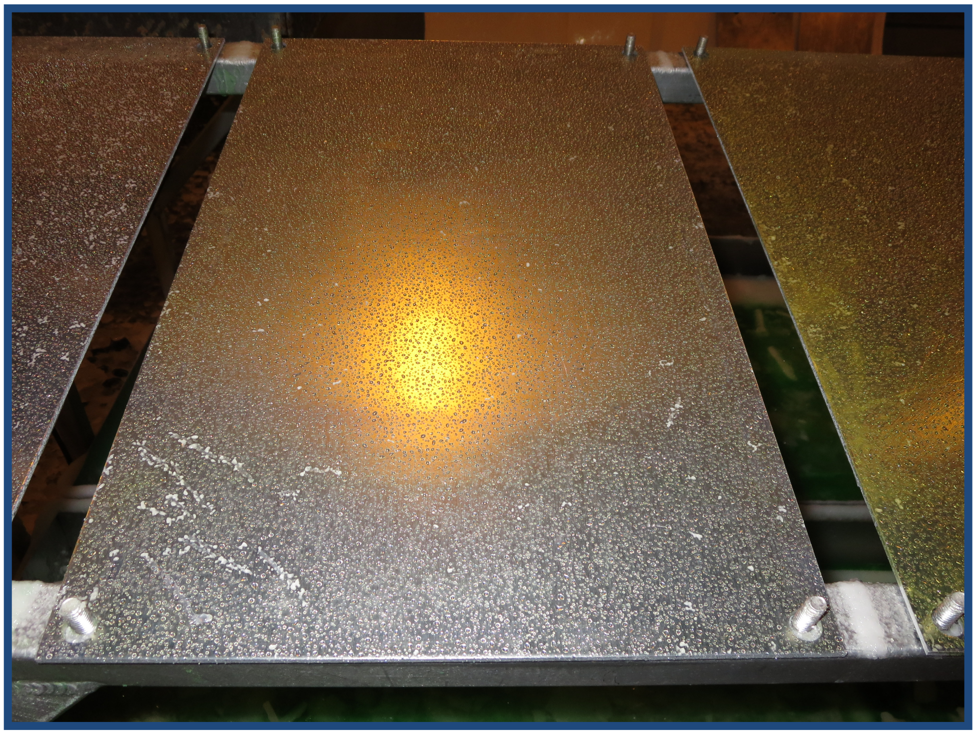
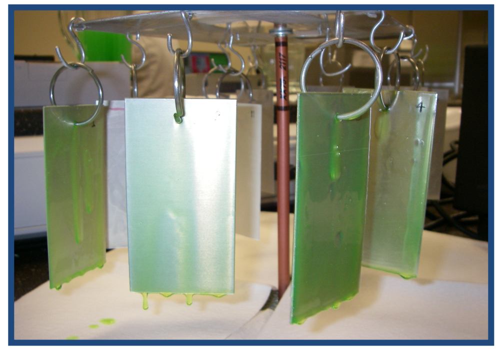
TP 15275E

INVESTIGATION OF ICE PHOBIC TECHNOLOGIES TO REDUCE AIRCRAFT ICING IN NORTHERN AND COLD CLIMATES
VOLUME 1 OF 4
SUMMARY REPORT





Prepared for
Transportation Development Centre

In cooperation with

Civil Aviation
Transport Canada

and

The Federal Aviation Administration
William J. Hughes Technical Center

Prepared by:

APS Aviation Inc.

October 2014
Final Version 1.0

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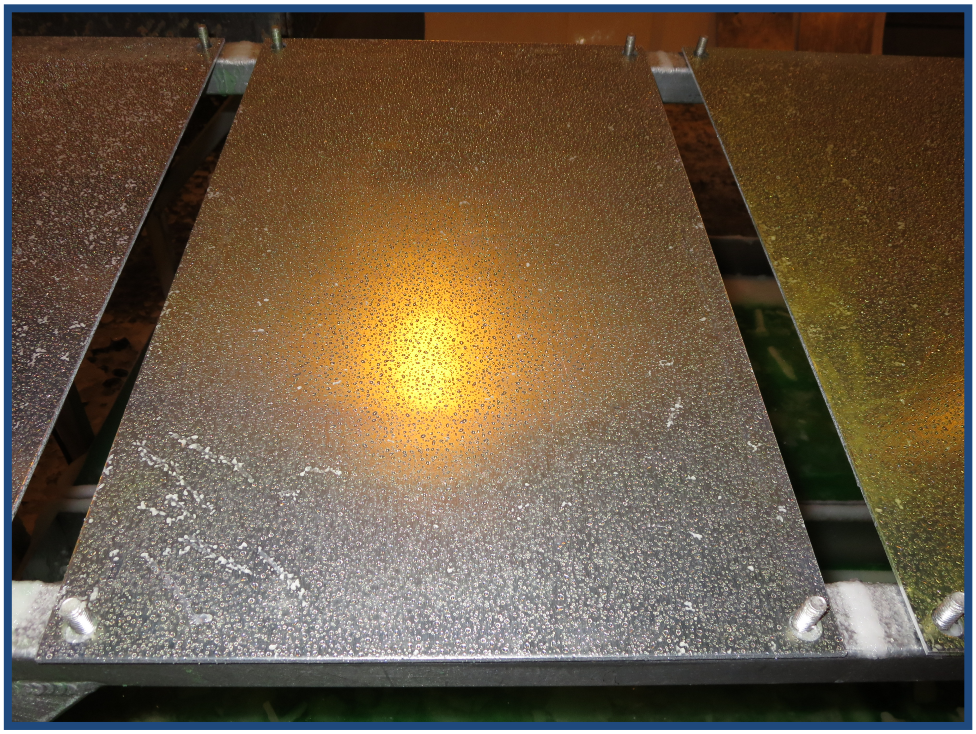

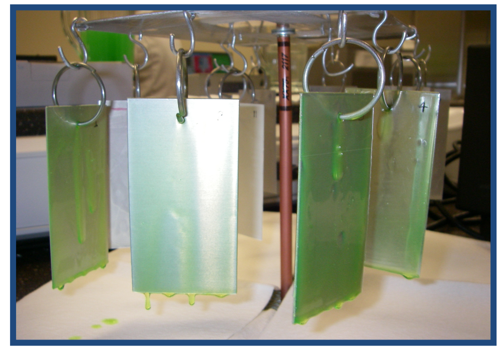

by

Marco Ruggi

Prepared by:

APS Aviation Inc.

