity Score (%)	Training Score (%)	Safety Score (%)	Score (%)
10	Spot deicing for frost	0.3	1.5	1.9	2.3	0.6	0.9	1.2	8.7
11	Spray-and-go deicing	0.2	0.8	1.7	2.1	0.5	0.8	2.3	8.3
13	Threshold deicing	0.1	0.1	1.8	2.0	0.5	0.8	2.3	7.5
5	Forced air used to remove contamination	0.2	1.1	1.4	1.6	0.6	0.7	1.2	6.8
6	Implementation of holdover time determination systems	0.1	1.2	0.8	1.9	0.3	0.1	2.3	6.6
16	Use of anti-icing fluid dilutions	0.2	1.4	1.1	0.9	0.6	1.0	1.2	6.5
14	Type III fluids	0.3	1.3	0.6	1.4	0.4	1.0	1.2	6.3
12	Tempered steam as a non-glycol gate deicing or pre-deicing tool	0.1	1.0	1.5	1.8	0.2	0.4	1.2	6.1
15	Use of 10°C Type I buffer	0.3	1.3	0.9	1.0	0.6	0.6	1.2	5.8
1	Blowers and/or other mechanical means to remove dry contamination	0.3	0.9	1.3	1.5	0.6	0.6	0.3	5.6
7	Non-glycol freeze point depressant fluids	0.3	0.5	1.6	0.8	0.1	1.0	1.2	5.5
4	Fluids applied before the start of precipitation to prevent bonding	0.3	0.6	0.4	1.1	0.6	1.0	1.2	5.3
18	Use of weather forecasting products for deicing process	0.1	0.3	0.3	1.3	0.2	0.1	2.3	4.6
2	Deicing-only fluid buffer reduction	0.3	0.8	0.7	0.6	0.4	0.5	0.3	3.6
9	Remote ice detection sensors to scan aircraft critical surfaces before departure runway	0.1	0.4	0.2	0.3	0.1	0.3	2.3	3.6
17	Use of infrared deicing technology	0.0	0.2	1.0	0.4	0.3	0.3	1.2	3.4
8	Point detection sensors to indicate fluid condition and contamination on aircraft surfaces	0.0	0.3	0.1	0.1	0.0	0.2	2.3	3.0
3	First-step deicing fluid buffer reduction	0.3	0.7	0.5	0.5	0.3	0.4	0.3	3.0
	TOTAL	3.6%	14.3%	17.9%	21.4%	7.1%	10.7%	25.0%	100.0%

Table 16. APS criteria weights.

Criteria	Decision Scores	Score+1	Weight %
Capital Cost	3	4	**14.3**
Operating Cost	2	3	**10.7**
Environmental Impact	1	2	**7.1**
Operational Efficiency	4	5	**17.9**
Maturity	5	6	**21.4**
Training	0	1	**3.6**
Safety	6	7	**25.0**
TOTAL	**21**	**28**	**100.0%**

evaluation analytical process provided the ranking shown in Table 17.

Table 17 demonstrates that the overall ranking of the optimization technologies or procedures does not change significantly with the different sets (research agency and focus group) of criterion weights.

Conclusions and Recommendations

Conclusions

Aircraft ground deicing technical reports; manufacturer product reports; regulatory, government, and industry documentation; guidance material and standards; and deicing-related patents and applications were reviewed to identify technologies and procedures that could potentially optimize the use of current de/anti-icing methodologies, most predominantly glycol-based fluids.

The review produced a list of 34 potential technologies and procedures. Many of the potential technologies and procedures were deemed to possess technical or operational deficiencies, or were deemed to not offer an adequate environmental or operational enhancement over the current status quo, and were eliminated from further evaluation. Additional technologies and procedures of similar nature were merged under generic titles to eliminate commercial or competitive issues. This process of elimination and merger produced a final list of 18 proposed technologies and procedures for further review. A series of seven analytical criteria (capital cost, operating cost, environmental impact, training, maturity, operational efficiency, safety) was developed and defined to assist in the evaluation of the 18 technologies and procedures for future study. A ranking (1 to 18) of each of the technologies and procedures was then performed for each analytical criterion, to identify the comparative strengths and weaknesses of each proposed item.

A focus group of industry experts was surveyed for inputs on the usefulness of the 18 proposed technologies, as well as on the weighting of the analytical criteria employed for analyzing and ranking of the technologies and procedures for future study. This exercise produced a final ranking of the de/anti-icing optimization technologies and procedures for future study. The final list was comprised of numerous "quick hit" approaches (ones that are currently in use but could be readily improved upon), as well as many approaches requiring greater levels of research.

Recommendations for Further Study

The research performed in Phase I identified and ranked 18 potential de/anti-icing optimization technologies and procedures for further study. The top 10 ranked de/anti-icing optimization technologies and procedures were selected from this list. This eliminated the bottom eight ranked technologies and procedures:

- Item 2, *Deicing-only fluid buffer reduction;*
- Item 3, *First-step deicing fluid buffer reduction;*
- Item 4, *Fluids applied before the start of precipitation to prevent bonding;*
- Item 7, *Non-glycol freeze point depressant fluids;*
- Item 8, *Point detection sensors to indicate fluid condition and contamination on aircraft surfaces;*
- Item 9, *Remote ice detection sensors to scan aircraft critical surfaces before departure runway;*
- Item 17, *Use of infrared deicing technology;* and
- Item 18, *Use of weather forecasting products for deicing process.*

The remaining technologies and procedures were then grouped into two categories:

Table 17. Comparison of focus group and APS ranking of technologies and procedures.

#	Optimization Technology or Procedure	Focus Group Final Score (%)	APS Final Score (%)		Focus Group Rank	APS Rank
10	Spot deicing for frost	8.7	8.5		1	1
11	Spray-and-go deicing	8.3	7.7		2	2
13	Threshold deicing	7.5	6.7		3	4
5	Forced air used to remove contamination	6.8	6.9		4	3
6	Implementation of holdover time determination systems	6.6	6.3		5	9
16	Use of anti-icing fluid dilutions	6.5	6.5		6	5
14	Type III fluids	6.3	6.4		7	7
12	Tempered steam as a non-glycol gate deicing or pre-deicing tool	6.1	5.1		8	11
15	Use of 10°C Type I buffer	5.8	6.5		9	6
1	Blowers and/or other mechanical means to remove dry contamination	5.6	6.2		10	10
7	Non-glycol freeze point depressant fluids	5.5	4.9		11	12
4	Fluids applied before the start of precipitation to prevent bonding	5.3	6.3		12	8
18	Use of weather forecasting products for deicing process	4.6	4.9		13	13
2	Deicing-only fluid buffer reduction	3.6%	4.1%		14	14
9	Remote ice detection sensors to scan aircraft critical surfaces before departure runway	3.6	3.5		15	15
17	Use of infrared deicing technology	3.4	3.2		16	17
8	Point detection sensors to indicate fluid condition and contamination on aircraft surfaces	3.0	3.0		17	18
3	First-step deicing fluid buffer reduction	3.0	3.5		18	16

- **Mature Technologies and Procedures (quick hits):** These technologies and procedures include those that could be supported and advanced by efforts such as production of cost benefit analysis, a lesser level of research in some cases, and development of industry information aids. In general, these items have reached a level of maturity that enables rapid application and implementation. The effort associated with this group would be directed toward developing supporting material to influence decision-makers for field operations to implement approaches that are appropriate to their own operation.
- **Research and Development Technologies and Procedures:** The technologies and procedures included in this group are those that are not yet fully developed. They offer strong potential for optimizing the use of glycol and have been identified as desirable in the focus group survey. The effort associated with this group would be directed toward supporting and advancing the research and development process required to bring these items to the implementation stage.

The results of the categorization are shown in Table 18.

Recommendations for Phase II

The top two quick hit procedures and the top two research technologies from Table 18 were recommended for further development and evaluation in Phase II of the project:

1. Implementation of Holdover Time Determination Systems (research);
2. Spot Deicing for Frost (quick hit);

Table 18. Top 10 ranking de/anti-icing technologies and procedures.

Rank	Optimization Technology or Procedure	Item #	Type of Activity
1	Spot deicing for frost	10	Quick Hit
2	Spray-and-go deicing	11	Quick Hit
3	Threshold deicing	13	Quick Hit
4	Forced air used to remove contamination	5	Quick Hit
5	Implementation of holdover time determination systems	6	Research
6	Use of anti-icing fluid dilutions	16	Quick Hit
7	Type III fluids	14	Quick Hit
8	Tempered steam as a non-glycol gate deicing or pre-deicing tool	12	Research
9	Use of 10°C Type I buffer	15	Quick Hit
10	Blowers and/or other mechanical means to remove dry contamination	1	Quick Hit

3. Spray-and-Go Deicing (quick hit); and
4. Tempered Steam as a Non-Glycol Gate Deicing or Pre-Deicing Tool (research).

After review of these recommendations, ACRP selected Technologies 1 and 2 for comprehensive evaluation in Phase II of the project. The results of these evaluations are described in detail in Chapter 3 and 4 respectively.

Bibliography

Aircraft Ground Deicing Technical Reports

Subject Matter: Deicing Procedures—Fluid Freeze Point Buffer

Dawson, P., *Examination of the Role of Fluid Freeze Point Buffers,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 13129E (1997).

Dawson, P., *Aircraft Deicing Fluid Freeze Point Buffer Requirements: Deicing Only and First Step of Two-Step Deicing,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 13315E (1998).

Dawson, P., *Aircraft Deicing Fluid Freeze Point Buffer Requirements for Deicing-Only Conditions,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 13478E (1999).

Subject Matter: Fluid Characteristics—Characteristics of Aircraft Anti-Icing Fluids Subjected to Precipitation

Chaput, M. et al, *Characteristics of Aircraft Anti-Icing Fluids Subjected to Precipitation,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 13317E (1998).

Hunt, M., Chaput, M. et al, *Characteristics of Aircraft Anti-Icing Fluids Subjected to Precipitation,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 13484E (2001).

Moc, N., *Adhesion of Aircraft Anti-Icing Fluids on Aluminum Surfaces,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 14149E (not yet published) (2004).

Moc, N., *Adhesion of Aircraft Anti-Icing Fluids on Aluminum Surfaces: Phase II,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 14377E (not yet published) (2004)

Subject Matter: Ice Detection Sensors

Bendickson, S., *A Sensor for Detecting Anti-Icing Fluid Failure: Phase I,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 14382E (not yet published) (2004).

Bendickson, S., *A Sensor for Detecting Anti-Icing Fluid Failure: Phase II,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 14446E (not yet published) (2005).

Dawson, P. and Peters, A., *Feasibility of Use of Ice Detection Sensors of End-of-Runway Wing Checks,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 13481E (1999).

Dawson, P. and Hunt, M., *Ice Detection Sensor Capabilities for End-of-Runway Wing Checks: Phase 2 Evaluation,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 13662E (2000).

Weisser, Carl F., *Final Report Operational Evaluation for the Two Sensor Contaminant/Fluid Integrity Measuring System (C/FIMS) Midway Airlines F-100 Aircraft,* Allied Signal Aerospace, Etobicoke, Canada, Transportation Development Centre report TP 12979E (1997).

Weisser, Carl F., *Operational Evaluation for the Four Sensor Contaminant/Fluid Integrity Measuring System (C/FIMS) Midway Airlines F-100 Aircraft,* Allied Signal Aerospace, Etobicoke, Canada, Transportation Development Centre report TP 13254E (1997).

Subject Matter: Hot Water Deicing

Dawson, P., *Hot Water Deicing Trials for the 1994–95 Winter,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 12653E (1995).

Dawson, P., and Hanna, M., *Hot Water Deicing of Aircraft,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 13483E (1999).

Dawson, P., and Hanna, M., APS *Hot Water Deicing of Aircraft: Phase 2,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 13663E (2000).

Subject Matter: Forced Air Deicing

Bendickson, S., *A Protocol for Testing Fluids Applied with Forced Air Systems,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 14380E (not yet published) (2004).

Bendickson, S., *Evaluation of Type IV Fluids Using FedEx Forced Air Assist Equipment,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 14445E (not yet published) (2005).

Dawson, P., *Endurance Times of Fluids Applied with Forced Air Systems,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 14153E (2003).

Subject Matter: Alternative Deicing Approaches

Dawson, P. and Hanna, M., APS *Evaluation of Warm Fuel as an Alternative Approach to Deicing,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 13482E (1999).

Ruggi, E., and Pole, C., APS *Deicing with a Mobile Infra-Red System,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 13489E (2005).

Posteraro, D. and Chaput, M., *Evaluation of the Chinook Tempered Steam Deicing Technology for Aircraft Deicing Applications,* APS Aviation Inc., Montreal, Canada (not yet published) (2007).

Subject Matter: Aircraft De/Anti-Icing Fluid Research

Chaput, M., *A Potential Solution for De/Anti-Icing of Commuter Aircraft,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 14152E (2003).

Chaput, M., *APS Development of Holdover Time Guidelines for Type III Fluids,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 14379E (2004).

Subject Matter: Aircraft De/Anti-Icing Fluid Testing

Chebil, S. and Alwaid, A., *Influence of Application Procedure on Anti-icing Fluid Viscosity,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 13996E (2002).

Dawson, P., *SAE Type I Fluid Endurance Time Test Protocol,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 13827E (2003).

Moc, N., *Effect of Heat on Endurance Times of Anti-icing Fluids,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 14447E (not yet published) (2005).

Youssef, D., Dawson, P., *Effect of Heat on Endurance Times of Anti-icing Fluids (Research 2005–2007),* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report (not yet published) (2007).

Subject Matter: Application of Fluid Holdover Time Guidelines

Bendickson, S., *Relationship Between Visibility and Snowfall Intensity,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 14151E (2003).

Subject Matter: Holdover Time Determination Systems

Chaput, M., *Technical Assessment of the Dan-Ice Detection and Information System,* APS Aviation Inc., Montreal, Canada (2004).

Chaput, M., *Operational Assessment of the Dan-Ice Detection and Information System (DIIS) Winter 2003–04,* APS Aviation Inc., Montreal, Canada (2004).

Chaput, M., and Ruggi, M., *Continued Technical Assessment of the Dan-Ice Information System,* APS Aviation Inc., Montreal, Canada (2006).

Ruggi, M. and Moc, N., *Evaluation of a Real-Time Snow Precipitation Gauge for Aircraft Deicing Operations,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 14150E (2003).

Ruggi, M. and Moc, N., *Evaluation of a Real-Time Snow Precipitation Gauge for Aircraft Deicing Operations (2003–04),* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 14150E (2004).

Subject Matter: Aerodynamic Penalties of Clean or Partially Expended De/Anti-icing Fluid

Chaput, M. and Campbell, R., *Aircraft Takeoff Test Program for Winter 2001–02: Testing to Evaluate the Aerodynamic Penalties of Clean or Partially Expended De/Anti-Icing Fluid,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 13995E (2002).

Subject Matter: Aircraft Ground Deicing Exploratory Research

Bendickson, S., Chebil, S., Moc, N. and Vepsa, K., *Aircraft Ground Icing General and Exploratory Research Activities for the 2003–04 Winter,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 14381E Winter (not yet published) (2004).

Chebil, S., Mayodon, M., Dawson, P., *Aircraft Ground Icing Exploratory Research for the 2002–03 Winter,* APS Aviation Inc., Montreal, Canada, Transportation Development Centre report TP 14154E (not yet published) (2003).

Regulatory, Government and Industry Documentation, Guidance Material and Standards

U.S. Federal Aviation Administration (FAA)

U.S., Federal Aviation Administration AFS-2508, *FAR Part 135 Icing Limitations,* Advisory Circular (AC) 135-9, U.S. Federal Aviation Administration, Washington, DC (5/30/1981).

U.S. Federal Aviation Administration AWS-100, *Hazards Following Ground Deicing and Ground Operations in Conditions Conducive to Aircraft Icing,* Advisory Circular (AC) 20-117, Federal Aviation Administration, Washington, DC (reissued 3/29/1988).

U.S. Federal Aviation Administration AFS-400, *Pilot Guide—Large Aircraft Ground Deicing,* Advisory Circular (AC) 120-58, U.S. Federal Aviation Administration, Washington, DC, (9/30/1992).

U.S. Federal Aviation Administration AFS-2507, *Ground Deicing and Anti-Icing—Training and Checking,* Advisory Circular (AC) 135-16, U.S. Federal Aviation Administration, Washington, DC (12/12/1994).

U.S. Federal Aviation Administration AFS-200, *Pilot Guide—Small Aircraft Ground Deicing,* Advisory Circular (AC) 135-17, U.S. Federal Aviation Administration, Washington, DC (12/14/1994).

U.S. Federal Aviation Administration AFS-220, *Pilot Guide—Flight in Icing Conditions,* Advisory Circular (AC) 91-74, U.S. Federal Aviation Administration, Washington, DC (12/12/2002).

U.S. Federal Aviation Administration AFS-22010, *Aircraft Deicing and Anti-icing Program,* Advisory Circular (AC) 120-60B, U.S. Federal Aviation Administration, Washington, DC (12/05/2004).

U.S. Federal Aviation Administration AFS-2209, *Ground Deicing Using Infrared Energy,* Advisory Circular (AC) 120-89, U.S. Federal Aviation Administration, Washington, DC (12/13/2005).

U.S. Federal Aviation Administration AIR-120, *Aircraft Ice Protection,* Advisory Circular (AC) 20-73A, Federal Aviation Administration, Washington, DC (10/16/2006).

U.S. Federal Aviation Administration AFS-20011, *Approved Deicing Program Updates, Winter 2006–07,* FAA N8000.329, U.S. Federal Aviation Administration, Washington, DC (10/27/2006).

U.S. Federal Aviation Administration ACE-1006, *Certification of Part 23 Airplanes for Flight in Icing Conditions,* Advisory Circular (AC) 23-1419-2D, U.S. Federal Aviation Administration, Washington, DC (4/19/2007).

U.S. Environmental Protection Agency (EPA)

Barash, S., J. Covington, and C. Tamulonis, *EPA—821-R-00-016: Preliminary Data Summary Airport Deicing Operations,* U.S. Environmental Protection Agency, Office of Water, (2000).

Transport Canada (TC)

Transport Canada, *Holdover Time (HOT) Guidelines 2006–2007,* Transport Canada, Ottawa, Canada (July 2006).

Transport Canada, Ingold, D., *Guidelines for Aircraft Ground Operations and Holdover Time Guidelines for Winter 2006–2007,* Commercial and Business Aviation Advisory Circular (CBAAC) 0025R3, Transport Canada, Commercial and Business Aviation, Ottawa, Canada (July 21, 2006).

Transport Canada, Ingold, D., *Guidelines for Aircraft Ground Icing Operations,* Transport Canada, Ottawa, Canada, Transport Canada document TP 14052E (April 17, 2007).

Society of Automotive Engineers (SAE)

SAE G-12 Methods Subcommittee, *SAE Aerospace Recommended Practice (ARP) 4737G Aircraft Deicing/Anti-Icing Methods With Fluids,* SAE Aerospace Inc., Warrendale, PA (November 2005).

Association of European Airlines (AEA)

Association of European Airlines Deicing/Anti-icing Working, *Recommendations for Deicing/Anti-Icing of Aircraft on* *the Ground 21st Edition,* Association of European Airlines (AEA), Brussels, Belgium (September 2006).

Association of European Airlines Deicing/Anti-icing Working, Fieandt, J., *AEA Training Recommendations and Background Information for Deicing/Anti-icing of Aircraft on the Ground 3rd Edition,* Association of European Airlines (AEA), Brussels, Belgium (September 2006).

Other

International Civil Aviation Organization (ICAO)/International Air Transport Association (IATA) Safety Committee, *Manual of Aircraft Ground Deicing/Anti-icing Operations, Second Edition,* International Civil Aviation Organization, Montreal, Canada, Document 9640 (2000).

Joint Aviation Authorities (JAA), *Ice and Other Contaminants (Ground Procedures),* Joint Aviation Requirements (JAR) OPS 1.345, Joint Aviation Authorities, Hoopdorp, Netherlands (1/3/1998).

New Zealand Civil Aviation Authority, *New Zealand Aircraft Icing Handbook, 1st Edition,* New Zealand Civil Aviation Authority, Wellington, New Zealand (June 14, 2000).

International Organization for Standardization (ISO) Technical Committee 20/SC-9 with Association of European Airlines (AEA) and the SAE G-12 Aircraft Ground Deicing Committee Technical Specialists, *ISO 11076 Aircraft—Ground Based Deicing/Anti-icing Methods with Fluids,* ISO Copyright Office, Geneva, Switzerland (November 15, 2006).

CHAPTER 3

Holdover Time Variance Across an Airfield

Introduction

Holdover time determination systems (HOTDS), such as D-Ice A/S Deicing Information System and NCAR Check-time, measure meteorological parameters at airport sites that then are used to calculate expected de/anti-icing fluid HOT, thus facilitating better fluid selection. HOT is directly dependent on precipitation intensity, so it is vital that the intensity measured and used by the determination system reflects the highest intensity to which the aircraft may be exposed during its departure taxi. The key question, then, is whether a precipitation sensor at a single location at an airport can provide data with sufficient reliability for this application.

This part of the report presents the results, findings, and conclusions of an experiment to determine if a single location precipitation sensor can reliably report precipitation conditions for the entire airport. Precipitation intensity was measured at several locations at an airport simultaneously. Tests were conducted over two winter seasons, 2007–08 and 2008–09.

Preliminary Testing (Winter 2007–08)

In the winter of 2007–08, Montreal-Trudeau airport (YUL) was selected as the primary location for testing. Montreal-Mirabel airport (YMX) was selected as an alternative site; however, no data collection was gathered at that airport during the first season.

Testing was performed during 11 natural precipitation events at YUL, and approximately 140 comparative data points were collected during this period. For each event, data collection teams were separated by distances ranging from 4,200 to 13,300 ft at the airport. Data collected by each team included precipitation rate and other relevant meteorological parameters affecting fluid HOT. The procedure consisted of collecting the precipitation rate data (as well as the other relevant data) over a 10-minute period at two sites at the airport simultaneously using a stringent data collection protocol. The data collected were then compared to evaluate the variance in rates attributed to distance.

In general, the results indicated that the data on rate of precipitation was similar; therefore the overall variance on the resulting HOT values provided by the HOTDS positioned at these sites would be minimal. That said, the preliminary results indicated that the rate variance increased as the distance between the rate collection sites increased and therefore that additional data should be gathered at sites separated by longer distances. A full statistical analysis of the data collected as part of this task was completed in August 2008. The results indicated that a single HOTDS positioned at a central location at an airport with small surface area would likely be sufficient to provide accurate information for the entire airport site. However, at airports with large surface area, such as Denver International Airport, the distances from a central location at the airport to a departure runway may exceed 16,000 ft. No data for similar distances were collected in 2007–08, and it was therefore decided to conduct additional testing to verify whether airports with large surface areas would require additional HOTDS installations to provide reliable data.

Additional Testing (Winter 2008–09)

During the winter of 2008–09, the work effort was expanded to collect data at three additional airports. This work satisfied two requirements: (1) the collection of data from sites with larger separation distances, approximately 25,000 to 29,000 ft and (2) the collection of data to examine between-site differences in precipitation rates as a result of lake-effect snowfall.

The examination of variance at distances ranging from approximately 25,000 to 29,000 ft required data collection at Mirabel Airport (YMX) and at Denver International Airport (DEN). The investigation of between-site differences in precipitation rates was conducted at Syracuse Hancock International Airport (SYR), with a focus on lake-effect snow. Lake-effect snow is produced in the winter when cold arctic winds move across long expanses of warmer lake water, providing energy and picking up water vapor, which freezes and is deposited on the lee shores. The areas surrounding lake-effect snow are called snow belts. As lake-effect snow can cause significant variance in precipitation rates in small areas, it was of particular interest to examine the ability of a single HOTDS to provide sufficient coverage at an airport site impacted by lake-effect snow.

Research Approach and Methodologies

Test Procedures for Data Collection

The test procedure developed for use during HOTDS testing is based on the precipitation intensity measurement procedure included in Society of Automotive Engineers (SAE) Aerospace Recommended Practice (ARP) 5485. This is the same rate measurement procedure that has been employed in the development of de/anti-icing fluid holdover time tables since 1990. Separate test procedures were developed for each work element; these procedures, while relying the same general methodology in data collection, were individualized to the particular airport with specific contact lists, airport diagrams, and a communication plan. The test procedures are included in Appendix A.

Focus Airports

Montreal-Trudeau International Airport YUL (Montreal, Quebec)

Montreal-Trudeau Airport (YUL) was selected as the primary location for the preliminary test program as efficiencies were obtained by conducting research at the airport where the APS test site is located. The test procedure for data collection was developed, tested, and refined at this primary location. The majority of all data collection was completed at YUL.

Mirabel International Airport YMX (Mirabel, Quebec)

Mirabel Airport (YMX) was selected to serve as a test area for long distance data collection. YMX was envisioned to be the second largest airport in the world in terms of surface area, with a planned area of 39,660 hectares (396.6 km^2). Economic factors eventually led to YMX being relegated to the role of a cargo airport, and therefore was not expanded to this planned area. However, YMX still provided the necessary distance for an appropriate analysis.

Denver International Airport DEN (Denver, Colorado)

Denver International Airport (DEN) is one of the largest airports in the world from the perspective of surface area, with over 30,000 ft separating certain active runway departure points. For this reason, as well as for reasons related to the historical nature and severity of winter precipitation in Denver, DEN was selected as a desired test location for the continuation of the HOTDS long distance collection.

Syracuse Hancock International Airport SYR (Syracuse, New York)

Syracuse Hancock International Airport (SYR) was identified as an ideal airport to collect lake-effect snowfall data. Lake-effect snow on the Tug Hill Plateau (east of Lake Ontario) can frequently set daily records for snowfall in the United States. Syracuse, New York is directly south of the Tug Hill Plateau and receives significant lake-effect snow from Lake Ontario. Snowfall amounts at this location are significant and average 115.6 in (294cm) a year.

Test Locations and Remote Test Unit

Test Locations

All data collection was collected on non-airside land surrounding each airport. Locations used were kept non-airside to minimize disruptions to airport operations. In addition, it allowed APS personnel full autonomy to come and go as required by each precipitation event. Typical locations were:

- Perimeter roads (city owned);
- Perimeter business parking lots;
- Long-term parking lots; and
- Fixed-base operator parking lots.

Remote Test Unit

A remote laboratory was established with all the necessary testing equipment installed into a 16-foot cube van (Figure 1). This allowed for testing in any desired remote location. Testing at the off-site location was conducted in a mobile test unit, housed within a cube van, and powered by generators.

Equipment and Methodology for Precipitation Measurement

A snow-catching methodology was employed in this research. This test procedure was developed based upon the rate measurement methodology employed for holdover time

Figure 1. Remote test unit.

Figure 2. Snow catch pan.

testing and described in SAE ARP 5485. Because it was necessary to acquire data with limited errors, a far more comprehensive and stringent methodology was applied to the procedure for this testing. The method establishes a rate of icing intensity by catching the precipitation with a known-dimension pan over a specified period of time. This allows for a subsequent calculation of the rate usually represented in $g/dm^2/h$.

The following sections describe in detail the test equipment used in this snow-catching methodology.

Snow-Catch Pan

A snow-catch pan, placed at a 10° inclination on the test stand, was used to collect and weigh precipitation. The positioning of the snow-catch pan on the test stand was such that the longer dimension axis of the pan is parallel with the longer dimension axis of the test plate.

A typical serving pan commonly found in the restaurant industry proved to be an adequate snow-catching pan. A matching lid allowed full control of precipitation collection. Four snow-catch pans were employed at each site.

Figure 2 shows the pans that were used in testing. Figure 3 is an accurate depiction of the dimensions of each pan.

Test Stand

Specially designed test stands were fabricated to form-fit the snow-catch pans and ensure that the pans would sit at a 10° inclination. This 10° inclination is representative of the leading edge of an aircraft wing. In testing locations where ground surfaces were uneven, the test stands were manually leveled. There were no flanges or obstructions close to the edges of the plates that could interfere with the airflow over the collection pans. Figure 4 depicts the test stand.

