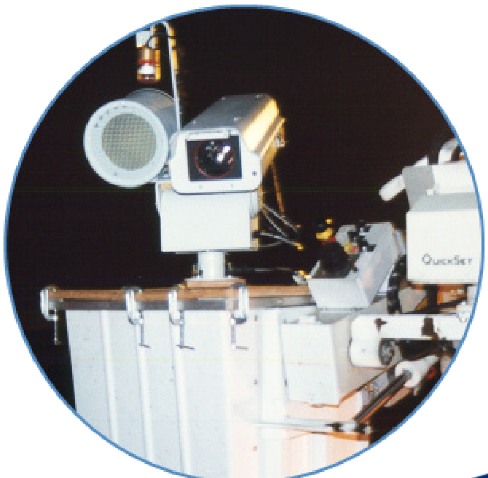
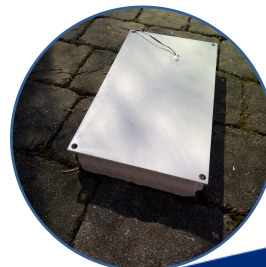
TP 15200E

Cold Climate Technologies – Investigation of Sensor Technologies as an Alternative Means of Detecting Aircraft Icing

(Year 1 of 3)





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In cooperation with

Civil Aviation
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and

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William J. Hughes Technical Center

Prepared by

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December 2012
Final Version 1.0

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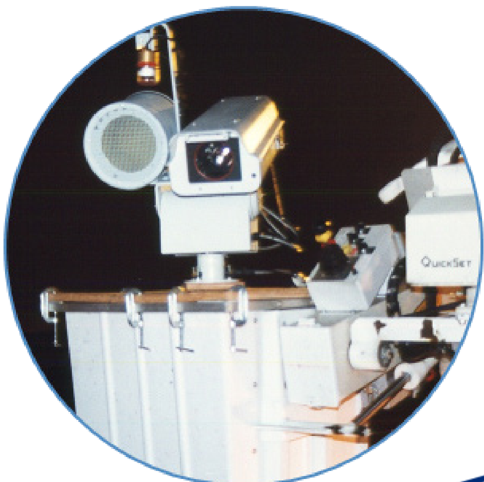

by

John D'Avirro and Marco Ruggi

December 2012
Final Version 1.0

The contents of this report reflect the views of APS Aviation Inc. and not necessarily the official view or opinions of the Transportation Development Centre of Transport Canada.

The Transportation Development Centre does not endorse products or manufacturers. Trade or manufacturers' names appear in this report only because they are essential to its objectives.

DOCUMENT ORIGIN AND APPROVAL RECORD

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Un sommaire français se trouve avant la table des matières.

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PREFACE

Under contract to the Transportation Development Centre of Transport Canada with support from the Federal Aviation Administration, APS Aviation Inc. has undertaken a research program to advance aircraft ground de/anti-icing technology. The specific objectives of the APS Aviation Inc. test program are the following:

- To develop holdover time data for all newly-qualified de/anti-icing fluids and update and maintain the website for the holdover time guidelines;
- To evaluate weather data from previous winters that can have an impact on the format of the holdover time guidelines;
- To conduct tests to evaluate the effect of deployed flaps and slats prior to anti-icing;
- To conduct tests and research on surfaces treated with ice phobic products;
- To develop an SAE AIR for the evaluation of aircraft coatings;
- To support the evaluation of the NRC propulsion icing wind tunnel to determine its flow characteristics;
- To evaluate the use of sensors in determining active frost conditions;
- To continue research for development of ice detection capabilities for pre-deicing, engine deicing and departing aircraft at the runway threshold;
- To update the regression coefficient report with the newly-qualified de/anti-icing fluids; and
- To evaluate if Type II/IV holdover times can be developed for light and very light snow categories.

The research activities of the program conducted on behalf of Transport Canada during the winter of 2011-12 are documented in six reports. The titles of the reports are as follows:

- TP 15198E Regression Coefficients and Equations Used to Develop the Winter 2012-13 Aircraft Ground Deicing Holdover Time Tables;
- TP 15199E Research to Assess the Need for Remote On-Ground Ice Detection Systems (ROGIDS) at End-of-Runway;
- TP 15200E Cold Climate Technologies – Investigation of Sensor Technologies as an Alternative Means of Detecting Aircraft Icing (Year 1 of 3);
- TP 15201E Winter Weather Impact on Holdover Time Table Format (1995-2012);
- TP 15202E Aircraft Ground Icing General Research Activities During the 2011-12 Winter; and
- TP 15203E Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2011-12 Winter.

In addition, the following three interim reports are being prepared:

- *Evaluation of Endurance Times on Extended Flaps and Slats;*
- *Further Development of Ice Pellet Allowance Times: Characterization and Calibration of Wind Tunnel for Examining Anti-Icing Fluid Flow-Off Characteristics; and*
- *Investigation of Ice Phobic Technologies to Reduce Aircraft Icing in Northern and Cold Climates.*

This report, TP 15200E has the following objective:

- To investigate sensor technologies as an alternative means of detecting aircraft icing in northern and cold climates.

This objective was met by conducting seven individual research projects, each focusing on a different research initiative which included the use and development of sensor systems for ground de/anti-icing applications.

PROGRAM ACKNOWLEDGEMENTS

This multi-year research program has been funded by Transport Canada with support from the Federal Aviation Administration, William J. Hughes Technical Center, Atlantic City, NJ. This program could not have been accomplished without the participation of many organizations. APS Aviation Inc. would therefore like to thank the Transportation Development Centre of Transport Canada, the Federal Aviation Administration, National Research Council Canada, the Meteorological Service of Canada, and several fluid manufacturers.

APS Aviation Inc. would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data. This includes the following people: Steven Baker, Stephanie Bendickson, Jeffrey Bourgerois, John D’Avirro, Jesse Dybka, Daniel Fata, Benjamin Guthrie, Dany Posteraro, Marco Ruggi, James Smyth, David Youssef and Victoria Zoitakis.

Special thanks are extended to Howard Posluns, Yvan Chabot, Doug Ingold and Warren Underwood, who on behalf of the Transportation Development Centre and the Federal Aviation Administration, have participated, contributed and provided guidance in the preparation of these documents.

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

Several research reports for testing of de/anti-icing technologies were produced for previous winters on behalf of Transport Canada. These are available from the Transportation Development Centre. Several reports were produced as part of this winter's research program. Their subject matter is outlined in the preface. This project was co-sponsored by the Federal Aviation Administration.