October 2014

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

Prepared by:		July 28, 2017
	Marco Ruggi, Eng., M.B.A. Project Leader	Date
Reviewed by:		July 28, 2017
	John D'Avirro, Eng. Director, Aviation Services	Date
Approved by:	**	
	John Detombe Chief Engineer, Defence and Security ADGA Group Consultants Inc.	Date

**This report was prepared and signed by Marco Ruggi, reviewed and signed by John D'Avirro, and approved by John Detombe in (October 2014) as part of the first submission to Transport Canada (Final Draft 1.0). A final Transport Canada technical and editorial review was completed in (July 2017); John Detombe was not available to participate in the final review or to sign the current version of this report.

Un sommaire français se trouve avant la table des matières.

PREFACE

Under contract to the Transportation Development Centre of Transport Canada with support from the Federal Aviation Administration (FAA), APS Aviation Inc. (APS) has undertaken a research program to advance aircraft ground de/anti-icing technology. The specific objectives of the APS 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 general and exploratory de/anti-icing research;
- To conduct tests to evaluate the effect of deployed flaps/slats prior to anti-icing;
- To conduct tests and research on surfaces treated with ice phobic products;
- To conduct tests with the snowmaker to support ARP5485 changes;
- To conduct tests to evaluate holdover times in heavy snow conditions;
- 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 develop holdover time guidance for operation in ice crystal conditions;
- To continue research for development of ice detection capabilities for pre-deicing, engine deicing and departing aircraft at the runway threshold;
- To develop a performance specification for electronic holdover time applications;
- To investigate pre-take-off contamination check 5-minute allowance;
- To conduct full-scale general aviation aircraft windshield washer fluid deicing testing to substantiate and support flat plate testing results;
- To develop training and fluid failure photos/videos for global archive;
- To update the regression coefficient report with the newly-qualified de/anti-icing fluids; and
- To develop guidelines on radiation cooling during taxi.

The research activities of the program conducted on behalf of Transport Canada during the winter of 2013-14 are documented in seven reports. The titles of the reports are as follows:

- TP 15268E Winter Weather Impact on Holdover Time Table Format (1995-2014);
- TP 15269E Aircraft Ground Icing General Research Activities During the 2013-14 Winter;
- TP 15270E Regression Coefficients and Equations Used to Develop the Winter 2014-15 Aircraft Ground Deicing Holdover Time Tables;

- TP 15271E — Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2013-14 Winter;
- TP 15272E — Cold Climate Aviation Technologies - Investigation of Sensor Technologies as an Alternative Means of Detecting Aircraft Icing;
- TP 15273E — Development of Ice Pellet Allowance Times: Wind Tunnel Trials to Examine Anti-Icing Fluid Flow-Off Characteristics, Winter 2013-14;
- TP 15274E — Exploratory Wind Tunnel Aerodynamic Research Examination of Anti-Icing Fluid Flow-Off Characteristics, Winter 2013-14; and
- TP 15275E — Investigation of Ice Phobic Technologies to Reduce Aircraft Icing in Northern and Cold Climates.

In addition, the following one interim report is being prepared:

- *Evaluation of Endurance Times on Extended Flaps and Slats.*

This report, TP 15275E has the following objective:

- To conduct tests and research on surfaces treated with ice phobic products; and
- To develop an SAE AIR for the evaluation of aircraft coatings.

These objectives were met by conducting small scale flat plate and wind tunnel tests to evaluate the coated surface performance compared to a baseline uncoated surface. Research conducted has also become the basis for the development of an SAE document for the evaluation of the interaction of aircraft after-market coatings and de/anti-icing fluids.

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 would therefore like to thank the Transportation Development Centre of Transport Canada, the Federal Aviation Administration, National Research Council Canada, and several fluid manufacturers.

APS 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: Yelyzaveta Asnytska, Brandon Auclair; Steven Baker, Stephanie Bendickson, John D'Avirro, Jesse Dybka, Ben Falvo, Benjamin Guthrie, Michael Hawdur, Eric Perocchio, Dany Posteraro, Marco Ruggi, Gordon Smith, James Smyth, David Youssef, Nondas Zoitakis and Victoria Zoitakis.

Special thanks are extended to Howard Posluns, Yvan Chabot, Doug Ingold, Warren Underwood and Charles J. Enders, 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 (TDC). 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 report has the following objectives: to conduct tests and research on surfaces treated with ice phobic products and to develop an SAE AIR for the evaluation of aircraft coatings.

Under contract to TDC, APS Aviation Inc. (APS) undertook a test program to investigate the performance of de/anti-icing fluids on aluminum surfaces treated with ice phobic products and the possibility to reduce aircraft icing in northern and cold climates.
This report (Volume 1) contains a summary of the ice phobic research conducted during the three-year program.

- Summary of 2011-12 Testing (Section 2)

  The main purpose of this testing was to investigate some additional areas of research not previously studied to gain some new insight into the potential applications of these coatings for aircraft operations, and to continue the research to include newly developed coating formulations.

- Summary of 2012-13 Testing (Section 3)

  Testing served as a scoping study to gain some new insight into the potential applications of these coatings for aircraft operations, and to continue the research to include newly developed coating formulations.

- Summary of 2013-14 Testing (Section 4)

  Testing expanded on the previous work conducted the year before. New coating formulations were tested and evaluated using the methodologies developed in the previous years.

- Recommendations for Future Testing (Section 5)

Details from the individual testing years can be found in the related Volumes 2, 3, and 4.