The test stand was oriented facing into the predominant wind direction. A test stand is defined as facing into the wind when the long axes of the collection plates are facing into the wind direction. Wind direction was constantly monitored and adjustments were made, but not, however, during any 10-minute collection period.

Precipitation Measurement Balance

A Sartorius EA series balance was employed for all testing. With a resolution of 0.2 g, this balance allowed for an accurate reading of precipitation accumulation. Figure 5 depicts the balance.

Methodology for Snow-Catch Collection

Four snow-catch pans were used, numbered from one to four. Each pan was coated with 450 ml of standard Type IV fluid. The wetted pans were weighed to the nearest 0.2 g.

All four pans were placed under precipitation for a period of 10 minutes. The snow-catch pans were turned 180° at intervals of two minutes to ensure that no snow build-up would occur at either end of the pan. Past research has proven that pan rotation ensures no loss of accumulation and hence gives the true precipitation accumulation.

At the end of a 10-minute period, all four pans were re-weighed. The difference in weight before and after exposure to precipitation was used to compute the precipitation rate.

Other Equipment

Other support equipment used in the field are described in Appendix A.

Sequence of Events

The following sections describe the timing and communication protocols as well as the sequence of testing protocols

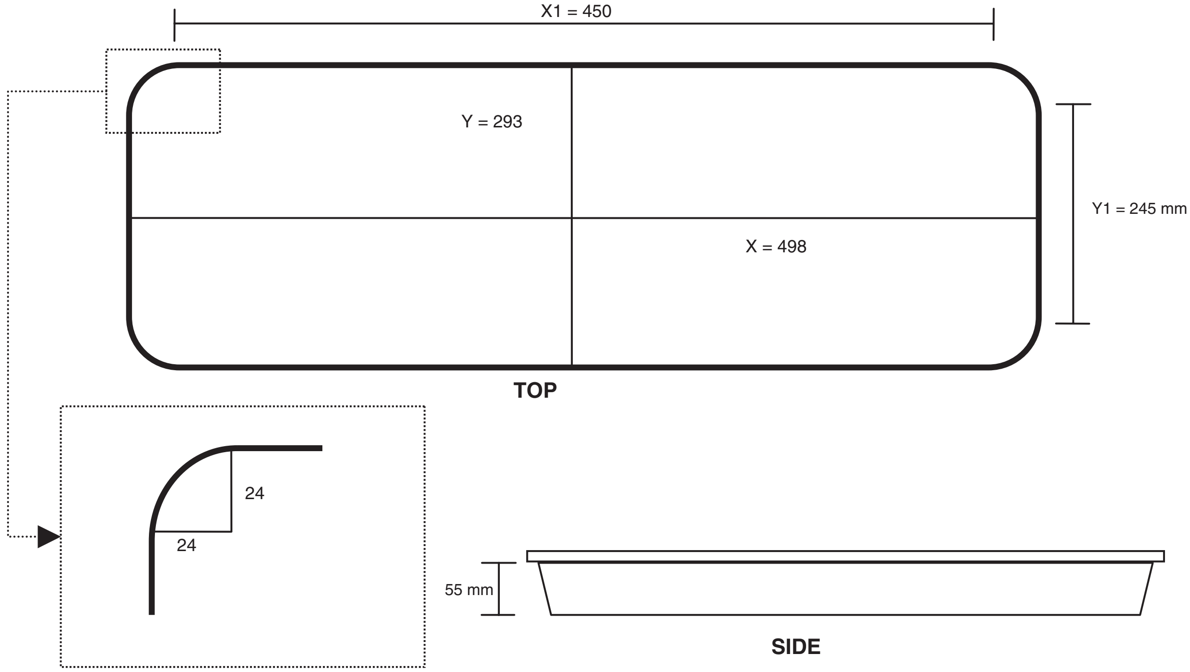

Figure 3. Dimensions of snow-catch pan.

that were followed during the precipitation events at each airport.

Timing and Communication

Timepieces were synchronized before testing commenced. A detailed schedule of events was distributed before testing and an agreed upon start time established.

In order to achieve simultaneous collection of precipitation, a well-organized system of communication was incorporated into all testing. Standard Motorola VHF radios were employed and used frequently in testing; sometimes cell phones were employed.

Sequence of Testing

All testing followed the same sequence. This allowed for the collection of three measurements per hour. This sequence was identical for both testing locations at each airport.

The typical sequence for the first collection period is detailed in Table 19.

Ten minutes elapsed between the end of the first collection and the start of the second collection.

The typical sequence for the second collection period is detailed in Table 20.

Figure 4. Test stand.

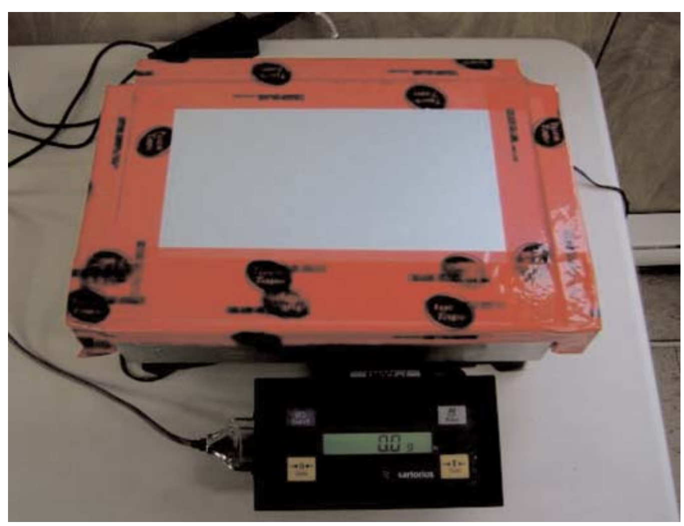

Figure 5. Precipitation measurement balance.

Table 19. Typical sequence for the first collection.

Time	Tester 1	Tester 2
T = - 5 Minutes	Weigh and record initial weight	Weigh and record initial weight
T = -3 Minutes	Verify wind direction and adjust stand	Verify wind direction and adjust stand
T = -2 minutes	Place two covered plates on stand	Place two covered plates on stand
T = 0	Remove Covers	Remove Covers
T= 2 minutes	Rotate Pans	
T= 4 minutes	Rotate Pans	
T= 6 minutes	Rotate Pans	
T= 8 minutes	Rotate Pans	
T= 10 minutes	Cover pans and bring in for measurement	Cover pans and bring in for measurement

Ten minutes elapsed between the end of the second collection and the start of the third collection.

The typical sequence for the third collection period is detailed in Table 21.

A similar sequence was used for subsequent measurements.

Personnel

For most of the initial testing in the winter of 2007–08, four APS personnel were required for testing. For the YUL tests, two personnel operated the mobile unit in the remote location and two remained at the APS test site. However for the second winter of testing, the test technicians were more experienced and only two personnel were needed to operate the two mobile units used for testing at YMX, DEN, and SYR.

Data Forms

One general data form was used to record precipitation collection. This data form is shown in Figure 6.

Description of Data and Methodology Used to Process

The data collected for the holdover time variance across an airfield task and its processing are described in this section.

Tests Conducted

Tests were conducted over two winter seasons, 2007–08 and 2008–09, at nine different pairs of collection sites.

Tests Conducted in the Winter of 2007–08

Tests conducted during the winter of 2007–08 included nine snowstorm events from February 1, 2008 to March 13, 2008. These tests were all conducted at Montreal-Trudeau Airport, at various locations. A total of 126 tests were conducted. Of these, the data from 18 tests was excluded from analysis. The principal reasons for excluding data were cases where the measured precipitation rate exceeded 50 $g/dm^2/h$, and cases where there was a considerable amount of blowing snow at one of the test sites. After exclusion of this data, 108 tests remained, and this set of tests was subjected to analysis.

Table 20. Typical sequence for the second collection.

Time	Tester 1	Tester 2
T = 18 minutes	Place pans back on stand. Verify wind direction and adjust stand	Place pans back on stand. Verify wind direction and adjust stand
T = 20 minutes	Remove Covers	Remove Covers
T= 22 minutes		Rotate Pans
T= 24 minutes		Rotate Pans
T= 26 minutes		Rotate Pans
T= 28 minutes		Rotate Pans
T= 30 minutes	Cover pans and bring in for measurement	Cover pans and bring in for measurement

Table 21. Typical sequence for the third collection.

Time	Tester 1	Tester 2
T = 38 minutes	Place pans back on stand. Verify wind direction and adjust stand	Place pans back on stand. Verify wind direction and adjust stand
T = 40 minutes	Remove Covers	Remove Covers
T= 42 minutes	Rotate Pans	
T= 44 minutes	Rotate Pans	
T= 46 minutes	Rotate Pans	
T= 48 minutes	Rotate Pans	
T= 50 minutes	Cover pans and bring in for measurement	Cover pans and bring in for measurement

LOCATION: DATE:

PLATE PAN WEIGHT MEASUREMENTS

PAN #	t TIME BEFORE (h:min:s)	t TIME AFTER (h:min:s)	w WEIGHT BEFORE (g)	w WEIGHT AFTER (g)	DELTA WEIGHT (g)

METEO OBSERVATIONS

TIME (h:min)	Precipitation Type

AIR TEMPERATURE AT START OF TEST ______°C

WIND DIRECTION AT START OF TEST ________°

TEST STAND ORIENTATION
(measured along long axes of the test panels)

COMMENTS :

PRINT SIGN

WRITTEN & PERFORMED BY :

Figure 6. Implementation of holdover time determination systems data form.

Table 22. Test site locations for Winter 2007–08—Montreal-Trudeau Airport.

Site 1 Location	Site 2 Location	Separation Distance		Number of Events	Number of Tests
		(ft)	(m)		
Chemin St François 45º 28' 33" N 73º 45' 12" W	APS Test Site 45º 28' 6" N 73º 44' 28" W	4,167	1,270	1	18
Marshall Rd Snow Dump 4º 27' 28" N 73º 44' 14" W	APS Test Site 45º 28' 6" N 73º 44' 28" W	4,232	1,290	3	40
Ch. Cote Vertu 45º 28' 40" N 73º 43' 33" W	APS Test Site 45º 28' 6" N 73º 44' 28" W	5,052	1,540	1	9
Chemin St François 45º 28' 33" N 73º 45' 12" W	Ch. Cote Vertu 45º 28' 40" N 73º 43' 33" W	7,017	2,139	2	15
Chemin St François 45º 28' 33" N 73º 45' 12" W	Marshall Rd Snow Dump 46º 27' 28" N 73º 44' 14" W	7,933	2,418	1	16
APS Office Parking Lot 45º 28' 60" N 73º 41' 36" W	APS Test Site 45º 28' 6" N 73º 44' 28" W	13,390	4,081	1	10

As described, each test set consisted of data collected simultaneously at two separate sites. At each site, precipitation was measured simultaneously on four rate pans. Thus, each test set comprised a total of eight data points.

Different testing sites were used during the course of the test season to produce data for various distances between test sites. Six different pairs of sites were used for testing, with separation distances as shown in Table 22.

The test site locations and separation distances are shown in Figure 7. Figure 8 shows that the longest distance between departure points was 13,991 ft (4,265 m). Figure 9 shows distances from a central site to runway departure points. One

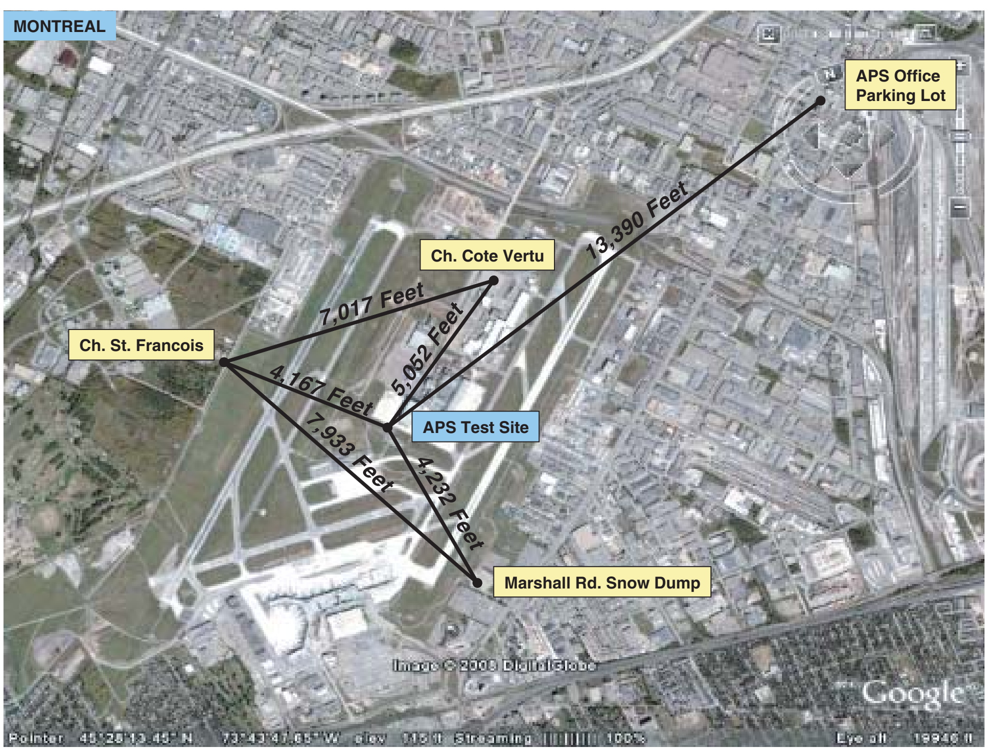

Figure 7. Site locations: Montreal Trudeau International Airport (YUL).

Figure 8. Longest active distance at Montreal Trudeau International Airport (YUL).

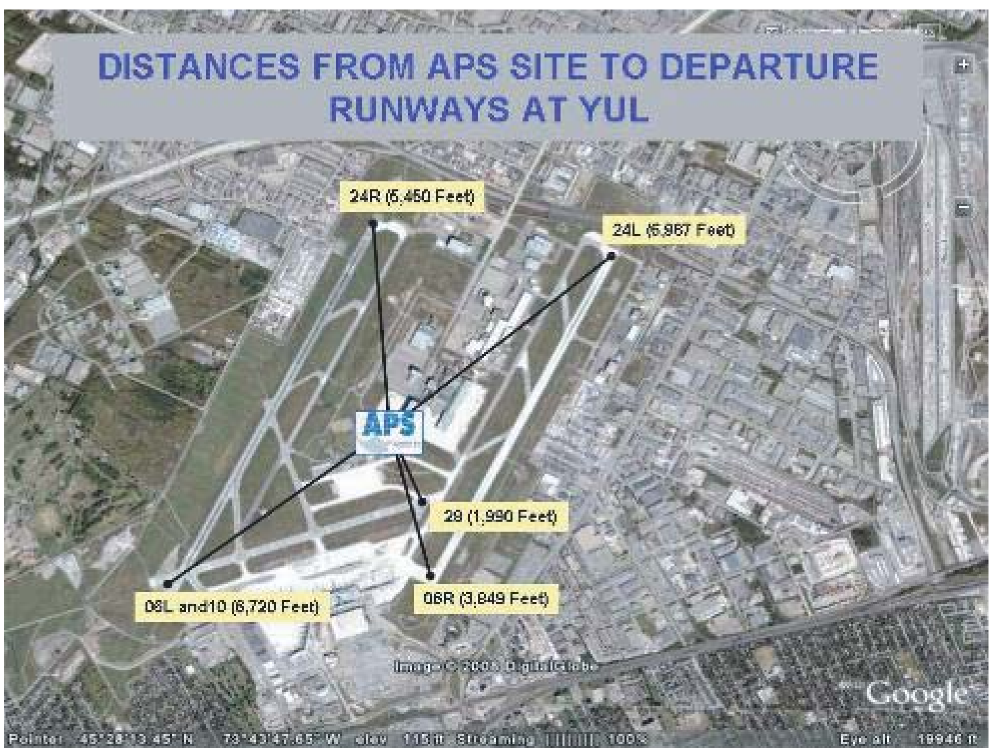

Figure 9. Distances from APS test site to departure runways at Montreal Trudeau International Airport (YUL).

Table 23. Test site locations for Winter 2008–09.

Airport	Site 1 Location	Site 2 Location	Separation Distance (ft)	Separation Distance (m)	Number of Events	Number of Tests
Montreal-Mirabel International Airport (YMX)	Cargo C Parking Lot 45º 40' 46" N 74º 02' 53" W	Ch. Charles Parking Lot 45º 41' 27" N 73º 56' 17" W	28,500	8687	2	41
Syracuse Hancock International Airport (SYR)	Tuskegee Rd Parking Lot 43º 06' 19" N 76º 06' 56" W	South Bay Rd. Parking Lot 43º 07' 01" N 76º 08 '33" W	8,300	2530	1 (non-lake-effect)	9
					1 (lake-effect)	32
Denver International Airport (DEN)	E. 71st Ave Parking Lot 39º 54' 26" N 104º 40' 13" W	Trussville St. Parking Lot 39º 54' 01" N 104º 40' 12" W	27,800	8473	2	52

test site of each pair was located close to the airport central deicing facility (CDF), thus the noted distances are a good indication of typical distances from a centrally located HOTDS to runway departure points at YUL airport.

The selected site pairs generated separation distances that provided a good reflection of the airport geography.

Tests Conducted in the Winter of 2008–09

Tests conducted during 2008–09 included six snowstorm events from December 9, 2008 to April 4, 2009. Tests were conducted at three different airports as shown in Table 23. A total of 135 tests were conducted. Of these, the data from one test was removed due to a measurement error and excluded from the analysis.

Testing at SYR offered the opportunity to study lake-effect snowfall. Precipitation rates were recorded during one such event. Figure 10 shows the site locations at SYR.

Figures 11 and 12 show the locations of the two test sites at YMX and DEN, respectively. The long separation distances between runway departure points are apparent from these images.

Figure 10. Site locations: Syracuse Hancock International Airport (SYR).

Figure 11. Site locations: Mirabel International Airport (YMX).

Figure 12. Site locations: Denver International Airport (DEN).

Table 24. Summary of test events.

Event #	Date	Location	Separation Distance (ft)	# of Tests	Average Temp (°C)	Average Wind Speed (kph)	Predominant Weather
1	Feb 1, 2008	YUL	4,232	16	-5.3	32	Snow, Ice Pellets
2	Feb 5, 2008	YUL	4,232	13	-4.4	21	Snow
3	Feb 9, 2008	YUL	5,052	9	-3	12	Snow
4	Feb 13, 2008	YUL	4,167	18	-9.3	19	Snow
5	Feb 15, 2008	YUL	4,232	11	-5.3	15	Snow
6	Feb 26, 2008	YUL	7, 017	10	-4.2	33	Snow
7	Mar 5, 2008	YUL	7, 017	5	-8.1	43	Snow
8	Mar 8, 2008	YUL	7,933	16	-2.1	29	Snow, Fog
9	Mar 13, 2008	YUL	13,390	10	-7.9	20	Snow
10	Dec 9, 2008	YMX	28,500	24	-11.5	11	Light Snow
11	Dec 12, 2008	YMX	28,500	17	-7.1	9	Light Snow
12	Jan 8, 2009	SYR	8,300	9	-3.2	21	Light Snow
13	Jan 8, 2009	SYR	8,300	32	-5.3	25	Light Snow
14	Mar 26, 2009	DEN	27, 800	35	-9.9	32	Light Snow
15	Apr 4, 2009	DEN	27,800	17	-0.1	22	Light Snow
Total:				242			

Summary of Test Events

Fifteen test events were completed over the course of the two winter seasons. Table 24 summarizes the events and the conditions present for each event. The table provides a description of the test dates, location of the tests, separation distances between sites, number of tests conducted for each event, along with the weather conditions (average temperature, wind speed, and predominant precipitation condition).

Test Data Log

The log of test data collected over the two winters and subjected to analysis is included in Appendix B.

Each row in this log contains data specific to one test set and records data collected at both test locations during an event. The log of data is separated by event and sorted sequentially by calendar date as the tests were conducted. Table 25 excerpts the details of tests that were conducted for Event #1 on February 1st, 2008 at YUL airport with a separation distance of 4,232 ft.

Following is a brief description of the column headings used in the test log:

- Set no.: Sequential number given to the test set. Sequencing was restarted at number 201 for the second season. Certain tests that were removed from the analysis are not included in this log;
- Time before: Time at start of test;
- Time after: Time at end of test;
- Pan delta: Measured weight (in grams) of precipitation collected during the test, for each of the four rate pans;
- Closest to mean: Two "closest to mean" pans chosen for further analysis;
- Average variance: Average variance (in grams);
- Average variance: Average variance (in percent);
- Temp: Outside air temperature during the test session (in °C);
- Wind dir: Direction of wind on rate pan (in 10's deg);
- Wind speed (kph): Wind speed (in kilometers per hour);
- Visibility: Visibility (in km); and
- Weather: Description of snow intensity.

The test data logs for the remaining 14 events are included in Appendix B. These test logs contain all the data collected and subjected to analysis.

Scatter Diagram of Logged Data

Figure 13 provides a depiction of the precipitation data collected at short distances in both winters as a scatter diagram. The *x* and *y* coordinates for each point reflect the precipitation rates measured at Site 1 and Site 2. The best-fit line drawn through the points shows limited scatter. Figure 14 shows a similar scatter plot of the medium separation distance data; the data collected at SYR during the lake-effect event is shown with a different symbol. Figure 15 charts the precipitation data collected at the long separation distances (YMX and DEN).

The charts clearly show that the precipitation rate differences increase as a function of site separation distance.

Table 25. Example of detailed test log, Event #1.

EVENT #1 FEBRUARY 1, 2008 MONTREAL (YUL) (4,232 ft Separation)
SITE A: Marshall Road Snow Dump Facility (45º 27' 28" N 73º 44' 14" W)
SITE B: APS Test Facility (45º 28' 6" N 73º 44' 28" W)

Set No.	Time Before	Time After	SITE 1 Pan Delta (g)				SITE 1	SITE 1 Closest to Mean (g)			SITE 2 Pan Delta (g)				SITE 2	SITE 2 Closest to Mean (g)			Variance Analysis: Difference Between Avg. Best	Variance Analysis: Variance in Avg. Best	MSC Data: Temp.	Wind Direction	Wind Sp	Visibility	Weather
			Δ1	Δ2	Δ3	Δ4	ΔAVG	Best 1	Best 2	Avg Best	Δ1	Δ2	Δ3	Δ4	ΔAVG	Best 1	Best 2	Avg Best	Absolute Value (g)	%	(°C)	(10's deg)	(kph)	(km)	
1	13:00	13:10	61.4	60.6	59.2	59	60.1	60.6	59.2	59.9	62.2	61	53.4	52.2	57.2	61	53.4	57.2	2.7	4.60%	-7.1	5	33	0.8	Moderate Snow
2	13:20	13:30	86.8	81.6	79.6	78	81.5	81.6	79.6	80.6	79	77	71.6	71.6	74.8	77	71.6	74.3	6.3	8.10%	-6.7	5	33	0.8	Moderate Snow
3	13:50	14:00	87.6	91	86.8	87.4	88.2	87.6	87.4	87.5	87	87.2	86.8	89.2	87.6	87.2	87	87.1	0.4	0.50%	-6	5	26	0.8	Moderate Snow
4	14:10	14:20	129	125	121	119	124	125	121	123	135	133	135	134	134	135	134	134	11.3	8.80%	-5.7	5	26	0.8	Moderate Snow
5	14:40	14:50	103	103	106	103	104	103	103	103	114	113	114	116	114	114	114	114	10.8	9.90%	-5.4	7	30	3.2	Snow ,Ice Pellets
6	15:00	15:10	59.6	60.8	58.2	62	60.2	59.6	60.8	60.2	68	66.8	68.6	69.4	68.2	68	68.6	68.3	8.1	12.60%	-4.9	7	30	3.2	Snow ,Ice Pellets
7	15:20	15:30	61.6	60	59.2	60	60.2	60	60	60	64.6	62.8	66.2	66.8	65.1	64.6	66.2	65.4	5.4	8.60%	-4.9	7	30	3.2	Snow ,Ice Pellets
8	15:40	15:50	52.6	56.8	53.8	53.6	54.2	53.8	53.6	53.7	44	43.8	44	44.8	44.2	44	44	44	9.7	19.90%	-5	5	33	1.6	Snow
9	16:00	16:10	93.6	90.4	88.8	90.2	90.8	90.4	90.2	90.3	77.6	78.6	80.8	79.2	79.1	79.2	78.6	78.9	11.4	13.50%	-5	5	33	1.6	Snow
10	17:40	17:50	54.6	55.6	53.6	55.8	54.9	54.6	55.6	55.1	50.6	50.8	51.6	52.2	51.3	51.6	50.8	51.2	3.9	7.30%	-5.2	6	32	1.2	Snow
11	18:00	18:10	99.6	98.8	99.6	98.6	99.2	98.8	99.6	99.2	102	102	101	103	102	102	102	102	2.8	2.80%	-5	6	32	1.2	Snow
12	18:20	18:30	98.8	100	102	99.6	100	100	99.6	99.9	107	110	109	110	109	110	109	109	9.2	8.80%	-5	6	32	1.2	Snow
13	18:40	18:50	93	93.8	92.8	93.2	93.2	93.2	93	93.1	105	107	107	108	107	107	107	107	14.1	14.10%	-4.9	6	30	2	Snow ,Ice Pellets
14	19:00	19:10	104	103	104	103	104	104	103	103	119	120	118	121	119	120	119	119	16	14.40%	-4.9	6	30	2	Snow ,Ice Pellets
15	19:30	19:40	118	117	116	117	117	117	117	117	119	120	120	124	121	120	120	120	2.9	2.40%	-4.9	6	37	2.4	Snow ,Ice Pellets
16	19:50	20:00	113	111	110	111	111	111	111	111	121	120	123	123	122	121	123	122	10.4	8.90%	-4.9	6	37	2.4	Snow ,Ice Pellets
17	20:10	20:20	102	104	101	104	103	102	104	103	110	111	113	113	112	111	113	112	8.8	8.20%	-4.8	6	37	2.4	Snow ,Ice Pellets

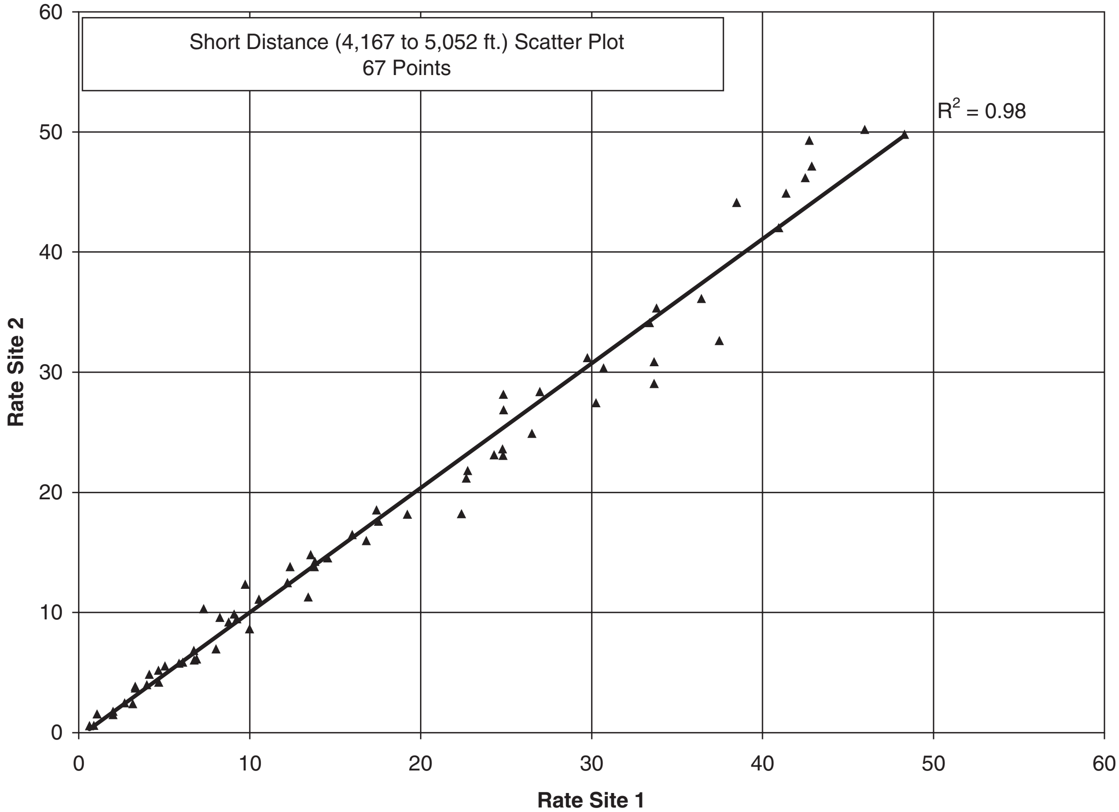

Figure 13. Precipitation rate comparison data for short separation distances.