16. Abstract

This research program aims to respond to the emerging challenges and opportunities for Canada and its northern communities and address Transport Canada's adaptation to cold and changing climates and sustainable transportation research and development strategic priorities.

The objective of the program is to investigate sensor technologies as an alternative means of detecting aircraft icing in northern and cold climates. Seven research projects, each with a different research initiative, were completed in the winter of 2011-12 to meet the program objective. The research projects are listed below.

1. Support for the Use of Ice Detection Cameras at End-of-Runway (including Flight Crew Survey and Analysis of Incident Reports).
2. Regression Coefficients and Equations Used to Develop the Winter 2012-13 Aircraft Ground Deicing Holdover Time Tables.
3. Development of Light and Very Light Snow Holdover Times for Type II and Type IV Fluids (Phases 1 & 2).
4. Support for Development of Specifications for HOTDS.
5. Non-Precipitation Type Dependent Regression Curves for LWE and HOTDS.
6. Variance Analysis of HOTDS 10-Minute Intensity Measurements.
7. Evaluation of Sensor for Nowcasting Active Frost.

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

Plusieurs rapports de recherche sur des essais de technologies de dégivrage et d'antigivrage ont été produits au cours des hivers précédents pour le compte de Transports Canada. Ils sont disponibles au Centre de développement des transports. De nombreux rapports ont été rédigés dans le cadre du programme de recherche de cet hiver. Leur objet apparaît à l'avant-propos. Ce projet était coparrainé par la Federal Aviation Administration.

16. Résumé

Ce programme de recherche vise à répondre aux possibilités et aux défis émergents qui se présentent au Canada et à ses communautés nordiques, ainsi qu'à se pencher sur les priorités stratégiques en matière de recherche et développement que sont pour Transports Canada l'adaptation au froid et aux changements climatiques et le transport durable.

L'objectif de ce programme est d'examiner l'utilisation des technologies de détection comme un autre moyen de déceler le givrage des aéronefs dans les climats nordiques et froids. Sept projets de recherche, chacun proposant une initiative de recherche différente, ont été menés au cours de l'hiver 2011-2012 afin d'atteindre l'objectif du programme. Ces projets de recherche sont énumérés ci-dessous.

1. Soutien à l'utilisation de caméras de détection de givre en bout de piste (incluant un sondage auprès des membres d'équipage et une analyse des comptes rendus d'incidents).
2. Coefficients et équations de régression utilisés pour produire les tableaux des durées d'efficacité relatives au dégivrage d'aéronefs au sol pour l'hiver 2012-2013.
3. Établissement des durées d'efficacité des liquides de type II et de type IV dans des conditions de neige faible et très faible (phases 1 et 2).
4. Soutien au développement de spécifications pour les HOTDS.
5. Courbes de régression indépendantes du type de précipitations pour les systèmes LWE et les HOTDS.
6. Analyse de la variance des mesures d'intensité relatives aux HOTDS par périodes de 10 minutes.
7. Évaluation des détecteurs pour les prévisions immédiates de givre actif.

17. Mots clés ROGIDS, détection de givre, comptes rendus d'incidents, sondage auprès des membres d'équipage, HOTDS, LWE, givre actif, neige très faible, dégivrage, durée d'efficacité	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires

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EXECUTIVE SUMMARY

Under contract to the Transportation Development Centre (TDC), APS Aviation Inc. (APS) undertook a research program to investigate sensor technologies as an alternative means of detecting aircraft icing in northern and cold climates. The research program was completed in response to the Government of Canada's Northern Strategy, which seeks to meet emerging challenges and opportunities for Canada's northern communities, and to Transport Canada's (TC) adaptation to cold and changing climates initiative and sustainable transportation research and development strategic priorities. This report contains the sensor technology research for the first year of a three-year program.

The research program involved three types of sensor technologies: ice detection on aircraft wings, sensor technology to measure precipitation intensity and type, and sensors to detect active frost.

Seven research projects, each with a different research initiative, were completed in the winter of 2011-12 as part of the sensor technologies research program. The following provides a summary of the conclusions and recommendations.

Support for the Use of Ice Detection Cameras at End-of-Runway (including Flight Crew Survey and Analysis of Incident Reports)

APS completed two research projects to evaluate the need for Remote On-Ground Ice Detection Systems (ROGIDS) at end-of-runway, which included a survey of flight crews and an analysis of accident reporting databases. Both research projects concluded that locating a ROGIDS at the departure end of the runway could have a significant positive impact on safety. As a result, it was recommended that resources be allocated to advance the use of ROGIDS technology for the end-of-runway application and that this work should be conducted with the guidance and support of the ROGIDS working group.

Regression Coefficients and Equations Used to Develop the Winter 2012-13 Aircraft Ground Deicing Holdover Time Tables

The 2012-13 regression information was published online on the TC Holdover Time (HOT) Guidelines website on July 18, 2012. The information can be used by Holdover Time Determination Systems (HOTDS) manufactures to calculate holdover times during the winter of 2012-13. It was recommended that both regression publications – the online document and the technical report – be updated in one year to reflect any changes made to the HOT Guidelines for the winter of 2013-14.

Development of Light and Very Light Snow Holdover Times for Type II and Type IV Fluids (Phases 1 & 2)

A four-phase project plan was developed. As part of Phases 1 and 2, a detailed analysis was completed to evaluate the robustness of existing snow data sets at light and very light rates of precipitation. The data sets that were identified as sufficiently robust can be used to calculate light and very light snow holdover times without further analysis or testing. Additional testing and analysis is required to determine light and very light snow holdover times for the data sets identified as non-robust. This work will be completed in the winter of 2012-13. The analysis also resulted in a table of HOTDS and Liquid Water Equivalent (LWE) systems. These rates were published in the TC Regression Information Publication in July 2012.

Support for Development of Specifications for HOTDS

Several years ago, APS participated in discussions with TC, Environment Canada and NAV CANADA to examine issues for certification of these systems. Discussions indicated that the system outputs consist of an operational tool and therefore could be introduced under an exemption to the Canadian Aviation Regulations (CARs). It was agreed that a performance-based specification would be developed to permit HOTDS to be operated under an Exemption to the *CAR Standard 622.11 – Ground Icing Operations*. The Federal Aviation Administration (FAA) is currently working on similar documentation. There was very limited activity by APS in the development of the TC Exemption and the FAA specification development in the winter of 2011-12.