17. Key Words Holdover Time, Endurance Time, Viscosity, Wind Tunnel, SAE AIR 6232, Vertical Stabilizer, Adherence Testing, Fluid Wetting, Fluid Thickness, Fluid Drainage	18. Distribution Statement Limited number of copies available from the Transportation Development Centre

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

Plusieurs rapports de recherches sur les essais de technologies de dégivrage et d'antigivrage ont été produits pour le compte de Transports Canada au cours des hivers précédents. Ils peuvent être obtenus du Centre de développement des transports (CDT). Plusieurs rapports ont été produits dans le cadre du programme de recherches de l'hiver en cours. Leur objet est exposé à la préface. Le présent projet a été coparrainé par la Fédéral Aviation Administration (FAA).

16. Résumé

Le présent rapport couvre les objectifs suivants : Mener des essais et des recherches sur des surfaces traitées avec des produits glaciophobes et élaborer un rapport d'information aéronautique (AIR) de la SAE sur l'évaluation de revêtements d'aéronefs.

En vertu d'un contrat avec le CDT, APS Aviation Inc. (APS) a entrepris un programme d'essais pour évaluer la performance de liquides de dégivrage et d'antigivrage sur des surfaces d'aluminium traitées avec des produits glaciophobes et sur la possibilité de réduire le givrage d'aéronefs dans les climats nordiques et froids. Le présent rapport (volume 1) comprend un sommaire des recherches sur les produits glaciophobes menées au cours du programme de trois ans.

- Sommaire des essais de 2011-2012 (Section 2)

  Ces essais avaient pour objectif principal d'examiner des domaines de recherche additionnels non étudiés auparavant, afin de mieux comprendre les applications possibles de ces revêtements pour l'exploitation d'aéronefs, ainsi que de poursuivre la recherche en y incluant des formules de revêtement nouvellement élaborées.

- Sommaire des essais de 2012-2013 (Section 3)

  Les essais ont servi d'étude exploratoire pour mieux comprendre les applications possibles de ces revêtements pour l'exploitation d'aéronefs, ainsi que de poursuivre la recherche en y incluant des formules de revêtement nouvellement élaborées.

- Sommaire des essais de 2013-2014 (Section 4)

  Les essais menés l'année précédente ont approfondi les travaux menés l'année antérieure. Les nouvelles formules de revêtement ont été mises à l'essai et évaluées à l'aide de méthodologies élaborées les années antérieures.

- Recommandations d'essais à venir (Section 5)

Les détails des essais de chaque année prise individuellement se trouvent aux volumes 2, 3, and 4 connexes.

17. Mots clés Durée d'efficacité, endurance, Viscosité, soufflerie, SAE AIR 6232, stabilisateur vertical, essais d'adhésion, mouillage de liquide, épaisseur du liquide, drainage du liquide.	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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EXECUTIVE SUMMARY

Under contract to TDC, APS Aviation Inc. (APS) undertook a test program to investigate the performance of de/anti-icing fluids on aluminum surfaces treated with ice phobic products and the possibility to reduce aircraft icing in northern and cold climates.

Ice build-up on aircraft is a major safety concern for both on-ground and in-flight aircraft operations. In recent years, there has been significant industry interest in the use of coatings to protect aircraft critical surfaces. Some recent work has studied these coatings (sometimes designed and marketed as ice phobic coatings) during in-flight operations, but the behaviour and performance of these coatings during ground icing operations has yet to be fully investigated.

Preliminary work has been conducted during the winters of 2009-10 and 2010-11 and the results are described in the TC report TP 15055E, *Emerging De/Anti-Icing Technology: Evaluation of Ice Phobic Products for Potential Use in Aircraft Operation* (1) and in the TC report TP 15158E, *Aircraft Ground Icing Research General Activities During the 2010-11 Winter* (2).

In 2011-2012, a three-year project was launched to assess the safety and effectiveness of ice phobic materials/coating and investigate the feasibility of employing ice phobic materials in the design of aircraft or specific aircraft sections that are more prone to icing.

This report contains a summary of the ice phobic research conducted during the three-year program. Details from the individual testing years can be found in the related Volumes 2, 3, and 4.

Testing in 2011-12 (Year 1 of 3) included natural snow testing, indoor simulated freezing precipitation testing, and wind tunnel testing. The main purpose of this testing was to investigate some additional areas of research not previously studied to gain some new insight into the potential applications of these coatings for aircraft operations, and to continue the research to include newly developed coating formulations. TC report, TP 15275E*, Investigation of Ice Phobic Technologies to Reduce Aircraft Icing in Northern and Cold Climates, Volume 2 of 4 (Year 1 of 3: 2011-2012 Testing Report)* contains the research from Year 1 of the three-year program.

Testing continued in 2012-13 and served as a scoping study to gain some new insight into the potential applications of these coatings for aircraft operations, and to continue the research to include newly developed coating formulations. Inconclusive but potentially promising results were observed on vertical surfaces, which are subject to early fluid failure due to the steeper surface slopes. The use of coatings on the vertical surfaces (i.e. vertical stabilizer, winglets, fuselage, etc.) could provide added protection from adherence of contamination. Preliminary work done simulating aerodynamically quiet areas in aircraft also indicated potential benefits to using ice phobic coatings; a potential solution to minimize residue formation which could apply to such areas. The application of coatings to the main wing sections demonstrated mixed results and is highly dependent on the coatings used. Some coatings have proven to be better than others in terms of compatibility with fluids. In general, testing has indicated that, with proper knowledge of the effects these coatings have on de/anti-icing fluid, the benefits of using these coatings can be had through adapted deicing procedures without compromising aircraft safety. TC report, TP 15275E, *Investigation of Ice Phobic Technologies to Reduce Aircraft Icing in Northern and Cold Climates, Volume 3 of 4 (Year 2 of 3: 2012-13 Testing Report)* contains the research from Year 2 of the three-year program.