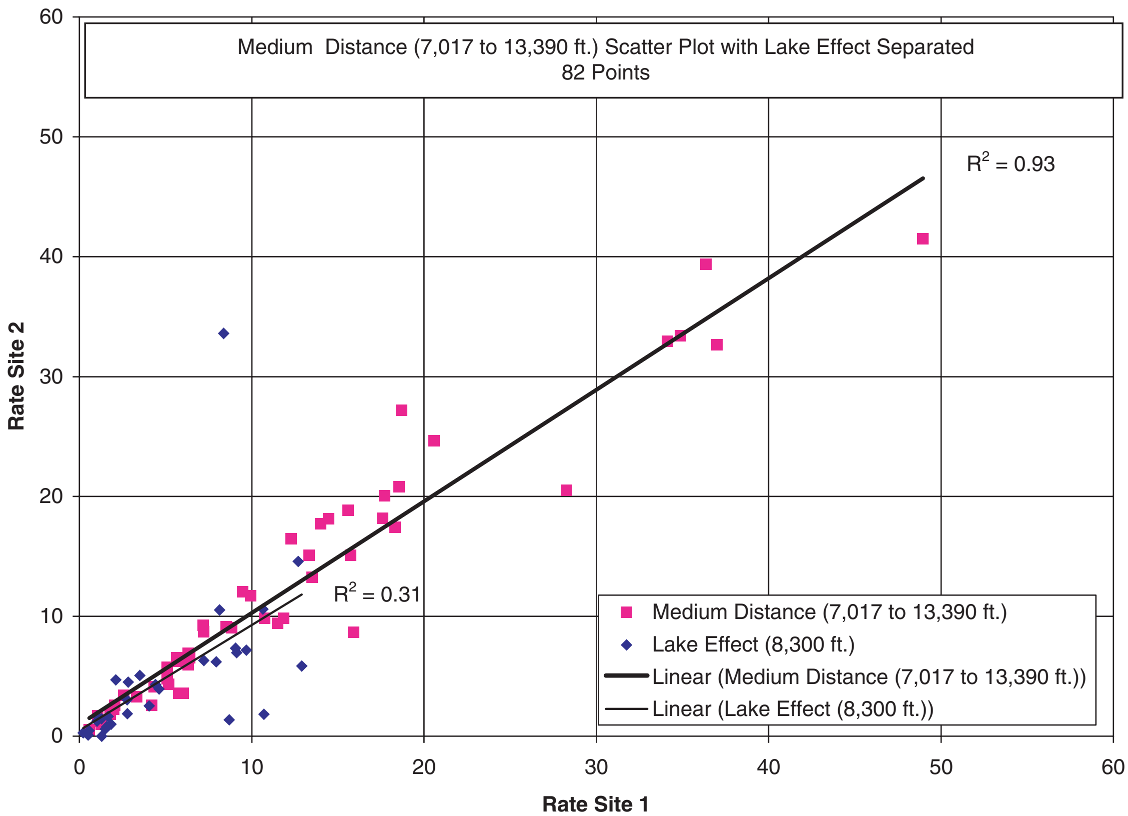

Figure 14. Precipitation rate comparison data for medium separation distances.

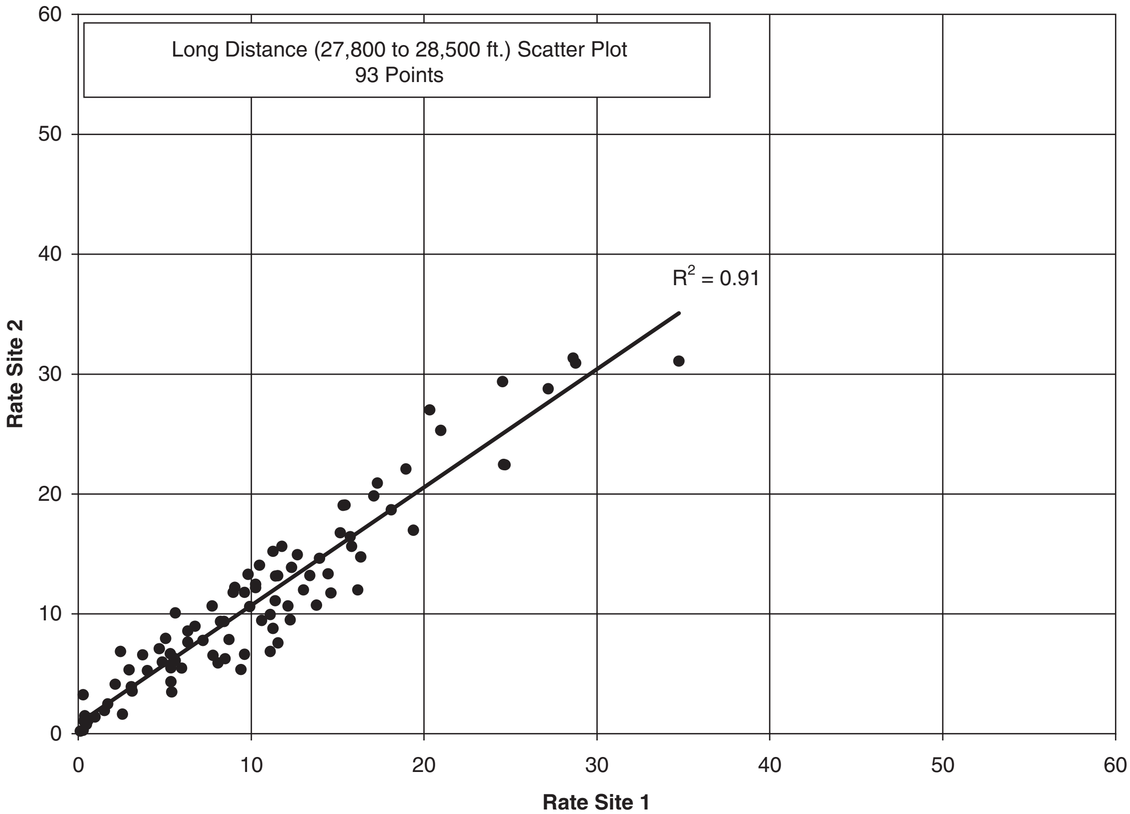

Figure 15. Precipitation rate comparison data for long separation distances.

An R^2 value was determined for each of the data sets in Figures 10 to 12:

- Short separation distance R^2=0.98;
- Medium separation distance R^2=0.93;
- Long separation distance R^2=0.91; and
- Lake-effect data R^2=0.31.

The R^2 parameter provides a sense of the variance in the data and shows that the variance between the two sites increases as the distance between the sites is increased. The R^2 value for the lake-effect snowfall data clearly shows that this type of precipitation event also increases the variance in precipitation rate.

While the variation of the points around the best-fit lines reflects random effects, it may also indicate real differences in precipitation between sites. The task of the analysis is to identify which of the data sets result from random effects, and which reflect real differences, and for those differences that are real, to evaluate their operational significance.

The next sections describe the approach taken to answer these questions.

Data Analysis

The analysis was applied to the consolidated data collected over the two test seasons.

The analysis was aimed at determining the effect that any real difference in precipitation between the two sites would have on fluid holdover times. The initial treatment of the data thus required calculation of precipitation rates, followed by calculation of fluid holdover times for a variety of fluids.

Subsequently, the calculated fluid holdover times for each precipitation data point were examined statistically to determine which test sets had differences that could be ascribed to random effects and which had real differences in holdover times generated by each of the two sites.

The analysis is described in detail in the following sections.

Calculation of Precipitation Rates

The precipitation rate calculation is based on the measured weight of precipitation collected over a measured time span, on a surface of known dimensions.

The rate pans used to collect precipitation had a surface area of 14.53 dm^2 (1.56 ft^2). The duration of test time was determined from the data test start and end time. For a 10-minute test interval, the precipitation rate is calculated as:

$$\text{Rate}\left[g/dm^2/h\right] = \frac{\text{Weight of collected precipitation } [g]}{14.53\ \left[dm^2\right] \cdot 10/60\ [h]}$$

Any test sets where the average rate calculated for a site exceeded 50 $g/dm^2/h$, were excluded from the analysis. The rationale for this exclusion is as follows.

The currently published holdover time guidelines for snow have an upper limit on precipitation rates:

- Very light snow: 4 $g/dm^2/h$;
- Light snow: 4 and 10 $g/dm^2/h$; and
- Moderate snow: 10 and 25 $g/dm^2/h$.

During the process of collecting fluid endurance time data to generate HOT guidelines, a good deal of data has been collected during heavy snow events, that is, beyond 25 $g/dm^2/h$. In the past, this data has served to enhance the accuracy of the regression equations used to develop HOT guidelines for snow at rates up to moderate. However, there has been interest in extending the guidelines to reflect rates greater than moderate. Discussions at the 2006 SAE G-12 HOT subcommittee meeting indicated that an upper limit should not go beyond 50 $g/dm^2/h$ considering that:

- The frequency of heavy snow (> 25 $g/dm^2/h$) is about 3%;
- Most of this occurs in the range 25 to 50 $g/dm^2/h$; and
- Most of the endurance time data in heavy snow was collected in the range 25 to 50 $g/dm^2/h$.

This analysis has taken the perspective of evaluating the risk when holdover times would actually be generated, and thus only those test sets are examined.

Calculation of Fluid Holdover Times

Holdover time guidelines, which are published annually, provide pilots with tables of the protection times provided by de/anti-icing fluids in winter conditions. The values in the holdover time tables are developed through regression analysis of recorded fluid endurance time data.

Aircraft de/anti-icing fluid holdover time is a function of fluid dilution, precipitation rate, precipitation type, and ambient temperature. All the tests reported here were conducted in snow conditions.

The following regression equation is used to calculate holdover times in snow:

$$t = 10^{I} R^{A} (2 - T)^{B}$$

where:

t = time (minutes);
R = rate of precipitation ($g/dm^2/h$);
T = temperature (°C); and
I, A, B = coefficients determined from the regression.

This equation substitutes 2-T for the variable T in order to prevent taking the log of a negative number, as natural snow can occur at temperatures approaching +2°C.

HOTDS produce holdover times by applying the same regression equations and coefficients used to calculate the values in the current holdover time guidelines.

To assess the effect that separate HOTDS sites might have on holdover times, each measured precipitation weight data point was converted to holdover time, using the regression equations and coefficients for a selection of fluid brands that are currently in operational use.

Those fluid brands and strengths are given in Table 26, along with the regression coefficients used to calculate holdover times provided in the winter 2007–08 guidelines. Although different regression coefficients may apply when ambient temperatures are lower than −14°C, such temperatures did not occur during data collection.

In accordance with the current practice for HOT table development for snow, holdover times were capped at 120 minutes.

Holdover times for fluid strength of 50/50 concentration are constrained to OAT −3°C and above. This constraint resulted in setting aside some data sets when evaluating the effect on this fluid's holdover times.

Statistical Analysis to Compute HOT Difference Between Sites

Each test set consisted of data collected simultaneously at two separate sites. At each site, precipitation was measured simultaneously on four rate pans. Thus, each test set usually comprised a total of eight data points. The foregoing analy-

Table 26. Fluid holdover time regression coefficients.

Coefficients	SAE Type I	Clariant Safewing MP IV 2012 Protect 100/0	Octagon MaxFlo 100/0	Kilfrost ABC-S 75/25	Kilfrost ABC-S 50/50
I	2.0072	2.9261	3.0846	2.5569	2.3232
A	-0.5752	-0.6725	-0.8545	-0.7273	-0.8869
B	-0.5585	-0.5399	-0.3781	-0.1092	-0.2936

sis then produced eight values of fluid holdover time for each test set. In several cases, only three data points were recorded at one of the sites, and the statistical analysis took this into account.

The objective then was to examine the difference in HOTs for the two sites.

Because a maximum of four HOT values existed for each of the two sites for each test, the comparison was conducted using small sample theory. This complies with the general rule that statistical analysis of samples with size less than 30 must be corrected for sample size. The Student—t distribution, which corrects for sample size, was applied to learn if there was a statistically significant difference between the holdover times generated at the two site locations, for each test set.

In tests such as these, where a small number of data points exist for each of two conditions and the objective is to determine whether there is a difference between the two, the common analytical approach is to apply a null hypothesis, which assumes that there is no difference between the two sets. This assumption enables the two databases for each test set to be combined, which produces a better estimate of the population standard deviation. The analysis then examines the data to statistically test the null hypothesis.

Before the t-test can be used in this way, the two sets of four HOTs must first be examined to see if their variances are sufficiently alike to justify the assumption that they each could be estimates of the same population variance. This examination of statistical variance uses the F-distribution.

If there is a significant difference in statistical variance, then those test sets cannot be combined. For those test sets, a different statistical approach using separate variances t-test is applied.

The F-test was applied to the HOTs for each test set in the following manner:

- Calculate F-value, which is the ratio of the statistical variance of the two sets of HOTs, with the highest in the numerator;
- Retrieve the appropriate F-value from an F-distribution table calculated for a 0.05 significance level. The tables are formatted by number of degrees of freedom for the numerator and denominator, with the highest number in the numerator. The number of degrees of freedom is the site test sample size minus 1 ($n_x - 1$);
- Compare the calculated F-value to the table F-value;
- If the calculated F-value is less than the table F-value, then one can assume that the variances of the two sets are not significantly different, and the data from the two sites can be combined for the t-test using the null hypothesis approach; and
- If the calculated F-value is greater than the table F-value, then the variances of the two sets are significantly different, and the data from the two sites cannot be combined for the t-test. These data sets are then analyzed using a separate variances t-test.

For ease of description, the following refers to tests comprised of four HOTs for each site. The actual analysis examined the real number of samples recorded.

The t-test for those test sets that passed the F-test was applied, as follows:

- Calculate standard deviation (SD) for each site; and
- Calculate a combined variance for the two sites and its square root for a combined SD. The combination is weighted by degrees of freedom:

$$\text{Combined Variance} = \frac{\left((n_1 - 1)SD_1^2 + (n_2 - 1)SD_2^2\right)}{(n_1 + n_2 - 2)}$$

where: SD = standard deviation
SD^2 = variance
n_1 = number of tests in test set from site 1

- Calculate t:

$$t = \frac{(\text{mean holdover time}_1 - \text{mean holdover time}_2)}{\left[\text{combined SD} * \text{sqrt}(1/n_1 + 1/n_2)\right]}$$

- Compare calculated t-value to t-table value for t at a significance level of 0.025, for 6 degrees of freedom ($n_1 + n_2 - 2$). This is a two-tailed test, thus the resulting level of significance is 0.05; and
- If the calculated t is less than the t-table value, then accept the hypothesis that there is no difference between the two tests.

The t-test for those test sets that failed the F-test was applied, as follows:

- Calculate t:

$$t = \frac{(\text{mean holdover time}_1 - \text{mean holdover time}_2)}{\text{sqrt}(\text{variance}_1/n_1 + \text{variance}_2/n_2)}$$

- Calculate degrees of freedom:

$$\text{D. F.} = \frac{\left(SD_1^2/n_1 + SD_2^2/n_2\right)^2}{\frac{\left(SD_1^2/n_1\right)^2}{(n_1 - 1)} + \frac{\left(SD_2^2/n_2\right)^2}{(n_2 - 1)}}$$

- Compare calculated t-value to t-table value for t at a significance level of 0.025, for the calculated number of degrees of freedom; and
- If the calculated t is less than the t-table value, then accept the hypothesis that there is no difference between the two tests.

The test sets were then sorted to separate those that the t-test indicated were from the same population, from those that were from different populations. For tests that were determined to be from the same population, we can consider that any difference between the two sites is a random event due to sampling, and can assume there is no real difference between sites.

For tests that were from different populations, the difference in mean holdover times was then calculated as a percentage of the lower of the two values. These values, as well as the absolute difference in holdover times, were then examined for significance from an operational perspective and for any dependency on distance between sites.

Secondary Analysis Methodology to Account for CARs Exemption

An exemption from Canadian Aviation Regulations (CARs) (1) pertaining to ground deicing operations has been granted to a Canadian carrier for the purpose of permitting operational use of HOTs generated by a HOTDS. This exemption is subject to a number of conditions, some of which affect the calculation of holdover times. Those conditions are:

a) Holdover times shall be calculated on the basis of measured precipitation rates, increased by certain tolerances:
   - From 0 to 10 g/dm²/h: + 3.0 g/dm²/h;
   - Above 10 to 25 g/dm²/h: + 6.0 g/dm²/h; and
   - Above 25 g/dm²/h: + 14.0 g/dm²/h.

b) The precipitation rate input for the purpose of computing fluid holdover times shall not be less than 2.0 g/dm²/h.

c) Holdover time determinations shall be inhibited in snow conditions exceeding 50 g/dm²/h.

d) Holdover time determinations in snow for Type II and IV de/anti-icing fluids shall be capped at 120 minutes.

A secondary analysis was conducted wherein the measured data was adjusted according to these conditions. The statistical analysis then proceeded as described for the base case.

This process caused a further number of test sets to be excluded from analysis when their actual precipitation rate was less than 2.0 g/dm²/h or their augmented precipitation rate value exceeded 50 g/dm²/h.

Findings and Applications

The findings and applications of the work completed for the HOT variance across an airfield task are presented in this section. They are presented as follows:

- Between-site Differences in HOT. This section provides a summary of the between-site differences in HOTs along with the operational significance of these differences. A secondary analysis was also completed that examines the between-site differences using the conditions that are stipulated in the CARs exemption;
- Examination of Site Separation Distance. This section examines the relationship of site separation distance and the extent of HOT differences due to these distances;
- Examination of Lake-effect Snowfall on HOT Differences. This section examines the impact of lake-effect snow;
- Comparison of HOTDS Results to Current Operational Practices. This section provides a comparison of the HOTDS results to example cases of information that pilots might derive from the use of current operational practices which use METAR reports or the FAA/TC visibility tables to estimate HOTs; and
- HOTDS Implementation Strategy and Timeline. This section describes possible implementation strategies.

Between-Site Differences in HOT

Based on the previously described data analysis methodology, potential differences in HOTs were determined for specific fluids from the consolidated data collected over the two test seasons.

This analysis was conducted to determine the effect that any real difference in precipitation rate between the two sites would have on fluid HOTs. The initial treatment of the data thus required calculation of precipitation rates, followed by calculation of fluid HOTs for a variety of fluids.

The calculated HOTs for each precipitation data point were examined statistically to determine which test sets had differences that could not be attributed to random effects and the extent of difference in HOTs generated for each of the two sites. The analysis produced a table of results for each fluid; as an example, the table for Octagon MaxFlo 100/0 is presented in Table 27.

This fluid provides a good example of the extent of difference in holdover times based on data collected at two separate sites. Similar charts for all fluids examined are included in Appendix C.

Columns 1 through 4 show the test set number, the distance between sites, the outside air temperature (OAT) at which the test was conducted, and the average precipitation rate in snow based on all rate measurements from both sites.

Columns 5 and 6 show the mean fluid HOTs for each site, calculated for Octagon MaxFlo at 100/0 strength; Column 7 shows the calculated difference between Columns 5 and 6; Column 8 is the percentage difference between Columns 5 and 6, based on the lower of the two values; and Columns 9 and 10 show the number and percentage of test sets grouped by various parameters for between-site differences. For this fluid, this grouping shows:

Table 27. Holdover time differences for Octagon MaxFlo 100/0 at two sites.

Set No.	Distance Between Sites (feet)	Temp (°C)	Avg. Rate Both Sites ($g/dm^2/h$)	Comparison of Endurance Times (min)			Difference as % of Lowest Site	Number of Tests in Specified Difference Range	
				Site 1	Site 2	Difference		#	%
Test sets concluded as coming from same population								95	39%
Test sets forced to equality by 120 minute rule								37	15%
Test sets where difference is <20%								69	29%
221	28500	-9	17.2	47.7	39.6	8.1	20.5%		
237	28500	-6	13.2	55.9	67.5	11.6	20.7%		
95	7933	0.4	16.3	103.7	85.6	18.0	21.1%		
312	27800	-10	6.0	113.8	93.9	19.8	21.1%		
248	8300	-3.3	15.9	67.9	55.5	12.4	22.3%		
65	4232	-3.2	11.0	93.1	76.1	17.0	22.4%		
254	8300	-4	5.0	98.0	120.0	22.0	22.4%		
233	28500	-6	10.0	70.0	86.6	16.6	23.7%		
276	8300	-5.6	7.1	96.0	118.8	22.8	23.7%		
304	27800	-10	12.3	50.5	62.6	12.2	24.1%		
235	28500	-6	10.9	65.1	80.9	15.8	24.3%		
258	8300	-4	9.3	103.2	82.6	20.6	25.0%		
231	28500	-8	5.9	120.0	95.6	24.4	25.6%	**difference range from 20 to <30%**	
275	8300	-6	8.0	83.7	105.6	21.8	26.1%		
306	27800	-10	10.4	72.9	57.8	15.2	26.2%		
293	27800	-10	13.7	57.7	45.3	12.3	27.2%		
218	28500	-10	23.7	36.2	28.4	7.8	27.4%		
203	28500	-14	7.9	83.4	65.4	18.0	27.5%		
242	8300	-3.3	14.4	75.8	59.0	16.8	28.5%		
299	27800	-10	14.1	44.3	56.9	12.7	28.6%		
251	8300	-3.3	8.4	93.1	120.0	26.9	28.9%		
294	27800	-10	10.6	72.3	56.0	16.3	29.0%		
210	28500	-12	13.2	56.6	43.8	12.8	29.2%		
241	28500	-6	7.5	114.3	88.3	25.9	29.4%		
228	28500	-8	11.6	72.4	55.8	16.5	29.6%	25	10%
300	27800	-10	12.3	64.6	49.7	14.9	**30.1%**		
201	28500	-14	7.2	68.4	89.1	20.7	**30.3%**		
230	28500	-8	7.0	85.2	111.6	26.4	**30.9%**		
290	27800	-10	9.2	82.7	63.0	19.7	**31.2%**		
107	7933	-3.9	24.4	35.8	47.0	11.3	**31.5%**	**difference range from 30 to <50%**	
30	4232	-4.8	8.8	107.7	80.1	27.5	**34.4%**		
317	27800	-10	8.1	68.6	94.4	25.7	**37.5%**		
246	8300	-3.3	22.9	53.0	38.5	14.5	**37.7%**		
229	28500	-8	9.6	62.8	90.2	27.4	**43.6%**	9	4%
308	27800	-10	9.0	60.7	91.7	31.0	**51.0%**		
240	28500	-6	7.8	120.0	77.0	43.0	**55.8%**		
259	8300	-5	6.3	76.8	120.0	43.2	**56.2%**		
226	28500	-9	7.4	72.2	117.3	45.0	**62.3%**	**difference range >50%**	
249	8300	-3	12.3	62.1	104.7	42.6	**68.7%**		
253	8300	-4	9.4	69.4	120.0	50.6	**72.9%**		
252	8300	-4	21.0	100.4	30.6	69.8	**227.8%**	7	3%
Total tests analyzed								242	

- 39% of 242 test sets had no significant difference in HOTs between sites;
- 15% of all test sets were forced to equality by the 120-minute rule;
- 29% had between-site holdover time differences less than 20%;
- 10% had between-site holdover time differences from 20 to 30%;
- 4% had between-site holdover time differences from 30 to 50%; and
- 3% had between-site holdover time differences greater than 50%.

Table 28. Assessment of operational significance (based on Octagon MaxFlo).

Range of Between-Site Differences as % of Lowest Site	Tests Within Range (%)	Average Between-Site Difference in HOT (min)	Average HOT Both Sites (min)
0 to 10	11%	3	50
10 to 20	18%	8	64
20 to 30	10%	17	83
30 and higher	7%	32	75

Operational Significance of Between-Site Differences in HOT

Of the 242 test sets analyzed for the Octagon MaxFlo 100/0, 46% showed real between-site differences in HOTs. The extent of the difference and its operational significance varied greatly among the data sets. To assess the likely impact on field operations, the absolute size of between-site differences was examined. Table 28 shows average values for between-site differences and HOT for selected ranges. This format shows the relationship between absolute HOT differences and the average value of HOT generated at both sites, and demonstrates an increase in HOT difference as the between-site differences grow larger.

For the range where the between-site differences are above zero but less than 10% of the lowest site, the average HOT difference was 3 minutes and the average HOT at both sites was 50 minutes. A difference of 3 minutes on a base of 50 minutes is not considered to be of large operational importance.

Similarly, for the next highest range, between 10 and 20%, the average HOT difference was 8 minutes and the average HOT at both sites was 64 minutes. Although larger than in the previous range, the difference of 8 minutes on a base of 64 minutes is still not judged to be of great operational importance.

For the range where the between-site differences lie between 20 and 30%, the average HOT difference was 17 minutes and the average HOT at both sites was 8 minutes. A difference of 17 minutes on a base of 83 minutes may have operational consequences.

For the last range, where the between-site differences are greater than 30%, the average HOT difference was 32 minutes and the average HOT at both sites was 75 minutes. A difference of 32 minutes on a base of 75 minutes has a definite operational effect.

It was concluded from this analysis that between-site differences in HOTs on the order of 20 to 30% are of potential operational interest, and between-site differences greater than 30% are of definite interest.

Summary of Differences—Base Case

The analysis described in the previous section was applied to each fluid in the manner shown for Octagon MaxFlo 100/0 in Table 28. The resulting tables are provided in Appendix C; Table 29 is a summary of the results for all fluids examined.

For all fluids examined, there was no statistical difference in the HOT times for the two sites for 39 to 40% of the data sets collected.

Holdover times for a number of data sets for thickened non-Newtonian fluids were constrained to 120 minutes, with the consequence that there was no difference in HOT be-

Table 29. Summary of between-site difference in fluid holdover time—base case.

		SAE Type I Fluid		Clariant MP IV 2012 100/0		Octagon MaxFlo 100/0		Kilfrost ABC-S 75/25		Kilfrost ABC-S 50/50	
No Statistical Difference		94	39%	95	39%	95	39%	95	39%	17	40%
Forced to Equality by 120 Minute Rule		0	0%	26	11%	37	15%	15	6%	1	2%
Test Sets where Dif. in Endurance Time as % of Lowest Site is:	**< 20 %**	110	45%	88	36%	69	29%	88	36%	12	29%
	20 to 30 %	13	5%	21	9%	25	10%	27	11%	4	10%
	30 to 50 %	14	6%	7	3%	9	4%	10	4%	2	5%
	> 50 %	11	5%	5	2%	7	3%	7	3%	6	14%
Total Test Sets Analyzed		242	100%	242	100%	242	100%	242	100%	42	100%

tween the two sites. Full strength fluids were affected by this rule 11 to 15% of the time.

Other than the 50/50 mix, all fluids showed between-site HOT differences greater than 20% of the lower site value, 14 to 18% of the time.

For thickened fluids at full strength and 75/25 mix, between-site HOT differences greater than 30% were expected 5 to 7% of the time and differences greater than 50% were expected 2 to 3% of the time.

For Type I fluid, between-site HOT differences greater than 30% were expected 11% of the time and differences greater than 50% were expected 5% of the time.

For the 50/50 fluid strength case, between-site HOT differences were larger than for the other fluids, with HOT differences greater than 20% about 29% of the time, greater than 30% about 19% of the time, and greater than 50% about 14% of the time.

Summary of Differences—CAR Exemption Case

A secondary analysis was conducted wherein the measured data were adjusted according to the conditions described for the CARs exemption case. The statistical analysis proceeded as described above for the base case.