Non-Precipitation Type Dependent Regression Curves for LWE and HOTDS

APS conducted further investigation into the feasibility of developing and using non-precipitation type dependent regression curves to predict holdover times. Although the current analysis approach provides appropriate non-precipitation type dependent regression curves for many fluids, it does not provide them for all fluids. Further work would be required to determine a methodology analysis that would be appropriate for determining regression curves that are independent of freezing precipitation type for all fluids. Although the approach would be more complex, it does appear to be possible and would provide significant benefits to developers and users of HOTDS and LWE systems.

Variance Analysis of HOTDS 10-Minute Intensity Measurements

An analysis was completed and shows that using longer measurement periods would reduce tolerance and allow HOTDS to benefit from longer holdover times, notably at lower precipitation rates. Further analysis is recommended to examine data at higher rates (lower holdover times). Another step is to calculate the 95 percent confidence in terms of a percentage of the measured rate rather than an absolute value.

Evaluation of Sensor for Nowcasting Active Frost

A series of tests were conducted in frost conditions to investigate the accuracy of predicting frost using the standard frosticator plate that is used for frost endurance time testing. Results indicate that this type of technology is feasible, but that more data is needed for further development and to enable use of the technology.

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SOMMAIRE

En vertu d'un contrat conclu avec le Centre de développement des transports, APS Aviation Inc. (APS) a entrepris de mener un programme de recherche afin d'examiner l'utilisation des technologies de détection comme un autre moyen de déceler le givrage des aéronefs dans les climats nordiques et froids. Ce programme de recherche a été mis en œuvre en réponse à la Stratégie pour le Nord du gouvernement du Canada, qui vise à relever les possibilités et les défis émergents qui se présentent au Canada et à ses communautés nordiques, ainsi qu'aux priorités stratégiques en matière de recherche et développement que sont pour Transports Canada (TC) l'adaptation au froid et aux changements climatiques et le transport durable. Ce rapport traite des études menées sur les technologies de détection au cours de la première année de ce programme de trois ans.

Le programme de recherche s'attardait à trois types de technologies de détection : la détection de givre sur les ailes des aéronefs, la technologie de détection permettant de mesurer l'intensité et le type de précipitations et les détecteurs de givre actif.

Sept projets de recherche, chacun proposant une initiative de recherche différente, ont été menés au cours de l'hiver 2011-2012 dans le cadre de ce programme sur les technologies de détection. Les pages qui suivent présentent un résumé des conclusions et recommandations mises de l'avant.

Soutien à l'utilisation de caméras de détection de givre en bout de piste (incluant un sondage auprès des membres d'équipage et une analyse des comptes rendus d'incidents)

APS a mené deux projets de recherche visant à évaluer la nécessité d'avoir des systèmes de détection à distance du givrage au sol (ROGIDS) en bout de piste. Ces projets incluaient, entre autres, un sondage auprès des membres d'équipage et l'analyse des bases de données sur les comptes rendus d'accidents. Ces deux projets de recherche ont permis de conclure que l'installation d'un ROGIDS à l'extrémité de départ d'une piste pouvait avoir d'importantes répercussions positives sur la sécurité. Par conséquent, il a été recommandé que des ressources soient allouées afin de promouvoir le recours à la technologie des ROGIDS en bout de piste, et que ce travail soit mené avec l'aide et le soutien du groupe de travail sur les ROGIDS.

Coefficients et équations de régression utilisés pour produire les tableaux des durées d'efficacité relatives au dégivrage d'aéronefs au sol pour l'hiver 2012-2013

L'information de régression pour 2012-2013 a été publiée en ligne le 18 juillet 2012, par l'entremise du site Web sur les lignes directrices relatives aux durées d'efficacité de TC. Elle peut servir aux fabricants de systèmes de détermination des durées d'efficacité (HOTDS) pour calculer les durées d'efficacité pour l'hiver 2012-2013. Il a été recommandé que les deux publications sur la régression — le document en ligne et le rapport technique – soient actualisées dans un an, afin de refléter tout changement apporté aux lignes directrices relatives aux durées d'efficacité pour l'hiver 2013-2014.

Établissement des durées d'efficacité des liquides de type II et de type IV dans des conditions de neige faible et très faible (phases 1 et 2)

Un plan de projet en quatre phases a été élaboré. Dans le cadre des phases 1 et 2, une analyse détaillée a été menée dans le but d'évaluer la solidité des ensembles existants de données relatives à la neige, à des taux de précipitations faibles et très faibles. Les ensembles de données jugés suffisamment solides peuvent être utilisés pour calculer les durées d'efficacité dans des conditions de neige faible et très faible, sans qu'il soit nécessaire de procéder à d'autres analyses ou tests. Des tests et analyses supplémentaires sont toutefois requis pour déterminer les durées d'efficacité dans des conditions de neige faible et très faible en ce qui concerne les ensembles de données considérés comme non solides. Cet exercice sera achevé durant l'hiver 2012-2013. L'analyse effectuée a également mené à la création d'un tableau pour les HOTDS et les systèmes d'équivalence en eau liquide (LWE). Ces taux apparaissent dans l'information de régression publiée par TC en juillet 2012.

Soutien au développement de spécifications pour les HOTDS

Il y a quelques années, APS a pris part, avec TC, Environnement Canada et NAV CANADA, à des discussions visant à examiner les questions entourant la certification de ces systèmes. Ces discussions ont révélé que les données de sortie de ces systèmes constituent un outil opérationnel et sont susceptibles, de ce fait, d'être utilisées en vertu d'une exemption au *Règlement de l'aviation canadien (RAC)*. Les participants à ces échanges ont convenu qu'une spécification basée sur la performance serait mise au point afin de permettre l'utilisation des HOTDS en vertu d'une exemption à la *Norme 622.11 du RAC – Opérations dans des conditions de givrage au sol*. La Federal Aviation Administration (FAA) travaille actuellement sur des documents similaires. Au cours de l'hiver 2011-2012, APS a consacré très peu de temps à la préparation de l'exemption de TC et à la mise au point de la spécification de la FAA.

Courbes de régression indépendantes du type de précipitations pour les systèmes LWE et les HOTDS

APS a mené de plus amples recherches sur la possibilité de concevoir et d'utiliser des courbes de régression indépendantes du type de précipitations pour prévoir les durées d'efficacité. Même si l'approche analytique actuellement employée fournit des courbes de régression indépendantes du type de précipitations appropriées pour plusieurs liquides, elle ne le fait pas pour tous les liquides. D'autres études seraient requises pour déterminer une analyse méthodologique qui s'avérerait adéquate pour établir des courbes de régression indépendantes du type de précipitations verglaçantes pour l'ensemble des liquides. Bien que cette approche soit plus complexe, elle semble possible, et serait susceptible d'apporter d'importants avantages aux concepteurs et aux utilisateurs des HOTDS et des systèmes LWE.