The third year of the testing program was performed in 2013-14, which expanded on the previous work conducted the year before. New coating formulations were tested and evaluated using the methodologies developed in the previous years. Similar testing results were observed in that results were highly dependent on the coatings used. Some coatings have proven to be better than others in terms of compatibility with fluids. TC report, TP 15275E, *Investigation of Ice Phobic Technologies to Reduce Aircraft Icing in Northern and Cold Climates, Volume 4 of 4 (Year 3 of 3: 2013-14 Testing Report)* contains the research from Year 3 of the three-year program.

SOMMAIRE

En vertu d'un contrat avec le CDT, APS Aviation Inc. (APS) a entrepris un programme d'essais pour évaluer la performance de liquides de dégivrage et d'antigivrage sur des surfaces d'aluminium traitées avec des produits glaciophobes et sur la possibilité de réduire le givrage d'aéronefs dans les climats nordiques et froids.

La formation de glace sur les aéronefs est une préoccupation importante en terme de sécurité, autant pour l'exploitation d'aéronefs au sol qu'en vol. Au cours des dernières années, l'industrie a démontré un grand intérêt dans l'utilisation de recouvrements pour protéger les surfaces critiques des aéronefs. Des travaux récents ont étudié ces recouvrements (parfois conçus et mis en marché sous le nom de recouvrements glaciophobes) en vol, mais leur comportement et leur performance lors de dégivrages au sol n'ont pas encore été complètement examinés.

Les résultats des travaux préliminaires menés durant les hivers 2009-2010 et 2010-2011 sont précisés dans le rapport TP 15055E de TC : *Emerging De/Anti-Icing Technology: Evaluation of Ice Phobic Products for Potential Use in Aircraft Operation* (1) et dans le rapport TP 15158E de TC: *Aircraft Ground Icing Research General Activities During the 2010-11 Winter* (2).

En 2011-2012, un projet d'une durée de trois ans a été mis sur pied pour évaluer la sécurité et l'efficacité de matériaux et recouvrements glaciophobes et étudier la faisabilité d'utiliser des matériaux glaciophobes dans la conception d'aéronefs ou de sections particulières d'aéronefs plus sujettes au givrage.

Le présent rapport contient un sommaire des recherches glaciophobes menées au cours du programme de trois ans. Les détails des essais de chaque année prise individuellement se trouvent aux volumes 2, 3, and 4 connexes.

Les essais de l'année 2011-12 (1ère de 3 années) comprenaient des essais à l'extérieur dans la neige, des essais à l'intérieur dans la précipitation verglaçante simulée et des essais en soufflerie. Ces essais avaient pour objectif principal d'examiner des domaines de recherche additionnels non étudiés auparavant, afin de mieux comprendre les applications possibles de ces revêtements pour l'exploitation d'aéronefs, ainsi que de poursuivre la recherche en y incluant des formules de revêtement nouvellement élaborées. Le rapport TP 15275E de TC: *Investigation of Ice Phobic Technologies to Reduce Aircraft Icing in Northern and Cold Climates, Volume 2 of 4 (*1ère de 3 années *: Rapport d'essais de 2011-2012)* couvre la recherche de la première année du programme de trois ans.

Les recherches se sont poursuivies en 2012-2013 et ont servi d'étude exploratoire pour mieux comprendre les applications possibles de ces revêtements pour l'exploitation d'aéronefs, ainsi que pour poursuivre la recherche en y incluant des formules de revêtement nouvellement élaborées. Des résultats peu concluants mais éventuellement prometteurs ont été observés sur les surfaces verticales, qui sont sujettes à un échec précoce du liquide en raison de l'inclinaison plus prononcée des surfaces. L'utilisation de revêtements sur les surfaces verticales (par exemple le stabilisateur vertical, les ailettes de bout d'aile, le fuselage, etc.) pourrait ajouter une protection contre l'adhésion de contamination. Des travaux préliminaires qui simulaient les zones à l'abri d'écoulement aérodynamique indiquaient également des bénéfices potentiels à utiliser des revêtements glaciophobes, une solution possible pour réduire la formation de résidus sur ces zones. L'application de revêtements sur les principales sections des ailes a donné des résultats mitigés et dépend grandement des revêtements utilisés. Certains revêtements se sont avérés meilleurs que d'autres en termes de compatibilité avec les liquides. De façon générale, les essais ont démontré que, si l'on connait les effets de ces revêtements sur le liquide de dégivrage ou d'antigivrage, leur utilisation accompagnée de procédures adaptées de dégivrage peut être bénéfique, sans compromettre la sécurité aérienne. Le rapport TP 15275E de TC : *Investigation of Ice Phobic Technologies to Reduce Aircraft Icing in Northern and Cold Climates, Volume 3 of 4 (*2^e^ de 3 années *: Rapport d'essais de 2012-13)* couvre la recherche de la deuxième année du programme de trois ans.

Les travaux de la troisième année du programme d'essais ont eu lieu en 2013-2014 et poursuivaient les travaux menés l'année précédente. De nouvelles formules de revêtement ont été mises à l'essai et évaluées avec les méthodologies élaborées les années précédentes. Des résultats semblables ont été constatés, c'est-à-dire qu'ils étaient grandement sujets aux revêtements utilisés; certains revêtements se sont avérés meilleurs que d'autres en terme de compatibilité avec les liquides. Le rapport TP 15275E de TC : *Investigation of Ice Phobic Technologies to Reduce Aircraft Icing in Northern and Cold Climates, Volume 4 of 4 (*3^e^ de 3 années *: Rapport d'essais de 2013-14)* couvre la recherche de la troisième année du programme de trois ans.

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GLOSSARY

APS	APS Aviation Inc.
AIR	Aerospace Information Report
ARP	Aerospace Recommended Practice
FAA	Federal Aviation Administration
HOT	Holdover Time
NRC	National Research Council Canada
MSC	Meteorological Service of Canada
SAE	SAE International
TDC	Transportation Development Centre

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1. INTRODUCTION

Over the past several years, the Transportation Development Centre (TDC), 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 US Federal Aviation Administration (FAA), the National Research Council (NRC), 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 TDC, APS Aviation Inc. (APS) undertook a test program to investigate the performance of de/anti-icing fluids on aluminum surfaces treated with ice phobic coatings and the potential to reduce aircraft icing in northern and cold climates.