Table 30 summarizes the differences using the CARs exemption conditions. The total number of tests analyzed is lower than for the base case due to the exclusion of test sets when their actual precipitation rate was less than 2.0 g/dm^2/h or when their augmented precipitation rate value exceeded 50 g/dm^2/h.

Fewer test sets are affected by the 120-minute capping rule as a consequence of the higher augmented precipitation rates and shorter HOT values.

In comparison to the base case, there is a decrease in the frequency of differences in the range from 20 to 30% and an increase in the range from 30 to <50%. A major reason for these changes is the stepped augmentation of measured rates in accordance with the CARs exemption. In the case of the Octagon fluid, of the 18 data set pairs falling in the 30 to <50% difference range, 10 experienced a differential in augmentation, where the measured rates of one site were slightly below 10 g/dm^2/h and thus were augmented by 6 g/dm^2/h, while the rates of the other site were over 10 g/dm^2/h and thus were augmented by 14 g/dm^2/h.

Examination of Site Separation Distance

To examine the relationship of distance between test sites and size of between-site HOT differences, data sets were sorted by distance for the base case only. The tests were grouped into three distance ranges that each offered a reasonably large and similar number of tests. The distance range limits are shown in Table 31.

The results for all data are shown in Table 31, and provide the following findings:

- At the shortest distance range for all fluids, there was only one case of between-site differences greater than 30%;
- For the Type I fluid base case, the frequency of tests generating a percentage difference greater than 20% increased from:
  - 4% at the shortest distance; to
  - 25% at mid-range distance; and
  - 15% at the longest distance.
- For the Clariant 2012 100/0 base case, the frequency of tests generating a percentage difference greater than 20% increased from:
  - 1% at the shortest distance; to
  - 14% at mid-range distance; and
  - 21% at the longest distance.

Table 30. Summary of between-site difference in fluid holdover time—CAR exemption case.

		SAE Type I Fluid		Clariant MP IV 2012 100/0		Octagon MaxFlo 100/0		Kilfrost ABC-S 75/25		Kilfrost ABC-S 50/50	
No Statistical Difference		69	36%	69	36%	69	36%	69	36%	9	31%
Forced to Equality by 120 Minute Rule		0	0%	10	5%	11	6%	0	0%	0	0%
Test Sets where Dif. in Endurance Time as % of Lowest Site is:	**< 20%**	94	49%	81	42%	73	38%	82	43%	11	38%
	20 to 30%	19	10%	15	8%	13	7%	18	9%	2	7%
	30 to 50%	7	4%	13	7%	18	9%	17	9%	5	17%
	> 50%	2	1%	3	2%	7	4%	5	3%	2	7%
Total Test Sets Analyzed		191	100%	191	100%	191	100%	191	100%	29	100%

Table 31. Relationship of between-site differences and distance—all data 2007 to 2008.

Type I Holdover Times in Snow - Measured Rates

Distance Range (ft)		Number of tests where difference between sites is				
		<20%	20% to 29.9 %	30% to 49.9 %	> 50%	Total
4167	5052	64	3			67
		96%	4%			100%
7017	13390	62	4	8	8	82
		76%	5%	10%	10%	100%
27800	28500	78	6	6	3	93
		84%	6%	6%	3%	100%
Total tests analyzed		204	13	14	11	242
		84%	5%	6%	5%	100%

Clariant 2012 100/0 Holdover Times in Snow - Measured Rates

Distance Range (ft)		Number of tests where difference between sites is				
		<20%	20% to 29.9 %	30% to 49.9 %	> 50%	Total
4167	5052	66	1			67
		99%	1%			100%
7017	13390	70	6	1	5	82
		85%	7%	1%	6%	100%
27800	28500	73	14	6		93
		78%	15%	6%		100%
Total Tests Analyzed		209	21	7	5	242
		86%	9%	3%	2%	100%

Octagon Maxflo 100/0 Holdover Times in Snow - Measured Rates

Distance Range (ft)		Number of tests where difference between sites is				
		<20%	20% to 29.9 %	30% to 49.9 %	> 50%	Total
4167	5052	65	1	1		67
		97%	1%	1%		100%
7017	13390	68	8	2	4	82
		83%	10%	2%	5%	100%
27800	28500	68	16	6	3	93
		73%	17%	6%	3%	100%
Total Tests Analyzed		201	25	9	7	242
		83%	10%	4%	3%	100%

ABC-S 75/25 Holdover Times in Snow - Measured Rates

Distance Range (ft)		Number of tests where difference between sites is				
		<20%	20% to 29.9 %	30% to 49.9 %	> 50%	Total
4167	5052	66	1			67
			1%			100%
7017	13390	65	9	3	5	82
			11%	4%	6%	100%
27800	28500	67	17	7	2	93
		72%	18%	8%	2%	100%
Total Tests Analyzed		198	27	10	7	242
		82%	11%	4%	3%	100%

ABC-S 50/50 Holdover Times in Snow - Measured Rates

Distance Range (ft)		Number of tests where difference between sites is				
		<20%	20% to 29.9 %	30% to 49.9 %	> 50%	Total
4167	5052	12				12
		100%				100%
7017	13390	8	3	0	2	13
		62%	23%	0%	15%	100%
27800	28500	10	1	2	4	17
		59%	6%	12%	24%	100%
Total Tests Analyzed		30	4	2	6	42
		71%	10%	5%	14%	100%

- For the Octagon MaxFlo 100/0 base case, the frequency of tests generating a percentage difference greater than 20% increased from:
  - 2% at the shortest distance; to
  - 17% at mid-range distance; and
  - 26% at the longest distance.
- For the ABC-S 75/25 base case, the frequency of tests generating a percentage difference greater than 20% increased from:
  - 1% at the shortest distance; to
  - 21% at mid-range distance; and
  - 28% at the longest distance.
- For the ABC-S 50/50 base case, the frequency of tests generating a percentage difference greater than 20% increased from:
  - 0% at the shortest distance; to
  - 38% at mid-range distance; and
  - 42% at the longest distance.

The mid-range distance showed a higher frequency of cases having between-site differences greater than 50%.

This examination shows that a relationship does exist between site-separation distance and size of between-site holdover time differences.

Examination of Lake-Effect Snowfall on HOT Differences

The impact of lake-effect snowfall was examined by looking at the lake-effect snowfall data in isolation and comparing it to other data collected within the same site-separation range.

The lake-effect data was collected at a between-site distance of 8,300 ft, placing it in the mid-range for distance analysis. To examine its influence on HOT at the two sites, the lake-effect data was compared to the other data collected at the mid-range distance. The results are given in Table 32. Because the lake-effect data was collected at an OAT lower than −3°C (26.6°F), fluid ABC-S at the 50/50 strength is not included in the analysis.

The table shows that the frequency of cases where the between-site difference in HOT is 20% or more of the lower site value is substantially greater for the lake-effect data. Much of the increase shows up in the above 50% difference category.

Relationship Between Site-Separation-Distance and Between-Site HOT Differences Excluding Lake-Effect Data

Syracuse Hancock International Airport was selected for tests as it offered an opportunity to study lake-effect snowfall. Precipitation rates were recorded during one event, on January 8, 2009.

The lake-effect snowfall data was included in the previous analysis of between-site HOT differences versus distance separation between sites. Because this data occurred only in the mid-range distance, it would distort the true relationship of between-site HOT differences versus distance. The base case data was re-examined with the lake-effect snowfall data removed. The results of the analysis with the lake-effect snowfall data removed are given in Table 33.

Removal of the lake-effect data produces a smoother relationship of HOT difference to distance, removing the bulge at the mid-range distance seen in the previous analysis (Table 31). The final results by fluid type are:

- For the Type I fluid base case, the frequency of tests generating a percentage difference greater than 20% increased from:
  - 4% at the shortest distance to
  - 12% at mid-range distance and
  - 15% at the longest distance.

Table 32. Effect of lake-effect snowfall on between-site HOT differences (2007–2008).

Fluid Type	Distance Range 7017 to 13390 ft	Number of Tests where Difference Between Sites is # (%)				
		<20%	20 to 29.9%	30 to 49.9%	>50%	Total
Type I HOTs in Snow	no lake-effect	44 (88%)	2 (4%)	4 (8%)	0 (0%)	50 (100%)
	lake-effect	18 (56%)	2 (6%)	4 (13%)	8 (25%)	32 (100%)
Clariant 2012 100/0 HOTs in Snow	no lake-effect	45 (90%	3 (6%)	1 (2%)	1 (2%)	50 (100%)
	lake-effect	25 (78%)	3 (9%)	0 (0%)	4 (13%)	32 (100%)
Octagon MaxFlo 100/0 HOTs in Snow	no lake-effect	44 (88%)	3 (6%)	2 (4%)	1 (2%)	50 (100%)
	lake-effect	24 (75%)	5 (16%)	0 (0%)	3 (9%)	32 (100%)
ABC-S 75/25 HOTs in Snow	no lake-effect	43 (86%)	4 (8%)	2 (4%)	1 (2%)	50 (100%)
	lake-effect	22 (69%)	5 (16%)	1 (3%)	4 (13%)	32 (100%)

Table 33. Relationship of between-site differences and distance (excluding lake-effect data 2007–2009).

Type I Holdover Times in Snow - Measured Rates
(without lake-effect data)

Distance Range (ft)		Number of tests where difference between sites is				
		<20%	20% to 29.9%	30% to 49.9 %	> 50%	Total
4167	5052	64	3			67
		96%	4%			100%
7017	13390	44	2	4		50
		88%	4%	8%	0%	100%
27800	28500	78	6	6	3	93
		84%	6%	6%	3%	100%
Total tests analyzed		186	11	10	3	210
		89%	5%	5%	1%	100%

Clariant 2012 100/0 Holdover Times in Snow - Measured Rates
(without lake-effect data)

Distance Range (ft)		Number of tests where difference between sites is				
		<20%	20% to 29.9%	30% to 49.9%	> 50%	Total
4167	5052	66	1			67
		99%	1%			100%
7017	13390	45	3	1	1	50
		90%	6%	2%	2%	100%
27800	28500	73	14	6		93
		78%	15%	6%		100%
Total tests analyzed		184	18	7	1	210
		88%	9%	3%	0%	100%

Octagon MaxFlo 100/0 Holdover Times in Snow - Measured Rates
(without lake-effect data)

Distance Range (ft)		Number of tests where difference between sites is				
		<20%	20% to 29.9 %	30% to 49.9 %	> 50%	Total
4167	5052	65	1	1		67
		97%	1%	1%		100%
7017	13390	44	3	2	1	50
		88%	6%	4%	2%	100%
27800	28500	68	16	6	3	93
		73%	17%	6%	3%	100%
Total tests analyzed		177	20	9	4	210
		84%	10%	4%	2%	100%

ABC-S 75/25 Holdover Times in Snow - Measured Rates
(without lake-effect data)

Distance Range (ft)		Number of tests where difference between sites is				
		<20%	20% to 29.9%	30% to 49.9%	> 50%	Total
4167	5052	66	1			67
		99%	1%			100%
7017	13390	43	4	2	1	50
		86%	8%	4%	2%	100%
27800	28500	67	17	7	2	93
		72%	18%	8%	2%	100%
Total tests analyzed		176	22	9	3	210
		84%	10%	4%	1%	100%

ABC-S 50/50 Holdover Times in Snow - Measured Rates
(no lake-effect data due temp restriction for 50/50)

Distance Range (ft)		Number of tests where difference between sites is				
		<20%	20% to 29.9 %	30% to 49.9 %	> 50%	Total
4167	5052	12				12
		100%				100%
7017	13390	8	3	0	2	13
		62%	23%	0%	15%	100%
27800	28500	10	1	2	4	17
		59%	6%	12%	24%	100%
Total tests analyzed		30	4	2	6	42
		71%	10%	5%	14%	100%

- For the Clariant 2012 100/0 base case, the frequency of tests generating a percentage difference greater than 20% increased from:
  - 1% at the shortest distance to
  - 10% at mid-range distance and
  - 21% at the longest distance.
- For the Octagon MaxFlo 100/0 base case, the frequency of tests generating a percentage difference greater than 20% increased from:
  - 2% at the shortest distance to
  - 12% at mid-range distance and
  - 26% at the longest distance.

- For the ABC-S 75/25 base case, the frequency of tests generating a percentage difference greater than 20% increased from:
  - 1% at the shortest distance to
  - 14% at mid-range distance and
  - 28% at the longest distance.
- For the ABC-S 50/50 base case, the frequency of tests generating a percentage difference greater than 20% increased from:
  - 0% at the shortest distance to
  - 38% at mid-range distance and
  - 42% at the longest distance.

Comparison of HOTDS Results to Current Operational Practices

A brief comparison was made of HOT guideline times that were in effect during the testing versus HOT times as generated by HOTDS systems using the precipitation measurements at the two test sites. This analysis is based on the "base case" and does not consider the CARs exemption criteria.

The values that could have been in use by pilots were constructed from the current HOT guidelines, existing weather information (METAR reports), and the visibility chart that is used to convert visibility to snowfall rate.

METAR is a routine aviation weather report that typically comes from airports or permanent weather observation stations. Reports are generated once an hour. If conditions change significantly, they can be updated in special reports. A typical METAR report contains data for the temperature, dew point, wind speed and direction, precipitation, cloud cover and heights, visibility, and barometric pressure. A METAR report may also contain other information including precipitation amounts.

To establish the HOT values that could have been in effect, actual METAR reports in effect during selected tests were retrieved from archives. The METAR report gives the pilot two alternative ways to establish a value for snow intensity, which is then used to extract holdover time from the HOT guidelines:

a) Using information on METAR visibility and time of day (daylight or darkness), the snowfall intensity can be read from a visibility chart that is part of the HOT guidance material. That snowfall intensity and temperature can then be used to select the appropriate cell in the HOT table; and
b) The METAR report also gives a direct indication of snowfall intensity (light, moderate, or heavy). This indicated snowfall intensity, along with temperature, can be used by the pilot to select the appropriate cell in the HOT table.

In addition, in an actual operation, the pilot has the option of visually estimating visibility distance (based on runway markers or local landmarks) and converting that value to snow intensity using the visibility table. This approach was not available for this comparison.

Comparison of Snow Intensity Indicated by METAR Reports and Test Data

To examine the differences in snow intensity from the different sources, Table 34 was developed for four selected tests. The column headings show the source for the indicated snow intensity.

Test 95 offers a good illustration of the variance in METAR-indicated intensity that pilots have to deal with in actual operations, with one indication being heavy and the other one light, whereas the actual measured intensity was moderate.

Test 97 also shows a significant variance in METAR-indicated intensity, with one indication being heavy and the other one light, whereas the measured intensity was light and very light.

Comparison of HOT Values Based on METAR and Test Data

The snow intensity indications shown in Table 34 were then used to construct Table 35 with holdover times.

Table 34. Comparison of snow intensity from different pilot aids.

Test #	Time Interval	Daylight/ Darkness	Visibility (Statute Miles)	OAT (°C)	Snow Intensity		HOTDS	
					METAR Visibility Report and Visibility Chart	METAR Snow Intensity Report	Site 1 Measured Snow Intensity ($g/dm^2/h$)	Site 2 Measured Snow Intensity ($g/dm^2/h$)
95	00:10 - 00:20	Darkness	3/4	0	Heavy	Light	14.5	18.1
107	15:10 - 15:20	Daylight	1/2	-4	Moderate	Moderate	28.3	20.5
97	00:50 - 01:00	Darkness	1/2	0	Heavy	Light	6	3.6
123	22:40 - 22:50	Darkness	3	-8	Light	Light	5.8	3.6

Table 35. Comparison of HOT generated from different pilot aids.

Test #	Daylight/ Darkness	Visibility (Statute Miles)	OAT (°C)	Fluid Analyzed	METAR Visibility Report and Snow Visibility Chart	METAR Snow Intensity Report	HOTDS	
							Site 1 HOT (min)	Site 2 HOT (min)
95	Darkness	3/4	0	Octagon MaxFlo 100/0	no HOT	40 - 90	86	104
107	Daylight	1/2	-4		25 - 60	25 - 60	36	47
97	Darkness	1/2	0	ABC-S 75/25	no HOT	30 - 55	93	120
123	Darkness	3	-8		25 - 50	25 - 50	79	112

The differences in snow intensity derived from the various sources have a large impact on holdover guidelines:

- The maximum snow intensity covered in the HOT table is moderate, thus for any snow intensity indications of heavy, there is no HOT value available to the pilot.
- Similarly, in cases where the METAR report leads to an indication of light snow, the HOT table for Types II and IV fluid will provide a HOT time based on moderate snow. This HOT time will usually be notably shorter than is really necessary for light snow.
- In Test 95, where the METAR reported the intensity of snow as light, the corresponding HOT table provides a range of holdover time from 40 to 90 minutes, based on moderate snow. The interpretation of this range can lead to further shortening of holdover times. The Transport Canada Holdover Time Guidelines caution as follows: "The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell." Thus, in Test 95, the applicable holdover time based on METAR would be 40 minutes.
- For the two test sites, the HOT values shown are based on the actual test data. In the case of Test 95, the HOT values are 104 and 86 minutes, much longer than that based on the METAR report.
- The same observations apply to the other tests selected for comparison. In all cases, the shortest HOT of the two test sites is longer than the applicable HOT derived from METAR sources.
- The range in HOT determined by METAR snow intensity (e.g., for Test 95, 90-40= 50 min) compared to the variance in HOT (e.g., for Test 95, 104-86= 18 min) from the two test sites is shown in Table 36.

HOTDS Implementation Strategy and Timeline

The examination of HOT generated from METAR indications showed that there is a genuine possibility that very different values can result from the two alternative ways of applying METAR forecasts.

The use of METAR indications to generate HOT has some inherent shortcomings:

- An important one is its frequency of issue, generally on an hourly basis;
- The HOT values generated from METAR indications have airport-wide application, regardless of airport size;
- The precipitation rate reported in METARs (as light, moderate, or heavy) is not correlated with the liquid water equivalent (LWE) used during fluid testing to establish HOT guidelines; and
- Pilots must use subjective judgment when using METAR indications or when using personally estimated visibility distance in conjunction with HOT Guidelines to establish a HOT value.

Table 36. Range in HOTS.

Fluid Analyzed	Test #	Range in HOTS (minutes)	
		From METAR	From Test Data
Octagon MaxFlo 100/0	95	50	18
Octagon MaxFlo 100/0	107	35	11
ABC-S 75/25	97	25	27
ABC-S 75/25	123	25	33

The availability of accurate information on rate of precipitation, along with true indications of temperature and precipitation type, is the key to the generation of reliable HOT values. The current use of METAR indications and subjective assessments of weather conditions does not take full advantage of the accuracy and consistency provided by the scientific approach used to generate HOT Guidelines.

In contrast, the HOTDS measures actual precipitation (LWE). These data are used along with temperature, precipitation type, and the regression curves and coefficients generated during the fluid endurance testing, to generate HOT values. Subjectivity is removed and the complete process is scientifically based. In addition, HOT values can be updated every 10 minutes.

Implementation of a single HOTDS system at any airport, regardless of size, may potentially produce HOT values superior to those now generated through the use of METAR indications.

Conclusions and Recommendations

This task of ACRP Project 10-01 was conducted to determine if a single location precipitation sensor can reliably report precipitation intensity for an entire airport. The conclusions and recommendations resulting from this task are presented in this section.

Conclusions

Test Methodology

The approach to collecting test data was effective, and the data provided a suitable base for comparing HOTs generated from two separate test sites at an airport. The test methodology developed and applied in the collection of data proved satisfactory. The repeatability of precipitation rates measured amongst the four samples collected at each site proved to be better than for rate collection during fluid endurance time tests.

Two sets of analysis were conducted. One was based on the data as collected (base case) and the second was based on the precipitation rate data adjusted by the CAR exemption conditions. In each case, HOTs were calculated for a selection of currently active fluids at specific strengths.

Operational Significance of Between-Site Differences

The extent of the between-site difference in HOT and its level of impact on the operation varied greatly. Examination of the absolute size of between-site differences led to the conclusion that between-site differences in holdover times on the order of 20 to 30% are of potential operational interest, and between-site differences greater than 30% are operationally significant.

Base Case Examination of Between-Site Differences

For all fluids examined, there was no statistical difference in HOTs for the two sites in about 40% of the data sets collected.

For all fluids examined, there was no statistical difference in HOT values in approximately 40% of the data sets collected. Between-site differences in HOT values varied by fluid type and fluid strength:

- For thickened fluids at full strength and in a 75/25 mix, between-site HOT differences greater than 30% were seen 5 to 7% of the time and differences greater than 50% were seen 2 to 3% of the time.
- For Type I fluid, between-site HOT differences greater than 30% were seen 11% of the time and differences greater than 50% were seen 5% of the time.
- For the 50/50 fluid strength case, between-site HOT differences were larger than for the other fluids, with HOT differences greater than 20% about 29% of the time, greater than 30% about 19% of the time, and greater than 50% about 14% of the time.

CAR Exemption Case Examination of Between-Site Differences

In comparison to the base case, there was a decrease in the frequency of between-site differences in the range of 20 to 30% and an increase in the range of 30 to 50% when looking at HOTs using the CARs exemption conditions.

A major reason for this shift was the stepped augmentation of measured rates in accordance with the CARs exemption. In the case of the Octagon fluid, for example, of the 18 data set pairs falling in the 30 to less than 50% difference range, 10 experienced a differential in augmentation, where the measured rates of one site were slightly below 10 $g/dm^2/h$ and thus were augmented by 6 $g/dm^2/h$, while the rates of the other site were over 10 $g/dm^2/h$ and thus were augmented by 14 $g/dm^2/h$.

Examination of Site Separation Distance

Sorting the base case data into three separation-distance ranges showed a distinct relationship between site distance and HOT difference. The longest separation distances showed a considerably higher frequency of occurrence of large between-site differences in HOT.

The frequency of tests generating a between-site difference greater than 20% varied by shortest distance separation, midrange, and longest distance as shown in Table 37 (note that lake-effect data has been removed).

Table 37. Frequency of tests generating between-site differences > 20%.

Fluid	Frequency (%) at Separation Distance		
	Shortest (4,167-5,052 ft)	Mid-Range (7,017-13,390 ft)	Longest (27,800-28,500 ft)
Type I	4	12	15
Clariant 2012 100/0	1	10	21
Octagon MaxFlo 100/0	2	12	26
Kilfrost ABC-S 75/25	1	14	28
Kilfrost ABC-S 50/50	0	38	42

Examination of Lake-Effect Snowfall on HOT Differences

The lake-effect data, collected at a between-site distance of 8,300 ft, was compared to the other data collected at the mid-range distance. The frequency of cases where the between-site difference in HOT was 30% or more of the lower site value was substantially greater for the lake-effect data. Much of the increase showed up in the > 50% difference category.

Comparison of HOTDS Results to Current Operational Practices

There is considerable variance in the snow intensity derived from METAR sources and test data.

The METAR report gives the pilot two alternative ways to establish a value for snow intensity. METAR reports retrieved for selected periods of testing gave conflicting intensities for the two alternatives, such as heavy and light snow. In some cases, the corresponding intensity from collected data was moderate.

The variability in snow intensity indications leads to large differences in HOT. In some cases, the METAR visibility and snow visibility charts led to no HOT availability, while the test data produced operationally valuable holdover times. The lower HOT from the two test sites generally was longer than the HOT value derived from either alternative using METAR reports.

These results suggest that a single HOTDS installation may be able to produce HOT values superior to those now generated through the use of METAR indications, despite the variance in precipitation over the airfield.

General Conclusion

In general, differences in between-site HOTs for snow can be significant to the operation, and they are a function of distance. The extent of the differences can be worsened by lake-effect snowfall.

Differences in HOT generated from different sites begin to impact the operation when the sites are separated by mid-range distances (7,017 to 13,390 ft), and have a definite impact at long separation distances (27,800 to 28,500 ft).

The finding of variances in precipitation rate and HOT over a large airport should not be a consideration or obstacle to further development of the HOTDS over the short term.

Recommendations

In the short term, the finding of variances in precipitation rate and HOT over a large airport should not be a consideration or obstacle to further development of the HOTDS. This condition should be considered only in the further development and application of the HOTDS systems for large airports where the taxi distance from deicing locations to the assigned departure runway can be very long. Smaller airports with shorter taxi distances in the order of 5,000 ft are not affected. A possible solution may be to compare the accuracy in HOTs generated from current processes to HOTs generated from a single HOTDS installation at a large airport. If the single installation HOTDS is more accurate than the current processes, then the single installation HOTDS may be deemed adequate.

In the longer term, a study should be conducted to compare the accuracy in HOT generated from a single HOTDS installation at a large airport to the accuracy associated with HOT values generated from current processes using METAR indications and pilot assessments. Two approaches may be considered:

1. Install more than one HOTDS system, with the actual number being dependent on each airport's layout and geography. This approach ultimately leads to questions as to where and how many systems need to be installed, and subsequently how the different indications should be interpreted:

- Should the average of all sites be used?
- Should only the value from the installed site nearest the entrance to the departure runway be used?
- Should the lowest HOT value be used?

2. Develop a correction factor-of-safety rule to be applied to indications generated from a single airport system. It may be necessary to develop an appropriate correction factor for each individual airport to address its unique size, runway layout, and type of winter precipitation expected. A guideline to gathering and collecting information necessary for the development of a local correction rule for a single HOTDS system would be required. Additional data on the relationship between separation distances and rate of winter precipitation of all types, and on lake-effect snowfall, would be needed.

References

1. Exemption from Subsection 602.11(4) of the *Canadian Aviation Regulations* and Sections 1.0, 3.0, 6.0, 6.2, 6.3 and 7.1.1.1 of Standard 622.11 *Ground Icing Operations*.
2. Bendickson, S., *Regression Coefficients Used To Develop Aircraft Ground Deicing Holdover Time Tables: Winter 2007–08,* APS Aviation Inc., Transportation Development Centre, Montreal, December 2007, TP14782E.

CHAPTER 4

Increased Use of Spot Deicing for Aircraft Frost Removal

Introduction

Deicing for Frost Removal

Frost occurs when aircraft surfaces cool below 0°C (32°F) due to radiation effects, and water vapor in the air sublimates on the aircraft surfaces. Aircraft frost deicing (defrosting) with deicing fluids generally consists of a one-step deicing approach. Defrosting is usually performed using a heated mixture of deicing fluid sprayed in a sweeping motion using a fan shaped nozzle spray pattern. Holdover times are not required if the frost is not active.

Frost conditions typically affect aircraft that are parked outside overnight. Thus, frost deicing activities are a concentrated effort to deice aircraft prior to their first departure of the day. A survey conducted in 2004 indicated approximately one third of all aircraft de/anti-icing activities worldwide occur in frost conditions (see Figure 16).

In recent years, air carriers have begun to examine different ways for deicing aircraft in frost conditions, as morning deicing events can be very disruptive to operations. At airports with centralized deicing facilities, the aircraft first pushes back from the gate, taxies to the designated deicing pad or facility, is defrosted, and then taxies to the runway threshold for takeoff.

Spot Deicing for Frost Removal

The term "Spot Deicing for Frost Removal" is defined as the use of deicing fluids to treat small affected aircraft wing upper surfaces areas (patches of frost that are typically ≤ 20% of wing upper surface area) to remove (non-active) frost that may have formed during a ground overnight stay. The entire wing is not treated; however, both wings are treated symmetrically, regardless if they both require defrosting. If any frost is observed on the leading edge of the wings, it must be removed. Depending on ambient temperature and precipitation conditions, the wing may not require anti-icing. If the wing is not anti-iced, then holdover times do not apply.

The primary benefit of using spot deicing is a reduction in the amount of glycol used to achieve aerodynamically clean aircraft wings prior to takeoff, compared to the amount used in treating an entire upper wing surface. Reduced glycol consumption leads to lower fluid purchasing costs, lower fluid recovery costs, and reduced environmental impact.

Another benefit of spot deicing is a significant reduction in defrosting time (to as short as 10 minutes, depending on aircraft size, extent of frost coverage and ambient conditions). This reduced time leads to greater efficiencies in the use of deicing and other airport facilities. At remote deicing facilities, where aircraft are deiced with engines running, reduced engine run-time lowers fuel burn and its related carbon emissions, and lowers aircraft operating costs.