Analyse de la variance des mesures d'intensité relatives aux HOTDS par périodes de 10 minutes

L'analyse effectuée démontre que le recours à de plus longues périodes de mesure aurait pour effet de réduire la tolérance et de permettre aux HOTDS de profiter de durées d'efficacité prolongées, particulièrement à des taux de précipitations plus faibles. Un examen plus poussé est recommandé afin d'étudier les données obtenues à des taux plus élevés (durées d'efficacité moindres). Une autre mesure consiste à calculer le niveau de confiance de 95 pour cent comme un pourcentage du taux mesuré plutôt que comme une valeur absolue.

Évaluation des détecteurs pour les prévisions immédiates de givre actif

Une série de tests ont été menés dans des conditions de givre afin d'étudier l'exactitude des prévisions de givre obtenues à l'aide de la plaque à générateur d'humidité standard utilisée pour les essais d'endurance dans des conditions de givre. Les résultats de ces tests indiquent que ce type de technologie est possible, mais que plus de données sont nécessaires pour la développer davantage et permettre son utilisation.

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GLOSSARY

AIRA	Aircraft Icing Research Alliance
APS	APS Aviation Inc.
ASRS	Aviation Safety Reporting System (United States)
CADORS	Civil Aviation Daily Occurrence Reporting System (Canada)
FAA	Federal Aviation Administration
HOT	Holdover Time
HOTDS	Holdover Time Determination System
LWE	Liquid Water Equivalent
MSC	Meteorological Service of Canada
NRC	National Research Council Canada
ROGIDS	Remote On-Ground Ice Detection Systems
SAE	SAE International
TC	Transport Canada
TDC	Transportation Development Centre

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1. INTRODUCTION

Under winter precipitation conditions, aircraft are cleaned with a freezing point depressant fluid and protected against further accumulation by an additional application of such a fluid, possibly thickened to extend the protection time. Aircraft ground deicing had, until recently, never been researched and there is still an incomplete understanding of the hazard and potential solutions to reduce the risks posed by the operation of aircraft in winter precipitation conditions. This "winter operations contaminated aircraft – ground" program of research is aimed at overcoming this lack of knowledge.

Since the early 1990s, the Transportation Development Centre (TDC) of Transport Canada (TC) has managed and conducted de/anti-icing related tests at various sites in Canada; it has also coordinated worldwide testing and evaluation of evolving technologies related to de/anti-icing operations with the co-operation of the United States Federal Aviation Administration (FAA), the National Research Council Canada (NRC), the Meteorological Service of Canada (MSC), several major airlines, and deicing fluid manufacturers. The TDC is continuing its research, development, testing and evaluation program.

Under contract to the TDC, with financial support from the FAA, APS Aviation Inc. (APS) has undertaken research activities to further advance aircraft ground de/anti-icing technology.

The research program aims to respond to the Government of Canada's Northern Strategy, which seeks to meet emerging challenges and opportunities for Canada's northern communities, and address TC's adaptation to cold and changing climates initiative and sustainable transportation research and development strategic priorities. Additionally, Canada is an active member of the Aircraft Icing Research Alliance (AIRA), a strategic partnership that collaborates on aircraft icing research activities that improve the safety of aircraft operations in icing conditions.

1.1 Background

Cold temperature precipitation on various sections of aircraft, including wings and engines, poses a great risk for their safe functioning; these conditions tend to occur at greater length and increased intensity in Canada's cold climate regions. Additionally, airports with de/anti-icing capabilities can run the risk of departing aircraft with heavily contaminated anti-icing fluid if misleading information is used to determine the appropriate fluid holdover time.

To operate using ground de/anti-icing methods and fluids, both ground crews and flight crews must assess whether takeoff is safe based on weather information, visual assessments, and the use of standardized guidelines. Changing climatic conditions over recent years have made this practice more challenging. Another area of concern is the overuse of deicing and anti-icing fluids. Many of Canada's more remote airports are not fully equipped to manage run-off fluids in an environmentally sound manner and, as a consequence, there can be contamination of the surrounding sensitive ecological areas.

In response to these concerns, a research program was undertaken to examine and support the development of sensor devices that can detect ice and/or anti-icing fluid contamination conditions and the means for utilising and integrating into operations such devices for these purposes. These sensor technologies may be utilised to assist ground crews in cold climate deicing and anti-icing practices, assist airport operators in determining precise amounts of deicing and anti-icing fluids required, and assist flight crews in the assessment of aircraft overall airworthiness and safe takeoff conditions.

1.2 Objective

The objective of this project was to investigate sensor technologies as an alternative means of detecting aircraft icing in northern and cold climates. This report contains the sensor technology research for the first year of a three-year program. The research involved three types of sensor technologies: ice detection on aircraft wings, sensor technology to measure precipitation intensity and type, and sensors to detect active frost.

The work required for this research program was divided into seven projects, each focusing on a different research initiative. The seven projects, listed below, were conducted during the winter of 2011-12.

1. Support for the Use of Ice Detection Cameras at End-of-Runway (including Flight Crew Survey and Analysis of Incident Reports).
2. Regression Coefficients and Equations Used to Develop the Winter 2012-13 Aircraft Ground Deicing Holdover Time Tables.
3. Development of Light and Very Light Snow Holdover Times for Type II and Type IV Fluids (Phases 1 & 2).
4. Support for Development of Specifications for HOTDS.
5. Non-Precipitation Type Dependent Regression Curves for LWE and HOTDS.
6. Variance Analysis of HOTDS 10-Minute Intensity Measurements.
7. Evaluation of Sensor for Nowcasting Active Frost.

1.3 Report Format

This report provides a summary of each of the seven projects completed as part of the research program. The individual projects are documented in detail in three separate reports (referenced in the respective sections of this report). The goal of this report is to provide an overview of all research completed for the sensor technology project. Figure 1.1 demonstrates the relationship of each of the detailed project reports with respect to this report.