NOTE: The documentation of this project has been divided into four separate volumes: one summary report, and three detailed reports on each of the respective testing years' activities. The volumes are as follows:

Volume 1:	*Summary Report*
Volume 2:	*Year 1 of 3: 2011-12 Testing Report*
Volume 3:	*Year 2 of 3: 2012-13 Testing Report*
Volume 4:	*Year 3 of 3: 2013-14 Testing Report*

This report is Volume 1 of 4.

1.1 Background

Ice build-up on aircraft is a major safety concern for both on-ground and in-flight aircraft operations. In recent years, there has been significant industry interest in the use of coatings to protect aircraft critical surfaces. Some recent work has studied these coatings (sometimes designed and marketed as ice phobic coatings) during in-flight operations, but the behaviour and performance of these coatings during ground icing operations has yet to be fully investigated.

The results of testing in 2009-10 indicated that ice phobic products investigated were not an appropriate stand-alone substitute for de/anti-icing as they did not necessarily prevent freezing and adhesion of contamination, but could delay the onset of freezing. With respect to fluid thickness and endurance time testing, some ice phobic products demonstrated minimal differences compared to the baseline, whereas others demonstrated significant wetting issues and resulting endurance time reductions; these differences were coating and fluid specific. These results are described in detail in the TC report, TP 15055E, *Emerging De/Anti-Icing Technology: Evaluation of Ice Phobic Products for Potential Use in Aircraft Operation* (1).

In addition to the 2009-10 testing, work was conducted during the winter of 2010-11. This testing was limited and preliminary due to limited available funding and the timing of the tests. The main purpose of this testing was to obtain some initial insight into the potential new applications of these coatings for aircraft operations, and to continue the research to include newly developed coating formulations. These results are described in detail in the TC report, TP 15158E, *Aircraft Ground Icing Research General Activities During the 2010-11 Winter* (2).

In 2011-2012, a three-year project was launched to assess the safety and effectiveness of ice phobic materials/coating and investigate the feasibility of employing ice phobic materials in the design of aircraft or specific aircraft sections that are more prone to icing. This report contains a summary of the ice phobic research conducted during the three-year program. Details from the individual testing years can be found in the related Volumes 2, 3, and 4.

Testing in 2011-12 (Year 1 of 3) included natural snow testing, indoor simulated freezing precipitation testing, and wind tunnel testing. The main purpose of this testing was to investigate some additional areas of research not previously studied to gain some new insight into the potential applications of these coatings for aircraft operations, and to continue the research to include newly developed coating formulations. TC report, TP 15275E*, Investigation of Ice Phobic Technologies to Reduce Aircraft Icing in Northern and Cold Climates, Volume 2 of 4 (Year 1 of 3: 2011-12 Testing Report)* contains the research from Year 1 of the three-year program.

Testing continued in 2012-13 and served as a scoping study to gain some new insight into the potential applications of these coatings for aircraft operations, and to continue the research to include newly developed coating formulations. Potentially promising results were observed on vertical surfaces, which are subject to early fluid failure due to the steeper surface slopes. The use of coatings on the vertical surfaces (i.e. vertical stabilizer, winglets, fuselage, etc.) could provide added protection from adherence of contamination. Preliminary work done simulating aerodynamically quiet areas in aircraft also indicated potential benefits to using ice phobic coatings; a potential solution to minimize residues formation which could be applicable to such areas. The application of coatings to the main wing sections demonstrated mixed results and is highly dependent on the coatings used. Some coatings have proven to be better than others in terms of compatibility with fluids. In general, testing has indicated that with proper knowledge of the effects these coatings have on de/anti-icing fluid, the benefits of using these coatings can be had without compromising aircraft safety through adapted deicing procedures. TC report, TP 15275E, *Investigation of Ice Phobic Technologies to Reduce Aircraft Icing in Northern and Cold Climates, Volume 3 of 4 (Year 2 of 3: 2012-13 Testing Report)* contains the research from Year 2 (2012-13) of the three-year program.

The third year of the testing program was performed in 2013-14 which expanded on the previous work conducted the year before. New coating formulations were tested and evaluated using the methodologies developed in the previous years. Similar testing results were observed in that results were highly dependent on the coatings used; some coatings have proven to be better than others in terms of compatibility with fluids. TC report, TP 15275E, *Investigation of Ice Phobic Technologies to Reduce Aircraft Icing in Northern and Cold Climates, Volume 4 of 4 (Year 3 of 3: 2013-14 Testing Report)* contains the research from Year 3 of the three-year program.

1.2 Program Objectives

The objective of this program was to investigate the endurance time performance of fluids applied to surfaces treated with ice phobic products, as well as the performance of bare surfaces treated with ice phobic products.

1.3 Report Format

This report provides a summary of each of the three years of testing conducted as part of the research program. The individual projects are documented in detail in three separate reports included as Volumes to this report. The goal of this report is to provide a brief overview of research completed from 2011-12 to 2013-14. Figure 1.1 demonstrates the relationship of each of the detailed project reports with respect to this report.