Several other relevant features of spot deicing for frost removal are:

- Additional operator and flight crew training is required to implement this procedure;
- Adoption of this procedure requires closer checking and inspections by qualified personnel; and
- Conventional ground deicing equipment, suitable for normal defrosting usage, can be used to perform spot deicing for frost removal.

Objective

The objective of this task was to gain a better understanding of the current practices employed for spot deicing for frost removal, quantify its potential benefits, and provide tools for decision makers to determine whether this procedure is suitable for their operation.

The objective was met by completing the following activities:

- Conducting a literature review of current government and industry regulations, guidance material, and standards to

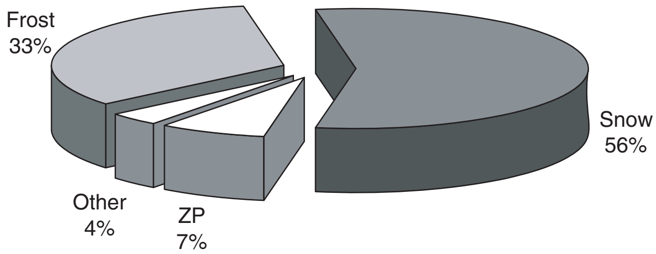

Figure 16. Worldwide deicing operations in various precipitation conditions.

document industry regulations and practices related to spot deicing for frost removal;

- Conducting phone interviews with deicing service providers and airlines;
- Developing a survey to gather pertinent information from a wider audience, including airlines, deicing service providers, deicing consultants, deicing instruction facilities, and regulators;
- Designing and conducting tests to examine appropriate fluid strength, temperature and quantities for spot frost deicing applications;
- Identifying if changes to any industry standards, recommended practices, or both are required and supporting the changes and/or development of guidance material as necessary;
- Developing a cost-benefit model;
- Developing presentation aids to influence and aid decision makers; and
- Preparing a technical report to document the work completed for this task.

Research Approach and Methodologies

This section presents the research approach and methodologies employed to examine the current practices and regulations, opportunities, limitations, obstacles, and potential benefits associated with the usage of spot deicing for aircraft frost removal. Four activities were conducted, and they are addressed herein as follows:

- Literature review;
- Laboratory tests;
- Focus group survey; and
- Cost-benefit model.

Examination of Current Government and Industry Regulations, Guidance Materials, and Standards

A review of current government and industry regulations, guidance material, and standards related to spot deicing for frost removal was conducted to determine the need for changes or further approvals to accommodate the use of this procedure.

The primary literature and documents that were reviewed and found pertinent to the use of spot deicing are listed below (a complete list of documents is contained in Appendix A):

- Society of Automotive Engineers (SAE) guidelines in Aerospace Recommended Practice (ARP) 4737 and ARP 5149 that address procedures for spot deicing for frost removal;
- Holdover time guidance material and documentation published annually by Transport Canada and the FAA; and
- Association of European Airlines (AEA) Recommendations for De/Anti-Icing of Aircraft on the Ground.

Laboratory Tests

Laboratory tests were conducted to collect data to support the development of guidance material for spot deicing of frost, specifically to provide procedural guidance on fluid strength, fluid temperature at application, and fluid amounts.

Background

Frost can form in local areas on the wing surface by two different mechanisms.

The first is the ordinary type of frost that results from radiation cooling of the wing surface under a clear night sky. Not all areas on the wing surface cool to the same extent. For example, control panels may cool to a lower temperature than the main wing due to their different construction and skin thickness. If they cool sufficiently, frost may form on these local colder areas while the main wing remains frost-free. As morning approaches, frost generation may cease, however the affected areas remain frost covered. This is considered to be non-active frost.

A second type of local frost condition is related to cold-soaked wings. Wing surface temperatures can be considerably below ambient due to contact with cold fuel and/or close proximity to large masses of cold-soaked metal in the wing structure. In these areas, frost can build up. If localized frost patches still exist at the departure time of the subsequent flight, the operator may assume that it is no longer active, and treat it as ordinary frost. However, if the fuel is still cold, as might be the case for short aircraft ground-times, then frost generation could still be active.

In the spot deicing procedure under examination, a heated deicing fluid would be applied only to the frosted areas, sometimes prior to departure. The equipment used for applying fluid could vary from portable sprayers, to fluid impregnated mops, to standard deicing vehicles. Accordingly, the fluid quantity and temperature could vary widely. As well, the interval from time of fluid application to flight departure could vary considerably.

Although spot deicing for frost is generally considered to apply only to non-active frost conditions, its feasibility for active frost conditions is also of interest. If its application in active frost conditions is deficient, then field operators must be cautioned that an unsafe condition may result from such use.

Because of this concern, test procedures were developed to examine spot deicing during both non-active and active frost conditions.

Objective

The laboratory tests were conducted to collect data to support the development of guidance material for spot deicing of frost. The following work elements were planned:

- Examine whether fluid mixed to 18°F (10°C) fluid freeze point buffer is adequate or whether full strength fluid is required to protect wing surfaces that are colder than outside air temperature (OAT);
- Determine the fluid temperature at which fluid should be applied;
- Determine strength of fluid required at different temperatures, especially at cold OATs; and
- Gather data on amounts of fluid required for spot deicing applications.

Methodology

Initial work to prepare for frost testing in natural frost conditions was begun in March 2008. The limited outdoor tests conducted proved inconclusive due to insufficient frost accumulation occurring at the end of the 2007–08 winter.

Alternate plans were subsequently made to conduct laboratory tests indoors with frost generated artificially on test plate surfaces. Tests were conducted at the National Research Council (NRC) Climatic Engineering Facility in Ottawa, Canada, from July 7 to July 10, 2008. In an effort to minimize the financial impact of indoor testing, the tests were conducted at the same time as tests that were being conducted in the facility for a TC project. The advantage of the "pigging-backing" of projects was that the costs for the test facility were shared; the disadvantage was that the conditions available in the climatic chamber were not always optimal.

A complete description of the laboratory test procedure is provided in Appendix B. This procedure is based on the natural frost test procedure and includes the modifications required for indoor laboratory testing. A short description of the procedure is provided in the following subsections.

General Methodology for Simulating Non-Active/Active Frost. A procedure to develop frost in laboratory conditions was developed prior to testing. This procedure involved filling aluminum boxes with Type I fluid that had been cooled to a temperature approximately 18°F (10°C) lower than ambient temperature. Because the surface of the box was colder than ambient temperature, frost readily formed.

The aluminum boxes employed were the same wing-leading-edge thermal equivalent boxes used for measuring heated Type I fluid endurance times in natural snow and for measuring Type I/II/III/IV fluid endurance times in simulated rain on cold soaked wing. The box upper surface consists of an aluminum plate of the same dimensions (20 in. × 12 in.) as a standard fluid endurance test plate. For testing, the boxes were placed on a test stand, at a 10° slope (Figure 17).

To simulate non-active frost conditions, the filled box was exposed to the laboratory environment for one hour, then emptied of its cold fluid content, and kept open to bring the temperature of the air in the box close to ambient temperature. The box top-surface temperature thus warmed to match that of the test chamber, and frost stopped accumulating. Simulated non-active frost testing followed.

To simulate active frost, the filled box was exposed to the laboratory environment for one hour. Testing began immediately with the box remaining filled as shown in Figure 18. The ongoing temperature differential between box surface and ambient continued to generate frost throughout the test. This test simulated the particular condition where frost is generated by cold-soaked wings, as opposed to the condition where frost is generated by radiative cooling of wing surfaces.

The amount of frost that had accumulated on the test surface at the beginning of the test was determined from a parallel set of boxes, which were treated in the same manner as the test surfaces. The frost on the parallel boxes was scraped off, collected and weighed as shown in Figure 19.

Test Surfaces, Fluids, and Application Techniques. Tests were conducted on test surfaces that were subjected to both

Figure 17. Set-up for leading edge thermal equivalent boxes on test stands at NRC climatic engineering facility.

Figure 18. Active and non-active frost simulation method.

Figure 20. Spray method for fluid application on a test plate surface.

non-active and active frost conditions at various ambient temperatures, including: –13°F (–25°C), 6.8°F (–14°C), 14°F (–10°C), 26.6°F (–3°C), and 33.8°F (+1°C).

Type I Propylene Glycol (PG) fluid prepared at Standard Mix (63% glycol) and at a fluid freeze point buffer of 18°F (10°C) was used for these tests. Fluids were tested either heated to 86°F (30°C) or cooled to the chamber's ambient test temperature. The selection of the 86°F (30°C) fluid temperature for the heated fluid tests was based on previous field tests on aircraft that measured the actual at-wing fluid temperature for frost deicing sprays when the fluid temperature at the spray nozzle was 140°F (60°C). These tests showed a considerable drop in fluid temperature between the spray nozzle and wing surface for the typical fan-shaped spray patterns used for defrosting.

A fluid application method was developed to represent the manner in which fluid is applied from a deicer spray nozzle in the field. The method consisted of spraying the fluid from a standard push-spray bottle as shown in Figure 20. In addition, each test set included one test where the Type I heated fluid was applied according to the conventional test method with the use of a fluid spreader as shown in Figure 21.

Equipment, Personnel, and Data Forms

The test procedure (see Appendix B) provides the detailed equipment and personnel required for testing. The procedure also includes copies of the data forms that were used. The data forms were used to record frost accretion, fluid strength, temperature, and fluid endurance times.

Tests Conducted

Eight sets of tests were conducted producing a total of 75 individual tests. The test variables are described below.

1. Quantity of fluid used per test: 0.003 US gal (10 mL), 0.005 US gal (20 mL), 0.011 US gal (40 mL), 0.021 US gal (80 mL), and 0.042 US gal (160 mL);

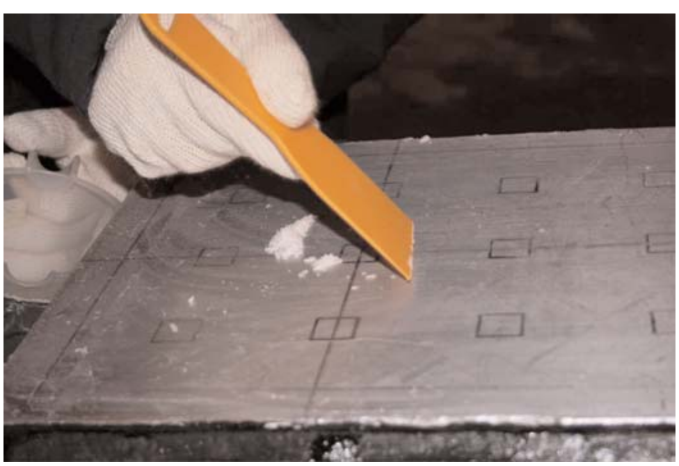

Figure 19. Scraping frost off test plate surface to measure rate.

Figure 21. Standard method for fluid application on a test plate surface.

Figure 22. Fluid brix measurements taken from 6-inch line on test plate surface.

Figure 23. Surface temperature measurements taken from 6-inch line on test plate surface.

2. Fluid strength: 18°F (10°C) buffer or standard mix (63% glycol);
3. Fluid temperature: 86°F (30°C) or ambient;
4. Method of fluid application, sprayed or standard application;
5. Ambient temperature of test chamber: −13°F (−25°C), 6.8°F (−14°C), 14°F (−10°C), 26.6°F (−3°C) and 33.8°F (+1°C);
6. Active or non-active frost condition; and
7. Fluid strength and test plate surface temperatures: recorded progressively at 1 min, 5 min, 15 min, 30 min, 45 min, 60 min, 90 min, and 120 min after application as show in Figure 22 and Figure 23.

Test Plan

Table 38 presents the test plan used for each set of tests. Fluid strength was mixed to either an 18°F (10°C) below ambient temperature fluid freeze point buffer or at the standard fluid mix as delivered. Eight sets of tests were conducted at a range of temperatures as shown in Table 39.

Two "baseline" tests were designated for each test set:

1. 0.1321 U.S. gal (500 mL) of fluid prepared at 18°F (10°C) buffer, poured at 68°F (20°C) with a spreader; and
2. 0.011 U.S. gal (40 mL) of fluid prepared at 18°F (10°C) buffer, applied at 86°F (30°C) with a sprayer.

Baseline Test #1 was similar to the procedure used in hold-over time testing in active frost conditions except the frost was not removed from the test surface prior to fluid application.

Baseline Test #2 was a baseline test for spot deicing, and was based on results from preliminary tests conducted during outdoor active frost conditions. Test variables for the remaining tests were changed or modified in reference to this baseline test.

The objective of all tests was to remove the frost accumulated on the test surfaces by spraying fluid at various strengths, amounts, and temperatures. Success was indicated by complete frost removal without early freezing of the applied fluid. Fluid endurance time was also measured for tests in active frost.

Table 38. Spot deicing test plan.

TEST #	**1** HOT baseline	**2** spot baseline	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Plate #	1	2	3	4	5	6	7	8	9	10	11	12
Fluid Qty. (mL)	500	40	40	40	40	10	20	80	160	40	40	40
Fluid Strength	10° buffer	10° buffer	std. mix	10° buffer	std. mix	10° buffer	10° buffer	10° buffer	10° buffer	10° buffer	std. mix	10° buffer
Fluid Temp. (°C)	20°C	30°C	30°C	OAT	OAT	30°C	30°C	30°C	30°C	30°C	30°C	OAT
Frost Event Type	active	active	active	active	active	active	active	active	active	non-active	non-active	non-active
Method of Fluid App.	pour w/ spreader	spray	spray	spray	spray	spray	spray	spray	spray	spray	spray	spray

Table 39. Planned OAT for test sets.

Test Set #	OAT (°F)	OAT (°C)
1	-13.0	-25
2	6.8	-14
3	26.6	-3
3a	26.6	-3
3b	26.6	-3
3c	26.6	-3
4	14.0	-10
5	33.8	+1

Log of Tests

A log of tests is given in Table 40. Each row in the log contains data specific to one test set. Chamber temperatures for Test Sets 1, 2, 3, and 3a were lower than planned due to the location of the test stands in the cold chamber. For the remaining tests, the stands were repositioned to an area of the chamber where temperatures were more suitable.

Focus Group Survey

Preliminary phone interviews were conducted with several deicing service providers (Contego Systems, Integrated Deicing Solutions), several airlines (Alaska, Northwest, US Airways), a major freight hauler (FedEx) and the FAA to examine current spot deicing for frost removal practices and to ascertain the current extent of its usage. Information gathered from these interviews varied. Replies covered a wide range:

- "We have been using a spot defrosting procedure for several seasons;"
- "We do not allow this procedure on our aircraft since it is not covered by FAA guidance documents;" and
- "This procedure would require additional inspections and training."

Following the preliminary phone interviews, a focus group consisting of key individuals from the deicing industry was put together to gather a more thorough and detailed understanding of the industry's perceptions and current usage of diluted fluids.

Feedback was obtained from the focus group through an online survey.

Survey Objectives

The objectives of the survey were:

- To determine which frost removal methodologies the industry is familiar with and which frost removal methodologies the industry currently employs;
- To determine the relative cost of frost removal methodologies;
- To determine the perceived effectiveness of frost removal methodologies;
- To determine the perceived advantages and disadvantages of using spot deicing for frost removal;
- To document current practices of companies using spot deicing for frost removal;
- To determine what is preventing companies who are not using spot deicing for frost removal from using this methodology;
- To determine what changes (regulatory or otherwise) need to take place in order for these companies to employ spot deicing; and
- To quantify fluid savings that would be realized by using spot deicing for frost removal.

Table 40. Log of tests.

Test Set	Date	Total Tests	Active Frost Tests	Non-Active Frost Tests	Test Plan Chamber Temp. (°C)	Average Chamber Temp. (°C)	Avg. Plate Temp. Before Pour (°C)	Frost Accumulated on Plate Before Pour (g/1 hour)	Frost Accumulated on Plate After Pour (g/2.5 hours)
1	July 7	12	9	3	-25	-28.6	-28.5	1.1	2.1
2	July 7	12	9	3	-14	-16.6	-20.5	2.1	3.6
3	July 8	12	9	3	-3	-4.2	-6.3	1.4	4
3a	July 8	6	4	2	-3	-4.2	-6.7	0.5	0.7
3b	July 10	12	9	3	-3	-3	-13	3.8	10.9
3c	July 10	6	6	0	-3	-3	-7.2	4.5	4.2
4	July 9	12	9	3	-10	-10.3	-13.7	0.8	0.6
5	July 10	3	3	0	1	1.9	-4.1	3.2	3.2

Composition of Focus Group

The focus group included individuals from a number of organizations, including deicing service providers, passenger airlines of varying sizes, cargo airlines, government agencies, and airport authorities. These individuals were invited to the focus group because they are key decision makers for aircraft ground operations in winter conditions in their respective organizations.

In addition, several key consultants in the deicing industry were included. These individuals have many years experience in the deicing industry and are now involved in training programs.

The following organizations were represented in the focus group:

- Aero Tech Consulting
- Aeroflot
- Aeromag 2000, Montreal
- Aeromag-Contego, Cleveland
- Air Canada
- Air France
- Alaska Airlines
- All Nippon Airways
- American Airlines
- Basic Solutions
- British Airways
- Contego Systems
- Contego Systems, Denver
- Continental Airlines
- Delta Airlines
- East Line Techniques
- EFM Munich
- FAA
- FedEx
- Horizon Air
- Hungarian Airlines
- Integrated Deicing Systems
- KLM
- Leading Edge Deicing Specialists
- Malmö Aviation
- MeteoGroup
- N*ICE Aircraft Services, Frankfurt
- Northwest Airlines
- Port of Portland
- Salzburg Airport
- Servisair Canada
- Servisair, Toronto
- Swissport
- Transport Canada
- UK CAA
- United Airlines
- United Parcel Service
- US Airways
- WestJet

It should be noted that a concerted effort was made to include individuals involved in deicing operations in North America, Europe, and elsewhere in the world. The following countries were represented in the focus group: United States, Canada, United Kingdom, Finland, Norway, Sweden, Germany, France, Netherlands, Austria, Hungary, Russia, and Japan.

Survey Format

The survey consisted of 25 multiple choice and short answer questions. The final question was an optional open-ended question used to collect additional comments/observations on the topics that were not addressed by the survey questions. A copy of the survey is included in Appendix C.

Not all of the survey questions were applicable to each person in the focus group. For example, questions related to amounts of fluid used in actual operations were not relevant to individuals from government organizations, as their organizations do not conduct de/anti-icing operations. The survey software described in the next section was used to set up the surveys to ask respondents only those questions that were applicable to their organization type (the first question ascertained their organization type). A matrix showing the questions that were asked to each organization type is included in Appendix C.

The applicability of some of the questions in the survey was determined by respondents' answer to Question 7, which asked if their affiliated organization was currently using the spot deicing methodology, planned to use it in the future, or did not plan to use it in the future. The survey software was used to route respondents to the appropriate questions based on their response to this question. The questions that were asked upon each of the three responses are provided in the spot deicing routing diagram given in Appendix C.

Survey Administration

Specialized software was used to administer the survey online. The software was used to create the survey, publish it to a secure website, and collect and collate the responses.

Response Rate

The survey was sent to 41 focus group members. Twenty-seven individuals (66%) completed the survey. Table 41 shows a breakdown of the survey respondents by organization type.

Table 41. Survey respondents by affiliated organization type.

Airlines	**44% (12)**
Major Airline	30% (8)
National Airline	7% (2)
Regional Airline	4% (1)
Major Air Carrier (non passenger)	4% (1)
Small (on demand) Air Carrier	0% (0)
DSPs	**33% (9)**
Deicing Service Provider (non airlines)	26% (7)
Airport Authority	7% (2)
Others	**22% (6)**
Deicing Trainer	4% (1)
Regulator/Government	11% (3)
Other	7% (2)
All Respondents	**100% (27)**

Cost-Benefit Model

A cost-benefit model was developed to assist operators in determining the financial feasibility of implementing spot deicing for frost.

Development of the model was completed using a two-step approach. The first step identified potential parameters for use in the model, assessed their typical values and estimated their influence from a cost-benefit perspective. The second step used the selected parameters to develop and test a model.

Step 1: Examination of Potential Cost-Benefit Model Parameters

A detailed examination of potential parameters was undertaken to determine their impact on model outcome. In the course of this examination, typical values for each parameter were established. These values were then combined in a preliminary cost-benefit assessment. The preliminary assessment showed substantial benefits per aircraft deiced, with savings ranging from eight gallons of fluid and $35 in operational cost savings for a small turbo-prop aircraft to 60 gallons and $280 in operational cost savings for a heavy wide body transport.

A detailed examination of potential cost-benefit model parameters is provided in Appendix D.

In addition to its use for selecting parameters to be included in the model, the examination provided parameter values that may be useful to operators in their application of the model. Typical amounts of deicing fluids utilized in conventional frost deicing operations and the anticipated amounts for spot deicing are documented for different aircraft types. Average cost savings per aircraft spray are calculated based on a stated value for fluid costs. Estimates of operational costs for additional training and inspection are stated. Use of these parameter values may enable the user to conduct a preliminary feasibility study using the model, before going to the effort of developing costs specific to their own situation.

The potential parameters considered for the cost-benefit model are:

- Additional equipment;
- Addition training of deicing personnel;
- Additional inspection requirements;
- Additional training documentation;
- Additional training of flight crews;
- Deicing fluid amount savings;
- Deicing fluid cost savings;
- Additional guidance provided by north american regulators;
- Savings in deicing time through-put; and
- Savings to the environment.

In the examination of potential parameters, it was concluded that any additional guidance provided by North American regulators would not be a direct cost to the operator so that parameter was excluded.

The direct saving in deicing time throughput was estimated to be a small value, mainly because the staff must be available and equipment must be kept at the ready in any case, and was not included in the model. However there may be an impact on aircraft block times, which is included as a model parameter.

And while there may be a quantitative value associated with reduced environmental impact of lower fluid usage, this is not a factor lying within the potential users financial budget, and thus that factor was eliminated from the model development.

The remaining parameters were incorporated into the cost-benefit model.

The preliminary examination addressed the effect of spot deicing individual aircraft, but did not extend to the overall deicing process because of the complexity involved. The introduction of spot deicing may substantially change the local deicing process, for example, relocating frost deicing from remote deicing sites and central deicing facilities to on-gate deicing. Such a change may necessitate a capital expenditure for additional equipment, whereas the preliminary examination assumed there would be no need for such an expense. Similarly, the preliminary examination assumed no change to deicing times and thus no effect on costs, whereas a relocation of the frost deicing from remote facilities to on-gate deicing may have a considerable effect on aircraft block times, which are high value factors. Thus the final model incorporated several parameters not included in the preliminary examination.

Step 2: Cost-Benefit Model Development and Testing

The cost-benefit model went through several iterations before the final version was completed. The various aspects of the model and its functionality are described below.

Model Objective

The objective of building the cost-benefit model was to create a model that can determine the number of years required to recoup the initial investment required to implement spot deicing for frost. The model does this by comparing the cost of current (standard) frost operations to the cost of frost spot deicing to determine the annual operational savings that will be gained, and then comparing the annual savings to the initial investment required to determine the number of years until the initial investment is recouped.

Model Structure

The model was developed as a Microsoft Excel workbook. There are five worksheets (or pages) in the workbook. The user works sequentially from the first page to the last page, following the instructions provided on the first page and at the bottom of each subsequent page. Specific instructions and/or comments for some cells are provided in notes attached to the cells. The content of each of the five pages is described below.

Instructions: This page describes what the model will do, provides general instructions for using the model, and provides a disclaimer about the use of assumptions in the model.

Background: This page requires user input. It contains a number of questions to assess the current operation and to determine how the future spot deicing operation will be conducted.

Costs: This page also requires user input. The user is required to enter costs under four categories: capital costs (new equipment), set-up costs, fixed annual costs, and variable annual costs. Not all of the costs input cells are applicable to all operations. The model categorizes the user's scenario by when and how both standard deicing and spot deicing will take place (determined by user input on the background page) according to Table 42.

Table 42. User scenarios.

		Where/When Spot Frost Deicing Occurs		
		Remote Location following scheduled departure	**Gate** following scheduled departure	**Gate** prior to scheduled departure
Where/When Standard Frost Deicing Occurs	**Remote Location** following scheduled departure	A	B	C
	Gate following scheduled departure	n/a	D	E
	Gate prior to scheduled departure	n/a	F	G

For example, the cost to move frost deicing from a remote location to gates is not applicable for scenarios A, D, E, F and G. Therefore, "not applicable" appears in this cost input cell (L18) when the user fits into this scenario. The cost input cells that are not applicable to the user's scenario are automatically filled with "not applicable."

Results: This page provides the results of the model analysis. The key results are the annual financial savings, annual glycol savings, and number of years to breakeven.

Breakeven Schedule: This page shows the annual change in cash flow year by year. The key item on this page is the year that the initial investment (capital costs and setup costs) is paid off by the annual operational savings.

User Inputs Required

In order to complete the model, users must have the following information available:

- Where and when standard/spot frost deicing are/will be performed;
- Who (contractor or operator) performs/will perform standard/spot frost deicing;
- The amount of glycol used annually for frost deicing;
- The annual number of frost deicings conducted;
- Whether new/different equipment will be required for spot deicing:
- Cost of new equipment required for spot deicing*;
- Cost of new access equipment for spot deicing inspector*;
- Cost to gain in-house approval from all affected branches to proceed;

- Cost to develop, publish, and approve new procedures;
- Cost to include new procedures in airline deicing program and get approval;
- Cost to develop training materials for spot deicing;
- Cost to move frost deicing from remote location to gate*;
- For both standard and spot frost deicing: annual equipment maintenance costs and annual equipment operation costs;
- Additional flight crew and ground crew training costs for spot deicing;
- Contractor cost, block time cost, glycol cost, staff cost, inspector cost, and cleanup; and
- Cost per deicing for both standard and spot frost deicing*.

All inputs are not required in all scenarios.

Model Output

The primary output of the model is the number of years until initial investment is recouped (years to breakeven). The financial and glycol savings to be gained annually by implementing spot deicing for frost are also calculated.

The annual financial savings are determined by:

- Comparing the annual fixed costs of standard frost deicing only with the annual fixed costs of operating with a mix of standard and spot frost deicing to determine the annual fixed cost expense or savings;
- Comparing the per-deicing variable cost of standard frost deicing only with the per-deicing variable cost of a spot frost deicing to determine the variable cost savings per spot frost deicing conducted; and
- Multiplying the variable cost savings per deicing by the number of spot deicings that will be conducted (total annual frost deicings times percentage of frost deicings that will use a spot frost deicing procedure) and adding the annual fixed cost savings (or subtracting the annual fixed cost expense).

The annual glycol savings are determined by:

- Multiplying the annual glycol consumption by the additional glycol required for a standard deicing relative to a spot deicing multiplied by the percentage of frost deicings that will use a spot frost deicing procedure.

The years to breakeven are determined by:

- Comparing the annual financial savings of implementing spot deicing for frost to the initial investment required (set-up costs and capital costs) and determining how many years it will take for the annual savings to pay for the initial investment.

Model Testing

The cost-benefit model was refined and validated through a testing process. The testing process involved running the developed model through a variety of scenarios and situations created by inputting various parameter values representing both typical and extreme operations. This process confirmed that the model can provide reasonably accurate outcomes for a variety of situations and users.

Findings and Applications

The findings and applications of the work completed to examine the current practices and regulations, opportunities, limitations, obstacles, and potential benefits associated with the usage of spot deicing for frost removal are discussed in this section:

- Findings of the literature review;
- Results of laboratory tests;
- Findings of the focus group survey; and
- Application of findings to create cost-benefit model.

Examination of Current Government and Industry Regulations, Guidance Material, and Standards

Aircraft ground deicing procedures used by most North American air carriers are prepared by the airlines and are based on general guidance information contained in the appropriate aircraft manufacturer's maintenance manuals, aircraft deicing industry documents, and regulatory guidance. Specific guidelines for deicing are contained in SAE, AEA, FAA, International Civil Aviation Organization (ICAO), and Joint Aviation Authorities (JAA) documents. Of these documents, SAE ARP 4737 is the premier document and is referenced by all major air carriers internationally.