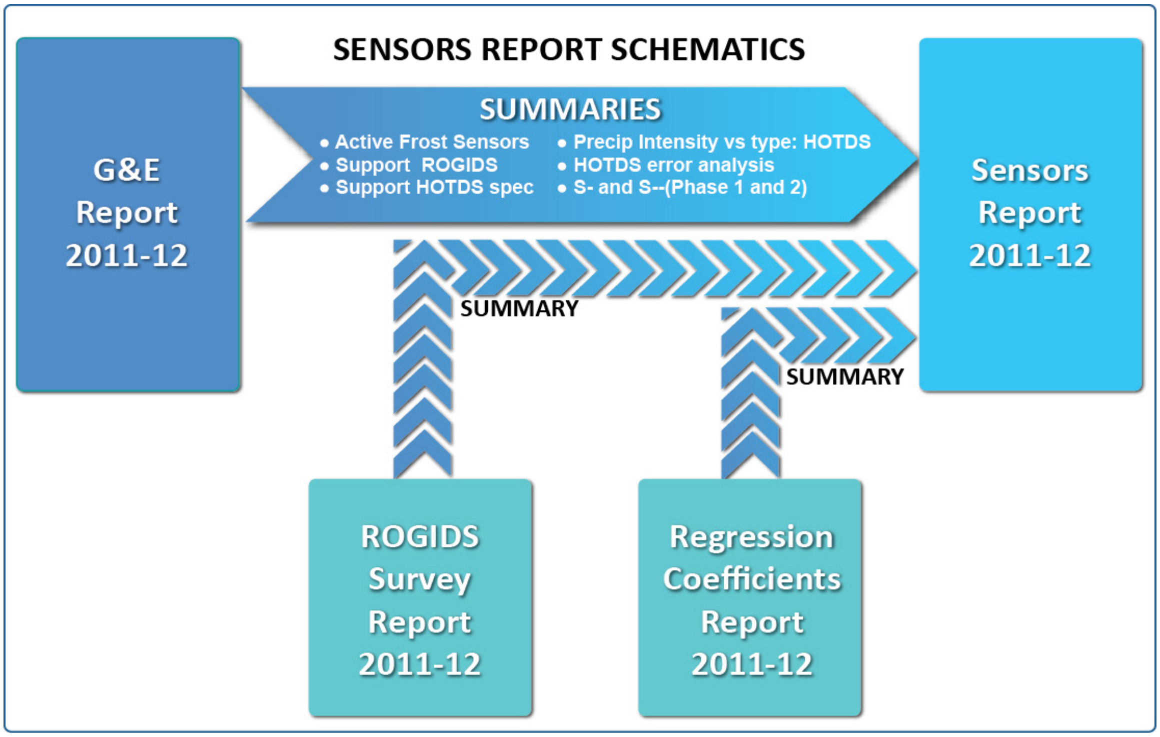


Figure 1.1: Report Relationship Schematic

Each of the following chapters summarizes one of the seven research projects completed as part of the sensor technologies research program. The content of the chapters is as follows:

- Section 2: Support for the use of Ice Detection Cameras at End-of-Runway (including Flight Crew Survey and Analysis of Incident Reports);
- Section 3: Regression Coefficients and Equations Used to Develop the Winter 2012-13 Aircraft Ground Deicing Holdover Time Tables;
- Section 4: Development of Light and Very Light Snow Holdover Times for Type II and Type IV Fluid (Phase 1 & 2);
- Section 5: Support for Development of Specifications for HOTDS;

- Section 6: Non-Precipitation Type Dependent Regression Curves for LWE and HOTDS;
- Section 7: Variance Analysis on 10-Minute Intensity Measurement for HOTDS; and
- Section 8: Evaluation of Sensor for Nowcasting Active Frost.

The sections of the TDC work statement pertaining to the work described in this report are provided in the separate detailed reports, and a copy has been included in Appendix A for reference.

1.4 Purpose of Consolidated Report

The TC – FAA joint aircraft ground icing research program is funded from several sources. Two components of the program are funded by TC: research on sensor technologies and research on ice phobic technologies. This report has been developed to document the work completed for the sensor technologies funding.

The report provides summaries of the seven projects completed as part of the sensor technologies research program, with the goal of providing an overview of all work completed as part of the program. Three separate reports document the seven projects in more detail. References to these reports are made in each project summary that follows.

2. SUPPORT FOR THE USE OF ICE DETECTION CAMERAS AT END-OF-RUNWAY (INCLUDING FLIGHT CREW SURVEY AND ANALYSIS OF INCIDENT REPORTS)

Remote on-ground ice detection systems (ROGIDS) have been in development for the aircraft ground icing industry for many years (see Photo 2.1). A significant amount of research has been conducted with these systems to assess their performance, with varying results over the years.

A turning point was reached in the winter of 2004-05, when research demonstrated that in certain scenarios, ROGIDS are more reliable than human visual and/or tactile checks in detecting clear ice on aircraft critical surfaces. An SAE International (SAE) work group was subsequently formed to develop an aerospace standard defining the minimum operational performance requirements for ROGIDS in this application. The standard was published by the SAE in September 2007 and was followed by TC and FAA Advisory Circulars in the years following.

Discussions in the working group about other potential applications for ROGIDS (end-of-runway, engine icing, and pre-deicing) determined the next application that should be focused on was the use of ROGIDS at the departure end of the runway. The working group determined that before operational research and new regulatory documents were considered, the need for ROGIDS at end-of-runway should be researched and documented.

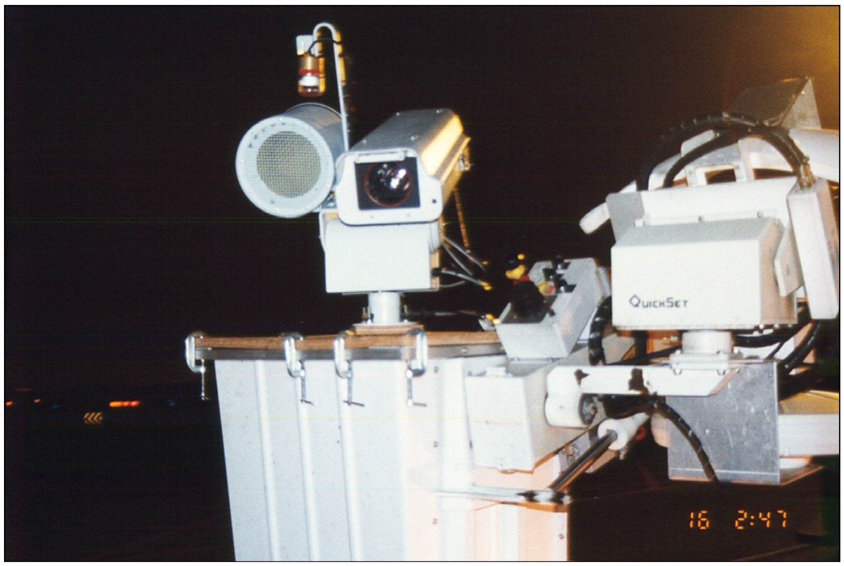
In addition to active participation in the work group, APS completed two research projects to evaluate the need for ROGIDS at end-of-runway, which included a survey of flight crews and an analysis of accident reporting databases.

- Flight Crew Survey: A survey of Canadian, American and international pilots was carried out to gather information on pre-takeoff contamination checks, to determine if pilots would accept/want a ROGIDS at the departure end of the runway, and to gather anecdotal information on the frequency of deicing-related turn backs.
- Analysis of Incident Reporting Data: Two incident reporting databases, Civil Aviation Daily Occurrence Report System (CADORS) and Aviation Safety Reporting System (ASRS), were investigated, with the objective of determining if ROGIDS could have prevented any reported incidents from occurring. The CADORS database did not provide sufficient detail to make this assessment, but 42 relevant reports were found in the ASRS database.

Both research projects concluded that locating a ROGIDS at the departure end of the runway could have a significant positive impact on safety. As a result, it was recommended that resources be allocated to advance the use of ROGIDS technology for the end-of-runway application and that this work should be conducted with the guidance and support of the ROGIDS working group.

For a detailed account of the work completed for this project, refer to TC report, TP 15199E, *Research to Assess the Need for Remote On-Ground Ice Detection Systems (ROGIDS) at End-of-Runway* (1).

Photo 2.1: Ice Detection Camera



3. REGRESSION COEFFICIENTS AND EQUATIONS USED TO DEVELOP THE WINTER 2012-13 AIRCRAFT GROUND DEICING HOLDOVER TIME TABLES

In recent years, several companies have developed systems that measure temperature, precipitation type, and precipitation rate in real-time. These systems, referred to as Holdover Time Determination Systems (HOTDS), use the weather data they collect and holdover time regression information to calculate more specific holdover times than the ranges that are currently provided in the HOT Guidelines.

In order for HOTDS to be used by operators, the regulatory authorities must make the regression information underlying the HOT Guidelines available to users. TC publishes two documents on holdover time regression information annually:

- An online document, which provides users with the regression information for the current winter's HOT Guidelines in a timely manner and user-friendly format; and
- A technical report, which documents how and from where the regression information provided in the online document was obtained.

The 2012-13 regression information was published online on the TC HOT Guidelines website on July 18, 2012. The information can be used by HOTDS manufactures to calculate holdover times during the winter of 2012-13.

It was recommended that both regression publications – the online document and the technical report – be updated in one year to reflect any changes made to the HOT Guidelines for the winter of 2013-14.

The TC report, TP 15198E, *Regression Coefficients and Equations Used to Develop the Winter 2012-13 Aircraft Ground Deicing Holdover Time Tables* (2), provides a detailed description of the work completed for this project.

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4. DEVELOPMENT OF LIGHT AND VERY LIGHT SNOW HOLDOVER TIMES FOR TYPE II AND TYPE IV FLUIDS (PHASES 1 & 2)

Through the forum of the SAE G-12 Holdover Time Committee, the aircraft ground deicing industry expressed the need for increased operational flexibility in lighter snow conditions. Specifically, a motion was passed at the May 2011 SAE G-12 Holdover Time Committee meeting in San Francisco requesting that TC and the FAA add light and very light snow columns to the Type II and Type IV holdover time tables to provide longer holdover times in lighter snow conditions.

Preliminary work was conducted following the May 2011 meeting to evaluate the feasibility of developing light and very light snow holdover times for Type II and Type IV fluids using the existing endurance time data and standard regression analysis methodology. It was concluded that sufficient data exists to develop light and very light snow holdover times using the standard regression analysis methodology for many, but not all, Type II and Type IV fluids.

Subsequently, a four-phase project plan was developed:

- Phase 1: Determine a minimum acceptable precipitation rate input for HOTDS and Liquid Water Equivalent (LWE) Systems;
- Phase 2: Evaluate the robustness of Type II, III and IV snow data sets at light and very light precipitation rates and identify non-robust data sets;
- Phase 3: Collect and evaluate new data for non-robust data sets and use this data to validate existing regression coefficients or determine appropriate new regression coefficients for these data sets; and
- Phase 4: Incorporate light and very light snow holdover times for Type II and Type IV fluids into the HOT guidelines.

As part of Phases 1 and 2, a detailed analysis was completed to evaluate the robustness of existing snow data sets at light and very light rates of precipitation. The data sets that were identified as sufficiently robust can be used to calculate light and very light snow holdover times without further analysis or testing. Additional testing and analysis is required to determine light and very light snow holdover times for the data sets identified as non-robust. This work will be completed in the winter of 2012-13. The analysis also resulted in a table of HOTDS and LWE systems. These rates were published in the TC Regression Information Publication in July 2012.

A complete account of the Phase 1 and Phase 2 activities can be found in TC report, TP 15202E, *Aircraft Ground Icing General Research Activities During the 2011-12 Winter* (3).

5. SUPPORT FOR DEVELOPMENT OF SPECIFICATIONS FOR HOTDS

HOTDS measure current weather conditions at pre-determined intervals (see Photo 5.1) and are designed for use at airports in winter weather conditions. The systems determine the current precipitation type, precipitation rate, and air temperature. With this information, they are able to determine a "single-value" fluid holdover time for the current conditions using published regression information (see Section 3). This information can then be relayed electronically to pilots in the flight deck.

Several years ago, APS participated in discussions with TC, Environment Canada and NAV CANADA to examine issues for certification of these systems. Discussions indicated that the system outputs consist of an operational tool and, therefore, could be introduced under an exemption to the Canadian Aviation Regulations (CARs). It was agreed that a performance-based specification would be developed to permit HOTDS to be operated under an Exemption to the *CAR Standard 622.11 – Ground Icing Operations*. The FAA is currently working on similar documentation.

There was very limited activity by APS in the development of the TC Exemption and the FAA specification development in the winter of 2011-12. A complete account of the Phase 1 and Phase 2 activities can be found in TP 15202E (3).

Photo 5.1: HOTDS Equipment

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6. NON-PRECIPITATION TYPE DEPENDENT REGRESSION CURVES FOR LWE AND HOTDS

LWE and HOTDS have been in development for almost a decade. These systems measure temperature, precipitation type, and precipitation rate in real-time and, in conjunction with fluid and holdover time regression information, use these measurements to calculate specific real-time holdover times. The holdover times are relayed directly to the cockpit and provide a number of benefits over holdover time tables, including extended holdover times, ease of use (by providing a single holdover time rather than a holdover time range), environmental savings and cost savings.

Although a number of these systems are in development, currently only one HOTDS is approved for use in Canada and no systems are approved for use in the United States. One of the reasons that these systems have not been commercialized is the inherent difficulty they have in determining precipitation type. As precipitation type determines which regression coefficients need to be used to determine holdover times, this difficulty has prevented many of the systems from being approved for use.

An idea was put forward to create non-precipitation type dependent curves for use with LWE and HOTDS. These curves would be derived from existing endurance time data. If the curves are reasonably accurate, the need for HOTDS and LWE systems to distinguish between precipitation types would be eliminated, thereby allowing more of the systems to be approved for use.

APS conducted further investigation into the feasibility of developing and using non-precipitation type dependent regression curves to predict holdover times. Although the current analysis approach provides appropriate non-precipitation type dependent regression curves for many fluids, it does not provide them for all fluids. Further work would be required to determine a methodology analysis that would be appropriate for determining regression curves that are independent of freezing precipitation type for all fluids. Although the approach would be more complex, it does appear to be possible and would provide significant benefits to developers and users of HOTDS and LWE systems.

A full account of the work completed for this project is provided in TP 15202E (3).

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7. VARIANCE ANALYSIS OF HOTDS 10-MINUTE INTENSITY MEASUREMENTS

The current TC exemption for use of HOTDS describes tolerances for precipitation rates that were determined using statistical analysis. The analysis was carried out using 10-minute precipitation rate data and a 95 percent confidence level was applied to the data. The objective of this project was to determine whether longer precipitation rate measurement periods would result in less variance.

An analysis was completed and shows that using longer measurement periods would reduce tolerance and allow HOTDS to benefit from longer holdover times, notably at lower precipitation rates. Further analysis is recommended to examine data at higher rates (lower holdover times).

Another step is to calculate the 95 percent confidence in terms of a percentage of the measured rate rather than an absolute value. For example, the 95 percent confidence additive should be much lower in absolute terms at 10.1 $g/dm^2/h$ than at 24.9 $g/dm^2/h$. This would allow a more realistic calculation of the measured rate plus the 95 percent confidence tolerance over all precipitation intensities, avoiding the artificial jumps crossing from 9.9 to 10.1 $g/dm^2/h$ or from 24.9 to 25.1 $g/dm^2/h$.

For a detailed account of the work completed for this project, refer to TP 15202E (3).

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8. EVALUATION OF SENSOR FOR NOWCASTING ACTIVE FROST

Frost is an important consideration in aircraft deicing. The irregular and rough frost accretion patterns can result in a significant loss of lift on critical aircraft surfaces. This potential hazard is amplified by the frequent occurrence of frost accretion in winter operations.

Currently, no standardized technology or manual approach is being used in aircraft operations to determine active frost conditions. Typically, visual inspections of aircraft surfaces and surroundings are performed to determine if frost conditions are active.

A series of tests were conducted in frost conditions to investigate the accuracy of predicting frost using the standard frosticator plate (see Photo 8.1) that is used for frost endurance time testing. Results indicate that this type of technology is feasible, but that more data is needed for further development and to enable use of the technology.

A complete account of this research can be found in TP 15202E (3).

Photo 8.1: Standard Frosticator Plate

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9. CONCLUSIONS AND RECOMENDATIONS

Seven research projects, each with a different research initiative, were completed in the winter of 2011-12 as part of the sensor technologies research program. The following provides a summary of the conclusions and recommendations.

9.1 Support for the Use of Ice Detection Cameras at End-of-Runway (including Flight Crew Survey and Analysis of Incident Reports)

APS completed two research projects to evaluate the need for ROGIDS at end-of-runway, which included a survey of flight crews and an analysis of accident reporting databases. Both research projects concluded that locating a ROGIDS at the departure end of the runway could have a significant positive impact on safety. As a result, it was recommended that resources be allocated to advance the use of ROGIDS technology for the end-of-runway application and that this work should be conducted with the guidance and support of the ROGIDS working group.

9.2 Regression Coefficients and Equations Used to Develop the Winter 2012-13 Aircraft Ground Deicing Holdover Time Tables

The 2012-13 regression information was published online on the TC HOT Guidelines website on July 18, 2012. The information can be used by HOTDS manufactures to calculate holdover times during the winter of 2012-13. It was recommended that both regression publications – the online document and the technical report – be updated in one year to reflect any changes made to the HOT Guidelines for the winter of 2013-14.

9.3 Development of Light and Very Light Snow Holdover Times for Type II and Type IV Fluids (Phases 1 & 2)

A four-phase project plan was developed. As part of Phases 1 and 2, a detailed analysis was completed to evaluate the robustness of existing snow data sets at light and very light rates of precipitation. The data sets that were identified as sufficiently robust can be used to calculate light and very light snow holdover times without further analysis or testing. Additional testing and analysis is required to determine light and very light snow holdover times for the data sets identified as non-robust. This work will be completed in the winter of 2012-13. The analysis also resulted in a table of HOTDS and LWE systems. These rates were published in the TC Regression Information Publication in July 2012.

9.4 Support for Development of Specifications for HOTDS

Several years ago, APS participated in discussions with TC, Environment Canada and NAV CANADA to examine issues for certification of these systems. Discussions indicated that the system outputs consist of an operational tool and therefore could be introduced under an exemption to the Canadian Aviation Regulations (CARs). It was agreed that a performance-based specification would be developed to permit HOTDS to be operated under an Exemption to the *CAR Standard 622.11 – Ground Icing Operations*. The FAA is currently working on similar documentation. There was very limited activity by APS in the development of the TC Exemption and the FAA specification development in the winter of 2011-12.

9.5 Non-Precipitation Type Dependent Regression Curves for LWE and HOTDS

APS conducted further investigation into the feasibility of developing and using non-precipitation type dependent regression curves to predict holdover times. Although the current analysis approach provides appropriate non-precipitation type dependent regression curves for many fluids, it does not provide them for all fluids. Further work would be required to determine a methodology analysis that would be appropriate for determining regression curves that are independent of freezing precipitation type for all fluids. Although the approach would be more complex, it does appear to be possible and would provide significant benefits to developers and users of HOTDS and LWE systems.

9.6 Variance Analysis of HOTDS 10-Minute Intensity Measurements

An analysis was completed and shows that using longer measurement periods would reduce tolerance and allow HOTDS to benefit from longer holdover times, notably at lower precipitation rates. Further analysis is recommended to examine data at higher rates (lower holdover times). Another step is to calculate the 95 percent confidence in terms of a percentage of the measured rate rather than an absolute value.

9.7 Evaluation of Sensor for Nowcasting Active Frost

A series of tests were conducted in frost conditions to investigate the accuracy of predicting frost using the standard frosticator plate (see Photo 8.1) that is used for frost endurance time testing. Results indicate that this type of technology is feasible, but that more data is needed for further development and to enable use of the technology.

REFERENCES

1) Bendickson, S., *Research to Assess the Need for Remote On-Ground Ice Detection Systems (ROGIDS) at End-of-Runway,* APS Aviation Inc., Transportation Development Centre, Montreal, November 2012, TP 15199E, XX (to be published).

2) Bendickson, S., *Regression Coefficients and Equations Used to Develop the Winter 2012-13 Aircraft Ground Deicing Holdover Time Tables,* APS Aviation Inc., Transportation Development Centre, Montreal, November 2012, TP 15198E, 42.

3) Bendickson, S., D'Avirro, J., Gravito, P., Ruggi, M., Youssef, D, Zoitakis, V., *Aircraft Ground Icing General Research Activities During the 2011-12 Winter,* APS Aviation Inc., Transportation Development Centre, Montreal, March 2013, TP 15202E, XX (to be published).

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APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE WORK STATEMENT EXCERPT – AIRCRAFT & ANTI-ICING FLUID – WINTER TESTING 2011-12

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT –
AIRCRAFT & ANTI-ICING FLUID –
WINTER TESTING 2011-12

3.16 Investigation of Sensor Technologies as an Alternative Means of Detecting Aircraft Icing

The focus of this project will be to examine and support the development of sensor devices that can detect ice, or can detect anti-icing fluid contamination conditions and the means for integrating such devices for these purposes:

The overall goal of this project will be to analyze sensor technologies that may be utilized to assist ground crew in typical cold climate deicing and anti-icing practices, assist airport operators in determining precise amounts of deicing and anti-icing fluids required and assist cockpit crew in the assessment of the aircraft's overall air worthiness and safe take-off conditions.

The specific research and work required for these activities include:

- A review of previous work completed on detection of ice on aircraft stabilizer, wing and engine surfaces at various locations throughout Canada to obtain a representative sample of current activities.
- Conduct stakeholder consultations and participate with industry members (airport authorities, aircraft operators, fluid manufacturers) to identify priorities and discuss issues with respect to innovative sensor technologies and the need to further investigate this area in the context flight safety, environmental sustainability and cost savings.
- In addition to potential current sensor technologies uses, investigate the feasibility of applicability to other aircraft parts or mechanisms (e.g. engine fan blades and cowlings).
- Identify the limitations of various northern and cold climate airport activity infrastructures (e.g. airstrips, deicing fluid mixing facilities) to manage excess and run-off fluids, determine exact requirements and potentially evaluate environmental compliance with various environmental standards.
- Identify the limitations and technological of current technologies for various climatic scenarios.
- Evaluate options of utilizing modern sensor technologies considering safety and efficiency of current de/anti-icing procedures and financial constraints of airport authorities and aircraft authorities.

- Carry out testing and simulations of sensor technologies and provide informed reports to Transport Canada and various stakeholders.

As part of this project, work will be conducted according to the following tasks:

3.16.1 Evaluation of Sensors for Determining Active Frost Conditions (For Nowcasting)

NOTE: Preliminary work was conducted with one sensor during the winter of 2009-10 and 2010-11 and results were promising. It is anticipated that testing will continue with this sensor, however additional technologies may be evaluated if they become available.

a) Conduct testing according to test plan;

b) Develop implementation plan for incorporating this technology into aircraft operations;

c) Evaluate potential use of technology for Nowcasting active frost conditions;

d) Analyze data collected; and

e) Report on the findings and present, as required, the results at the industry meetings.

3.16.2 Support: Pre-Deicing, Engine, and Runway Threshold Ice Detection

a) Review previous work completed on detection of ice on aircraft surfaces at a location close to the runway threshold. In addition, investigate feasibility of using this technology for pre-deicing applications and engine applications (fan blades and cowlings);

b) Identify the limitations of current technologies for the specific applications. Evaluate option of using low-tech alternative to sensor (i.e. binoculars) to allow for initial procedural implementation in operations while technology is being further developed;

c) Participate with industry members to discuss the need to further investigate this area of study; It is anticipated that four meetings of two days will be needed with the work group to develop a test implementation plan;

d) Determine testing requirements for preliminary full-scale or flat plate testing based on the recommendations from industry meetings. These tests will be defined during the meetings. While it would be desirable to do testing outdoors in natural snow, testing in simulated indoor conditions may be less costly and more realistic due to time constraints on the equipment;

e) Develop methodology and procedure for indoor NRC testing;

f) Conduct testing at the NRC CEF. Eight days of testing are anticipated at the NRC facility. This will require one person for all conditions;

g) Analyze data and results; and

h) Report the findings and prepare presentation material for the SAE G-12 meetings.

3.16.3 Support for Development of HOTDS Specifications and Systems

NOTE: This activity is to provide technical advice, and does not include testing or detailed assessment of HOTDS installations.

a) Provide support to evaluate data provided by HOTDS manufacturers.

3.16.4 Update: Regression Coefficients Used to Compute Holdover Times

a) Add FAA coefficients to cells where FAA and TC differ;

b) Prepare document suitable for online publication; and

c) Prepare a final report to document the applicable regression coefficients and verification tables required for the winter of 2012-13.

3.16.5 Use of Precipitation Intensity vs. Type for Determination of HOT's for LWE Systems

a) Develop analysis methodology for grouping different precipitation types;

b) Perform analysis to develop new regression equations independent of precipitation type;

c) Demonstrate impact of using intensity vs. type when generating HOT's; and

d) Report the findings and prepare presentation material for the SAE G-12 meetings.

3.16.6 HOTDS Error Analysis on 10-Minute Cycle vs. HOT

a) Develop analysis methodology for increasing comparative rate intervals;

b) Perform analysis to develop new performance specification of a HOTDS system based on longer rate intervals;

c) Demonstrate impact of using longer rate intervals on required tolerances; and

d) Report the findings and prepare presentation material for the SAE G-12 meetings.

3.18 S- & S—Phase 4 (Optional): Implementation of S- & S—HOT's

a) Use information gathered in Phase 2 and 3 to develop light and very light snow HOTs for all fluid-specific and generic Type II/III/IV HOT tables.

b) Meet with Transport Canada and FAA to determine how to incorporate new HOTs and how to address current outstanding issues (capping rules, operational concerns, HOTs for -25°C temperature band, TC/FAA harmonization, etc.).

c) Update HOT guidelines accordingly.

d) Report the findings and present, as required, the results at the industry meetings.