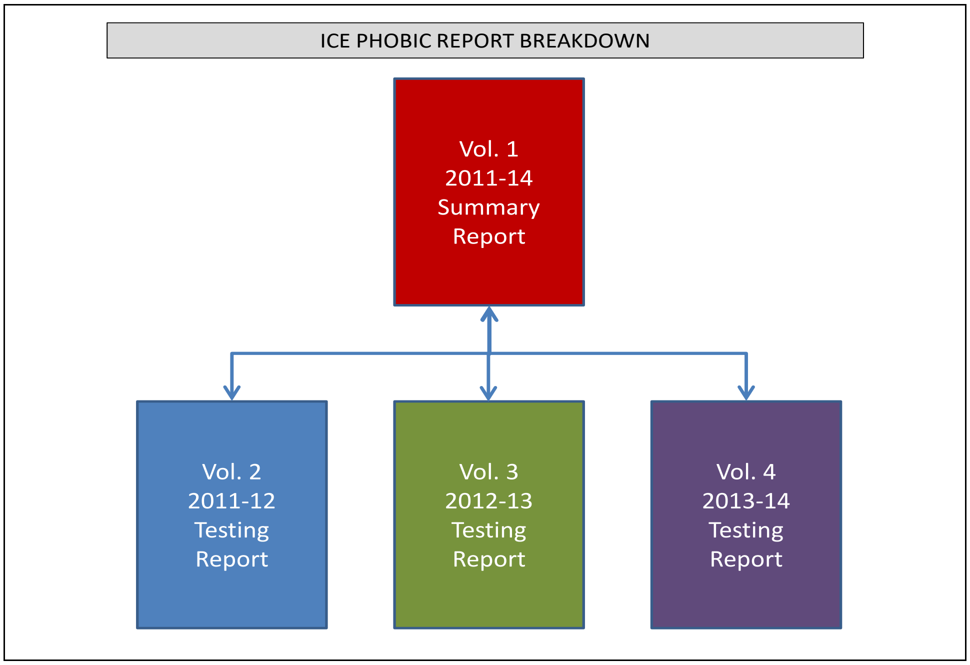

Figure 1.1: Report Relationship Schematic

Each of the following sections summarizes one of the three research years completed as part of the ice phobic research program. The content of the chapters is as follows:

- Section 2: Summary of 2011-12 Testing;
- Section 3: Summary of 2012-13 Testing;
- Section 4: Summary of 2013-14 Testing; and
- Section 5: Recommendations for future testing.

The sections of the TDC work statement pertaining to the work described in this report are provided in the separate detailed reports.

1.4 Purpose of Summary Report

Since 2011-12, a significant amount of work and analysis has been performed to investigate the use of ice phobic coatings and materials for use in aircraft ground icing applications. As the work has been ongoing, the reports were compiled as "Interim" and never officially published. The purpose of having a summary report with each of the previous interim reports included as volumes is to have an official documentation of the work completed. This also required a lesser level of effort as compared to a consolidated report; all interim reports have been included as volumes in "as-is" format.

2. SUMMARY OF 2011-12 TESTING

The details of this testing can be found in TC report, TP 15275E, entitled "*Investigation of Ice Phobic Technologies to Reduce Aircraft Icing in Northern and Cold Climates*, *Volume 2 of 4 (Year 1 of 3: 2011-12 Testing Report)*".

2.1 General Comments Regarding 2011-12 Testing

Testing conducted was limited and served as a scoping study. Only a limited number of products and conditions were tested. The main purpose of this testing was to investigate some additional areas of research not previously studied, to gain some new insight into the potential applications of these coatings for aircraft operations, and to continue the research to include newly developed coating formulations. More extensive material-specific data would be needed to demonstrate usability of products on aircraft critical surfaces.

2.2 Fluid Endurance Time Testing

The Type I results indicated longer protection times (not endurance times) for the I-PH B11 and I-PH C2 coated surfaces, primarily due to the hydrophobic nature of the coatings. The Type IV tests however, indicated reductions in protection time on the I-PH B11 coated plate when fluid dilutions were used. Comparatively, the I-PH C2 coating had a minimal effect on the Type IV performance in natural snow conditions. As compared to the Type I tests, the hydrophobic nature of the coating does not add to the Type IV protection time because the ice forms in the thin fluid layer of Type IV fluid as compared to on the bare plate surface for the Type I tests.

2.3 Fluid Wetting and Fluid Thickness Testing

The I-PH B11 coating seemed to have some adverse effects on the fluid's ability to properly become wet and provide adequate thickness on the surface. As compared to previous coating formulations provided by the same manufacturer, the coating tested in 2011-12 appears to be in the mid-range regarding fluid wetting and thickness performance.

2.4 Adherence Testing

When left undisturbed, the I-PH B11 coated surface was able to delay the onset of adherence and ice formation, as compared to the baseline test plate. In addition, the removal of the contamination was easier on the surface which was coated.

Some concern remains with the ice formation on the coated surface. The coated surface typically results in bumpier, higher contact angle ice formations. Aerodynamic research to investigate the effects is recommended. Similar trends were seen with other coatings from the same manufacturer.

2.5 Vertical Stabilizer Testing

The Type IV results indicated slightly longer endurance times for the vertical I-PH B3 coated surface. As testing was conducted with Type IV fluids only, no adherence was observed.

The application of ice phobic coatings on vertical surfaces has indicated potential benefits. Future testing should also focus on the use of Type I fluid on vertical surfaces, as in these cases, the ice phobic coating may provide additional protection against adhered contamination. Research should also be expanded to include winglets which may also be subject to early fluid failure.

2.6 Wind Tunnel Testing of Streamline Posts

The I-PH B11 coated streamline post appeared to have fluid in isolated areas, whereas the baseline uncoated surface was generally completely covered in a thin fluid film. The hydrophobic properties of the ice phobic coating may be repelling some of the fluid and causing the generally “streaky” fluid film coverage, which may in turn effect and possibly reduce fluid residue formation.

2.7 Fluid Drainage Testing from Aerodynamically Quiet Areas in Aircraft

The cups coated with I-PH B2 and I-PH B4 appeared to have fluid in isolated areas whereas the baseline and the I-PH A coated cup were generally completely covered in a thin fluid film. The hydrophobic properties of the I-PH B2 and I-PH B4 coating may be repelling some of the fluid and causing the fluid to puddle in isolated areas, which may in turn effect and possibly reduce fluid residue formation.

2.8 Overnight Ice Testing

The testing indicated that early on, the I-PH B3 coated surface was better able to shed super-cooled precipitation from the surface. However, this resulted in larger and longer icicles on the bottom of the test plate. Eventually, once both plates became covered with ice, there were no apparent differences; however, the coated surface did make it slightly easier to remove the frozen ice. Future testing should look at the overall thickness of ice formed to try and further quantify the ice phobic properties.

2.9 Development of SAE AIR

The working group approach proved to be an effective medium for developing and refining the SAE AIR. Communication with the working group should continue to include email and teleconference discussions along with in-person meetings in conjunction with the SAE G-12 meetings.

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3. SUMMARY OF 2012-13 TESTING

The details of this testing can be found in TC report, TP 15275E, entitled "*Investigation of Ice Phobic Technologies to Reduce Aircraft Icing in Northern and Cold Climates, Volume 3 of 4 (Year 2 of 3: 2012-13 Testing Report)*".

3.1 General Comments Regarding 2012-13 Testing

Testing conducted was limited and served as a scoping study; only a limited number of products and conditions were tested. The main purpose of this testing was to investigate some additional areas of research not previously studied, to gain some new insight into the potential applications of these coatings for aircraft operations, and to continue the research to include newly developed coating formulations. More extensive material-specific data would be needed to demonstrate usability of products on aircraft critical surfaces.

3.2 Fluid Endurance Time Testing

Fluid endurance time performance varied depending on individual coatings. Natural snow endurance times on coated surface with Type IV fluids were on average 75 percent of the baseline, ranging from 63 to 90 percent. Coating B12 and B13 sometimes demonstrated a different failure mechanism in which fluid was shed early allowing snow to bridge on the surface.

Freezing precipitation endurance times on coated surface with Type IV fluids were on average 94 percent of the baseline, ranging from 92 to 96 percent.

Freezing precipitation endurance times on coated surface with Type I fluids demonstrated similar results with the exception of coating B12 and B13, which demonstrated different failure mechanisms. At -3°C, these coatings delayed ice from forming on the surface, resulting in endurance times of 180 percent and 177 percent for B12 and B13, respectively.

3.3 Adherence Testing

When left undisturbed, some of the coated surfaces were able to slightly delay the onset of adherence and ice formation, as compared to the baseline test plate. All plates eventually accreted ice, however, the removal of the contamination was easier on the surface which was coated.

Some concern remains with the ice formation on the coated surface. Coated surfaces typically result in bumpier high contact angle ice formations. Aerodynamic research to investigate the effects is recommended.

3.4 Fluid Wetting and Fluid Thickness Testing

The Type I wetting tests indicated potential wetting problems with the coated test surfaces. Wetting issues were observed 5 minutes after fluid application; this wetting issue worsened with 10º buffer fluid as compared to standard mix fluid which is more concentrated.

With the exception of coating D1, the Type IV fluid thickness test demonstrated minor degradation in fluid thickness 5 minutes after application. Coating D1 appeared to react chemically with the fluid and caused a reduction in thickness right from the start.

3.5 Hot Water Testing

The hot water endurance times on the coated surfaces were generally comparable to the Type I endurance times on the baseline plate. In some cases, the coated surfaces delayed the onset of adhered contamination and provided slightly longer protection times.

3.6 Fluid Viscosity Testing

In the development of AIR6232, the question was raised as to whether lowest on-wing viscosity fluid or mid-viscosity fluid should be used for evaluation of endurance times on coated surfaces. The results of this testing indicate that either lowest on wing viscosity fluid or mid-viscosity fluid are adequate for evaluation of coatings with respect to endurance times.

3.7 Vertical Stabilizer Testing

The endurance times of the vertical coated surfaces were less than the vertical baseline surface.

In all cases, the endurance times of the vertical surfaces were significantly shorter than the 10° baseline plate.

3.8 Residues Testing for Aerodynamically Quiet Areas in Aircraft

Results indicate a potential solution to reduce residues formation in aerodynamically quiet areas in aircraft. Consideration should be given to including this test methodology in a future revision of AIR6232.

3.9 Wind Tunnel Testing - Ice Phobic Coatings

Testing is still preliminary and exploratory, however early testing indicates that:

- Coatings alone may have effects on aerodynamic performance (either for better or for worse);
- Frozen contamination on coated surfaces can be aerodynamically rougher; and
- Coatings do not seem to have significant effects on fluid flow-off performance.

The testing methodology is still premature, and future work should focus on repeatability in order to better develop the testing procedures. However, the wind tunnel can be a good platform for a full-scale evaluation of the coating performance. If the methodology does mature, consideration should be given to including the details in a future revision of AIR6232.

3.10 Development of SAE AIR6232

The principle focus of this AIR document is the impact coatings have on aircraft ground de/anti-icing fluid. This is addressed in two main section of the AIR:

- Section 3: Fluid Endurance Time Testing
- Section 4: Fluid Aerodynamic Testing

An additional Section 5 has also been included in the AIR to reference other test methods which may provide informational insight into the performance of the coatings which may or may not be directly related to the impact on de/anti-icing fluid HOT's.

The AIR format was selected because the workgroup felt that the development of an SAE AIR would be faster than the development of an ARP. The AIR could eventually be changed to an ARP once performance criteria were developed.

A draft document was prepared and finalized. The final ballot was passed in June 2013, and published in August 2013.

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4. SUMMARY OF 2013-14 TESTING

The details of this testing can be found in TC report, TP 15275E, entitled *"Investigation of Ice Phobic Technologies to Reduce Aircraft Icing in Northern and Cold Climates, Volume 4 of 4 (Year 3 of 3: 2013-14 Testing Report)"*.

4.1 General Comments Regarding 2013-14 Testing

Testing conducted was limited and served as a scoping study; only a limited number of products and conditions were tested. The main purpose of this testing was to investigate some additional areas of research not previously studied or with limited data, to gain some new insight into the potential applications of these coatings for aircraft operations, and to continue the research to include newly developed coating formulations. More extensive material-specific data would be needed to demonstrate usability of products on aircraft critical surfaces.

4.2 Fluid Endurance Time Testing

Fluid endurance time performance varied depending on individual coatings.

In general the B14 and B15 coatings did not significantly affect the fluid endurance time performance, and in some cases even extended the protection time (mostly observed during the Type I tests). Limited one-off testing was conducted with the R1, G1, G2, and G3 coatings, therefore trends could not be identified, however the initial data indicated that protection times could be comparable to the baseline test.

4.3 Adherence Testing

When left un-disturbed, the coated surfaces were able to delay the onset of adherence and ice formation, as compared to the baseline test plate. In addition, the removal of the contamination was generally easier on the surface which was coated.

Some concern remains with the ice formation on the coated surface. The coated surface typically results in bumpier, higher contact angle ice formations; preliminary aerodynamic research to investigate the effects of this adhered ice has been conducted.

4.4 Fluid Wetting and Fluid Thickness Testing

The Type I wetting tests indicated potential wetting problems with the coated test surfaces. Wetting issues were observed shortly after fluid application; this wetting issue was worse with 10º buffer fluid as compared to standard mix fluid which is more concentrated. It should be noted that during the endurance time tests with Type I fluids, the lack of wetting was offset by the ability of the coating to delay the onset of freezing in most cases, therefore generating equal or longer protection times in most cases tested. The Type IV fluid thickness test however demonstrated minor degradation in fluid thickness 5-minutes following application.

4.5 Hot Water Testing

The hot water endurance times on the coated surfaces were generally comparable to the Type I endurance times on the baseline plate. In some cases, the coated surfaces delayed the onset of adhered contamination and provided longer protection times. Coated plates tended to have beads of ice, whereas the baseline plate had a smooth layer of ice.

4.6 Vertical Stabilizer Testing

The average ET ratio of coated vertical surfaces to the baseline vertical surface was 94 percent for I-PH B14 and 87 percent for I-PH B15. This was comparable to the ratio obtained on the 10º plates, indicating that the effect of the vertical orientation on the coated surfaces was comparable to the effect on the baseline non-coated surface.

In general, the fluid performance on the coated surfaces was comparable to the baseline aluminum surfaces, however some added benefit may exist with the coated surfaces in the event the contamination becomes adhered.

4.7 Wind Tunnel Testing - Ice Phobic Coatings

Testing is still preliminary and exploratory, however early testing indicates that:

- The wing skins alone will cause a degradation in lift performance;
- The results with the wing skins demonstrated good repeatability;

- Coatings alone may have effects on aerodynamic performance (either better or worse);
- Frozen contamination on coated surfaces can be aerodynamically rougher; and
- Coatings do not seem to have significant effects on fluid flow-off performance.

The testing methodology is still premature, and future work should focus on repeatability in order to better develop the testing procedures; however, the wind tunnel can be a good platform for a full-scale evaluation of the coating performance. Consideration should be given to testing the wing skins in the wind tunnel prior to coating to determine the aerodynamic influence of the wing skin, which will provide a better indication of the influence of the coating alone. If the methodology does mature, consideration should be given to including the details in a future revision of AIR6232.

4.8 Development of SAE AIR6232

Following the publication of the AIR6232 in August 2013, there was no strong need to continue the working group meetings on a regular basis. The working group was advised that meetings would only be held in the event that changes would need to be issued

The working group approach has been proving to be an effective medium for developing and refining the SAE AIR. It is anticipated that communication with the working group shall continue to include email and teleconference discussions along with in person meeting in conjunction with the SAE G-12 meetings.

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5. RECOMMENDATIONS FOR FUTURE TESTING

The following recommendations were taken from the latest report entitled *"Investigation of Ice Phobic Technologies to Reduce Aircraft Icing in Northern and Cold Climates Volume 4 of 4 (Year 3 of 3: 2013-14 Testing Report)"* which encompasses the most current information.

5.1 Potential Future Applications

The results obtained have demonstrated a potential for future applications of ice phobic coatings in aircraft operations. More specifically, promising results have been observed on vertical surfaces which are subject to early fluid failure due to the steeper surface slopes. The use of coatings on the vertical surfaces (i.e. vertical stabilizer, winglets, fuselage, et cetera) could provide added protection from adherence of contamination.

The application of coatings to the main wing sections has demonstrated mixed results and is highly dependent on the coatings used; some coatings have proven to be better than others in terms of compatibility with fluids.

Aerodynamically, the coatings tested have indicated that they can influence the performance of the wing, therefore careful investigation of these products should be performed prior to using these products on aerodynamically critical surfaces.

In general, testing has indicated that with proper knowledge of the effects these coatings have on de/anti-icing fluid, the benefits of using these coatings can be had through adapted deicing procedures without compromising aircraft safety.

5.2 Future Research and Activities

The following are potential areas for future research:

- Conduct evaluation of newly developed coatings;
- Conduct wind tunnel testing with a thin high performance wing model to refine the test methodology, and to investigate coating performance during ground icing conditions with and without fluid, and with contamination;

- Investigate potential use of coatings in areas prone to icing but where de/anti-icing protection is limited, or not available (e.g. cowlings, landing gear);
- Investigation of different types of adhered contamination on vertical surfaces, and their effects on aerodynamics;
- Investigate dynamic taxi situation, simulating aircraft vibration;
- Continue to support the further development of the SAE AIR6232 document; and
- Disseminate the information gathered to date through conferences or site visits with coating manufacturers to encourage industry synergies.

5.3 Operational Considerations

Testing is still preliminary, therefore more extensive material specific data would be needed to demonstrate usability of products on aircraft critical surfaces. If there is a strong industry request to evaluate these products for use in aircraft operations, SAE AIR6232 has been developed and should be referenced to evaluate these technologies with respect to fluid HOTs.

REFERENCES

1) Ruggi, M., Emerging De/Anti-Icing Technology: Evaluation Of Ice Phobic Products For Potential Use In Aircraft Operations Montreal, APS Aviation, Transport Development Centre, March 2011 TP 15055E, XX, (to be published).

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