SAE

There are two SAE documents where guidance on spot deicing procedures may appear: ARP 4737 (Aircraft De/Anti-Icing Methods document) and ARP 5149 (Training Guidelines for Deicing and Anti-Icing Aircraft on the Ground).

At the time the literature review was conducted, there were no specific guidelines in either of the SAE documents that addressed procedures for spot deicing for frost removal. The general guideline in ARP 4737 for removal of frost and light ice, i.e., paragraph 6.1.2.2, simply stated:

> A nozzle setting giving a fan spray is recommended. NOTE: Providing that the hot fluid is applied close to the aircraft skin, a minimal amount of fluid will be required to melt the deposit.

However, at the May 21, 2009 meeting of the SAE G-12 Aircraft Ground Deicing Methods Subcommittee, the addition of wording related to spot deicing was discussed. The following proposed wording for paragraph 6.5 was agreed to by the subcommittee:

> For non-active frost limited to a small patch on the upper wing surface or horizontal stabilizer, and when no precipitation is falling or expected, 'local area' deicing may be carried out. Spray the affected area with a heated fluid/water mix suitable for a One-Step Procedure, and then spray the same area on the other wing. Both wings must be treated identically (same areas, same amount and type of fluid, even if the frost is only present on one wing. (Refer to aircraft manufacturers requirements for specific guidance)
>
> The trained and qualified person releasing the aircraft must visually check that the treatment was done symmetrically and that all frozen deposits have been removed, and then report the details of the treatment to the Flight Crew.
>
> *CAUTION: Holdover times do not apply.*

Adoption and passage of the revised version of ARP 4737 (ARP 4737H) is anticipated prior to the start of the 2009–10 winter deicing season.

AEA

A specific AEA recommended procedure for spot deicing for frost is found in paragraph 3.9.1.3.2 of the AEA document, *Recommendations for De/Anti-icing of Aircraft on the Ground:*

> For frost limited to a small patch on the upper wing surface only, and when no precipitation is falling or expected, 'local area' deicing may be carried out. Spray the affected area with a heated fluid/water mix suitable for a One-Step Procedure, then spray the same area on the other wing. Both wings must be treated identically (same areas, same amount and type of fluid, same mixture strength), even if the frost is only present on one wing.
>
> The trained and qualified person releasing the aircraft must check that the treatment was done symmetrically and that all frozen deposits have been removed, and then report the details of the treatment to the Commander.
>
> *CAUTION: Holdover times do not apply.*

FAA

The FAA Ground Icing Research Lead participated in the survey discussed above and indicated the following position on spot deicing for frost removal: "currently spot deicing is not prohibited by the FAA; however it is not specifically encouraged. Generally the FAA would expect the operator to follow instructions from the airframe manufacturer in the aircraft maintenance manual. . . ."

Aircraft Manufacturers

In performing spot deicing for frost removal, standard fluid application procedures are typically employed, in which a fan spray nozzle setting is used. Also, Type I fluids applied at a 60°C temperature (at the nozzle) are used extensively. Of the air carriers that have adopted spot deicing for frost removal procedures, the survey indicated that this practice is performed on most current commercial aircraft, thus precluding the need for additional guidance from aircraft manufacturers.

As an example, page 307, paragraph 9 of the Boeing Aircraft Maintenance Manual (AMM-12-33-01) for the B-737 600-900 series of aircraft states:

> The right and left side of the wing and the horizontal stabilizer must get the same ice removal/anti-icing treatment.
>
> a) If contamination exists only in a limited area (such as spoiler panel) and there is no active precipitation, it is permitted to deice only that area, but the same area should be treated on the other wing.

Summary

Although government and industry regulations, guidance material, and standards current at the time of the literature review did not appear to provide sufficient guidance for conducting spot deicing for frost removal, changes recommended to SAE ARP 4737, which are expected to be adopted for the winter 2009–10 operating season, should correct this deficiency. Changes in FAA and aircraft manufacturer guidance materials do not appear to be necessary.

Laboratory Tests

This section examines results of the laboratory tests from the perspectives of spot deicing for non-active frost (due to radiation cooling) and for active frost (due to cold-soaked surfaces). A detailed log of tests showing test variables and measured results is provided in Appendix E.

Assessment of Frost Severity

The test plates were allowed to accumulate frost for a one-hour period prior to conducting the spot deicing tests. The amount of frost on the plate at test time is of interest as the water content of the melted frost can trigger early freezing due to fluid dilution.

To assess frost severity for non-active frost deicing, the frost amounts for the various test sets were simply compared, using the highest as the base case. The results shown in Table 43 indicate that test surfaces for test sets 3b, 3c and 5 had collected considerably more frost than for the other test sets.

Table 43. Assessment of frost severity for frost spot-deicing.

Test Set	Chamber Temp °F (°C)	Test Surface Delta Temp °F (°C)	Frost for Deice* (g/hr)	Frost for Deice* ($g/dm^2/h$)	Ranking of Frost Accumulation (% of greatest amount)
1	-19.5 (-28.6)	32 (0)	1.1	0.09	0.24
2	2.1 (-16.6)	5.4 to 10.8 (3 to 6)	2.1	0.16	0.47
3	24.4 (-4.2)	3.6 to 5.4 (2 to 3)	1.4	0.11	0.31
3a	24.4 (-4.2)	1.8 to 7.2 (1 to 4)	0.5	0.04	0.11
3b	26.6 (-3.0)	12.6 to 19.8 (7 to 11)	3.8	0.29	0.84
3c	26.6 (-3.0)	7.2 (4)	4.5	0.35	1.00
4	13.5 (-10.3)	7.2 (4)	0.8	0.06	0.18
5	35.4 (1.9)	10.8 (6)	3.2	0.25	0.71

* Test surfaces were exposed to chamber conditions for one-hour prior to test to accumulate frost on test surfaces.

To assess frost severity during the active frost tests, measured frost rates were compared to rates proposed for frost testing in natural conditions. These rates were proposed in previous studies to determine test methodology for fluid endurance times in natural frost, and vary for different ambient conditions. The results are shown in Table 44.

Test 3b experienced a rate of frost generation much greater than proposed for standard testing as shown in Figure 24, while tests 1 and 2 were close to proposed standard test rates.

Quantity of Fluid Needed to Remove Frost

Results from both active and non-active frost tests generally indicated that 10 mL of fluid was not enough to cover and de-ice the entire surface plate area, 20 mL was barely enough, and 40 mL was sufficient to remove frost from test plate surfaces.

Results for Spot Deicing in Non-Active Frost

Forty (40) mL of fluid (0.011 U.S. gal) prepared at an 18°F (10°C) buffer and applied at 86°F (30°C) was of sufficient amount and strength to de-ice non-active frost surfaces. Most non-active frost test surfaces subjected to spot deicing with this fluid condition remained clean for the duration of the test (2.5 hrs). The shortest interval until refreezing was 115 minutes.

Forty (40) mL of fluid on a test plate is equivalent to $0.27 L/m^2$. The application of fluid at a minimum rate of ⅓ L/m^2 (approximately ⅓ US quart per 10 ft^2) could be used as a guide to field operations.

The fluid should be applied at a temperature not less than 140°F (60°C) at the spray nozzle as this generally produces an on-wing fluid temperature of 86°F (30°C) due to cooling between nozzle and wing.

Table 44. Assessment of frost severity for anti-icing in cold-soak conditions.

Test Set	Chamber Temp. °F (°C)	Test Surface Delta Temp °F (°C)	Anti-ice Test Rate (g/2.5hr)	Anti-ice Test Rate (g/hr)	Anti-ice Test Rate (g/dm2/h)	Recommended Standard Test Rate* ($g/dm^2/hr$)	% of Standard Rate
1	-19.5 (-28.6)	32 (0)	2.1	0.84	0.07	0.08	**81%**
2	2.1 (-16.6)	5.4 to 10.8 (3 to 6)	3.6	1.44	0.11	0.13	**86%**
3	24.4 (-4.2)	3.6 to 5.4 (2 to 3)	4	1.6	0.12	0.21	**59%**
3a	24.4 (-4.2)	1.8 to 7.2 (1 to 4)	0.7	0.28	0.02	0.21	**10%**
3b	26.6 (-3.0)	2.6 to 19.8 (7 to 11)	10.9	4.36	0.34	0.23	**147%**
3c	26.6 (-3.0)	7.2 (4)	4.2	1.68	0.13	0.23	**57%**
4	13.5 (-10.3)	7.2 (4)	0.6	0.24	0.02	0.15	**12%**
5	35.4 (1.9)	10.8 (6)	3.2	1.28	0.10	0.28	**35%**

* Recommended frost generation rate for Type I fluid tests; see Transport Canada report TP 14145E, Figure 4.10.

Figure 24. Simulation of a severe frost event on test plate surfaces.

Results for Spot Deicing in Active Frost

In this examination of endurance times for active frost with cold-soaked surfaces, the degree of cold soaking is indicated by the value of ΔT (surface temperature minus OAT).

Of the eight test sets, only three experienced an active frost rate considered to be more than light frost (Table 44). Those test sets were 1, 2, and 3b.

These three tests were examined to assess whether they are realistic representations of cold-soaked wing surfaces, and if so, the measured fluid endurance times were reviewed.

Test 1 is not a realistic representation of cold soaking as the test surface temperature was essentially equal to OAT.

Test 3b is not realistic due to its very large ΔT at −18°F (−10°C). This large ΔT resulted in very short endurance times.

Test 2 is viewed as a good representation of active frost on cold-soaked wing surfaces. Its ΔT at −8.6°F (−4.8°C) falls within the range of ΔT values measured for previous cold-soaked wing studies, which generally identified a maximum ΔT of −12.6°F (−7°C). As well, the frost rate is close to that proposed for fluid endurance testing in natural frost.

In Test 2, the endurance times differ by fluid strength:

- For fluid strength at an 18°F (10°C) buffer, endurance times are in the order of mid-20 to mid-30 minutes, regardless of fluid quantity; and
- For the standard mix, endurance times are about 1.5 hrs.

Results from this test indicate that applying the spot deicing procedure to cold-soaked surfaces may not produce endurance times adequate to protect the aircraft surface until takeoff. The times produced by the 18°F (10°C) buffer fluid ranged from 24 to 36 minutes, considerably less than the current HOT guidelines for Type I fluid for natural frost at 45 minutes. This result is of particular concern because more and more operators are introducing deicers equipped with on-board fluid blenders to enable the use of Type I fluids diluted to the 18°F (10°C) buffer.

Based on the results from this single test, the spot deicing procedure should clearly indicate that it is not intended for application on cold-soaked surfaces.

This test result also raises a question regarding the applicability of the current HOT frost guidelines to the condition of frost resulting from cold-soaked wings. The current fluid endurance test in natural frost is conducted on a special frost insulated plate that has been developed to represent wings subjected to heated fluid spray. The heat from the fluid raises the wing surface temperature, resulting in fluid enrichment due to evaporation and in a delay to frost initiation until the surface cools to below OAT. If the wing is cold-soaked with cold fuel, the additional heat sink would cause a quite different wing surface temperature response, and the same endurance times may not be produced.

Focus Group Survey

The detailed results of the focus group survey are provided question by question in Appendix F. For multiple choice questions, the percentage of respondents selecting each response is listed. For most multiple choice questions, the responses are also additionally broken out by organization type (i.e., airlines, deicing service providers, others). Each and every response provided for the short answer questions and comments areas is provided.

Some key findings from the survey include:

- Approximately half of the survey respondents (48%) are familiar with the spot deicing for frost removal procedure; slightly fewer (43%) currently employ the procedure in their operations.
- Spot deicing for frost was believed by the respondents to be one of the cheapest frost removal methodologies and also one of the most effective.
- The majority of respondents (89%) were aware of the AEA guidelines for local wing frost removal. 57% indicate they already use a local wing frost removal methodology; 19% would consider using one; and 24% would not consider using one.
- Of those respondents indicating they already use a local wing frost removal methodology:
  - Most (75%) use Type I fluid mixed to a 10°C buffer; the remainder (25%) use ready-to-mix Type I fluid for spot deicing;
  - All respondents (100%) indicated that the fluid used for spot deicing is maintained at 60°C; and
  - The majority (92%) apply fluid for spot deicing with a regular deicing vehicle.
- Training, lack of qualified individuals to make assessments about its usage, and resulting risks to safety were identified as the key obstacles in employing spot deicing for frost removal. Lack of specific guidance in SAE ARP 4737 was also mentioned.

- Respondents listed the need for symmetrical application and the need to follow AEA recommendations as the key restrictions they impose or would impose on spot deicing.
- The key benefits of spot deicing for frost removal were listed as: time savings, fluid savings, cost savings, and reduced environment impact.
- Respondents believe a fluid savings of 30 to 60% could be achieved by employing spot deicing in place of conventional methods for frost removal. Percentage savings were seen to increase with aircraft size.
- Respondents indicated that a spot deicing methodology would be less suitable at lower temperatures (86% indicated it would be suitable at 0°C or above; only 10% indicated suitability at below −25°C).
- There was a general lack of knowledge and acceptance among the respondents of the frost polishing methodology for frost.

Cost-Benefit Model

The cost-benefit model is a user-friendly tool that can be used by operators to determine if switching from standard to spot deicing for frost removal is financially advantageous. The model will estimate the annual financial savings, annual glycol savings, and number of years until the initial investment has been recouped.

The model was tested for different situations by inputting various parameter values representing typical and extreme operations. The model was refined and validated by this process. The final version of the model may be downloaded at the link found at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=122.

When applied to typical airport conditions, the model output clearly shows the value of implementing spot deicing. In many cases, the financial outlay to implement spot deicing for frost removal can be recouped in a year or two.

Sample Completed Model

The figures here provide an example of running the cost-benefit model.

Figure 25—Instructions Page: The user is not required to enter any information on this page. The page does not change from user to user.

Figure 26—Background Page: The user has indicated on this page that (1) a contractor currently conducts standard frost deicing at a remote location following the scheduled departure time and (2) the operator will conduct spot frost deicing at the gate, prior to scheduled departure time. This categorizes the scenario as a "scenario C" according to Table 42. The user has also indicated 2,400 frost deicings are conducted annually (using 400,000 liters of fluid) and spot deicing could be used for 50% of them. The default value of 40% glycol usage for spot deicing is selected, as is the need to purchase new equipment.

Figure 27—Costs Page: The user has estimated the required costs on the costs page. In this scenario (scenario "C"), equipment operation and maintenance costs are not required for standard deicing, as standard deicing is performed by a contractor. For the same reason, staff, inspector, and cleanup costs per deicing are not required for standard deicing. Contractor costs are not required for spot deicing as the operator will be doing the operation. Finally, block time costs are not applicable for spot deicing, as it will be done prior to the scheduled departure time.

Figure 28—Results Page: This page provides the results of the model analysis. It shows there is an annual fixed cost expense of $68,000 and cost savings of $530 per deicing if spot deicing for frost is implemented. The operator will save $568,000 and prevent 120,000 liters of fluid from entering the environment annually by implementing spot deicing. The initial investment required (setup costs and capital costs) will be recouped in the second year.

INSTRUCTIONS

Welcome to the spot deicing for frost cost-benefit model. This model will calculate the number of years it will take to breakeven from the initial investment required to implement spot deicing.

Instructions: Fill in all cells that are shaded blue, except those where "not applicable" is indicated. When you have filled in all cells on a page, follow the instructions that appear in red at the bottom of the page. Further comments/instructions are provided in some cells. These comments/instructions are indicated by red triangles that appear in the upper right corner of the cell and can be seen by hovering over the cell.

Disclaimer: This model has been prepared by APS Aviation Inc. for the Transportation Research Board. The model makes several assumptions that may not be accurate in every business and/or operational environment. The user is recommended to conduct further analysis if required.

To begin, go to the next page (Background)

Figure 25. Sample instructions page.

BACKGROUND QUESTIONS

1. **Where/when** is standard frost deicing performed?	At a remote location, following scheduled departure time	
2. **Who** performs standard frost deicing?	Contractor	
3. **Where/when** will spot frost deicing be performed?	At the gate, prior to scheduled departure time	
4. **Who** will perform spot frost deicing?	Operator	
5. How much glycol is used for frost deicing annually?	400,000	liters
6. How many frost deicings are conducted annually?		2,400
7. What percentage of frost deicings will use a spot frost deicing procedure?		50%
9. Relative to a standard frost deicing, how much glycol will be used for a spot frost deicing?		40%
8. Will new/different equipment (i.e. trucks) be required for spot deicing?		yes

This page is complete. Please go to the next page (Costs).

Figure 26. Sample background page.

Figure 29—Breakeven Schedule Page: This page shows the initial investment will be recouped in year two.

This case study uses typical parameter values to examine the costs and benefits of relocating frost deicing from a remote central deicing facility to the gate. Even with the one-time capital costs for new deicing equipment, this examination shows cost-recovery within one year, and substantial operational savings thereafter. This is an interesting situation, involving a significant reduction in aircraft block time and engine run time. For this operator, using a spot deicing procedure for frost deicing is a financially sound and environmentally advantageous decision.

Conclusions, Recommendations, and Suggested Research

The conclusions, recommendations, and suggested research resulting from this task are provided in this section.

Conclusions

The review of current government and industry regulations, guidance material, and standards related to spot deicing for frost removal found that:

- Changes to FAA and aircraft manufacturer guidance materials were not required; and
- SAE ARP 4737, the premier document referenced by all major air carriers nationally and internationally for aircraft de/anti-icing methods, was lacking guidance material related to spot deicing for frost removal. However, changes to ARP 4737 were proposed and accepted at the May 2009 meeting of the SAE G-12 Aircraft Ground Deicing Methods Subcommittee. These changes are expected to be adopted for the 2009–10 winter operating season, and should provide adequate guidance for operators wishing to implement spot deicing for frost removal.

Experimental tests were conducted to quantify the required amount, strength, and temperature of fluid to conduct spot deicing for frost operations. The following conclusions were drawn from the tests:

- The application of fluid at a minimum rate of ⅓ L/m^2 (approximately ⅓ quart per 10 ft^2) can be used as a guide to field operations;
- Application of fluid mixed to an 18°F (10°C) freeze point buffer is adequate for the spot deicing application;
- The fluid should be applied at a temperature not less than 140°F (60°C) at the spray nozzle;
- Unless further testing is conducted and proves otherwise, spot deicing should be used only for non-active frost conditions; and
- Additional testing with positive results would be needed before spot deicing could be approved for active cold-soak frost deicing.

A group of key individuals from the deicing industry were surveyed to gather a more thorough and detailed

CAPITAL COSTS - NEW EQUIPMENT

a) Cost of new equipment required for spot deicing	$ 500,000
b) Cost of new access equipment for spot deicing inspector	$ 200,000

FIXED COSTS - ONE TIME SETUP COSTS

a) Cost to gain in-house approval from all affected branches to proceed	$ 2,000
b) Cost to develop, publish and approve new procedures	$ 2,000
c) Cost to include new procedures in airline deicing program, get approval	$ 3,000
d) Cost to develop training materials for spot deicing	$ 5,000
e) Cost to move frost deicing from remote location to gate	$ 5,000

FIXED COSTS - ANNUAL

Costs for standard frost deicing:

a) Equipment maintenance costs (annual)	not applicable
b) Equipment operation costs (annual)	not applicable

Costs for frost deicing if spot deicing implemented (assume mix of standard/spot operations):

a) Equipment maintenance costs (annual)						$ 5,000
b) Equipment operation costs (annual)						$ 15,000
c) Additional flight crew training costs	*employees*	50	x	*cost per employee*	$ 800	$ 40,000
d) Additional ground crew training costs	*employees*	40	x	*cost per employee*	$ 200	$ 8,000

VARIABLE COSTS

Costs for standard frost deicing:

a) Contractor cost (per deicing)						$ 200
b) Block time costs (per deicing)						$ 400
c) Glycol cost (per deicing)	*liters*	200	x	*cost per liter*	$ 4	$ 800
d) Staff cost (per deicing)						not applicable
e) Inspector cost (per deicing)						not applicable
f) Cleanup cost (per deicing)						not applicable

Costs for spot frost deicing:

a) Contractor cost (per deicing)						not applicable
b) Block time costs (per deicing)						not applicable
c) Glycol cost (per deicing)	*liters*	80	x	*cost per liter*	$ 4	$ 320
d) Staff cost (per deicing)						$ 100
e) Inspector cost (per deicing)						$ 100
f) Cleanup cost (per deicing)						$ 350

This page is complete. Please go to the next page (Results).

Figure 27. Sample costs page.

RESULTS	
Fixed Costs of Frost Deicing (per winter season)	
Using Standard Deicing Only	$0
Using Mix of Spot and Standard Deicing	$68,000
Cost Savings from Implementing Spot Deicing	**-$68,000**
Variable Costs of Frost Deicing (per operation)	
Using Standard Deicing Procedure	$1,400
Using Spot Deicing Procedure	$870
Cost Savings from Implementing Spot Deicing	**$530**
Impact of Implementing Spot Deicing (per winter season)*	
Financial Savings	**$568,000**
Glycol Savings	**120000 liters**
Initial Investment Required to Implement Spot Deicing	
Set-up Costs	$17,000
Capital Costs	$700,000
Winter Seasons to Breakeven	**2**

**Assumes: 2400 frost deicings conducted annually; 50% of frost deicings use spot procedure; and spot deicing procedure uses 40% of the glycol of a standard procedure.*

See next page (Breakeven Schedule) for further details

Figure 28. Sample results page.

understanding of the industry's perceptions and current usage of diluted fluids. Key findings are:

- Although a reasonable number of operators are currently using spot deicing, there are many operators who are not familiar with this methodology for frost removal.
- Spot deicing is seen to be a cheap and effective methodology for frost removal. Cost and fluid and time savings are notable benefits of spot deicing compared to conventional deicing. Fluid savings are estimated to be between 30 and 60%.
- Spot deicing for frost removal is currently being employed using Type I fluid mixed to a 10°C buffer heated to 60°C and applied using a regular deicing vehicle.
- Training, lack of qualified individuals to make assessments about its usage, and asymmetrical application resulting in risks to safety, were identified as the key obstacles in employing spot deicing for frost removal.
- The methodology was seen to be more suitable for operations at warmer temperatures.

A cost-benefit model was developed for use by operators to determine if making a switch from standard to spot deicing for frost removal would be financially advantageous for their operation. The model estimates the annual financial savings, annual glycol savings, and number of years until the initial investment has been recouped. When applied to typical airport conditions, the model output clearly shows the value of implementing spot deicing. In many cases, the financial outlay to implement spot deicing for frost removal can be recouped in a year or two.

If implementation of spot deicing enables relocation of the defrosting activity from remote sites to passenger terminal gates, very significant benefits can be achieved in reduced operating costs, improved on-time performance, and reduced environmental impact from spent fluid and from carbon emissions due to fuel burn.

Recommendations

The following recommendations resulted from the work conducted for the spot deicing for frost removal task:

- Although it does not appear to be required in order for operators to implement spot deicing for frost removal, it is recommended that the regulatory authorities (FAA and

BREAKEVEN SCHEDULE						
Winter Season	Capital Costs	Setup Costs	Operational Savings	Total Savings	Lifetime Savings	Breakeven Year
1	$700,000	$17,000	$568,000	-$149,000	-$149,000	no
2	n/a	n/a	$568,000	$568,000	$419,000	**yes**
3	n/a	n/a	$568,000	$568,000	$987,000	*reached prior*
4	n/a	n/a	$568,000	$568,000	$1,555,000	*reached prior*
5	n/a	n/a	$568,000	$568,000	$2,123,000	*reached prior*
6	n/a	n/a	$568,000	$568,000	$2,691,000	*reached prior*
7	n/a	n/a	$568,000	$568,000	$3,259,000	*reached prior*
8	n/a	n/a	$568,000	$568,000	$3,827,000	*reached prior*
9	n/a	n/a	$568,000	$568,000	$4,395,000	*reached prior*
10	n/a	n/a	$568,000	$568,000	$4,963,000	*reached prior*
11	n/a	n/a	$568,000	$568,000	$5,531,000	*reached prior*
12	n/a	n/a	$568,000	$568,000	$6,099,000	*reached prior*
13	n/a	n/a	$568,000	$568,000	$6,667,000	*reached prior*
14	n/a	n/a	$568,000	$568,000	$7,235,000	*reached prior*
15	n/a	n/a	$568,000	$568,000	$7,803,000	*reached prior*
16	n/a	n/a	$568,000	$568,000	$8,371,000	*reached prior*
17	n/a	n/a	$568,000	$568,000	$8,939,000	*reached prior*
18	n/a	n/a	$568,000	$568,000	$9,507,000	*reached prior*

Figure 29. Sample breakeven schedule page.

TC) incorporate appropriate spot deicing for frost removal clarification/guidance information in the annual FAA-Approved Deicing Program Updates (Notice 8900.xx) and the Transport Canada Guidelines for Aircraft Ground Icing Operations (TP 14052).

- It is also recommended that the AEA harmonize language contained in paragraph 3.9.1.3.2 of the AEA De/Anti-icing Recommendations Document to agree with the new wording of paragraph 6.5 of ARP 4737. (These changes are deemed to be minor editorial changes.)
- It is recommended that spot deicing be applied only to non-active frost resulting from natural frost generation.
- As part of this project, a cost-benefit model and presentation aids were developed (see Appendix G) to assist airlines and deicing service providers to better understand the benefits of employing spot deicing for frost in their operations. The cost-benefit model will also assist users by forecasting the financial benefits of employing spot deicing and a promotional campaign be implemented to market these tools.

Suggested Research

The application of current Type I fluid HOT guidelines to de/anti-icing frost from surfaces subjected to cold soaking should be examined to ensure suitability as the large cold-sink presented by the mass of cold wing structure and cold fuel may decrease the fluid endurance time.

CHAPTER 5

Increased Use of Aircraft De/Anti-Icing Fluid Dilutions

Introduction

This part of the report documents the task that examined the use of aircraft de/anti-icing fluid dilutions.

Background

Industry Use of 10°C Type I Fluid Buffer

SAE ARP 4737 states that Type I fluids used for either one-step de/anti-icing or as the anti-icing fluid in a two-step operation must have a FFP at least 10°C (18°F) below the ambient temperature. Type I fluid holdover times are measured using fluids mixed with water to this FFP. In the past, the general industry practice when de/anti-icing with Type I fluid had been to apply Type I fluid at the standard, as-delivered fluid concentration, typically a 50/50 (50% water/50% glycol) or a 55/45 mix. Other specific mixes such as 60/40 are available from fluid manufacturers. These special mixes are selected to provide optimum FFP performance at colder temperatures and are usually based upon prior climatic records of prevailing OATs at a given airport. Although Type I fluid mixes are required to have only a 10°C buffer, the Type I fluid 50/50 mixes typically have FFP well below the required 10°C buffer for most prevailing temperatures during aircraft deicing operations. This practice results in dispensing much more glycol content than is necessary, and could lead to unnecessary operational costs and increased stress on the environment. Currently, this trend is being reversed and many airlines that perform their own deicing and many deicing service providers (DSPs) have converted to the use of deicing equipment with proportional blending capabilities.

In the recent past, deicer manufacturers have incorporated fluid blending systems into their deicing units that blend Type I fluid with water. In addition, at major hubs where a significant number of de/anti-icing operations are carried out annually, such as Pittsburgh and Denver, the trend has been to install pedestal mounted deicing equipment that are supplied fluid mixes from remote blending systems with large storage capabilities. Broad application of such systems to dispense Type I fluid at the approved 10°C fluid freeze point buffer reduces the amount of glycol dispensed in Type I operations.

Industry Use of Type II, III, and IV Fluids Mixes

Type II, III, and IV anti-icing fluids are available at fluid concentrations of 100/0, 75/25, and 50/50. Fluid holdover times are derived from endurance time test results measured using fluid mixed to these concentrations. Some 75/25 fluid concentrations have published holdover times similar to 100/0 fluids. Also, most 50/50 anti-icing fluids have holdover times in excess of Type I fluids. Despite the opportunity to employ lower concentrations of Type II, III, and IV fluids, anti-icing operations in North America use 100/0 Type IV fluid concentrations almost exclusively. As a result, there is considerable opportunity to reduce the amount of glycol dispensed by applying these fluids at lower, already approved concentrations.

Objective

The objective of this task was to examine current practices and regulations related to the increased use of fluid dilutions and to document the opportunities, limitations, obstacles, and potential benefits associated with their use.

The objective was met by completing the following work elements:

- Conduct a literature review of current government and industry regulations, guidance material, and standards to document current industry regulations and practices related to the use of fluid dilutions;
- Conduct phone interviews with DSPs and airlines;
- Conduct a survey to gather pertinent information from a wider audience, including airlines, DSPs, deicing consultants, deicing instruction facilities, and regulators;

- Identify if changes to any industry standards and/or recommended practices are required and supporting the changes and/or development of guidance material as necessary; and
- Develop a cost-benefit model and presentation aids to influence and aid decision makers.

Research Approach and Methodologies

This section presents the research approach and methodologies employed to examine the current practices and regulations, opportunities, limitations, obstacles, and potential benefits associated with the usage of diluted aircraft de/anti-icing fluids.

Examination of Current Government and Industry Regulations, Guidance Materials, and Standards Related to the Use of Fluid Dilutions

A literature review was conducted of current government and industry regulations, guidance material, and standards related to the use of fluid dilutions to identify if there is a need for changes or further approvals to accommodate the use of fluid dilutions. The documents that were reviewed included:

- SAE guidelines in SAE ARP 4737 that address procedures for the application of Type I, II, III, and IV fluids in both one-step and two-step de/anti-icing procedures;
- Various regulatory, government and industry documentation, guidance material, and standards; and
- Holdover time guidance material and documentation published annually by TC, AEA, and the FAA.

All documents reviewed are referenced in Appendix A.

Focus Group Survey

Preliminary phone interviews were conducted with several DSPs (Integrated Deicing Systems and Contego Systems), several airlines (Alaska, US Airways, and North West), a major freight hauler (FedEx), and the FAA to examine current trends and practices associated with the use of dilutions and to ascertain the current extent of its usage. The replies were quite varied. The replies covered a realm of knowledge and activities. Some of the answers are quoted below.

- "We don't have equipment with proportional blending capabilities."
- "We have equipment with proportional blending capability, however we use a ready mix Type I most of the time."
- "We use the older conventional deicing equipment with two tanks at our regional sites."
- "We don't use pre-mixed Type I fluid. The average mixture rate of Type I fluid loaded on the equipment which has no proportional mixing system is 30%. We always use Type IV undiluted fluid for the second step."

Following the preliminary phone interviews, a focus group consisting of key individuals from the deicing industry was put together to gather a more thorough and detailed understanding of the industry's perceptions and current usage of diluted fluids.

Feedback was obtained from the focus group through an online survey.

Survey Objectives

The objectives of the survey were:

- To quantify the amount of de/anti-icing fluid used during the de/anti-icing of an aircraft in different precipitation conditions on select aircraft types;
- To determine if current regulations are perceived to be adequate to allow use of fluid dilutions;
- To determine the extent that heated water is being used for deicing by the industry;
- To determine the extent that diluted fluids (Type I/II/III/IV) are being used by the industry;
- To determine which factors influence decisions to use ready-to-use mix Type I fluids rather than Type I fluids mixed to appropriate buffers;
- To determine which factors influence decisions to use concentrated Type IV fluids rather than dilute Type IV fluids;
- To determine what levels of fluid freeze point buffers are being used;
- To evaluate the use of proportional blending systems; and
- To determine whether use of fluid dilutions is different at regional airports compared to major/hub airports.

Composition of Focus Group

The focus group included individuals from a number of organizations, including DSPs, passenger airlines of varying sizes, cargo airlines, government agencies, and airport authorities. These individuals were invited to the focus group because they are key decision makers for aircraft ground operations in winter conditions in their respective organizations.

In addition, several key consultants in the deicing industry were included. These individuals have many years experience in the deicing industry and are now involved in training programs.

The following organizations were represented in the focus group:

- Aero Tech Consulting
- Aeroflot
- Aeromag 2000, Montreal
- Aeromag-Contego, Cleveland
- Air Canada
- Air France
- Alaska Airlines
- All Nippon Airways
- American Airlines
- Basic Solutions
- British Airways
- Contego Systems
- Contego Systems, Denver
- Continental Airlines
- Delta Airlines
- East Line Techniques
- EFM Munich
- FAA
- FedEx
- Horizon Air
- Hungarian Airlines
- Integrated Deicing Systems
- KLM
- Leading Edge Deicing Specialists
- Malmö Aviation
- MeteoGroup
- N*ICE Aircraft Services, Frankfurt
- Northwest Airlines
- Port of Portland
- Salzburg Airport
- Servisair Canada
- Servisair, Toronto
- Swissport
- Transport Canada
- UK CAA
- United Airlines
- United Parcel Service
- US Airways
- WestJet

It should be noted that a concerted effort was made to include individuals involved in deicing operations in North America, Europe, and elsewhere in the world. The following countries were represented in the focus group: United States, Canada, United Kingdom, Finland, Norway, Sweden, Germany, France, Netherlands, Austria, Hungary, Russia, and Japan.

Survey Format

The survey consisted of 24 multiple choice and short answer questions. The final question was an optional open-ended question used to collect additional comments/observations on the topics that were not addressed by the survey questions. A copy of the survey is included in Appendix B.

Not all of the survey questions were applicable to each person in the focus group. For example, questions related to amounts of fluid used in actual operations were not relevant to individuals from government organizations, as their organizations do not conduct de/anti-icing operations. The survey software was used to set up the surveys to ask respondents only those questions that were applicable to their organization type (the first question ascertained their organization type). A matrix showing the questions that were asked to each organization type is included in Appendix B.

Survey Administration

Specialized software was used to administer the survey online. The software was used to create the survey, publish it to a secure website, and collect and collate the responses.

Response Rate

The fluid dilution survey was sent to 38 focus group members. Twenty-four individuals (63%) completed the survey. Table 45 shows a breakdown of respondents by the type of affiliated organization.

Results

The survey results are discussed under Findings and Applications. The detailed survey results are provided in Appendix C.

Table 45. Survey respondents by affiliated organization type.

Airlines	**45% (11)**
Major Airline	33% (8)
National Airline	4% (1)
Regional Airline	4% (1)
Major Air Carrier (non passenger)	4% (1)
Small (on demand) Air Carrier	0% (0)
DSPs	**25% (6)**
Deicing Service Provider (non	25% (6)
Airport Authority	0% (0)
Others	**29% (7)**
Deicing Trainer	8% (2)
Regulator/Government	13% (3)
Other	8% (2)
All Respondents	**100% (24)**

Cost-Benefit Model

A cost-benefit model was developed to assist operators in determining whether incorporating diluted fluids into their operations would be financially advantageous.

Development of the cost-benefit model was completed using a two-step approach. The first step identified potential parameters for use in the model, assessed their typical values, and estimated their influence from a cost-benefit perspective. The second step used the selected parameters to develop a model.

Step 1: Examination of Potential Cost-Benefit Model Parameters

A detailed examination of potential parameters was undertaken to determine their impact on model outcome. In the course of this examination, typical values for each parameter were established. These values were then combined in a preliminary assessment of potential savings by aircraft type, and an estimate of the number of deicing events necessary in order to recoup the investment. The preliminary assessment showed that use of fluid dilutions may be cost beneficial depending upon the cost of deicing equipment, cost of fluid, and the number of deicing operations per season.

A detailed examination of potential cost-benefit model parameters is provided in Appendix D.

In addition to its use for selecting parameters to be included in the model, the examination provided parameter values that may be useful to operators in their application of the model. Typical costs for purchasing different fluid blends are documented, as well as supplemental capital costs for proportional blending systems, and operational costs for additional training and maintenance. The examination discusses typical fluid amounts dispensed for various aircraft types. Use of these parameter values may enable the user to conduct a preliminary feasibility study using the model, before going to the effort of developing costs specific to their own situation.

The potential parameters considered for the cost-benefit model are given in the following list:

1. Deicing equipment with proportional blending versus conventional equipment;
2. Cost of aircraft de/anti-icing fluids;
3. Additional training of deicing personnel;
4. Additional inspection requirements;
5. Additional training documentation;
6. Additional training for the flight crew;
7. Additional maintenance requirements;
8. Environmental concerns—savings;
9. Savings in de/anti-icing time; and
10. Preliminary estimate of cost/fluid savings using dilutions.

In the examination of potential parameters, it was concluded that there is no need for additional inspections or for additional flight crew training. Time taken for deicing and anti-icing is not affected by the use of dilute fluid, so that parameter was also excluded. Finally, whereas there may be a quantitative value associated with reduced environmental impact of lower glycol usage, this is not a factor lying within the potential user's financial budget, and thus this factor was also eliminated from the model development.

The remaining six parameters on the list were incorporated into the cost-benefit model.

Step 2: Cost-Benefit Model Development and Testing

The cost-benefit model went through several iterations before the final version was completed. The various aspects of the model and its functionality are described below.

Model Objective

The model was built to determine the financial and glycol costs/savings that operators could achieve by incorporating diluted fluids into their operations. The model evaluates two potential changes:

1. Switching from Type I ready-to-use fluid to buffer fluid; and
2. Switching from Type II/III/IV neat fluid to a combination of neat fluid and diluted fluids.

The model can be used to evaluate the impact of a Type I change alone, a Type II/III/IV change alone, or the impact of changing both Type I and Type II/III/IV fluids.

Model Structure

The model was developed as a Microsoft Excel workbook. There are six worksheets (or pages) in the workbook. The user works sequentially from the first page to the last page, following the instructions provided on the first page and at the bottom of each subsequent page. Specific instructions and/or comments for some cells are provided in notes attached to the cells. The content of each of the six pages is described below.

Instructions: This page describes what the model will do, provides general instructions for using the model, describes some of the assumptions in the model, and provides a disclaimer about the use of the model.

Assumptions: This page lists the assumptions used in the model. The user is able to alter several default values on this page.

Background: This page requires user input. It contains a number of background questions. These questions determine if the model will be used for Type I fluid, Type II/III/IV fluid, or both. They also determine variables unique to the user and their current operation.

Costs: This page also requires user input. The user is required to enter costs involved in making the change or changes to the type of fluid being used. There are four cost categories: capital costs, one time set-up costs, annual fixed costs, and variable costs.

Results: This page provides the results of the model analysis. The key results are the annual financial savings, annual glycol savings, and number of years to breakeven.

Breakeven Schedule: This page shows the annual change in cash flow year by year. The key item on this page is the year that the initial investment (capital costs plus one time set-up costs) is paid off by the savings in fluid consumption.

User Inputs Required

In order to complete the model, users must have the following information available:

- Operations per winter season at different temperature ranges (for the fluid type or types that will be considered by the model);
- Average amount of fluid used per winter season (for the fluid type or types that will be considered by the model);
- Glycol percentage in currently used fluid(s);
- Price of currently used fluid(s);
- Price of fluid(s) to be used in diluted operation. Net cost of new equipment required to implement a diluted fluid operation, i.e., blending and storage equipment;
- Set-up costs, including: cost to gain in-house approval from all affected branches to proceed; cost to develop, publish, and approve new procedures; cost to include new procedures in airline deicing program and get approval; and cost to develop training materials;
- Cost of additional annual training that will be required for ground crews; and
- Additional maintenance costs for blending/storage equipment.

Assumptions Used in the Model

The model makes several assumptions in its calculations. Some of these assumptions are stated up front, some are user controlled, and some reside within the formulae in the workbook. The assumptions are listed on the assumptions page and described here:

1. If the user indicates a switch to a Type I buffer fluid and/or a diluted Type II/III/IV fluid is being considered, the model assumes the user is currently using a Type I ready-to-use and/or a Type II/III/IV neat fluid.
2. The model assumes if a switch is made to diluted Type I buffer fluid, all Type I fluids will be diluted to a selected buffer, even fluids used in the first step of a two step operation.
3. As glycol recovery costs are typically assessed on the amount of fluid, not glycol dispensed, no savings for glycol recovery costs were built into the model.
4. The model makes no distinction between Type II, Type III, and Type IV fluid. This was done as most stations have only one of these fluid types available.
5. The model does not include a factor for inflation, nor does it include a calculation to determine current value of future cash flows. This is relevant to the breakeven analysis.
6. In the glycol savings calculation, it is assumed that Type I concentrate is 100% glycol.
7. The percentage concentrate of Type I fluid required to achieve a specific FFP is assumed to be the same for all Type I fluids (the percentages used in the model are the average values of twelve Type I fluids), even though small differences are known to exist, specifically between propylene and ethylene based fluids.
8. The default FFP buffer for Type I fluids is 10°C. The user can modify the buffer to 15°C or 20°C on the assumptions page.
9. Assumptions were made in the calculation of fluid savings. These are described in detail in the following sections.

Calculation of Type I Fluid Savings

Several assumptions had to be made in order to estimate the amount of concentrate Type I fluid that would be required for diluted fluid operations. This section describes these assumptions and the specific calculations that are used in the model.

To calculate the volume of Type I concentrate required to produce the volume of Type I ready-to-use fluid currently used annually, three figures are required:

- The volume of fluid required at each OAT;
- The required FFP for each OAT; and
- The percentage concentrate of fluid required to achieve the required FFPs for the OATs.

To determine the volume of fluid required at different OATs, the user-entered data for annual number of operations at specific temperature ranges and the total amount of Type I fluid used per season were compared to determine the volume of fluid required in each temperature range. The lowest OAT in the range was assumed to be the OAT for all operations in the range.

The FFP required for each OAT is determined by the FFP buffer selected. The default value in the model is a 10°C buffer, but a 15°C or 20°C buffer can also be selected. For example, if the OAT is –3°C and a 10°C buffer is required, the fluid must have a FFP of –13°C.

The percentage concentrate required for each FFP was determined using a FFP curve developed using FFP—fluid concentrate content data collected for 12 Type I fluids. The data for the 12 fluids are shown in Table 46.

The percentage concentrate required for each FFP was then multiplied by the volume of fluid required at each FFP to determine the annual volume of Type I concentrate required. For example, if 2000 liters of ready-to-use fluid are used in operations at –15°C, then 2000 liters of fluid with a FFP of –25°C are required for a 10°C buffer operation. Since the average amount of concentrate required for a FFP of –25°C is 48%, the model will calculate 960 liters of concentrate (2000 L × 48%) are required to produce 2000 liters of Type I fluid at the appropriate FFP.

Calculation of Type II/III/IV Fluid Savings

Several assumptions had to be made in order to estimate the amount of neat Type II/III/IV fluid that would be required for diluted fluid operations. This section describes the assumptions and the specific calculations that were used in the model.

To calculate the amount of neat fluid required for a Type II/III/IV diluted fluid operation, two figures are required:

- The volume of fluid required at different OATs; and
- The percentage of operations that will use neat, 75/25, and 50/50 fluid at each OAT.

The volume of fluid required at different OATs is derived from the user-entered data for annual number of operations at specific temperature ranges and the total amount of Type II/III/IV fluid used per season.

The percentage of operations that use neat, 75/25 and 50/50 fluid at each OAT has to be estimated. The model uses the default values show in Table 47, but these values can be changed by the user on the assumptions page. The default values were set based on consultations with several individuals responsible for operations currently using diluted fluids.

To calculate the volume of neat fluid required for the diluted fluid operation, the volume of fluid required at each OAT is divided into the volume of fluid of each dilution. The volume of neat fluid required can then be calculated. For example, based on the usage information provided in Table 47, if 10,000 liters of fluid are required in the "< –3 to –6°C" temperature range, 50% of these operations would use neat fluid (50% × 10,000 liters × 100% = 5000 liters neat fluid required) and 50% would use 75/25 fluid (50% × 10,000 liters × 75% = 3750 liters neat fluid required) for a grand total of 8,750 liters neat fluid required (5000 + 3750 liters).

Model Output

The primary outputs of the model are the annual financial and glycol savings to be gained by implementing the selected changes in fluid use. The number of years until the initial investment is recouped (years to breakeven) is also calculated.

The annual financial savings are determined by:

- Calculating the annual savings in fluid costs by comparing the cost of fluid in the current operation (volume of fluid required in the current operation × price of current Type I ready-to-use and/or Type II/III/IV concentrate fluid) to the cost of the fluid in a diluted operation (volume of concen-

Table 46. Concentrate required to achieve Type I FFPs.

FFP (°C)	Concentrate Required for FFP						
	Fluid A	Fluid B	Fluid C	Fluid D	Fluid E	Fluid F	Fluid G
-9	28%	26%	27%	28%	25%	26%	27%
-13	32%	34%	35%	35%	30%	33%	33%
-16	n/a	n/a	n/a	38%	35%	36%	37%
-20	43%	44%	45%	43%	n/a	41%	42%
-25	n/a	n/a	50%	50%	n/a	48%	47%
-30	n/a	n/a	n/a	53%	48%	n/a	51%
-35	57%	59%	59%	n/a	55%	n/a	55%
-40	n/a	n/a	n/a	60%	n/a	60%	58%

FFP (°C)	Concentrate Required for FFP					
	Fluid H	Fluid I	Fluid J	Fluid K	Fluid L	12 Fluid Average
-9	21%	28%	28%	31%	20%	26%
-13	27%	35%	35%	35%	27%	33%
-16	32%	40%	40%	38%	32%	36%
-20	36%	45%	45%	43%	38%	42%
-25	42%	53%	51%	48%	44%	48%
-30	46%	58%	56%	53%	49%	52%
-35	50%	63%	62%	57%	54%	57%
-40	55%	68%	67%	60%	58%	61%

Table 47. Operations (%) using different Type II/III/IV fluid dilutions at given OAT ranges.

OAT Range	Operations Using Each Fluid Dilution		
	Neat	75/25	50/50
> 0°C	0%	50%	50%
< 0 to -3°C	25%	50%	25%
< -3 to -6°C	50%	50%	0%
< -6 to -10°C	75%	25%	0%
< -10 to -15°C	100%	0%	0%
< -15 to -20°C	100%	0%	0%
< -20 to -25°C	100%	0%	0%
< -25°C	100%	0%	0%

trate fluid required in a diluted operation × price of new Type I concentrate and/or Type II/III/IV concentrate); and

- Subtracting the additional annual fixed costs.

The annual glycol savings are determined by:

- Type I: Subtracting the liters of concentrate fluid required in the diluted operation (concentrate is assumed to be 100% glycol) from the liters of glycol required in the current operation (liters ready-to-use fluid required × glycol percentage in ready-to-use fluid); and
- Type II/III/IV: Subtracting the liters of neat fluid required in the diluted operation from the liters of neat fluid required in the standard operation and multiplying by the glycol percentage in the neat fluid.

The years to breakeven are determined by:

- Comparing the annual financial savings to the initial investment required (set-up costs plus capital costs) and determining how many years it will take for the annual savings to pay for the initial investment.

Model Testing

The cost-benefit model was refined and validated through a testing process. The testing process involved running the developed model through a variety of scenarios and situations created by inputting various parameter values representing both typical and extreme operations. This process confirmed that the model can provide reasonably accurate outcomes for a variety of situations and users.

Findings and Applications

The findings and applications of the work completed to examine the current practices and regulations, opportunities, limitations, obstacles, and potential benefits associated with the usage of diluted aircraft de/anti-icing fluids are addressed in this section.

Examination of Current Government and Industry Regulations, Guidance Material, and Standards Related to the Use of Fluid Dilutions

Adequacy of Current Regulations

Specific guidelines in SAE ARP 4737 address procedures for the application of Type I, II, III, and IV fluids in both one-step and two-step de/anti-icing procedures. These general guidelines are also contained in the guidance documents published annually by TC, the FAA, and the AEA. The TC documents are provided in Table 48 (SAE Type I Deicing Fluid Application Procedures) and Table 49 (SAE Type II, Type III, Type IV Anti-icing Fluid Application Procedures) for reference. These tables are taken from the Transport Canada Holdover Time Guidelines and are very similar to the tables in the SAE ARP 4737, FAA, and AEA guidance materials.

Results from the survey indicate that both airlines and DSPs feel the information contained in these tables provides adequate guidance for the use of fluids and their dilutions. Neither group recommended changes to the guidance material.

However, deicing trainers and others expressed the need for a possible modification, with the objective of encouraging greater use of fluid dilutions. This possible modification could be summed up in a direct quote from one respondent:

> The FAA and Transport Canada could add more language not necessarily to regulation CFR 14 121.629, or the Canadian equivalent, but perhaps to TP 14052, AC 120-60, or any annual guidance published by either regulator. Language could be included to encourage dilutions, and examples provided showing that dilutions are not as difficult to accomplish as perceived by numerous deicing entities. The AEA Deicing recommendations could employ a similar strategy. Since ARP 4737 is a recommended practice, language again could be added to better show the merits of more closely following FPD buffers instead of always using 50/50, or some other concentration where the buffer is much larger than needed.

Implication of the Availability of Diluted Fluid Holdover Times

Documents related to endurance time testing and the determination of holdover times were reviewed as part of the literature review.

Type I holdover times have been derived from endurance time tests with various fluids mixed to a 10°C buffer (i.e., the fluids are applied at a concentration such that the freezing point of the fluid is at least 10°C below that ambient temperature). The temperature and quantity of fluid applied in these tests is such that it replicates typical application of fluid on aircraft. In the course of the testing to develop these holdover times, associated research was conducted to compare the endurance times of fluids applied at a 10°C buffer versus fluid applied at standard 50/50 mixes which had more glycol. The research showed that the extra glycol 50/50 mixes did not provide significant endurance time benefits; generally, it was found that the heat from the fluid was a greater contributor to holdover times than the additional glycol. This result was also found to be true when research was conducted to examine the use of negative buffers that can be used for the first step of a two-step application. This research is documented in a TC Report TP13315E, *Aircraft Deicing Fluid Freeze Point Buffer*

Table 48. SAE Type I deicing fluid application procedures.

SAE TYPE I DEICING FLUID APPLICATION PROCEDURES

Guidelines for the application of SAE Type I fluid mixtures at minimum concentrations for the prevailing outside air temperature (OAT)

Outside Air Temperature (OAT)[1]	One-Step Procedure Deicing/Anti-icing	Two-Step Procedure	
		First Step: Deicing	Second Step: Anti-icing[2]
-3°C (27°F) and above	Heated mix of fluid and water with a freezing point of at least 10°C (18°F) below OAT	Heated water or a heated mix of fluid and water	Heated mix of fluid and water with a freezing point of at least 10°C (18°F) below OAT
Below -3°C (27°F)		Freezing point of heated fluid mixture shall not be more than 3°C (5°F) above OAT	

1 Fluids must not be used at temperatures below their lowest operational use temperature (LOUT).
2 To be applied before first step fluid freezes, typically within 3 minutes.

NOTES

- Temperature of water or fluid/water mixtures shall be at least 60°C (140°F) at the nozzle. Upper temperature limit shall not exceed fluid and aircraft manufacturers' recommendations.
- To use Type I holdover time guidelines in snow conditions, at least 1 litre/m² (~ 2 gal./100 sq. ft.) must be applied to the deiced surfaces.
- This table is applicable for the use of Type I Holdover Time Guidelines. If holdover times are not required, a temperature of 60°C (140°F) at the nozzle is desirable.
- The lowest operational use temperature (LOUT) for a given fluid is the higher of:
  a) The lowest temperature at which the fluid meets the aerodynamic acceptance test for a given aircraft type; or
  b) The actual freezing point of the fluid plus its freezing point buffer of 10°C (18°F).

CAUTION

- **Wing skin temperatures may differ and in some cases may be lower than outside air temperatures; a stronger mix (more glycol) may be needed under these conditions.**

Source: Table 6 of TC Holdover Time Guidelines

Requirements: Deicing Only and First Step of Two-Step Deicing, and in TP14714E, *Evaluation of Fluid Freeze Points in First-Step Application of Type I Fluids.*

Type II/III/IV fluid holdover times are derived from endurance time tests of fluids that are in pre-set concentrations: these are 100/0, 75/25, and 50/50. What is interesting with Type II/III/IV fluids is that in many cases the holdover times of the 75/25 fluids are equivalent to the holdover times of the 100/0 fluids; in a few cases the holdover time of the 75/25 dilution is slightly higher. Many fluids are designed such that the viscosity is higher at the 75/25 dilution than the viscosity at the 100/0 dilution; this fluid design characteristic provides the enhancement in the holdover times of the 75/25 dilution.

Type I and Type II/III/IV fluid holdover times have been developed at the concentrations that are described above. From a safety perspective, the holdover times are suitable for use with the described dilutions. The enhancement in holdover time is not significant as a result of using richer glycol mixes of Type I fluid nor when using a 100/0 mix of Type II/III/IV fluid versus a 75/25 mix. It can thereby be concluded that fluid dilutions provide an opportunity to reduce glycol without a significant loss of holdover time.

Findings of the Focus Group Survey

The detailed results of the focus group survey are provided question by question in Appendix C. For multiple choice questions, the percentage of respondents selecting each response is listed. For most multiple choice questions, the responses are also additionally broken out by organization type (i.e., airlines, DSPs, others). Each response provided for the short answer questions and comment areas is provided.

Table 49. SAE Type II, Type III, Type IV anti-icing fluid application procedures.

SAE TYPE II, TYPE III and TYPE IV ANTI-ICING FLUID APPLICATION PROCEDURES

Guidelines for the application of SAE Type II, III and IV fluid mixtures (minimum concentrations in % by volume) as a function of outside air temperature (OAT)

Outside Air Temperature (OAT)[1]	One-Step Procedure Deicing/Anti-icing	Two-Step Procedure	
		First Step: Deicing	Second Step: Anti-icing[2]
-3°C (27°F) and above	50/50 Heated[3] Type II/III/IV	Heated water or a heated mix of Type I, II, III or IV with water	50/50 Type II/III/IV
-14°C (7°F) and above	75/25 Heated[3] Type II/III/IV	Heated suitable mix of Type I, Type II/III/IV and water with FP not more than 3°C (5°F) above actual OAT	75/25 Type II/III/IV
-25°C (-13°F) and above	100/0 Heated[3] Type II/III/IV	Heated suitable mix of Type I, Type II/III/IV and water with FP not more than 3°C (5°F) above actual OAT	100/0 Type II/III/IV
Below -25°C (-13°F)	Type II/III/IV fluid may be used below -25°C (-13°F) provided that the OAT is at or above the LOUT. Consider the use of Type I when Type II/III/IV fluid cannot be used (see Table 6).		

1 Fluids must not be used at temperatures below their lowest operational use temperature (LOUT).
2 To be applied before first step fluid freezes, typically within 3 minutes.
3 Clean aircraft may be anti-iced with unheated fluid.

NOTES
- For heated fluids, a fluid temperature not less than 60°C (140°F) at the nozzle is desirable. When the first step is performed using a fluid/water mix with a freezing point above OAT, the temperature at the nozzle shall be at least 60°C and at least 1 litre/m^2 (2 gal./100 sq. ft.) shall be applied to the surfaces to be de-iced.
- Upper temperature limit shall not exceed fluid and aircraft manufacturers' recommendations.
- The lowest `operational use temperature (LOUT) for a given fluid is the higher of:
  a) The lowest temperature at which the fluid meets the aerodynamic acceptance test for a given aircraft type; or
  b) The actual freezing point of the fluid plus its freezing point buffer of 7°C (13°F).

CAUTIONS
- **Wing skin temperatures may differ and in some cases may be lower than outside air temperatures; a stronger mix (more glycol) may be needed under these conditions.**
- **Whenever frost or ice occurs on the lower surface of the wing in the area of the fuel tank, indicating a cold soaked wing, the 50/50 dilutions of Type II, III or IV shall not be used for the anti-icing step because fluid freezing may occur.**
- **An insufficient amount of anti-icing fluid may cause a substantial loss of holdover time. This is particularly true when using a Type I fluid mixture for the first step in a two-step procedure.**

Source: Table 7 of TC Holdover Time Guidelines

Some key findings from the survey include:

- De/anti-icing fluid use varies considerably from an approximate average of 100 liters for frost removal on a small turbo-prop transport to 1,500 liters for an operation in light freezing rain on a super jet transport.
- The majority of respondents (75%) feel that the current guidance material is adequate for conducting operations with diluted fluids.
- The top five factors given for influencing use of fluid dilutions were: fluid storage requirements, prevailing OAT during the winter deicing season, cost of fluid, cost of blending equipment, and replacement cost of modern deicing equipment.
- Of all anti-icing fluid types (Type II/III/IV) and dilutions (100/0, 75/25, 50/50) available, Type IV fluid 100/0 is used almost exclusively; diluted Type II/III/IV fluids are not commonly used.

- Ready-to-use Type I fluid is the most common form of Type I fluid used; 65% of Type I fluid use reported by respondents was with ready-to-use fluid rather than fluid mixed to specific FFP buffers.
- The majority (85%) of respondents do not use Type II, III or IV fluid mixes for one-step procedures.
- Of the respondents having proportional blending equipment, a 10°C buffer was most commonly used for Type I fluids.
- The majority of respondents (82 to 88%) do not use hot water for deicing as the first step in a two-step procedure, regardless if Type I fluid or Type II/III/IV fluid is used for the second step; nor do they use hot water for defrosting operations.
- Most operations at non-hub airports do not make use of diluted fluids.

The survey results are discussed further in the next section.

Application of Findings to Current Practice

The combined findings of the literature review, phone interviews, and focus group survey are examined in this section as they relate to current practices.

Extent of Use of Fluid Dilutions

Of all survey respondents, 65% use a ready-to-use Type I fluid mix such as 50/50 or 55/45, and 76% use a Type II or Type IV 100/0 fluid mix. No respondents indicated current use of a Type III fluid mix at this time.

For Type I fluid applications, the extent of use of a 10°C buffer and a 10 to 20°C buffer were about equal. A small percentage indicated use of a buffer of 30°C or higher: no explanation was given for the use of this high buffer. A large number of airline respondents were unsure as to the extent of use of high buffer fluids; presumably this is due to operations performed for them by DSPs.

Of those respondents who had Type I fluid proportioning equipment installed on deicers, 25% applied first-step deicing fluid with a FFP buffer of –3°C, while 41% used fluid with a FFP buffer of 10°C. For the same operators, 55% of anti-icing with Type I fluid was performed with a 10°C buffer.

Interviews indicated that airports with limited facilities, milder temperatures, or both use Type I mixes for anti-icing. The main use of Type II and Type IV blends was for defrosting related activities.

Over 85% of the airlines and DSPs interviewed do not use Type II, III or IV fluid mixes for the one-step de/anti-icing procedure. The respondents who do use Type II/III/IV fluids for this procedure indicated Type II 50/50 and Type IV 100/0 as the most commonly used fluids/mixes for this procedure.

Most deicing and anti-icing procedures occurring in freezing precipitation are performed using the two-step procedure. For the anti-icing step in the two-step procedure, 76% of all respondents indicated that they use a Type IV 100/0 fluid mix.

A number of interesting comments on the use of diluted fluids were given (see details in Appendix C). In general, they addressed:

- The respondents own particular situation or approach to using diluted fluids;
- A desire for a different mix (60/40) for Type II fluid;
- A lack of awareness or willingness of some DSP customers to accept use of fluid diluted to the full extent of the approved buffer;
- The need for attention to wing temperature differences from OAT; and
- Constraints due to limited labor skills.

Of those operators and DSPs that used deicing equipment with fluid proportioning capabilities, it was indicated that substantial savings in Type I fluid usage could be achieved. One respondent claimed reductions in Type I fluid glycol consumption as much as 63% in one season through use of dilutions.

Factors Influencing Decision to Use Fluid Dilutions

The survey asked respondents to rank the influence of a number of factors in the decision to use Type I ready-to-use mixes instead of fluids blended to appropriate buffer mixes, and 100/0 concentrations of Type IV fluids rather than 75/25 or 50/50 mixes. Tables 50 and 51 present the factors ranked in descending order of importance by the survey respondents for Type I fluid and Type IV fluid, respectively.

Several respondents indicated that additional fluid savings could be realized if forced air could be used in conjunction with proportional blending for deicing. To proceed with this approach, research would be required to determine if the use of forced air either in conjunction with Type I proportional blending or with full strength fluid is a suitable and safe procedure.

Use of 0°C to –3°C Buffer for First-Step Deicing

The optimum use of fluid dilutions occurs with the use of a 0/100 dilution or "Hot Water" for deicing. Regulatory guidance documents allow this procedure in the first step of a two-step application when the ambient temperature is –3°C and above. However, 88% of the survey respondents do not use this procedure. One concern mentioned was that the follow-up anti-icing fluid coating had to be a mix heated to 60°C, with the appropriate buffer, if Type I fluid was used. The 12%

Table 50. Decision factors for Type I fluid ready-to-use mix versus dilutions.

Rank	Decision Factors (Ranked in descending order of importance)
1	Fluid Storage Requirements
2	Prevailing OAT during the Winter Deicing Season
3	Cost of Fluid
4	Cost of Blending Equipment
5	Replacement Cost of Modern Deicing Equipment
6	Environmental Issues/Concerns
7	Cost of Fluid Application Equipment
8	Training of Deicing Personnel
9	Availability of Suitable Water to Effect Blending
10	Large Variations in OAT during a De/Anti-Icing Event
11	Protection Against Freeze up in Deicing Vehicle Systems
12	Fluid Quality Control Checks
13	Geographic Location of Airport
14	Location of Available Airport Space for Deicing Operations
15	Fluid Reclaim, Reuse, Reblending Factors
16	Fluid Availability
17	Checking/Inspection Equipment and Requirements
18	Need for Changes to Regulations/Guidance Documents
19	Fluid Application Time
20	Proximity to Fluid Manufacturer's Plant

Table 51. Decision factors for Type IV fluid 100/0 concentration versus 75/25 or 50/50 concentrations.

Rank	Decision Factors (Ranked in descending order of importance)
1	Cost of Blending Equipment
2	Prevailing OAT during the Winter Deicing Season
3	Cost of Fluid
4	Fluid Storage Requirements
5	Replacement Cost of Modern Deicing Equipment
6	Training of Deicing Personnel
7	Large Variations in OAT during a De/Anti-Icing Event
8	Environmental Issues/Concerns
9	Cost of Fluid Application Equipment
10	Geographic Location of Airport
11	Checking/Inspection Equipment and Requirements
12	Fluid Quality Control Checks
13	Fluid Reclaim, Reuse, Reblending Factors
14	Fluid Availability
15	Availability of Suitable Water to Effect Blending
16	Location of Available Airport Space for Deicing Operations
17	Fluid Application Time
18	Need for Changes to Regulations/Guidance Documents
19	Proximity to Fluid Manufacturer's Plant

that do use hot water for deicing reported no problems with its usage.

Similarly, regulations allow use of Type I fluids mixed to a −3°C buffer for first-step deicing when OAT is below −3°C. Only 24% of respondents make use of this procedure.

Use of Type I Ready-to-Use Mixes

Ready-to-use mixes of Type I fluids have been a mainstay of aircraft deicing operations in the past. Currently these mixes are still prevalent at most commercial service airports (hub, non-hub, reliever/feeder airports, and, to a greater extent, general aviation airports). The ready-to-use mixes are typically supplied in ≥ 1000 gallon tanks and 55 gallon drums. They are used with older or conventional deicing equipment that do not have proportional blending capabilities. Fluid manufacturers supply these ready-to-use mixes in blends requested by the user. The mix ratio may change during the deicing season to accommodate the colder months of the winter, with lower strength blends being supplied in the late fall, early winter time frame and in the early spring time frame. In addition, many airports will opt for the stronger concentrations, i.e., 60/40, if their site has a history of extreme cold climatic conditions throughout the deicing season.

Of these ready-to-use mixes, the 55/45 blend is possibly the mix used most often, as its freeze point is around −34°C for a propylene-glycol based fluid and is deemed to be adequate for most temperatures in the United States. The survey indicated that only 1 to 2% of airlines annual operations are delayed or suspended due to lowest operational use temperature (LOUT) inadequacies from deicing fluids.

The freeze point of a typical Type I 50/50 fluid mix varies from approximately −26°C to approximately −38°C depending primarily upon the type of glycol used. Thus, in the majority of deicing activities that occur in the −10°C to +3°C temperature band, an excessive fluid concentration is used.

The survey indicated 35% of respondents do not use a Type I ready-to-use mix. Of the remaining 65% that do use ready-to-use mixes, 24% used them most of the time, and only 12% used them all of the time.

Of those operators equipped with deicers having proportional blending capability, about 40% used ready-to-use mixes half of the time.

Use of Type I Concentrated Aircraft Deicing Fluid

Interviews indicated that many North American deicers at major hubs and large satellite airports procure Type I fluid in 100/0 concentration. These airports have blending capabilities (vehicular mounted or remote blending stations for pedestal mounted systems) and use 10°C buffer criteria for blend concentrations. To a lesser extent, Type I neat concentrations are supplied to outlying stations, however these stations must have blending capabilities since Type I 100/0 must be blended before application. In areas where there is a large excursion in temperatures, remote blending stations may require that the mixes be reblended often.

Use of Type II Fluids

Type II anti-icing fluids are a mainstay of the Western European and some Asian aviation communities, and are used in all concentrations. Airports with warmer prevailing climates such as London Gatwick (LGW) typically opt for the lower concentrations of 50/50 or 75/25 whereas many of the Northern European airports use the stronger concentrations as dictated by holdover time requirements. There was no record of Type II fluids being used in North America in recent years.

The survey respondents indicated that only diluted Type II (50/50 or 75/25) fluid is used in the one-step de/anti-icing procedure. For the second step of the two-step procedure, Type II showed very little use and that only at 100/0 strength.

Use of Type III Fluids

This fluid type, introduced early in the first decade of the 21st century, was intended to fill the need for a longer holdover time than Type I fluids, while being able to be pumped and applied by the existing conventional deicing units with a piston type pump system. Type III holdover times are significantly longer than those of Type I fluids. Of the DSPs and airlines surveyed, none use Type III fluids at this time; however, the fluid manufacturer has indicated that some airlines are using the fluid. This fluid is fully developed and approved. Endurance time tests have been conducted and holdover time guidelines are available for Type III fluid at all three concentrations.

Use of Type IV Fluids

Type IV fluid is the primary anti-icing fluid and is used by North American, Western European, and Asian deicers. In the 100/0 concentration it typically possesses the longest holdover times and is used in this concentration throughout North America, even though in many cases a 75/25 or 50/50 dilution would be sufficient to effect a safe takeoff in the prevailing freezing climatic condition. In several climatic conditions, the holdover times for 75/25 mixes of some Type IV fluids exceed those of the 100/0 concentration. This has been attributed to the fact that when water is added to the concentrated version of the fluid, the fluid builds up thicker on the surface, due to an increase in viscosity. This phenomenon in turn produces longer holdover times. Although most airlines are aware of this performance, Type IV fluid is still routinely applied in the 100/0 concentration. The survey indicated that 76% of users apply only full strength Type IV fluid for the second-step anti-icing application.

In the few cases where dilutions of Type IV fluid are applied, these mixes are typically of a 50/50 concentration and are used in frost removal procedures.

Deicing Equipment Requirements

Current deicing equipment is available in several configurations that include conventional equipment with one, two, three, or four tanks. For operations at general aviation and small regional airports, the one-tank system may be employed. It is usually non-motorized, holds 250–500 gallons, and would be filled with a 50/50 mix of Type I fluid. At many satellite and major airports the two-tank system is used. Here, one tank would hold a ready-to-use Type I fluid mix and the other would hold a much smaller quantity of 100/0 Type IV fluid. The three-tank system usually has a medium-to-large tank with capacities of ≥1000 gallons up to 3000+gallons. In this system one tank would contain water, one would contain Type I fluid, and one would contain either Type II or Type IV fluid. Water would normally be blended with the Type I fluid to achieve mixes with the required freeze point. In the four-tank system there would be a small standby tank for instant mixing and heating of deicing fluids just before application.

Some of these deicing systems may be equipped with a high velocity forced air system. This equipment has been shown to use less fluid than those of conventional design to achieve the same de/anti-icing capability. The least amount of fluid usage was obtained with those systems using a combination of forced air and a proportional blended Type I mix for deicing when climatic conditions permitted. Some deicing providers did not have the latter equipment with the forced air capability.

The survey indicated that more DSPs than airlines had deicers equipped with proportional blending capability. Forty-nine percent (49%) of operations conducted by DSPs are conducted with deicers having proportional blending capability, compared to 28% of aircraft deiced by airlines.

Use of Fluid Dilutions at Regional Airports

The survey indicated that regional non-hub and general aviation airports are unlikely to have equipment with proportional blending capabilities. Type I ready-to-use mix is the most commonly used fluid at these airports.

Manpower Requirements

Additional manpower is not required for the application of de/anti-icing fluid dilutions. However, additional training in the correct selection of dilution blends for ambient conditions, skin temperatures, or both is very important. Normally senior deicing inspection/checking personnel will dictate the correct blend requirements for ongoing deicing events. At sites with remote blending capabilities, vigilance is required in checking fluid concentrations to ensure that required FFPs and associated holdover time guideline performance are met.

Practice Limitations

De/anti-icing fluid dilutions should be used in accordance with the general guidelines contained in Tables 48 and 49. The operator must ensure that the requisite buffer requirement is adhered to for Type I fluids. In addition, for Type II, III, and IV fluids, the fluid concentration must be selected such that the LOUT and aerodynamic performance requirements (fluid flow off criteria) are met. SAE AIR 5633 presents information on the aforementioned forced air systems.

Application of Findings to Create Cost-Benefit Model

The cost-benefit model is a user-friendly tool that can be used by operators to determine if making a switch from ready-to-use Type I fluid or neat Type II/III/IV fluid to diluted fluids is financially advantageous. The model will estimate the annual cost savings, annual glycol savings, and number of years until the initial investment has been recouped.

The model was tested for different situations by inputting various parameter values representing typical and extreme operations. The model was refined and validated by this process. The final version of the model may be downloaded at the link found at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=122.

When applied to typical airport conditions, the model output clearly shows the value of implementing the use of diluted fluids in the deicing operation. In many cases, the financial outlay to implement use of diluted fluids can be recouped in a year or two. A sample of a completed model run using typical values for evaluating the introduction of diluted Type I fluid is provided. In the example, the model indicates that an initial investment of just over $1 million can be recouped in the course of one season, leading to operational savings of over $1 million per season thereafter.

Sample Completed Model

The following figures provide an example of running the model.

Figure 30—Instructions Page: The user is not required to enter any information on this page. The page does not change from user to user.

Figure 31—Assumptions Page: The user is not required to enter any information on this page, but may alter the default values used for the percentage of Type II/III/IV operations by fluid dilution and temperature if desired and/or the FFP buffer for Type I fluid. The user in this case has not altered the default values.

Figure 32—Background Page: The user has indicated on this page that he is considering a switch to Type I fluid mixed to a 10°C buffer, but not a switch to diluted Type II/III/IV fluids. The user has entered the number of annual operations with Type I fluid at the required temperature ranges, the amount of Type I fluid used per season (1,500,000 liters), the cost of the current Type I fluid ($2.00/liter), and the percentage of glycol in the current Type I fluid (55%).

INSTRUCTIONS

Welcome to the fluid dilutions cost-benefit model. This model will calculate the estimated annual glycol savings and cost savings that can be achieved by switching from a Type II/III/IV neat fluid only operation to a fluid dilutions operation and/or by switching from a Type I ready-to-use fluid operation to a Type I 10° buffer fluid operation. The model will also calculate the number of years it will take to breakeven from the initial investment required to implement diluted fluid operations.

Instructions: Fill in all cells that are shaded blue, except those where "not applicable" is indicated. When you have filled in all cells on a page, follow the instructions that appear in red at the bottom of the page. Further comments/instructions are provided in some cells. These comments/instructions are indicated by red triangles that appear in the upper right corner of the cell and can be seen by hovering over the cell.

Disclaimer: This model has been prepared by APS Aviation Inc. for the Transportation Research Board. The model makes several assumptions that may not be accurate in every business and/or operational environment. The user is recommended to review the assumptions listed on the next page and consider conducting further analysis if required.

To begin, go to the next page (Assumptions)

Figure 30. Sample instructions page.

ASSUMPTIONS USED IN THE MODEL

This model makes several assumptions about operations, fluid and fluid use that may not apply to every user. Users are encouraged to review the assumptions below to asses whether further analysis if required.

1. If considering a switch to diluted Type I and/or Type II/III/IV, the user currently uses Type I ready-to-use and/or Type II/III/IV neat fluid.
2. If a switching to diluted Type I fluid, all Type I fluid used will be diluted to the buffer, even fluid used in the first step of a two step operation.
3. Glycol recovery costs are not achieved by switching to diluted fluids, as they are assessed on the amount of fluid, not glycol, dispensed.
4. There is no distinction between Type II, Type III and Type IV fluid.
5. Inflation / current value of future cash flows are not relevant.
6. Type I concentrate is 100% glycol (for glycol savings calculation).
7. The percentage concentrate of Type I fluid required to achieve a specific fluid freeze point (FFP) is the same for all Type I fluids (the percentages used in the model are the average values of 12 Type I fluids).
8. The default fluid freeze point (FFP) buffer for Type I fluids is 10°C. The user can modify this to 15°C or 20°C to the right. **Type I FFP Buffer:** 10°C buffer
9. The percentage of Type II/III/IV operations that will use neat, 75/25 and 50/50 fluid at each OAT range must be estimated. The values below are the default values and are assumed to be correct unless modified by the user.

Temperature Range	Neat	75/25	50/50
a) > 0°C	0%	50%	50%
b) < 0 to -3°C	25%	50%	25%
c) < -3 to -6°C	50%	50%	0%
d) < -6 to -10°C	75%	25%	0%
e) < -10 to -15°C	100%	0%	0%
f) < -15°C	100%	0%	0%

Go to the next page (Background)

Figure 31. Sample assumptions page.

Figure 33—Costs Page: The user has estimated the costs associated with making a switch to diluted Type I fluid, including capital costs, setup costs, fixed annual costs and the price of the Type I concentrated fluid that will be used ($3.00/liter). It should be noted that in this scenario, the cost of the concentrated fluid that will be used is more than the cost of the premix fluid currently being used ($3.00/liter vs. $2.00/liter).

Figure 34—Results Page: This page provides the results of the model analysis. It shows that by switching to Type I diluted fluids, the user in this scenario will save $1,111,122 annually, will prevent 203,307 liters of glycol from entering the environment, and will recoup the initial investment (capital costs and setup costs) in the second year.

Figure 35—Breakeven Schedule Page: This page shows the initial investment required to switch to diluted fluid operations will be recouped in year two.

Clearly for this operator, switching from a Type I ready-to-use fluid to a Type I concentrated fluid blended to a 10°C buffer is a financially sound and environmentally advantageous decision.

Conclusions and Recommendations

The conclusions and recommendations resulting from this study of the use of diluted fluids for de/anti-icing aircraft are provided in this section.

Conclusions

A review was conducted of current government and industry regulations, guidance material, and standards related to the use of fluid dilutions. Several important conclusions came out of the literature review.

- Regulations do exist for the use of fluids and their dilutions and were deemed to be adequate. (A survey of airline and

BACKGROUND QUESTIONS - GENERAL

Question	Type I Fluid	Type II/III/IV Fluid
1. Are you considering switching from a Type I ready-to-use fluid to a Type I buffer fluid?	yes	
2. Are you considering switching from a Type II/III/IV neat fluid only operation to a Type II/III/IV neat and diluted fluid operation?	no	
3. How will you procure diluted Type II/III/IV fluid?	*not applicable*	
4. Do you prefer to complete this analysis using litres or gallons?	liters	
5. How many operations are conducted per winter season?	**Type I Fluid**	**Type II/III/IV Fluid**
a) above 0°C	250	*not applicable*
b) below 0°C to -3°C	500	*not applicable*
c) below -3°C to -6°C	1,200	*not applicable*
d) below -6°C to -10°C	1,700	*not applicable*
e) below -10°C to -15°C	800	*not applicable*
f) below -15°C to -20°C	450	*not applicable*
g) below -20°C to -25°C	200	*not applicable*
h) below -25°C	25	*not applicable*
All temperatures	5,125	*not applicable*
6. Average amount of fluid (in liters) used per winter season:	1,500,000	*not applicable*
7. Price (per litre) of currently used fluid:	$2.00	*not applicable*
8. Glycol (%) in currently used fluid:	55%	*not applicable*

This page is complete. Please go to the next page (Costs).

Figure 32. Sample background page.

CAPITAL COSTS - NEW EQUIPMENT

a) Cost of new blending trucks/equipment	$ 1,000,000
b) Cost of new fluid storage equipment	$ 150,000

FIXED COSTS - ONE TIME SETUP COSTS

a) Cost to gain in-house approval from all affected branches to proceed	$ 2,000
b) Cost to develop, publish and approve new procedures	$ 2,000
c) Cost to include new procedures in airline deicing program, get approval	$ 5,000
d) Cost to develop training materials	$ 10,000

FIXED COSTS - ANNUAL

a) Addtitional equipment maintenance costs					$ 15,000
b) Additional ground crew training costs	*employees*	55	*x cost per employee*	$ 160	$ 8,800

VARIABLE COSTS

Type I

a) Price (per liter) of Type I concentrate fluid	$ 3.00

Type II/III/IV

a) Price (per liter) of Type II/III/IV neat fluid	*not applicable*
a) Price (per liter) of Type II/III/IV 75/25 fluid	*not applicable*
a) Price (per liter) of Type II/III/IV 50/50 fluid	*not applicable*

Please fill in ALL of the empty blue cells above

Figure 33. Sample costs page.

RESULTS	
Type I Fluid Costs (per winter season)	
Current ready-to-use operation	$3,000,000
Proposed 10°C buffer operation	$1,865,078
Type II/III/IV Fluid Costs (per winter season)	
Current neat fluid operation	*not applicable*
Proposed diluted fluid operation	*not applicable*
Annual Fixed Costs (per winter season)	
Additional fixed costs related to fluid switch	$23,800
Impact of Implementing Fluid Switch (per winter season)	
Financial Savings	**$1,111,122**
Glycol Savings	**203307 liters**
Initial Investment Required to Switch to Diluted Fluids	
Set-up Costs	$19,000
Capital Costs	$1,150,000
Winter Seasons to Breakeven	**2**
See next page (Breakeven Schedule) for further details	

Figure 34. Sample results page.

DSPs later confirmed that users also feel that current regulations are adequate, although several respondents noted some clarification or elaboration of the regulations could be useful.); and

- Holdover times exist for diluted fluids and are published on an annual basis. In the case of Type I fluids, holdover times have been developed with fluids mixed to a 10°C buffer. In the case of Type II/III/IV fluids, holdover times have been developed for 100/0, 75/25, and 50/50 dilutions. Notably, the enhancement in holdover time is not significant as a result of using richer glycol mixes of Type I fluid nor when using 100/0 Type II/III/IV fluid rather than 75/25 diluted fluid. Therefore in many cases, glycol usage can be reduced without holdover times being reduced significantly.

A focus group from the deicing industry was surveyed to gather a more thorough and detailed understanding of the industry's perceptions and current usage of diluted fluids. Key findings from the survey are:

- Deicing and anti-icing fluid use varies considerably depending on aircraft size and precipitation condition.
- The top five factors influencing use of fluid dilutions are: fluid storage requirements, prevailing OAT during the winter deicing season, cost of fluid, cost of blending equipment, and replacement cost of modern deicing equipment.
- Of all anti-icing fluid types (Type II/III/IV) and strengths (100/0, 75/25, 50/50) available, Type IV 100/0 is used almost exclusively.
- Ready-to-use fluid is the most commonly used mixture of Type I fluid; Type I fluids mixed to FFP buffers are not commonly used.
- Type II, III or IV fluid mixes are infrequently used for one-step procedures.
- A 10°C buffer is the most common buffer used for Type I fluids by operators with proportional blending equipment.
- Hot water is rarely used for deicing as the first step in a two-step procedure, nor is hot water often used for defrosting operations.
- Most operations at non-hub airports do not make use of diluted fluids.
- Proportional blending systems to provide deicing fluids at the required buffers are readily achievable, and their costs can usually be recovered in one or two deicing seasons, depending upon the amount of deicing fluid sprayed.
- Additional training is required for both the deicing specialist and the senior deicing specialist on a yearly

BREAKEVEN SCHEDULE						
Winter Season	Capital Costs	Setup Costs	Operational Savings	Total Savings	Lifetime Savings	Breakeven Year
1	$1,150,000	$19,000	$1,111,122	-$57,878	-$57,878	no
2	n/a	n/a	$1,111,122	$1,111,122	$1,053,243	**yes**
3	n/a	n/a	$1,111,122	$1,111,122	$2,164,365	*reached prior*
4	n/a	n/a	$1,111,122	$1,111,122	$3,275,487	*reached prior*
5	n/a	n/a	$1,111,122	$1,111,122	$4,386,609	*reached prior*
6	n/a	n/a	$1,111,122	$1,111,122	$5,497,730	*reached prior*
7	n/a	n/a	$1,111,122	$1,111,122	$6,608,852	*reached prior*
8	n/a	n/a	$1,111,122	$1,111,122	$7,719,974	*reached prior*
9	n/a	n/a	$1,111,122	$1,111,122	$8,831,095	*reached prior*
10	n/a	n/a	$1,111,122	$1,111,122	$9,942,217	*reached prior*
11	n/a	n/a	$1,111,122	$1,111,122	$11,053,339	*reached prior*
12	n/a	n/a	$1,111,122	$1,111,122	$12,164,460	*reached prior*
13	n/a	n/a	$1,111,122	$1,111,122	$13,275,582	*reached prior*
14	n/a	n/a	$1,111,122	$1,111,122	$14,386,704	*reached prior*
15	n/a	n/a	$1,111,122	$1,111,122	$15,497,826	*reached prior*
16	n/a	n/a	$1,111,122	$1,111,122	$16,608,947	*reached prior*
17	n/a	n/a	$1,111,122	$1,111,122	$17,720,069	*reached prior*
18	n/a	n/a	$1,111,122	$1,111,122	$18,831,191	*reached prior*

Figure 35. Sample breakeven schedule page.

non-recurring basis. Additional maintenance training is required, since most modern blending systems incorporate microprocessor controllers and in-line refractometers.

- Additional flight crew training is not required.

A user-friendly cost-benefit model was developed for use by operators to determine if making a switch from ready-to-use Type I fluid or neat Type II/III/IV fluid to diluted fluids is financially advantageous. The model will estimate the annual cost savings, annual glycol savings, and number of years until the initial investment has been recouped. When applied to typical airport conditions, the model output clearly shows the value of implementing the use of dilute fluids in the deicing operation. In many cases, the financial outlay to implement use of diluted fluids can be recouped in a year or two.

Recommendations

Several survey respondents expressed the need for clarification and possibly expansion of the current guidance material related to fluid dilutions; it is therefore recommended that language be added to the guidance material to encourage the use of dilutions. Examples could also be provided to show that diluted fluids are not as difficult to incorporate into operations as commonly perceived.

Appendixes

Appendixes from this report are available at the ACRP Project 10-01 webpage at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=122.

Chapter 1
Appendix A: Revised Experimental Plan

Chapter 2
Appendix A: Summary of Optimization Procedures or Technologies for Consideration in ACRP 10-01
Appendix B: Regulatory, Government and Industry Documentation, Guidance Material and Standards Review
Appendix C: Rating of Regulatory, Government and Industry Documentation
Appendix D: Review of Aircraft Ground Deicing-Related Patents
Appendix E: Focus Group Survey
Appendix F: List of Survey Respondents
Appendix G: Detailed Survey Results

Chapter 3
Appendix A: Test Procedures Used For Data Collection
- Montreal/Mirabel Data Collection
- Syracuse Data Collection 2008–2009
- Denver Data Collection 2008–2009

Appendix B: Detailed Log of Tests
- YUL, Events 1 to 9
- YMX, Events 10 and 11
- DYR, Events 12 and 13
- DEN, Events 14 and 15

Appendix C: Between-Site Differences in HOT For Selected Fluids

Chapter 4
- Spot Deicing for Frost Cost-Benefit Model
- Presentation Aids for Increased Use of Spot Deicing for Aircraft Frost Removal

Chapter 5
- Fluid Dilutions Cost-Benefit Model
- Presentation Aids for Increased Use of ADAF Dilutions

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation