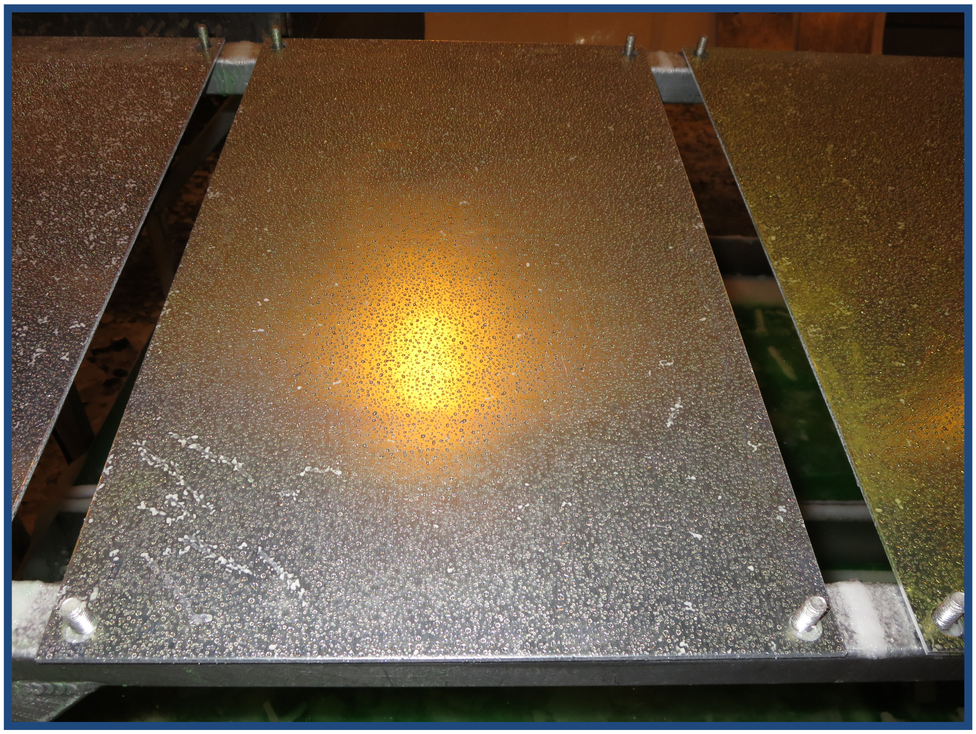
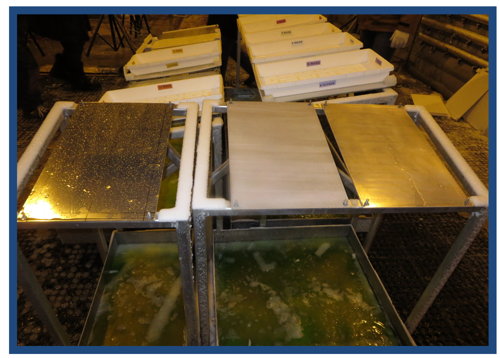
TP 15275E

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)





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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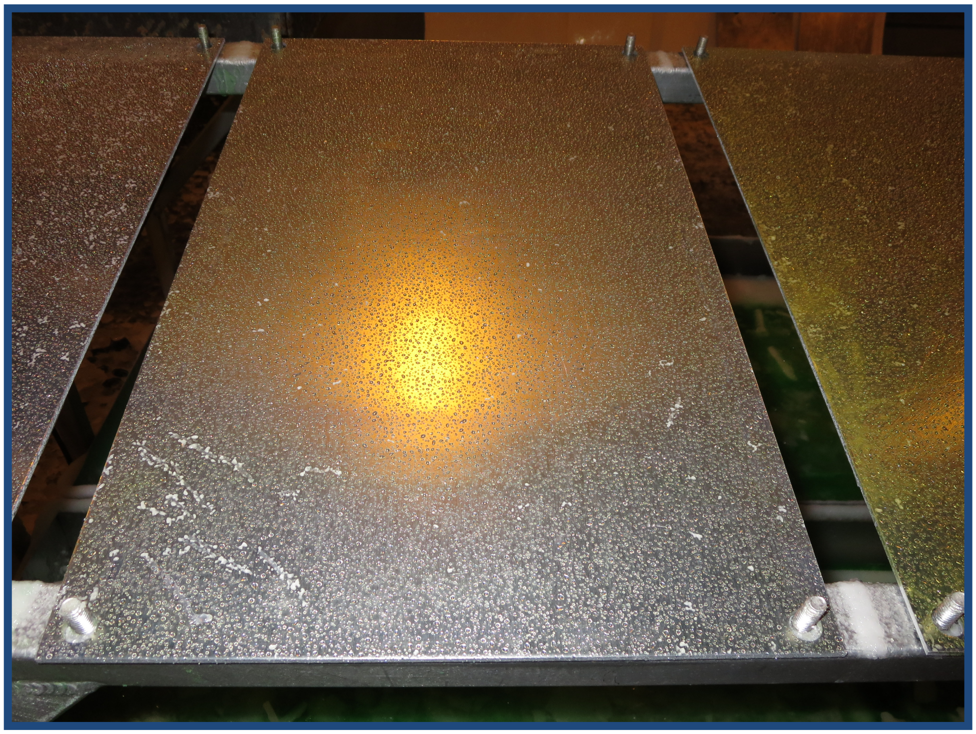

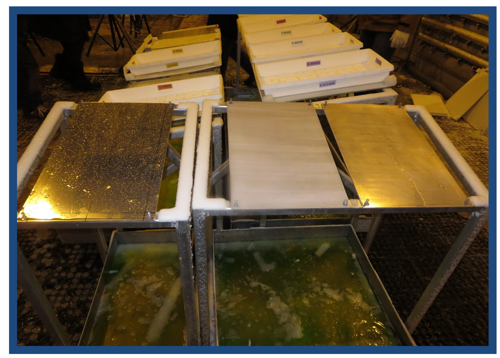

by

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

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**This report was prepared and signed by Marco Ruggi, reviewed and signed by John D'Avirro, and approved by John Detombe in (December 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.

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 Operations* (1) and in the TC report TP 15158E, *Aircraft Ground Icing Research General Activities During the 2010-11 Winter* (2).

In 2011-12, 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.

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 aircraft aerodynamically quiet areas in aircraft also indicated potential benefits to using ice phobic coatings, which can be a potential solution to minimize residues formation in those 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.

This report contains the ice phobic research from Year 3 (2013-14) of the three-year program. It should be noted that this report is not cumulative; therefore data from Year 1 (2011-12) and Year 2 (2012-13) of three years are not included or referenced in this report.

General Comments and Recommendations

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.

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, etc.) 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.

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.

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.

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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 2009-10 et 2010-11 sont précisés dans le rapport TP 15055E de TC : *Emerging De/Anti-Icing Technology: Evaluation of Ice Phobic Products for Potential Use in Aircraft Operations* (1) et dans le rapport TP 15158E de TC : *Aircraft Ground Icing Research General Activities During the 2010-11 Winter* (2).

En 2011-12, un projet d'une durée de trois ans a été entrepris pour évaluer la sécurité et l'efficacité de matériaux et recouvrements glaciophobes et pour examiner la faisabilité d'utiliser des matériaux glaciophobes dans la conception d'aéronefs ou de sections particulières d'aéronef qui sont plus sujettes au givrage.

Les essais de 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*) comprend la recherche de la 1ère année du programme de 3 ans.

Les recherches se sont poursuivies en 2012-13 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 potentiellement prometteurs ont été observés sur des surfaces verticales sujettes à une défaillance précoce du liquide en raison de l'angle plus prononcé 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 façon possible de minimiser la formation de résidus, qui pourrait convenir aux zones d'aéronefs à l'abri d'écoulement aérodynamique. 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 manière générale, les essais ont démontré que, si l'on connait bien les effets de ces recouvrements sur le liquide de dégivrage et d'antigivrage, leur utilisation peut apporter des bénéfices en adaptant les procédures de dégivrage, sans compromettre la sécurité des aéronefs. 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 2012-2013*) couvre la recherche de la 2^e^ année du programme de 3 ans.

Le présent rapport comprend la recherche sur les matériaux glaciophobes de la troisième (2013-14) des trois années du programme. Il est à noter que ce rapport n'est pas cumulatif; en conséquence, les données de la première (2011-12) et de la deuxième (2012-13) des trois années ne sont ni incluses ni citées en référence dans ce rapport.

Observations générales et recommandations

Les essais étaient limités et ont servi d'étude exploratoire. Un nombre limité seulement de produits et de conditions a été mis à l'essai. Ces essais avaient pour objectif principal d'examiner des domaines de recherche additionnels non étudiés auparavant ou dont les données sont limitées, 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. Des données plus complètes, spécifiques aux matériaux utilisés, seraient nécessaires pour prouver l'utilité des produits sur les surfaces critiques des aéronefs.

Les résultats obtenus ont démontré un potentiel pour l'application de revêtements glaciophobes aux aéronefs à l'avenir. Plus précisément, des bénéfices importants sont possibles sur les surfaces verticales qui sont plus sujettes à une défaillance précoce du liquide en raison de l'angle plus prononcé 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.

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.

Sur le plan aérodynamique, les revêtements soumis aux essais ont indiqué qu'ils peuvent influencer la performance de l'aile; en conséquence, un examen minutieux de ces produits devrait être fait avant de les appliquer aux surfaces aérodynamiques critiques.

De manière générale, les essais ont démontré que, si l'on connait bien les effets de ces recouvrements sur le liquide de dégivrage et d'antigivrage, leur utilisation peut apporter des bénéfices en adaptant les procédures de dégivrage, sans compromettre la sécurité des aéronefs.

Les domaines suivant pourraient faire l'objet de recherches futures :

- Évaluer les revêtements nouvellement élaborés;
- Mener des essais en soufflerie avec un modèle d'aile mince de haute performance afin de raffiner la méthodologie des essais, ainsi que pour examiner le rendement du revêtement dans des conditions de givrage au sol, avec ou sans liquide et avec contamination;
- Examiner la possibilité d'utiliser des revêtements sur les zones sujettes au givrage lorsque la protection contre le dégivrage ou l'antigivrage est limitée ou non disponible (par exemple le capot ou le train d'atterrissage);
- Examiner les différents types de contamination adhérés aux surfaces verticales et leurs effets sur l'aérodynamisme;
- Examiner des situations dynamiques de circulation au sol qui simulent la vibration de l'aéronef;
- Poursuivre l'appui au développement ultérieur du document SAE AIR6232; et
- Diffuser l'information accumulée jusqu'ici par le biais de conférences ou de visites aux fabricants de recouvrements afin d'encourager les synergies dans l'industrie.

Les essais sont encore préliminaires et par conséquent, des données plus complètes, spécifiques aux matériaux utilisés, seraient nécessaires pour prouver l'utilité des produits sur les surfaces critiques des aéronefs. S'il y a une demande pressante de l'industrie pour évaluer l'utilisation de ces produits pour l'exploitation d'aéronefs, le document SAE AIR6232 qui a été élaboré devrait être cité en référence, lorsqu'on évalue ces technologies en fonction des durées d'efficacité des liquides.

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF PHOTOS

GLOSSARY

AIR	Aerospace Information Report
APS	APS Aviation Inc.
ARP	Aerospace Recommended Practice
AS	Aerospace Standard
CEF	Climatic Engineering Facility
FAA	Federal Aviation Administration
HOT	Holdover Time
ISO	International Organisation for Standardization
MSC	Meteorological Service of Canada
NRC	National Research Council Canada
PIWT	Propulsion and Icing Wind Tunnel
SAE	Society of Automotive Engineers
TC	Transport Canada
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 4 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 Operations* (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 research including 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 2011-12, 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.

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)* (3) contains the research from Year 1 (2011-12) 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 aircraft aerodynamically quiet areas also indicated potential benefits to using ice phobic coatings; a potential solution to minimize residue formation which could be applicable aircraft aerodynamically quiet 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. The 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.

This report contains the ice phobic research from Year 3 (2013-14) of the three-year program. It should be noted that this report is not cumulative; therefore data from Year 1 (2011-12) and Year 2 (2012-13) of three years are not included or referenced in this report.

1.2 Objective

The objective of this project was to investigate the holdover time (HOT) performance of fluids applied to surfaces treated with ice phobic products, as well as the performance of bare surfaces treated with ice phobic products.

Six types of tests, described below, were conducted to meet the objective.

1. **Endurance Time Tests**: Evaluate fluid endurance times of Type I and IV fluids when applied to surfaces treated with ice phobic products;
2. **Adherence Tests**: Evaluate potential to delay the onset of adherence on bare surfaces treated with ice phobic products during freezing precipitation conditions;
3. **Fluid Wetting and Thickness Tests**: Evaluate de/anti-icing fluid ability to properly wet and provide appropriate fluid thickness when applied to ice phobic surfaces;
4. **Hot Water Deicing Tests**: Evaluate the anti-icing performance of coated surfaces when treated with standard hot water;
5. **Vertical Stabilizer Tests**: Evaluate the endurance time performances of vertical surfaces treated with an ice phobic coating; and
6. **Wind Tunnel Tests**: To investigate the aerodynamic performance of a coated airfoil, with and without de/anti-icing fluids.

In addition, work was done to support the new Society of Automotive Engineers (SAE) Aerospace Information Report (AIR) AIR6232 for evaluating the interaction of de/anti-icing fluids with aircraft after-market coatings.

The sections of the TDC work statement pertaining to the work described in this report are provided in Appendix A.

1.3 Report Format

The following list provides short descriptions of the main sections of this report:

a) Section 2 provides a description of the methodology used to carry out the tests during the winter of 2013-14;

b) Section 3 summarizes the results from endurance time testing conducted during the winter of 2013-14;

c) Section 4 summarizes the results from the adherence testing conducted during the winter of 2013-14;

d) Section 5 summarizes the results from the fluid wetting and fluid thickness testing conducted during the winter of 2013-14;

e) Section 6 summarizes the results from the hot water deicing testing conducted during the winter of 2013-14;

f) Section 7 summarizes the results from the vertical stabilizer testing conducted during the winter of 2013-14;

g) Section 8 summarizes the results from the wind tunnel testing conducted during the winter of 2013-14;

h) Section 9 summarizes the activities performed for supporting the SAE AIR6232 developed for evaluating the interaction of de/anti-icing fluids with aircraft after-market coating;

i) Section 10 presents the observations conclusions; and

j) Section 11 presents the recommendations.

2 METHODOLOGY

This section describes the overall approach, test parameters and experimental procedures followed during the 2013-14 project.

APS measurement instruments and test equipment are calibrated and verified on an annual basis. This calibration is carried out according to a calibration plan derived from approved ISO 9001:2008 standards, and developed internally by APS.

2.1 Test Facilities

The following sections describe the different testing facilities used to conduct the various ice phobic tests.

2.1.1 APS Pierre Elliott Trudeau (P.E.T.) Airport Outdoor Test Site

Fluid endurance time testing during natural snow conditions was conducted at the APS test site (Photo 2.1 and Photo 2.2) located at the P.E.T. International Airport (Montreal-Trudeau) in Montreal. Testing was conducted by APS personnel. The location of the test site is shown on the plan view of the airport in Figure 2.1.

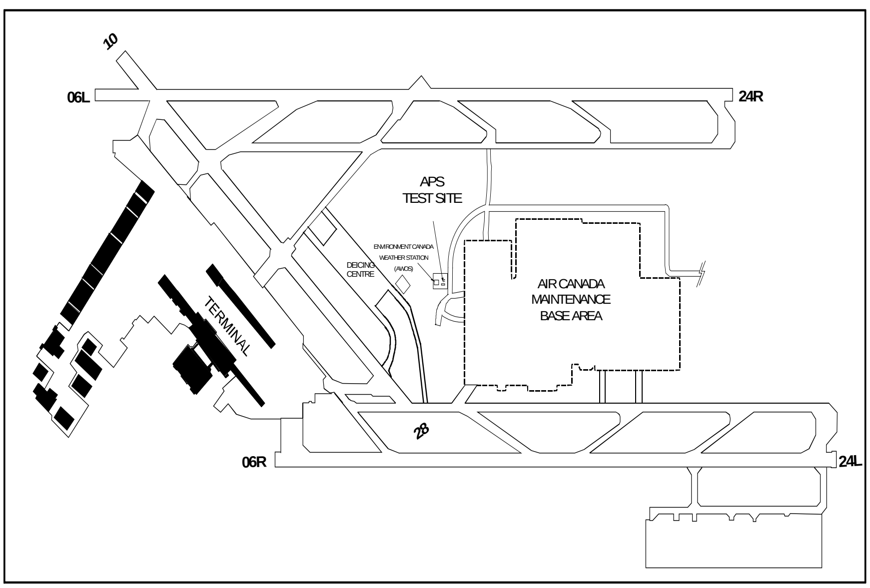

Figure 2.1: Plan View of APS Montreal-Trudeau Airport Test Site

2.1.2 NRC Climatic Engineering Facility (CEF)

To obtain the necessary fluid endurance time data for the freezing precipitation conditions, testing was carried out at the NRC CEF (Photo 2.3) using a sprayer assembly (Photo 2.4) to simulate the required freezing precipitation conditions. Testing was conducted by APS personnel. Figure 2.2 provides a schematic of the NRC Uplands campus showing the location of the U-88/U-89 facility.

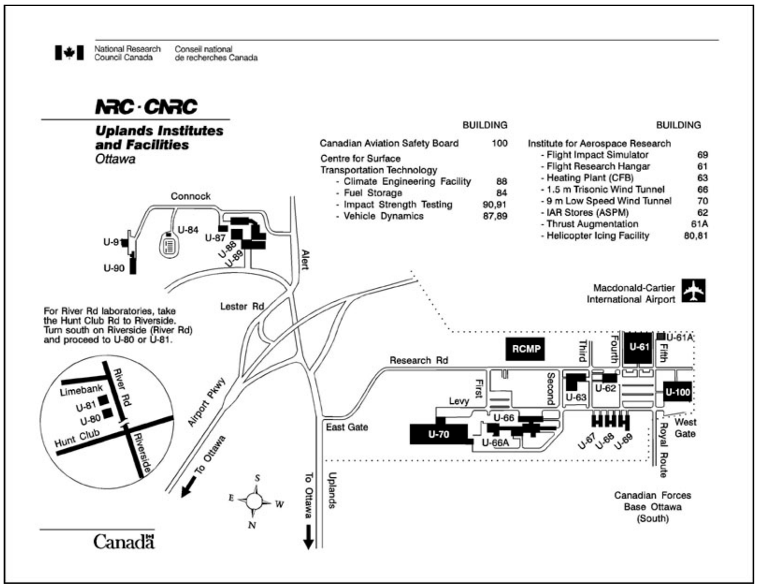

Figure 2.2: Schematic of NRC Uplands Campus

2.1.3 NRC Open Circuit Wind Tunnel Test Site

The Propulsion and Icing Wind Tunnel (PIWT) tests were performed at NRC Aerospace Facilities, Building M-46, at the NRC Montreal Road campus, located in Ottawa, Canada. Figure 2.3 provides a schematic of the NRC Montreal Road campus showing the location of the NRC PIWT. Photo 2.5 shows an outside view of the wind tunnel test facility. Photo 2.6 shows an inside view of the wind tunnel test section. The open-circuit layout, with fan at entry, permits contaminants associated with the test articles (such as heat, or de/anti-icing fluid) to discharge directly, without re-circulating or coming into contact with the fan. The fan is normally driven electrically, but high-speed operations can be accommodated by a gas turbine drive system. Due to the requirements of both high speed and low speed operation during the testing, the gas turbine was selected to allow for greater flexibility. The gas turbine drive can perform both low and high-speed operations whereas the electric drive is limited to low-speed operations.

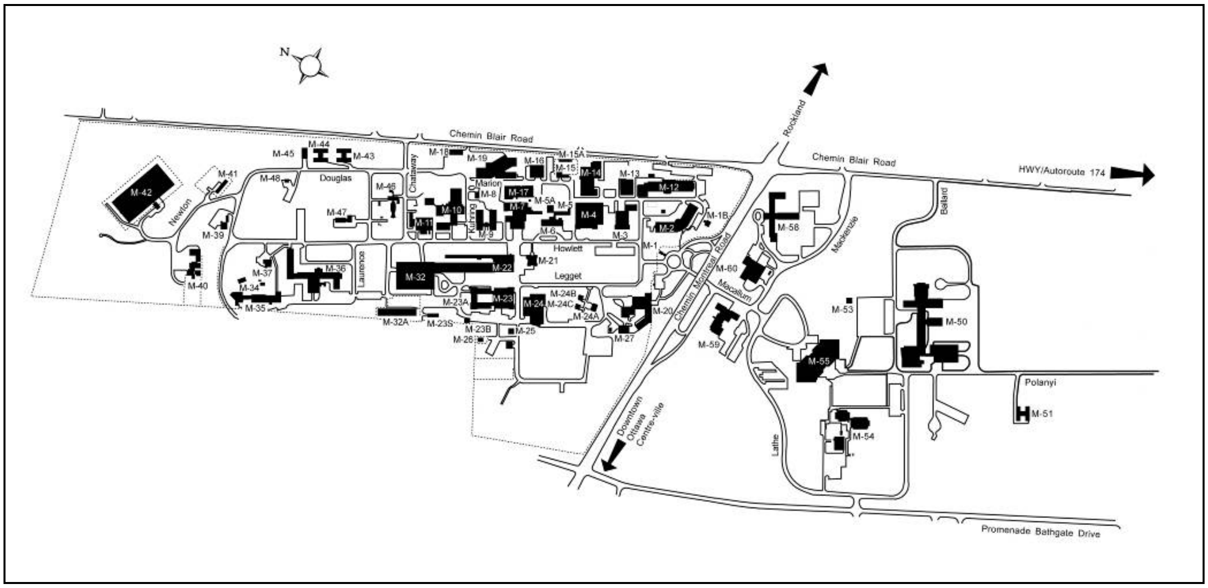

Figure 2.3: Schematic of NRC Montreal Road Campus

2.2 Materials Tested

2.2.1 Ice Phobic Products

To investigate the effects of ice phobic treated aluminum surfaces on de/anti-icing fluid performance, twelve products were evaluated during the winter of 2013-14, four samples of which had already been tested during the winter of 2012-13. The choices in materials were made based on availability and the potential for use in current aircraft operations. Table 2.1 lists the products tested to date, along with the reference codes used in this report. Only materials tested in 2013-14 and their respective results are described in this report.

2.2.2 Flat Plate Testing Baseline Surfaces

During each flat plate test, the performance of the ice phobic treated standard aluminum test plate was compared to a baseline untreated standard 2024-T3 aluminum test plate. In previous years, during some limited flat plate tests, a polished and a painted plate were also used for comparison (the objective was to compare the ice phobic performance to industry available surface finishes). Table 2.2 lists the baseline surfaces used for comparison.

Table 2.1: List of Ice Phobic Product Tested and Reference Codes

Testing Year	APS Reference Code	Manufacturer Code	Product Applied Code
2013-14	I-PH B12	Manufacturer B	Product 10 (2012-13 Sample)
2013-14	I-PH B13	Manufacturer B	Product 11 (2012-13 Sample)
2013-14	I-PH B14	Manufacturer B	Product 12
2013-14	I-PH B15	Manufacturer B	Product 13
2013-14	I-PH C3	Manufacturer C	Product 1 (2012-13 Sample)
2013-14	I-PH D1	Manufacturer D	Product 1 (2012-13 Sample)
2013-14	I-PH E1	White Painted Plate	Aircraft Grade Primer and Paint
2013-14	I-PH E1b	White Painted Plate (duplicate)	Aircraft Grade Primer and Paint (duplicate)
2013-14	I-PH F1	Manufacturer F	Product 1
2013-14	I-PH G1	Manufacturer G	Sample 0
2013-14	I-PH G2	Manufacturer G	Sample 1
2013-14	I-PH G3	Manufacturer G	Sample 3

Table 2.2: List of Flat Plate Baseline Surfaces Tested

APS Reference Code	Material	Treatment Used
Baseline	2024-T3 Aluminum	Not Treated

2.3 Test Methodology

The test methodologies used to conduct the various ice phobic tests are described in the following sections.

2.3.1 Description of Fluid Endurance Time Testing Procedures

2.3.1.1 Description of Indoor Fluid Endurance Time Testing Procedure

Testing was conducted in simulated precipitation conditions at the NRC climatic engineering facility. Tests were carried out using standard endurance time testing protocol. When possible, Brix and thickness measurements were taken 5 minutes after fluid application and at the time of failure. Testing was conducted with ice phobic products as well as the baseline aluminum plate. Details of this procedure are included in Appendix B. (Note: this procedure was developed several years ago; the same procedure applies).

2.3.1.2 Description of Outdoor Fluid Endurance Time Testing Procedure

Testing was conducted in natural snow conditions at the APS P.E.T Airport test site. Tests were carried out using standard endurance time testing protocol. When possible, Brix and thickness measurements were taken 5 minutes after fluid application and at the time of failure. Testing was conducted with ice phobic products as well as the baseline aluminum plate. Testing was limited and ad-hoc, therefore no official procedure was published. Details of this procedure are included in Appendix C. (Note: this procedure was developed several years ago; the same procedure applies).

2.3.2 Description of Adherence Testing Procedure

Testing was conducted without fluid to evaluate the potential to delay the onset of adherence on surfaces treated with ice phobic products relative to the baseline aluminum surface. Comparative flat plate tests were conducted with all ice phobic products as well as the baseline plate. Testing was conducted in light freezing rain. The dry, clean plates were simultaneously exposed to the simulated freezing contamination. Data regarding the time for ice to form on 30 percent and 100 percent of the surface were recorded. The ice was verified to be adhered using the "APS Adherence Tester", which has historically been used, and has been calibrated to represent the shear forces typically experienced during takeoff. Observational data during the tests was also recorded. Details of this procedure are included in Appendix B.

2.3.3 Description of Fluid Wetting and Thickness Testing Procedure

The testing methodology was based on the protocol used to measure fluid thickness of new endurance time fluids. The procedure is entitled Experimental Program to Establish Film Thickness Profiles for Deicing and Anti-Icing Fluids on Flat Plates and can be found in Appendix I of TC Report TP 13991E*, Aircraft Ground De/Anti- icing Fluid Holdover Time and Endurance Time Test Program for the 2001-02 Winter* (4). Comparative flat plate tests were conducted with all ice phobic products as well as the baseline aluminum plate. These tests were conducted in dry conditions (no precipitation). The thickened fluid tests consisted of recording the fluid thickness decay over a 30 minute period. The Type I tests, however, consisted of recording the percentage of the plate that remained wetted over a period of 30 minutes. Due to the thinness of the fluid layer, fluid thickness was not an appropriate evaluation method. Details of this procedure are included in Appendix B.

2.3.4 Description of Hot Water Testing Procedure

Testing was conducted to compare the anti-icing performance of coated surfaces when treated with hot water versus non-coated surfaces when treated with a glycol based deicing fluid. Comparative flat plate tests were conducted with all ice phobic products as well as the baseline plate. Testing was conducted in light freezing rain.

2.3.5 Description of Vertical Stabilizer Testing Procedure

Due to the early fluid failures observed on vertical surfaces, it was suggested that tests be conducted with ice phobic treated surfaces to investigate any potential benefits. Tests were conducted under natural snow conditions at the APS test site facility located at the Montreal-Trudeau Airport in Montreal. Tests were done in conjunction with the outdoor ice phobic endurance time testing. Standard endurance time tests and rate collection protocol were followed during the execution of these tests. Type IV tests were conducted with a vertical plate (positioned at 80º instead of the typical 10º) which was coated with an ice phobic coating, and the performance was compared to a vertical plate which was not coated. Details of this procedure are included in Appendix D.

2.3.6 Description of Wind Tunnel Testing Procedure

Testing was conducted using wing skins specifically manufactured to fit onto the existing thin high performance wing section and was secured by flush-mounted screws. To cover the entire test wing, two individual wing skin-halves were required. The wing skins were treated with the various coatings prior to testing to allow for proper curing times.

The general methodology used for these tests was in accordance with the methodologies used for typical fluid and contamination tests conducted in the wind tunnel. The evaluation methodology was modified to allow a comparison among the different wing skin performances. Details of this procedure are included in Appendix E.

2.4 Data Forms

The data forms used for the various test objectives are provided in the respective procedures given in Appendix B, C D, and E.

2.5 Equipment

The test equipment for standard HOT testing and typical wind tunnel testing was used to conduct the ice phobic product evaluation. Subsections 2.5.1 to 2.5.4 briefly describe some of the equipment used.

2.5.1 Wind Tunnel Super-Critical Wing Section

A new generation thin and flat wing section (Figure 2.4) was used for testing in the NRC PIWT. The dimensions indicated are in inches. This wing section was constructed by the NRC specifically for the conduct of these tests following extensive consultations with an airframe manufacturer to ensure a representative super-critical design.

Testing was conducted using wing skins made of 2024 T3 aluminum, specifically manufactured to fit onto the existing thin high performance wing section and be secured by 68 flush mounted screws. To cover the entire test wing, two individual wing skin halves were required.

The general methodology that was used during these tests is in accordance with the methodologies used for typical fluid and contamination tests conducted in the wind tunnel.

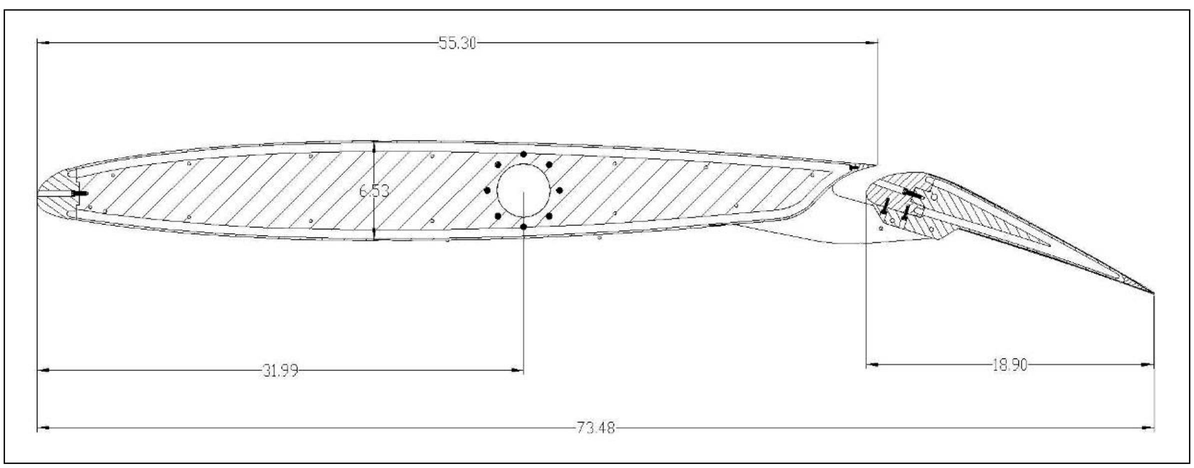

Figure 2.4: Wing Section

2.5.2 Test Surfaces

Flat plate endurance time testing was conducted using standard aluminum test plates that were treated with ice phobic products (paint, or polish), or left un-treated (baseline). A schematic of a test plate is shown in Figure 2.5.

For all wind tunnel testing, custom made wing skins were manufactured and coated with ice phobic products (Photo 2.7).

2.5.3 Wet Film Thickness Gauge

Wet film fluid thickness measurements were recorded during endurance time tests. Figure 2.6 shows the schematic of the wet film thickness gauges.

2.5.4 Brixometer

The Brixometer provides data relevant to the fluid concentration (Brix measurements) and monitors fluid dilution. Figure 2.7 shows a hand- held Brixometer.

2.6 Fluids

Commercially available Type I, II, III and IV fluids were used in this testing. For certain objectives, lowest-on-wing viscosity fluid samples were used.

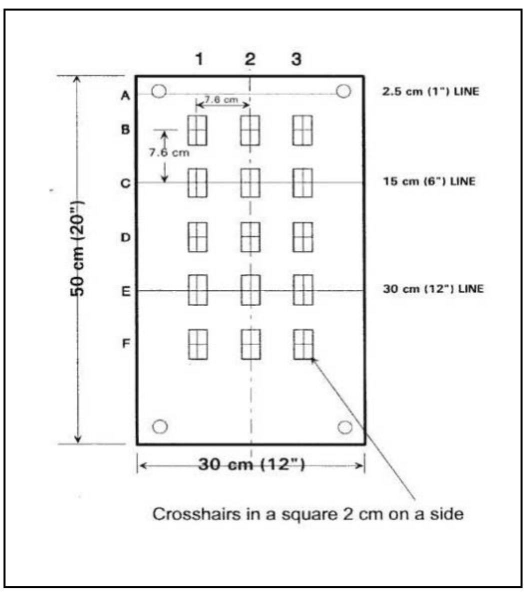

Figure 2.5: Schematic of Standard Holdover Time Test Plate

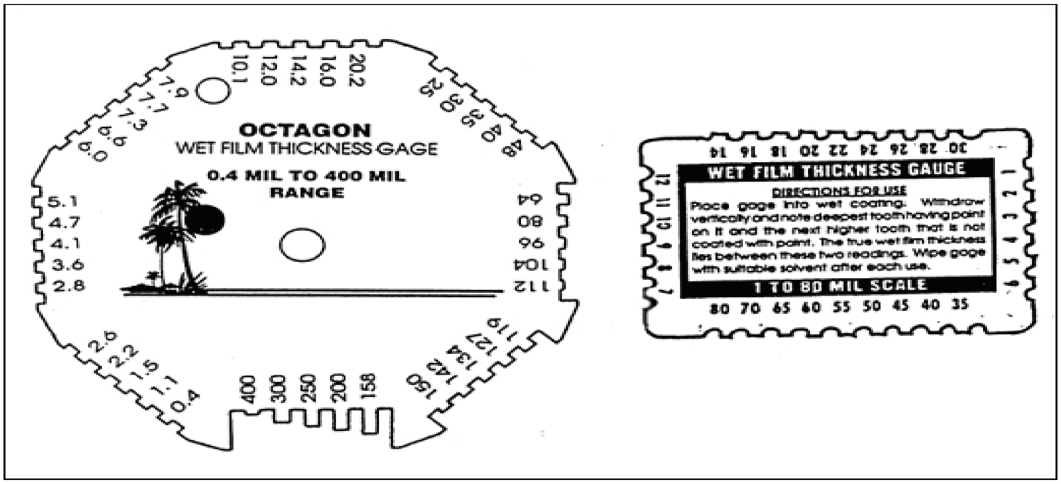

Figure 2.6: Wet Film Thickness Gauges

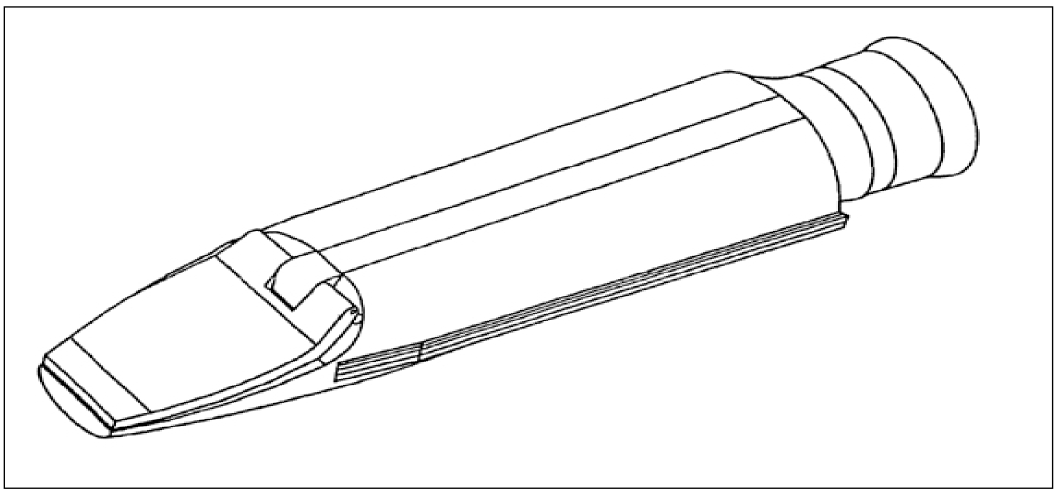

Figure 2.7: Hand-Held Brixometer

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Photo 2.1: APS Test Site - View from Test Pad

Photo 2.2: APS Test Site - View from Trailer

Photo 2.3: Inside View of NRC Climate Engineering Facility

Photo 2.4: Sprayer Assembly Used to Produce Fine Droplets

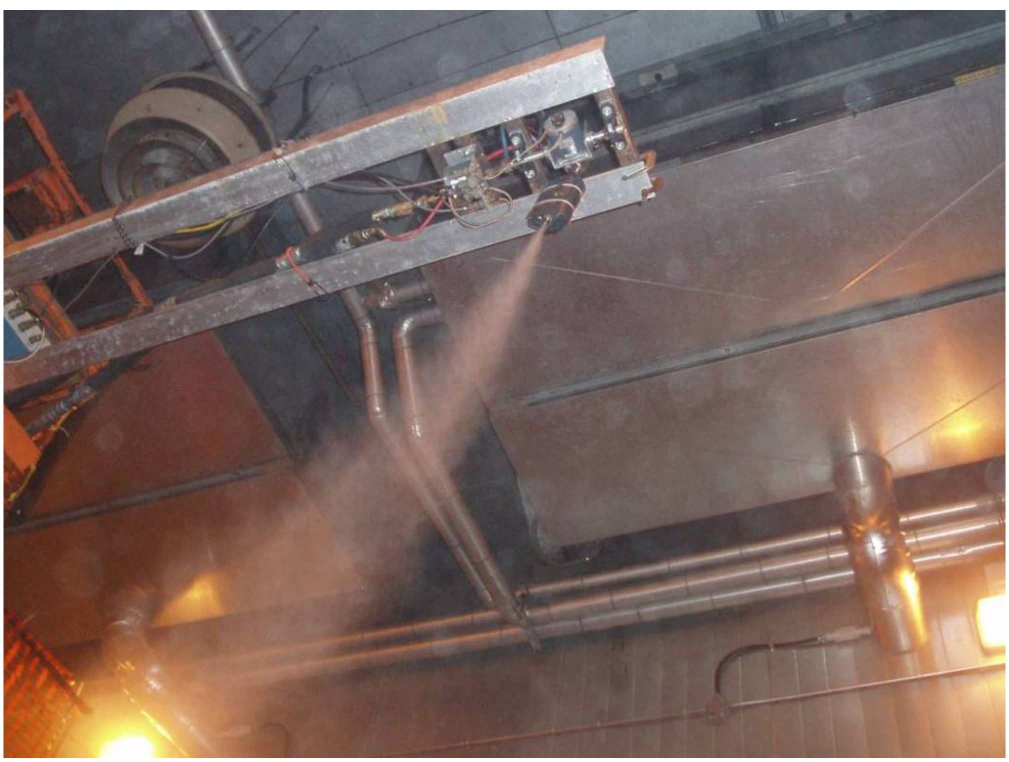


Photo 2.5: Outside View of NRC Wind Tunnel Facility

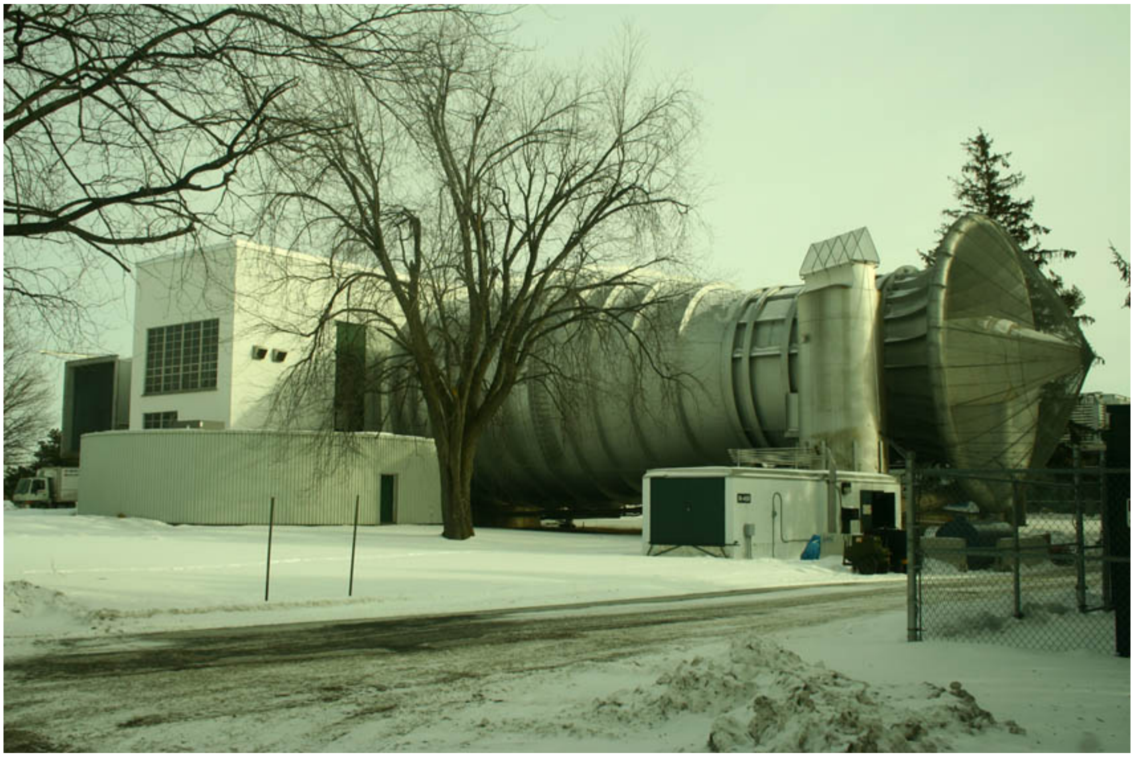


Photo 2.6: Inside View of NRC Wind Tunnel Test Section

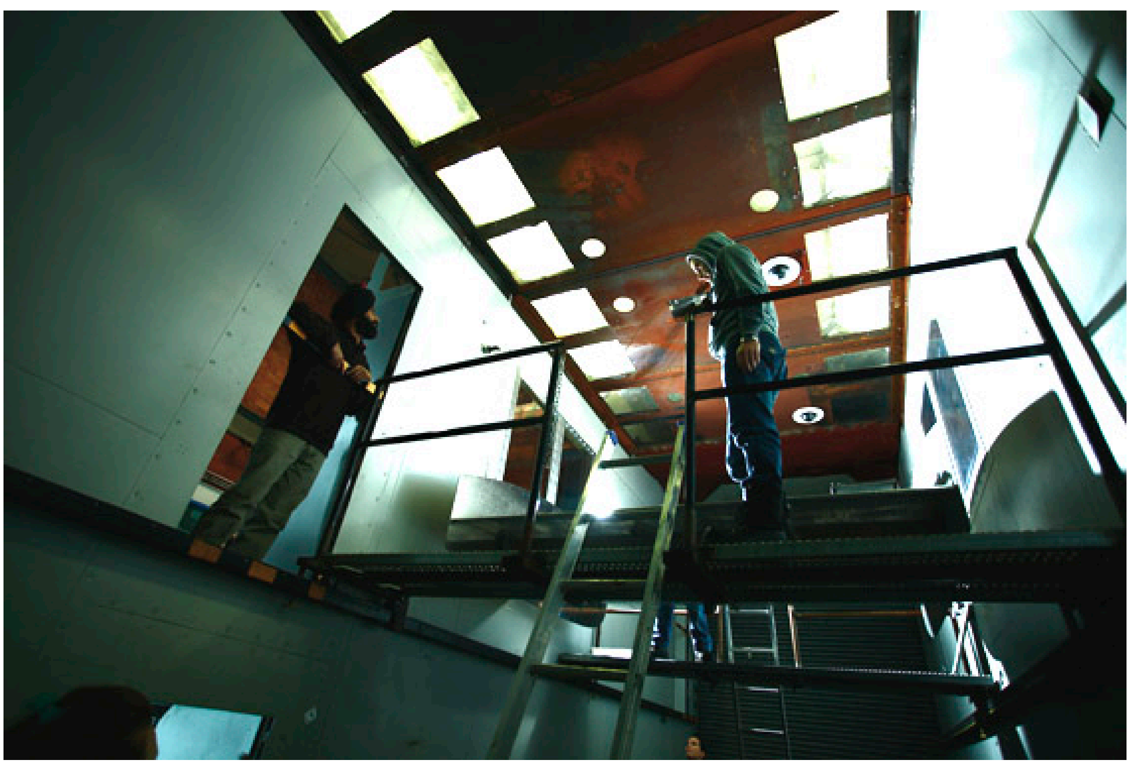
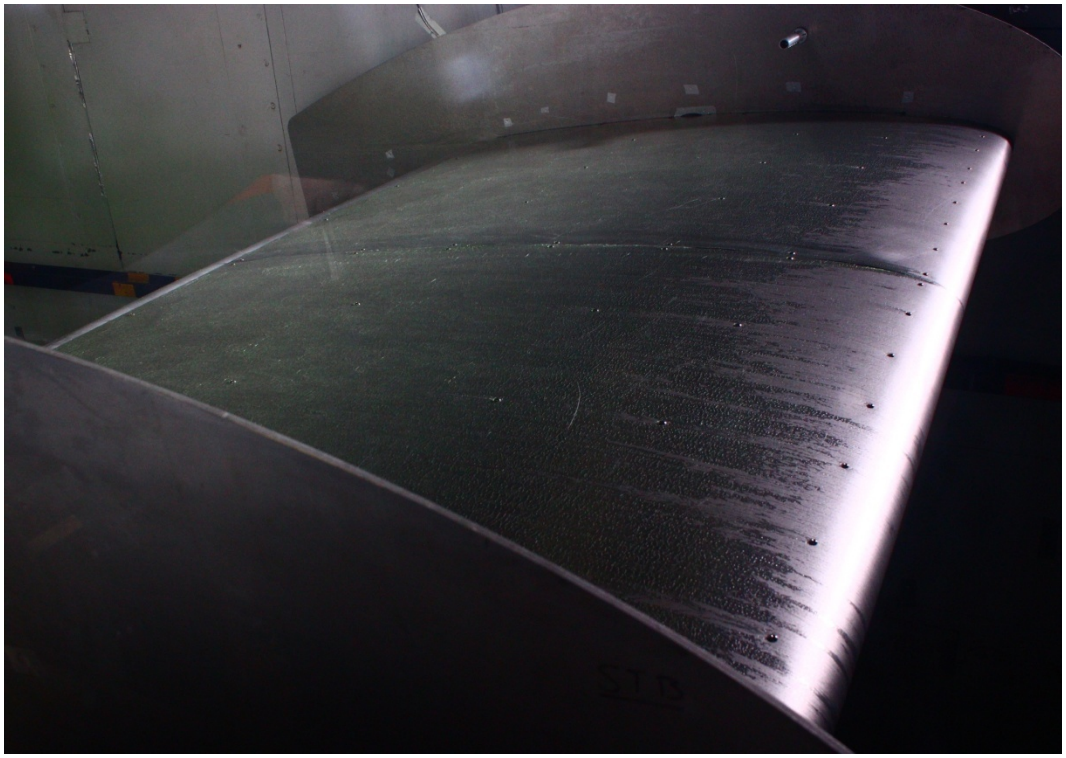


Photo 2.7: Custom Designed Wing Skin



3 ENDURANCE TIME TESTING DATA AND RESULTS

In this section, the endurance time testing data collected during the winter of 2013-14 is analysed and discussed. The treated surfaces were evaluated against the baseline plate to investigate potential adverse effects on fluid holdover times (HOT) when applied to surfaces treated with ice phobic products. Testing was conducted with the five new coatings: B14, B15, R1, G1, G2, and G3.

3.1 Log of Endurance Time Tests Conducted

To facilitate the accessibility of the data collected, a log was created for the series of tests conducted by APS at the National Research Council Canada (NRC) Climatic Engineering Facility (CEF) and at the Pierre Elliot Trudeau (P.E.T.) airport site during the winter of 2013-14. The log presented in Table 3.1 and Table 3.2 provides relevant information for each of the tests, as well as final values used for the data analysis. Each row contains data specific to one test. Table 3.1 presents the log of simulated precipitation endurance time tests conducted at the NRC CEF (the different setups are shown in Photo 3.1, Photo 3.2, and Photo 3.3). Table 3.2 presents the log of natural snow endurance time tests conducted at the P.E.T. airport test site (the setup is shown in Photo 3.4). It should be noted that vertical stabilizer tests were conducted in conjunction with the natural snow tests, hence why the test numbers are not sequential. The balance of these tests is described in Section 7.

Table 3.1: Log of Simulated Precipitation Endurance Time Tests

Run #	Test #	Condition	Date	Fluid	Dilution	Surface	Start Time (hh:mm:ss)	End Time (hh:mm:ss)	Endurance Time (min)	Adjusted ET (min)	% of Baseline	EC OAT (°C)	Precip. Rate (g/dm²/h)	Thickness @ 5 min	Brix @ Fail
1	PH1	Freezing Drizzle	21-Mar-14	Dow UCAR ADF (EG)	10°BUF	Baseline	13:51:40	14:08:00	16.3	16.3	100%	-3	5.9	n/a	n/a
1	PH2	Freezing Drizzle	21-Mar-14	Dow UCAR ADF (EG)	10°BUF	B14	13:52:10	14:15:00	22.8	23.2	142%	-3	6.0	n/a	n/a
1	PH3	Freezing Drizzle	21-Mar-14	Dow UCAR ADF (EG)	10°BUF	B15	13:52:30	14:09:30	17.0	16.7	102%	-3	5.8	n/a	n/a
2	PH4	Freezing Drizzle	21-Mar-14	Octagon Octafllo EF	10°BUF	Baseline	13:31:52	13:44:30	12.6	12.6	100%	-3	5.9	n/a	n/a
2	PH5	Freezing Drizzle	21-Mar-14	Octagon Octafllo EF	10°BUF	B14	13:32:22	13:49:00	16.6	16.4	129%	-3	5.8	n/a	n/a
2	PH6	Freezing Drizzle	21-Mar-14	Octagon Octafllo EF	10°BUF	B15	13:32:43	13:47:00	14.3	14.5	115%	-3	6.0	n/a	n/a
3	PH7	Freezing Drizzle	19-Mar-14	Clariant Flight PLUS	50/50	Baseline	16:19:14	16:28:00	8.8	8.8	100%	-3	15.0	0.2	6.00
3	PH8	Freezing Drizzle	19-Mar-14	Clariant Flight PLUS	50/50	B14	16:18:52	16:36:00	17.1	16.1	184%	-3	14.1	0.2	1.00
3	PH9	Freezing Drizzle	19-Mar-14	Clariant Flight PLUS	50/50	F1	16:18:32	16:29:30	11.0	9.9	113%	-3	13.5	0.1	3.00
4	PH10	Freezing Drizzle	19-Mar-14	Dow UCAR ADF (EG)	10°BUF	Baseline	16:40:30	16:52:00	11.5	11.5	100%	-3	15.0	n/a	0.50
4	PH11	Freezing Drizzle	19-Mar-14	Dow UCAR ADF (EG)	10°BUF	B14	16:40:00	17:00:00	20.0	18.8	163%	-3	14.1	n/a	0.50
4	PH12	Freezing Drizzle	19-Mar-14	Dow UCAR ADF (EG)	10°BUF	F1	16:39:45	16:59:00	19.3	17.3	151%	-3	13.5	n/a	3.00
5	PH13	Freezing Drizzle	20-Mar-14	ABAX Ecowing 26	75/25	Baseline	13:45:40	13:58:30	12.8	12.8	100%	-10	13.3	0.5	12.50
5	PH14	Freezing Drizzle	20-Mar-14	ABAX Ecowing 26	75/25	B15	13:45:50	14:02:00	16.2	15.6	121%	-10	12.8	0.6	14.00
5	PH15	Freezing Drizzle	20-Mar-14	ABAX Ecowing 26	75/25	B14	13:46:12	14:02:10	16.0	16.7	130%	-10	13.9	0.6	14.50
6	PH16	Light Freezing Rain	21-Mar-14	Clariant Flight	75/25	Baseline	9:07:45	9:47:00	39.3	39.3	100%	-3	24.1	2.2	4.00
6	PH17	Light Freezing Rain	21-Mar-14	Clariant Flight	75/25	B15	9:08:20	9:37:00	28.7	30.5	78%	-3	25.6	2.2	3.50
6	PH18	Light Freezing Rain	21-Mar-14	Clariant Flight	75/25	B14	9:08:05	9:35:00	26.9	26.4	67%	-3	23.6	2.2	3.00
7	PH19	Light Freezing Rain	20-Mar-14	Clariant Flight Plus	75/25	Baseline	16:33:46	16:54:25	20.7	20.7	100%	-10	13.1	1.0	14.50
7	PH20	Light Freezing Rain	20-Mar-14	Clariant Flight Plus	75/25	B14	16:34:07	16:58:00	23.9	23.3	113%	-10	12.8	1.1	16.50
7	PH21	Light Freezing Rain	20-Mar-14	Clariant Flight Plus	75/25	B15	16:34:30	16:57:00	22.5	22.3	108%	-10	13.0	1.1	14.50
8	PH22	Light Freezing Rain	20-Mar-14	Octagon Octafllo EF	10°BUF	Baseline	17:03:24	17:09:30	6.1	6.1	100%	-10	13.1	n/a	n/a
8	PH23	Light Freezing Rain	20-Mar-14	Octagon Octafllo EF	10°BUF	B14	17:03:50	17:12:00	8.2	8.0	131%	-10	12.8	n/a	n/a
8	PH24	Light Freezing Rain	20-Mar-14	Octagon Octafllo EF	10°BUF	B15	17:04:13	17:11:30	7.3	7.2	118%	-10	13.0	n/a	n/a
9	PH25	Light Freezing Rain	20-Mar-14	Dow UCAR ADF (EG)	100/0	Baseline	19:00:30	19:50:00	49.5	49.5	100%	-10	25.6	1.8	19.50
9	PH26	Light Freezing Rain	20-Mar-14	Dow UCAR ADF (EG)	100/0	B14	19:01:30	19:53:30	52.0	51.8	105%	-10	25.5	2.2	10.50
9	PH27	Light Freezing Rain	20-Mar-14	Dow UCAR ADF (EG)	100/0	B15	19:01:00	19:42:30	41.5	39.2	79%	-10	24.2	1.8	8.50
10	PH28	Freezing Drizzle	24-Apr-14	Kil P2586	75/25	Baseline	16:57:00	17:22:30	25.5	25.5	100%	-10	5.9	0.6	17.5
10	PH29	Freezing Drizzle	24-Apr-14	Kil P2587	75/26	G1	16:57:15	17:24:00	26.8	29.9	117%	-10	6.6	0.7	18
10	PH30	Freezing Drizzle	24-Apr-14	Kil P2588	75/27	G2	16:57:45	17:25:00	27.3	25.9	101%	-10	5.6	0.7	17
10	PH31	Freezing Drizzle	24-Apr-14	Kil P2589	75/28	G3	16:58:15	17:27:00	28.7	25.8	101%	-10	5.3	0.7	17

Table 3.2: Log of Natural Snow Endurance Time Tests

Run #	Test #	Date	Fluid/Dilution	Plate Angle	Surface	Start Time (hh:mm:ss)	End Time (hh:mm:ss)	Endurance Time (min)	Adjusted ET (min)	% of baseline	Precip. Rate (g/dm2/h)	EC OAT (°C)	EC Wind Speed (km/h)	Thickness @ 5 min	Brix @ Fail
1	PH-ET1	01-Feb-14	AD 49, 100/0	10°	Aluminum	17:52:03	19:32:00	100.0	100.0	100%	11.17	-2.2	8.3	N/A	11.00
1	PH-ET2	01-Feb-14	AD 49, 100/0	10°	B14	17:52:21	19:24:00	91.6	84.3	84%	10.28	-1.9	8.3	N/A	10.50
1	PH-ET3	01-Feb-14	AD 49, 100/0	10°	B15	17:52:47	19:25:00	92.2	86.0	86%	10.42	-1.9	8.3	N/A	12.00
2	PH-ET7	01-Feb-14	ABC-S +, 100/0	10°	Aluminum	19:57:21	20:55:00	57.6	57.6	100%	23.51	-3.1	12.0	1.20	9.50
2	PH-ET8	01-Feb-14	ABC-S +, 100/0	10°	B14	19:57:46	20:52:00	54.2	53.5	93%	23.19	-3.1	12.0	1.10	9.00
2	PH-ET9	01-Feb-14	ABC-S +, 100/0	10°	B15	19:58:15	20:59:00	60.7	62.0	108%	24.00	-3.1	12.0	1.60	9.00
3	PH-ET13	01-Feb-14	EG 106, 100/0	10°	Aluminum	22:25:28	23:28:00	62.5	62.5	100%	11.49	-3.7	8.0	1.80	8.50
3	PH-ET14	01-Feb-14	EG 106, 100/0	10°	B14	22:25:44	23:33:30	67.8	68.9	110%	11.69	-3.8	7.6	1.70	5.50
3	PH-ET15	01-Feb-14	EG 106, 100/0	10°	B15	22:26:02	23:29:00	63.0	63.2	101%	11.54	-3.7	8.0	1.70	6.00
4	PH-ET19	05-Feb-14	PG Advance, 100/0	10°	Aluminum	10:29:33	14:30:00	240.5	240.5	100%	4.87	-9.5	22.2	2.20	15.75
4	PH-ET20	05-Feb-14	PG Advance, 100/0	10°	B14	10:29:52	13:46:00	196.1	192.5	80%	4.78	-9.5	22.2	2.20	15.50
4	PH-ET21	05-Feb-14	PG Advance, 100/0	10°	B15	10:30:11	13:46:45	196.6	192.9	80%	4.78	-9.5	22.2	2.20	15.75
5	PH-ET25	05-Feb-14	EG 106, 100/0	10°	Aluminum	14:33:58	16:25:00	111.0	111.0	100%	9.03	-9.7	22.5	2.20	11.75
5	PH-ET26	05-Feb-14	EG 106, 100/0	10°	B14	14:34:16	16:11:00	96.7	100.8	91%	9.41	-9.7	22.5	2.20	13.00
5	PH-ET27	05-Feb-14	EG 106, 100/0	10°	B15	14:34:31	16:11:00	96.5	100.7	91%	9.42	-9.7	22.5	1.80	13.50
6	PH-ET31	13-Feb-14	ABC-S +, 100/0	10°	Aluminum	23:15:12	0:16:00	60.8	60.8	100%	10.80	-6.4	30.0	0.60	11.75
6	PH-ET32	13-Feb-14	ABC-S +, 100/0	10°	B14	23:15:33	0:28:24	72.85	67.5	111%	10.00	-6.4	30.0	0.70	11.50
6	PH-ET33	13-Feb-14	ABC-S +, 100/0	10°	B15	23:15:55	0:24:00	68.1	64.3	106%	10.20	-6.4	30.0	0.70	11.25
7	PH-ET37	14-Feb-14	AD 49, 100/0	10°	Aluminum	2:03:36	2:42:00	38.4	38.4	100%	16.37	-5.5	16.0	N/A	N/A
7	PH-ET38	14-Feb-14	AD 49, 100/0	10°	B14	2:03:11	2:42:00	38.8	38.6	101%	16.29	-5.5	16.0	N/A	N/A
7	PH-ET39	14-Feb-14	AD 49, 100/0	10°	B15	2:02:38	2:43:00	40.4	40.0	104%	16.22	-5.5	16.0	N/A	N/A
8	PH-ET44	12-Mar-14	PG Advance, 100/0	10°	Aluminum	14:12:15	15:37:35	85.3	85.3	100%	15.33	-10.0	28.5	0.70	14.00
8	PH-ET45	12-Mar-14	PG Advance, 100/0	10°	B14	14:12:33	15:44:10	91.6	91.6	107%	15.33	-10.0	28.5	0.70	14.50
8	PH-ET46	12-Mar-14	PG Advance, 100/0	10°	B15	14:12:58	15:40:30	87.5	87.1	102%	15.26	-10.0	28.5	0.70	14.00
9	PH-ET50	12-Mar-14	EG 106, 100/0	10°	Aluminum	16:51:53	17:59:00	67.1	67.1	100%	25.51	-10.7	27.0	N/A	12.00
9	PH-ET51	12-Mar-14	EG 106, 100/0	10°	B14	16:52:09	17:57:00	64.85	64.4	96%	25.35	-10.7	27.0	N/A	12.00
9	PH-ET52	12-Mar-14	EG 106, 100/0	10°	B15	16:52:25	17:55:00	62.6	61.6	92%	25.10	-10.7	27.0	N/A	11.00
10	PH-ET56	12-Mar-14	PG Advance, 100/0	10°	Aluminum	19:46:09	20:49:00	62.9	62.9	100%	15.03	-11.6	29.5	0.80	19.00
10	PH-ET57	12-Mar-14	PG Advance, 100/0	10°	B14	19:46:31	20:43:00	56.5	56.4	90%	15.01	-11.6	29.5	1.00	19.00
10	PH-ET58	12-Mar-14	PG Advance, 100/0	10°	B15	19:46:55	20:42:00	55.1	55.1	88%	15.04	-11.6	29.5	0.80	19.00

3.2 Data Analysis

The endurance time testing results were separated into three groups to provide a general summary of the results. The three test groupings are as follows:

- Natural Snow Testing with Type IV Fluids;
- Freezing Precipitation Testing with Type IV Fluids; and
- Freezing Precipitation Testing with Type I Fluids.

Figure 3.1 to Figure 3.3 indicate the endurance time results of ice phobic coated surfaces as compared to the baseline standard aluminum surface. The baseline surface is represented in the graph as 100 percent.

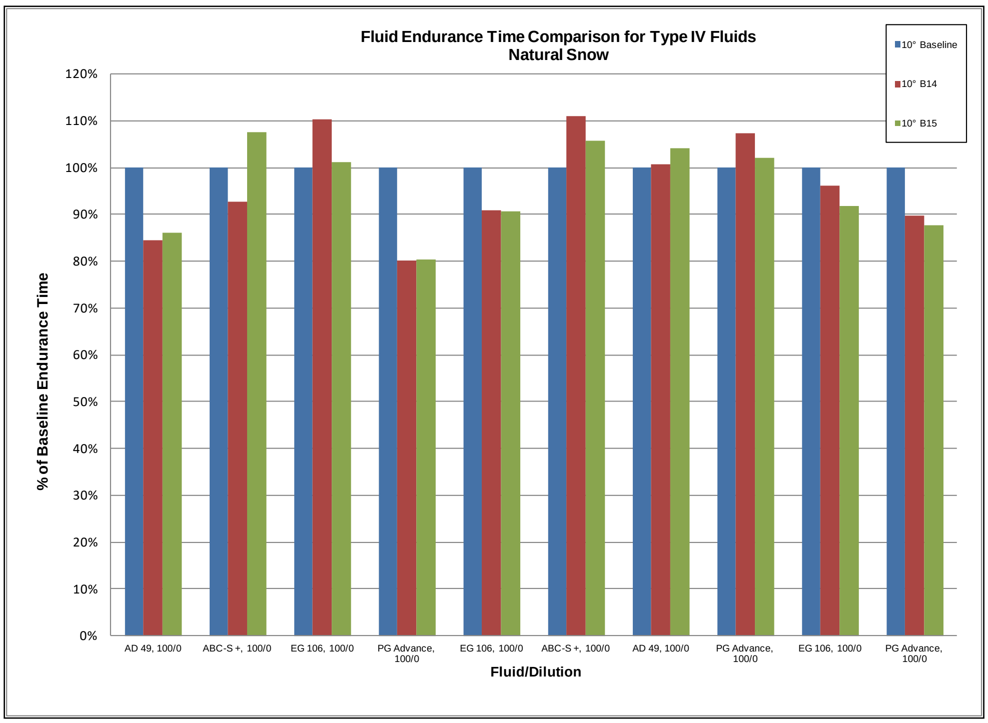


Figure 3.1 Fluid Endurance Time Comparison for Type IV Fluids – Natural Snow

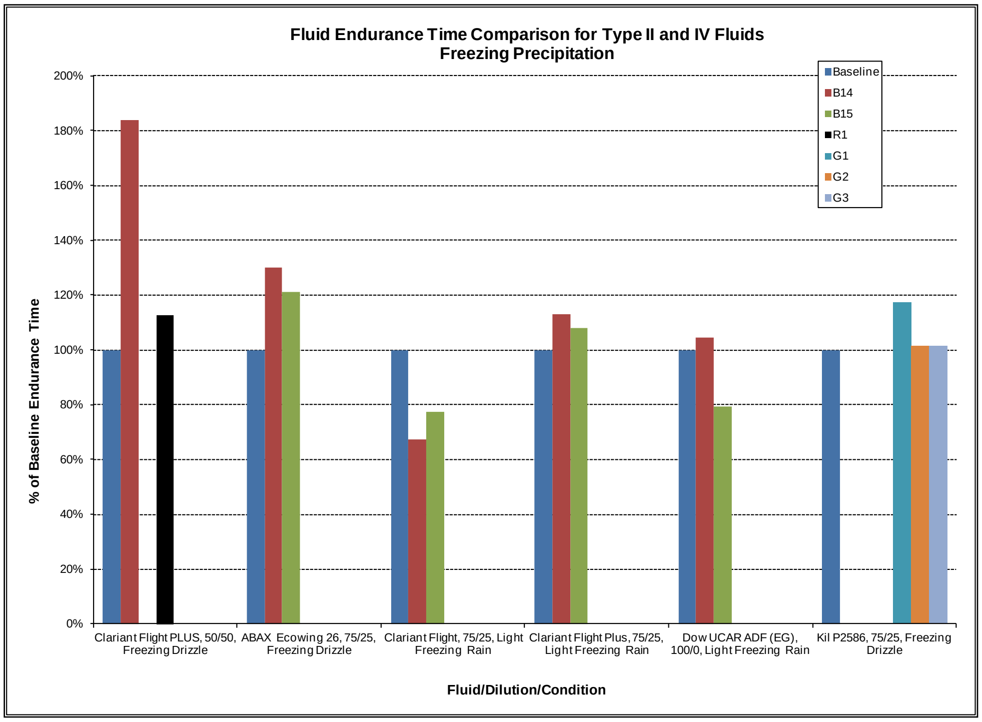


Figure 3.2: Fluid Endurance Time Comparison for Type IV Fluids – Freezing Precipitation

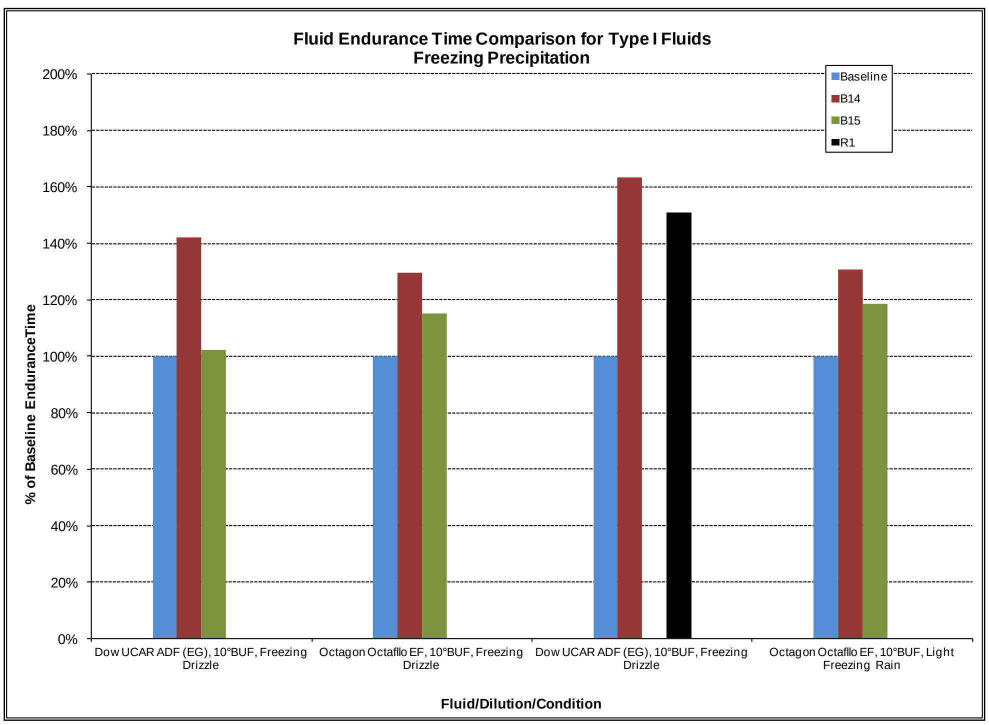


Figure 3.3: Fluid Endurance Time Comparison for Type I Fluids – Freezing Precipitation

3.3 General Observations

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. Table 3.3 depicts a summary of the results.

Table 3.3: Summary of Results

Coating	Average ET as percent of Baseline Aluminum Plate		
	Type IV Snow	Type II & IV ZP	Type I ZP
B14	96%	120%	141%
B15	96%	99%	112%
G1	N/A	117%*	N/A
G2	N/A	101%*	N/A
G3	N/A	101%*	N/A
R1	N/A	113%*	151%*

*Value is only one data point

Photo 3.1: Test Stand Setup (Freezing Precipitation) for I-PH B14 and I-PH B15

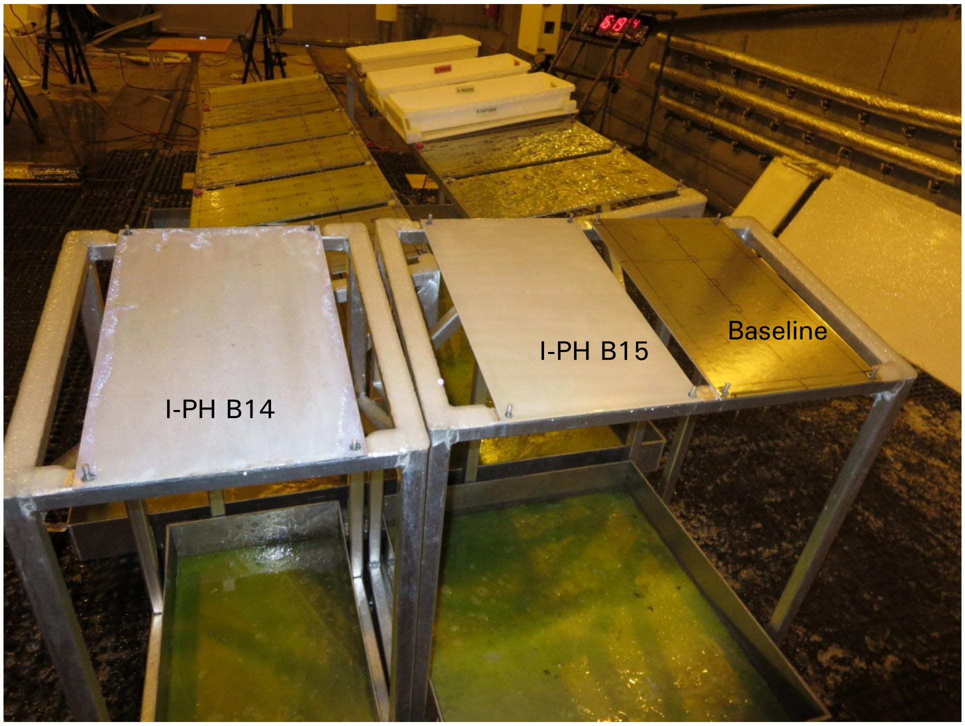


Photo 3.2: Test Stand Setup (Freezing Precipitation) for I-PH G1, G2, and G3

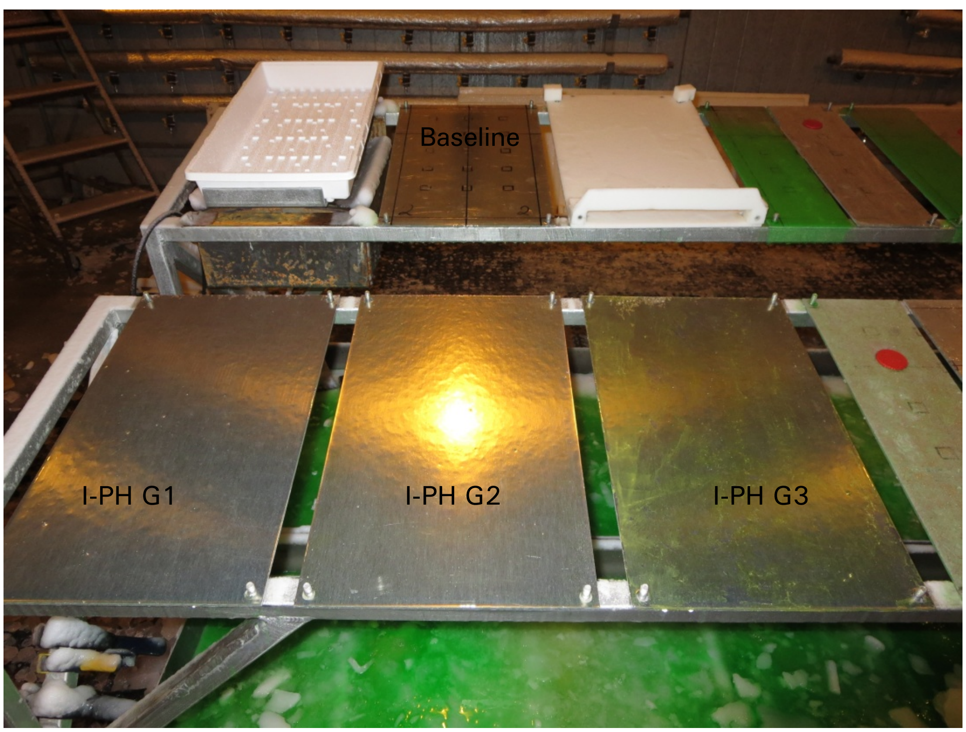


Photo 3.3: Test Stand Setup (Freezing Precipitation) for I-PH R1

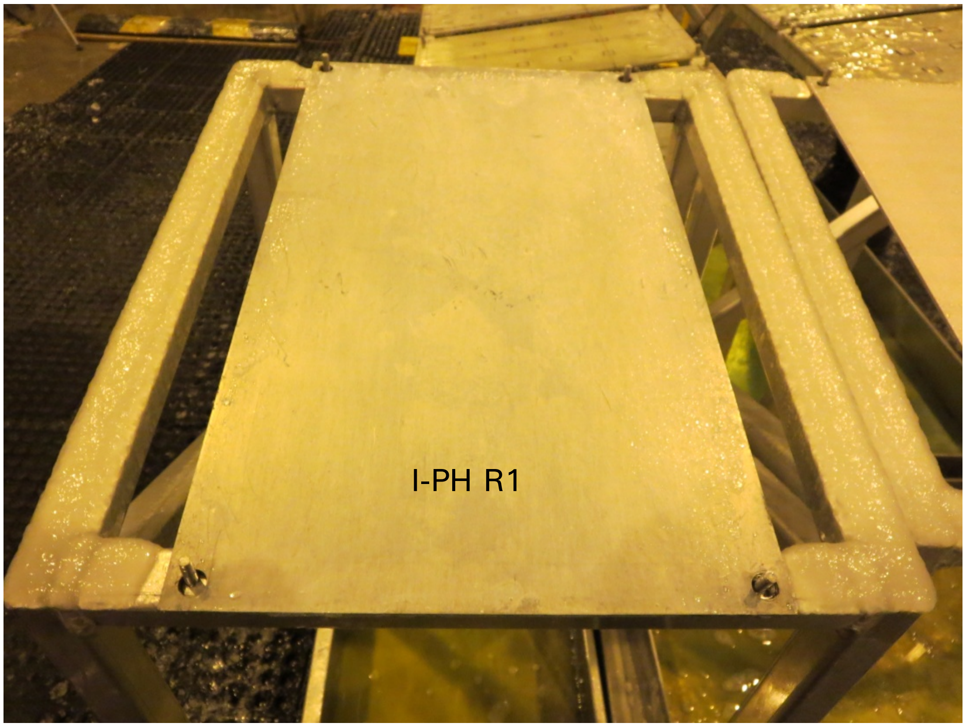
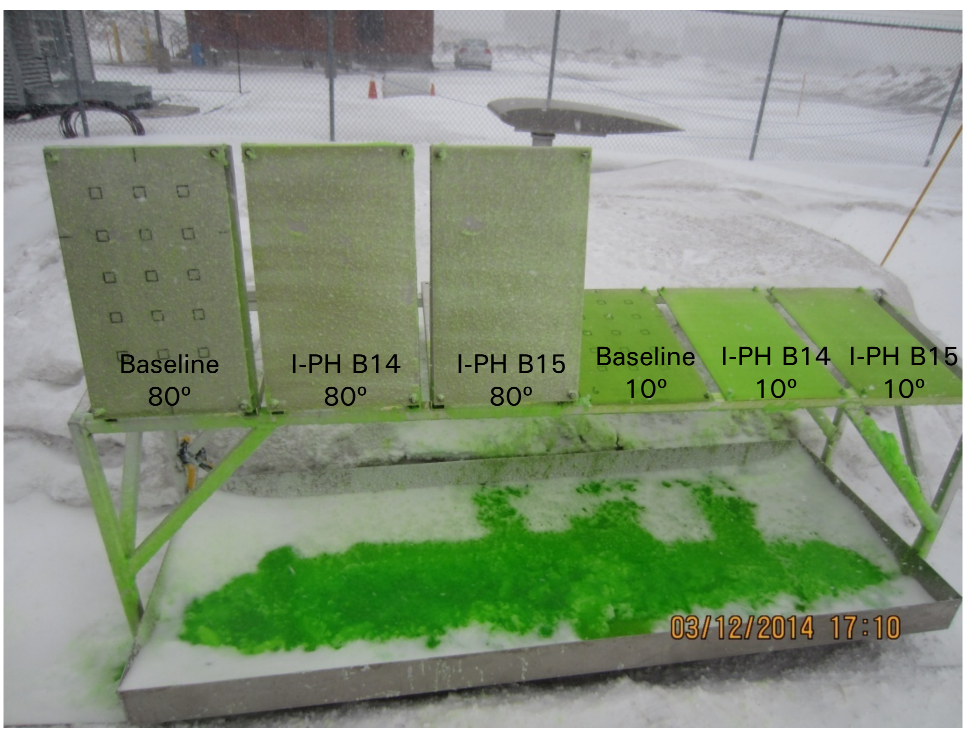


Photo 3.4: Test Stand Setup (Natural Snow) for I-PH B14 and I-PH B15



4 ADHERENCE TESTING DATA AND RESULTS

In this section, the adherence testing data collected during the winter of 2013-14 is analysed and discussed. The coated surfaces were evaluated against the baseline plate based on the potential to delay the onset of adherence when exposed to simulated freezing contamination. Testing was conducted in light freezing rain as this is considered a worst case scenario with regards to adhesion onto surfaces.

4.1 Log of Adherence Tests Conducted

To facilitate the accessibility of the data collected, a log was created for the tests conducted by APS at the NRC CEF during the winter of 2013-14. The log presented in Table 4.1 provides relevant information for each of the tests, as well as final values used for the data analysis. Each row contains data specific to one test.

Table 4.1: Log of Adherence Tests Conducted

Test #	Precip. Type	Temp (ºC)	Precip. Rate (g/dm²/h)	Test Surface	Time (min): 30% Ice Coverage	Comments on Characteristics
PH-AD1	Light Freezing Rain	-10	13.1	Baseline	1.0	Smooth Ice
PH-AD2	Light Freezing Rain	-10	12.8	I-PH B14	1.0	Bumpier Ice but almost instantly froze
PH-AD3	Light Freezing Rain	-10	13	I-PH B15	1.0	Bumpier Ice but almost instantly froze
PH-AD1 (repeat)	Light Freezing Drizzle	-10	5.9	Baseline	3.0*	Smother ice. Time Recorded is at 100% Ice Coverage
PH-AD4	Freezing Drizzle	-10	6.6	I-PH G1	3.0*	Bumpier Ice. Time Recorded is at 100% Ice Coverage
PH-AD5	Freezing Drizzle	-10	5.6	I-PH G2	7.5*	Bumpier Ice. Time Recorded is at 100% Ice Coverage
PH-AD6	Freezing Drizzle	-10	5.3	I-PH G3	8.5*	Bumpier Ice. Time Recorded is at 100% Ice Coverage

*time of 30% ice coverage was not recorded.

4.2 Test Summary

Testing was completed with a baseline aluminum plate and five coated plates. Frozen ice was present on all plates shortly after exposure. There was a minimal delay observed with the coated plates, however all plates eventually formed ice.

Some differences in adhered contamination exist between the baseline and the coated plates with respect to the surface roughness of the plate after freezing. Photo 4.1 and Photo 4.2 demonstrates the setup used in this testing.

4.3 General Observations

In some cases, when left undisturbed, the coated surfaces were able to delay the onset of adherence and ice formation. In addition, the removal of the contamination was generally easier on the coated surface.

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 and will be described in Section 8.

Photo 4.1: Adherence Test in Light Freezing Rain with I-PH B14, B15

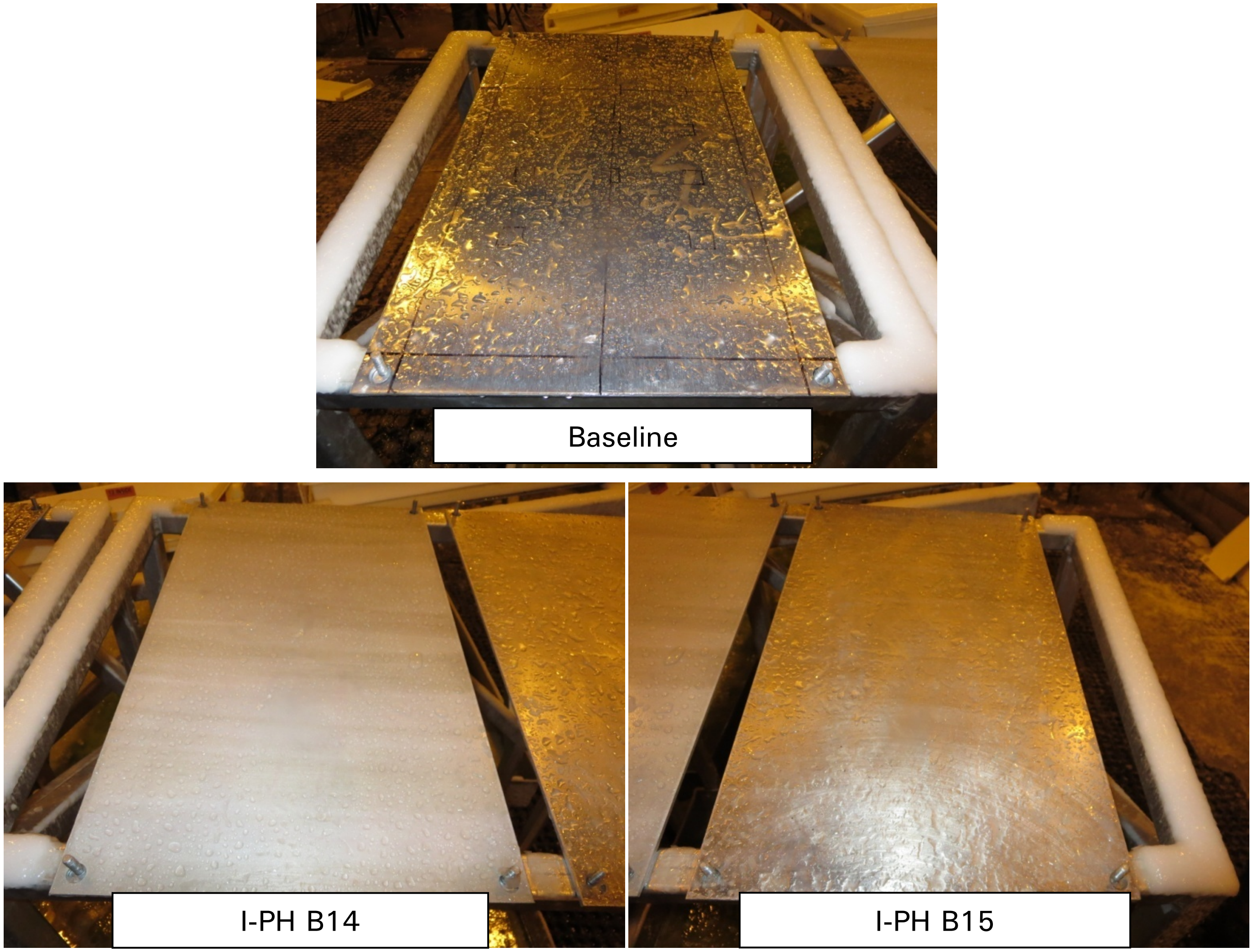
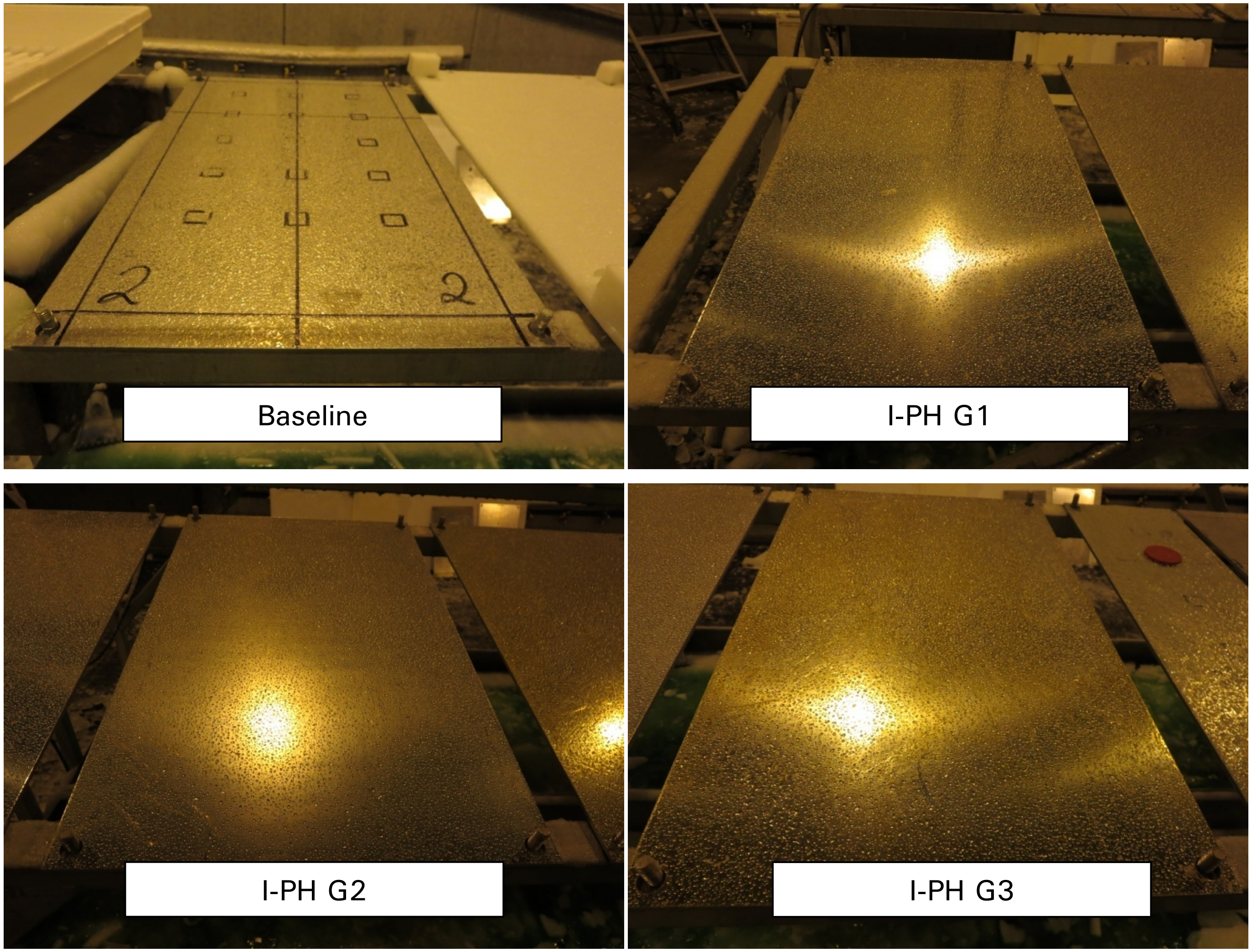


Photo 4.2: Adherence Test in Light Freezing Drizzle with I-PH G1, G2, G3



5 FLUID WETTING AND FLUID THICKNESS TESTING DATA AND RESULTS

In this section, the fluid thickness testing data collected during the winter of 2013-14 is analysed and discussed. The coated surface was evaluated against the baseline plate based on de/anti-icing fluid ability to properly wet and provide appropriate fluid thickness when applied to the test surface. Testing was conducted at -3°C in non-precipitation conditions at the NRC CEF. Fluid thickness was measured for the Type IV fluid test (fluid wetting was not necessary, as plates typically remain fully wetted). Fluid wetting was measured for Type I fluids because fluid thickness is not representative (thickness is usually less than 0 to 1 mm for all Type I fluids) and because wetting issues are more apparent due to the lack of fluid thickeners.

5.1 Log of Tests Conducted

To facilitate the accessibility of the data collected, a log was created for the tests conducted by APS at NRC CEF during the winter of 2013-14. The log presented in Table 5.1 and Table 5.2 provides relevant information for each of the tests, as well as final values used for the data analysis. Each row contains data specific to one test. It should be noted that tests were not conducted with coatings I-PH R1, G1, G2, or G3.

5.2 Test Summary

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 when 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 (see Photo 5.1). The Type IV fluid thickness test, however, (Photo 5.2) demonstrated minor degradation in fluid thickness 5 minutes after application.

Table 5.1: Log of Type I Fluid Wetting Tests Conducted

Run #	Fluid Name	Fluid Type	Fluid Dilution	Test Surface	% of Plate Wetted @ 2 Min	% of Plate Wetted @ 5 Min	% of Plate Wetted 15 Min	% of Plate Wetted @ 30 Min
1	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	Baseline	100%	100%	100%	100%
1	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	B14	80%	60%	10%	< 5%
1	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	B15	30%	< 5%	< 5%	< 5%
2	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	Baseline	100%	100%	100%	100%
2	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	B14	95%	85%	50%	< 5%
2	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	B15	60%	10%	< 5%	< 5%

Note: Testing was conducted at -3ºC

Table 5.2: Log of Type IV Fluid Thickness Tests Conducted

Run #	Fluid Name	Fluid Type	Fluid Dilution	Test Surface	Thickness @ 2 min (mm)	Thickness @ 5 min (mm)	Thickness @ 15 min (mm)	Thickness @ 30 min (mm)
1	Clariant Max Flight Sneg	Type IV PG	100/0	Baseline	1.7	1.5	1.2	1.1
1	Clariant Max Flight Sneg	Type IV PG	100/0	B14	1.3	1.1	0.8	0.6
1	Clariant Max Flight Sneg	Type IV PG	100/0	B15	1.7	1.5	0.8	0.6

Note: Testing was conducted at -3ºC

Photo 5.1: Type I Fluid Wetting Test

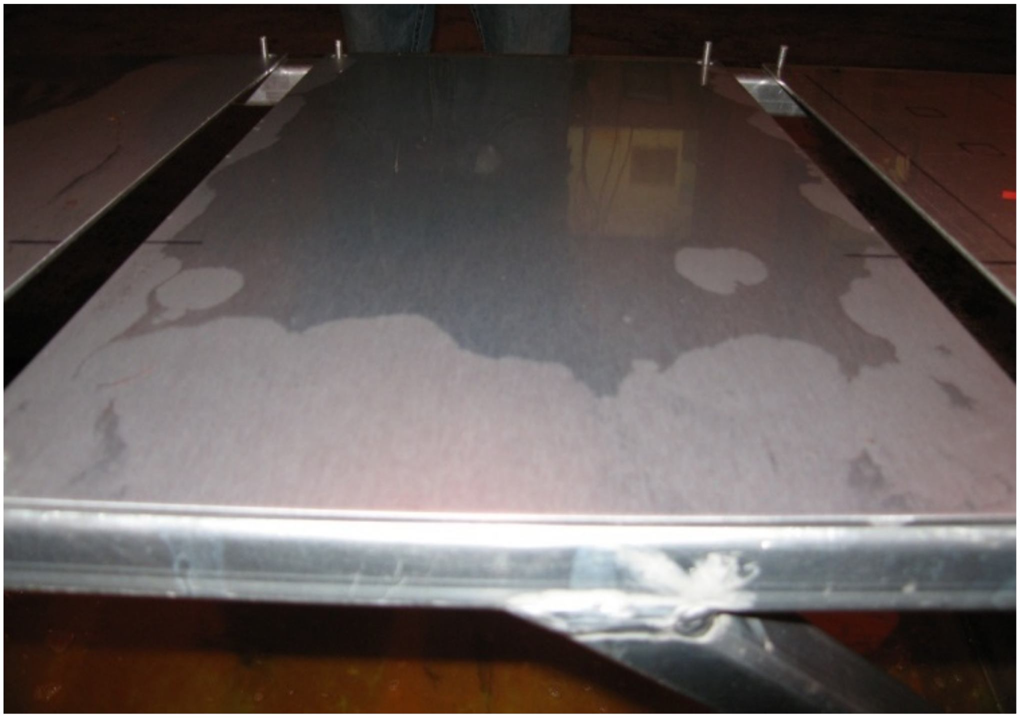
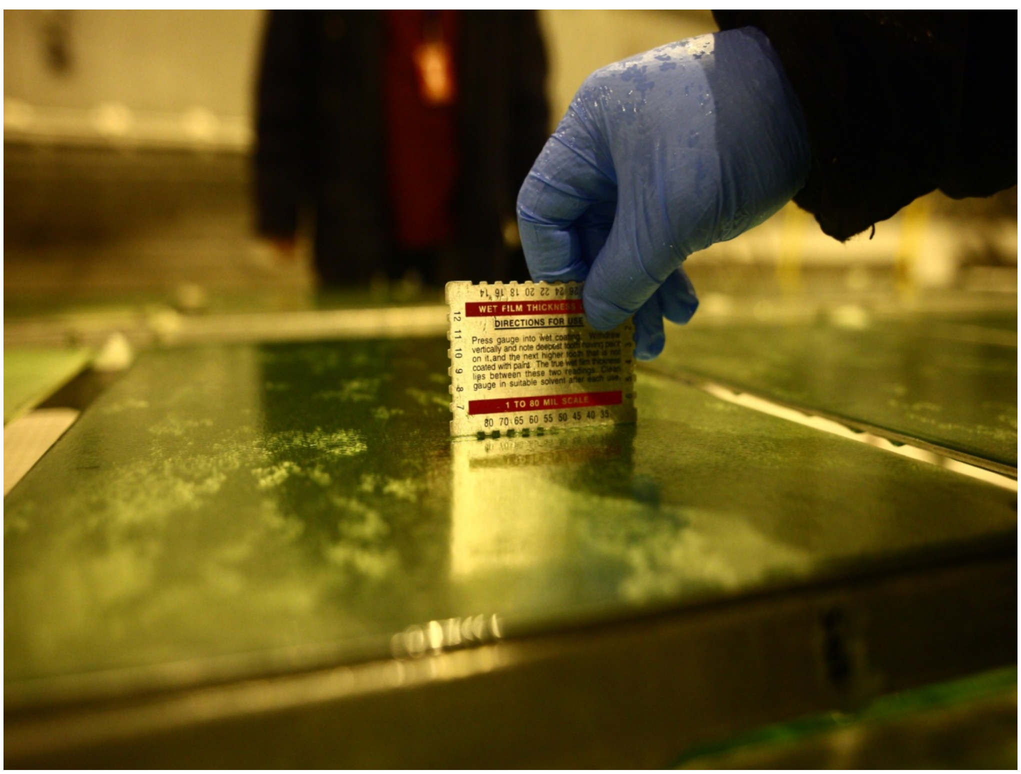


Photo 5.2: Type IV Fluid Thickness Test



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6 HOT WATER DEICING FOR COATINGS

Some coating manufacturers have indicated that, for the first-step of a two-step de/anti-icing process, it may be possible to use hot water in conjunction with coated surfaces as a substitute for glycol. This is due to the slope of the treated surface allowing water to slide off the wing before nucleating into ice. The same effect would happen if glycol was applied, which calls into question whether glycol would even be needed when deicing ice phobic surfaces. This was observed in the Type I wetting tests where lack of wetting was observed on coated surfaces shortly after fluid application.

If effective, this approach could have significant environmental benefits.

In this section, the hot water testing data collected during the winter of 2013-14 is analysed and discussed. The coated surface (treated with hot water) was evaluated against the baseline plate (treated with Type I deicing fluid at a 10°C buffer).

6.1 Log of Hot Water Tests Conducted

To facilitate the accessibility of the data collected, a log was created for the tests conducted (two preliminary test runs were conducted) by APS at the NRC CEF during the winter of 2013-14. The log presented in Table 6.1 provides relevant information for each of the tests, as well as the final values used for the data analysis. Each row contains data specific to one test.

Table 6.1: Log of Hot Water Tests Conducted

Run #	Test #	Date	Condition	Fluid	Dilution	Surface	Fluid Dilution	Adjusted Endurance Time (min)	% of Baseline ET	Actual Rate of Precip (g/dm²/hr)	Ambient Temp (°C)
1	PH-HW1	20-Mar-14	Light Freezing Rain	Octagon Octaflo EF	10°B (B=27.0)	Baseline Aluminum Type I	10°B (B=27.0)	6.1	100%	13.1	-10
	PH-HW2	20-Mar-14	Light Freezing Rain	Hot Water (1L @20°C)	n/a	Aluminum	n/a	7.5	123%	13.1	-10
	PH-HW3	20-Mar-14	Light Freezing Rain	Hot Water (1L @20°C)	n/a	B14	n/a	6.2	101%	12.8	-10
	PH-HW4	20-Mar-14	Light Freezing Rain	Hot Water (1L @20°C)	n/a	B15	n/a	6.9	114%	13.0	-10
2	PH-HW5	24-Apr-14	Freezing Drizzle	Octagon Octaflo EF	10°B (B=27.0)	Baseline Aluminum Type I	10°B (B=27.0)	6.0	100%	5.9	-10
	PH-HW6	24-Apr-14	Freezing Drizzle	Hot Water (1L @20°C)	n/a	G1	n/a	9.5	158%	6.6	-10
	PH-HW7	24-Apr-14	Freezing Drizzle	Hot Water (1L @20°C)	n/a	G2	n/a	6.2	103%	5.6	-10
	PH-HW8	24-Apr-14	Freezing Drizzle	Hot Water (1L @20°C)	n/a	G3	n/a	5.8	97%	5.3	-10

6.2 Test Summary

Testing was conducted at -10°C in both freezing rain and freezing drizzle. Both Type I and hot water were applied according to the standard of 1 litre with a fluid temperature of 20°C. Figure 6.1 and Figure 6.2 demonstrate the two tests conducted.

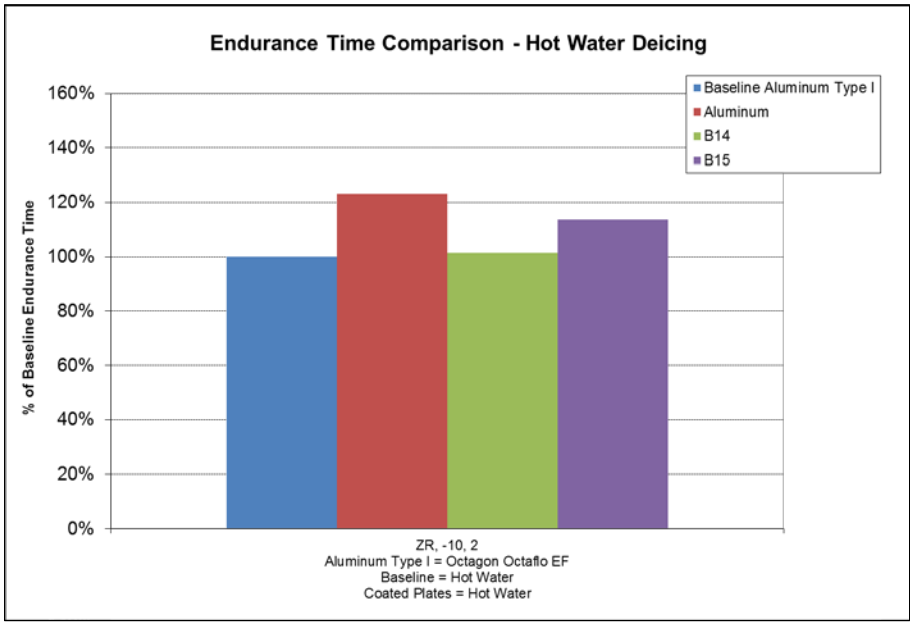

Figure 6.1: Hot Water Deicing Results for I-PH B14 and B15

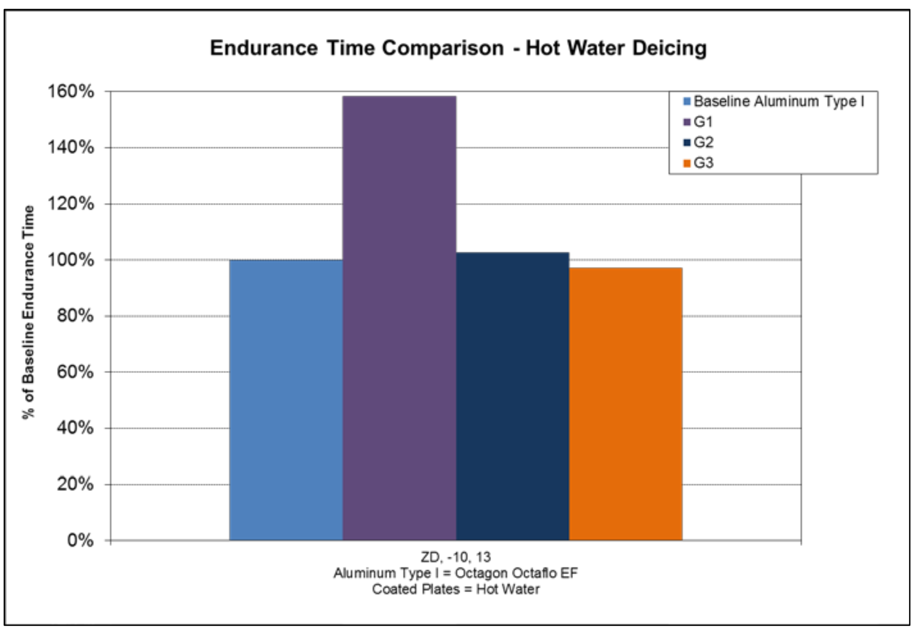

Figure 6.2: Hot Water Deicing Results for I-PH G1, G2, and G3

6.3 General Observations

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

Photo 6.1 and Photo 6.2 show the conditions of the plates, which all formed ice by the end of the test. Coated plates tended to have beads of ice, whereas the baseline plate had a smooth layer of ice. This is of general interest but not pertinent to first-step deicing where the deiced surface must be entirely clear of ice at time of anti-icing application.

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Photo 6.1: End of Hot Water Test with I-PH B13 and B14

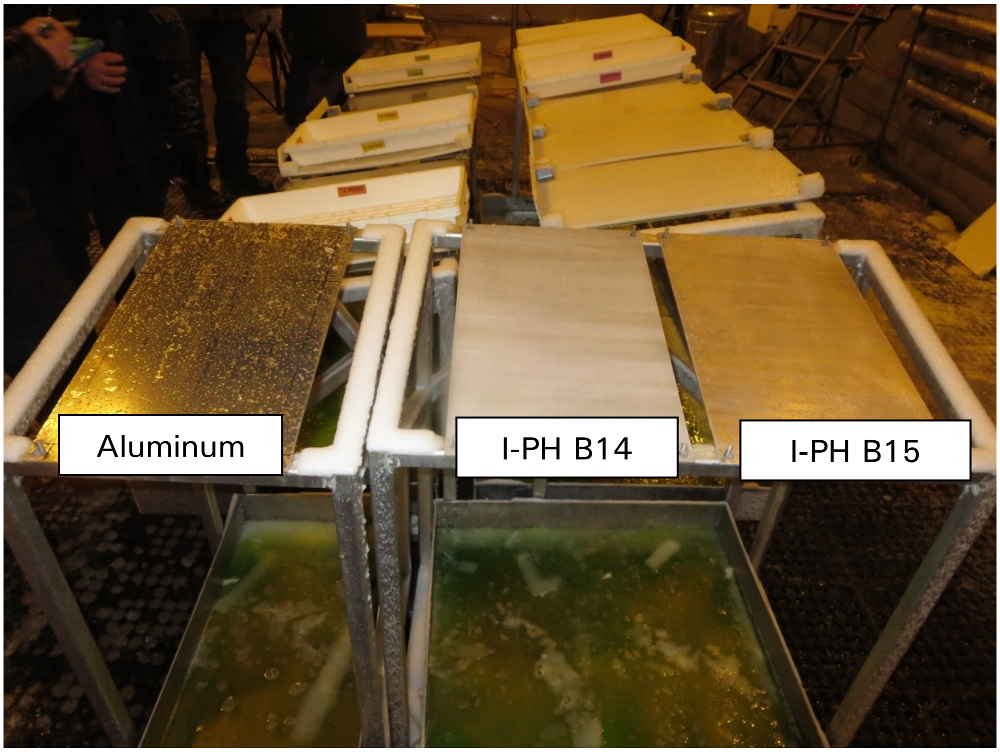
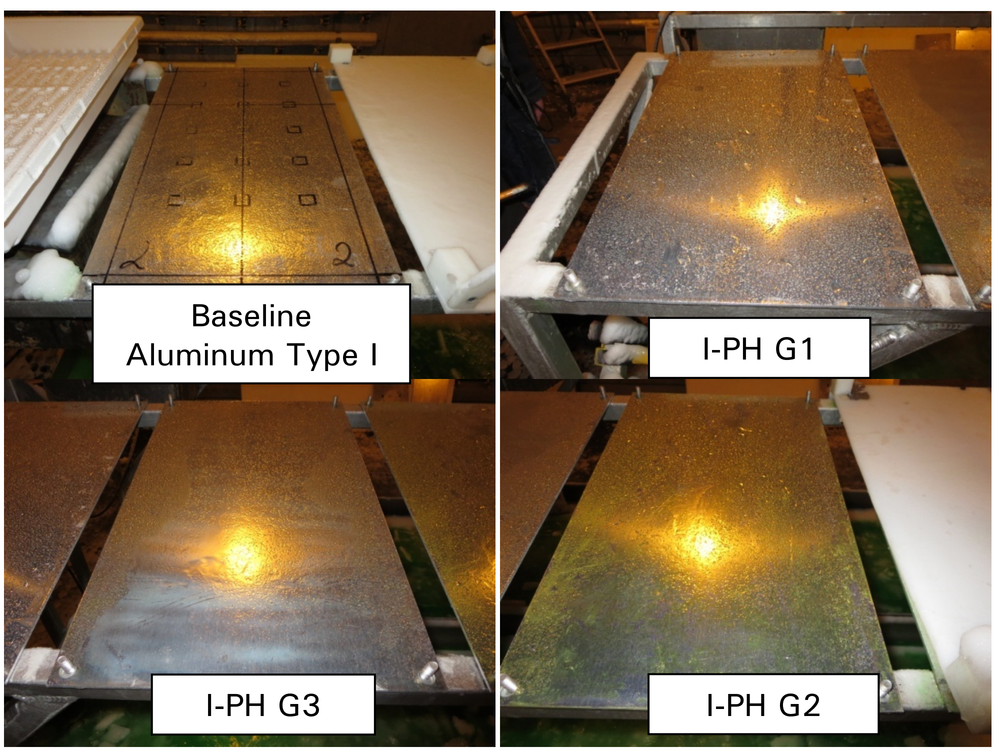


Photo 6.2: End of Hot Water Test with I-PH G1, G2, and G3



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7 VERTICAL STABILIZER TESTING DATA AND RESULTS

In this section, the vertical stabilizer testing data collected during the winter of 2013-14 is analysed and discussed. Due to the early fluid failures observed on vertical surfaces, it was suggested that tests be conducted with ice phobic treated surfaces to investigate any potential benefits. Type IV tests were conducted with vertical plates, which were coated with an ice phobic coating, and the ET performance was compared to a baseline vertical plate which was not coated. Photo 7.1 and Photo 7.2 show the testing setup.

7.1 Log of Endurance Time Tests Conducted

To facilitate the accessibility of the data collected, a log was created for the series of tests conducted by APS at the P.E.T. Airport test site during the winter of 2013-14. The log presented in Table 7.1 provides relevant information for each of the tests, as well as the final values used for the data analysis. Each row contains data specific to one test. In addition, the 10º flat plate results using the same plates were also included and serve as reference; the grey highlighted cells identify the 80º vertical plate tests.

Table 7.1: Log of Vertical Stabilizer Endurance Time Tests (10º and 80º Flat Plate Data)

Run #	Test #	Date	Fluid/Dilution	Plate Angle	Surface	Adjusted ET (min)	% of baseline	Precip. Rate ($g/dm^2/h$)	EC OAT (°C)	EC Wind Speed (km/h)	Thickness @ 5 min	Brix @ Fail
1	PH-ET1	01-Feb-14	AD 49, 100/0	10°	Aluminum	100.0	100%	11.17	-2.2	8.3	N/A	11.00
1	PH-ET2	01-Feb-14	AD 49, 100/0	10°	B14	84.3	84%	10.28	-1.9	8.3	N/A	10.50
1	PH-ET3	01-Feb-14	AD 49, 100/0	10°	B15	86.0	86%	10.42	-1.9	8.3	N/A	12.00
1	PH-ET4	01-Feb-14	AD 49, 100/0	80°	Aluminum	50.5	50%	7.76	-1.9	7.0	N/A	9.50
1	PH-ET5	01-Feb-14	AD 49, 100/0	80°	B14	46.0	46%	7.42	-1.9	7.0	N/A	9.50
1	PH-ET6	01-Feb-14	AD 49, 100/0	80°	B15	43.3	43%	7.33	-1.9	7.0	N/A	9.50
2	PH-ET7	01-Feb-14	ABC-S +, 100/0	10°	Aluminum	57.6	100%	23.51	-3.1	12.0	1.20	9.50
2	PH-ET8	01-Feb-14	ABC-S +, 100/0	10°	B14	53.5	93%	23.19	-3.1	12.0	1.10	9.00
2	PH-ET9	01-Feb-14	ABC-S +, 100/0	10°	B15	62.0	108%	24.00	-3.1	12.0	1.60	9.00
2	PH-ET10	01-Feb-14	ABC-S +, 100/0	80°	Aluminum	13.8	24%	20.38	-2.8	11.0	0.30	5.00
2	PH-ET11	01-Feb-14	ABC-S +, 100/0	80°	B14	13.1	23%	20.41	-2.8	11.0	0.30	4.50
2	PH-ET12	01-Feb-14	ABC-S +, 100/0	80°	B15	12.3	21%	20.45	-2.8	11.0	0.30	4.00
3	PH-ET13	01-Feb-14	EG 106, 100/0	10°	Aluminum	62.5	100%	11.49	-3.7	8.0	1.80	8.50
3	PH-ET14	01-Feb-14	EG 106, 100/0	10°	B14	68.9	110%	11.69	-3.8	7.6	1.70	5.50
3	PH-ET15	01-Feb-14	EG 106, 100/0	10°	B15	63.2	101%	11.54	-3.7	8.0	1.70	6.00
3	PH-ET16	01-Feb-14	EG 106, 100/0	80°	Aluminum	19.0	30%	10.33	-3.7	8.0	0.50	9.50
3	PH-ET17	01-Feb-14	EG 106, 100/0	80°	B14	15.3	24%	10.20	-3.7	8.0	0.50	10.00
3	PH-ET18	01-Feb-14	EG 106, 100/0	80°	B15	14.6	23%	10.18	-3.7	8.0	0.50	7.00
4	PH-ET19	05-Feb-14	PG Advance, 100/0	10°	Aluminum	240.5	100%	4.87	-9.5	22.2	2.20	15.75
4	PH-ET20	05-Feb-14	PG Advance, 100/0	10°	B14	192.5	80%	4.78	-9.5	22.2	2.20	15.50
4	PH-ET21	05-Feb-14	PG Advance, 100/0	10°	B15	192.9	80%	4.78	-9.5	22.2	2.20	15.75
4	PH-ET22	05-Feb-14	PG Advance, 100/0	80°	Aluminum	50.4	21%	4.28	-9.3	20.0	0.50	16.00
4	PH-ET23	05-Feb-14	PG Advance, 100/0	80°	B14	43.9	18%	4.68	-9.3	22.0	0.70	15.50
4	PH-ET24	05-Feb-14	PG Advance, 100/0	80°	B15	40.2	17%	4.86	-9.3	22.0	0.70	15.50
5	PH-ET25	05-Feb-14	EG 106, 100/0	10°	Aluminum	111.0	100%	9.03	-9.7	22.5	2.20	11.75
5	PH-ET26	05-Feb-14	EG 106, 100/0	10°	B14	100.8	91%	9.41	-9.7	22.5	2.20	13.00
5	PH-ET27	05-Feb-14	EG 106, 100/0	10°	B15	100.7	91%	9.42	-9.7	22.5	1.80	13.50
5	PH-ET28	05-Feb-14	EG 106, 100/0	80°	Aluminum	23.4	21%	8.47	-9.7	19.0	0.60	10.00
5	PH-ET29	05-Feb-14	EG 106, 100/0	80°	B14	22.5	20%	8.44	-9.7	19.0	0.70	10.00
5	PH-ET30	05-Feb-14	EG 106, 100/0	80°	B15	20.1	18%	8.18	-9.7	19.0	0.70	6.00

Table 7.1: Log of Vertical Stabilizer Endurance Time Tests (10º and 80º Flat Plate Data) (cont'd)

Run #	Test #	Date	Fluid/Dilution	Plate Angle	Surface	Adjusted ET (min)	% of baseline	Precip. Rate (g/dm2/h)	EC OAT (°C)	EC Wind Speed (km/h)	Thickness @ 5 min	Brix @ Fail
6	PH-ET31	13-Feb-14	ABC-S +, 100/0	10°	Aluminum	60.8	100%	10.80	-6.4	30.0	0.60	11.75
6	PH-ET32	13-Feb-14	ABC-S +, 100/0	10°	B14	67.5	111%	10.00	-6.4	30.0	0.70	11.50
6	PH-ET33	13-Feb-14	ABC-S +, 100/0	10°	B15	64.3	106%	10.20	-6.4	30.0	0.70	11.25
6	PH-ET34	13-Feb-14	ABC-S +, 100/0	80°	Aluminum	18.6	31%	10.58	-6.4	30.0	1.10	15.00
6	PH-ET35	13-Feb-14	ABC-S +, 100/0	80°	B14	18.2	30%	10.58	-6.4	30.0	1.70	15.00
6	PH-ET36	13-Feb-14	ABC-S +, 100/0	80°	B15	16.0	26%	10.56	-6.4	30.0	1.70	14.25
7	PH-ET37	14-Feb-14	AD 49, 100/0	10°	Aluminum	38.4	100%	16.37	-5.5	16.0	N/A	N/A
7	PH-ET38	14-Feb-14	AD 49, 100/0	10°	B14	38.6	101%	16.29	-5.5	16.0	N/A	N/A
7	PH-ET39	14-Feb-14	AD 49, 100/0	10°	B15	40.0	104%	16.22	-5.5	16.0	N/A	N/A
7	PH-ET40	14-Feb-14	AD 49, 100/0	80°	Aluminum	8.5	22%	16.90	-5.5	19.5	N/A	N/A
7	PH-ET41	14-Feb-14	AD 49, 100/0	80°	B14	9.1	24%	16.88	-5.5	19.5	N/A	N/A
7	PH-ET42	14-Feb-14	AD 49, 100/0	80°	B15	9.6	25%	16.72	-5.5	19.5	N/A	N/A
7	PH-ET43	14-Feb-14	AD 49, 100/0	80° Rotating	Aluminum	7.7	20%	16.46	-5.5	16.0	N/A	N/A
8	PH-ET44	12-Mar-14	PG Advance, 100/0	10°	Aluminum	85.3	100%	15.33	-10.0	28.5	0.70	14.00
8	PH-ET45	12-Mar-14	PG Advance, 100/0	10°	B14	91.6	107%	15.33	-10.0	28.5	0.70	14.50
8	PH-ET46	12-Mar-14	PG Advance, 100/0	10°	B15	87.1	102%	15.26	-10.0	28.5	0.70	14.00
8	PH-ET47	12-Mar-14	PG Advance, 100/0	80°	Aluminum	22.0	26%	15.69	-9.5	30.3	1.70	14.00
8	PH-ET48	12-Mar-14	PG Advance, 100/0	80°	B14	21.9	26%	16.11	-9.5	30.3	2.20	16.00
8	PH-ET49	12-Mar-14	PG Advance, 100/0	80°	B15	19.2	23%	15.89	-9.5	30.3	2.20	15.00
9	PH-ET50	12-Mar-14	EG 106, 100/0	10°	Aluminum	67.1	100%	25.51	-10.7	27.0	N/A	12.00
9	PH-ET51	12-Mar-14	EG 106, 100/0	10°	B14	64.4	96%	25.35	-10.7	27.0	N/A	12.00
9	PH-ET52	12-Mar-14	EG 106, 100/0	10°	B15	61.6	92%	25.10	-10.7	27.0	N/A	11.00
9	PH-ET53	12-Mar-14	EG 106, 100/0	80°	Aluminum	13.2	20%	22.76	-10.7	29.0	N/A	13.50
9	PH-ET54	12-Mar-14	EG 106, 100/0	80°	B14	12.5	19%	22.76	-10.7	29.0	N/A	13.50
9	PH-ET55	12-Mar-14	EG 106, 100/0	80°	B15	11.3	17%	22.77	-10.7	29.0	N/A	13.00
10	PH-ET56	12-Mar-14	PG Advance, 100/0	10°	Aluminum	62.9	100%	15.03	-11.6	29.5	0.80	19.00
10	PH-ET57	12-Mar-14	PG Advance, 100/0	10°	B14	56.4	90%	15.01	-11.6	29.5	1.00	19.00
10	PH-ET58	12-Mar-14	PG Advance, 100/0	10°	B15	55.1	88%	15.04	-11.6	29.5	0.80	19.00
10	PH-ET59	12-Mar-14	PG Advance, 100/0	80°	Aluminum	8.8	14%	11.69	-11.3	27.0	2.50	20.00
10	PH-ET60	12-Mar-14	PG Advance, 100/0	80°	B14	8.1	13%	11.70	-11.3	27.0	2.50	19.00
10	PH-ET61	12-Mar-14	PG Advance, 100/0	80°	B15	8.1	13%	11.75	-11.3	27.0	2.50	17.00

7.2 Data Analysis

The ratio of coated vertical surfaces to a baseline aluminum vertical surface was the primary focus of analysis. Table 7.2 and Figure 7.1 demonstrates the ratio of each coated vertical surface to that of the baseline coated surface.

Table 7.2: Ratio of Coated Vertical Surfaces to Baseline Coated Surface

Coating	Average ET as percent of 10° Baseline Aluminum Plate	Average ET as percent of 80° Baseline Aluminum Plate
	Type IV Snow	Type IV Snow
10° Baseline	100%	n/a
10° B14	96%	n/a
10° B15	96%	n/a
80° Baseline	26%	100%
80° B14	24%	94%
80° B15	23%	87%

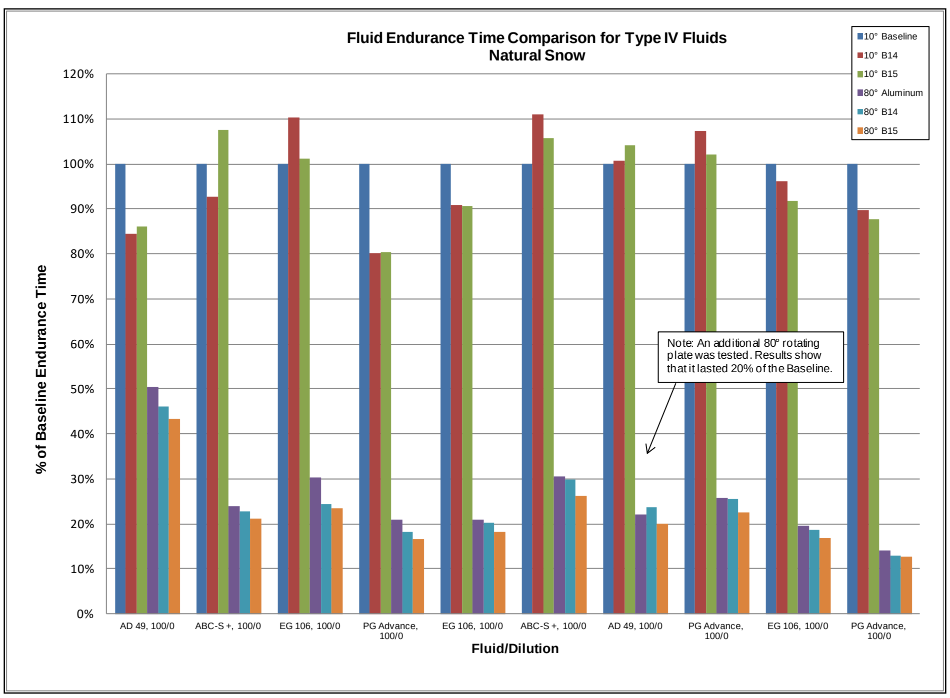

Figure 7.1: Vertical Stabilizer Ice Phobic Testing

7.3 General Observations

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 benefits may exist with the coated surfaces in the event the contamination becomes adhered as the forces to remove the adhered contamination is generally less with a coated surface.

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Photo 7.1: Vertical Test Surfaces Setup

Photo 7.2: Setup Showing 100 Percent Failure on All Vertical Surfaces

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8 WIND TUNNEL TESTING – ICE PHOBIC COATINGS

8.1 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.

A broader test plan was developed and conducted during the winter of 2013-14 to investigate some additional areas to gain new insight into the potential applications of these coatings for aircraft operations, and to continue the research to include newly developed coating formulations. As part of this test plan, it was recommended that testing continue to investigate the effects of these coatings on de/anti-icing fluids from a HOT and aerodynamic perspective.

8.2 Objective

To investigate the aerodynamic performance of an airfoil treated with a coating, with and without de/anti-icing fluids.

8.3 General Methodology

Testing was conducted using wing skins specifically manufactured to fit onto the existing thin, high performance wing section, and was secured by flush-mounted screws. To cover the entire test wing, two individual wing skin halves were required. The wing skins were treated with the various coatings prior to testing to allow the proper curing times. Photo 8.1 to Photo 8.8 show a sample of the wing skins tested (duplicate or repeat skins are not shown).

The general methodology used for these tests was in accordance with the methodologies used for typical fluid and contamination tests conducted in the wind tunnel. The evaluation methodology was modified to allow a comparison among the different wing skin performances as well as to the baseline un-treated wing skin and the original wing without a skin. The following describes the typical testing plan per coating. Additional or fewer tests may have been completed at the discretion of the project management team (TC/FAA/APS).

- Test Plan for Evaluating Ice Phobic Coatings:
  a) 3 x 100 knots 8º Rotation Takeoff;
  b) 3 x 100 knots -2º to 8º Pitch Pause;
  c) 3 x 80 knots Drag Evaluation at -2º, 0º, and 2º;
  d) 3 x 100 knots Drag Evaluation at -2º, 0º, and 2º;
  e) 3 x 115 knots Drag Evaluation at -2º, 0º, and 2º;
  f) 3 x 80 knots Rotation to Stall;
  g) 3 x 100 knots 8º Rotation Takeoff (Repeat);
  h) 3 x 100 knots 8º Rotation Takeoff with Fluid Only (EG 106);
  i) 2 x 100 knots 8º Rotation Takeoff to Evaluate Fluid Seepage; and
  j) 1 x 100 knots 8º Rotation Takeoff with ZR on Unprotected Wing.

It should be noted that the original test plan called for an extensive set of comparative tests contingent on the fact that some tests would be omitted or added during the testing period.

8.4 Data Collected

A summary of the test data has been separated by wing configuration (coated or not) and these tables are included as Table 8.1 to Table 8.12.

Table 8.1: Summary of I-PH B12 Coating Tests

I-PH B12

Run #	Test #	Date	Fluid Name	Objective	Corrected for 3D Effects % Lift Loss On 8° Cl vs Dry Cl	Avg Lift Loss	Coefficient of Drag @2°	Avg Drag @2°	Stall Angle(°)	Avg Stall Angle(°)	Tunnel Temp. Before Test (°C)	Avg Tunnel Temp (°C)
1	140	15-Jan-14	none	100 Kts 8°Rotation	0.76%	0.63%	-	-	-	-	-1.5	-1.5
	141	15-Jan-14			0.93%						-1.5	
	142	15-Jan-14			0.20%						-1.5	
2	143	15-Jan-14	none	100 Kts -2° to 8° Pitch Pause	0.25%	0.27%	-	-	-	-	-1.5	-1.5
	144	15-Jan-14			0.29%						-1.5	
	145	15-Jan-14			-						-1.5	
3	146	15-Jan-14	none	80 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.100965	0.100833	-	-	-1.5	-1.5
	147	15-Jan-14					0.100623				-1.5	
	148	15-Jan-14					0.100911				-1.5	
4	149	15-Jan-14	none	100 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.097669	0.097696	-	-	-1.5	-1.5
	150	15-Jan-14					0.097723				-1.5	
	151	15-Jan-14					0.097696				-1.5	
5	152	15-Jan-14	none	115 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.096665	0.096766	-	-	-1.5	-1.5
	153	15-Jan-14					0.096816				-1.5	
	154	15-Jan-14					0.096816				-1.5	
6	155	15-Jan-14	none	80 Kts Stall	1.59%	1.71%	-	-	18.5	18	-1.5	-1.5
	156	15-Jan-14			1.49%				18		-1.5	
	157	15-Jan-14			2.05%				17.5		-1.5	
7	158	15-Jan-14	none	100 Kts 8°Rotation	0.82%	0.77%	-	-	-	-	-1.5	-1.5
	159	15-Jan-14			0.69%						-1.5	
	160	15-Jan-14			0.80%						-1.5	
8	161	15-Jan-14	EG106	100 Kts Fluid Only	2.70%	2.68%	-	-	-	-	-1.2	-1.43
	162	15-Jan-14			2.68%						-1.3	
	163	15-Jan-14			2.66%						-1.8	

Table 8.2: Summary of I-PH B13 Coating Tests

I-PH B13													
Run #	**Test #**	**Date**	**Fluid Name**	**Objective**	**Corrected for 3D Effects % Lift Loss On 8° Cl vs Dry Cl**	**Avg Lift Loss**	**Coefficient of Drag @2°**	**Avg Drag @2°**	**Stall Angle(°)**	**Avg Stall Angle(°)**	**Tunnel Temp. Before Test (°C)**	**Avg Tunnel Temp (°C)**
1	195	16-Jan-14	none	100 Kts 8°Rotation	0.39%	0.64%	-	-	-	-	-2.3	-2.3
	196	16-Jan-14			0.66%						-2.3	
	197	16-Jan-14			0.86%						-2.3	
2	198	16-Jan-14	none	100 Kts -2° to 8° Pitch Pause	0.32%	0.23%	-	-	-	-	-2.3	-2.3
	199	16-Jan-14			0.25%						-2.3	
	200	16-Jan-14			0.13%						-2.3	
3	201	16-Jan-14	none	80 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.098460	0.099019	-	-	-2.3	-2.3
	202	16-Jan-14					0.098497				-2.3	
	203	16-Jan-14					0.100100				-2.3	
4	204	16-Jan-14	none	100 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.101579	0.101659	-	-	-2.3	-2.3
	205	16-Jan-14					0.101639				-2.3	
	206	16-Jan-14					0.101758				-2.3	
5	207	16-Jan-14	none	115 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.097253	0.097256	-	-	-2.3	-2.3
	208	16-Jan-14					0.097291				-2.3	
	209	16-Jan-14					0.097224				-2.3	
6	210	16-Jan-14	none	80 Kts Stall	1.78%	1.73%	-	-	17.5	17.5	-2.3	-2.3
	211	16-Jan-14			1.81%				17.5		-2.3	
	212	16-Jan-14			1.60%				17.5		-2.3	
7	213	16-Jan-14	none	100 Kts 8°Rotation	0.49%	0.62%	-	-	-	-	-2.3	-2.3
	214	16-Jan-14			0.70%						-2.3	
	215	16-Jan-14			0.66%						-2.3	
8	216	16-Jan-14	EG106	100 Kts Fluid Only	2.68%	2.72%	-	-	-	-	-0.8	-1.37
	217	16-Jan-14			2.84%						-1.1	
	218	16-Jan-14			2.65%						-2.2	
9	219	16-Jan-14	none	100 Kts Fluid Seepage	1.21%	1.11%	-	-	-	-	-1.8	-1.8
	220	16-Jan-14			1.01%						-1.8	
10	221	16-Jan-14	none	100 Kts Light Freezing Rain	2.59%	2.59%	-	-	-	-	-1.8	-1.8

Table 8.3: Summary of I-PH B14 Coating Tests

I-PH B14												
Run #	Test #	Date	Fluid Name	Objective	Corrected for 3D Effects % Lift Loss On 8° Cl vs Dry Cl	Avg Lift Loss	Coefficient of Drag @2°	Avg Drag @2°	Stall Angle(°)	Avg Stall Angle(°)	Tunnel Temp. Before Test (°C)	Avg Tunnel Temp (°C)
1	109	14-Jan-14	none	100 Kts 8°Rotation	0.33%	0.36%	-	-	-	-	4.4	4.4
	110	14-Jan-14			0.50%						4.4	
	111	14-Jan-14			0.25%						4.4	
2	112	14-Jan-14	none	100 Kts -2° to 8° Pitch Pause	-0.02%	-0.01%	-	-	-	-	4.4	4.4
	113	14-Jan-14			0.06%						4.4	
	114	14-Jan-14			-0.07%						4.4	
3	115	14-Jan-14	none	80 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.10009	0.10020	-	-	4.4	4.4
	116	14-Jan-14					0.10028				4.4	
	117	14-Jan-14					0.10024				4.4	
4	118	14-Jan-14	none	100 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.09775	0.09756	-	-	4.4	4.4
	119	14-Jan-14					0.09743				4.4	
	120	14-Jan-14					0.09752				4.4	
5	121	14-Jan-14	none	115 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.09684	0.09671	-	-	4.4	4.4
	122	14-Jan-14					0.09664				4.4	
	123	14-Jan-14					0.09665				4.4	
6	124	14-Jan-14	none	80 Kts Stall	1.43%	1.42%	-	-	18.00	18.67	4.4	4.4
	125	14-Jan-14			1.53%				19.00		4.4	
	126	14-Jan-14			1.30%				19.00		4.4	
7	127	14-Jan-14	none	100 Kts 8°Rotation	0.50%	0.70%	-	-	-	-	4.4	4.4
	128	14-Jan-14			0.76%						4.4	
	129	14-Jan-14			0.85%						4.4	
8	130	14-Jan-14	EG106	100 Kts Fluid Only	2.65%	2.70%	-	-	-	-	1.2	1.16667
	131	14-Jan-14			2.62%						1.2	
	132	14-Jan-14			2.83%						1.1	
9	133	14-Jan-14	none	100 Kts Fluid Seepage	1.45%	1.40%	-	-	-	-	-0.3	-0.3
	134	14-Jan-14			1.36%						-0.3	

Table 8.4: Summary of I-PH B15 Coating Tests

I-PH B15												
Run #	**Test #**	**Date**	**Fluid Name**	**Objective**	**Corrected for 3D Effects % Lift Loss On 8° Cl vs Dry Cl**	**Avg Lift Loss**	**Coefficient of Drag @2°**	**Avg Drag @2°**	**Stall Angle(°)**	**Avg Stall Angle(°)**	**Tunnel Temp. Before Test (°C)**	**Avg Tunnel Temp (°C)**
1	222	16-Jan-14	none	100 Kts 8°Rotation	0.50%	0.78%	-	-	-	-	-3.4	-3.4
	223	16-Jan-14			0.71%						-3.4	
	224	16-Jan-14			1.14%						-3.4	
2	225	16-Jan-14	none	100 Kts -2° to 8° Pitch Pause	0.29%	0.39%	-	-	-	-	-3.4	-3.4
	226	16-Jan-14			0.50%						-3.4	
	227	16-Jan-14			-						-3.4	
3	228	16-Jan-14	none	80 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.101585	0.101350	-	-	-3.4	-3.4
	229	16-Jan-14			-		0.101110				-3.4	
	230	16-Jan-14			-		0.101355				-3.4	
4	231	16-Jan-14	none	100 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.098600	0.098234	-	-	-3.4	-3.4
	232	16-Jan-14			-		0.098259				-3.4	
	233	16-Jan-14			-		0.097844				-3.4	
5	234	16-Jan-14	none	115 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.097213	0.097119	-	-	-3.4	-3.4
	235	16-Jan-14			-		0.097063				-3.4	
	236	16-Jan-14			-		0.097082				-3.4	
6	237	16-Jan-14	none	80 Kts Stall	2.09%	2.00%	-	-	21.5	21.33	-3.4	-3.4
	238	16-Jan-14			1.80%				21		-3.4	
	239	16-Jan-14			2.10%				21.5		-3.4	
7	240	16-Jan-14	none	100 Kts 8°Rotation	1.03%	1.22%	-	-	-	-	-3.4	-3.4
	241	16-Jan-14			1.50%						-3.4	
	242	16-Jan-14			1.12%						-3.4	
8	243	16-Jan-14	EG106	100 Kts Fluid Only	2.96%	3.11%	-	-	-	-	-1.6	-2
	244	16-Jan-14			2.94%						-3.3	
	245	17-Jan-14			3.47%						-1.8	
	246	17-Jan-14			3.07%						-1.3	
9	247	17-Jan-14	none	100 Kts Fluid Seepage	1.13%	1.13%	-	-	-	-	-2.6	-2.3
	248	17-Jan-14			-						-2.6	
10	249	17-Jan-14	none	100 Kts Light Freezing Rain	1.34%	1.34%	-	-	-	-	-1.5	-1.5

Table 8.5: Summary of I-PH C3 Coating Tests

I-PH C3												
Run #	Test #	Date	Fluid Name	Objective	Corrected for 3D Effects % Lift Loss On 8° Cl vs Dry Cl	Avg Lift Loss	Coefficient of Drag @2°	Avg Drag @2°	Stall Angle(°)	Avg Stall Angle(°)	Tunnel Temp. Before Test (°C)	Avg Tunnel Temp (°C)
1	169	15-Jan-14	none	100 Kts 8°Rotation	0.45%	0.48%	-	-	-	-	-1	-1
	170	15-Jan-14			0.44%						-1	
	171	15-Jan-14			0.56%						-1	
2	172	15-Jan-14	none	100 Kts -2° to 8° Pitch Pause	-0.20%	-0.16%	-	-	-	-	-1	-1
	173	15-Jan-14			-0.07%						-1	
	174	15-Jan-14			-0.20%						-1	
3	175	15-Jan-14	none	80 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.100564	0.100664	-	-	-1	-1
	176	15-Jan-14					0.100746				-1	
	177	15-Jan-14					0.100681				-1	
4	178	15-Jan-14	none	100 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.098181	0.098385	-	-	-1	-1
	179	15-Jan-14					0.098964				-1	
	180	15-Jan-14					0.098011				-1	
5	181	15-Jan-14	none	115 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.096591	0.096599	-	-	-1	-1
	182	15-Jan-14					0.096598				-1	
	183	15-Jan-14					0.096607				-1	
6	184	15-Jan-14	none	80 Kts Stall	2.04%	1.83%	-	-	20	19.67	-1	-1
	185	15-Jan-14			1.35%				19.5		-1	
	186	15-Jan-14			2.09%				19.5		-1	
7	187	15-Jan-14	none	100 Kts 8°Rotation	0.81%	0.68%	-	-	-	-	-1	-1
	188	15-Jan-14			0.68%						-1	
	189	15-Jan-14			0.54%						-1	
8	190	15-Jan-14	EG106	100 Kts Fluid Only	2.46%	2.55%	-	-	-	-	-0.3	-0.37
	191	15-Jan-14			2.80%						-0.5	
	192	15-Jan-14			2.40%						-0.3	
9	193	16-Jan-14	none	100 Kts Fluid Seepage	0.25%	0.44%	-	-	-	-	-0.3	-0.3
	194	16-Jan-14			0.62%						-0.3	

Table 8.6: Summary of I-PH E1 Coating Tests

I-PH E1												
Run #	**Test #**	**Date**	**Fluid Name**	**Objective**	**Corrected for 3D Effects % Lift Loss On 8° Cl vs Dry Cl**	**Avg Lift Loss**	**Coefficient of Drag @2°**	**Avg Drag @2°**	**Stall Angle(°)**	**Avg Stall Angle(°)**	**Tunnel Temp. Before Test (°C)**	**Avg Tunnel Temp (°C)**
	260	20-Jan-14			0.18%						-8.3	
1	261	20-Jan-14	none	100 Kts 8°Rotation	0.68%	0.38%	-	-	-	-	-8.3	-8.3
	262	20-Jan-14			0.27%						-8.3	
	263	20-Jan-14			-0.16%						-8.3	
2	264	20-Jan-14	none	100 Kts -2° to 8° Pitch Pause	-0.17%	-0.20%	-	-	-	-	-8.3	-8.3
	265	20-Jan-14			-0.27%						-8.3	
	266	20-Jan-14			-		0.100688				-8.3	
3	267	20-Jan-14	none	80 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.100658	0.100664	-	-	-8.3	-8.3
	268	20-Jan-14			-		0.100646				-8.3	
	269	20-Jan-14			-		0.097644				-8.3	
4	270	20-Jan-14	none	100 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.097785	0.097769	-	-	-8.3	-8.3
	271	20-Jan-14			-		0.097879				-8.3	
	272	20-Jan-14			-		0.097083				-8.3	
5	273	20-Jan-14	none	115 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.097223	0.097107	-	-	-8.3	-8.3
	274	20-Jan-14			-		0.097014				-8.3	
	275	20-Jan-14			1.83%				21		-8.3	
6	276	20-Jan-14	none	80 Kts Stall	1.59%	1.73%	-	-	20.5	20.83	-8.3	-8.3
	277	20-Jan-14			1.77%				21		-8.3	
	278	20-Jan-14			0.63%						-8.3	
7	279	20-Jan-14	none	100 Kts 8°Rotation	0.62%	0.64%	-	-	-	-	-8.3	-8.3
	280	20-Jan-14			0.66%						-8.3	
	281	20-Jan-14			2.75%						-8.7	
8	282	20-Jan-14	EG106	100 Kts Fluid Only	2.91%	2.85%	-	-	-	-	-8.7	-9.07
	283	20-Jan-14			2.88%						-9.8	
9	284	20-Jan-14	none	100 Kts Fluid Seepage	0.26%	0.39%	-	-	-	-	-10.1	-10.1
	285	20-Jan-14			0.52%						-10.1	
10	286	20-Jan-14	none	100 Kts Light Freezing Rain	2.47%	2.47%	-	-	-	-	-10.3	-10.3

Table 8.7: Summary of I-PH E1B Coating Tests

I-PH E1 B												
Run #	**Test #**	**Date**	**Fluid Name**	**Objective**	**Corrected for 3D Effects % Lift Loss On 8° Cl vs Dry Cl**	**Avg Lift Loss**	**Coefficient of Drag @2°**	**Avg Drag @2°**	**Stall Angle(°)**	**Avg Stall Angle (°)**	**Tunnel Temp. Before Test (°C)**	**Avg Tunnel Temp (°C)**
	290	20-Jan-14			-0.10%						-13	
1	291	20-Jan-14	none	100 Kts 8°Rotation	0.03%	-0.03%	-	-	-	-	-13	-13
	292	20-Jan-14			-0.01%						-13	

Table 8.8: Summary of Original Wing Tests

Original Wing												
Run #	**Test #**	**Date**	**Fluid Name**	**Objective**	**Corrected for 3D Effects % Lift Loss On 8° Cl vs Dry Cl**	**Avg Lift Loss**	**Coefficient of Drag @2°**	**Avg Drag @2°**	**Stall Angle(°)**	**Avg Stall Angle (°)**	**Tunnel Temp. Before Test (°C)**	**Avg Tunnel Temp (°C)**
1	28	13-Jan-14	none	100 Kts 8°Rotation	-0.29%	-0.41%	-	-	-	-	5.7	5.7
	29	13-Jan-14			-0.37%						5.7	
	30	13-Jan-14			-0.56%						5.7	
2	31	13-Jan-14	none	100 Kts -2° to 8° Pitch Pause	-1.10%	-1.12%	-	-	-	-	5.7	5.7
	32	13-Jan-14			-1.14%						5.7	
	33	13-Jan-14			-1.11%						5.7	
3	34	13-Jan-14	none	80 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.099497	0.099489	-	-	5.7	5.7
	35	13-Jan-14					0.099671				5.7	
	36	13-Jan-14					0.099298				5.7	
4	37	13-Jan-14	none	100 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.096827	0.096774	-	-	5.7	5.7
	38	13-Jan-14					0.09678				5.7	
	39	13-Jan-14					0.096714				5.7	
5	40	13-Jan-14	none	115 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.096162	0.096126	-	-	5.7	5.7
	41	13-Jan-14					0.096156				5.7	
	42	13-Jan-14					0.096059				5.7	
6	43	13-Jan-14	none	80 Kts Stall	0.26%	0.07%	-	-	22	22.14	5.7	5.7
	44	13-Jan-14			-0.03%				22.43		5.7	
	45	13-Jan-14			-0.03%				22		5.7	
7	46	13-Jan-14	none	100 Kts 8°Rotation	-0.63%	-0.39%	-	-	-	-	5.7	5.7
	47	13-Jan-14			-0.27%						5.7	
	48	13-Jan-14			-0.26%						5.7	
8	164	15-Jan-14	EG106	100 Kts Fluid Only	1.99%	1.98%	-	-	-	-	0.3	-0.7667
	165	15-Jan-14			1.95%						-2.9	
	166	15-Jan-14			2.00%						0.3	

Table 8.8: Summary of Original Wing Tests (cont'd)

Original Wing Cont'd												
Run #	**Test #**	**Date**	**Fluid Name**	**Objective**	**Corrected for 3D Effects % Lift Loss On 8° Cl vs Dry Cl**	**Avg Lift Loss**	**Coefficient of Drag @2°**	**Avg Drag @2°**	**Stall Angle(°)**	**Avg Stall Angle (°)**	**Tunnel Temp. Before Test (°C)**	**Avg Tunnel Temp (°C)**
9	49	13-Jan-14	none	100 Kts 8°Rotation	-	-	0.123675	0.122818	-	-	6.4	6.4
	50	13-Jan-14					0.122718				6.4	
	51	13-Jan-14					0.12206				6.4	
10	52	13-Jan-14	none	100 Kts -2° to 8° Pitch Pause	-	-	0.105396	0.105333	-	-	6.4	6.4
	53	13-Jan-14					0.105181				6.4	
	54	13-Jan-14					0.105423				6.4	
11	55	13-Jan-14	none	80 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.099641	0.099851	-	-	6.4	6.4
	56	13-Jan-14					0.099948				6.4	
	57	13-Jan-14					0.099963				6.4	
12	58	13-Jan-14	none	100 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.096957	0.097049	-	-	6.4	6.4
	59	13-Jan-14					0.097056				6.4	
	60	13-Jan-14					0.097134				6.4	
13	61	13-Jan-14	none	115 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.095991	0.095938	-	-	6.4	6.4
	62	13-Jan-14					0.096062				6.4	
	63	13-Jan-14					0.095761				6.4	
14	64	13-Jan-14	none	80 Kts Stall	1.21%	0.46 %	-	-	22.5	22.5	6.4	6.4
	65	13-Jan-14			0.09%				22.5		6.4	
	66	13-Jan-14			0.09%				22.5		6.4	

Table 8.9: Summary of Skin with No Coating Tests

Skin No Coating											
Run #	Test #	Date	Fluid Name	Objective	Corrected for 3D Effects % Lift Loss On 8° Cl vs Dry Cl	Avg Lift Loss	Coefficient of Drag @2°	Avg Drag @2°	Stall Angle(°)	Avg Stall Angle(°)	Tunnel Temp. Before Test (°C)	Avg Tunnel Temp (°C)
	67	14-Jan-14			-0.08%						4.3	4.3
1	68	14-Jan-14	none	100 Kts 8°Rotation	0.44%	0.23%	-	-	-	-	4.3	
	69	14-Jan-14			0.33%						4.3	
	70	14-Jan-14			-0.38%						4.3	4.3
2	71	14-Jan-14	none	100 Kts -2° to 8° Pitch Pause	-0.32%	-0.34%	-	-	-	-	4.3	
	72	14-Jan-14			-0.32%						4.3	
	73	14-Jan-14			-		0.100009				4.3	4.3
3	74	14-Jan-14	none	80 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.100035	0.099986	-	-	4.3	
	75	14-Jan-14			-		0.099913				4.3	
	76	14-Jan-14			-		0.097245				4.3	4.3
4	77	14-Jan-14	none	100 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.097367	0.097351	-	-	4.3	
	78	14-Jan-14			-		0.09744				4.3	
	79	14-Jan-14			-		0.096527				4.3	4.3
5	80	14-Jan-14	none	115 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.096278	0.096379	-	-	4.3	
	81	14-Jan-14			-		0.096331				4.3	
	82	14-Jan-14			1.11%				17.5		4.3	4.3
6	83	14-Jan-14	none	80 Kts Stall	1.14%	1.16%	-	-	17.5	17.67	4.3	
	84	14-Jan-14			1.24%				18		4.3	
	85	14-Jan-14			0.46%						4.3	4.3
7	86	14-Jan-14	none	100 Kts 8°Rotation	0.27%	0.31%	-	-	-	-	4.3	
	87	14-Jan-14			0.20%						4.3	
	135	15-Jan-14			2.71%						1.4	0.6
8	136	15-Jan-14	EG106	100 Kts Fluid Only	2.74%	2.62%	-	-	-	-	-0.5	
	137	15-Jan-14			2.42%						0.9	

Table 8.10: Summary of Skin with No Coating (Re-Installed) Tests

Skin No Coating Re-Install												
Run #	Test #	Date	Fluid Name	Objective	Corrected for 3D Effects % Lift Loss On 8° Cl vs Dry Cl	Avg Lift Loss	Coefficient of Drag @2°	Avg Drag @2°	Stall Angle(°)	Avg Stall Angle(°)	Tunnel Temp. Before Test (°C)	Avg Tunnel Temp (°C)
1	88	14-Jan-14	none	100 Kts 8°Rotation	0.11%	0.15 %	-	-	-	-	4.3	4.3
	89	14-Jan-14			0.04%						4.3	
	90	14-Jan-14			0.30%						4.3	
2	91	14-Jan-14	none	100 Kts -2° to 8° Pitch Pause	-0.31%	-0.36 %	-	-	-	-	4.3	4.3
	92	14-Jan-14			-0.44%						4.3	
	93	14-Jan-14			-0.33%						4.3	
3	94	14-Jan-14	none	80 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.099971	0.099823	-	-	4.3	4.3
	95	14-Jan-14					0.099677				4.3	
	96	14-Jan-14					0.099822				4.3	
4	97	14-Jan-14	none	100 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.097158	0.097273	-	-	4.3	4.3
	98	14-Jan-14					0.097308				4.3	
	99	14-Jan-14					0.097353				4.3	
5	100	14-Jan-14	none	115 Kts Drag Pitch Pause -2°, 0°, +2°	-	-	0.096281	0.096409	-	-	4.3	4.3
	101	14-Jan-14					0.096386				4.3	
	102	14-Jan-14					0.09656				4.3	
6	103	14-Jan-14	none	80 Kts Stall	1.37%	1.26 %	-	-	16.5	16.67	4.3	4.3
	104	14-Jan-14			1.44%				16.5		4.3	
	105	14-Jan-14			0.97%				17		4.3	
7	106	14-Jan-14	none	100 Kts 8°Rotation	0.17%	0.28 %	-	-	-	-	4.3	4.3
	107	14-Jan-14			0.36%						4.3	
	108	14-Jan-14			0.31%						4.3	

Table 8.11: Summary of 2nd Skin with No Coating Tests

2nd Skin No Coating												
Run #	Test #	Date	Fluid Name	Objective	Corrected for 3D Effects % Lift Loss On 8° Cl vs Dry Cl	Avg Lift Loss	Coefficient of Drag @2°	Avg Drag @2°	Stall Angle(°)	Avg Stall Angle(°)	Tunnel Temp. Before Test (°C)	Avg Tunnel Temp (°C)
1	287	20-Jan-14	none	100 Kts 8° Rotation	-0.08%	0.05%	-	-	-	-	-11.6	-11.6
	288	20-Jan-14			0.13%						-11.6	
	289	20-Jan-14			0.10%						-11.6	
Note: baseline, wing skins were templated and not designed for testing, overlap on TE may have caused discrepancy in results												

Table 8.12: Summary of 2nd Skin with No Coating (Re-Installed) Tests

2nd Skin No Coating Re-Install												
Run #	Test #	Date	Fluid Name	Objective	Corrected for 3D Effects % Lift Loss On 8° Cl vs Dry Cl	Avg Lift Loss	Coefficient of Drag @2°	Avg Drag @2°	Stall Angle(°)	Avg Stall Angle(°)	Tunnel Temp. Before Test (°C)	Avg Tunnel Temp (°C)
1	365	28-Jan-14	none	100 Kts 8° Rotation	0.13%	0.44%	-	-	-	-	-10.4	-10.4
	366	28-Jan-14			0.67%						-10.4	
	367	28-Jan-14			0.52%						-10.4	

8.5 Data Analysis

To evaluate the aerodynamic performance of the different wing skins tested, comparative plots were prepared for each of the testing objectives. To simplify the data sets, only the average values of each test run were plotted instead of each individual data point.

Figure 8.1 demonstrates the 8º rotation data. The percentage delta in lift coefficient was compared to the average dry wing 8º C_L calculated based on all the dry wing tests conducted during the 2013-14 testing campaign. The results indicated that the un- coated wing skin alone will cause a degradation in lift of about 0.5 percent to 1 percent as compared to the original wing. All of the coatings tested demonstrated a slight degradation in aerodynamic performance as compared to the skin with no coating.

Figure 8.2 demonstrates the 8º pitch pause data. This data differs from the data in Figure 8.1 because the wing was set to fixed angles (the physical angle of the model, not the aerodynamic angle of attack) between -2º to 8º. The results supported the dynamic 8º rotation takeoff data collected and demonstrated a similar trend in the relationship of the data.

Figure 8.3, Figure 8.4, and Figure 8.5 demonstrates C_D data, which provides an indication of potential increases in drag caused by the skins and coatings. These tests were conducted at 80 knots, 100 knots, and 115 knots, respectively. Although data were collected at angle of attack -2º, 0º, and +2º, only the average of the +2º data is presented to simplify the data. The data indicated an overall reduction in drag as a function of speed. The results also indicated that the skins alone and the coated skins increased the amount of drag recorded. Data collected with I-PH B13 seems to have generated erroneous information, as the data is not in line with the expected results.

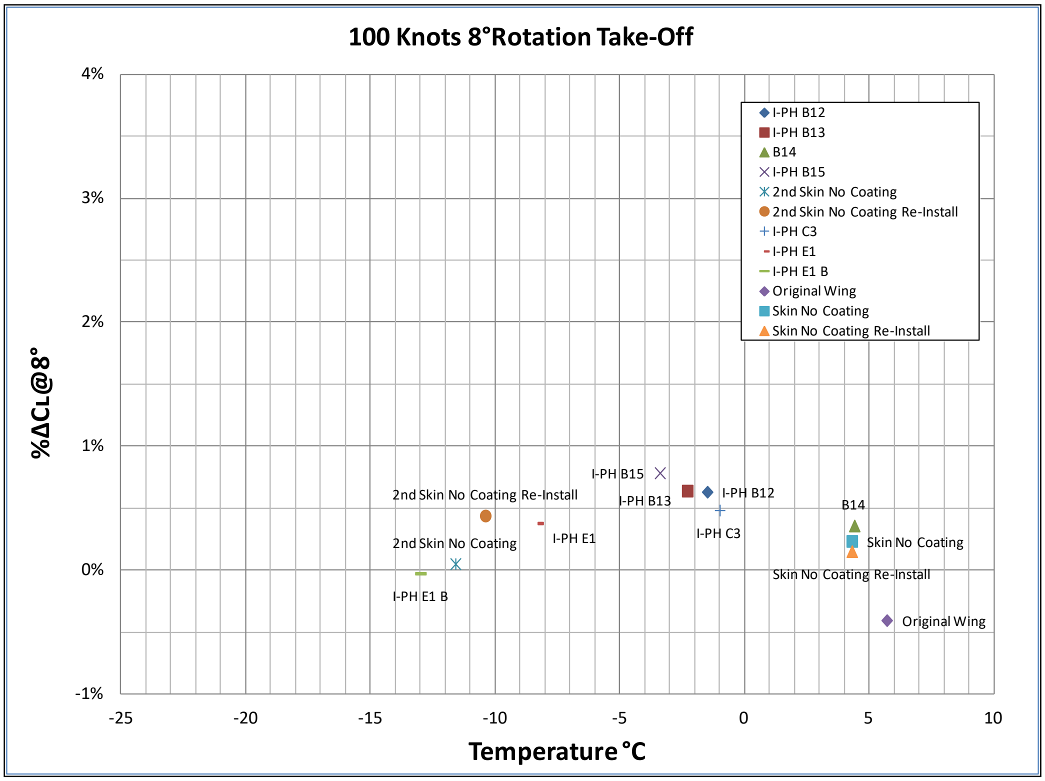


Figure 8.1: 100 knots 8° Rotation Takeoff

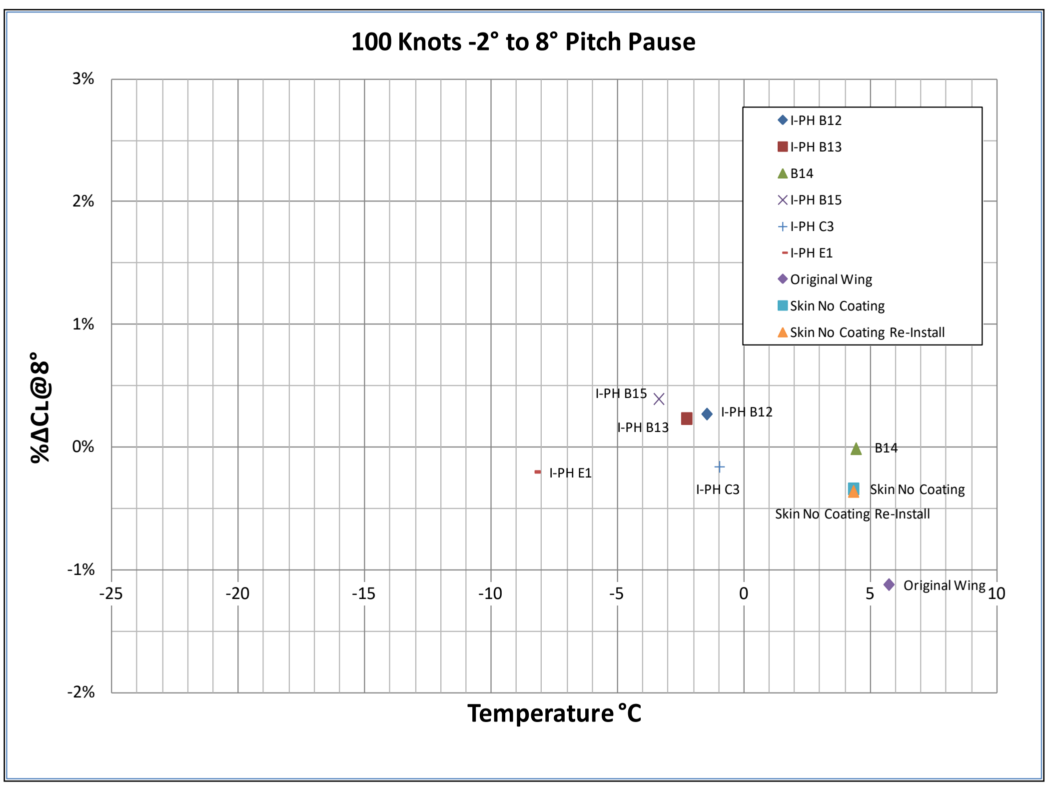


Figure 8.2: 100 knots -2° to 8° Pitch Pause

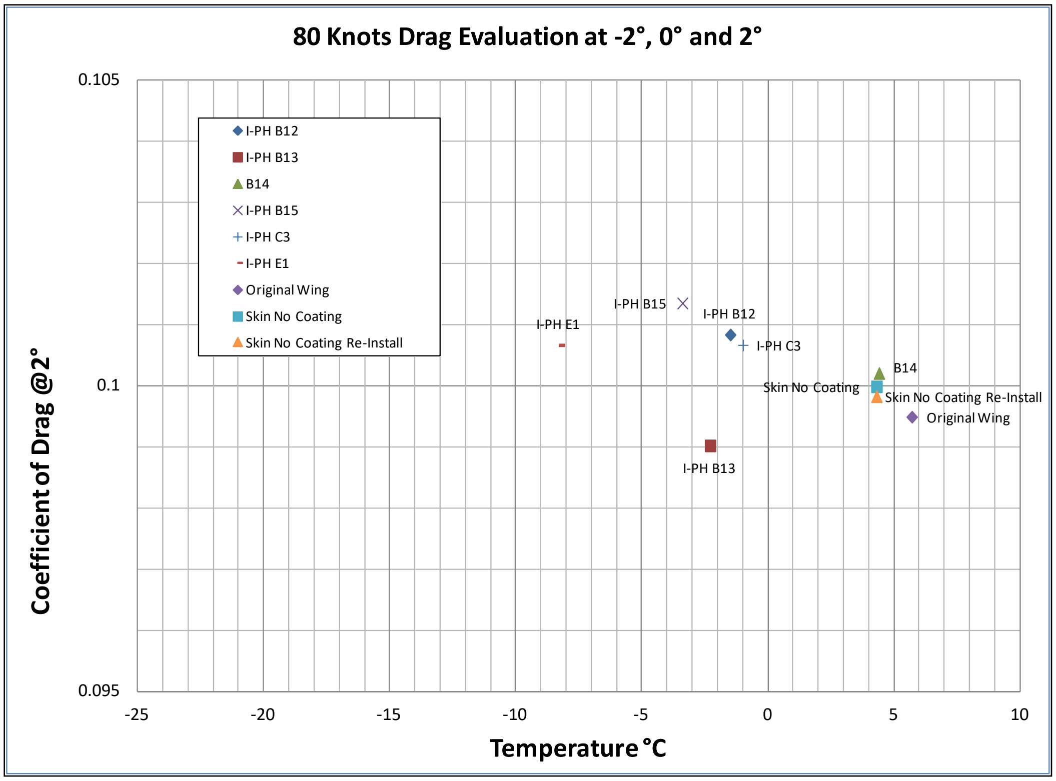


Figure 8.3: 80 knots Drag Evaluation at -2°, 0°, and 2°

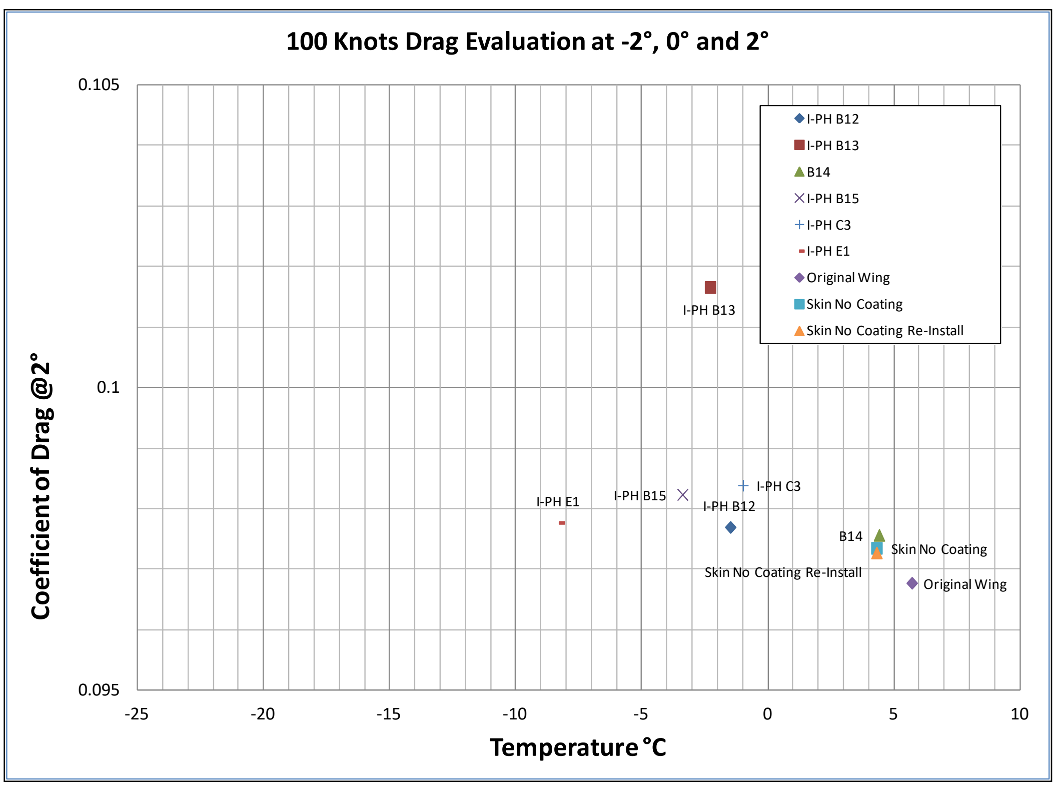


Figure 8.4: 100 knots Drag Evaluation at -2°, 0°, and 2°

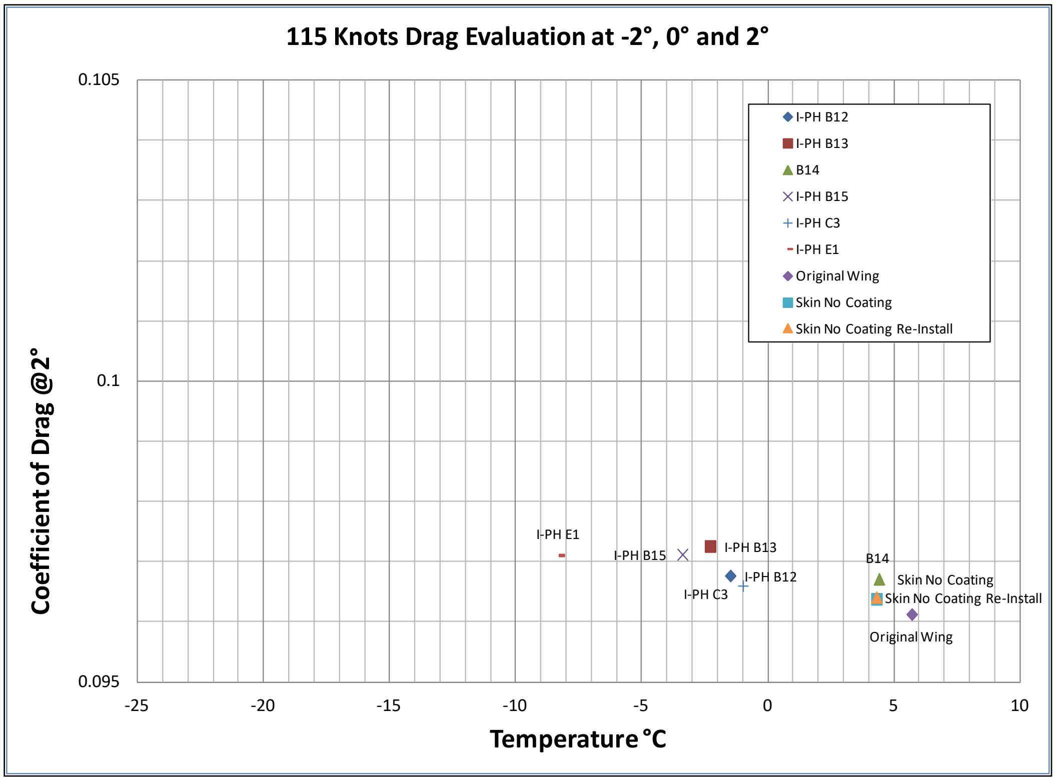


Figure 8.5: 115 knots Drag Evaluation at -2°, 0°, and 2°

Figure 8.6 demonstrates the data collected during the stall runs performed at 80 knots. For each series of tests, the average stalling angle was calculated. The results indicated that the original wing (without skins or coatings) produced the highest stall angle, as expected. Interestingly, some of the coated wing skins had higher stall angles when compared to the wing skins alone, indicating that some coatings may have aerodynamic benefits.

Figure 8.7 demonstrates the repeated 8° rotation data. These tests were performed to ensure repeatability of results following a series tests to ensure that the wing skin would not deform and affect results. In general, the results demonstrated the same relative trend amongst the coatings and the data were very similar and within experimental error to the first data set shown in Figure 8.1.

Figure 8.8 demonstrates the fluid testing results. Testing was conducted to investigate whether the coatings would impact fluid flow-off performance. All tests were conducted with Type IV EG106 fluid. In general, fluid flow-off is more difficult at colder temperatures causing higher lift losses. The data indicated that the flow-off on coated wing skins was generally comparable to the wing skin alone indicating that no adverse effects were observed, and in fact, in some cases, the flow-off may have been slightly improved.

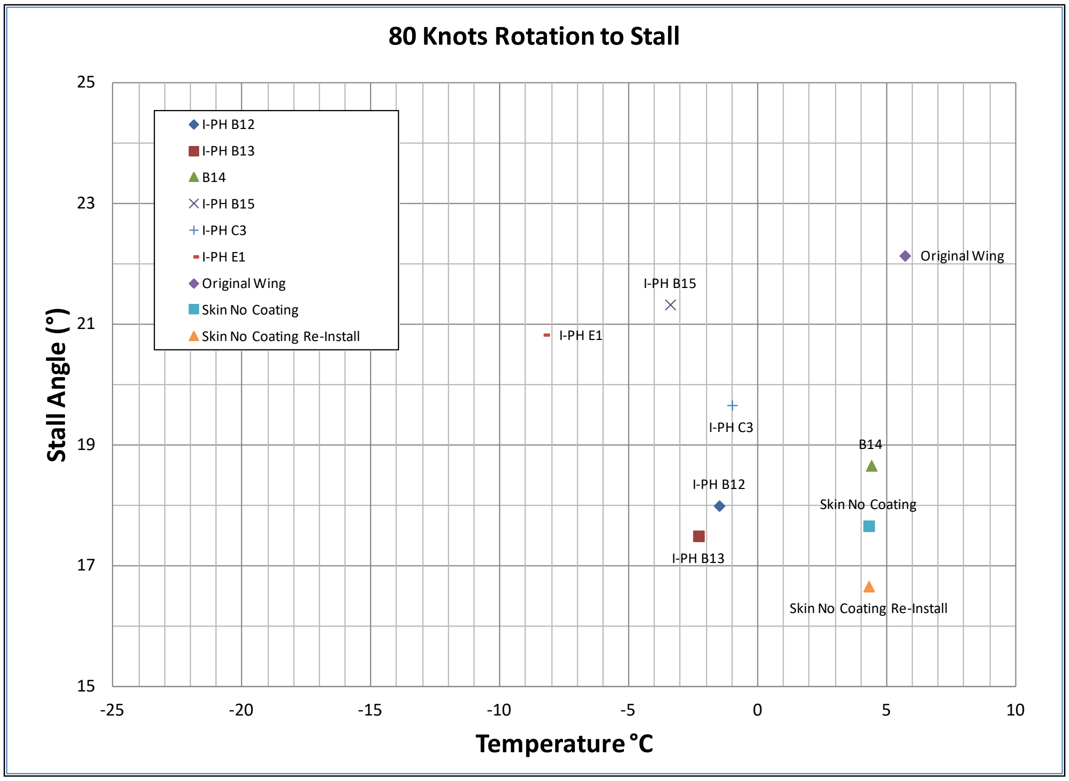


Figure 8.6: 80 knots Rotation to Stall

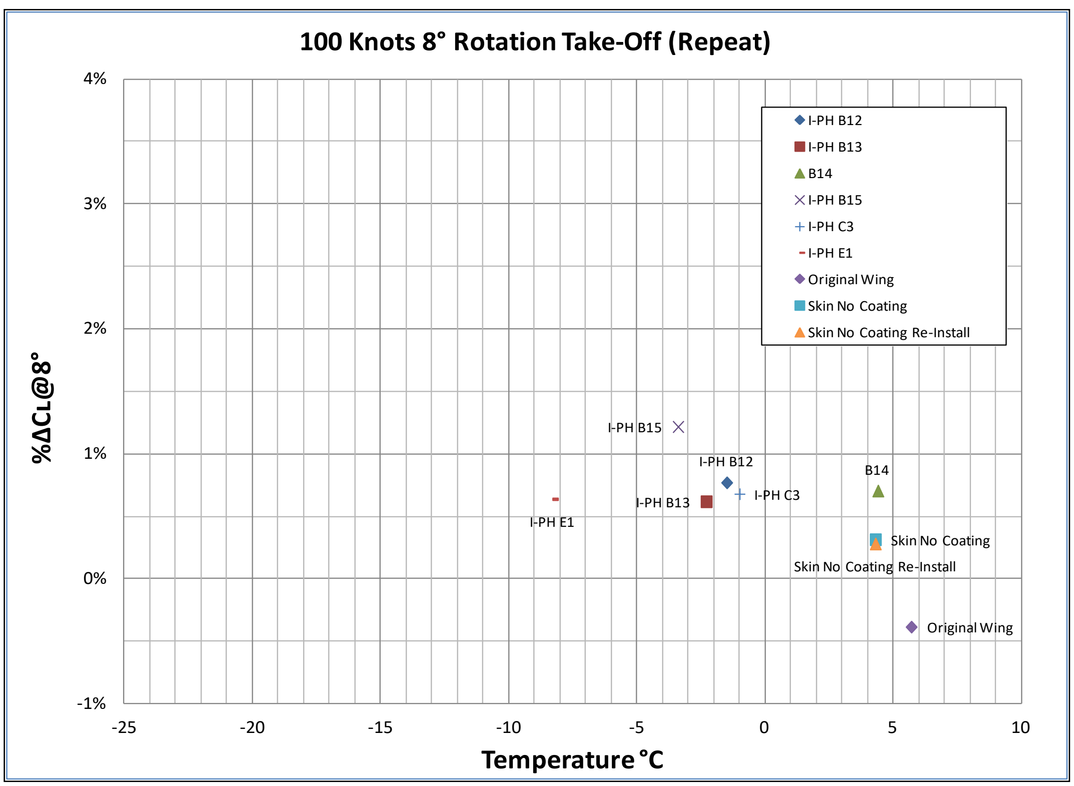


Figure 8.7: 100 knots 8° Rotation Takeoff (Repeat)

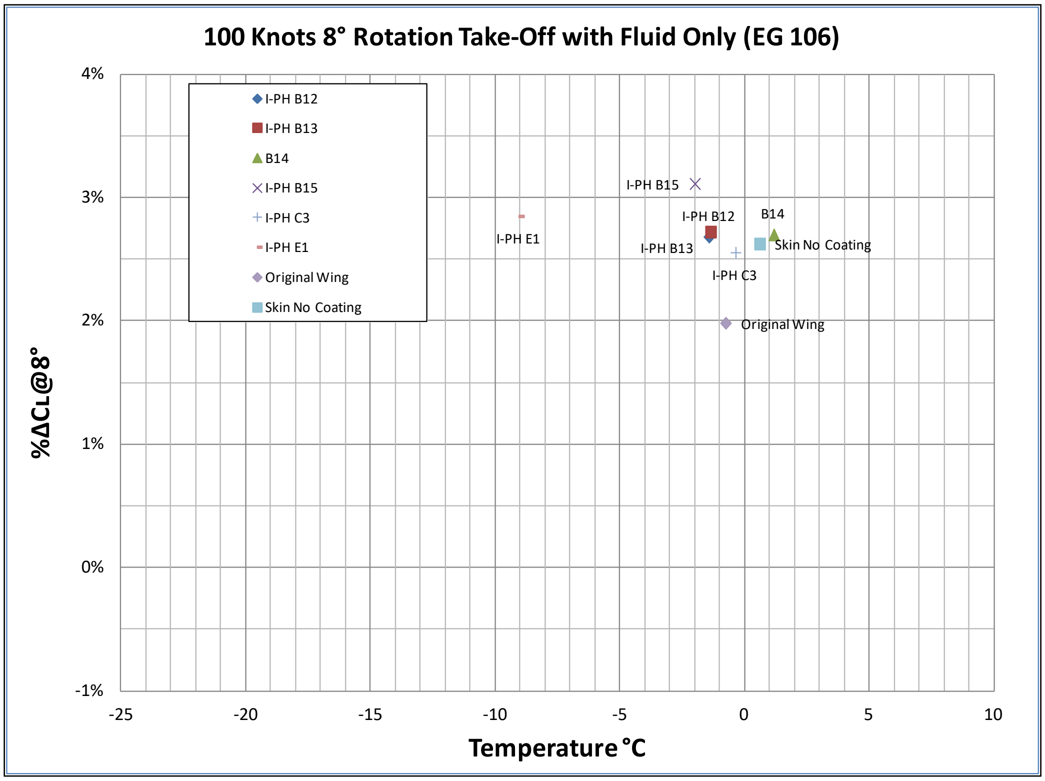


Figure 8.8: 100 knots 8º Rotation Takeoff with Fluid Only (EG 106)

Figure 8.9 demonstrates the results from the fluid seepage tests. Testing was conducted to investigate whether fluid trapped underneath the wing skin would seep out during dry wing tests and effect aerodynamics. When comparing the results in Figure 8.9 as compared to Figure 8.7 and Figure 8.1 the results indicated that fluid seepage can affect results up to about 1 percent in percentage delta C_L. This finding emphasizes the importance of properly cleaning the wing skins following fluid runs to ensure that the dry wing tests are not affected.

Figure 8.10 demonstrates the results from the freezing rain on a dry wing tests. The results demonstrated that the freezing rain will typically freeze in small beads on the surface of the wing causing an "aerodynamically rougher" surface. This was observed in the data, which indicated an increase in the percentage delta C_L as a result of the freezing rain.

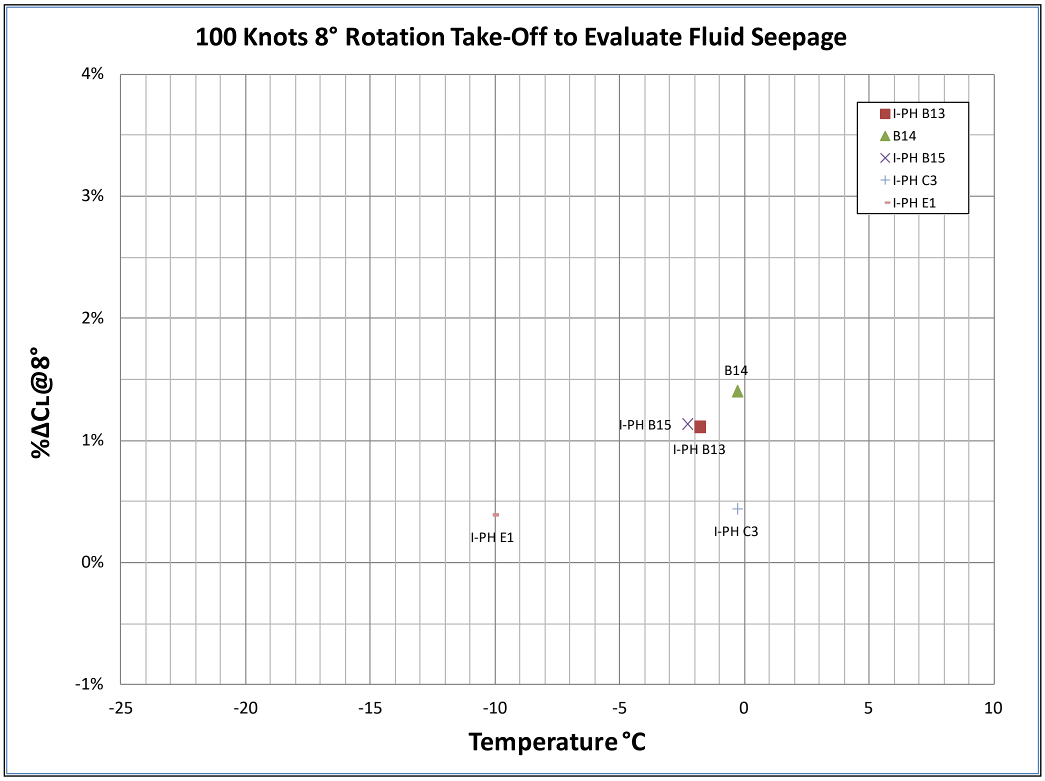


Figure 8.9: 100 knots 8° Rotation Takeoff to Evaluate Fluid Seepage

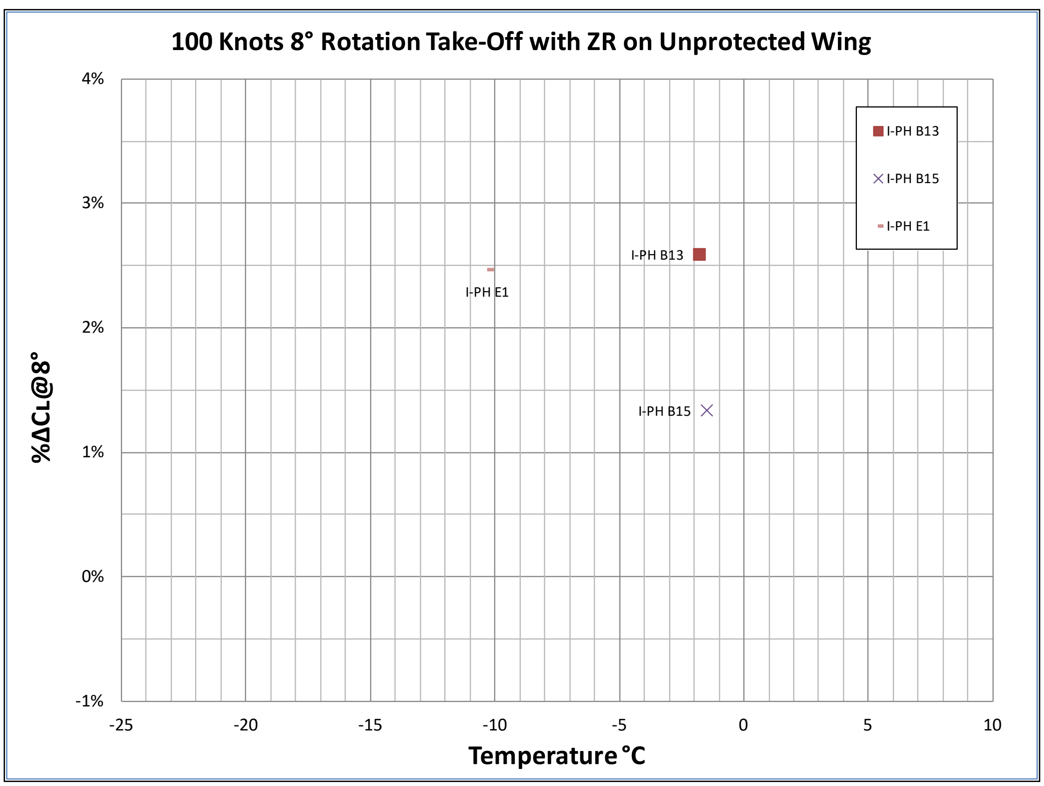


Figure 8.10: 100 knots 8° Rotation Takeoff with ZR on Unprotected Wing

8.6 Summary of Test Results

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 is 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.

Photo 8.1: Coating I-PH B12

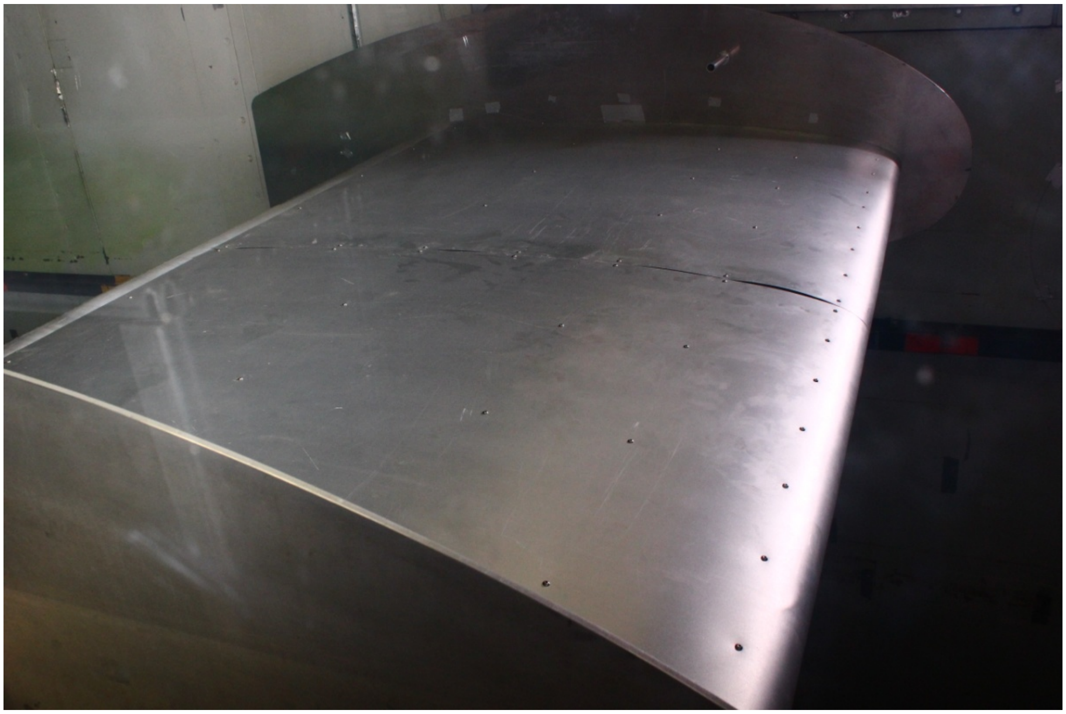


Photo 8.2: Coating I-PH B13

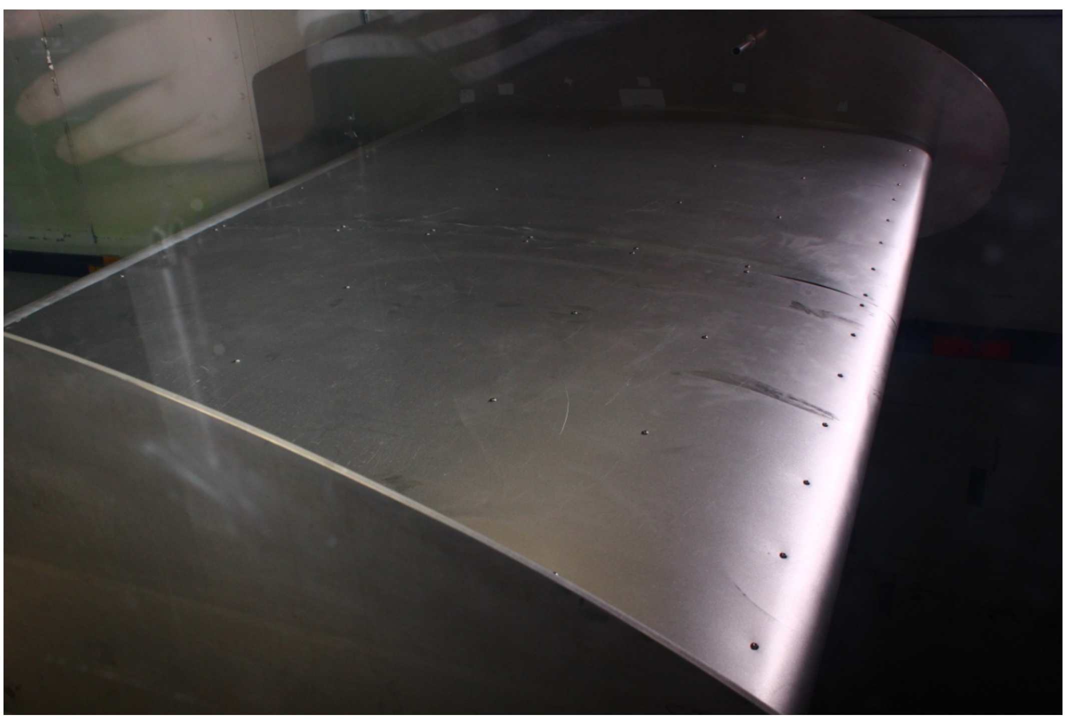


Photo 8.3: Coating I-PH B14

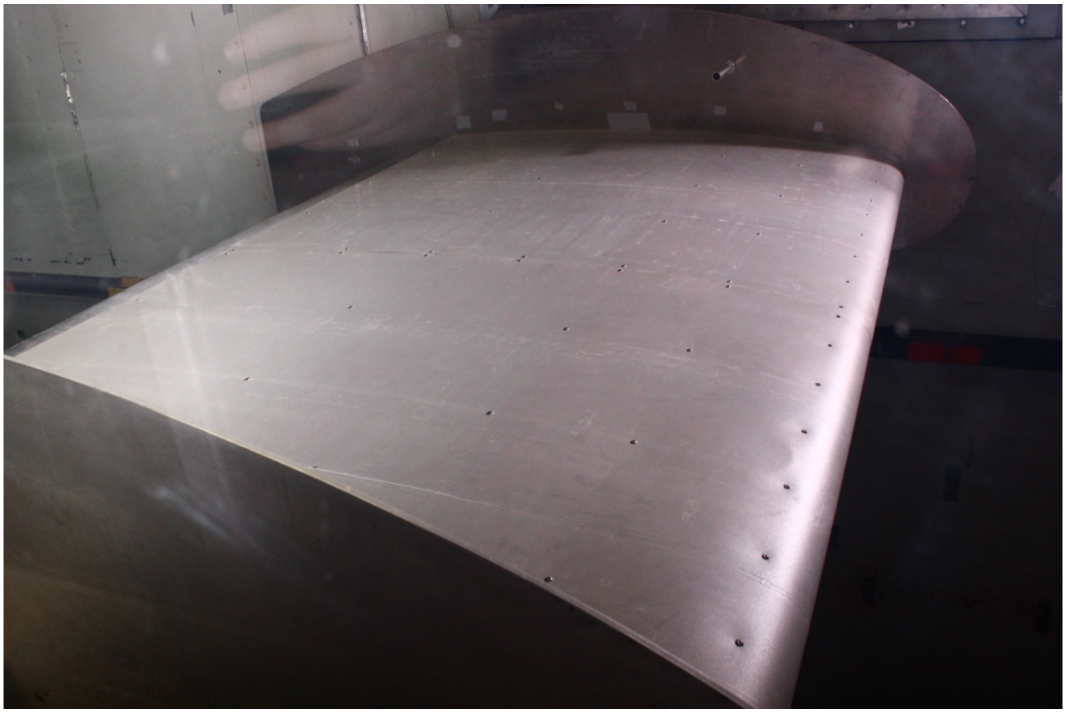


Photo 8.4: Coating I-PH B15

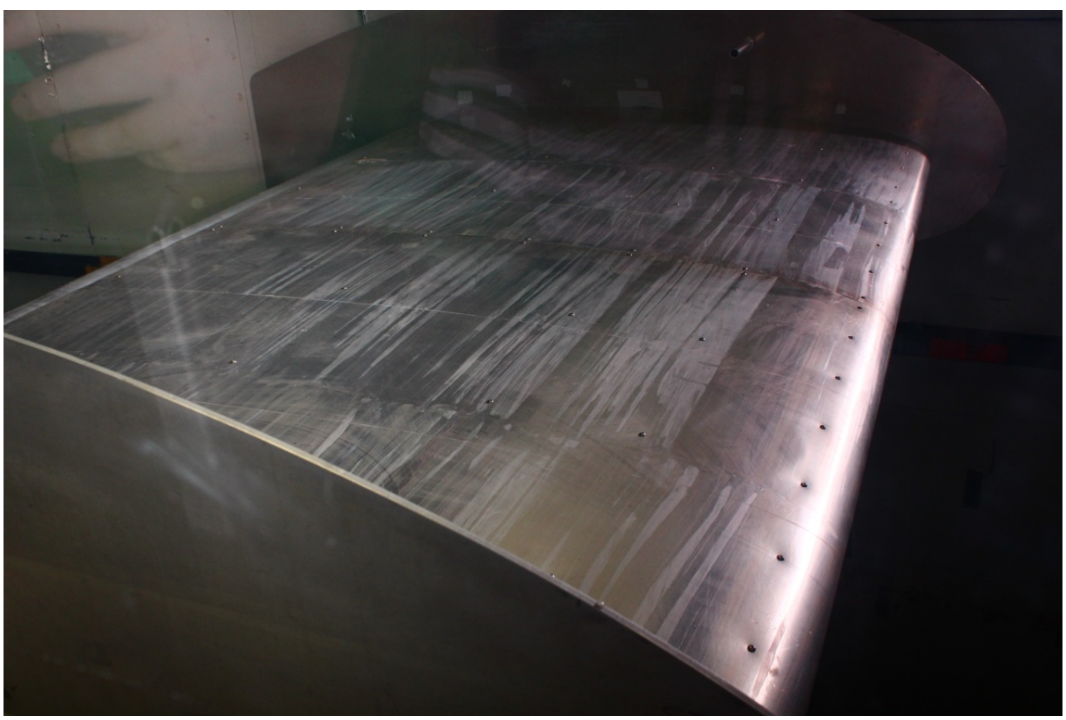


Photo 8.5: Coating I-PH C3

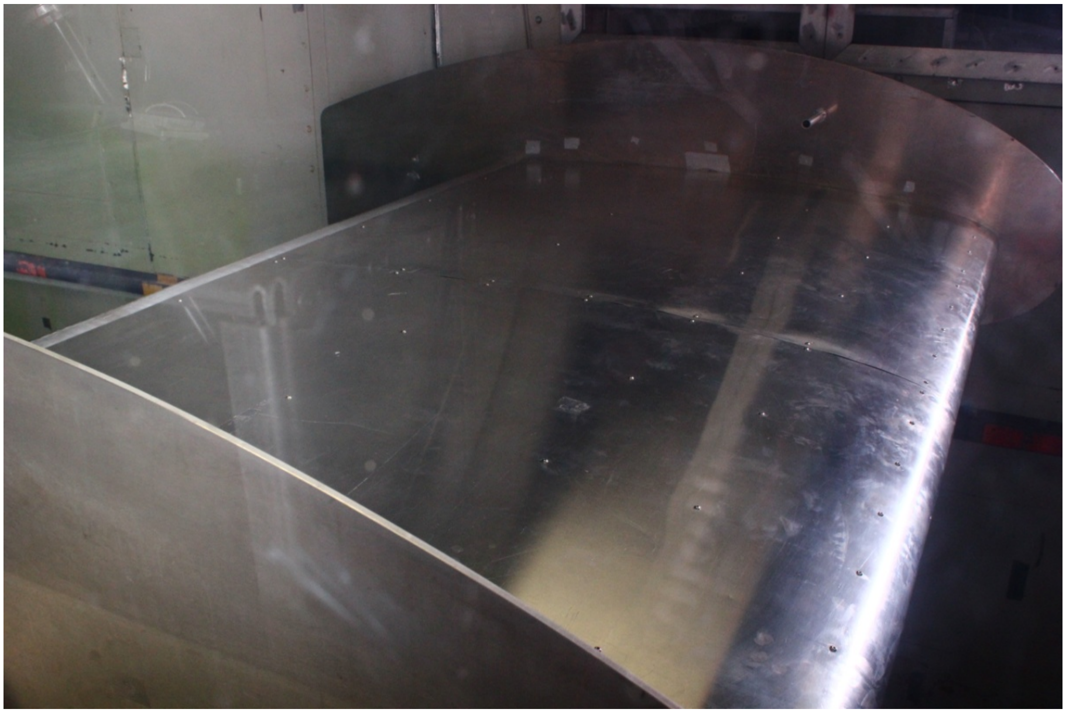


Photo 8.6: Coating I-PH E1

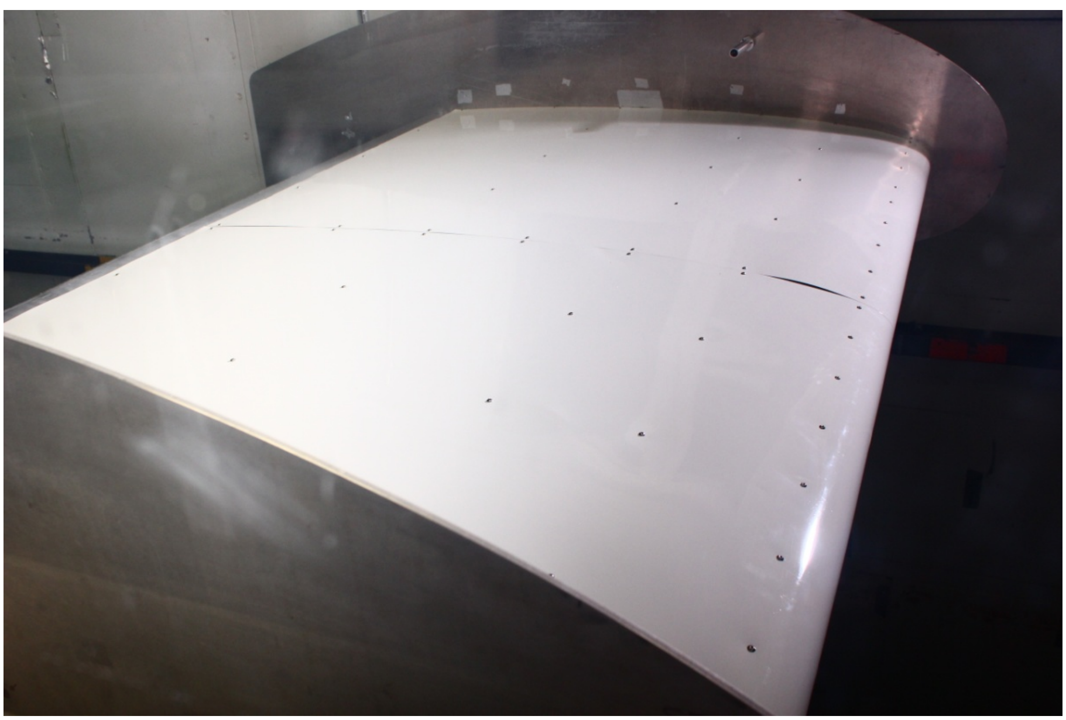
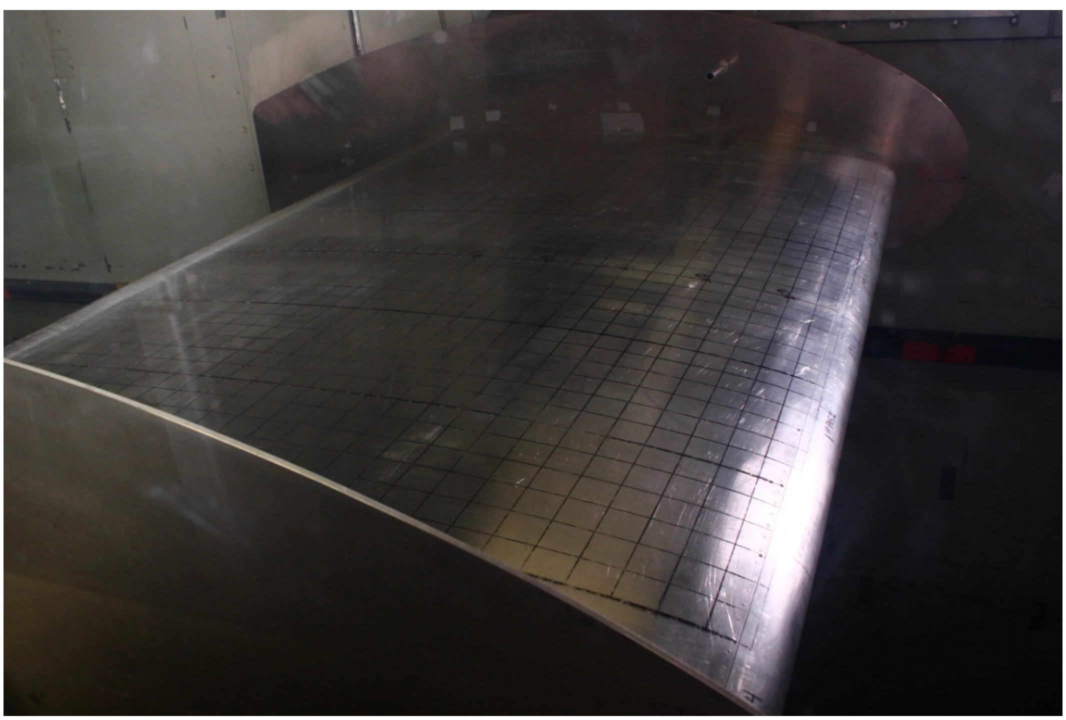


Photo 8.7: Wing Skin No Coating

Photo 8.8: Original Wing



9 DEVELOPMENT OF SAE AIR6232

In this section, the activities related to the development of the new Society of Automotive Engineers (SAE) Aerospace Information Report (AIR) for evaluating the interaction of de/anti-icing fluids with aircraft after-market coatings are discussed.

9.1 Background Leading to the Development of the SAE AIR6232

Prior to August 2013, there was no standardized approach for evaluating aircraft after-market coatings with respect to fluid HOT's. Although limited research had been conducted by TC and FAA, a minimum set of evaluation criteria had yet to be developed. At the November 2011 SAE G-12 Fluids Committee meeting in YUL, a workgroup was formed with the objective of developing an SAE specification for evaluating coating technologies with respect to fluid HOT's. This working group consisted of close to 30 industry members including operators, airframe manufacturers, fluid manufacturers, coating manufacturers, and research laboratories, providing a good cross section of the SAE G-12 demographic.

Discussions within the working group were held via email and teleconference following the November 2011 SAE G-12 meeting. In addition, in-person meetings were held in conjunction with the SAE G-12 meetings in Prague (May 2012) and Montreal (November 2012). The working group discussed document content, changes, and overall development. It was agreed that APS would make changes to the document on behalf of the working group based on the feedback received. In February 2013, changes were made to the document and a Final Version Draft 1.0 was issued, to begin the balloting process. The final ballot was passed in June 2013, and the AIR6232 was published in August 2013.

9.2 Principle Focus of Draft AIR

The latest draft of the SAE AIR has been included in Appendix F.

The principle focus of the 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
    - To evaluate how coatings impact fluid HOT's;
    - Flat plate testing protocol modelled after AA Tests;
    - Methodology based on ARP 5945 and ARP 5485; and
    - Provides good indication of potential effects of coating.

- Section 4: Fluid Aerodynamic Testing
  - o To evaluate how coatings influence fluid flow-off; and
  - o Methodology currently being developing based on AS5900.

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. In addition, the AIR could eventually be changed to an ARP once performance criteria were developed.

9.3 Recent and Future Activities

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 needed 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.

9.4 Future Initiatives

Future working group discussion/meetings will be organized on an as-needed basis.

Future focuses of the group should include:

- Changes based on operational feedback;
- Potential evolution of the AIR to an ARP;
- Information dissemination to non-G12 members; and
- Surface coatings being used or considered for aircraft use should be tested according to the test methods described in AIR6232.

10 OBSERVATIONS AND CONCLUSIONS

The observations and conclusions drawn from the tests performed during the winter of 2013-14 are described in this section.

10.1 General Comments Regarding 2013-14 Testing

Testing conducted was limited and served as a scoping study, as 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.

10.2 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 or to the baseline test.

10.3 Adherence Testing

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

Some concern remains with the ice formation on the coated surface. The coated surface typically resulted in bumpier ice formations. Preliminary aerodynamic research to investigate the effects of this adhered ice has been conducted and will be described in Section 8.

10.4 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 (see Photo 5.1). The Type IV fluid thickness test, however, (Photo 5.2) demonstrated minor degradation in fluid thickness 5-minutes after application.

10.5 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. This is not pertinent to first-step deicing where the deiced surface must be entirely clear of ice at time of anti-icing application.

10.6 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 adheres to the surface.

10.7 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 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 is 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.

10.8 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 needed to be issued.

The working group approach has proven 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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11 RECOMMENDATIONS

The following recommendations were compiled following the testing conducted during the winter of 2013-14 as well as industry feedback regarding the results obtained.

11.1 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, etc.) 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 without compromising aircraft safety through adapted deicing procedures.

11.2 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.

11.3 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., APS Aviation Inc., Transportation Development Centre, Montreal, March 2011, TP 15055E, XX, (to be published).

2) Bendickson, S., D'Avirro, J., Gravito, P., Ruggi, M., Youssef, D., Zoitakis, V., Aircraft Ground Icing Research General Activities During the 2010-11 Winter, APS Aviation Inc., Transportation Development Centre, Montreal, January 2012, TP 15158E, XX, (to be published).

3) Ruggi, M., 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), APS Aviation Inc., Transportation Development Centre, Montreal, December 2014, TP 15275E, XX, (to be published).

4) Chaput, M., Campbell, R, Aircraft Ground De/Anti-Icing Fluid Holdover Time and Endurance Time Test Program for the 2001-02 Winter, APS Aviation Inc., Transportation Development Centre, Montreal, December 2002, TP 13991E, XX, (to be published).

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APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT
AIRCRAFT & ANTI-ICING FLUID
WINTER TESTING 2013-14

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT
AIRCRAFT & ANTI-ICING FLUID
WINTER TESTING 2013-14

5.11 Investigation on the Effects of De/Anti-Icing Fluids Ice Phobic Technologies to Reduce Aircraft Icing in Northern and Cold Climates

The overall goals of this multi-year project will be to assess the safety and effectiveness of ice phobic materials as a means to manage aircraft icing, provide a comparative analysis of these ice phobic materials/coatings and investigate the feasibility of employing ice phobic materials in the design of aircraft or specific aircraft sections that are more prone to icing (e.g. stabilizers). There is the potential use of this technology as a supplement or substitute to existing or future ice management technologies recognizing the potential limitations and drawbacks of these current technologies. This project will also comparatively examine the technological costs and benefits between existing de/anti-icing fluids and ice phobic materials and coatings.

The specific research and work required for these activities include:

- A review of existing or emerging ice phobic technologies utilized within various industry sectors, including aviation;
- Identify optimal ice phobic material or coating technologies for further research and technical assessment, and identify technical limitations;
- Conduct stakeholder consultations and participate with industry members (ice phobic materials manufacturers, aircraft manufacturers and operators) to identify research priorities and development of testing parameters;
- Carry out multi-staged testing of ice phobic technologies in various climatic conditions and provide reports to Transport Canada and stakeholders;
- Identify technological implications, benefits and limitations of ice phobic technologies;
- Evaluate potential air safety and environmental impacts of ice phobic technologies; and
- Disseminate the results via presentations and documents.

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

Use of Ice Phobic Products on Aircraft Surfaces Prone to Icing Issues

a) Solicit manufacturers of ice phobic materials to determine potential new research areas of interest and to encourage participation in research. Based on recent industry feedback, some potential areas prone to icing on which application of ice phobic materials could be feasible and beneficial include: vertical stabilizer, winglets, flap leading edges, quiet areas, fan blades and cowlings, landing gears, as well as runways and deicing pads etc.;

b) Develop methodology and procedure for the preliminary evaluation of the performance of ice phobic products on selected surfaces. Testing will primarily include a scoping study to investigate:

   I. The behaviour of de/anti-icing fluid on ice phobic treated surfaces; and

   II. The behaviour of ice adherence on ice phobic treated surfaces;

a) Coordinate samples and prepare samples for testing;

b) Conduct limited preliminary testing in natural snow conditions at the P.E.T test site. It is anticipated that testing will be conducted in conjunction with standard HOT testing;

c) Conduct limited preliminary testing in simulated freezing precipitation conditions at the NRC chamber. It is anticipated that testing will be conducted in conjunction with standard HOT testing;

d) Analyze data and results; and

e) Prepare a test report of the findings and prepare presentation material for the SAE G-12 meetings.

Support the Further Development of AIR 6232 (Ice Phobic Coatings)

a) Support the further development of AIR 6232 document for testing aircraft after-market coatings with respect to de/anti-icing fluid performance;

b) Organize and participate in G-12 coatings working group meetings, as necessary, consisting of regulators, manufacturers, airlines, and industry members;

c) Address industry comments and feedback with respect to AIR guidance, develop required revisions to the document, and submit revisions for balloting; and

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

Vertical Stabilizer, Winglets, and Other Higher Angle Wing Surface Anti-Icing and Use of Ice Phobics

a) Review (and modify if necessary) methodology and procedure for simulating high angle anti-icing with and without ice phobic treated surfaces;

b) Conduct comparative endurance time testing with select fluids in natural snow conditions at the P.E.T test site. Testing should be conducted in various wind speed conditions. Testing should include Type I testing (as well as Type IV) as previous results have shown potential benefits to using coated surfaces on vertical surfaces;

c) Consideration should also be given to:

    I. Simulating a taxi by rotating the test plate orientations;

    II. Evaluating the adhesive properties of the failed fluid and effects on aerodynamics; and

    III. Testing at the NRC CEF in simulated freezing precipitation conditions to evaluate the different failure mechanisms on high angle surfaces.

d) Analyze data and results;

e) Possibly develop alternatives for potential guidance material for anti-icing vertical stabilizer surfaces;

f) Consult with the SAE G-12 Aerodynamics working group regarding best practice solutions; and

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

Travel to Visit Ice Phobic Manufacturer Laboratories or Coating Related Conferences/Meetings to Develop Industry Synergies

a) Participate in related industry meetings that may not be part of the ground icing group to disseminate research findings. Attempts should be made to minimize travel costs by piggybacking on existing travel plans;

b) Conduct site visit of manufacturer laboratories to build closer relationships with these manufacturers due to the direct impact of guidance being developed for coating interaction with deicing fluids to ensure developed guidance does not "kill" future technologies, ensure manufacturer interest is protected, to gain manufacturer insight onto technology, and to identify synergies to further advance technology.

Attempts should be made to minimize travel costs by piggybacking on existing travel plans; and

c) Report findings.

5.39.2 Testing to Support the Development of Aircraft Ground Deicing Related Procedures and Technologies (1 Week)

Testing will be done according to the procedures and methodologies used for "Testing to Further Refine Ice Pellet Allowance Times":

a) Meet and discuss with NRC personnel as necessary for specific project related tasks (i.e. preparation of ice phobic wing skins);

Note: The NRC facility costs associated with testing at M46 are not included in this task and are dealt with directly with TC through a M.O.U. agreement with NRC;

b) Develop procedure for conducting wind tunnel testing in accordance with the existing ice pellet allowance time testing methodology;

c) Perform wind tunnel tests over a period of five (5) days to support the development of aircraft ground deicing related procedures and technologies; and

I. Aircraft coating testing to evaluate lift, drag, and other dry wing properties for take-off, climb-out, and cruise flight portions;

II. Aircraft coating testing to evaluate fluid and fluid/contamination testing;

III. Aircraft coating testing to evaluate repeatability, and proof of methodology; and

IV. Testing to address industry concerns and interests.

Analyze the data collected, Report the findings, and prepare presentation material for the SAE G-12 meetings.

APPENDIX B

PROCEDURE:
OVERALL PROGRAM OF TESTS AT NRC, MARCH 2014

CM2265.003 (13-14)

OVERALL PROGRAM OF TESTS AT NRC, MARCH 2014

Winter 2013-14

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Stephanie Bendickson

Reviewed by: John D'Avirro

March 17, 2014
Version 1.0

OVERALL PROGRAM OF TESTS AT NRC, MARCH 2014
Winter 2013-14

1. INTRODUCTION

This document was prepared to bring together several projects that require testing at the National Research Council Climactic Engineering Facility (NRC) in Ottawa. Tests will be carried out from March 19-26, 2014.

The primary objective of the test session is to measure the endurance times of new de/anti-icing fluids. Testing for several other related research projects will be scheduled around the endurance time tests as time and space permit. This document provides the schedule, personnel, fluid, and equipment requirements for each of the projects involved.

A tentative test schedule is included in Figure 1.

2. PROJECTS, PROCEDURES AND OBJECTIVES

The projects that will be carried out at the March 2014 NRC test session are listed in this section. Each project has been given a shortened name (shown in brackets following full title) which is used in subsequent sections of this document. A description of each project, its objective and its test procedure are provided. The test procedures for several projects are provided in separate detailed documents, which are referenced in the appropriate subsection and listed in Section 9.

General comments on procedures and setup:

- Endurance time tests will be carried out according to the protocol provided in Aerospace Recommended Practice 5485, *Endurance Time Tests for Aircraft Deicing/Anti-Icing Fluids SAE Type II, III, and IV* (1), except as noted;
- There will be two test stands positioned under the sprayer (main stand with two 6-position stands and side stand with one 3-position stand) and a third stand that will be positioned outside the spray area in the small area of the climate chamber. The test stands should be situated in the cold chamber as per the measurements provided in Figure 2; and
- A complex rate management program was developed in the early 2000s to assist in managing the measurement of precipitation rates. This

program will be used. A guide to the rate management program is available to help with training of new rate station managers.

2.1 Endurance Times of New Fluids (New Fluid ETs)

The objective of this project is to measure endurance times of new fluids. This will include Type II and Type IV tests, as listed below. Each fluid will be tested over the entire range of freezing precipitation conditions encompassed by the Type II/IV HOT tables.

- Clariant Max Flight Sneg (Type IV);
- Newave Aerochemical FCY 9311 (Type II); and
- LNT Solutions P250-2 (Type II).

The procedure for conducting endurance time tests is given in the document *Test Requirements for Simulated Freezing Precipitation Flat Plate Testing* (2). Cold soak boxes should be prepared using the procedure provided in Attachment 1.

The test plan for new fluid endurance time tests is given in Table 1. All tests will be conducted on the main test stand.

2.2 Type III Tests (Type III)

Tests will be conducted with a Type III fluid to achieve several objectives. All tests will be carried out using the Type I test protocol (i.e. fluids applied at 20°C) using Clariant Safewing MP III 2031 ECO.

1. Testing with this fluid in April 2013 resulted in somewhat surprising results in freezing fog at -10°C; the endurance times in this condition were longer than in freezing fog at -3 and -25°C. The freezing fog tests at -10°C will be repeated to confirm the 2013 findings.
2. As a continuation of previous research, several tests will be conducted to evaluate the effect of composite surfaces on endurance times of Type III fluids applied heated. Detailed temperature and Brix measurements will be taken as part of these tests.

The test plan for Type III tests is given in Table 2. All tests will be conducted on the main test stand.

2.3 Thickness of New Fluids (Fluid Thickness)

The objective of these tests is to measure the thickness new fluids on flat plates. The procedure for these tests is entitled *Experimental Program to Establish Film Thickness Profiles for De-Icing and Anti-Icing Fluids on Flat Plates* (3) and can be found in Transport Canada Report TP 13991E, Appendix I. All tests will be conducted with fluid at -3°C.

The test plan for Fluid Thickness tests is given in Table 3. The tests will be conducted at the small end of the chamber outside of the spray area.

2.4 Inspection Immediately Prior to Takeoff (5 Minute Rule)

These tests are a continuation of previous work which examined the appropriateness of guidance which allows takeoff for five minutes following a contamination inspection. Tests were previously conducted in March 2012 and April 2013. The objective of 2014 testing is to collect additional data and measurements.

This project will be carried out by conducting additional observations on tests being conducted for other projects. There is no formal procedure; the following will be used as guidance:

- After fluid failure is recorded for a selected test, the test plate will be left under the freezing precipitation spray for five minutes;
- At the five minute mark the percentage of the plate covered with fluid failure will be recorded; and
- Brix measurements, thickness measurements and photos will be taken:
    - every 5 minutes for tests $<$ 20 minutes;
    - every 10 minutes for tests $>$ 20 minutes; and
    - at failure and 5 minutes past failure for all tests.

The test plan for the 5 minute rule tests is given in Table 4.

2.5 Evaluation of Ice Phobic Products (Ice Phobic)

The objective of this project is to continue the evaluation of newly developed ice phobic products. The project has four sub-objectives as described below.

1. **Endurance Times:** Evaluation of impact of ice phobic products on fluid endurance times. Tests will be conducted with two coatings. The procedure for the conduct of these tests is provided in the document *Effect of Ice Phobic Products on HOTs* (4). The test plan is given in Table 5.
2. **Thickness:** Evaluation of ice phobic products on fluid thickness. The standard procedure for measuring fluid thickness will be used (see Subsection 2.3). Notably, thickness (Type IV fluid) or percent wetted (Type I fluid) will be measured at 15 cm line at time of application and 2, 5, 15, and 30 minutes after. The test plan is given in Table 6. Tests will be conducted at the small end of the chamber outside of the spray area.
3. **Adhesion:** Evaluation of impact of ice phobic products on fluid adhesion. These tests will be conducted without fluid. The test plan is given in Table 7.
4. **Hot Water:** Evaluate the potential for using only hot water as a deicer for end of runway or deicing only type applications. Some coatings may delay the onset of adherence of precipitation and therefore may result in equal or longer protection times than Type I fluid. The test plan is given in Table 8.
5. **Rust-oleum Never Wet:** Research will be conducted with this product on an ad-hoc basis to determine if it is a true ice phobic product. Testing will be conducted in the spray area during light freezing rain, -3°C, low rate. This is noted in the test schedule.

Except where noted, tests will be conducted on the main and/or side stand.

2.6 Endurance Times on Flaps/Slats (Flaps/Slats ETs)

The objective of this project is to continue the evaluation of endurance time performance of anti-icing fluids on wing surfaces with deployed flaps. Testing with Type I, Type II and Type III fluids will being carried out to supplement previously collected data.

The procedure for the conduct of these tests is provided in the document *Evaluation of Endurance Times on Deployed Flaps* (5). The procedure was written for testing in outdoor conditions; changes to the procedure required for indoor testing and the indoor test plan are provided herein.

Tests will be conducted using standard holdover time testing procedures. Each comparative test will include a baseline test (conducted on plate inclined to a 10° slope) and two non-nested flap tests (conducted on plates inclined to a 20° and 35° slope).

The test plan for Deployed Flaps tests is given in Table 9. The tests will be conducted on the main and/or side stand. Tests requiring plates oriented to 20º or 35º must be positioned on the lower main stand or on the side stand.

2.7 Flap/Slat Extension Tests (Flap/Slat Extension)

Tests will be conducted to investigate the effects of extending a flap or slat during the holdover time. This will be achieved by overlapping two plates in either a flap or a slat configuration and fully separating them midway during the expected holdover time. Particular attention will be given to investigating how the bare areas on the plates behave with the precipitation.

The test plan for the flap/slat extension tests is provided in Table 10. The tests will be conducted on the main and/or side stand.

2.8 Ice Pellet Testing (Ice Pellets)

Wind tunnel tests were conducted during the winter of 2013-14 to develop allowance times for Type III fluid. Testing conducted with heated or warm Type III fluid showed signs of adhered contamination, and it was suggested that flat plate testing be conducted to understand this occurrence and to further validate the results observed in the wind tunnel.

The objective of this project is to verify the level of adhered contamination at the end of the allowance time for Type III heated fluids and to compare the severity to a Type IV heated fluid. There is no formal procedure for this project; however, the following points are of importance:

- The level of heat will be varied to represent heated application, as well as involuntary heating scenarios i.e. truck parked indoors, poor insulation in double tank trunk, etc.
- Testing will target proposed allowance times developed based on data collected at the wind tunnel during the winter of 2013-14 and existing allowance times. An additional five minutes can be applied to the allowance time of all tests to investigate potential safety buffers in the allowance times.

The test plan for Ice Pellets is given in Table 11. Testing will be done outside the test spray area to minimize the impact on the testing schedule.

2.9 Windshield Washer Fluid (WWF)

Previous testing in 2011-12 indicated windshield washer fluid does not provide adequate protection time and causes ice to form shortly after spraying. In addition, windshield washer fluid may be hazardous in operations because as it freezes, the wing surface still appears wet. A taxi test indicated that the fluid would likely freeze before the takeoff. Isopropyl alcohol has been identified as another alternative to windshield washer fluid.

The objective of this project is to evaluate the protection time of isopropyl alcohol as compared to standard Type I fluid and windshield washer fluid. Tests will be carried out using the standard endurance time test procedure, including 1 litre of test fluid applied at 20ºC.

The test plan for Windshield Washer Fluid is given in Table 12. The tests will be conducted on the main and/or side stand.

2.10 Update of NRC Rate Calculation Software (Rate Software)

The software currently being used to manage the precipitation rate station at NRC is more than 10 years old. Several key areas for improvement were identified which could streamline, simplify and increase efficiency of the rate station. A computer programmer was retained to implement these changes. The updated software will be tested at the March 2014 test session.

The updated software will be run concurrently with the existing software the first day of testing. Issues and areas of improvement will be documented during this day. The computer programmer will come to NRC the following day to discuss the items and will then have several days to implement the changes. The updated software will be tested again the second week of the test session; this may require concurrent running of old and new software until there is full confidence in the new software.

2.11 Develop Fluid Failure Photos (Failure Photos)

A project was undertaken in winter 2013-14 to obtain photos of de/anti-icing fluids failing in all conditions encompassed by the holdover time guidelines. Review of existing materials indicated some of the needed photos do not exist.

A photographer will attend the test session and take the needed photos, including photos of the beginning of each test, first failure, and actual failure.

The majority of photos will be taken of tests being conducted for other projects. Fifteen unique Type I and Type III tests will also be conducted (test numbers P1 to P15). Table 13 lists the tests to be photographed in each condition.

3. PERSONNEL REQUIREMENTS/RESPONSIBILITIES

The personnel responsibilities are listed below.

1. New Fluid ETs:
    - Manager: JD (pours fluids, calls failures)
    - Assistant: VZ (preps fluids/data forms)
    - Rates Team
2. Type III:
    - Manager: JD (pours fluids, calls failures)
    - Assistant: VZ (preps fluids/data forms)
    - Rates Team
3. Fluid Thickness:
    - Manager: MR (runs tests, takes measurements)
    - Assistant: YOW2 (records measurements)
4. 5 Minute Rule:
    - Manager: VZ (tracks timing, records measurements)
    - Failure Calls: JD
    - Photographer: BG
    - Rates Team
5. Ice Phobic:
    - Manager: MR (runs tests, takes measurements)
    - Assistant: YOW2 (records measurements, assists as needed)
    - Rates Team
6. Flaps/Slats ETs:
    - Manager: MR (runs tests, takes measurements)
    - Assistant: YOW2 (records measurements)
    - Rates Team

7. Flaps/Slats Extension:
    - Manager: MR (runs tests, takes measurements)
    - Assistant: YOW2 (records measurements)
    - Rates Team
8. Ice Pellets:
    - Manager: DY
    - Assistant: YOW3 (make/dispense ice pellets)
9. WWF:
    - Manager: MR (runs tests, takes measurements)
    - Assistant: YOW2 (records measurements)
    - Rates Team
10. Rate Software:
    - Manager: SB
    - Programmer: BF
    - Rate Manager Alternate: DY
11. Failure Photos:
    - Manager: JD
    - Assistant: VZ
    - Photographer: BG

The Rates Team will consist of:

- Rate Manager: SB (runs rate station)
- Rate Manager Alternate: DY (runs rate station)
- Rate Assistant: YOW1 (runs pans, refills fluids)

In the condition of Cold Soak Wing, additional personnel will be required:

- Box Prep Manager: MR
- Box Prep Assistants: YOW2, YOW3

In addition, personnel will be designated responsible for:

- Equipment: MR
- Pre-test Setup: MR/DP
- Data Form Manager: VZ
- Fluid Management: VZ/SB

4. FLUIDS

The required fluids and fluid quantities are shown in Table 14. Type I fluids will be diluted prior to testing using the dilution tables provided in Table 15. Fluids that will be used the first day of testing should be packed into coolers at the APS test site and plugged into power overnight.

5. EQUIPMENT

Table 16 provides a list of required equipment.

6. DATA FORMS

The data forms required for each project are listed below.

1. New Fluid ETs:
   - Freezing Precipitation Endurance Time Data Form (Figure 3)
   - Rate Management Form (Figure 4)
   - NRC Continuous Rate Form (Figure 5)
2. Type III:
   - Freezing Precipitation Endurance Time Data Form (Figure 3)
   - Fluid Brix/Thickness Data Form (Figure 6)
3. Fluid Thickness:
   - Fluid Thickness Data Form (Figure 7)
4. 5 Minute Rule:
   - Observations will be recorded on Freezing Precipitation Endurance Time Data Form (Figure 3) of piggybacked test
   - Fluid Brix/Thickness Data Form (Figure 6)
   - Photographer’s Data Form (Figure 8)
5. Ice Phobic ETs:
   - Ice Phobic End Condition Data Form (Figure 9)
   - Ice Phobic Thickness Data Form (Figure 10)
6. Flaps/Slats ETs:
   - Freezing Precipitation Endurance Time Data Form (Figure 3)
7. Flaps/Slat Extension:

- Freezing Precipitation Endurance Time Data Form (Figure 3)

8. Ice Pellets:
   - Freezing Precipitation Endurance Time Data Form (Figure 3)
   - Adherence of Fluid Failure Form (Figure 11)
9. WWF:
   - Freezing Precipitation Endurance Time Data Form (Figure 3)
10. Rate Software:
    - No data form required
11. Failure Photos:
    - Photographer's Data Form (Figure 8)

7. PRE–TEST SET–UP ACTIVITIES

The following activities need to be completed prior to arrival at the NRC:

1. Mark plates with plate numbers (MR/DP)
2. ~~Check rate pans: check quantity, check for holes, and check all pans are properly labelled~~
3. Ensure plates and boxes are equipped with operational and verified thermistors or smart buttons (MR/DP)
4. Prepare labels for pour containers (VZ)
5. Ensure fluids are prepared in advance according to Table 14 (DP)
6. Clean and label 1 litre pour containers (DP)
7. Check laptops (2) work for rate station (MR)
8. ~~Rent cube van (VZ)~~
9. ~~Book hotel (VZ)~~
10. Update and print chamber settings file (DY)
11. Print data forms and procedures (SB/EA)
12. Print chamber condition sheets (SB/VZ)
13. ~~Contact Medhat (SB)~~
    - ~~confirm availability of NRC camera system~~
    - ~~waste tote~~
    - ~~cold soak fluid + wooden stand + pump~~

- ~~coffee~~
- ~~cell repeater~~
- ~~rate monitoring system~~

~~14. Speak to BG re testing schedule (MR)~~

~~15. Install Trendreader on all laptops (MR/VZ)~~

~~16. Talk to BF re rate station observation (SB)~~

~~17. Find personnel for ice pellets (MR/VZ)~~

18. The following items should be purchased prior to NRC (MR/VZ):
    - Rate station computer
    - Boot dryer
    - Inclinometer x 2
    - Small canon camera x1
    - Printer & Ink Cartridge
    - Ice for IP fabrication
    - Rust-oleum Never Wet
    - Smart Buttons Adhesives
    - Vise grip (large) + rubber opener
    - Windshield Washer Fluid (same as Rockcliffe)

8. SAFETY ISSUES

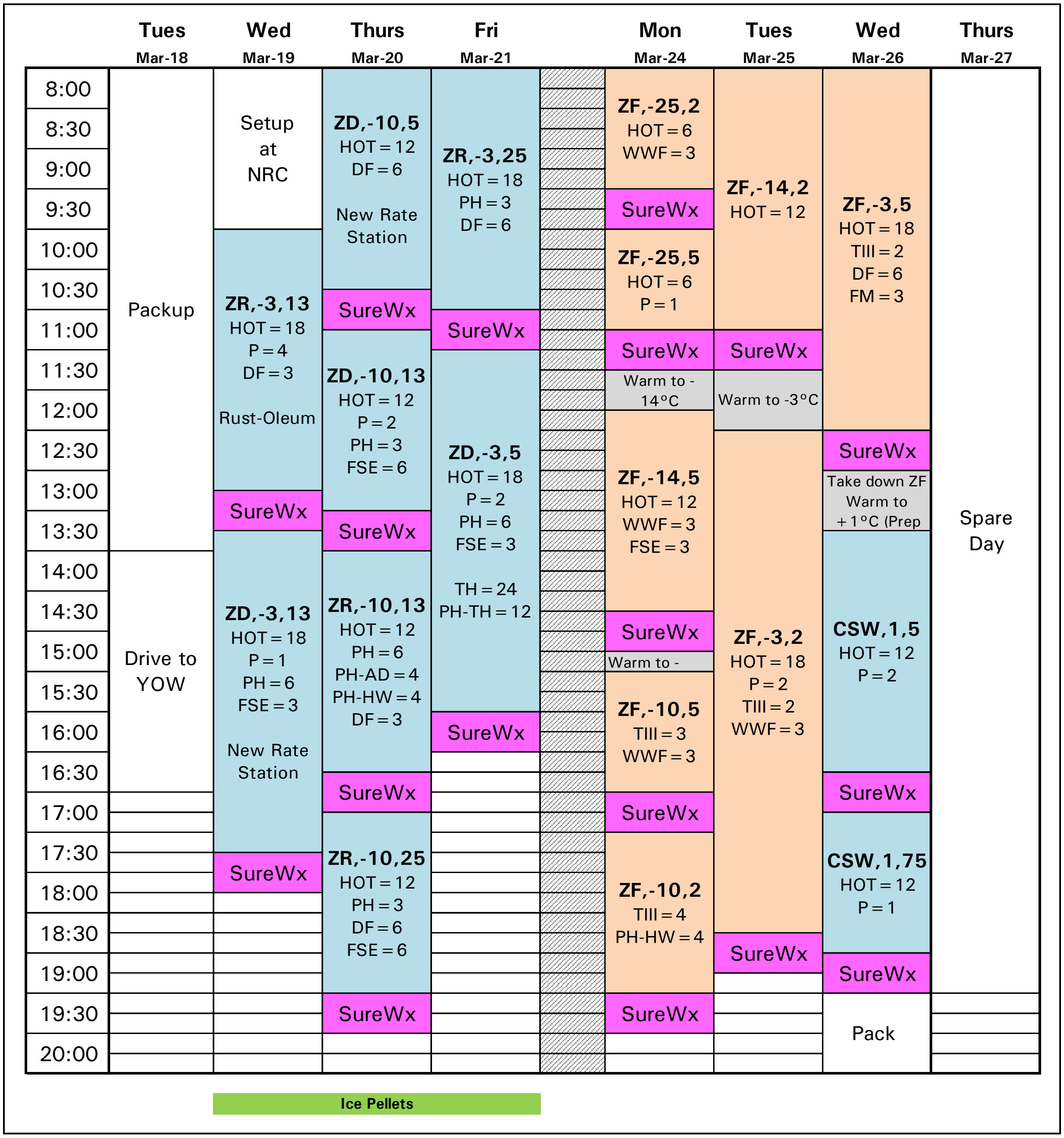
Managers of each subproject must ensure that personnel involved in the set-up and conduct of their respective projects are aware of the following:

1. Fluid MSDS sheets are available for review;
2. Waterproof clothing and gloves are available;
3. Rubber mats must be properly placed in and around the test area and cleaned as necessary;
4. Care should be taken when circulating near the test stand due to slipperiness;
5. First aid kit, water and fire extinguisher are available; and
6. All NRC safety guidelines must be followed.

9. REFERENCES

1. SAE Aerospace Recommended Practice 5485, Endurance Time Tests for Aircraft Deicing/Anti-icing Fluids: SAE Type II, III, and IV, July 2004.
2. Test Requirements For Simulated Freezing Precipitation Flat Plate Testing, Version 1.0, January 15, 2004.
3. Experimental Program to Establish Film Thickness Profiles for De-Icing and Anti-Icing Fluids on Flat Plates, Version 1.0, April 3, 2002.
4. Effect of Ice Phobic Products on Holdover Times, Final Version 1.0, December 24, 2009.
5. Evaluation of Endurance Times on Deployed Flaps, Final Version 1.0, January 25, 2012.

FIGURE 1: TEST SCHEDULE



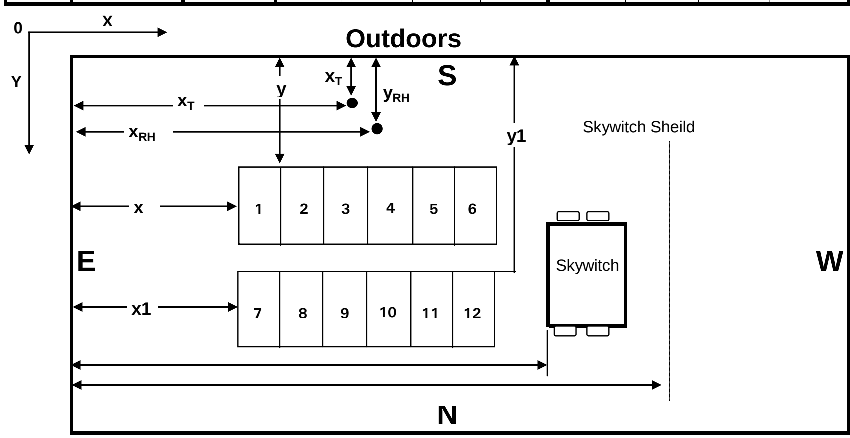
Project Abbreviations

HOT = HOT of New Fluids
DF = Deployed Flaps
FSE = Flaps / Slats Extension
PH = Phobic ET Testing
PH-AD = Phobic Adherence
PH-HW = Phobic Hot Water
TIII = Type III Latent Heat+ HOT
WWWF = Windshield Washer Fluid
P = Photo Documentation of Failure

FIGURE 2: TEST STAND LOCATION MEASUREMENTS

LOCATION: CEF (Ottawa)	DATE:	CONDITION: ZR3H ZR3L ZR10H ZR10L ZD3H ZD3L ZD10H ZD10L ZF3H ZF3L ZF10H ZF10L ZF14H ZF14L ZF25H ZF25L CSWH CSWL

Test	Date of Final Position	Condition	Sensor Position				Stand Position				Skywitch Position	Skywitch Sheild Position (*)	Nozzle Position (**)	Rate	Height of nozzle over plate	Comments
			X_T	Y_T	X_{RH}	Y_{RH}	x	y	x1	y1						
1	04-Apr-01	ZR3H					24' 2"	7'	22' 7"	9' 10"				Very Good		Top Stand 19' from snow fence
2	04-Apr-01	ZR3L					24' 2"	7'	22' 7"	9' 10"				Very Good		Top Stand 19' from snow fence
3	02/04/2001	ZR10H					24'	6' 9"	24' 5"	9' 6"				Very Good		Top stand is 20 ft. from snow fence
4	02-Apr-01	ZR10L					24'	6' 9"	24' 5"	9' 6"				Very Good		Top stand is 20 ft. from snow fence
5	27-Mar-01	ZD3H					24' 5"	6'6"	22'	10'4"				Very Good		
6	28-Mar-01	ZD3L					25' 3"	7'3"	25' 3"	9' 6"				Good		
7	02-Apr-01	ZD10H					24'	7'11"	25' 3"	9' 6"				Very Good		
8	02-Apr-01	ZD10L					24'	7' 7"	24' 7"	9' 11"				Good		20 ft. from Snow Fence
9	10-Apr-01	ZFog3H					24'	6'6"	21'11"	8'10"	34' 2"from x	40'2" from x	top of plate 11	Good	144"	
10	10-Apr-01	ZFog3L					24'	6'6"	21'11"	8'10"	34' 2"from x	40'2" from x	top of plate 11	Good	144"	
11	10-Apr-01	ZFog10H					24'	6'6"	21'11"	8'10"	34' 2"from x	40'2" from x	top of plate 11	Good	144"	
12	10-Apr-01	ZFog10L					24'	6'6"	21'11"	8'10"	34' 2"from x	40'2" from x	top of plate 11	Good	144"	
13	09-Apr-01	ZFog14H					24'	6'6"	21'11"	8'10"	34' 2"from x	40'2" from x	top of plate 11	Good	144"	
14	09-Apr-01	ZFog14L					24'	6'6"	21'11"	8'10"	34' 2"from x	40'2" from x	top of plate 11	Good	144"	
15	06-Apr-01	ZFog25H					24'	6'6"	21'11"	8'10"	34' 2"from x	40'2" from x	top of plate 11	Good	144"	
16	06-Apr-01	ZFog25L					24'	6'6"	21'11"	8'10"	34' 2"from x	40'2" from x	top of plate 11	Good	144"	
17	29-Mar-01	CSWH					25'3"		25'3"	9' 6"						
18	29-Mar-01	CSWL					23'11"	7'3"	25'3"	9' 6"						



Notes:

* - "From X" refers to the distance from the East wall.
** - The nozzle should be between positions 5 and 11
RH - Relative Humidity Sensor
T - Temperature Sensor

WEIGH SCALE TECHNICIAN: ____________________

LEADER: ____________________

NEW VALUES (IF DIFFERENT)

Test	Date of Final Position	Condition	Sensor Position				Stand Position				Skywitch Position	Skywitch Sheild Position (*)	Nozzle Position (**)	Rate	Height of nozzle over plate	Comments
			X_T	Y_T	X_{RH}	Y_{RH}	x	y	x1	y1						

ATTACHMENT 1: COLD SOAK BOX PREPARATION PROCEDURE

1. Put containers (20 L) of CSW box fluid (propylene 65/35) in cold (-30 ± 5°C) freezer overnight. Freezers to be kept in large end of the chamber.

2. Put all filled CSW boxes in warmer (-11 ± 1°C) freezer overnight.

3. Next morning, if freezer in step (2) does not provide fluid and box temperature of -11 ± 1°C, then empty boxes in pail and achieve fluid at -12 ± 1°C in pail.

4. Prepare step (3) in corner of large chamber that is at + 1°C; ensure boxes are cooled to about -11°C. Go to step (6).

5. After first series of tests, empty fluid from boxes into separate pail. Put empty boxes in freezer to keep cool at -11 ± 2°C.

6. Prepare fluid to -12 ± 1°C by mixing (use small amounts of hot water and/or cold fluid). Agitate fluid mixture frequently.

7. Fill boxes, ensure -11 ± 1°C on surface of box. This process shall be done while rates are being measured.

8. Position on stand with cover, but no insulation on top surface. Connect thermocouples.

9. Allow warming to -10 ± 0.5°C. This process needs monitoring with rates measurement to not overshoot temperature (place insulation on top surface if required).

10. Start test.

11. At end of test, remove box from stand, measure rates, and go to step (5).

TABLE 1: NEW FLUID ENDURANCE TIMES TEST PLAN

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid	Fluid Dilution (%)	Test Surface	Comments
1	Freezing Fog	-25	2	Clariant Max Flight Sneg	100	Al. Plate	PHOTOS
2	Freezing Fog	-25	2	Clariant Max Flight Sneg	100	Al. Plate	
3	Freezing Fog	-25	2	Newave FCY 9311	100	Al. Plate	
4	Freezing Fog	-25	2	Newave FCY 9311	100	Al. Plate	
5	Freezing Fog	-25	2	LNT P250-2	100	Al. Plate	PHOTOS
6	Freezing Fog	-25	2	LNT P250-2	100	Al. Plate	
7	Freezing Fog	-25	5	Clariant Max Flight Sneg	100	Al. Plate	PHOTOS
8	Freezing Fog	-25	5	Clariant Max Flight Sneg	100	Al. Plate	
9	Freezing Fog	-25	5	Newave FCY 9311	100	Al. Plate	
10	Freezing Fog	-25	5	Newave FCY 9311	100	Al. Plate	
11	Freezing Fog	-25	5	LNT P250-2	100	Al. Plate	PHOTOS
12	Freezing Fog	-25	5	LNT P250-2	100	Al. Plate	
13	Freezing Fog	-14	2	Clariant Max Flight Sneg	100	Al. Plate	PHOTOS
14	Freezing Fog	-14	2	Clariant Max Flight Sneg	100	Al. Plate	
15	Freezing Fog	-14	2	Newave FCY 9311	100	Al. Plate	
16	Freezing Fog	-14	2	Newave FCY 9311	100	Al. Plate	
17	Freezing Fog	-14	2	LNT P250-2	100	Al. Plate	PHOTOS
18	Freezing Fog	-14	2	LNT P250-2	100	Al. Plate	
19	Freezing Fog	-14	2	Clariant Max Flight Sneg	75	Al. Plate	PHOTOS
20	Freezing Fog	-14	2	Clariant Max Flight Sneg	75	Al. Plate	
21	Freezing Fog	-14	2	Newave FCY 9311	75	Al. Plate	
22	Freezing Fog	-14	2	Newave FCY 9311	75	Al. Plate	
23	Freezing Fog	-14	2	LNT P250-2	75	Al. Plate	PHOTOS
24	Freezing Fog	-14	2	LNT P250-2	75	Al. Plate	
25	Freezing Fog	-14	5	Clariant Max Flight Sneg	100	Al. Plate	PHOTOS
26	Freezing Fog	-14	5	Clariant Max Flight Sneg	100	Al. Plate	
27	Freezing Fog	-14	5	Newave FCY 9311	100	Al. Plate	
28	Freezing Fog	-14	5	Newave FCY 9311	100	Al. Plate	
29	Freezing Fog	-14	5	LNT P250-2	100	Al. Plate	PHOTOS
30	Freezing Fog	-14	5	LNT P250-2	100	Al. Plate	
31	Freezing Fog	-14	5	Clariant Max Flight Sneg	75	Al. Plate	PHOTOS
32	Freezing Fog	-14	5	Clariant Max Flight Sneg	75	Al. Plate	
33	Freezing Fog	-14	5	Newave FCY 9311	75	Al. Plate	
34	Freezing Fog	-14	5	Newave FCY 9311	75	Al. Plate	
35	Freezing Fog	-14	5	LNT P250-2	75	Al. Plate	
36	Freezing Fog	-14	5	LNT P250-2	75	Al. Plate	PHOTOS
37	Freezing Fog	-3	2	Clariant Max Flight Sneg	100	Al. Plate	PHOTOS
38	Freezing Fog	-3	2	Clariant Max Flight Sneg	100	Al. Plate	
39	Freezing Fog	-3	2	Newave FCY 9311	100	Al. Plate	
40	Freezing Fog	-3	2	Newave FCY 9311	100	Al. Plate	
41	Freezing Fog	-3	2	LNT P250-2	100	Al. Plate	PHOTOS
42	Freezing Fog	-3	2	LNT P250-2	100	Al. Plate	
43	Freezing Fog	-3	2	Clariant Max Flight Sneg	75	Al. Plate	PHOTOS
44	Freezing Fog	-3	2	Clariant Max Flight Sneg	75	Al. Plate	
45	Freezing Fog	-3	2	Newave FCY 9311	75	Al. Plate	
46	Freezing Fog	-3	2	Newave FCY 9311	75	Al. Plate	
47	Freezing Fog	-3	2	LNT P250-2	75	Al. Plate	PHOTOS

TABLE 1: NEW FLUID ENDURANCE TIMES TEST PLAN (CONT'D)

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm^2/h)	Fluid	Fluid Dilution (%)	Test Surface	Comments
48	Freezing Fog	-3	2	LNT P250-2	75	Al. Plate	
49	Freezing Fog	-3	2	Clariant Max Flight Sneg	50	Al. Plate	PHOTOS
50	Freezing Fog	-3	2	Clariant Max Flight Sneg	50	Al. Plate	
51	Freezing Fog	-3	2	Newave FCY 9311	50	Al. Plate	
52	Freezing Fog	-3	2	Newave FCY 9311	50	Al. Plate	
53	Freezing Fog	-3	2	LNT P250-2	50	Al. Plate	PHOTOS
54	Freezing Fog	-3	2	LNT P250-2	50	Al. Plate	
55	Freezing Fog	-3	5	Clariant Max Flight Sneg	100	Al. Plate	
56	Freezing Fog	-3	5	Clariant Max Flight Sneg	100	Al. Plate	PHOTOS
57	Freezing Fog	-3	5	Newave FCY 9311	100	Al. Plate	
58	Freezing Fog	-3	5	Newave FCY 9311	100	Al. Plate	
59	Freezing Fog	-3	5	LNT P250-2	100	Al. Plate	PHOTOS
60	Freezing Fog	-3	5	LNT P250-2	100	Al. Plate	
61	Freezing Fog	-3	5	Clariant Max Flight Sneg	75	Al. Plate	PHOTOS
62	Freezing Fog	-3	5	Clariant Max Flight Sneg	75	Al. Plate	
63	Freezing Fog	-3	5	Newave FCY 9311	75	Al. Plate	
64	Freezing Fog	-3	5	Newave FCY 9311	75	Al. Plate	
65	Freezing Fog	-3	5	LNT P250-2	75	Al. Plate	PHOTOS
66	Freezing Fog	-3	5	LNT P250-2	75	Al. Plate	
67	Freezing Fog	-3	5	Clariant Max Flight Sneg	50	Al. Plate	PHOTOS
68	Freezing Fog	-3	5	Clariant Max Flight Sneg	50	Al. Plate	
69	Freezing Fog	-3	5	Newave FCY 9311	50	Al. Plate	
70	Freezing Fog	-3	5	Newave FCY 9311	50	Al. Plate	
71	Freezing Fog	-3	5	LNT P250-2	50	Al. Plate	
72	Freezing Fog	-3	5	LNT P250-2	50	Al. Plate	PHOTOS
73	Freezing Drizzle	-10	5	Clariant Max Flight Sneg	100	Al. Plate	PHOTOS
74	Freezing Drizzle	-10	5	Clariant Max Flight Sneg	100	Al. Plate	
75	Freezing Drizzle	-10	5	Newave FCY 9311	100	Al. Plate	
76	Freezing Drizzle	-10	5	Newave FCY 9311	100	Al. Plate	
77	Freezing Drizzle	-10	5	LNT P250-2	100	Al. Plate	PHOTOS
78	Freezing Drizzle	-10	5	LNT P250-2	100	Al. Plate	
79	Freezing Drizzle	-10	5	Clariant Max Flight Sneg	75	Al. Plate	PHOTOS
80	Freezing Drizzle	-10	5	Clariant Max Flight Sneg	75	Al. Plate	
81	Freezing Drizzle	-10	5	Newave FCY 9311	75	Al. Plate	
82	Freezing Drizzle	-10	5	Newave FCY 9311	75	Al. Plate	
83	Freezing Drizzle	-10	5	LNT P250-2	75	Al. Plate	PHOTOS
84	Freezing Drizzle	-10	5	LNT P250-2	75	Al. Plate	
85	Freezing Drizzle	-10	13	Clariant Max Flight Sneg	100	Al. Plate	
86	Freezing Drizzle	-10	13	Clariant Max Flight Sneg	100	Al. Plate	PHOTOS
87	Freezing Drizzle	-10	13	Newave FCY 9311	100	Al. Plate	
88	Freezing Drizzle	-10	13	Newave FCY 9311	100	Al. Plate	
89	Freezing Drizzle	-10	13	LNT P250-2	100	Al. Plate	PHOTOS
90	Freezing Drizzle	-10	13	LNT P250-2	100	Al. Plate	
91	Freezing Drizzle	-10	13	Clariant Max Flight Sneg	75	Al. Plate	PHOTOS
92	Freezing Drizzle	-10	13	Clariant Max Flight Sneg	75	Al. Plate	
93	Freezing Drizzle	-10	13	Newave FCY 9311	75	Al. Plate	
94	Freezing Drizzle	-10	13	Newave FCY 9311	75	Al. Plate	
95	Freezing Drizzle	-10	13	LNT P250-2	75	Al. Plate	PHOTOS

TABLE 1: NEW FLUID ENDURANCE TIMES TEST PLAN (CONT'D)

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm^2/h)	Fluid	Fluid Dilution (%)	Test Surface	Comments
96	Freezing Drizzle	-10	13	LNT P250-2	75	Al. Plate	
97	Freezing Drizzle	-3	5	Clariant Max Flight Sneg	100	Al. Plate	PHOTOS
98	Freezing Drizzle	-3	5	Clariant Max Flight Sneg	100	Al. Plate	
99	Freezing Drizzle	-3	5	Newave FCY 9311	100	Al. Plate	
100	Freezing Drizzle	-3	5	Newave FCY 9311	100	Al. Plate	
101	Freezing Drizzle	-3	5	LNT P250-2	100	Al. Plate	PHOTOS
102	Freezing Drizzle	-3	5	LNT P250-2	100	Al. Plate	
103	Freezing Drizzle	-3	5	Clariant Max Flight Sneg	75	Al. Plate	PHOTOS
104	Freezing Drizzle	-3	5	Clariant Max Flight Sneg	75	Al. Plate	
105	Freezing Drizzle	-3	5	Newave FCY 9311	75	Al. Plate	
106	Freezing Drizzle	-3	5	Newave FCY 9311	75	Al. Plate	
107	Freezing Drizzle	-3	5	LNT P250-2	75	Al. Plate	PHOTOS
108	Freezing Drizzle	-3	5	LNT P250-2	75	Al. Plate	
109	Freezing Drizzle	-3	5	Clariant Max Flight Sneg	50	Al. Plate	
110	Freezing Drizzle	-3	5	Clariant Max Flight Sneg	50	Al. Plate	PHOTOS
111	Freezing Drizzle	-3	5	Newave FCY 9311	50	Al. Plate	
112	Freezing Drizzle	-3	5	Newave FCY 9311	50	Al. Plate	
113	Freezing Drizzle	-3	5	LNT P250-2	50	Al. Plate	PHOTOS
114	Freezing Drizzle	-3	5	LNT P250-2	50	Al. Plate	
115	Freezing Drizzle	-3	13	Clariant Max Flight Sneg	100	Al. Plate	PHOTOS
116	Freezing Drizzle	-3	13	Clariant Max Flight Sneg	100	Al. Plate	
117	Freezing Drizzle	-3	13	Newave FCY 9311	100	Al. Plate	
118	Freezing Drizzle	-3	13	Newave FCY 9311	100	Al. Plate	
119	Freezing Drizzle	-3	13	LNT P250-2	100	Al. Plate	PHOTOS
120	Freezing Drizzle	-3	13	LNT P250-2	100	Al. Plate	
121	Freezing Drizzle	-3	13	Clariant Max Flight Sneg	75	Al. Plate	PHOTOS
122	Freezing Drizzle	-3	13	Clariant Max Flight Sneg	75	Al. Plate	
123	Freezing Drizzle	-3	13	Newave FCY 9311	75	Al. Plate	
124	Freezing Drizzle	-3	13	Newave FCY 9311	75	Al. Plate	
125	Freezing Drizzle	-3	13	LNT P250-2	75	Al. Plate	PHOTOS
126	Freezing Drizzle	-3	13	LNT P250-2	75	Al. Plate	
127	Freezing Drizzle	-3	13	Clariant Max Flight Sneg	50	Al. Plate	
128	Freezing Drizzle	-3	13	Clariant Max Flight Sneg	50	Al. Plate	PHOTOS
129	Freezing Drizzle	-3	13	Newave FCY 9311	50	Al. Plate	
130	Freezing Drizzle	-3	13	Newave FCY 9311	50	Al. Plate	
131	Freezing Drizzle	-3	13	LNT P250-2	50	Al. Plate	PHOTOS
132	Freezing Drizzle	-3	13	LNT P250-2	50	Al. Plate	
133	Light Freezing Rain	-10	13	Clariant Max Flight Sneg	100	Al. Plate	PHOTOS
134	Light Freezing Rain	-10	13	Clariant Max Flight Sneg	100	Al. Plate	
135	Light Freezing Rain	-10	13	Newave FCY 9311	100	Al. Plate	
136	Light Freezing Rain	-10	13	Newave FCY 9311	100	Al. Plate	
137	Light Freezing Rain	-10	13	LNT P250-2	100	Al. Plate	
138	Light Freezing Rain	-10	13	LNT P250-2	100	Al. Plate	PHOTOS
139	Light Freezing Rain	-10	13	Clariant Max Flight Sneg	75	Al. Plate	
140	Light Freezing Rain	-10	13	Clariant Max Flight Sneg	75	Al. Plate	PHOTOS
141	Light Freezing Rain	-10	13	Newave FCY 9311	75	Al. Plate	
142	Light Freezing Rain	-10	13	Newave FCY 9311	75	Al. Plate	
143	Light Freezing Rain	-10	13	LNT P250-2	75	Al. Plate	PHOTOS

TABLE 1: NEW FLUID ENDURANCE TIMES TEST PLAN (CONT'D)

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid	Fluid Dilution (%)	Test Surface	Comments
144	Light Freezing Rain	-10	13	LNT P250-2	75	Al. Plate	
145	Light Freezing Rain	-10	25	Clariant Max Flight Sneg	100	Al. Plate	
146	Light Freezing Rain	-10	25	Clariant Max Flight Sneg	100	Al. Plate	PHOTOS
147	Light Freezing Rain	-10	25	Newave FCY 9311	100	Al. Plate	
148	Light Freezing Rain	-10	25	Newave FCY 9311	100	Al. Plate	
149	Light Freezing Rain	-10	25	LNT P250-2	100	Al. Plate	PHOTOS
150	Light Freezing Rain	-10	25	LNT P250-2	100	Al. Plate	
151	Light Freezing Rain	-10	25	Clariant Max Flight Sneg	75	Al. Plate	
152	Light Freezing Rain	-10	25	Clariant Max Flight Sneg	75	Al. Plate	PHOTOS
153	Light Freezing Rain	-10	25	Newave FCY 9311	75	Al. Plate	
154	Light Freezing Rain	-10	25	Newave FCY 9311	75	Al. Plate	
155	Light Freezing Rain	-10	25	LNT P250-2	75	Al. Plate	
156	Light Freezing Rain	-10	25	LNT P250-2	75	Al. Plate	PHOTOS
157	Light Freezing Rain	-3	13	Clariant Max Flight Sneg	100	Al. Plate	PHOTOS
158	Light Freezing Rain	-3	13	Clariant Max Flight Sneg	100	Al. Plate	
159	Light Freezing Rain	-3	13	Newave FCY 9311	100	Al. Plate	
160	Light Freezing Rain	-3	13	Newave FCY 9311	100	Al. Plate	
161	Light Freezing Rain	-3	13	LNT P250-2	100	Al. Plate	PHOTOS
162	Light Freezing Rain	-3	13	LNT P250-2	100	Al. Plate	
163	Light Freezing Rain	-3	13	Clariant Max Flight Sneg	75	Al. Plate	PHOTOS
164	Light Freezing Rain	-3	13	Clariant Max Flight Sneg	75	Al. Plate	
165	Light Freezing Rain	-3	13	Newave FCY 9311	75	Al. Plate	
166	Light Freezing Rain	-3	13	Newave FCY 9311	75	Al. Plate	
167	Light Freezing Rain	-3	13	LNT P250-2	75	Al. Plate	PHOTOS
168	Light Freezing Rain	-3	13	LNT P250-2	75	Al. Plate	
169	Light Freezing Rain	-3	13	Clariant Max Flight Sneg	50	Al. Plate	PHOTOS
170	Light Freezing Rain	-3	13	Clariant Max Flight Sneg	50	Al. Plate	
171	Light Freezing Rain	-3	13	Newave FCY 9311	50	Al. Plate	
172	Light Freezing Rain	-3	13	Newave FCY 9311	50	Al. Plate	
173	Light Freezing Rain	-3	13	LNT P250-2	50	Al. Plate	
174	Light Freezing Rain	-3	13	LNT P250-2	50	Al. Plate	PHOTOS
175	Light Freezing Rain	-3	25	Clariant Max Flight Sneg	100	Al. Plate	PHOTOS
176	Light Freezing Rain	-3	25	Clariant Max Flight Sneg	100	Al. Plate	
177	Light Freezing Rain	-3	25	Newave FCY 9311	100	Al. Plate	
178	Light Freezing Rain	-3	25	Newave FCY 9311	100	Al. Plate	
179	Light Freezing Rain	-3	25	LNT P250-2	100	Al. Plate	PHOTOS
180	Light Freezing Rain	-3	25	LNT P250-2	100	Al. Plate	
181	Light Freezing Rain	-3	25	Clariant Max Flight Sneg	75	Al. Plate	PHOTOS
182	Light Freezing Rain	-3	25	Clariant Max Flight Sneg	75	Al. Plate	
183	Light Freezing Rain	-3	25	Newave FCY 9311	75	Al. Plate	
184	Light Freezing Rain	-3	25	Newave FCY 9311	75	Al. Plate	
185	Light Freezing Rain	-3	25	LNT P250-2	75	Al. Plate	PHOTOS
186	Light Freezing Rain	-3	25	LNT P250-2	75	Al. Plate	
187	Light Freezing Rain	-3	25	Clariant Max Flight Sneg	50	Al. Plate	PHOTOS
188	Light Freezing Rain	-3	25	Clariant Max Flight Sneg	50	Al. Plate	
189	Light Freezing Rain	-3	25	Newave FCY 9311	50	Al. Plate	
190	Light Freezing Rain	-3	25	Newave FCY 9311	50	Al. Plate	
191	Light Freezing Rain	-3	25	LNT P250-2	50	Al. Plate	

TABLE 1: NEW FLUID ENDURANCE TIMES TEST PLAN (CONT'D)

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid	Fluid Dilution (%)	Test Surface	Comments
192	Light Freezing Rain	-3	25	LNT P250-2	50	Al. Plate	PHOTOS
193	Cold Soak Box	1	5	Clariant Max Flight Sneg	100	Al. Box	PHOTOS
194	Cold Soak Box	1	5	Clariant Max Flight Sneg	100	Al. Box	
195	Cold Soak Box	1	5	Newave FCY 9311	100	Al. Box	
196	Cold Soak Box	1	5	Newave FCY 9311	100	Al. Box	
197	Cold Soak Box	1	5	LNT P250-2	100	Al. Box	PHOTOS
198	Cold Soak Box	1	5	LNT P250-2	100	Al. Box	
199	Cold Soak Box	1	5	Clariant Max Flight Sneg	75	Al. Box	PHOTOS
200	Cold Soak Box	1	5	Clariant Max Flight Sneg	75	Al. Box	
201	Cold Soak Box	1	5	Newave FCY 9311	75	Al. Box	
202	Cold Soak Box	1	5	Newave FCY 9311	75	Al. Box	
203	Cold Soak Box	1	5	LNT P250-2	75	Al. Box	PHOTOS
204	Cold Soak Box	1	5	LNT P250-2	75	Al. Box	
205	Cold Soak Box	1	75	Clariant Max Flight Sneg	100	Al. Box	PHOTOS
206	Cold Soak Box	1	75	Clariant Max Flight Sneg	100	Al. Box	
207	Cold Soak Box	1	75	Newave FCY 9311	100	Al. Box	
208	Cold Soak Box	1	75	Newave FCY 9311	100	Al. Box	
209	Cold Soak Box	1	75	LNT P250-2	100	Al. Box	PHOTOS
210	Cold Soak Box	1	75	LNT P250-2	100	Al. Box	
211	Cold Soak Box	1	75	Clariant Max Flight Sneg	75	Al. Box	PHOTOS
212	Cold Soak Box	1	75	Clariant Max Flight Sneg	75	Al. Box	
213	Cold Soak Box	1	75	Newave FCY 9311	75	Al. Box	
214	Cold Soak Box	1	75	Newave FCY 9311	75	Al. Box	
215	Cold Soak Box	1	75	LNT P250-2	75	Al. Box	PHOTOS
216	Cold Soak Box	1	75	LNT P250-2	75	Al. Box	

TABLE 2: TYPE III TEST PLAN

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid	Fluid Dilution (%)	Test Surface	Comments
T1	Freezing Fog	-10	2	Clariant MP III 2031 WARM	100	Al. Plate	Brix and temp profile
T2	Freezing Fog	-10	2	Clariant MP III 2031 WARM	100	Al. Plate	Brix and temp profile
T3	Freezing Fog	-10	2	Clariant MP III 2031 WARM	75	Al. Plate	Brix and temp profile
T4	Freezing Fog	-10	2	Clariant MP III 2031 WARM	75	Al. Plate	Brix and temp profile
T5	Freezing Fog	-10	5	Clariant MP III 2031 WARM	100	Al. Plate	Brix and temp profile
T6	Freezing Fog	-10	5	Clariant MP III 2031 WARM	100	Al. Plate	Brix and temp profile
T7	Freezing Fog	-10	5	Clariant MP III 2031 WARM	100	Comp. Plate	Brix and temp profile
T8	Freezing Fog	-3	5	Clariant MP III 2031 WARM	100	Al. Plate	Brix and temp profile
T9	Freezing Fog	-3	5	Clariant MP III 2031 WARM	100	Comp. Plate	Brix and temp profile
T10	Freezing Fog	-3	2	Clariant MP III 2031 WARM	100	Al. Plate	Brix and temp profile
T11	Freezing Fog	-3	2	Clariant MP III 2031 WARM	100	Comp. Plate	Brix and temp profile

TABLE 3: FLUID THICKNESS TEST PLAN

Test #	Fluid	Fluid Dilution	Fluid Temp	Test Surface	Ambient Air Temp
TH1	Clariant Max Flight Sneg	100/0	-3°C	Al. Plate	-3°C
TH2	Clariant Max Flight Sneg	100/0	-3°C	Al. Plate	-3°C
TH3	Clariant Max Flight Sneg	75/25	-3°C	Al. Plate	-3°C
TH4	Clariant Max Flight Sneg	75/25	-3°C	Al. Plate	-3°C
TH5	Clariant Max Flight Sneg	50/50	-3°C	Al. Plate	-3°C
TH6	Clariant Max Flight Sneg	50/50	-3°C	Al. Plate	-3°C
TH7	LNT P250-2	100/0	-3°C	Al. Plate	-3°C
TH8	LNT P250-2	100/0	-3°C	Al. Plate	-3°C
TH9	LNT P250-2	75/25	-3°C	Al. Plate	-3°C
TH10	LNT P250-2	75/25	-3°C	Al. Plate	-3°C
TH11	LNT P250-2	50/50	-3°C	Al. Plate	-3°C
TH12	LNT P250-2	50/50	-3°C	Al. Plate	-3°C
TH13	Newave FCY 9311	100/0	-3°C	Al. Plate	-3°C
TH14	Newave FCY 9311	100/0	-3°C	Al. Plate	-3°C
TH15	Newave FCY 9311	75/25	-3°C	Al. Plate	-3°C
TH16	Newave FCY 9311	75/25	-3°C	Al. Plate	-3°C
TH17	Newave FCY 9311	50/50	-3°C	Al. Plate	-3°C
TH18	Newave FCY 9311	50/50	-3°C	Al. Plate	-3°C

Notes:

- The quantity of fluid that will be poured for each test is 1.0 L
- Measurements should be made at the 15-cm line at the time of fluid application, and after 2 minutes, 5 minutes, 15 minutes, and 30 minutes.
- If the results for one fluid vary by more than 10% repeat the two tests and disregard the highest and lowest values

TABLE 4: FIVE MINUTE RULE TEST PLAN

Test #	Piggyback Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid	Fluid Dilution (%)	Test Surface	Measurements
TYPE I TESTS								
FM1	PH22	Light Freezing Rain	-10	13	Octagon Octaflo EF	10°B (B=27.0)	Al. Plate	1L@20°C, Brix/thick 5 mins + fail + 5mins
FM2	PH10	Freezing Drizzle	-3	13	Dow UCAR ADF (EG)	10°B (B=17.6)	Al. Plate	1L@20°C, Brix/thick 5 mins + fail + 5mins
TYPE II, III, IV TESTS								
FM3	55	Freezing Fog	-3	5	Clariant Max Flight SNEG	100	Al. Plate	Brix/thick every 10 mins + fail + 5mins
FM4	63	Freezing Fog	-3	5	Newave FCY 9311	75	Al. Plate	Brix/thick every 10 mins + fail + 5mins
FM5	71	Freezing Fog	-3	5	LNT P250-2	50	Al. Plate	Brix/thick every 5 mins + fail + 5mins
FM6	191	Light Freezing Rain	-3	25	LNT P250-2	50	Al. Plate	Brix/thick every 5 mins + fail + 5mins
FM7	189	Light Freezing Rain	-3	25	Newave FCY 9311	50	Al. Plate	Brix/thick every 5 mins + fail + 5mins
FM8	139	Light Freezing Rain	-10	13	Clariant Max Flight SNEG	75	Al. Plate	Brix/thick every 10 mins + fail + 5mins
FM9	141	Light Freezing Rain	-10	13	Newave FCY 9311	75	Al. Plate	Brix/thick every 5 mins + fail + 5mins
FM10	137	Light Freezing Rain	-10	13	LNT P250-2	100	Al. Plate	Brix/thick every 10 mins + fail + 5mins
FM11	DF16	Light Freezing Rain	-10	25	Clariant MP III 2031 WARM	75	Al. Plate	1L@20°C, Brix/thick 5 mins + fail + 5mins
FM12	145	Light Freezing Rain	-10	25	Clariant Max Flight SNEG	100	Al. Plate	Brix/thick every 5 mins + fail + 5mins
FM13	147	Light Freezing Rain	-10	25	Newave FCY 9311	100	Al. Plate	Brix/thick every 5 mins + fail + 5mins
FM14	155	Light Freezing Rain	-10	25	LNT P250-2	75	Al. Plate	Brix/thick every 5 mins + fail + 5mins
FM15	109	Freezing Drizzle	-3	5	Clariant Max Flight SNEG	50	Al. Plate	Brix/thick every 10 mins + fail + 5mins
FM16	111	Freezing Drizzle	-3	5	Newave FCY 9311	50	Al. Plate	Brix/thick every 5 mins + fail + 5mins

TABLE 5: ICE PHOBIC ENDURANCE TIME TEST PLAN

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid Name	Fluid Dilution	Test Surface	Comments	Fluid Req'd (L)	Priority
PH1	Freezing Drizzle	-3	5	Dow UCAR ADF (EG)	10°B (B=17.6)	Baseline	1 L at 20°C, Thick @ 5 mins, Brix at fail	1	1
PH2	Freezing Drizzle	-3	5	Dow UCAR ADF (EG)	10°B (B=17.6)	B14	1 L at 20°C, Thick @ 5 mins, Brix at fail	1	1
PH3	Freezing Drizzle	-3	5	Dow UCAR ADF (EG)	10°B (B=17.6)	G1	1 L at 20°C, Thick @ 5 mins, Brix at fail	1	1
PH4	Freezing Drizzle	-3	5	Octagon Octaflo EF	10°B (B=21.25)	Baseline	1 L at 20°C, Thick @ 5 mins, Brix at fail	1	1
PH5	Freezing Drizzle	-3	5	Octagon Octaflo EF	10°B (B=21.25)	B15	1 L at 20°C, Thick @ 5 mins, Brix at fail	1	1
PH6	Freezing Drizzle	-3	5	Octagon Octaflo EF	10°B (B=21.25)	G1	1 L at 20°C, Thick @ 5 mins, Brix at fail	1	1
PH7	Freezing Drizzle	-3	13	Clariant Flight PLUS	50	Baseline	Thick @ 5 mins, Brix at fail	1	1
PH8	Freezing Drizzle	-3	13	Clariant Flight PLUS	50	B14	Thick @ 5 mins, Brix at fail	1	1
PH9	Freezing Drizzle	-3	13	Clariant Flight PLUS	50	G1	Thick @ 5 mins, Brix at fail	1	1
PH10	Freezing Drizzle	-3	13	Dow UCAR ADF (EG)	10°B (B=17.6)	Baseline	1 L at 20°C, Thick @ 5 mins, Brix at fail	1	2
PH11	Freezing Drizzle	-3	13	Dow UCAR ADF (EG)	10°B (B=17.6)	B14	1 L at 20°C, Thick @ 5 mins, Brix at fail	1	2
PH12	Freezing Drizzle	-3	13	Dow UCAR ADF (EG)	10°B (B=17.6)	G1	1 L at 20°C, Thick @ 5 mins, Brix at fail	1	2
PH13	Freezing Drizzle	-10	13	ABAX Ecowing 26	75	Baseline	Thick @ 5 mins, Brix at fail	1	1
PH14	Freezing Drizzle	-10	13	ABAX Ecowing 26	75	B15	Thick @ 5 mins, Brix at fail	1	1
PH15	Freezing Drizzle	-10	13	ABAX Ecowing 26	75	G1	Thick @ 5 mins, Brix at fail	1	1
PH10	Light Freezing Rain	-3	25	Clariant Flight	75	Baseline	Thick @ 5 mins, Brix at fail	1	2
PH17	Light Freezing Rain	-3	25	Clariant Flight	75	B15	Thick @ 5 mins, Brix at fail	1	2
PH18	Light Freezing Rain	-3	25	Clariant Flight	75	G1	Thick @ 5 mins, Brix at fail	1	2
PH19	Light Freezing Rain	-10	13	Clariant Launch Plus	75	Baseline	Thick @ 5 mins, Brix at fail	1	1
PH20	Light Freezing Rain	-10	13	Clariant Launch Plus	75	B14	Thick @ 5 mins, Brix at fail	1	1
PH21	Light Freezing Rain	-10	13	Clariant Launch Plus	75	G1	Thick @ 5 mins, Brix at fail	1	1
PH22	Light Freezing Rain	-10	13	Octagon Octaflo EF	10°B (B=27.0)	Baseline	1 L at 20°C, Thick @ 5 mins, Brix at fail	1	1
PH23	Light Freezing Rain	-10	13	Octagon Octaflo EF	10°B (B=27.0)	B14	1 L at 20°C, Thick @ 5 mins, Brix at fail	1	1
PH24	Light Freezing Rain	-10	13	Octagon Octaflo EF	10°B (B=27.0)	G1	1 L at 20°C, Thick @ 5 mins, Brix at fail	1	1
PH25	Light Freezing Rain	-10	25	Dow UCAR EG106	100	Baseline	Thick @ 5 mins, Brix at fail	1	1
PH26	Light Freezing Rain	-10	25	Dow UCAR EG106	100	B15	Thick @ 5 mins, Brix at fail	1	1
PH27	Light Freezing Rain	-10	25	Dow UCAR EG106	100	G1	Thick @ 5 mins, Brix at fail	1	1

NOTE: If G1 not available substitute B14 or B15

TABLE 6: ICE PHOBIC THICKNESS TEST PLAN

Test #	Priority	Fluid Name	Fluid Type	Fluid Dilution	Test Surface Treatment*	Ambient Air Temperature
PH-TH1	1	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	Baseline	-3°C
PH-TH2	1	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	B14	-3°C
PH-TH3	1	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	B15	-3°C
PH-TH4	1	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	G1	-3°C
PH-TH5	2	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	Baseline	-3°C
PH-TH6	2	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	B14	-3°C
PH-TH7	2	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	B15	-3°C
PH-TH8	2	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	G1	-3°C
PH-TH9	1	Clariant Max Flight Sneg	Type IV PG	100	Baseline	-3°C
PH-TH10	1	Clariant Max Flight Sneg	Type IV PG	100	B14	-3°C
PH-TH11	1	Clariant Max Flight Sneg	Type IV PG	100	B15	-3°C
PH-TH12	1	Clariant Max Flight Sneg	Type IV PG	100	G1	-3°C

Procedure: Measure thickness (TII) at 15 cm line or % wetted (TI) at application and 2, 5, 15, and 30 minutes after pouring

TABLE 7: ICE PHOBIC ADHERENCE TEST PLAN

Test #	Priority	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid	Fluid Dilution	Test Surface	Comments
PH-AD1	1	Light Freezing Rain	-10	13	No fluid	n/a	Baseline	Measure time of adherence
PH-AD2	1	Light Freezing Rain	-10	13	No fluid	n/a	B14	Measure time of adherence
PH-AD3	1	Light Freezing Rain	-10	13	No fluid	n/a	B15	Measure time of adherence
PH-AD4	1	Light Freezing Rain	-10	13	No fluid	n/a	G1	Measure time of adherence

TABLE 8: ICE PHOBIC HOT WATER TEST PLAN

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid Name	Fluid Dilution (%)	Test Surface	Comments	Fluid Required (L)	Priority
PH-HW1	Freezing Fog	-10	2	Octagon Octaflo EF	10°B (B=27.0)	Baseline	Measure time of adherence	10	2
PH-HW2	Freezing Fog	-10	2	Hot Water (1L @ 20°C)	n/a	B14	Measure time of adherence	10	2
PH-HW3	Freezing Fog	-10	2	Hot Water (1L @ 20°C)	n/a	B15	Measure time of adherence	10	2
PH-HW4	Freezing Fog	-10	2	Hot Water (1L @ 20°C)	n/a	G1	Measure time of adherence	10	2
PH-HW7	Light Freezing Rain	-10	13	Octagon Octaflo EF	10°B (B=27.0)	Baseline	Measure time of adherence	5	2
PH-HW8	Light Freezing Rain	-10	13	Hot Water (1L @ 20°C)	n/a	B14	Measure time of adherence	5	2
PH-HW9	Light Freezing Rain	-10	13	Hot Water (1L @ 20°C)	n/a	B15	Measure time of adherence	5	2
PH-HW9	Light Freezing Rain	-10	13	Hot Water (1L @ 20°C)	n/a	G1	Measure time of adherence	5	2

TABLE 9: DEPLOYED FLAPS TEST PLAN

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid Name	Fluid Dilution (%)	Test Surface	Comments	Priority
DF1	Freezing Drizzle	-10	5	Octagon Octaflo EF	10°B (B=27.0)	Plate (10°)	No measurements	1
DF2	Freezing Drizzle	-10	5	Octagon Octaflo EF	10°B (B=27.0)	Plate (20°)	No measurements	1
DF3	Freezing Drizzle	-10	5	Octagon Octaflo EF	10°B (B=27.0)	Plate (35°)	No measurements	2
DF4	Freezing Drizzle	-10	5	Newave FCY 9311	75	Plate (10°)	No measurements	1
DF5	Freezing Drizzle	-10	5	Newave FCY 9311	75	Plate (20°)	No measurements	1
DF6	Freezing Drizzle	-10	5	Newave FCY 9311	75	Plate (35°)	No measurements	2
DF7	Light Freezing Rain	-3	25	Octagon Octaflo EF	10°B (B=21.25)	Plate (10°)	No measurements	1
DF8	Light Freezing Rain	-3	25	Octagon Octaflo EF	10°B (B=21.25)	Plate (20°)	No measurements	1
DF9	Light Freezing Rain	-3	25	Octagon Octaflo EF	10°B (B=21.25)	Plate (35°)	No measurements	2
PH16	Light Freezing Rain	-3	25	Clariant Flight	75	Plate (10°)	No measurements	1
DF11	Light Freezing Rain	-3	25	Clariant Flight	75	Plate (20°)	No measurements	1
DF12	Light Freezing Rain	-3	25	Clariant Flight	75	Plate (35°)	No measurements	2
DF13	Light Freezing Rain	-10	25	Dow UCAR ADF (EG)	10°B (B=22.9)	Plate (10°)	No measurements	1
DF14	Light Freezing Rain	-10	25	Dow UCAR ADF (EG)	10°B (B=22.9)	Plate (20°)	No measurements	1
DF15	Light Freezing Rain	-10	25	Dow UCAR ADF (EG)	10°B (B=22.9)	Plate (35°)	No measurements	2
DF16	Light Freezing Rain	-10	25	Clariant MP III 2031	75	Plate (10°)	1 L @20C, No measurements	1
DF17	Light Freezing Rain	-10	25	Clariant MP III 2031	75	Plate (20°)	1 L @20C, No measurements	1
DF18	Light Freezing Rain	-10	25	Clariant MP III 2031	75	Plate (35°)	1 L @20C, No measurements	2
DF19	Freezing Fog	-3	5	Dow UCAR ADF (EG)	10°B (B=17.6)	Plate (10°)	No measurements	1
DF20	Freezing Fog	-3	5	Dow UCAR ADF (EG)	10°B (B=17.6)	Plate (20°)	No measurements	1
DF21	Freezing Fog	-3	5	Dow UCAR ADF (EG)	10°B (B=17.6)	Plate (35°)	No measurements	2
DF22	Freezing Fog	-3	5	Clariant MP III 2031	100	Plate (10°)	1 L @20C, No measurements	1
DF23	Freezing Fog	-3	5	Clariant MP III 2031	100	Plate (20°)	1 L @20C, No measurements	1
DF24	Freezing Fog	-3	5	Clariant MP III 2031	100	Plate (35°)	1 L @20C, No measurements	2
DF25	Light Freezing Rain	-10	13	Clariant MP III 2031	100	Plate (10°)	1 L @20C, No measurements	1
DF26	Light Freezing Rain	-10	13	Clariant MP III 2031	100	Plate (20°)	1 L @20C, No measurements	1
DF27	Light Freezing Rain	-10	13	Clariant MP III 2031	100	Plate (35°)	1 L @20C, No measurements	2
DF28	Light Freezing Rain	-3	13	LNT P250-2	50	Plate (10°)	No measurements	1
DF29	Light Freezing Rain	-3	13	LNT P250-2	50	Plate (20°)	No measurements	1
DF30	Light Freezing Rain	-3	13	LNT P250-2	50	Plate (35°)	No measurements	2

NOTE: 20° and 35° plates need to be positioned on bottom HOT stand (pos 7-12) or on side stand (1s-3s)

TABLE 10: FLAPS/SLATS EXTENSION TEST PLAN

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid	Fluid Dil. (%)	Test Surface	Comments	Fluid Required (L)	Priority
FSE1	Freezing Drizzle	-3	5	Newave FCY 9311	50	Plate (10°)	Thickness at 5 mins, Brix at fail	1	1
FSE2	Freezing Drizzle	-3	5	Newave FCY 9311	50	2 Plates (20°) Slat	Extend after 5-10min; thick at 5 mins, Brix at fail	1.5	1
FSE3	Freezing Drizzle	-3	5	Newave FCY 9311	50	2 Plates (20°) Flap	Extend after 5-10min; thick at 5 mins, Brix at fail	1.5	1
FSE4	Freezing Drizzle	-3	13	Clariant Max Flight Sneg	50	Plate (10°)	Thickness at 5 mins, Brix at fail	1	1
FSE5	Freezing Drizzle	-3	13	Clariant Max Flight Sneg	50	2 Plates (20°) Slat	Extend after 5-10min; thick at 5 mins, Brix at fail	1.5	1
FSE6	Freezing Drizzle	-3	13	Clariant Max Flight Sneg	50	2 Plates (20°) Flap	Extend after 5-10min; thick at 5 mins, Brix at fail	1.5	1
FSE7	Freezing Drizzle	-10	13	Clariant Max Flight Sneg	100	Plate (10°)	Thickness at 5 mins, Brix at fail	1	1
FSE8	Freezing Drizzle	-10	13	Clariant Max Flight Sneg	100	2 Plates (20°) Slat	Extend after 5-10min; thick at 5 mins, Brix at fail	1.5	1
FSE9	Freezing Drizzle	-10	13	Clariant Max Flight Sneg	100	2 Plates (20°) Flap	Extend after 5-10min; thick at 5 mins, Brix at fail	1.5	1
FSE10	Freezing Drizzle	-10	13	Octagon Octaflo EF	10°B (B=27.0)	Plate (10°)	Thickness at 5 mins, Brix at fail	1	2
FSE11	Freezing Drizzle	-10	13	Octagon Octaflo EF	10°B (B=27.0)	2 Plates (35°) Slat	Extend after 5-10min; thick at 5 mins, Brix at fail	1.5	2
FSE12	Freezing Drizzle	-10	13	Octagon Octaflo EF	10°B (B=27.0)	2 Plates (35°) Flap	Extend after 5-10min; thick at 5 mins, Brix at fail	1.5	2
FSE13	Light Freezing Rain	-10	25	Clariant MP III 2031 WARM	100	Plate (10°)	Thickness at 5 mins, Brix at fail	1	2
FSE14	Light Freezing Rain	-10	25	Clariant MP III 2031 WARM	100	2 Plates (35°) Slat	Extend after 5-10min; thick at 5 mins, Brix at fail	1.5	2
FSE15	Light Freezing Rain	-10	25	Clariant MP III 2031 WARM	100	2 Plates (35°) Flap	Extend after 5-10min; thick at 5 mins, Brix at fail	1.5	2
FSE16	Light Freezing Rain	-10	25	Clariant Max Flight Sneg	75	Plate (10°)	Thickness at 5 mins, Brix at fail	1	2
FSE17	Light Freezing Rain	-10	25	Clariant Max Flight Sneg	75	2 Plates (35°) Slat	Extend after 5-10min; thick at 5 mins, Brix at fail	1.5	2
FSE18	Light Freezing Rain	-10	25	Clariant Max Flight Sneg	75	2 Plates (35°) Flap	Extend after 5-10min; thick at 5 mins, Brix at fail	1.5	2
FSE19	Freezing Fog	-14	5	LNT P250-2	75	Plate (10°)	Thickness at 5 mins, Brix at fail	1	1
FSE20	Freezing Fog	-14	5	LNT P250-2	75	2 Plates (20°) Slat	Extend after 5-10min; thick at 5 mins, Brix at fail	1.5	1
FSE21	Freezing Fog	-14	5	LNT P250-2	75	2 Plates (20°) Flap	Extend after 5-10min; thick at 5 mins, Brix at fail	1.5	1

NOTE 1: 2 plates used. 1 on top of other at 10° to start (with overlap), then split into 10° and 20/35°

NOTE 2: Consider deicing with 1 litre standard mix Type I, holding for 1 minute, then applying Type IV

TABLE 11: ICE PELLETS TEST PLAN

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Exposure Time (min)	Fluid Code	Fluid Dilution (%)	Fluid Temp (°C)	Test Surface	Priority	Comments
IP1	Ice Pellets	-3	75	5	Type III 2031 Porter	100	5 to 10	Al. Plate	1	Document adherence, Brix at end
IP2	Ice Pellets	-3	75	5	Type III 2031 Porter	100	20	Al. Plate	2	Document adherence, Brix at end
IP3	Ice Pellets	-3	75	5	Type III 2031 Porter	100	OAT	Al. Plate	1	Document adherence, Brix at end
IP4	Ice Pellets	-3	75	5	Type III 2031 Porter	100	60	Al. Plate	1	Document adherence, Brix at end
IP5	Ice Pellets	-3	75	25	ABC-S Plus (WT)	100	5 to 10	Al. Plate	1	Document adherence, Brix at end
IP6	Ice Pellets	-3	75	25	ABC-S Plus (WT)	100	20	Al. Plate	2	Document adherence, Brix at end
IP7	Ice Pellets	-3	75	25	ABC-S Plus (WT)	100	OAT	Al. Plate	3	Document adherence, Brix at end
IP8	Ice Pellets	-3	75	25	ABC-S Plus (WT)	100	60	Al. Plate	3	Document adherence, Brix at end
IP9	Ice Pellets	-10	25	10	Type III 2031 Porter	100	5 to 10	Al. Plate	1	Document adherence, Brix at end
IP10	Ice Pellets	-10	25	10	Type III 2031 Porter	100	20	Al. Plate	2	Document adherence, Brix at end
IP11	Ice Pellets	-10	25	10	Type III 2031 Porter	100	OAT	Al. Plate	1	Document adherence, Brix at end
IP12	Ice Pellets	-10	25	10	Type III 2031 Porter	100	60	Al. Plate	1	Document adherence, Brix at end
IP13	Ice Pellets	-10	25	30	ABC-S Plus (WT)	100	5 to 10	Al. Plate	1	Document adherence, Brix at end
IP14	Ice Pellets	-10	25	30	ABC-S Plus (WT)	100	20	Al. Plate	2	Document adherence, Brix at end
IP15	Ice Pellets	-10	25	30	ABC-S Plus (WT)	100	OAT	Al. Plate	3	Document adherence, Brix at end
IP16	Ice Pellets	-10	25	30	ABC-S Plus (WT)	100	60	Al. Plate	3	Document adherence, Brix at end
IP17	Ice Pellets	-10	75	5	Type III 2031 Porter	100	5 to 10	Al. Plate	1	Document adherence, Brix at end
IP18	Ice Pellets	-10	75	5	Type III 2031 Porter	100	20	Al. Plate	2	Document adherence, Brix at end
IP19	Ice Pellets	-10	75	5	Type III 2031 Porter	100	OAT	Al. Plate	1	Document adherence, Brix at end
IP20	Ice Pellets	-10	75	5	Type III 2031 Porter	100	60	Al. Plate	1	Document adherence, Brix at end
IP21	Ice Pellets	-10	75	10	ABC-S Plus (WT)	100	5 to 10	Al. Plate	1	Document adherence, Brix at end
IP22	Ice Pellets	-10	75	10	ABC-S Plus (WT)	100	20	Al. Plate	2	Document adherence, Brix at end
IP23	Ice Pellets	-10	75	10	ABC-S Plus (WT)	100	OAT	Al. Plate	3	Document adherence, Brix at end
IP24	Ice Pellets	-10	75	10	ABC-S Plus (WT)	100	60	Al. Plate	3	Document adherence, Brix at end

NOTE: Consider doing on boxes

TABLE 12: WINDSHIELD WASHER FLUID TEST PLAN

Test #	Precipitation Type	Temp (°C)	Precip. Rate ($g/dm^2/h$)	Fluid	Fluid Dilution (%)	Test Surface
WWF1	Freezing Fog	-3	2	Octagon Octaflo EF	10°B (B=21.25)	Al. Plate
WWF2	Freezing Fog	-3	2	WWF	undiluted	Al. Plate
WWF3	Freezing Fog	-3	2	Isopropyl Alcohol	99%	Al. Plate
WWF4	Freezing Fog	-10	5	Dow UCAR ADF (EG)	10°B (B=22.9)	Al. Plate
WWF5	Freezing Fog	-10	5	WWF	undiluted	Al. Plate
WWF6	Freezing Fog	-10	5	Isopropyl Alcohol	99%	Al. Plate
WWF7	Freezing Fog	-14	5	Octagon Octaflo EF	10°B (B=29.5)	Al. Plate
WWF8	Freezing Fog	-14	5	WWF	undiluted	Al. Plate
WWF9	Freezing Fog	-14	5	Isopropyl Alcohol	99%	Al. Plate
WWF10	Freezing Fog	-25	5	Dow UCAR ADF (EG)	10°B (B=30.5)	Al. Plate
WWF11	Freezing Fog	-25	5	WWF	undiluted	Al. Plate
WWF12	Freezing Fog	-25	5	Isopropyl Alcohol	99%	Al. Plate

TABLE 13: FLUID FAILURE PHOTOS TEST PLAN (1 OF 3)

PRECIP TYPE		FREEZING FOG	FREEZING FOG	FREEZING FOG	FREEZING FOG	FREEZING FOG	FREEZING FOG
Temp		-3°C	-3°C	-10°C	-10°C	-14°C	-14°C
Rate		2 g/dm²/h	5 g/dm²/h	2 g/dm²/h	5 g/dm²/h	2 g/dm²/h	5 g/dm²/h
Type I	Alum*	WWF1 Octaflo ☐ I ☐ FF ☐ F	DF19 Dow ADF ☐ I ☐ FF ☐ F	→	WWF4 Dow ADF ☐ I ☐ FF ☐ F		
Type II	100/0	41 LNT P250-2 100 ☐ I ☐ FF ☐ F	59 LNT P250-2 100 ☐ I ☐ FF ☐ F			17 LNT P250-2 100 ☐ I ☐ FF ☐ F	29 LNT P250-2 100 ☐ I ☐ FF ☐ F
	75/25	47 LNT P250-2 75 ☐ I ☐ FF ☐ F	65 LNT P250-2 75 ☐ I ☐ FF ☐ F			23 LNT P250-2 75 ☐ I ☐ FF ☐ F	36 LNT P250-2 75 ☐ I ☐ FF ☐ F
	50/50	53 LNT P250-2 50 ☐ I ☐ FF ☐ F	72 LNT P250-2 50 ☐ I ☐ FF ☐ F				
Type III	100/0	T10 Clariant 2031 100 ☐ I ☐ FF ☐ F	T8/DF22 Clariant 2031 100 ☐ I ☐ FF ☐ F	T1 Clariant 2031 100 ☐ I ☐ FF ☐ F	T5 Clariant 2031 100 ☐ I ☐ FF ☐ F		
	75/25	P2 Clariant 2031 75 ☐ I ☐ FF ☐ F	←	T3 Clariant 2031 75 ☐ I ☐ FF ☐ F	↑		
	50/50	P3 Clariant 2031 50 ☐ I ☐ FF ☐ F	←				
Type IV	100/0	37 Clariant Sneg 100 ☐ I ☐ FF ☐ F	56 Clariant Sneg 100 ☐ I ☐ FF ☐ F			13 Clariant Sneg 100 ☐ I ☐ FF ☐ F	25 Clariant Sneg 100 ☐ I ☐ FF ☐ F
	75/25	43 Clariant Sneg 75 ☐ I ☐ FF ☐ F	61 Clariant Sneg 75 ☐ I ☐ FF ☐ F			19 Clariant Sneg 75 ☐ I ☐ FF ☐ F	31 Clariant Sneg 75 ☐ I ☐ FF ☐ F
	50/50	49 Clariant Sneg 50 ☐ I ☐ FF ☐ F	67 Clariant Sneg 50 ☐ I ☐ FF ☐ F				

*Photos on aluminum will also be used for composite

TABLE 13: FLUID FAILURE PHOTOS TEST PLAN (2 OF 3)

PRECIP TYPE		FREEZING FOG	FREEZING FOG	FREEZING DRIZZLE	FREEZING DRIZZLE	FREEZING DRIZZLE	FREEZING DRIZZLE
Temp		-25°C	-25°C	-3°C	-3°C	-10°C	-10°C
Rate		2 g/dm²/h	5 g/dm²/h	5 g/dm²/h	13 g/dm²/h	5 g/dm²/h	13 g/dm²/h
Type I	Alum*	→	WWF10 Dow ADF ☐ I ☐ FF ☐ F	→	PH10/FM2 Dow ADF ☐ I ☐ FF ☐ F	DF1 Octaflo ☐ I ☐ FF ☐ F	FSE10 Octaflo ☐ I ☐ FF ☐ F
Type II	100/0	5 LNT P250-2 100 ☐ I ☐ FF ☐ F	11 LNT P250-2 100 ☐ I ☐ FF ☐ F	101 LNT P250-2 100 ☐ I ☐ FF ☐ F	119 LNT P250-2 100 ☐ I ☐ FF ☐ F	77 LNT P250-2 100 ☐ I ☐ FF ☐ F	89 LNT P250-2 100 ☐ I ☐ FF ☐ F
	75/25			107 LNT P250-2 75 ☐ I ☐ FF ☐ F	125 LNT P250-2 75 ☐ I ☐ FF ☐ F	83 LNT P250-2 75 ☐ I ☐ FF ☐ F	95 LNT P250-2 75 ☐ I ☐ FF ☐ F
	50/50			113 LNT P250-2 50 ☐ I ☐ FF ☐ F	131 LNT P250-2 50 ☐ I ☐ FF ☐ F	n/a	n/a
Type III	100/0	→	P1 Clariant 2031 100 ☐ I ☐ FF ☐ F	P4 Clariant 2031 100 ☐ I ☐ FF ☐ F	←	→	P7 Clariant 2031 100 ☐ I ☐ FF ☐ F
	75/25			→	P6 Clariant 2031 75 ☐ I ☐ FF ☐ F	→	P8 Clariant 2031 75 ☐ I ☐ FF ☐ F
	50/50			P5 Clariant 2031 50 ☐ I ☐ FF ☐ F	←	n/a	n/a
Type IV	100/0	1 Clariant Sneg 100 ☐ I ☐ FF ☐ F	7 Clariant Sneg 100 ☐ I ☐ FF ☐ F	97 Clariant Sneg 100 ☐ I ☐ FF ☐ F	115 Clariant Sneg 100 ☐ I ☐ FF ☐ F	73 Clariant Sneg 100 ☐ I ☐ FF ☐ F	86 Clariant Sneg 100 ☐ I ☐ FF ☐ F
	75/25			103 Clariant Sneg 75 ☐ I ☐ FF ☐ F	121 Clariant Sneg 75 ☐ I ☐ FF ☐ F	79 Clariant Sneg 75 ☐ I ☐ FF ☐ F	91 Clariant Sneg 75 ☐ I ☐ FF ☐ F
	50/50			110 Clariant Sneg 50 ☐ I ☐ FF ☐ F	128 Clariant Sneg 50 ☐ I ☐ FF ☐ F	n/a	n/a

*Photos on aluminum will also be used for composite

TABLE 13: FLUID FAILURE PHOTOS TEST PLAN (3 OF 3)

PRECIP TYPE		FREEZING RAIN	FREEZING RAIN	FREEZING RAIN	FREEZING RAIN	COLD SOAK	COLD SOAK
Temp		-3°C	-3°C	-10°C	-10°C	+1°C	+1°C
Rate		13 g/dm²/h	25 g/dm²/h	13 g/dm²/h	25 g/dm²/h	5 g/dm²/h	75 g/dm²/h
Type I	Alum*	P9 Dow ADF ☐ I ☐ FF ☐ F	DF7 Octaflo ☐ I ☐ FF ☐ F	PH22 Octaflo ☐ I ☐ FF ☐ F	DF13 Dow ADF ☐ I ☐ FF ☐ F	P13 Dow ADF ☐ I ☐ FF ☐ F	←
Type II	100/0	161 LNT P250-2 100 ☐ I ☐ FF ☐ F	179 LNT P250-2 100 ☐ I ☐ FF ☐ F	138 LNT P250-2 100 ☐ I ☐ FF ☐ F	149 LNT P250-2 100 ☐ I ☐ FF ☐ F	197 LNT P250-2 100 ☐ I ☐ FF ☐ F	209 LNT P250-2 100 ☐ I ☐ FF ☐ F
	75/25	167 LNT P250-2 75 ☐ I ☐ FF ☐ F	185 LNT P250-2 75 ☐ I ☐ FF ☐ F	143 LNT P250-2 75 ☐ I ☐ FF ☐ F	156 LNT P250-2 75 ☐ I ☐ FF ☐ F	203 LNT P250-2 75 ☐ I ☐ FF ☐ F	215 LNT P250-2 75 ☐ I ☐ FF ☐ F
	50/50	174 LNT P250-2 50 ☐ I ☐ FF ☐ F	192 LNT P250-2 50 ☐ I ☐ FF ☐ F				
Type III	100/0	P10 Clariant 2031 100 ☐ I ☐ FF ☐ F	←	DF25 Clariant 2031 100 ☐ I ☐ FF ☐ F	FSE13 Clariant 2031 100 ☐ I ☐ FF ☐ F	→	P15 Clariant 2031 100 ☐ I ☐ FF ☐ F
	75/25	P11 Clariant 2031 75 ☐ I ☐ FF ☐ F	←	→	DF16 Clariant 2031 75 ☐ I ☐ FF ☐ F	P14 Clariant 2031 75 ☐ I ☐ FF ☐ F	←
	50/50	P12 Clariant 2031 50 ☐ I ☐ FF ☐ F	←				
Type IV	100/0	157 Clariant Sneg 100 ☐ I ☐ FF ☐ F	175 Clariant Sneg 100 ☐ I ☐ FF ☐ F	133 Clariant Sneg 100 ☐ I ☐ FF ☐ F	146 Clariant Sneg 100 ☐ I ☐ FF ☐ F	193 Clariant Sneg 100 ☐ I ☐ FF ☐ F	205 Clariant Sneg 100 ☐ I ☐ FF ☐ F
	75/25	163 Clariant Sneg 75 ☐ I ☐ FF ☐ F	181 Clariant Sneg 75 ☐ I ☐ FF ☐ F	140 Clariant Sneg 75 ☐ I ☐ FF ☐ F	152 Clariant Sneg 75 ☐ I ☐ FF ☐ F	199 Clariant Sneg 75 ☐ I ☐ FF ☐ F	211 Clariant Sneg 75 ☐ I ☐ FF ☐ F
	50/50	169 Clariant Sneg 50 ☐ I ☐ FF ☐ F	187 Clariant Sneg 50 ☐ I ☐ FF ☐ F				

*Photos on aluminum will also be used for composite

TABLE 14: LIST OF FLUIDS

Fluid	Batch #	Fluid Temp	Fluid Dil or Brix (FFP)	Litres Required per Project													Total Litres	Pour Bottles	Notes
				ET	TH	TIII	5-MIN	PH-ET	PH-TH	PH-AD	PH-HW	DF	FSE	IP	WWF	P			
Type II, IV (HOT)																			
LNT P250-2	C3/01/01	OAT	100	32	2	-	-	-	-	-	-	-	-	-	-	-	**34**	**8*+2~**	**3 jugs***
LNT P250-2	C3/01/01	OAT	75	28	2	-	-	-	-	-	-	-	4	-	-	-	**34**	**8*+2~**	**2 jugs***
LNT P250-2	C3/01/01	OAT	50	12	2	-	-	-	-	-	-	3	-	-	-	-	**17**	**8*+2~**	**1 jug***
Newave FCY 9311	201311002LS	OAT	100	32	2	-	-	-	-	-	-	-	-	-	-	-	**34**	**8*+2~**	**3 jugs***
Newave FCY 9311	201311002LS	OAT	75	28	2	-	-	-	-	-	-	3	-	-	-	-	**33**	**8*+2~**	**2 jugs***
Newave FCY 9311	201311002LS	OAT	50	12	2	-	-	-	-	-	-	-	4	-	-	-	**18**	**8*+2~**	**1 jug***
Clariant Max Flight Sneg	TV 534	OAT	100	32	2	-	-	-	-	-	-	-	4	-	-	-	**38**	**8*+2~**	**3 jugs***
Clariant Max Flight Sneg	TV 534	OAT	75	28	2	-	-	-	-	-	-	-	4	-	-	-	**34**	**8*+2~**	**2 jugs***
Clariant Max Flight Sneg	TV 534	OAT	50	12	2	-	-	-	4	-	-	-	4	-	-	-	**22**	**8*+2~**	**1 jug***
Type II, III, IV (R&D)																			
Clariant Safewing 2031 LV	USHA035838	20°C	100	-	-	9	-	-	-	-	-	-	-	-	-	5	**14**	**2**	**consolidate in 1 jug**
Clariant Safewing 2031 LV	USHA035838	20°C	75	-	-	2	-	-	-	-	-	-	-	-	-	5	**7**	**2**	**consolidate in 1 jug**
Clariant Safewing 2031 LV	USHA035838	20°C	50	-	-	-	-	-	-	-	-	-	-	-	-	3	**3**	**2**	**1 jug**
Clariant Safewing 2031 PORTER	Porter	20°C	100	-	-	-	-	-	-	-	-	6	4	12	-	-	**22**	**4**	**2 jugs**
Clariant Safewing 2031 PORTER	Porter	20°C	75	-	-	-	-	-	-	-	-	3	-	-	-	-	**3**	**3**	**no jug, dilute B=27.00**
ABAX Ecowing 26	L12 321	OAT	75	-	-	-	-	3	-	-	-	-	-	-	-	-	**3**	**3**	**no jug**
Clariant Safewing Flight	DEG4145318	OAT	75	-	-	-	-	3	-	-	-	3	-	-	-	-	**6**	**6**	**no jug**
Clariant Safewing Flight PLUS	TV513	OAT	50	-	-	-	-	3	-	-	-	-	-	-	-	-	**3**	**3**	**no jug**
Clariant Safewing Launch Plus	TV 523	OAT	75	-	-	-	-	3	-	-	-	-	-	-	-	-	**3**	**3**	**no jug**
Dow EG106	IJ0201GKDR	OAT	100	-	-	-	-	3	-	-	-	-	-	-	-	-	**3**	**3**	**no jug**
Kilfrost ABC-S Plus (WT)	WT-12.13	OAT	100	-	-	-	-	-	-	-	-	-	-	12	-	-	**12**	**2**	**1 jug**
Type I																			
Octagon Octaflo EF	WL 102009	20°C	21.25 (-13°C)	-	-	-	-	3	-	-	-	3	-	-	1	-	**7**	**3**	**1 jug conc. + 5L aquapak**
Octagon Octaflo EF	WL 102009	20°C	27.0 (-20°C)	-	-	-	-	3	-	-	2	3	4	-	-	-	**12**	**3**	**10L aquapak**
Octagon Octaflo EF	WL 102009	20°C	29.5 (-24°C)	-	-	-	-	-	-	-	-	-	-	-	1	-	**1**	**1**	**-**
Dow UCAR ADF (EG)	aeromag 2014	20°C	17.6 (-13°C)	-	-	-	-	6	4	-	-	3	-	-	-	2	**15**	**4**	**1 jug conc. + 12L aquapak**
Dow UCAR ADF (EG)	aeromag 2014	20°C	22.9 (-20°C)	-	-	-	-	-	-	-	-	3	-	-	1	-	**4**	**4**	**-**
Dow UCAR ADF (EG)	aeromag 2014	20°C	30.5 (-35°C)	-	-	-	-	-	4	-	-	-	-	-	1	-	**5**	**5**	**-**
All Fluids				**216**	**18**	**11**	**0**	**27**	**12**	**0**	**2**	**30**	**28**	**24**	**4**	**15**	**387**		

Notes
* pour bottles already exist at site, pack them
**2 pour bottles should be placed in a freezer set @ -5°C for fluid to be ready for the first test condition, 5 pour bottles are required for the LNT P-250-2 50/50
~ 2 pour bottles should be placed at the site for natural snow testing

Warm Storage Fluid
Cold Storage Fluid

TABLE 15: TYPE I DILUTION TABLES

Octagon Octaflo EF (PG)					
FFP (°C)	**Test Temp (10°B)**	**% Fluid**	**Brix**	**Glycol for 4 L**	**Water for 4 L**
-13	-3	32.0	21.25	1.3	2.7
-20	-10	43.0	27.0	1.7	2.3
-24	-14	47.0	29.50	1.9	2.1
-35	-25	56.0	34.50	2.2	1.8

Dow UCAR ADF (EG)					
FFP (°C)	**Test Temp (10°B)**	**% Fluid**	**Brix**	**Glycol for 4 L**	**Water for 4 L**
-13	-3	27.4	17.6	1.1	2.9
-20	-10	36.3	22.9	1.5	2.5
-35	-25	50.3	30.5	2.0	2.0

TABLE 16: GENERAL EQUIPMENT LIST

HOT, 5 MIN, PH-ET,THICKNESS AND PH-TH PROJECTS		
LOCATION: TEST SITE		
1L Pour containers (see separate list)		Precipitation Rate Pans x all
Barrel Opener		Printer & Ink Cartridge
Boards for cold-soak test x 15		Protective clothing (all) and personel clothing
Brixometer x 4		Rubber squeegees x 10
Calculators x 6		Sample bottles x 6
Cold-soak boxes x 15		Scrapers x 10
Collection pans for stands (one per stand)		Shelving unit x 1 (black one)
Composite Plates x 2		Shop Vac + Sump Pump + Tubing
Electrical Extension Cords x 4		Small canon camera x1
Empty 20 L cont. for -30C CSW fluid x 4		Small folding table x 1
Flashlights x 2		Smart button kits x 2 + extension wire
Fluids (see Table 14)		Speed tape x 1 and electrical tape x 5
Funnels x 4 (big and small)		Step ladders x2
Gloves - black and yellow		Tape measure (yellow + small)
Gloves - cotton (1 box)		Temperature probes: immersion x 3
Gloves - latex (2 boxes)		Temperature probes: surface x 3
Half plates x all		Temperature readers x 2
Hard water chemicals x 3 premixes		Test Stand Shims (poker chips) x 1 box
IKEA cart x2		Test Stands: 2 x 6 position small end) 1@ NRC
Inclinometer (yellow level) x 2		
Isopropyl x 15		Test Stands: 2 x 6-position (main stand)
Jigaloo x2 and Scotchguard x2		Test Stands: 3 position (side stand) (2+1)
K-Cup Coffee x 140		Thermistors x3 and Black Computer
Large digital clock x 2		Thickness Gauges (8 x small 4 x large)
Lock for truck		USB Extension cables x3
Marker for Waste x 2		Vise grip (large) + rubber opener
Measuring Cups x 10		Washers x 1 box
Mixing bins for CSW fluid x 5 (rubbermaids)		Waste containers (use 20 L pails) x 3
Nuts to separate plates x 100 (full box)		Water (1 x 18L) for hard water
Outdoor Rate Pan x1		Weigh Scale x 2 (sartorius) + wiring
Paper Towels (4 packs)		White boards for water run-off
Plate covers x 16		Yellow Carrying Cases x4
Plates: 12 w/smart buttons & 15 without		Yellow Ice Pic
Portable freezers x2		Watmans paper
Power bars x 8		

LOCATION: NRC		
Cold-soak box filling stand		Rubber Mats
Cold-soak fluid pump		Tie wraps
Copper tubing insulation (for passing wires)		Tools
Fluid for cold-soak boxes (barrel)		Tote for Waste Fluid

Note: Pack coolers with first day fluids and plug into power overnight

TABLE 16: GENERAL EQUIPMENT LIST (CONT'D)

HOT, 5 MIN, PH-ET,THICKNESS AND PH-TH PROJECTS	
LOCATION: OFFICE	
Accordian Folder	Laptop for smart button (MR)
Camera Suitcase (2 suitcases+backpack)	Laptop x5 (VZ,DY,SB,MR,BG)
Chamber Settings + Stand settings	Mouse for Rate Station and keypad
Clipboards x 10	Paper for printer (1 pack)
Data Forms (on water phobic paper)	Pencils (sharpened) + pens + markers
Envelopes (9x12) x box	Test Procedures x 2 (1 sided)
Falling Ball Viscometer + Syringes	Walkie Talkies x 8
Go pro camera	Waterproof paper (100 sheets)
iPads x 3	

ICE PELLET PROJECT	
EQUIPMENT	**LOCATION**
2-position stand x 1 + plates with smartbuttons	Site
Blenders x 4 in good condition	Site
Clean tarp	Site
Folding tables (1 large, 1 small)	Site
Ice Pellet control wires+boxes (all for new+old)	Site
Ice pellets dispersers x 4 (2 new and 2 old)	Site
Ice pellets sieves (base, 1.4 mm, 4 mm)	Site
Ice pellets Styrofoam containers x 10	Site
Measuring cups (1L+smaller ones for dispensing)	Site
Mesh screen for IP fabrication	Site
Microwave	Site
NCAR Scale x 1	Site
Stands for ice pellets dispensing devices x 2	Site
Tarp	Site
Thermos x 6 + carrying case	Site
White rate pans	Site
Wooden Spoons	Site
Ice x 60	NRC

ICE PHOBIC PROJECT	
EQUIPMENT	**LOCATION**
Adhesion probe	Site
Ice Phobic Plates x 4 (B14 x2 + B15 x2)	Site
Rust-o-leum Never Wet + 1 coated plate	Site
University of Georgia Test Plates x3	Site

DEPLOYED FLAPS/SLATS AND EXTENSION PROJECT	
EQUIPMENT	**LOCATION**
20º Stand with plates x 2	Site
35º Stand with plates x 2	Site
Drilled plates x 2	Site

WINDSHIELD WASHER PROJECT	
EQUIPMENT	**LOCATION**
Isopropyl 99%	Site
Windshield washer fluid (CDN Tire - Rockliffe)	Site

FIGURE 3: FREEZING PRECIPITATION ENDURANCE TIME DATA FORM

REMEMBER TO SYNCHRONIZE TIME

LOCATION: CEF (Ottawa) **DATE:** **RUN NUMBER:** **STAND # :**

TIME TO FAILURE FOR INDIVIDUAL CROSSHAIRS (real time)

	Plate 1	Plate 2	Plate 3	Plate 4	Plate 5	Plate 6
Time of Fluid Application:	______	______	______	______	______	______
Initial Plate Temperature (°C) (NEEDS TO BE WITHIN 0.5°C OF AIR TEMP)	______	______	______	______	______	______
Initial Fluid Temperature (°C) (NEEDS TO BE WITHIN 3°C OF AIR TEMP)	______	______	______	______	______	______
FLUID NAME/BATCH						
B1 B2 B3						
C1 C2 C3						
D1 D2 D3						
E1 E2 E3						
F1 F2 F3						
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA						
FAILURE CALL (circle)	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy
HRZ. AIR VELOCITY * (circle)	A B C	A B C	A B C	A B C	A B C	A B C

	Plate 7	Plate 8	Plate 9	Plate 10	Plate 11	Plate 12
Time of Fluid Application:	______	______	______	______	______	______
Initial Plate Temperature (°C) (NEEDS TO BE WITHIN 0.5°C OF AIR TEMP)	______	______	______	______	______	______
Initial Fluid Temperature (°C) (NEEDS TO BE WITHIN 3°C OF AIR TEMP)	______	______	______	______	______	______
FLUID NAME/BATCH						
B1 B2 B3						
C1 C2 C3						
D1 D2 D3						
E1 E2 E3						
F1 F2 F3						
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA						
FAILURE CALL (circle)	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy
HRZ. AIR VELOCITY * (circle)	A B C	A B C	A B C	A B C	A B C	A B C

PRECIP (circle): ZF , ZD , ZR-, MOD

AMBIENT TEMPERATURE: ________ °C

NOTE:
* A: HORIZONTAL AIR VELOCITY ≤ 0.4 m/s
B: 0.4 m/s < HORIZONTAL AIR VELOCITY ≤ 1.0 m/s
C: HORIZONTAL AIR VELOCITY > 1.0 m/s

COMMENTS: ________________________________

LEADER / MANAGER: ________________________

FIGURE 4: NRC RATE MANAGEMENT FORM

DATE: ____________________

CONDITION: ____________________ **TECHNICIAN:** ____________________

PAN #	TAB	TIME OUT	1^{st} or 2^{nd} Rate	PAN #	TAB	TIME OUT	1^{st} or 2^{nd} Rate

Retired: 1 2 3 4 5 6 7 8 9 10 11 12

FIGURE 5: NRC CONTINUOUS RATE FORM

Condition	Date	Plate Position	Average Continuous Rate	Comments
ZF, -25, 2				
ZF, -25, 5				
ZF, -14, 2				
ZF, -14, 5				
ZF, -10, 2				
ZF, -10, 5				
ZF, -3, 2				
ZF, -3, 5				
ZD, -3, 5				
ZD, -3, 13				
ZD, -10, 5				
ZD, -10, 13				
ZR, -3, 13				
ZR, -3, 25				
ZR, -10, 13				
ZR, -10, 25				
CS, 1, 5				
CS, 1, 75				

FIGURE 6: FLUID BRIX / THICKNESS DATA FORM

FLUID BRIX/THICKNESS DATA FORM

DATE: ______________ PERFORMED BY: ________________

RUN #: ______________ WRITTEN BY: ________________

STAND: ______________ LOCATION: ________________

Plate/BOX: Fluid:			Plate/BOX: Fluid:			Plate/BOX: Fluid:			Plate/BOX: Fluid:		
TIME	Brix at 15 cm Line	Thick. at 15 cm Line	TIME	Brix at 15 cm Line	Thick. at 15 cm Line	TIME	Brix at 15 cm Line	Thick. at 15 cm Line	TIME	Brix at 15 cm Line	Thick. at 15 cm Line

FIGURE 7: FLUID THICKNESS DATA FORM

DATE: ______________ **TEMPERATURE °C (beg.):** ______________ **PERFORMED BY:** ______________

TEST #: _______ to _______ **WIND SPEED, kph (beg.):** ______________ **WRITTEN BY:** ______________

STAND: ______________ **LOCATION:** ___CEF (NRC)____

THICKNESS (mil)											
Plate: **U** Run #: Fluid: Application Time:		Plate: **V** Run #: Fluid: Application Time:		Plate: **W** Run #: Fluid: Application Time:		Plate: **X** Run #: Fluid: Application Time:		Plate: **Y** Run #: Fluid: Application Time:		Plate: **Z** Run #: Fluid: Application Time:	
TIME	**6" LINE**	**TIME**	**6" LINE**	**TIME**	**6" LINE**	**TIME**	**6" LINE**	**TIME**	**6" LINE**	**TIME**	**6" LINE**

I:\Groups\Cm1680 (01-02)\Procedures\Thickness\Thickness Form

Notes:

- The quantity of fluid that will be poured for each test is 1.0 L
- Measurements should be made at the 15-cm line at the time of fluid application, and after 2, 5, 15 and 30 minutes
- If the results for one fluid vary by more than 10% repeat the two tests and disregard the highest and lowest values

FIGURE 8: PHOTOGRAPHER'S DATA FORM (1 OF 4)

FREEZING FOG, -3°C, 2 g/dm²/h					
Project	**Test #**	**Fluid**	**Dil.**	**Photos**	**Comments**
Photo Doc	WWF1	Octaflo	10°C Buffer	☐ I ☐ FF ☐ F	
Photo Doc	41	LNT P250-2	100	☐ I ☐ FF ☐ F	
Photo Doc	47	LNT P250-2	75	☐ I ☐ FF ☐ F	
Photo Doc	53	LNT P250-2	50	☐ I ☐ FF ☐ F	
Photo Doc	T10	Clariant 2031	100	☐ I ☐ FF ☐ F	
Photo Doc	P2	Clariant 2031	75	☐ I ☐ FF ☐ F	
Photo Doc	P3	Clariant 2031	50	☐ I ☐ FF ☐ F	
Photo Doc	37	Clariant Max Flight Sneg	100	☐ I ☐ FF ☐ F	
Photo Doc	43	Clariant Max Flight Sneg	75	☐ I ☐ FF ☐ F	
Photo Doc	49	Clariant Max Flight Sneg	50	☐ I ☐ FF ☐ F	

FREEZING FOG, -3°C, 5 g/dm²/h					
Project	**Test #**	**Fluid**	**Dil.**	**Photos**	**Comments**
Photo Doc	DF19	Dow ADF	10°C Buffer	☐ I ☐ FF ☐ F	
Photo Doc	59	LNT P250-2	100	☐ I ☐ FF ☐ F	
Photo Doc	65	LNT P250-2	75	☐ I ☐ FF ☐ F	
Photo Doc	72	LNT P250-2	50	☐ I ☐ FF ☐ F	
Photo Doc	T8/DF22	Clariant 2031	100	☐ I ☐ FF ☐ F	
Photo Doc	56	Clariant Max Flight Sneg	100	☐ I ☐ FF ☐ F	
Photo Doc	61	Clariant Max Flight Sneg	75	☐ I ☐ FF ☐ F	
Photo Doc	67	Clariant Max Flight Sneg	50	☐ I ☐ FF ☐ F	
Five Min Fail	55/FM3	Clariant Max Flight Sneg	100	☐ 5-10 ☐ F ☐ F+5	
Five Min Fail	63/FM4	Newave FCY 9311	75	☐ 5-10 ☐ F ☐ F+5	
Five Min Fail	71/FM5	LNT P250-2	50	☐ 5-10 ☐ F ☐ F+5	

FREEZING FOG, -10°C, 2 g/dm²/h					
Project	**Test #**	**Fluid**	**Dil.**	**Photos**	**Comments**
Photo Doc	T1	Clariant 2031	100	☐ I ☐ FF ☐ F	
Photo Doc	T3	Clariant 2031	75	☐ I ☐ FF ☐ F	

FREEZING FOG, -10°C, 5 g/dm²/h					
Project	**Test #**	**Fluid**	**Dil.**	**Photos**	**Comments**
Photo Doc	WWF4	Dow ADF	10°C Buffer	☐ I ☐ FF ☐ F	
Photo Doc	T5	Clariant 2031	100	☐ I ☐ FF ☐ F	

FIGURE 8: PHOTOGRAPHER'S DATA FORM (2 OF 4)

FREEZING FOG, -14°C, 2 g/dm²/h					
Project	**Test #**	**Fluid**	**Dil.**	**Photos**	**Comments**
Photo Doc	17	LNT P250-2	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	23	LNT P250-2	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	13	Clariant Max Flight Sneg	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	19	Clariant Max Flight Sneg	75	☐ **I** ☐ **FF** ☐ **F**	

FREEZING FOG, -14°C, 5 g/dm²/h					
Project	**Test #**	**Fluid**	**Dil.**	**Photos**	**Comments**
Photo Doc	29	LNT P250-2	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	36	LNT P250-2	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	25	Clariant Max Flight Sneg	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	31	Clariant Max Flight Sneg	75	☐ **I** ☐ **FF** ☐ **F**	

FREEZING FOG, -25°C, 2 g/dm²/h					
Project	**Test #**	**Fluid**	**Dil.**	**Photos**	**Comments**
Photo Doc	5	LNT P250-2	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	1	Clariant Max Flight Sneg	100	☐ **I** ☐ **FF** ☐ **F**	

FREEZING FOG, -25°C, 5 g/dm²/h					
Project	**Test #**	**Fluid**	**Dil.**	**Photos**	**Comments**
Photo Doc	WWF10	Dow ADF	10°C Buffer	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	11	LNT P250-2	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	P1	Clariant 2031	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	7	Clariant Max Flight Sneg	100	☐ **I** ☐ **FF** ☐ **F**	

COLD SOAK, +1°C, 5 g/dm²/h					
Project	**Test #**	**Fluid**	**Dil.**	**Photos**	**Comments**
Photo Doc	P13	Dow ADF	10°C Buffer	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	197	LNT P250-2	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	203	LNT P250-2	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	P14	Clariant 2031	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	193	Clariant Max Flight Sneg	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	199	Clariant Max Flight Sneg	75	☐ **I** ☐ **FF** ☐ **F**	

COLD SOAK, +1°C, g/dm²/h					
Project	**Test #**	**Fluid**	**Dil.**	**Photos**	**Comments**
Photo Doc	209	LNT P250-2	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	215	LNT P250-2	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	P15	Clariant 2031	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	205	Clariant Max Flight Sneg	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	211	Clariant Max Flight Sneg	75	☐ **I** ☐ **FF** ☐ **F**	

FIGURE 8: PHOTOGRAPHER'S DATA FORM (3 OF 4)

LIGHT FREEZING RAIN, -3°C, 13 g/dm²/h					
Project	**Test #**	**Fluid**	**Dil.**	**Photos**	**Comments**
Photo Doc	P9	Dow ADF	10°C Buffer	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	161	LNT P250-2	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	167	LNT P250-2	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	174	LNT P250-2	50	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	P10	Clariant 2031	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	P11	Clariant 2031	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	P12	Clariant 2031	50	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	157	Clariant Max Flight Sneg	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	163	Clariant Max Flight Sneg	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	169	Clariant Max Flight Sneg	50	☐ **I** ☐ **FF** ☐ **F**	

LIGHT FREEZING RAIN, -3°C, 25 g/dm²/h					
Project	**Test #**	**Fluid**	**Dil.**	**Photos**	**Comments**
Photo Doc	DF7	Octaflo	10°C Buffer	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	179	LNT P250-2	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	185	LNT P250-2	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	192	LNT P250-2	50	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	175	Clariant Max Flight Sneg	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	181	Clariant Max Flight Sneg	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	187	Clariant Max Flight Sneg	50	☐ **I** ☐ **FF** ☐ **F**	
Five Min Fail	191/FM6	LNT P250-2	50	☐ **5-10** ☐ **F** ☐ **F+5**	
Five Min Fail	189/FM7	Newave FCY 9311	50	☐ **5-10** ☐ **F** ☐ **F+5**	

LIGHT FREEZING RAIN, -10°C, 13 g/dm²/h					
Project	**Test #**	**Fluid**	**Dil.**	**Photos**	**Comments**
Photo Doc	PH22	Octaflo	10°C Buffer	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	138	LNT P250-2	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	143	LNT P250-2	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	DF25	Clariant 2031	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	133	Clariant Max Flight Sneg	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	140	Clariant Max Flight Sneg	75	☐ **I** ☐ **FF** ☐ **F**	
Five Min Fail	PH22/FM1	Octagon Octaflo EF	10°B (B=27.0)	☐ **5-10** ☐ **F** ☐ **F+5**	
Five Min Fail	139/FM8	Clariant Max Flight Sneg	75	☐ **5-10** ☐ **F** ☐ **F+5**	
Five Min Fail	141/FM9	Newave FCY 9311	75	☐ **5-10** ☐ **F** ☐ **F+5**	
Five Min Fail	137/FM10	LNT P250-2	100	☐ **5-10** ☐ **F** ☐ **F+5**	

LIGHT FREEZING RAIN, -10°C, 25 g/dm²/h					
Project	**Test #**	**Fluid**	**Dil.**	**Photos**	**Comments**
Photo Doc	DF13	Dow ADF	10°C Buffer	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	149	LNT P250-2	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	156	LNT P250-2	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	FSE13	Clariant 2031	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	DF16	Clariant 2031	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	146	Clariant Max Flight Sneg	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	152	Clariant Max Flight Sneg	75	☐ **I** ☐ **FF** ☐ **F**	
Five Min Fail	DF16/FM11	Clariant MP III 2031 WARM	75	☐ **5-10** ☐ **F** ☐ **F+5**	
Five Min Fail	145/FM12	Clariant Max Flight Sneg	100	☐ **5-10** ☐ **F** ☐ **F+5**	
Five Min Fail	147/FM13	Newave FCY 9311	100	☐ **5-10** ☐ **F** ☐ **F+5**	
Five Min Fail	155/FM14	LNT P250-2	75	☐ **5-10** ☐ **F** ☐ **F+5**	

FIGURE 8: PHOTOGRAPHER'S DATA FORM (4 OF 4)

FREEZING DRIZZLE, -3°C, 5 g/dm²/h					
Project	**Test #**	**Fluid**	**Dil.**	**Photos**	**Comments**
Photo Doc	101	LNT P250-2	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	107	LNT P250-2	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	113	LNT P250-2	50	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	P4	Clariant 2031	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	P5	Clariant 2031	50	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	97	Clariant Max Flight Sneg	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	103	Clariant Max Flight Sneg	50	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	110	Clariant Max Flight Sneg	100	☐ **I** ☐ **FF** ☐ **F**	
Five Min Fail	109/FM15	Clariant Max Flight Sneg	50	☐ **5-10** ☐ **F** ☐ **F+5**	
Five Min Fail	111/FM16	Newave FCY 9311	50	☐ **5-10** ☐ **F** ☐ **F+5**	

FREEZING DRIZZLE, -3°C, 13 g/dm²/h					
Project	**Test #**	**Fluid**	**Dil.**	**Photos**	**Comments**
Photo Doc	PH10/FM2	Dow ADF	10°C Buffer	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	119	LNT P250-2	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	125	LNT P250-2	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	131	LNT P250-2	50	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	P6	Clariant 2031	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	115	Clariant Max Flight Sneg	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	121	Clariant Max Flight Sneg	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	128	Clariant Max Flight Sneg	50	☐ **I** ☐ **FF** ☐ **F**	
Five Min Fail	PH10/FM2	Dow UCAR ADF (EG)	10°B (B=17.6)	☐ **5-10** ☐ **F** ☐ **F+5**	

FREEZING DRIZZLE, -10°C, 5 g/dm²/h					
Project	**Test #**	**Fluid**	**Dil.**	**Photos**	**Comments**
Photo Doc	DF1	Octaflo	10°C Buffer	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	77	LNT P250-2	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	83	LNT P250-2	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	73	Clariant Max Flight Sneg	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	79	Clariant Max Flight Sneg	75	☐ **I** ☐ **FF** ☐ **F**	

FREEZING DRIZZLE, -10°C, 13 g/dm²/h					
Project	**Test #**	**Fluid**	**Dil.**	**Photos**	**Comments**
Photo Doc	FSE10	Octaflo	10°C Buffer	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	89	LNT P250-2	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	95	LNT P250-2	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	P7	Clariant 2031	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	P8	Clariant 2031	75	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	86	Clariant Max Flight Sneg	100	☐ **I** ☐ **FF** ☐ **F**	
Photo Doc	91	Clariant Max Flight Sneg	75	☐ **I** ☐ **FF** ☐ **F**	

FIGURE 9: ICE PHOBIC END CONDITION DATA FORM

END CONDITION FORM FOR ENDURANCE TIME TESTING - ICE PHOBIC

LOCATION: NRC	DATE:	RUN #:	STAND #:

FLUID / DILUTION ______ ______ ______ ______ ______ ______

		Plate 1 Baseline	Plate 2 Coating ___	Plate 3 Coating ___	Plate 4 Coating ___	Plate 5 Coating ___	Plate 6 Coating ___
DESCRIBED ADHESION AND DRAW FAILURE AT TIME OF PLATE 1 FAILURE		1 2 3 / B ° ° ° / C ° ° ° / D ° ° ° / E ° ° ° / F ° ° °	1 2 3 / B ° ° ° / C ° ° ° / D ° ° ° / E ° ° ° / F ° ° °	1 2 3 / B ° ° ° / C ° ° ° / D ° ° ° / E ° ° ° / F ° ° °	1 2 3 / B ° ° ° / C ° ° ° / D ° ° ° / E ° ° ° / F ° ° °	1 2 3 / B ° ° ° / C ° ° ° / D ° ° ° / E ° ° ° / F ° ° °	1 2 3 / B ° ° ° / C ° ° ° / D ° ° ° / E ° ° ° / F ° ° °
TIME OF FLUID APPLICATION							
TIME OF FLUID FAILURE							
FAILURE TIME (MIN)							
BRIX MEASUREMENTS TIME / BRIX	5 MIN	/	/	/	/	/	/
	END	/	/	/	/	/	/
	AT P1 FAIL		/	/	/	/	/
THICKNESS MEAS. TIME / THICKNESS	5 MIN	/	/	/	/	/	/
	END	/	/	/	/	/	/
	AT P1 FAIL		/	/	/	/	/

FAILURES CALLED BY: ____________________

FIGURE 10: ICE PHOBIC THICKNESS DATA FORM

FORM FOR ICE PHOBIC THICKNESS TESTING

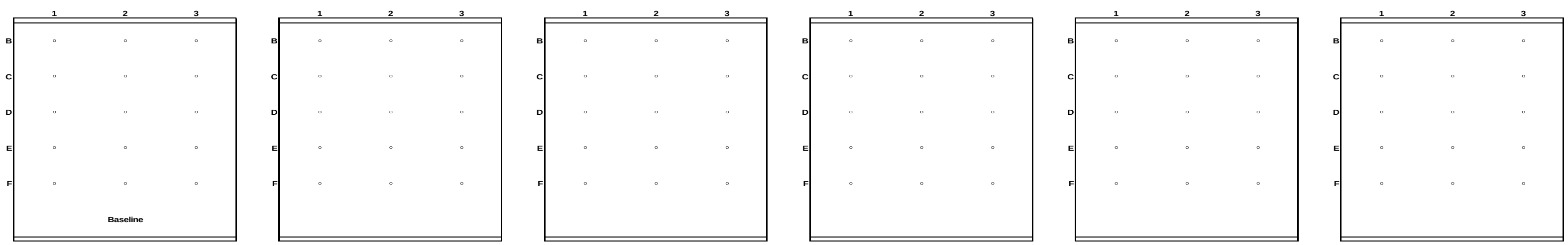
LOCATION: NRC　　CONDITION:　　DATE:　　RUN#:　　STAND#:

PLATE # ____ ____ ____ ____ ____ ____

SURFACE Baseline ____ ____ ____ ____ ____

FLUID/DIL. ____ ____ ____ ____ ____ ____

TIME OF FLUID APP. ____ ____ ____ ____ ____ ____



THICKNESS MEASUREMENTS (mil)

Time	6" LINE	Time	6" LINE	Time	6" LINE	Time	6" LINE	Time	6" LINE	Time	6" LINE

PERFORMED BY: ____________　　WRITTEN BY: ____________

FIGURE 11: ADHERENCE OF FLUID FAILURE DATA FORM

Date: ______________

Test #: __________ Fluid / Dilution: __________ Plate Location: ________

t =	1	2	3	
B	o	o	o	________
C	o	o	o	________
D	o	o	o	________
E	o	o	o	________
F	o	o	o	________
				________

t =	1	2	3	
B	o	o	o	________
C	o	o	o	________
D	o	o	o	________
E	o	o	o	________
F	o	o	o	________
				________

t =	1	2	3	
B	o	o	o	________
C	o	o	o	________
D	o	o	o	________
E	o	o	o	________
F	o	o	o	________
				________

Test #: __________ Fluid / Dilution: __________ Plate Location: ________

t =	1	2	3	
B	o	o	o	________
C	o	o	o	________
D	o	o	o	________
E	o	o	o	________
F	o	o	o	________
				________

t =	1	2	3	
B	o	o	o	________
C	o	o	o	________
D	o	o	o	________
E	o	o	o	________
F	o	o	o	________
				________

t =	1	2	3	
B	o	o	o	________
C	o	o	o	________
D	o	o	o	________
E	o	o	o	________
F	o	o	o	________
				________

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APPENDIX C

PROCEDURE:
EFFECT OF ICE PHOBIC PRODUCTS ON HOT'S

CM2169.002

PROCEDURE:
EFFECT OF ICE PHOBIC PRODUCTS ON HOT'S

Winter 2009-10

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Michelle Pineau

Reviewed by: John D'Avirro

December 24, 2009
Final Version 1.0

EFFECT OF ICE PHOBIC PRODUCTS ON HOT'S
WINTER 2009-10

1. BACKGROUND

Ice build-up can cause major safety concerns for both on-ground and in-flight aircraft operations. As a result, there has been a great industry interest in the use of ice phobic coatings to protect aircraft critical surfaces. Recent work has looked at in-flight operations, however the behavior and performance of the products during ground icing operations has yet to be investigated.

A series of preliminary outdoor tests will be conducted by APS personnel during the Winter 2009-10 testing season to evaluate the effect ice phobic products have on endurance times. Future work indoors at the National Research Council (NRC) climatic chamber is anticipated.

In addition, a discussion with NRC personnel on previous testing with ice phobic products for electrical power line applications may provide beneficial information while performing these tests.

2. OBJECTIVE

The objective of this project is to investigate the fluid performance of surfaces treated with ice phobic products using standard endurance time testing protocol. Limited testing will also look at the performance of bare plates treated with ice phobic products.

During the analysis stage, the performance of the fluid on the ice phobic treated surfaces will be compared to that of the baseline test. If positive results are demonstrated using the representative de/anti-icing fluids stated, additional preliminary work alongside the vertical stabilizer project will be considered.

This document describes the procedure for outdoor tests. A separate procedure for indoor tests will be developed following the successful completion of outdoor testing.

3. PROCEDURE

Tests will be conducted under natural snow conditions at the APS test site facility located at Montreal-Trudeau Airport in Montreal.

Standard endurance time test and rate collection protocol will be followed during the execution of these tests. A six-position test stand will be required to conduct tests, as shown in Figure 3.1. Position 1 will be the rate collection station, followed by the baseline standard aluminium plate in Position 2. The remaining plates, Position 3 through 6, will be standard aluminium plates treated with ice phobic products.

It is important to note, typical Type I HOT procedures call for Type I fluids to be applied to a cold-soak box in natural snow conditions. Due to these comparative tests being in the preliminary stage of investigation, standard aluminium plates will be used during these tests.

3.1 Behaviour of De/Anti-Icing Fluids on Ice Phobic Surfaces

Initial tests will aim at investigating the behaviour of de/anti-icing fluids on ice phobic treated surfaces. Factors which will be observed include fluid separation/fluid beading, fluid thickness and fluid endurance times (separate specific tests are planned in Section 3.3).

The following outlines the steps necessary to conduct tests:

i) 1 L of Type II/IV fluids will be applied to the test surfaces according to the test plan found in Attachment I. For Type I fluid, 0.5 L at 60°C will be applied. All pertinent information will be recorded on the end condition data form; and

ii) Thickness and brix measurements will be taken 5 minutes after pouring and at failure of the baseline plate. Measurements will be recorded on the fluid brix/thickness data form.

In addition to these tests, tests will be conducted to compare fluid performance of standard aluminium plates versus untreated ice phobic plates (see Section 3.2). Ice adherence will be monitored during these tests.

During the execution of these test runs, the ice phobic treated plates will be monitored. Should they begin to yield comparable results, the amount of treated plates may be reduced for testing purposes. A representative sample will be selected to facilitate testing.

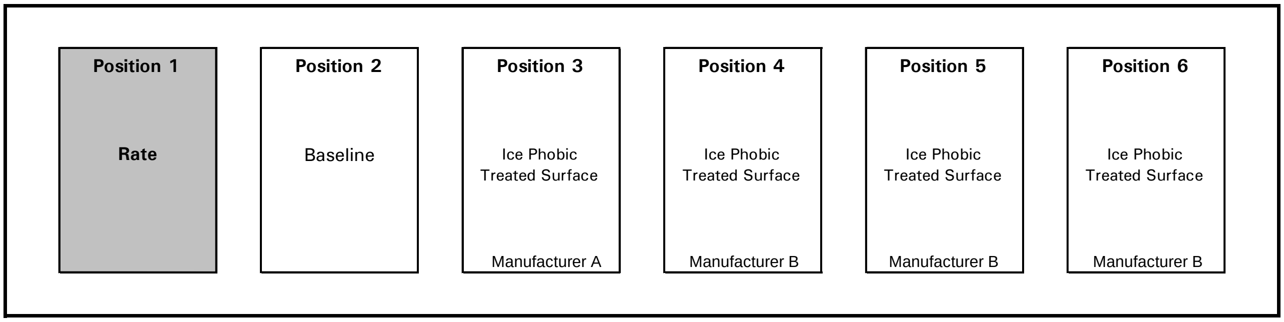


Figure 3.1: Example of Six-Position Test Stand Setup for ET Tests

3.2 Adhesion Tests During Precipitation

In addition to these tests, tests will be conducted to compare fluid performance of standard aluminium plates versus untreated ice phobic plates (see Section 3.2). Ice adherence will be monitored during these tests.

Notes:

- Do for one Manufacturer B product only;
- Measure adhesion;
- Do two runs only;
- Consider doing additional runs if results are positive;
- Do with Type I fluid (1st run);
- Do with Type IV fluid (2nd run); and
- See Figure 3.2.

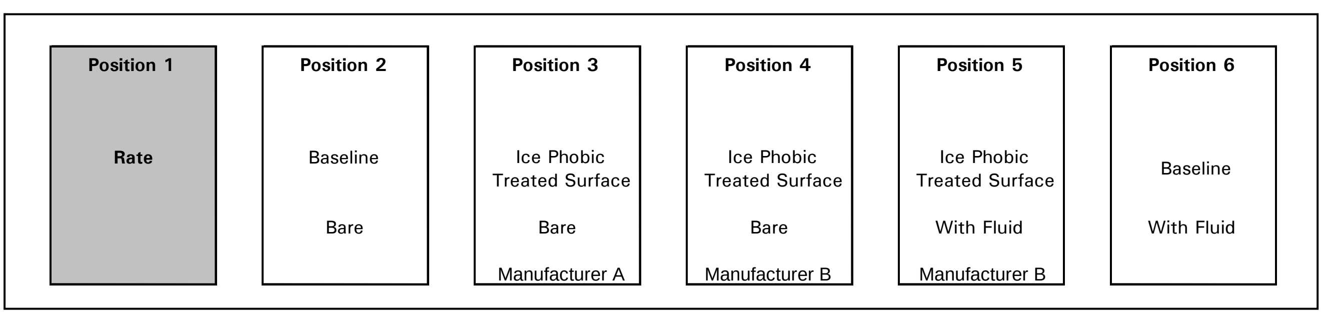


Figure 3.2: Example of Six-Position Test Stand Setup for Adhesion Tests

3.3 Thickness and Wetting Tests

In addition to the main set of endurance time tests, a series of thickness and wetting tests will be carried out.

Notes:

- o Do for each of the 5 fluids;
- o Do in sets of three (baseline, Manufacturer B (Product 1), Manufacturer A);
- o Consider set of four with 2nd Manufacturer B Product;
- o To be done outdoors if time permits on indoors at NRC;
- o To be done in non-precipitation;
- o Measure thickness over minimum 30 minutes at 15 cm line (see Attachment II);
- o Observe fluid separation or beading; and
- o See Attachment III.

4. FLUIDS

Five fluids will be used, including a Type I PG, a Type II PG, a Type IV EG and two Type IV PG fluids. Fluids are detailed in Table 4.1.

Table 4.1: Required Fluids

Fluid Manufacturer	Fluid Name	Batch Number	Fluid Type	Dilution	Quantity Required
Octagon Process Inc.	Octaflo EF	WL-120108	Type I PG	10°C Buffer	6 L
Kilfrost Limited	ABC-2000	KIL08-09LOWV	Type II PG	100/0	10 L
Clariant Produkte	Safewing MP IV LAUNCH	C02192009IV	Type IV PG	100/0	10 L
Kilfrost Limited	ABC-S PLUS	K21012009IV	Type IV PG	100/0	10 L
Dow Chemical Company	UCAR EG 106	XA2201GKI6	Type IV EG	100/0	10 L

5. TEST PLATES

Two ice phobic manufacturers provided samples for testing purposes, Manufacturer B and Manufacturer A.

Manufacturer A has provided APS with one treated ice phobic plate for testing purposes.

Manufacturer B has provided 6 varieties of ice phobic treated plates. Initial tests will be carried out with all six plates; only on or two of these will be used after the initial set of tests

6. TEST PLAN

Refer to Attachment I for a detailed plan for outdoor tests. Attachment III lists the necessary tests to measure thickness.

7. EQUIPMENT

Equipment identical to equipment used for standard endurance time tests will be used, as well as the following:

- Fluid thickness gauge;
- Brixometer; and
- Adhesion probe;

8. PERSONNEL

Two APS personnel will be required to conduct endurance time testing. A third person may be required to aid in initial setup or offer support during testing.

9. DATA FORMS

Attachment IV illustrates the end condition form for endurance time testing that will be completed during each test run.

ATTACHMENT I: TEST PLAN

TEST NO.	PLATE POSITION	FLUID NAME	FLUID TYPE	DILUTION	COMMENTS
1	2	Clariant MP IV LAUNCH	Type IV PG	100/0	Baseline
	3	Clariant MP IV LAUNCH	Type IV PG	100/0	Manufacturer A Treated Surface
	4	Clariant MP IV LAUNCH	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
	5	Clariant MP IV LAUNCH	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
	6	Clariant MP IV LAUNCH	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
	*EXTRA MANUFACTURE R B PLATES	Clariant MP IV LAUNCH	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
		Clariant MP IV LAUNCH	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
		Clariant MP IV LAUNCH	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
2	2	Octagon Octaflo EF	Type I PG	10° Buffer, Heated to 60°C	Baseline
	3	Octagon Octaflo EF	Type I PG	10° Buffer, Heated to 60°C	Manufacturer A Treated Surface
	4	Octagon Octaflo EF	Type I PG	10° Buffer, Heated to 60°C	Manufacturer B Ice Phobic Treated Surface
	5	Octagon Octaflo EF	Type I PG	10° Buffer, Heated to 60°C	Manufacturer B Ice Phobic Treated Surface
	6	Octagon Octaflo EF	Type I PG	10° Buffer, Heated to 60°C	Manufacturer B Ice Phobic Treated Surface
	*EXTRA MANUFACTURE R B PLATES	Octagon Octaflo EF	Type I PG	10° Buffer, Heated to 60°C	Manufacturer B Ice Phobic Treated Surface
		Octagon Octaflo EF	Type I PG	10° Buffer, Heated to 60°C	Manufacturer B Ice Phobic Treated Surface
		Octagon Octaflo EF	Type I PG	10° Buffer, Heated to 60°C	Manufacturer B Ice Phobic Treated Surface
3	2	Kilfrost ABC-S Plus	Type IV PG	100/0	Baseline
	3	Kilfrost ABC-S Plus	Type IV PG	100/0	Manufacturer A Treated Plate
	4	Kilfrost ABC-S Plus	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
	5	Kilfrost ABC-S Plus	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
	6	Kilfrost ABC-S Plus	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
	*EXTRA MANUFACTURE R B PLATES	Kilfrost ABC-S Plus	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
		Kilfrost ABC-S Plus	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
		Kilfrost ABC-S Plus	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
4	2	Dow UCAR EG106	Type IV EG	100/0	Baseline
	3	Dow UCAR EG106	Type IV EG	100/0	Manufacturer A Treated Surface
	4	Dow UCAR EG106	Type IV EG	100/0	Manufacturer B Ice Phobic Treated Surface
	5	Dow UCAR EG106	Type IV EG	100/0	Manufacturer B Ice Phobic Treated Surface
	6	Dow UCAR EG106	Type IV EG	100/0	Manufacturer B Ice Phobic Treated Surface
	*EXTRA MANUFACTURE R B PLATES	Dow UCAR EG106	Type IV EG	100/0	Manufacturer B Ice Phobic Treated Surface
		Dow UCAR EG106	Type IV EG	100/0	Manufacturer B Ice Phobic Treated Surface
		Dow UCAR EG106	Type IV EG	100/0	Manufacturer B Ice Phobic Treated Surface
5	2	Kilfrost ABC-2000	Type II PG	100/0	Baseline
	3	Kilfrost ABC-2000	Type II PG	100/0	Manufacturer A Treated Surface
	4	Kilfrost ABC-2000	Type II PG	100/0	Manufacturer B Ice Phobic Treated Surface
	5	Kilfrost ABC-2000	Type II PG	100/0	Manufacturer B Ice Phobic Treated Surface
	6	Kilfrost ABC-2000	Type II PG	100/0	Manufacturer B Ice Phobic Treated Surface
	*EXTRA MANUFACTURE R B PLATES	Kilfrost ABC-2000	Type II PG	100/0	Manufacturer B Ice Phobic Treated Surface
		Kilfrost ABC-2000	Type II PG	100/0	Manufacturer B Ice Phobic Treated Surface
		Kilfrost ABC-2000	Type II PG	100/0	Manufacturer B Ice Phobic Treated Surface
6	2	Clariant MP IV LAUNCH	Type IV PG	100/0	Baseline
	3	Clariant MP IV LAUNCH	Type IV PG	100/0	Manufacturer A Treated Surface
	4	Clariant MP IV LAUNCH	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
	5	Clariant MP IV LAUNCH	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
	6	Clariant MP IV LAUNCH	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
	*EXTRA MANUFACTURE R B PLATES	Clariant MP IV LAUNCH	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
		Clariant MP IV LAUNCH	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
		Clariant MP IV LAUNCH	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
7	2	Kilfrost ABC-S Plus	Type IV PG	100/0	Baseline
	3	Kilfrost ABC-S Plus	Type IV PG	100/0	Manufacturer A Treated Surface
	4	Kilfrost ABC-S Plus	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
	5	Kilfrost ABC-S Plus	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
	6	Kilfrost ABC-S Plus	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
	*EXTRA MANUFACTURE R B PLATES	Kilfrost ABC-S Plus	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
		Kilfrost ABC-S Plus	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
		Kilfrost ABC-S Plus	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface
8	2	Dow UCAR EG106	Type IV EG	100/0	Baseline
	3	Dow UCAR EG106	Type IV EG	100/0	Manufacturer A Treated Surface
	4	Dow UCAR EG106	Type IV EG	100/0	Manufacturer B Ice Phobic Treated Surface
	5	Dow UCAR EG106	Type IV EG	100/0	Manufacturer B Ice Phobic Treated Surface
	6	Dow UCAR EG106	Type IV EG	100/0	Manufacturer B Ice Phobic Treated Surface
	*EXTRA MANUFACTURE R B PLATES	Dow UCAR EG106	Type IV EG	100/0	Manufacturer B Ice Phobic Treated Surface
		Dow UCAR EG106	Type IV EG	100/0	Manufacturer B Ice Phobic Treated Surface
		Dow UCAR EG106	Type IV EG	100/0	Manufacturer B Ice Phobic Treated Surface
9	2	Kilfrost ABC-2000	Type II PG	100/0	Baseline
	3	Kilfrost ABC-2000	Type II PG	100/0	Manufacturer A Treated Surface
	4	Kilfrost ABC-2000	Type II PG	100/0	Manufacturer B Ice Phobic Treated Surface
	5	Kilfrost ABC-2000	Type II PG	100/0	Manufacturer B Ice Phobic Treated Surface
	6	Kilfrost ABC-2000	Type II PG	100/0	Manufacturer B Ice Phobic Treated Surface
	*EXTRA MANUFACTURE R B PLATES	Kilfrost ABC-2000	Type II PG	100/0	Manufacturer B Ice Phobic Treated Surface
		Kilfrost ABC-2000	Type II PG	100/0	Manufacturer B Ice Phobic Treated Surface
		Kilfrost ABC-2000	Type II PG	100/0	Manufacturer B Ice Phobic Treated Surface

ATTACHMENT II: BRIX/THICKNESS FORM

FLUID BRIX / THICKNESS DATA FORM

DATE: ______________ **PERFORMED BY:** ______________

RUN #: ______________ **WRITTEN BY:** ______________

STAND: ______________ **LOCATION:** ______________

Plate / BOX: Fluid:			Plate / BOX: Fluid:			Plate / BOX: Fluid:			Plate / BOX: Fluid:			Plate / BOX: Fluid:		
TIME	**Brix at 15 cm Line**	**Thick. at 15 cm Line**	**TIME**	**Brix at 15 cm Line**	**Thick. at 15 cm Line**	**TIME**	**Brix at 15 cm Line**	**Thick. at 15 cm Line**	**TIME**	**Brix at 15 cm Line**	**Thick. at 15 cm Line**	**TIME**	**Brix at 15 cm Line**	**Thick. at 15 cm Line**

ATTACHMENT III: TEST PLAN FOR THICKNESS TESTS

TEST NO.	PLATE POSITION	FLUID NAME	FLUID TYPE	DILUTION	COMMENTS
1	2	Clariant MP IV LAUNCH	Type IV PG	100/0	Baseline
	3	Clariant MP IV LAUNCH	Type IV PG	100/0	Manufacturer A Treated Surface
	4	Clariant MP IV LAUNCH	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface (Product 1)
2	2	Octagon Octaflo EF	Type IV PG	100/0	Baseline
	3	Octagon Octaflo EF	Type IV PG	100/0	Manufacturer A Treated Surface
	4	Octagon Octaflo EF	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface (Product 1)
3	2	Kilfrost ABC-S Plus	Type IV PG	100/0	Baseline
	3	Kilfrost ABC-S Plus	Type IV PG	100/0	Manufacturer A Treated Surface
	4	Kilfrost ABC-S Plus	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface (Product 1)
4	2	Dow UCAR EG106	Type IV PG	100/0	Baseline
	3	Dow UCAR EG106	Type IV PG	100/0	Manufacturer A Treated Surface
	4	Dow UCAR EG106	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface (Product 1)
5	2	Kilfrost ABC-2000	Type IV PG	100/0	Baseline
	3	Kilfrost ABC-2000	Type IV PG	100/0	Manufacturer A Treated Surface
	4	Kilfrost ABC-2000	Type IV PG	100/0	Manufacturer B Ice Phobic Treated Surface (Product 1)

ATTACHMENT IV: END CONDITION FORM FOR ENDURANCE TIME TESTING

END CONDITION FORM FOR ENDURANCE TIME TESTING

LOCATION: DORVAL TEST SITE | DATE: | RUN #: | STAND #:

SURFACE		______	______	______	______	______
FLUID NAME		______	______	______	______	______
DESCRIBE ADHESION AND DRAW FAILURE AT TIME OF PLATE 1 FAILURE		1 2 3 B ○ ○ ○ C ○ ○ ○ D ○ ○ ○ E ○ ○ ○ F ○ ○ ○	1 2 3 B ○ ○ ○ C ○ ○ ○ D ○ ○ ○ E ○ ○ ○ F ○ ○ ○	1 2 3 B ○ ○ ○ C ○ ○ ○ D ○ ○ ○ E ○ ○ ○ F ○ ○ ○	1 2 3 B ○ ○ ○ C ○ ○ ○ D ○ ○ ○ E ○ ○ ○ F ○ ○ ○	1 2 3 B ○ ○ ○ C ○ ○ ○ D ○ ○ ○ E ○ ○ ○ F ○ ○ ○
TIME OF FLUID APPLICATION		______	______	______	______	______
TIME OF FLUID FAILURE		______	______	______	______	______
FAILURE TIME (MIN)						
BRIX MEASUREMENTS TIME / BRIX	5 MIN	/	/	/	/	/
	END	/	/	/	/	/
	AT P1 FAIL		/	/	/	/
THICKNESS MEAS. TIME / THICKNESS	5 MIN	/	/	/	/	/
	END	/	/	/	/	/
	AT P1 FAIL		/	/	/	/
FAILURES CALLED BY:		______				

APPENDIX D

PROCEDURE:
ADDENDUM TO PROCEDURE:
EVALUATION OF ENDURANCE TIME PERFORMANCE ON VERTICAL SURFACES

CM2265.001

ADDENDUM TO PROCEDURE: EVALUATION OF ENDURANCE TIME PERFORMANCE ON VERTICAL SURFACES

Vertical Surfaces Treated with Ice Phobic Coatings

Winter 2011-12

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: David Youssef

Reviewed by: John D'Avirro

APS Aviation Inc.

January 25, 2012
Final Version 1.0

ADDENDUM TO PROCEDURE: EVALUATION OF ENDURANCE TIME PERFORMANCE ON VERTICAL SURFACES

Vertical Surfaces Treated with Ice Phobic Coatings

1. BACKGROUND

Preliminary testing results on vertical surfaces have indicated a reduction in fluid protection time when applied to vertical surfaces. It was therefore recommended that limited testing be conducted using vertical aluminum surfaces treated with ice phobic materials to identify any potential benefits in protection time or adhesion. Preliminary testing was conducted in 2010-11 in conjunction with the testing for vertical surfaces. It is recommended that additional testing be conducted during the winter of 2011-12 independent of the work done on vertical surfaces.

2. OBJECTIVE

To investigate the endurance time performances of vertical surfaces treated with an ice phobic coating. It is anticipated that 3 to 4 Type I or Type IV test runs will be conducted during 6 or more winter storms.

3. PROCEDURE

Endurance time tests will be conducted using the procedures outlined in the program procedure: *Evaluation of Endurance Time Performance on Vertical Surfaces, December 21st 2009.* Standard fluid endurance time test procedures will apply. A new setup will be used for this testing. Plate 4 will no longer be used for a two-step application test, but will be changed to an ice phobic treated plate; the coating used will be a Manufacturer B product unless other manufacturers provide samples for testing. Plate 3 will serve as the comparative baseline Type I or Type IV test. Plates 1 and 2 will not be used for these tests. Figure 3.1 demonstrates this new general setup for the conduct of the tests.

Note: Limited testing should also be conducted to investigate the effects of 80º (current setup) vs. 90º plates on fluid endurance times; 2-3 tests should be planned.

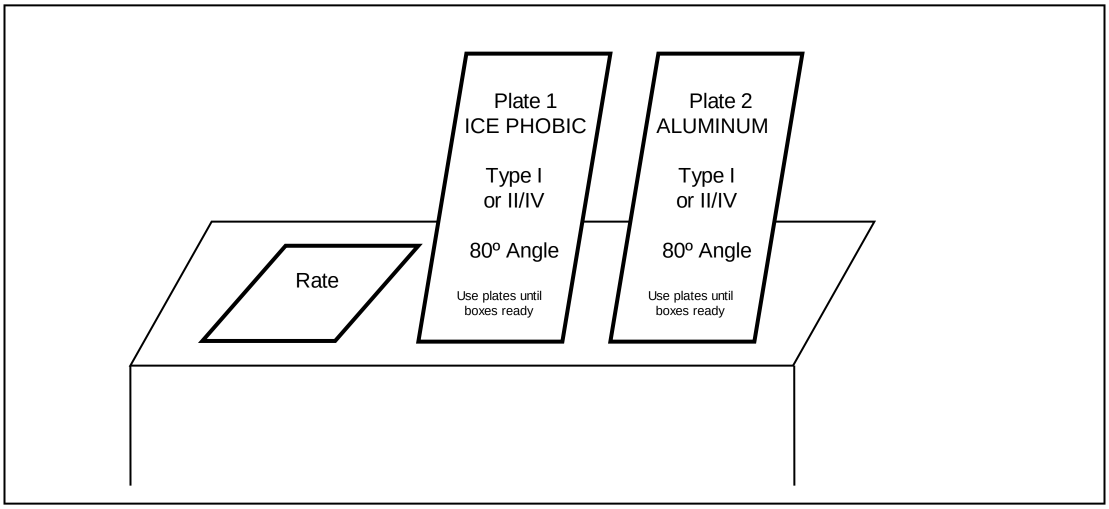


Figure 3.1: New General Setup

APPENDIX E

PROCEDURE:
WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH MIXED ICE PELLET PRECIPITATION CONDITIONS

CM2265.003

WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH MIXED ICE PELLET PRECIPITATION CONDITIONS

Winter 2013-14

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Marco Ruggi and Victoria Zoitakis

Reviewed by: John D'Avirro

APS Aviation Inc.

January 6, 2014
Final Version 1.0

WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH MIXED ICE PELLET PRECIPITATION CONDITIONS

1. BACKGROUND

Prior to the winter of 2006-07, Holdover Time (HOT) guidance material did not exist for ice pellet conditions, however aircraft could still depart during ice pellet conditions following aircraft deicing and a pre take off contamination check. This protocol was feasible for common air carrier aircraft that provided access to emergency exit windows overlooking the leading edge of the aircraft wings; however, it posed a significant problem for cargo aircraft that have limited visibility of the wings from the cabin.

On December 22, 2004, United Parcel Service (UPS) aircraft in Louisville were grounded for several hours due to extended ice pellet conditions. Due to cargo aircraft configuration, pre-take off contamination checks by the on-board crew were not possible. FedEx had been faced with similar problems in Memphis. Following this event, in October 2005, the FAA issued two notices restricting take offs in ice pellet conditions.

As a result of this costly incident, UPS set out to obtain experimental data to provide guidance and allow operations to continue in ice pellet conditions. During the winter of 2004-05, aerodynamic and endurance time testing were conducted in simulated ice pellet conditions. APS also conducted some preliminary flat plate research (see TP 14718E). Based on the preliminary data, an allowance of 20 minutes in light ice pellet conditions was proposed, however no changes to the HOT guidelines were made.

During the following winter of 2006-07, the FAA provided a 25 minute allowance as a preliminary guideline; TC issued a note indicating that no changes would be made to the HOT guidelines. This allowance was based on the previous research conducted during the winter of 2005-06, primarily as a result of Falcon 20 aerodynamic research (see TP 14716E); these results were presented at the Society of Automotive Engineers (SAE) meeting in Lisbon in May 2006. To address the option of a pre-take off contamination check, the 20 minute targeted allowance was extended to 25 minutes; pre-take off contamination checks would no longer apply. This allowance was followed by a list of conditions; one restriction was that operations would be limited to ice pellets alone (no mixed conditions).

Due to the high occurrence of ice pellets combined with freezing rain or snow, the industry requested additional guidance material for operations in mixed ice pellet conditions. Additional endurance time testing and aerodynamic research were conducted in simulated ice pellet conditions during the winter of 2006-07.

During the winter of 2007-08, the TC and FAA provided allowance time guidance material for operations in mixed conditions with ice pellets guideline. These allowance times were based on the research conducted during the winter of 2006-07 (see TP 14779E). The recommended allowance times were based on aerodynamic research conducted using the 3 m x 6 m Open Circuit Propulsion and Icing Wind Tunnel (PIWT) and the NRC Falcon 20 aircraft; these results were presented at the SAE meeting in San Diego in May 2007. These allowance time guidelines were followed by a list of restrictions based on the results obtained through the research conducted, and the lack of data in specific conditions.

During the winter of 2008-09, additional endurance time testing and aerodynamic research was conducted to support and further expand the ice pellet allowance times (see TP 14935E). Full-scale testing with the NRC PIWT was conducted in mixed conditions with ice pellets and in non precipitation conditions. Testing was geared towards validating the current ice pellet allowance times, and potentially expanding the guidance material to include different conditions, fluids, and acceleration profiles. A revised version of the ice pellet allowance times was published for the winter of 2009-10; changes were made to the high speed table allowance times only.

During the winter of 2009-10, additional aerodynamic research using a generic super-critical wing model was conducted at the NRC PIWT to support and further expand the ice pellet allowance times for use with newer generation aircraft. During the testing, fluid flow-off issues with the supercritical wing were observed with PG fluids at the lower temperatures; more specifically during light ice pellets and moderate ice pellet conditions below -10ºC. In addition fluid failure issues with the supercritical wing were observed with PG fluids during moderate ice pellets above -5ºC; the relatively flat surface of the wing had less fluid flow off during contamination and resulted in an earlier fluid failure for PG fluids. In general, higher lift losses were observed with the supercritical wing as compared to previous wings tested. A revised version of the ice pellet allowance times was published for the winter of 2009-10. Additional analysis paired with wind tunnel testing was recommended for the winter of 2010-11 to develop a correlation between the lift losses observed in the wind tunnel and those used as the basis of the aerodynamic acceptance tests for fluid certification.

Results from the 2010-11 testing demonstrated similar results to the 2009-10 testing in that the results indicated fluid flow-off issues with the supercritical wing when using PG fluids at the lower temperatures. The results indicated that the changes to the guidance material made the previous winter were still relevant and should remain in the allowance time table for the winter of 2011-12. However, a large part of the 2010-11 work was focused on developing a correlation between the PIWT and the aerodynamic acceptance test. Based on the work that was conducted by NASA and APS, it was determined that a maximum lift loss of 5.24% on the B737-200ADV airplane is equivalent to a lift loss of 7.29% on the PIWT model. Due to the scatter in the data, the standard error of the estimate resulted in a range of values which determined an upper limit of lift loss on the PIWT model of 9.2% and a lower limit of 5.4%. Currently the scatter in the “review” range is still large and causes complications when analyzing the data collected. It is anticipated that as future testing progresses, and as more data is collected, a single-value pass/fail cutoff maybe developed similar to the AAT and B737-200ADV airplane tests.

Due to industry concern with the validity of the results obtained, and the relevance of the test methods to operational aircraft, it was recommended that testing during the winter of 2011-12 focus on surveying and calibrating the wind tunnel to obtain a better sense of the repeatability of the results. With the support of NRC and under direction of NASA, a large series of test runs were conducted to better understand the performance characteristics of the wind tunnel and airfoil. The results indicated that the year-to-year equipment and facility upgrades have increased the integrity of the aerodynamic data produced, and the wind tunnel can closely simulate aircraft take-off profiles. The characterization of the current dry wing model with original endplates demonstrated appropriate aerodynamic behavior. The back-to-back fluid-only runs demonstrated excellent repeatability of test methods and this was reflected in the aerodynamic data collected. The repeatability of the testing was considered acceptable for this type of aerodynamic testing work and was not indicative of systematic errors in procedures or equipment.

FAA and TC were satisfied with calibration technical evaluation results, and therefore it was recommended that testing during the winter of 2012-13 revert back to the initial research and development objectives of further refining and substantiating the ice pellet allowance times. During the winter of 2012-13, the clean, dry wing aerodynamic repeatability was confirmed in comparison with previous data and the additional data collected in 2012-13 helped in substantiating these findings. The stalling characteristics of the wing with fluid (or fluid with contamination) appeared to be driven by secondary wave effects near the leading edge; these effects were difficult to interpret on the two-dimensional model relative to a fully three-dimensional wing and therefore should not be used in developing allowance times. Additional lift-loss scaling correlation data with different fluids at colder temperatures confirmed that previous lift loss limits were still valid. Forty ice pellet allowance time tests were conducted to validate and possibly expand the current guidance material. The data validated the current allowance times with new fluids and also indicated a potential to expand the allowance times for light ice pellets mixed with light snow and moderate snow.

For the Winter 2013-14, the primary focus of testing will be on the ice pellet allowance time validation and development and other R&D activities.

2. OBJECTIVES

The objective of this testing is to conduct aerodynamic testing with a super critical airfoil to:

- Ensure the repeatability of the dry wing performance;
- Expand the ice pellet allowance times for light ice pellets mixed with light or moderate snow conditions;
- Substantiate the current ice pellet allowance times with new fluids, fluids previously tested but with limited data, and temperatures close to the lowest operational use temperature (LOUT);
- Evaluate the equivalency of the new ice pellet/snow dispenser systems;
- Evaluate the effect of coatings on aerodynamics with and without fluids;
- Support the development of a Type III ice pellet allowance time table; and
- Evaluate Type I fluid flow-off performance for low speed rotation less than 80 knots.

Attachments I to VII provide additional information for performing some of these activities which may not use the typical wind tunnel testing methodology.

As lower priority objectives, testing may be conducted to investigate other objectives of high importance to industry which may include (and is described further in Section 6.11):

- o Evaluation of an airfoil performance monitor (APM) system;
- o Heavy snow;
- o Heavy contamination;
- o Effect of cooling system on testing repeatability;
- o Effect of fluid viscosity;

- o Fluid and contamination at LOUT;
- o Small hail;
- o Frost simulation in the wind tunnel;
- o Flaps/Slats testing to support YMX tests;
- o Mixed HOT conditions;
- o Snow on an un-protected wing;
- o Feasibility of IP testing at higher speed (130-150kts);
- o Windshield washer used as a Type I deicer;
- o Effect of fluid seepage on dry wing performance; and
- o Second wave of fluid at rotation.

To satisfy these objectives, a super-critical wing section (Figure 2.1) will be subjected to a series of tests in the NRC PIWT. The dimensions indicated are in inches. This wing section was constructed by NRC in 2009 specifically for the conduct of these tests following extensive consultations with an airframe manufacturer to ensure a representative super-critical design.

Fifteen days of testing have been scheduled for the conduct of these tests. The available testing days will be from January 8th to the 31st (see Figure 2.2). Testing will likely be conducted during overnight periods (i.e. 10 pm – 6 am), unless temperatures are suitable for day/evening testing. The weekends will be considered only if deemed necessary.

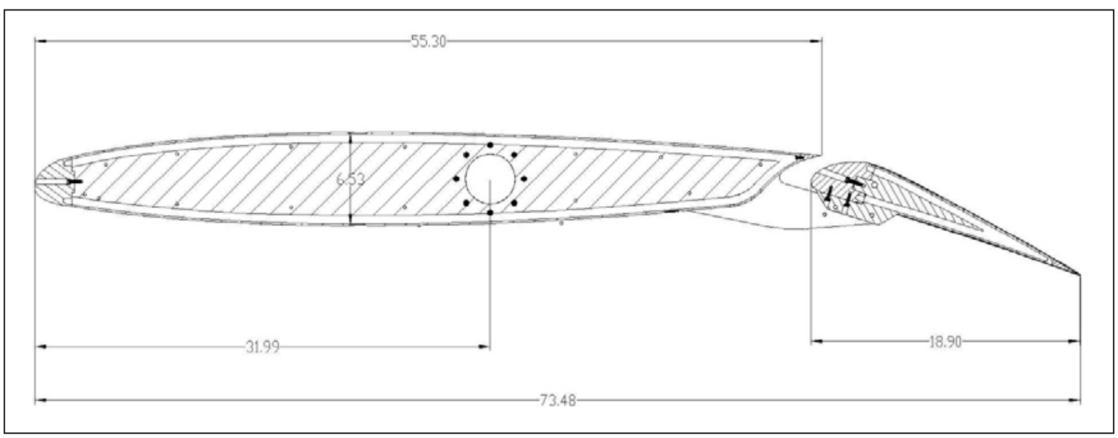


Figure 2.1: Super-Critical Wing Section

CALENDAR JANUARY 2014

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1	2 NRC back from holidays	3 **check forecast and ensure wx is good for the daytime testing (1st**	4
5	6 Ice Pellet Manufacturing Start	7 Pack Truck and leave for YOW Ice Pellet Manufacturing Continue	8 ***TEST DAY 1*** -Set-up,calibration, training, briefing *TESTING ACTIVITY TBD** ***day shift (8am-4pm)*** *WT Task: TBD*	9 ***TEST DAY 2*** TESTING ACTIVITY TBD ***day shift (8am-4pm)*** *WT Task: TBD*	10 ***TEST DAY 3*** TESTING ACTIVITY TBD ***day shift (8am-4pm)*** *WT Task: TBD*	11
12	13 ***TEST DAY 4*** TESTING ACTIVITY TBD *WT Task: TBD*	14 ***TEST DAY 5*** TESTING ACTIVITY TBD *WT Task: TBD*	15 ***TEST DAY 6*** TESTING ACTIVITY TBD *WT Task: TBD*	16 ***TEST DAY 7*** TESTING ACTIVITY TBD *WT Task: TBD*	17 ***TEST DAY 8*** TESTING ACTIVITY TBD *WT Task: TBD*	18
19	20 ***TEST DAY 9*** TESTING ACTIVITY TBD *WT Task: TBD*	21 ***TEST DAY 10*** TESTING ACTIVITY TBD *WT Task: TBD*	22 ***TEST DAY 11*** TESTING ACTIVITY TBD *WT Task: TBD*	23 ***TEST DAY 12*** TESTING ACTIVITY TBD *WT Task: TBD*	24 ***TEST DAY 13*** TESTING ACTIVITY TBD *WT Task: TBD*	25
26	27 ***TEST DAY 14*** TESTING ACTIVITY TBD *WT Task: TBD*	28 ***TEST DAY 15*** TESTING ACTIVITY TBD *WT Task: TBD*	29 ***BACKUP DAY*** TESTING ACTIVITY TBD *WT Task: TBD*	30 ***BACKUP DAY*** TESTING ACTIVITY TBD *WT Task: TBD*	31 ***BACKUP DAY*** TESTING ACTIVITY TBD *WT Task: TBD*	FEB 1

NOTES

Anticipate Mon-Fri Testing, However, Weekend May be Needed Due to Temperature.
Test Day 1, 2, and 3 of testing to be conducted during daytime and the following will be overnights. This is dependent on the weather forecast and required temperature needed for testin
Testing will Likely be Conducted During Overnight Periods (i.e. 10PM - 6AM), Unless Temperatures are Suitable for Day, Evening Testing. Typical Test Day is 8hrs for APS Staff.
If extra days are required, or if runnng late on schedule due to equipement malfunction, or weather, consider 1-2 hours longer per day to make-up.
Testing team will be JD, MR, DY, VZ, BG & YOW x 4
Spare days are available (Jan 29-31) should it be needed.

* Consider running the effect of cooling system tests on Day 1.

TESTING ACTIVITIES

Above 0ºC						***n/a*** **TYPE III ALLOWANCE TIMES** **(also some at above 0ºC)** ***WT Task: TIII***
0ºC to -5ºC	***#1*** **TYPE III ALLOWANCE TIMES** **(also some at above 0ºC)** ***WT Task: TIII***					
Below -5ºC	***#2*** **NEW ICE PELLET DISPENSER CALIBRATION** ***WT Task: IP***	***#3*** **Coatings: B14, B15** -Methodology Validation -Drag and Fuel Efiiciency -Effect on Fluid Flow Off -Effect with Contamination ***WT TASK: R&D***	***#4*** **SNC (skin no coating), OW (Original Wing)** -Methodology Validation -Drag and Fuel Efiiciency -Effect on Fluid Flow Off -Effect with Contamination ***WT TASK: R&D***	***#5*** **Coatings: E1, C3** -Methodology Validation -Drag and Fuel Efiiciency -Effect on Fluid Flow Off -Effect with Contamination ***WT TASK: R&D***	***#6*** **Coatings: B12, B13, SNC** -Methodology Validation -Drag and Fuel Efiiciency -Effect on Fluid Flow Off -Effect with Contamination -Installation Repeatability ***WT TASK: R&D***	***#7*** **R&D ACTIVITIES** **- APM UNIT** **- EFFECT OF COOLING** **- HEAVY SNOW** **- ETC** ***WT TASK: R&D / IP***
-5ºC to -10ºC	***#8*** **IP EXPANSION (IP/SN, IP/SN-)** **(also some at -10 to -30ºC)** ***WT Task: IP***	***#9*** **TYPE III ALLOWANCE TIMES** ***WT Task: TIII***				***n/a*** **TYPE I FOR VERY LOW SPEED T/O** **(also some at -5 to -10º)** ***WT Task: TI <60kts***
-10ºC to -20ºC	***#10*** **TYPE III ALLOWANCE TIMES** ***WT Task: TIII***	***#11*** **TYPE I FOR VERY LOW SPEED T/O** **(also some at -5 to -10º)** ***WT Task: TI <60kts***				***n/a*** **IP EXPANSION (IP/SN, IP/SN-)** **(also some at -10 to -30ºC)** ***WT Task: IP***
-20ºC to -30ºC	***#12*** **IP VALIDATION (NEW TEMPS & FLUIDS)** ***WT Task: IP***	***#13*** **IP VALIDATION (NEW TEMPS & FLUIDS)** ***WT Task: IP***	***#14*** **TYPE I FOR VERY LOW SPEED T/O** **(also some <-30ºC)** ***WT Task: TI <60kts***	***#15*** **TYPE III ALLOWANCE TIMES** ***WT Task: IP / R&D***		***n/a*** **IP EXPANSION (IP/SN, IP/SN-)** **(also some at -10 to -30ºC)** ***WT Task: IP***
Below -30ºC						***n/a*** **TYPE I FOR VERY LOW SPEED T/O** **(also some <-30ºC)** ***WT Task: TI <60kts***

Figure 10.1: Test Calendar

3. TEST PLAN

The NRC wind tunnel is an open circuit tunnel. The temperature inside the wind tunnel is dependent on the outside ambient temperature. Prior to testing, the weather should be monitored to ensure proper temperatures for testing.

Representative Type I/III/IV propylene and ethylene fluids in Neat form (standard mix for Type I) shall be evaluated against their uncontaminated performance; Attachments VIII to XIV present the generic holdover time guidelines for Type I and III as well as the fluid-specific holdover time guidelines for the representative Type IV fluids that will be tested. The current Ice Pellet Allowance Time table has been included in Attachment XV.

A preliminary list of test objectives is shown in Table 3.1. It should be noted that the order in which the tests will be carried out will be depend on weather conditions and TC/FAA directive. A detailed preliminary test matrix is shown in Table 3.2.

NOTE: The numbering of the test runs will be done in a sequential order starting with number 1.

A rating system has been developed for fluid and contamination tests, and will be filled out by the onsite experts when applicable. The overall rating will provide insight into the severity of the conditions observed. A test failure (failure to shed the fluid at time of rotation) shall be determined by the on-site experts based on residual contamination.

4. PRE-TESTING SETUP ACTIVITIES

The activities to be performed for planning and preparation, on the first day of testing, and prior to each testing day thereafter, have been detailed in a list included in Attachment XVI.

Table 4.1: Preliminary List of Testing Objectives for Winter 2012-13 Wind Tunnel Testing

Item #	Objective	Priority	Description	# of Days
1	Dry Wing Baseline Repeatability	1	Baseline test at beginning of each day. Ensure repeatability	-
2	IP Expansion (IP-/SN and IP-/SN-)	1	Expand IP Allowance Time Table for IP-/SN and IP-/SN-	1
3	IP Validation (New Temps & Fluids)	1	Substantiate current times with new fluids, fluids previously tested but with limited data, and temperatures close to LOUT	2
4	New Ice Pellet Dispenser Calibration	1	Evaluate the equivalency of the new ice pellet/snow dispenser systems	1
5	Ice Phobic Coating R&D	1	Evaluate the effect of coatings on aerodynamics with and without fluids	4
6	Type III IP Allowance Times	1	Support the development of a Type III high speed ice pellet allowance time table	4
7	Type I for Very Low Speed T/O	1	Evaluate Type I fluid flow-off performance for low speed rotation less than 80 knots	2
8	Other R&D Activites	1	To be selected from item # 8.1 to 8.16	1
8.1	Evaluation of an APM Sensor	2	Testing an airfoil performance monitor (APM) to evaluate potential for use in ground icing operations with and without fluids	-
8.2	Heavy Snow	2	Continue Heavy Snow Research comparing lift losses with Light/Moderate Snow vs. heavy Snow	-
8.3	Heavy Contamination (Aero vs. Visual Failure)	2	Continue work looking at aerodynamic failure vs. HOT defined failure, and effect of surface roughness on lift degredation	-
8.4	Tunnel Test Section Cooling System Evaluation	2	Evaluate effectiveness of new wind tunnel colling system and potential effects on data results	-
8.5	Effect of Viscosity on Fluid Aerodynamics	3	Evaluate effect of viscosity on aero flow-off to better understand year to year differences with same fluid (test high and low visc)	-
8.6	Fluid + Cont @ LOUT	3	Effect of contamination on fluid performance at LOUT with IP, SN, ZF, Frost etc.	-
8.7	Small Hail	3	Develop HOT Guidance for small hail. Requires consult with meteorologist for specific conditions	-
8.8	Simulate Frost in Wind Tunnel	3	Attempt to simulate frost conditions in wind tunnel.	-
8.9	Flaps/Slats to Support YMX	3	Conduct flaps failure research to support UPS/SWA trials, comparative fluid/cont. and possibly sandpaper tests	-
8.10	Mixed HOT Conditions	3	Develop HOT Guidance for mixed conditions i.e. ZR/SN, R/SN, ZD/SN	-
8.11	Snow on Un-protected Wing	3	Continue previous research	-
8.12	130-150 Knots IP Testing	3	Conduct IP testing at 130-150 knots or validate feasibility MAY NEED TO MODIFY TUNNEL	-
8.13	Windshield Washer Fluid Testing	3	Conduct aero testing to support full testing conducted at Rockliffe Flying Club in Ottawa	-
8.14	Effect of Fluid Seepage	3	Evaluate the effect of fluid seepage on dry wing performance and repeatability	-
8.15	2nd Wave of Fluid During Rotation	3	Investigate the aero effects of the 2nd wave of fluid created from fluid at the stagnation point which flows over the LE during rotation	-
8.16	Other	3	Any potential suggestions from industry	-

Total # of Days for Priority 1 Tests	**15**

Table 3.1: Proposed Test Plan

Test Plan #	Objective	Objective Priority	Test Condition	Rotation Angle	Ramp (s/kts)	Target OAT (ºC)	Fluid	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	ZR Rate (g/dm²/h)	R Rate (g/dm²/h)	Exposure Time	Coating	Priority	COMMENT
P001	Baseline	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	-	1	to be conducted daily before start ot tests
P002	Baseline	1	Dry Wing	stall	100	any (target <-5ºC)	none	-	-	-	-	-	-	1	to be conducted daily before start ot tests
P003	Type I Low Speed	1	Fluid Only	8	100	below -30	Polar Plus	-	-	-	-	-	-	1	
P004	Type I Low Speed	1	Fluid Only	8	60	below -30	Polar Plus	-	-	-	-	-	-	1	
P005	Type I Low Speed	1	Fluid Only	8	55	below -30	Polar Plus	-	-	-	-	-	-	1	
P006	Type I Low Speed	1	Fluid Only	8	55+3 sec	below -30	Polar Plus	-	-	-	-	-	-	1	
P007	Type I Low Speed	1	Fluid Only	8	100	-20 to -30	Polar Plus	-	-	-	-	-	-	1	
P008	Type I Low Speed	1	Fluid Only	8	60	-20 to -30	Polar Plus	-	-	-	-	-	-	1	
P009	Type I Low Speed	1	Fluid Only	8	55	-20 to -30	Polar Plus	-	-	-	-	-	-	1	
P010	Type I Low Speed	1	Fluid Only	8	55+3 sec	-20 to -30	Polar Plus	-	-	-	-	-	-	1	
P011	Type I Low Speed	1	Fluid Only	8	100	-20 to -30	Polar Plus	-	-	-	-	-	-	2	
P012	Type I Low Speed	1	Fluid Only	8	60	-20 to -30	Polar Plus	-	-	-	-	-	-	2	
P013	Type I Low Speed	1	Fluid Only	8	55	-20 to -30	Polar Plus	-	-	-	-	-	-	2	
P014	Type I Low Speed	1	Fluid Only	8	55+3 sec	-20 to -30	Polar Plus	-	-	-	-	-	-	2	
P015	Type I Low Speed	1	Fluid Only	8	60	-20 to -30	Polar Plus	-	-	-	-	-	-	3	
P016	Type I Low Speed	1	Fluid Only	8	100	-20 to -30	Dow ADF	-	-	-	-	-	-	1	
P017	Type I Low Speed	1	Fluid Only	8	60	-20 to -30	Dow ADF	-	-	-	-	-	-	1	
P018	Type I Low Speed	1	Fluid Only	8	55	-20 to -30	Dow ADF	-	-	-	-	-	-	1	
P019	Type I Low Speed	1	Fluid Only	8	55+3 sec	-20 to -30	Dow ADF	-	-	-	-	-	-	1	
P020	Type I Low Speed	1	Fluid Only	8	100	-10 to -20	Polar Plus	-	-	-	-	-	-	1	
P021	Type I Low Speed	1	Fluid Only	8	60	-10 to -20	Polar Plus	-	-	-	-	-	-	1	
P022	Type I Low Speed	1	Fluid Only	8	55	-10 to -20	Polar Plus	-	-	-	-	-	-	1	
P023	Type I Low Speed	1	Fluid Only	8	55+3 sec	-10 to -20	Polar Plus	-	-	-	-	-	-	1	
P024	Type I Low Speed	1	Fluid Only	8	60	-10 to -20	Polar Plus	-	-	-	-	-	-	2	
P025	Type I Low Speed	1	Fluid Only	8	100	-5 to -10	Polar Plus	-	-	-	-	-	-	1	

Table 3.1: Proposed Test Plan (cont'd)

P026	Type I Low Speed	1	Fluid Only	8	60	-5 to -10	Polar Plus	-	-	-	-	-	-	1	
P027	Type I Low Speed	1	Fluid Only	8	60	-5 to -10	Polar Plus	-	-	-	-	-	-	2	
P028	Type I Low Speed	1	Fluid Only	8	55	-5 to -10	Polar Plus	-	-	-	-	-	-	1	
P029	Type I Low Speed	1	Fluid Only	8	55+3 sec	-5 to -10	Polar Plus	-	-	-	-	-	-	1	
P030	Type III Allowance Times	1	IP-	8	100	-5 and above	2031 - Hot	25	-	-	-	10	-	1	
P031	Type III Allowance Times	1	IP Mod	8	100	-5 and above	2031 - Hot	75	-	-	-	5	-	1	
P032	Type III Allowance Times	1	IP- / ZR-	8	100	-5 and above	2031 - Hot	25	-	25	-	7	-	1	
P033	Type III Allowance Times	1	IP- / R	8	100	-5 and above	2031 - Hot	25	-	-	75	7	-	1	
P034	Type III Allowance Times	1	IP- / SN-	8	100	-5 and above	2031 - Hot	25	10	-	-	10	-	1	
P035	Type III Allowance Times	1	IP- / SN	8	100	-5 and above	2031 - Hot	25	25	-	-	10	-	1	
P036	Type III Allowance Times	1	IP-	8	100	-5 to -10	2031 - Hot	25	-	-	-	10	-	1	
P037	Type III Allowance Times	1	IP Mod	8	100	-5 to -10	2031 - Hot	75	-	-	-	5	-	1	
P038	Type III Allowance Times	1	IP- / ZR-	8	100	-5 to -10	2031 - Hot	25	-	25	-	5	-	1	
P039	Type III Allowance Times	1	IP- / SN-	8	100	-5 to -10	2031 - Hot	25	10	-	-	10	-	1	
P040	Type III Allowance Times	1	IP- / SN	8	100	-5 to -10	2031 - Hot	25	25	-	-	5	-	1	
P041	Type III Allowance Times	1	IP-	8	100	-10 to -20	2031 - Hot	25	-	-	-	10	-	1	
P042	Type III Allowance Times	1	IP Mod	8	100	-10 to -20	2031 - Hot	75	-	-	-	5	-	1	
P043	Type III Allowance Times	1	IP-	8	100	-20 to -30	2031 - Hot	25	-	-	-	10	-	1	
P044	Type III Allowance Times	1	IP Mod	8	100	-20 to -30	2031 - Hot	75	-	-	-	5	-	1	
P045	Type III Allowance Times	1	IP-	8	100	-5 and above	2031 - Cold	25	-	-	-	10	-	1	
P046	Type III Allowance Times	1	IP Mod	8	100	-5 and above	2031 - Cold	75	-	-	-	5	-	1	
P047	Type III Allowance Times	1	IP- / ZR-	8	100	-5 and above	2031 - Cold	25	-	25	-	7	-	1	
P048	Type III Allowance Times	1	IP- / SN-	8	100	-5 and above	2031 - Cold	25	10	-	-	10	-	1	
P049	Type III Allowance Times	1	IP- / SN	8	100	-5 and above	2031 - Cold	25	25	-	-	10	-	1	
P050	Type III Allowance Times	1	IP-	8	100	-5 and above	2031 - Cold	25	-	-	-	10	-	1	
P051	Type III Allowance Times	1	IP Mod	8	100	-5 to -10	2031 - Cold	75	-	-	-	5	-	1	
P052	Type III Allowance Times	1	IP- / ZR-	8	100	-5 to -10	2031 - Cold	25	-	25	-	5	-	1	

Table 3.1: Proposed Test Plan (cont'd)

P053	Type III Allowance Times	1	IP- / R	8	100	-5 to -10	2031 - Cold	25	-	-	75	7	-	1	
P054	Type III Allowance Times	1	IP- / SN-	8	100	-5 to -10	2031 - Cold	25	10	-	-	10	-	1	
P055	Type III Allowance Times	1	IP- / SN	8	100	-5 to -10	2031 - Cold	25	25	-	-	5	-	1	
P056	Type III Allowance Times	1	IP-	8	100	-10 to -20	2031 - Cold	25	-	-	-	10	-	1	
P057	Type III Allowance Times	1	IP Mod	8	100	-10 to -20	2031 - Cold	75	-	-	-	5	-	1	
P058	Type III Allowance Times	1	IP-	8	100	-20 to -30	2031 - Cold	25	-	-	-	10	-	1	
P059	Type III Allowance Times	1	IP Mod	8	100	-20 to -30	2031 - Cold	75	-	-	-	5	-	1	
P060	IP Expansion	1	IP- / SN-	8	100	-10 to -20	ABC-S Plus	25	10	-	-	15		2	
P061	IP Expansion	1	IP- / SN-	8	100	-10 to -20	Launch	25	10	-	-	15		2	
P062	IP Expansion	1	IP- / SN-	8	100	-10 to -20	Max-Flight	25	10	-	-	15		2	
P063	IP Expansion	1	IP- / SN-	8	100	-10 to -20	AD-49	25	10	-	-	15		2	
P064	IP Expansion	1	IP- / SN-	8	100	-10 to -20	Polar Guard Advance	25	10	-	-	15		2	
P065	IP Expansion	1	IP- / SN-	8	100	-20 to -30	EG106	25	10	-	-	15		1	
P066	IP Expansion	1	IP- / SN-	8	100	-20 to -30	ABC-S Plus	25	10	-	-	15		1	
P067	IP Expansion	1	IP- / SN-	8	100	-20 to -30	Launch	25	10	-	-	15		1	
P068	IP Expansion	1	IP- / SN-	8	100	-20 to -30	Max-Flight	25	10	-	-	15		1	
P069	IP Expansion	1	IP- / SN-	8	100	-20 to -30	AD-49	25	10	-	-	15		1	
P070	IP Expansion	1	IP- / SN-	8	100	-20 to -30	Polar Guard Advance	25	10	-	-	15		1	
P071	IP Expansion	1	IP- / SN	8	100	-5 to -10	ABC-S Plus	25	10	-	-	10		1	
P072	IP Expansion	1	IP- / SN	8	100	-5 to -10	Launch	25	10	-	-	10		1	
P073	IP Expansion	1	IP- / SN	8	100	-5 to -10	AD-49	25	10	-	-	10		1	
P074	IP Expansion	1	IP- / SN	8	100	-5 to -10	Polar Guard Advance	25	10	-	-	10		1	failed in 2012-13 test
P075	IP Validation with New Temps & Fluids	1	IP-	8	115	-20 to -30	ABC-S Plus	25	-	-	-	50	-	1	run @ LOUT
P076	IP Validation with New Temps & Fluids	1	IP-	8	115	-20 to -30	EG106	25	-	-	-	50	-	1	run @ LOUT
P077	IP Validation with New Temps & Fluids	1	IP-	8	115	-20 to -30	Launch	25	-	-	-	50	-	1	run @ LOUT
P078	IP Validation with New Temps & Fluids	1	IP-	8	115	-20 to -30	Max-Flight	25	-	-	-	50	-	1	run @ LOUT
P079	IP Validation with New Temps & Fluids	1	IP-	8	115	-20 to -30	AD-49	25	-	-	-	50	-	1	run @ LOUT

Table 3.1: Proposed Test Plan (cont'd)

P080	IP Validation with New Temps & Fluids	1	IP-	8	115	-20 to -30	Polar Guard Advance	25	-	-	-	50	-	1	run @ LOUT
P081	IP Validation with New Temps & Fluids	1	IP Mod	8	115	-20 to -30	ABC-S Plus	75	-	-	-	10	-	1	run @ LOUT
P082	IP Validation with New Temps & Fluids	1	IP Mod	8	115	-20 to -30	EG106	75	-	-	-	10	-	1	run @ LOUT
P083	IP Validation with New Temps & Fluids	1	IP Mod	8	115	-20 to -30	Launch	75	-	-	-	10	-	1	run @ LOUT
P084	IP Validation with New Temps & Fluids	1	IP Mod	8	115	-20 to -30	Max-Flight	75	-	-	-	10	-	1	run @ LOUT
P085	IP Validation with New Temps & Fluids	1	IP Mod	8	115	-20 to -30	AD-49	75	-	-	-	10	-	1	run @ LOUT
P086	IP Validation with New Temps & Fluids	1	IP Mod	8	115	-20 to -30	Polar Guard Advance	75	-	-	-	10	-	1	run @ LOUT
P087	IP Validation with New Temps & Fluids	1	Fluid Only	8	115	-20 to -30	ABC-S Plus	-	-	-	-	-	-	1	run @ LOUT
P088	IP Validation with New Temps & Fluids	1	Fluid Only	8	115	-20 to -30	EG106	-	-	-	-	-	-	1	run @ LOUT
P089	IP Validation with New Temps & Fluids	1	Fluid Only	8	115	-20 to -30	Launch	-	-	-	-	-	-	1	run @ LOUT
P090	IP Validation with New Temps & Fluids	1	Fluid Only	8	115	-20 to -30	Max-Flight	-	-	-	-	-	-	1	run @ LOUT
P091	IP Validation with New Temps & Fluids	1	Fluid Only	8	115	-20 to -30	AD-49	-	-	-	-	-	-	1	run @ LOUT
P092	IP Validation with New Temps & Fluids	1	Fluid Only	8	115	-20 to -30	Polar Guard Advance	-	-	-	-	-	-	1	run @ LOUT
P093	New Ice Pellet Dispenser Validation	1	IP Mod	8	100	below -5	Launch	75	-	-	-	10	-	1	new dispenser
P094	New Ice Pellet Dispenser Validation	1	IP Mod	8	100	below -5	Launch	75	-	-	-	10	-	1	new dispenser
P095	New Ice Pellet Dispenser Validation	1	IP Mod	8	100	below -5	Launch	75	-	-	-	10	-	2	new dispenser
P096	New Ice Pellet Dispenser Validation	1	IP Mod	8	100	below -5	Launch	75	-	-	-	10	-	1	old dispenser
P097	New Ice Pellet Dispenser Validation	1	IP Mod	8	100	below -5	Launch	75	-	-	-	10	-	1	old dispenser
P098	New Ice Pellet Dispenser Validation	1	IP Mod	8	100	below -5	Launch	75	-	-	-	10	-	2	old dispenser
P099	New Ice Pellet Dispenser Validation	1	IP-/SN-	8	100	below -5	Polar Guard Advance	25	25	-	-	15	-	1	new dispenser
P100	New Ice Pellet Dispenser Validation	1	IP-/SN-	8	100	below -5	Polar Guard Advance	25	25	-	-	15	-	1	new dispenser
P101	New Ice Pellet Dispenser Validation	1	IP-/SN-	8	100	below -5	Polar Guard Advance	25	25	-	-	15	-	1	old dispenser
P102	New Ice Pellet Dispenser Validation	1	IP-/SN-	8	100	below -5	Polar Guard Advance	25	25	-	-	15	-	1	old dispenser
P103	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B14	1	objective: baseline
P104	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B14	1	objective: baseline
P105	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B14	2	objective: baseline
P106	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	B14	1	objective: baseline

Table 3.1: Proposed Test Plan (cont'd)

P107	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	B14	1	objective: baseline
P108	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	B14	2	objective: baseline
P109	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	B14	1	objective: drag and fuel efficiency * SCENARIO 1: climb or cruise to be simulated, i.e: 0 º for 30 sec
P110	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	B14	2	objective: drag and fuel efficiency * SCENARIO 2: climb or cruise to be simulated, i.e: +2 º for 15 sec
P111	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	B14	3	objective: drag and fuel efficiency * SCENARIO 3: climb or cruise to be simulated, i.e:-2 º for 10 sec
P112	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	B14	1	objective: effect of coatings on fluid flow-off
P113	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	B14	1	objective: effect of coatings on fluid flow-off
P114	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	B14	2	objective: effect of coatings on fluid flow-off
P115	Ice Phobic R&D	1	ZR	8	100	below -5	none	-	-	25	-	20	B14	1	objective: effect of coatings with precip
P116	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B14	1	objective: baseline/ fluid seepage
P117	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B14	2	objective: baseline/ fluid seepage
P118	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B15	1	objective: baseline
P119	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B15	1	objective: baseline
P120	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B15	2	objective: baseline
P121	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	B15	1	objective: baseline
P122	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	B15	1	objective: baseline
P123	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	B15	2	objective: baseline
P124	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	B15	1	objective: drag and fuel efficiency * SCENARIO 1: climb or cruise to be simulated, i.e: 0 º for 30 sec
P125	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	B15	2	objective: drag and fuel efficiency * SCENARIO 2: climb or cruise to be simulated, i.e: +2 º for 15 sec

Table 3.1: Proposed Test Plan (cont'd)

P126	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	B15	3	objective: drag and fuel efficiency * SCENARIO 3: climb or cruise to be simulated, i.e:-2 º for 10 sec
P127	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	B15	1	objective: effect of coatings on fluid flow-off
P128	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	B15	1	objective: effect of coatings on fluid flow-off
P129	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	B15	2	objective: effect of coatings on fluid flow-off
P130	Ice Phobic R&D	1	ZR	8	100	below -5	none	-	-	25	-	20	B15	1	objective: effect of coatings with precip
P131	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B15	1	objective: baseline/ fluid seepage
P132	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B15	2	objective: baseline/ fluid seepage
P133	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	skin no coating	1	objective: baseline
P134	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	skin no coating	1	objective: baseline
P135	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	skin no coating	2	objective: baseline
P136	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	skin no coating	1	objective: baseline
P137	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	skin no coating	1	objective: baseline
P138	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	skin no coating	2	objective: baseline
P139	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	skin no coating	1	objective: drag and fuel efficiency * SCENARIO 1: climb or cruise to be simulated, i.e: 0 º for 30 sec
P140	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	skin no coating	2	objective: drag and fuel efficiency * SCENARIO 2: climb or cruise to be simulated, i.e: +2 º for 15 sec
P141	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	skin no coating	3	objective: drag and fuel efficiency * SCENARIO 3: climb or cruise to be simulated, i.e:-2 º for 10 sec
P142	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	skin no coating	1	objective: effect of coatings on fluid flow-off
P143	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	skin no coating	1	objective: effect of coatings on fluid flow-off
P144	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	skin no coating	2	objective: effect of coatings on fluid flow-off
P145	Ice Phobic R&D	1	ZR	8	100	below -5	none	-	-	25	-	20	skin no coating	1	objective: effect of coatings with precip
P146	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	skin no coating	1	objective: baseline/ fluid seepage

Table 3.1: Proposed Test Plan (cont'd)

P147	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	skin no coating	2	objective: baseline/ fluid seepage
P148	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	original wing	1	objective: baseline
P149	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	original wing	1	objective: baseline
P150	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	original wing	2	objective: baseline
P151	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	original wing	1	objective: baseline
P152	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	original wing	1	objective: baseline
P153	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	original wing	2	objective: baseline
P154	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	original wing	1	objective: drag and fuel efficiency * SCENARIO 1: climb or cruise to be simulated, i.e: 0 º for 30 sec
P155	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	original wing	2	objective: drag and fuel efficiency * SCENARIO 2: climb or cruise to be simulated, i.e: +2 º for 15 sec
P156	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	original wing	3	objective: drag and fuel efficiency * SCENARIO 3: climb or cruise to be simulated, i.e:-2 º for 10 sec
P157	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	original wing	1	objective: effect of coatings on fluid flow-off
P158	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	original wing	1	objective: effect of coatings on fluid flow-off
P159	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	original wing	2	objective: effect of coatings on fluid flow-off
P160	Ice Phobic R&D	1	ZR	8	100	below -5	none	-	-	25	-	20	original wing	1	objective: effect of coatings with precip
P161	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	original wing	1	objective: baseline/ fluid seepage
P162	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	original wing	2	objective: baseline/ fluid seepage
P163	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	E1	1	objective: baseline
P164	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	E1	1	objective: baseline
P165	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	E1	2	objective: baseline
P166	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	E1	1	objective: baseline
P167	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	E1	1	objective: baseline

Table 3.1: Proposed Test Plan (cont'd)

P168	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	E1	2	objective: baseline
P169	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	E1	1	objective: drag and fuel efficiency * SCENARIO 1: climb or cruise to be simulated, i.e: 0 º for 30 sec
P170	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	E1	2	objective: drag and fuel efficiency * SCENARIO 2: climb or cruise to be simulated, i.e: +2 º for 15 sec
P171	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	E1	3	objective: drag and fuel efficiency * SCENARIO 3: climb or cruise to be simulated, i.e:-2 º for 10 sec
P172	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	E1	1	objective: effect of coatings on fluid flow-off
P173	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	E1	1	objective: effect of coatings on fluid flow-off
P174	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	E1	2	objective: effect of coatings on fluid flow-off
P175	Ice Phobic R&D	1	ZR	8	100	below -5	none	-	-	25	-	20	E1	1	objective: effect of coatings with precip
P176	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	E1	1	objective: baseline/ fluid seepage
P177	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	E1	2	objective: baseline/ fluid seepage
P178	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	C3	1	objective: baseline
P179	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	C3	1	objective: baseline
P180	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	C3	2	objective: baseline
P181	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	C3	1	objective: baseline
P182	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	C3	1	objective: baseline
P183	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	C3	2	objective: baseline
P184	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	C3	1	objective: drag and fuel efficiency * SCENARIO 1: climb or cruise to be simulated, i.e: 0 º for 30 sec
P185	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	C3	2	objective: drag and fuel efficiency * SCENARIO 2: climb or cruise to be simulated, i.e: +2 º for 15 sec

Table 3.1: Proposed Test Plan (cont'd)

P186	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	C3	3	objective: drag and fuel efficiency * SCENARIO 3: climb or cruise to be simulated, i.e:-2 º for 10 sec
P187	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	C3	1	objective: effect of coatings on fluid flow-off
P188	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	C3	1	objective: effect of coatings on fluid flow-off
P189	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	C3	2	objective: effect of coatings on fluid flow-off
P190	Ice Phobic R&D	1	ZR	8	100	below -5	none	-	-	25	-	20	C3	1	objective: effect of coatings with precip
P191	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	C3	1	objective: baseline/ fluid seepage
P192	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	C3	2	objective: baseline/ fluid seepage
P193	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B12	1	objective: baseline
P194	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B12	1	objective: baseline
P195	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B12	2	objective: baseline
P196	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	B12	1	objective: baseline
P197	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	B12	1	objective: baseline
P198	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	B12	2	objective: baseline
P199	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	B12	1	objective: drag and fuel efficiency * SCENARIO 1: climb or cruise to be simulated, i.e: 0 º for 30 sec
P200	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	B12	2	objective: drag and fuel efficiency * SCENARIO 2: climb or cruise to be simulated, i.e: +2 º for 15 sec
P201	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	B12	3	objective: drag and fuel efficiency * SCENARIO 3: climb or cruise to be simulated, i.e:-2 º for 10 sec
P202	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	B12	1	objective: effect of coatings on fluid flow-off
P203	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	B12	1	objective: effect of coatings on fluid flow-off
P204	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	B12	2	objective: effect of coatings on fluid flow-off
P205	Ice Phobic R&D	1	ZR	8	100	below -5	none	-	-	25	-	20	B12	1	objective: effect of coatings with precip
P206	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B12	1	objective: baseline/ fluid seepage

Table 3.1: Proposed Test Plan (cont'd)

P207	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B12	2	objective: baseline/ fluid seepage
P208	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B13	1	objective: baseline
P209	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B13	1	objective: baseline
P210	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B13	2	objective: baseline
P211	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	B13	1	objective: baseline
P212	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	B13	1	objective: baseline
P213	Ice Phobic R&D	1	Dry Wing	8 pitch pause	100	any (target <-5ºC)	none	-	-	-	-	-	B13	2	objective: baseline
P214	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	B13	1	objective: drag and fuel efficiency * SCENARIO 1: climb or cruise to be simulated, i.e: 0 º for 30 sec
P215	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	B13	2	objective: drag and fuel efficiency * SCENARIO 2: climb or cruise to be simulated, i.e: +2 º for 15 sec
P216	Ice Phobic R&D	1	Dry Wing	n/a*	n/a*	any (target <-5ºC)	none	-	-	-	-	-	B13	3	objective: drag and fuel efficiency * SCENARIO 3: climb or cruise to be simulated, i.e:-2 º for 10 sec
P217	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	B13	1	objective: effect of coatings on fluid flow-off
P218	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	B13	1	objective: effect of coatings on fluid flow-off
P219	Ice Phobic R&D	1	Fluid Only	8	100	below -5	EG106	-	-	-	-	-	B13	2	objective: effect of coatings on fluid flow-off
P220	Ice Phobic R&D	1	ZR	8	100	below -5	none	-	-	25	-	20	B13	1	objective: effect of coatings with precip
P221	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B13	1	objective: baseline/ fluid seepage
P222	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	B13	2	objective: baseline/ fluid seepage
P223	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	skin no coating	1	objective: baseline/installation repeatability
P224	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	skin no coating	1	objective: baseline/installation repeatability
P225	Ice Phobic R&D	1	Dry Wing	8	100	any (target <-5ºC)	none	-	-	-	-	-	skin no coating	2	objective: baseline/installation repeatability
P226	R&D	1	APM Unit	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	-	1	
P227	R&D	1	S+++	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	-	1	
P228	R&D	1	HEAVY CONTAMINATION	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	-	1	
P229	R&D	1	EFFECT OF COOLING SYSTEM	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	-	1	

Table 3.1: Proposed Test Plan (cont'd)

P230	R&D	1	Effect of Viscosity	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	-	2	
P231	R&D	1	FLUID & CONT @ LOUT	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	-	2	
P232	R&D	1	SMALL HAIL	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	-	2	
P233	R&D	1	FROST	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	-	2	
P234	R&D	1	FLAPS/SLATS	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	-	2	
P235	R&D	1	MIXED CONDITIONS	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	-	2	
P236	R&D	1	SNOW NO FLUID	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	-	2	
P237	R&D	1	IP TESTs @ 130-150 KTS	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	-	2	
P238	R&D	1	WINDSHIELD WASHER FLUID	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	-	2	
P239	R&D	1	FLUID SEEPAGE	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	-	2	
P240	R&D	1	2ND WAVE	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	-	2	

5. DATA FORMS

The following data forms are required for the January 2014 wind tunnel tests:

- Attachment XVII – General Form;
- Attachment XVIII – Wing Temperature, Fluid Thickness and Fluid Brix Measurements and Condition of Wing and Plate Form;
- Attachment XIX, XX and XXI – Ice Pellet, Snow and Sifted Snow Dispensing Forms;
- Attachment XXII – Visual Evaluation Rating Form;
- Attachment XXIII – Fluid Receipt Form (Generic form used by APS; will be used for this project as appropriate); and
- Attachment XXIV – Log of Fluid Sample Bottles.

When and how the data forms will be used is described throughout Section 6.

6. PROCEDURE

The following sections describe the tasks to be performed during each test conducted. It should be noted that some sections (i.e. fluid application and contamination application) will be omitted depending on the objective of the test.

6.1 Initial Test Conditions Survey

- Record ambient conditions of the test (Attachment XVII); and
- Record wing temperature (Attachment XVIII).

6.2 Fluid Application (Pour)

- Hand pour 20L of anti-icing fluid over the test area (fluid can be poured directly out of pales or transferred into smaller 3L jugs);
- Record fluid application times (Attachment XVII);
- Record fluid application quantities (Attachment XVII);

- Let fluid settle for 5 minutes (as the wing section is relatively flat, last winter it required tilting the wing for 1-minute to enable fluid to be uniform);
- Measure fluid thickness at pre-determined locations on the wing (Attachment XVIII);
- Record wing temperature (Attachment XVIII);
- Measure fluid Brix value (Attachment XVIII);
- Photograph and videotape the appearance of the fluid on the wing; and
- Begin the time-lapse camera to gather photos of the precipitation application phase.

Note: At the request of TC/FAA, a standard aluminum test plate can be positioned on the wing in order to run a simultaneous endurance time test.

6.3 Application of Contamination

6.3.1 Ice Pellet/Snow Dispenser Calibration and Set-Up

Calibration work was performed during the winter of 2007-08 on the modified ice pellet/snow dispensers prior to testing with the Falcon 20. The purpose of this calibration work was to attain the dispenser's distribution footprint for both ice pellets and snow. A series of tests were performed in various conditions:

1. Ice Pellets, Low Winds (0 to 5 km/h);
2. Ice Pellets, Moderate Winds (10 km/h);
3. Snow, Low Wind (0 to 5 km/h); and
4. Snow, Moderate Wind (10 km/h).

These tests were conducted using 121 collection pans, each measuring 6 x 6 inches, over an area 11 x 11 feet. Pre-measured amounts of ice pellets/snow were dispersed over this area and the amount collected by each pan was recorded. A distribution footprint of the dispenser was attained and efficiency for the dispenser was computed.

6.3.2 Dispensing Ice Pellets/Snow for Wind Tunnel Tests

Using the results from these calibration tests, a decision was made to use two dispensers on each of the leading and trailing edges of wing; each of the four dispensers are moved to four different positions along each edge during the dispensing process. Attachments XIX and XX display the data sheets that will be used during testing in the wind tunnel. These data sheets will provide all the necessary information related to the amount of ice pellets/snow needed, effective rates and dispenser positions. During the winter of 2009-10, snow was also dispensed manually using sieves. This technique was used when higher rates of precipitation were required (for heavy snow) or when winds in the tunnel made dispensing difficult. The efficiency of this technique was estimated at 90% and a form to be used for this dispensing process along with dispensing instructions is included in Attachment XXI.

Note: Dispensing forms should be filled out and saved for each run and included and pertinent information shall be included in the general form (Attachment XVII). Any comments regarding dispensing activities should be documented directly on the form.

6.3.3 New Ice Pellets/Snow Dispensing Systems for 2014 Onwards

Yardworks seed spreaders were modified and used for applying ice pellets and snow during wind tunnel and flat plate testing. The spreaders are no longer available as the manufacturer has stopped production. A new replacement seed spreader system, Wolf Garten, was found which is similar (but not identical), and may be a suitable replacement (with necessary modifications). Some calibration work was required to demonstrate an equivalency in the two systems: the historical system versus the new replacement system. TC requested to evaluate the new system while at NRC Cold Chamber in September 2013.

The data collected demonstrates that the new system is very similar to old system. Some small variation is present in distribution within the footprint, but equivalent efficiency on the overall footprint. Based on this it was concluded that for ice pellets, the use of the new system can be made as a direct replacement. For snow, the new system is more efficient, therefore a reduction of 10% shall be used for the snow mass requested. The details of this calibration are described in TC report, TP 15230E*, Aircraft Ground Icing General Research Activities During the 2012-13 Winter.*

6.4 Prior to Engines-On Wind Tunnel Test

- Measure fluid thickness at the pre-determined locations on the wing (Attachment XVIII);
- Measure fluid Brix value (Attachment XVIII);
- Record wing temperatures (Attachment XVIII);
- Record start time of test (Attachment XVII); and
- Fill out visual evaluation rating form (Attachment XXII).

Note: In order to minimize the measurement time post precipitation, temperature should be measured 5 minutes before the end of precipitation, thickness measured 3 minutes before the end of precipitation, and Brix measured when the precipitation ends. Also consideration as been given to reducing the number of measures that are taken for this phase (i.e. locations 2 and 5 only).

6.5 During Wind Tunnel Test:

- Take still pictures and video the behavior of the fluid on the wing during the takeoff run, capturing any movement of fluid/contamination;
- Fill out visual evaluation rating form at the time of rotation (Attachment XXII); and
- Record wind tunnel operation start and stop times.

6.6 After the Wind Tunnel Test:

- Measure fluid thickness at the pre-determined locations on the wing (Attachment XVIII);
- Measure fluid Brix value (Attachment XVIII);
- Record wing temperatures (Attachment XVIII);
- Observe and record the status of the fluid/contamination (Attachment XVIII);
- Fill out visual evaluation rating form (Attachment XXII);
- Obtain lift data (excel file) from NRC; and
- Update APS test log with pertinent information.

6.7 Fluid Sample Collection for Viscosity Testing

Two litres of each fluid to be tested are to be collected on the first day of testing. The fluid receipt form (Attachment XXIII) should be completed indicating quantity of fluid and date received. Any samples extracted for viscosity purposes should be documented in the log of fluid samples data form (Attachment XXIV). A falling ball viscosity test should be performed on site to confirm that fluid viscosity is appropriate before testing.

6.8 At the End of Each Test Session

If required, APS personnel will collect the waste solution. At the end of the testing period, the glycol recovery service provider will be employed to safely dispose of the waste glycol fluid.

6.9 Camera Setup

It is anticipated that the camera setup will be similar to the setup used during the winter of 2011-12. Modifications may be necessary to account for the different airfoil. The flashes will be positioned on the control-room side of the tunnel, and the cameras will be positioned on the opposite side. The final positioning of the cameras and flashes should be documented to identify any deviation from the previous year's setup.

6.10 Demonstration of a Typical Wind Tunnel Test Sequence

Table 6.1 demonstrates a typical Wind Tunnel test sequence of activities, assuming the test starts at 08:00:00. Figure 6.1 demonstrates a typical wind tunnel run timeline.

Table 6.1: Typical Wind Tunnel Test

TIME	TASK
8:30:00	START OF TEST. ALL EQUIPMENT READY.
8:30:00	- Record test conditions.
8:35:00	- Prepare wing for fluid application (clean wing, etc).
8:45:00	- Measure wing temperature. - Ensure clean wing for fluid application
8:50:00	- Pour fluid over test area.
9:00:00	- Measure Brix, thickness, wing temperature. - Photograph test area.
9:05:00	- Apply contamination over test area. (i.e. 30 min)
9:35:00	- Measure Brix, thickness, wing temperature. - Photograph test area.
9:40:00	- Clear area and start wind tunnel
9:55:00	- Wind tunnel stopped
10:05:00	- Measure Brix, thickness, wing temperature. - Photograph test area. - Record test observations.
10:35:00	END OF TEST

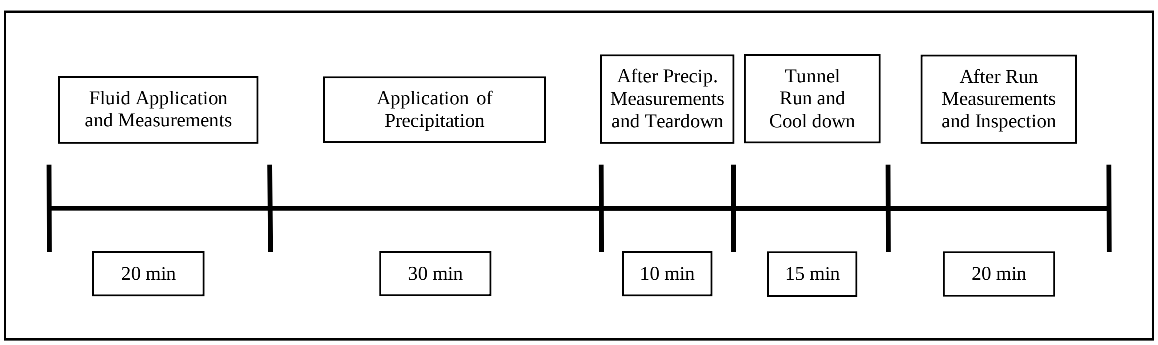


Figure 6.1: Typical Wind Tunnel Run Timeline

6.11 Procedures for R&D Activities

It is anticipated that testing will be conducted to support several research and development (R&D) activities. The objectives of these lower priority activities are as follows:

- Evaluation of an airfoil performance monitor (APM) system;
- Heavy snow;
- Heavy contamination;
- Effect of cooling system on testing repeatability;
- Effect of fluid viscosity;
- Fluid and contamination at LOUT;
- Small hail;
- Frost simulation in the wind tunnel;
- Flaps/Slats testing to support YMX tests;
- Mixed HOT conditions;
- Snow on an un-protected wing;
- Feasibility of IP testing at higher speed (130-150kts);
- Windshield washer used as a Type I deicer;
- Effect of fluid seepage on dry wing performance; and
- Second wave of fluid at rotation.

As these full-scale R&D activities have in general not been previously attempted, therefore brief summaries of the anticipated procedures have been prepared to provide guidance at the time of testing. These procedures are attached to this document as Attachments XXV to XXXIX. The procedures are preliminary and may change based on the quality of the results obtained in the wind tunnel.

7. EQUIPMENT

Equipment to be employed is shown in Table 7.1.

Table 7.1: Test Equipment Checklist

EQUIPMENT	STATUS		EQUIPMENT	STATUS
General Support and Testing Equipment			**Camera Equipment**	
20L containers x 12			AA Batteries x 48	
Adherence Probes Kit			C2032 Batteries x 4	
Barrel Opener (steel)			Digital still cameras x3 (two suitcases)	
Black Shelving Unit (or plastic)			Flashes and tripods (in APS storage)	
Blow Horns x 4			GoPro Camera	
Electrical tape x 5				
Envelopes and labels				
Exacto Knives x 2			**Ice Pellets Fabrication Equipment**	
Extension cords (power bars x 6 + reels x 4)			Blenders x 12 in good condition	
Falling Ball Viscometer			Folding tables (2 large, 1 small)	
Fluid pouring jugs x 60			Ice bags	
Fluids (ORDER and SHIP to Ottawa)			Ice bags storage freezer x 3	
Funnels(1 big + 1 small)			Ice pellets sieves (base, 1.4 mm, 4 mm)	1 set in YOW
Gloves - black and yellow			Ice pellets Styrofoam containers x20	
Gloves - cotton (1 box)			Measuring cups (1L and smaller ones for dispensing)	
Gloves - latex (2 boxes)			NCAR Scale x 1	
Grid Section + Location docs			Refrigerated Truck	
Hard water chemicals x 3 premixes			Rubber Mats x all	
Horse and tap for fluid barrel x all			Wooden Spoons	
Hot Plate x 3 and Large Pots with rubber handles for Type III				
Ice pellet box supports for railing x4			**Freezing Rain Equipment**	
Ice Pellet control wires and boxes (all for new and old)			APS PC equipped with rate station software	
Ice pellets dispersers x 12 (6 new and 6 old)			NRC Freezing rain sprayer (NRC will provide)	
Inclinometer (yellow level) x 2			Rubber suction cup feet for wooden boards	
Isopropyl x 24			White plastic rate pans (1 to 8 x 2)	
Large and small tape measure			Wooden boards for rate pans (x8)	
Large Sharpies for Grid Section				
Long Ruler for marking wing x 2				
Marker for waste x 2			**Office Equipment**	
Paper towel x 48			Accordian Folder	
Protective clothing (all) and personel clothing			APS Laptops x 6	
Protective clothing (all) and personel clothing			Calculators x 3	
Sample bottles for viscosity measurement x 8			Clip boards x 8	
Sartorius Weigh Scale x 1			Dry eraser markers	
Scrapers x 5			Envelopes (9x12) x box	
Shop Vac			Hard drive with all TC Deicing Projects	
Speed tape x 1 small			Hard Drive x 2	
Squeegees (5 small + 3 large floor)			Mouse for Rate Station and keypad	
Stands for ice pellets dispensing devices x 6			Pencils + wing markers for sample locations	
Stop Watches x 4			Projector for laptop	
Temperature probes: immersion x 3			Scissors	
Temperature probes: surface x 3			Small 90º aluminum ruler for wing	
Temperature readers x 2 + spare batteries			Test Procedures x 8, data forms, printer paper	
Test Plate x 1			YOW employee contracts	
Thermometer for Reefer Truck				
Thickness Gauges (5 small, 5 big)				
Vise grip (large) + rubber opener for containers				
Walkie Talkies x 12				
Water (2 x 18L) for hard water				
Watmans Paper and conversion charts				

8. FLUIDS

Mid-viscosity samples of ethylene glycol and propylene glycol IV fluid will be used in the wind tunnel tests. Although the number of tests conducted will be determined based on the results obtained, the fluid quantities available are shown in Table 8.1 (quantities to be confirmed once fluid is received). Fluid application will be performed by pouring the fluid (rather than spraying) to reduce any shearing to the fluid.

Table 8.1: Fluid Available for Wind Tunnel Tests

FLUID	QUANTITY ORDERED	QUANTITY ALREADY IN STOCK	COMBINED TOTAL OF FLUID AVAILABLE	TOTAL QUANTITY RQ'D
Kilfrost ABC-S Plus	400	250	**650**	120
Dow FlightGuard AD-49	0	440	**440**	120
Dow EG106	0	600	**600**	560
Clariant MP III 2031 ECO	200	150	**350**	300
Clariant MP IV Launch	0	200	**200**	240
Clariant Max-Flight	0	160	**160**	100
Cryotech Polar Guard Advance	400	120	**520**	200
Cryotech Polar Plus	240	0	**240**	230
Dow Type I ADF	60	0	**60**	40

3600 L Ordered For 2009-10 Testing (18 Days)
3200 L Ordered For 2010-11 Testing (15 Days)
1800 L Ordered For 2011-12 Testing (7 of 15 days will be fluid testing)
4200 L Ordered for 2012-13 Testing (15 Days)

9. PERSONNEL

Four APS staff members are required for the tests at the NRC wind tunnel. Four additional persons (with one back-up) will be required from Ottawa for making and dispensing the ice pellets and snow. One additional person from

Ottawa will be required to photograph the testing. Table 9.1 demonstrates the personnel required and their associated tasks.

Fluid and ice pellets applications will be performed by APS/YOW personnel at the NRC wind tunnel. NRC personnel will operate the NRC wind tunnel and operate the freezing rain/drizzle sprayer (if requested).

Table 9.1: Personnel List

Wind Tunnel 11-12- Tentative	
Person	**Responsibility**
John	Overall Co-ordinator
Marco	Co-ordinator / General
Victoria	Forms & Data Collection Manager / IP Manager / YOW Pers. Manager / Camera Documentation
Dave	Data Collection / IP Support / Fluid Application / Fluid Manager
YOW Personnel	
Ben/Jesse	Photography
James	Fluids / IP / Dispensing / General Support
YOW 1	Fluids / IP / Dispensing
YOW 2	Fluids / IP / Dispensing
YOW 3	Fluids / IP / Dispensing
YOW 4	Back-up

NRC Institute of Aerospace Research Contacts

- Lucio Del Ciotto: (613) 913-9720
- Catherine Clark: (613) 998-6932

10. SAFETY

- A safety briefing will be done on the first day of testing;
- Personnel should be familiar with NRC emergency procedures i.e. DO NOT CALL 9-1-1, instead call the NRC Emergency Center as they will contact and direct the necessary services;
- All personnel must be familiar with the Material Safety Data Sheets (MSDS) for fluids;
- Prior to operating the wind tunnel, loose objects should be removed from the vicinity;

- When wind tunnel is operating, ensure that ear plugs are worn if necessary and personnel keep safe distances;
- When working on ladders, ensure equipment is stable;
- CSA approved footwear and appropriate clothing for frigid temperatures are to be worn by all personnel;
- Caution should be taken when walking in the test section due to slippery floors, and dripping fluid from the wing section;
- If fluid comes into contact with skin, rinse hands under running water; and
- If fluid comes into contact with eyes, flush with the portable eye wash station.

ATTACHMENT I – Procedure: Dry Wing Performance

Background

A significant amount of work has been done in conjunction with NASA and NRC in order to calibrate and characterize the wind tunnel and airfoil model during the last two winter seasons. This work has further increased the confidence in the data produced, however ongoing verification is necessary in order to identify potential changes in the system performance.

Objective

Verify that clean model aerodynamic data agree with the data acquired in previous years with the same model. Given the various issues with repeatability and angle of attack offsets in the past, this is an important step prior to fluids testing.

Methodology

- Ensure the wing is clean and dry;
- Conduct a dry wing test using the regular take-off profile;
- Conduct a dry wing test using a take-off profile with rotation to stall;
- Compare lift performance to historical data; and
- Address potential discrepancies accordingly.

Test Plan

This testing should be conducted at the start of each testing day.

ATTACHMENT II – Procedure: Allowance Times in Light Ice Pellets Mixed with Light or Moderate Snow Conditions

Background

Historical winter weather data has indicated that a significant portion of "light ice pellets mixed with light snow" precipitation occurs below -10°C and "light ice pellets mixed with moderate snow" precipitation occurs below -5 to -10°C where no allowance times currently exist. Some additional data has been collected in 2012-13 which supports a potential for guidance in these conditions, however testing is still required in order to substantiate any proposed changes to the allowance times.

Objective

To conduct testing in conditions of "light ice pellets mixed with light snow" below -10°C and "light ice pellets mixed with moderate snow" below -5 to -10°C to support potential changes to the allowance times table.

Methodology

- Analyze existing data;
- Identify data gaps (fluids, temperatures, etc.);
- Conduct testing with appropriate conditions to address data gaps; and
- Adjust testing plan accordingly based on aerodynamic data collected.

Test Plan

One day of testing is planned, however testing could be expanded to 3 days.

ATTACHMENT III – Procedure: Ice Pellet Allowance Time Substantiation with New Fluids, Fluids Previously Tested with Limited Data, and Temperatures Close to the LOUT

Background

Previous testing has shown that typically lift losses will significantly increase at the lower temperatures. Limited data is available at (or very near) the fluid Lowest Operational Use Temperature (LOUT). Additional testing is recommended to obtain data close to the fluid LOUT to determine the aerodynamic effects of ice pellet contamination at these colder temperatures.

Objective

To determine the aerodynamic effects of ice pellet contamination close to the fluid LOUT.

Methodology

- Analyze existing data;
- Identify data gaps (fluids, temperatures, etc);
- Conduct testing close to the fluid LOUT (-20 to -30ºC) with appropriate conditions to address data gaps; and
- Adjust testing plan accordingly based on aerodynamic data collected.

Test Plan

Two days of testing are planned, however this testing is temperature critical and requires very low temperatures below -20ºC.

ATTACHMENT IV – Procedure: Equivalency of New IP/SN Dispenser Systems

Background

In the winter of 2012-13, seed spreaders historically modified and used for applying ice pellets during wind tunnel and flat plate testing, were no longer available as the manufacturer has stopped production of the model. A new replacement seed spreader system was found which is similar (but not identical). Some calibration work was required to demonstrate an equivalency in the two systems: testing was conducted to verify the distribution of the historical system versus the new replacement system. The data collected demonstrates that the new system is very similar to old system with some small variations. It is recommended comparative wind tunnel testing be conducted to validate the equivalency of the systems.

Objective

To evaluate the equivalency of the new and old generation dispenser systems through comparative wind tunnel testing.

Methodology

- Conduct 2-3 tests with the same fluid in an existing ice pellet only condition with the old dispenser systems;
- Conduct the same 2-3 tests with the new dispenser system;
- Compare the results and address discrepancies accordingly; and
- Repeat for snow conditions (consider doing 1-2 tests for each dispenser instead).

Test Plan

One day of testing is anticipated.

ATTACHMENT V – Procedure: Effect of Ice Phobic Coating on Aerodynamics With or Without Fluids

Background

In recent years, there has been significant industry interest in the use of coatings to protect aircraft critical surfaces. These coatings can sometimes designed and marketed as ice phobic coatings, but the behavior and performance of these coatings during ground icing operations has yet to be fully investigated Previous flat plate and wind tunnel work has been conducted since 2009-10 and has helped identify both strengths and weaknesses associated with these technologies. Additional aerodynamic testing was recommended to further develop the evaluation methodology and to investigate new product formulations.

Objective

To investigate the aerodynamic performance of ice phobic coatings with and without de/anti-icing fluids.

Methodology

Testing will be conducted using wing skins specifically manufactured to fit onto the existing thin high performance wing section and be secured by bolts. To cover the entire test wing, two individual wing skin halves are required.

Testing will consist of comparative test sets done with different sets of wing skins. The test set will consist of the following:

- Dry wing tests to 8degrees and to stall to understand effects of coatings and to evaluate the repeatability of the tests;
- Simulated climb-out or cruise runs to evaluate drag and fuel efficiency;
- Fluid only testing with a known fluid;
- Freezing rain with no fluid test to evaluate how contamination forms on the surface and the aerodynamic effects (beads of ice vs. smooth ice);
- Repeat dry wing tests to investigate fluid seepage issues associated with the wing skins and effect on repeatability;
- Un-install and re-install a wing skin to evaluate the repeatability of the installation process; and
- Compare the results with the coated wing skins to the un-coated wing skins. An additional comparison to the original wing is also useful.

Test Plan

Four days of testing are planned.

ATTACHMENT VI – Procedure: Development of a Type III Ice Pellet Allowance Time Table

Background

Several Canadian regional air operators (Porter & Skyregional) operating out of the Toronto Island airport, use Type III fluid for deicing and anti-icing of their turbo-prop aircraft. These operators were driven to use Type III fluids instead of Type IV fluids, due to aircraft performance penalties when using Type IV fluids. As this airport (and several other Canadian airports) is subject to ice pellet conditions, Porter has requested guidance from TC on the use of Type III fluids in ice pellet conditions. It is likely that other air operators will be requesting similar guidance in the near future, since both Skyregional and WestJet Encore also operate Dash 8-400 aircraft. Additional operational research is required by TC prior to providing operational guidance in this area due to the limited knowledge in using Type III fluids during ice pellet events.

Objective

To develop preliminary ice pellet allowance times for use with Type III fluids.

Methodology

- Conduct a thorough review of Type III data collected in previous years of ice pellet testing to determine information availability and requirements;
- Identify data requirements (fluids, temperatures, etc.);
- Conduct testing with appropriate conditions to address data requirements. Both hot and cold fluid application data should be collected; and
- Adjust testing plan accordingly based on aerodynamic data collected to support the development of a Type III allowance time table.

Test Plan

Four days of testing are anticipated.

ATTACHMENT VII – Procedure: Evaluation of Type I Fluid Flow-off for Low Speed Rotation Less than 80 Knots

Background

The lowest operational use temperature (LOUT) for a fluid is determined based on the higher of the fluid freeze point plus a buffer, or the lowest temperature which passes the aerodynamic test (AS5900) for either the low speed or high speed ramp. Currently the high speed ramp is representative of aircraft rotating at 100 knots or higher, whereas the low speed ramp is representative of aircraft rotating between 67 knots and 100 knots.

There currently does not exist any fluid qualification for aircraft rotating below 67 knots, however several operators have aircraft that rotate below 67 knots that encounter ground icing conditions during winter months. Aerodynamic testing in the NRC wind tunnel, and possibly according to AS5900, can provide insight into alternatives for operating in such conditions; i.e. limit LOUT for lower rotation speeds, use diluted fluid, delay rotation when at Vr, increase the rotation speed etc. These operators have requested that TC provide operational guidance when using Type I fluids on these aircraft. Additional operational research is required by TC prior to providing operational guidance in this area.

Objective

To evaluate the aerodynamic impact of using Type I fluid on aircraft with rotation speeds below 67 knots and resulting effect on the LOUT.

Methodology

- Comparative test sets should be done at all temperatures below -5ºC, but specifically data at or near the Polar Plus LOUT is especially useful;
- Conduct a high speed (100kts) test with Polar Plus Type I fluid to identify acceptable lift losses;
- Conduct comparative test runs with the same fluid at 60 kts, 55kts, and at 55kts with a 3 second delayed rotation to determine likely increases in lift losses;
- When testing close to the Polar Plus LOUT, conduct an additional set of test with a Type I EG fluid with a lower LOUT (i.e. Dow ADF); and
- Analyze results and modify test plan accordingly.

Test Plan

Two days of testing are anticipated.

ATTACHMENT VIII – Generic Type I Holdover Time Table

TABLE 1-A

SAE TYPE I FLUID HOLDOVER GUIDELINES ON ALUMINUM WING SURFACES FOR WINTER 2013-2014[1]

This table applies to aircraft with critical surfaces constructed predominantly or entirely of aluminum materials that have demonstrated satisfactory use of these holdover times.

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

<table>
<tr><th colspan="2">Outside Air Temperature[2]</th><th colspan="8">Approximate Holdover Times Under Various Weather Conditions (minutes)</th></tr>
<tr><th rowspan="2">Degrees Celsius</th><th rowspan="2">Degrees Fahrenheit</th><th rowspan="2">Freezing Fog or Ice Crystals</th><th colspan="3">Snow, Snow Grains or Snow Pellets</th><th rowspan="2">Freezing Drizzle[4]</th><th rowspan="2">Light Freezing Rain</th><th rowspan="2">Rain on Cold Soaked Wing[5]</th><th rowspan="2">Other[6]</th></tr>
<tr><th>Very Light[3]</th><th>Light[3]</th><th>Moderate</th></tr>
<tr><td>-3 and above</td><td>27 and above</td><td>11 – 17</td><td>18</td><td>11 – 18</td><td>6 – 11</td><td>9 – 13</td><td>4 – 6</td><td>2 – 5</td><td rowspan="4">CAUTION:
No holdover time guidelines exist</td></tr>
<tr><td>below -3 to -6</td><td>below 27 to 21</td><td>8 – 13</td><td>14</td><td>8 – 14</td><td>5 – 8</td><td>5 – 9</td><td>4 – 6</td><td rowspan="3"></td></tr>
<tr><td>below -6 to -10</td><td>below 21 to 14</td><td>6 – 10</td><td>11</td><td>6 – 11</td><td>4 – 6</td><td>4 – 7</td><td>2 – 5</td></tr>
<tr><td>below -10</td><td>below 14</td><td>5 – 9</td><td>7</td><td>4 – 7</td><td>2 – 4</td><td colspan="2"></td></tr>
</table>

NOTES

1 Type I Fluid / Water Mixture must be selected so that the freezing point of the mixture is at least 10°C (18°F) below outside air temperature.
2 Ensure that the lowest operational use temperature (LOUT) is respected.
3 Use light freezing rain holdover times in conditions of very light or light snow mixed with light rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 No holdover time guidelines exist for this condition for 0°C (32°F) and below.
6 Heavy snow, ice pellets, moderate and heavy freezing rain, and hail.

CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground de/anti-icing do not provide in-flight icing protection.**

ATTACHMENT IX – Generic Type III Holdover Time Table

Transport Canada Holdover Time Guidelines **Winter 2013-2014**

TABLE 3

SAE TYPE III FLUID HOLDOVER GUIDELINES FOR WINTER 2013-2014

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

Outside Air Temperature[1]		Type III Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (minutes)							
Degrees Celsius	Degrees Fahrenheit		Freezing Fog or Ice Crystals	Snow, Snow Grains or Snow Pellets: Very Light[2]	Snow, Snow Grains or Snow Pellets: Light[2]	Snow, Snow Grains or Snow Pellets: Moderate	Freezing Drizzle[3]	Light Freezing Rain	Rain on Cold Soaked Wing[4]	Other[5]
-3 and above	27 and above	100/0	20 – 40	35	20 – 35	10 – 20	10 – 20	8 – 10	6 – 20	CAUTION: No holdover time guidelines exist
		75/25	15 – 30	25	15 – 25	8 – 15	8 – 15	6 – 10	2 – 10	CAUTION: No holdover time guidelines exist
		50/50	10 – 20	15	8 – 15	4 – 8	5 – 9	4 – 6	CAUTION: No holdover time guidelines exist	CAUTION: No holdover time guidelines exist
below -3 to -10	below 27 to 14	100/0	20 – 40	30	15 – 30	9 – 15	10 – 20	8 – 10	CAUTION: No holdover time guidelines exist	CAUTION: No holdover time guidelines exist
		75/25	15 – 30[6]	25[6]	10 – 25[6]	7 – 10[6]	9 – 12[6]	6 – 9[6]	CAUTION: No holdover time guidelines exist	CAUTION: No holdover time guidelines exist
below -10	below 14	100/0	20 – 40	30	15 – 30	8 – 15	CAUTION: No holdover time guidelines exist	CAUTION: No holdover time guidelines exist	CAUTION: No holdover time guidelines exist	CAUTION: No holdover time guidelines exist

NOTES

1. Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I when Type III fluid cannot be used.
2. Use light freezing rain holdover times in conditions of very light or light snow mixed with light rain.
3. Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
4. No holdover guidelines exist for this condition for 0°C (32°F) and below.
5. Heavy snow, ice pellets, moderate and heavy freezing rain, and hail.
6. For aircraft with a take-off profile conforming to the low speed aerodynamic test criterion (refer to Section 8.1.6.1 f) of TP 14052E), these holdover times only apply to outside air temperatures from below -3°C to -9°C (below 27°F to 15.8°F). If uncertain whether the aircraft performance conforms to this criterion, consult the aircraft manufacturer.

CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground de/anti-icing do not provide in-flight icing protection.**

Page 27 of 61 August 2013

ATTACHMENT X – Dow Chemical UCAR Endurance EG106 Type IV Holdover Time Table

TABLE 4-D-E106

DOW CHEMICAL TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2013-2014[1]
UCAR™ ENDURANCE EG106

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

Outside Air Temperature[2]		Type IV Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)							
Degrees Celsius	Degrees Fahrenheit		Freezing Fog or Ice Crystals	Snow, Snow Grains or Snow Pellets: Very Light[3]	Snow, Snow Grains or Snow Pellets: Light[3]	Snow, Snow Grains or Snow Pellets: Moderate	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing[5]	Other[6]
-3 and above	27 and above	100/0	2:05 – 3:10	2:00	1:20 – 2:00	0:40 – 1:20	1:10 – 2:00	0:50 – 1:15	0:20 – 2:00	CAUTION: No holdover time guidelines exist
		75/25								
		50/50								
below -3 to -14	below 27 to 7	100/0	1:50 – 3:20	2:00	1:05 – 2:00	0:30 – 1:05	0:55 – 1:50[7]	0:45 – 1:10[7]		
		75/25								
below -14 to -27	below 7 to -16.6	100/0	0:30 – 1:05	0:40	0:30 – 0:40	0:15 – 0:30				

NOTES

1. These holdover times are derived from tests of this fluid having a viscosity as listed in Table 9.
2. Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I when Type IV fluid cannot be used.
3. Use light freezing rain holdover times in conditions of very light or light snow mixed with light rain.
4. Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5. No holdover guidelines exist for this condition for 0°C (32°F) and below.
6. Heavy snow, ice pellets, moderate and heavy freezing rain, and hail.
7. These holdover times only apply to outside air temperatures to -10°C (14°F) under freezing drizzle and light freezing rain.

CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground de/anti-icing do not provide in-flight icing protection.**

ATTACHMENT XI – Kilfrost ABC-S Plus Type IV Holdover Time Table

TABLE 4-K-ABC-S+

KILFROST TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2013-2014[1]
ABC-S PLUS

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

Outside Air Temperature[2]		Type IV Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)							
Degrees Celsius	Degrees Fahrenheit		Freezing Fog or Ice Crystals	Snow, Snow Grains or Snow Pellets: Very Light[3]	Snow, Snow Grains or Snow Pellets: Light[3]	Snow, Snow Grains or Snow Pellets: Moderate	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing[5]	Other[6]
-3 and above	27 and above	100/0	2:10 – 4:00	2:00	2:00 – 2:00	1:15 – 2:00	1:50 – 2:00	1:05 – 2:00	0:25 – 2:00	CAUTION: No holdover time guidelines exist
		75/25	1:25 – 2:40	2:00	1:15 – 2:00	0:45 – 1:15	1:00 – 1:20	0:30 – 0:50	0:10 – 1:20	
		50/50	0:30 – 0:55	1:00	0:30 – 1:00	0:15 – 0:30	0:15 – 0:40	0:15 – 0:20		
below -3 to -14	below 27 to 7	100/0	0:55 – 3:30	2:00	1:45 – 2:00	1:00 – 1:45	0:25 – 1:35[7]	0:20 – 0:30[7]		
		75/25	0:45 – 1:50	1:45	1:00 – 1:45	0:35 – 1:00	0:20 – 1:10[7]	0:15 – 0:25[7]		
below -14 to -28	below 7 to -18.4	100/0	0:40 – 1:00	0:40	0:30 – 0:40	0:15 – 0:30				

NOTES

1 These holdover times are derived from tests of this fluid having a viscosity as listed in Table 9.
2 Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I when Type IV fluid cannot be used.
3 Use light freezing rain holdover times in conditions of very light or light snow mixed with light rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 No holdover guidelines exist for this condition for 0°C (32°F) and below.
6 Heavy snow, ice pellets, moderate and heavy freezing rain, and hail.
7 These holdover times only apply to outside air temperatures to -10°C (14°F) under freezing drizzle and light freezing rain.

CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground de/anti-icing do not provide in-flight icing protection.**

ATTACHMENT XII – Clariant Safewing MP IV Launch Type IV Holdover Time Table

Transport Canada Holdover Time Guidelines **Winter 2013-2014**

TABLE 4-C-LAUNCH

CLARIANT TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2013-2014[1]
SAFEWING MP IV LAUNCH

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

Outside Air Temperature[2]		Type IV Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)							
Degrees Celsius	Degrees Fahrenheit		Freezing Fog or Ice Crystals	Snow, Snow Grains or Snow Pellets			Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing[5]	Other[6]
				Very Light[3]	Light[3]	Moderate				
-3 and above	27 and above	100/0	4:00 – 4:00	2:00	1:45 – 2:00	1:05 – 1:45	1:30 – 2:00	1:00 – 1:40	0:15 – 1:40	
		75/25	3:40 – 4:00	2:00	1:45 – 2:00	1:00 – 1:45	1:40 – 2:00	0:45 – 1:15	0:10 – 1:45	
		50/50	1:25 – 2:45	1:25	0:45 – 1:25	0:25 – 0:45	0:30 – 0:50	0:20 – 0:25	CAUTION: No holdover time guidelines exist	
below -3 to -14	below 27 to 7	100/0	1:00 – 1:55	2:00	1:20 – 2:00	0:50 – 1:20	0:35 – 1:40[7]	0:25 – 0:45[7]		
		75/25	0:40 – 1:20	2:00	1:25 – 2:00	0:45 – 1:25	0:25 – 1:10[7]	0:25 – 0:45[7]		
below -14 to -28.5	below 7 to -19.3	100/0	0:30 – 0:50	0:40	0:30 – 0:40	0:15 – 0:30				

NOTES

1 These holdover times are derived from tests of this fluid having a viscosity as listed in Table 9.
2 Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I when Type IV fluid cannot be used.
3 Use light freezing rain holdover times in conditions of very light or light snow mixed with light rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 No holdover guidelines exist for this condition for 0°C (32°F) and below.
6 Heavy snow, ice pellets, moderate and heavy freezing rain, and hail.
7 These holdover times only apply to outside air temperatures to -10°C (14°F) under freezing drizzle and light freezing rain.

CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground de/anti-icing do not provide in-flight icing protection.**

Page 32 of 61 August 2013

ATTACHMENT XIII – Cryotech Polar Guard Advance Type IV Holdover Time Table

TABLE 4-CR-PG-A

CRYOTECH TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2013-2014[1]
POLAR GUARD ADVANCE

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

Outside Air Temperature[2]		Type IV Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)							
Degrees Celsius	Degrees Fahrenheit		Freezing Fog or Ice Crystals	Snow, Snow Grains or Snow Pellets: Very Light[3]	Snow, Snow Grains or Snow Pellets: Light[3]	Snow, Snow Grains or Snow Pellets: Moderate	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing[5]	Other[6]
-3 and above	27 and above	100/0	2:50 – 4:00	2:00	1:50 – 2:00	1:20 – 1:50	1:35 – 2:00	1:15 – 1:30	0:15 – 2:00	CAUTION: No holdover time guidelines exist
		75/25	2:30 – 4:00	2:00	1:20 – 2:00	0:45 – 1:20	1:40 – 2:00	0:40 – 1:10	0:09 – 1:40	
		50/50	0:50 – 1:25	1:20	0:35 – 1:20	0:15 – 0:35	0:20 – 0:45	0:09 – 0:20		
below -3 to -14	below 27 to 7	100/0	0:55 – 2:30	1:45	1:15 – 1:45	0:55 – 1:15	0:35 – 1:35[7]	0:35 – 0:45[7]		
		75/25	0:40 – 1:30	1:45	1:00 – 1:45	0:35 – 1:00	0:25 – 1:05[7]	0:35 – 0:45[7]		
below -14 to -30.5	below 7 to -22.9	100/0	0:25 – 0:50	0:40	0:30 – 0:40	0:15 – 0:30				

NOTES
1. These holdover times are derived from tests of this fluid having a viscosity as listed in Table 9.
2. Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I when Type IV fluid cannot be used.
3. Use light freezing rain holdover times in conditions of very light or light snow mixed with light rain.
4. Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5. No holdover guidelines exist for this condition for 0°C (32°F) and below.
6. Heavy snow, ice pellets, moderate and heavy freezing rain, and hail.
7. These holdover times only apply to outside air temperatures to -10°C (14°F) under freezing drizzle and light freezing rain.

CAUTIONS
- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground de/anti-icing do not provide in-flight icing protection.**

ATTACHMENT XIV – ABAX ECOWING AD-49 Type IV Holdover Time Table

Transport Canada Holdover Time Guidelines — **Winter 2013-2014**

TABLE 4-D-AD-49

DOW CHEMICAL TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2013-2014[1]
UCAR™ FLIGHTGUARD AD-49

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

Outside Air Temperature[2]		Type IV Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)							
Degrees Celsius	Degrees Fahrenheit		Freezing Fog or Ice Crystals	Snow, Snow Grains or Snow Pellets: Very Light[3]	Snow, Snow Grains or Snow Pellets: Light[3]	Snow, Snow Grains or Snow Pellets: Moderate	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing[5]	Other[6]
-3 and above	27 and above	100/0	3:20 – 4:00	2:00	1:50-2:00	1:10 – 1:50	1:25 – 2:00	1:00 – 1:25	0:10 – 1:55	
		75/25	2:25 – 4:00	2:00	1:40-2:00	1:20 – 1:40	1:55 – 2:00	0:50 – 1:30	0:10 – 1:40	
		50/50	0:25 – 0:50	0:40	0:25-0:40	0:15 – 0:25	0:15 – 0:30	0:10 – 0:15	CAUTION: No holdover time guidelines exist	
below -3 to -14	below 27 to 7	100/0	0:20 – 1:35	2:00	1:50-2:00	1:10 – 1:50	0:25 – 1:25[7]	0:20 – 0:25[7]		
		75/25	0:30 – 1:10	2:00	1:40-2:00	1:20 – 1:40	0:15 – 1:05[7]	0:15 – 0:25[7]		
below -14 to -26	below 7 to -14.8	100/0	0:25 – 0:40	0:40	0:30 – 0:40	0:15 – 0:30				

NOTES

1. These holdover times are derived from tests of this fluid having a viscosity as listed in Table 9.
2. Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I when Type IV fluid cannot be used.
3. Use light freezing rain holdover times in conditions of very light or light snow mixed with light rain.
4. Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5. No holdover guidelines exist for this condition for 0°C (32°F) and below.
6. Heavy snow, ice pellets, moderate and heavy freezing rain, and hail.
7. These holdover times only apply to outside air temperatures to -10°C (14°F) under freezing drizzle and light freezing rain.

CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground de/anti-icing do not provide in-flight icing protection.**

Page 38 of 61 — August 2013

ATTACHMENT XV– Ice Pellet Allowance Time Table

TABLE 11

ICE PELLET ALLOWANCE TIMES FOR WINTER 2013-2014

This table is for use with SAE Type IV undiluted (100/0) fluids only.
All Type IV fluids are propylene glycol based with the exception of Dow Chemical EG106 which is ethylene glycol based.

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

	OAT -5°C and above	OAT less than -5°C to -10°C	OAT less than -10°C[1]
Light Ice Pellets	50 minutes	30 minutes	30 minutes[2]
Moderate Ice Pellets	25 minutes[3]	10 minutes	10 minutes[2]
Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle	25 minutes	10 minutes	
Light Ice Pellets Mixed with Light Freezing Rain	25 minutes	10 minutes	
Light Ice Pellets Mixed with Light Rain	25 minutes[4]		**Caution: No allowance times currently exist**
Light Ice Pellets Mixed with Moderate Rain	25 minutes[5]		
Light Ice Pellets Mixed with Light Snow	25 minutes	15 minutes	
Light Ice Pellets Mixed with Moderate Snow	10 minutes		

NOTES

1. Ensure that the lowest operational use temperature (LOUT) is respected.
2. No allowance times exist for propylene glycol (PG) fluids, when used on aircraft with rotation speeds less than 115 knots. (For these aircraft, if the fluid type is not known, assume zero allowance time).
3. Allowance time is 15 minutes for propylene glycol (PG) fluids or when the fluid type is unknown.
4. No allowance times exist in this condition for temperatures below 0°C; consider use of light ice pellets mixed with light freezing rain.
5. No allowance times exist in this condition for temperatures below 0°C.

CAUTIONS

- **Fluids used during ground de/anti-icing do not provide in-flight icing protection.**

ATTACHMENT XVI – Task List for Setup and Actual Tests

No.	Task	Person	Status
	Planning and Preparation		
1	Co-ordinate with NRC wind tunnel personnel	MR/JD	
2	Ensure fluid is received ny NRC and is stored outdoors	MR/JD	
3	Check with NRC the status of the testing site, tunnel etc	MR	
4	Arrange for hotel accommodations for APS personnel	VZ	
5	Arrange truck rental	VZ	
6	Arrange for ice and freezer delivery	DY	
7	Organize personnel travel to Ottawa;	VZ	
8	Hire YOW personnel	VZ	
9	Complete contract for YOW personnel	VZ	
10	Co-ordinate with APS photographer	MR	
11	Ensure availability of freezing rain sprayer equipment;	MR	
12	Prepare and Arrange Office Materials for YOW	VZ	
13	Prepare Data forms and procedure	VZ	
14	Back up hard drives with all TC projects	VZ	
15	Prepare Test Log and Merge Historical Logs for Reference	VZ	
16	Prepare weather forceast spreadsheet	VZ	
17	Prepare historical falling ball records spreadsheet	VZ	
18	Finalize and complete list of equipment/materials required	MR	
19	Prepare and Arrange Site Equipment for YOW	DY	
20	Ensure proper functioning of ice pellet dispenser equipment;	MR	
21	Review IP/ZR/SN dispersal techniques and location	VZ/MR	
22	Update IP Rate File (if necessary)	VZ/MR	
23	Check weather prior to finalizing test dates and Day vs. Night Shift,	MR/JD	
24	Arrange for pallets to lift up 1000L totes (if applicable)	MR	
25	Purchase new 20 L containers (as necessary)	DY	
26	Complete purchase list and shopping	VZ	
27	Pack and leave YUL for YOW on Monday Jan 7th for AM start on Jan	APS	
	Wednesday Jan 8		
28	Safety Briefing & Training (APS/YOW)	MR	
29	Unload Truck and organize equipement in lower, middle, or office area	APS	
30	Verify and Organize Fluid Recieved (labels and fluid receipt forms)	DY/JS	
31	Transfer Fluids from 1000 L Totes to 20 L containers	DY/JS	
32	Collect fluid samples for viscosity at APS office and for Falling Ball	DY/VZ	
33	Conduct falling ball verification	DY/VZ	
34	Confirm ice and freezer delivery	DY	
35	Setup general office and testing equipment	VZ	
36	Setup Projector	VZ	
37	Setup Printer	VZ	
38	Setup rate station (if necessary)	DY	
39	Setup IP/SN manufacturing material in reefer truck	JS	
40	Test and prepare IP dispensing equipment	JS	
41	Train IP making personnel (ongoing)	JS/YOW	
42	Co-ordinate fabrication of ice pellets/snow	VZ/JS	
43	IP/SN/ZR Calibration (if necessary)	DY/VZ/MR	
44	Start IP manufacturing	JS	
45	Mark wing (only if requested);	VZ	
46	Setup Still and Video Cameras same as 2010-11	BG/JsD	
47	Verify photo and video angles, resolution, etc, against 2010-11/11-12	BG/JsD/MR	
48	Document new final camera and flash locations	VZ/BG/JsD	
49	General safety briefing and update on testing	APS/NRC/YOW	
50	Dry Run of tests with APS and NRC (if necessary)	APS/NRC	
51	Start Testing (Dry wing tests may be possible while setup occurs)	APS/NRC	
	Each Testing Day		
52	Check with NRC the status of the testing site, tunnel, weather etc	MR	
53	Deicide personnel requirements for following day for 24hr notice	MR/WU	
54	Prepare equipment and fluid to be used for test	DY	
55	Manufacture ice pellets	JS/YOW	
56	Prepare photography equipment	BG	
57	Prepare data forms for test	VZ	
58	Conduct tests based on test plan	APS	
59	Modify test plan based on results obtained	WU/JD/MR	
60	Update ice pellet, snow, raw ice, and fluid Inventory (end of day)	VZ/JS	
61	Update Test Log and Test Plan (ongoing and end of day)	VZ	

ATTACHMENT XVII – General Form

Form 1

GENERAL FORM (EVERY TEST)

DATE: ____________ FLUID APPLIED: ____________ RUN # (Plan #): ____________

AIR TEMPERATURE (°C) BEFORE TEST: ____________ AIR TEMPERATURE (°C) AFTER TEST: ____________

TUNNEL TEMPERATURE (°C) BEFORE TEST: ____________ TUNNEL TEMPERATURE (°C) AFTER TEST: ____________

WIND TUNNEL START TIME: ____________ PROJECTED SPEED (S/KTS): ____________

ROTATION ANGLE: ____________ EXTRA RUN INFO: ____________

FLAP SETTING (20°, 0°): ____________

☐ Check if additional notes provided on a separate sheet

FLUID APPLICATION

Actual start time: ____________ Actual End Time: ____________

Fluid Brix: ____________ Amount of Fluid (L): ____________

Fluid Temperature (°C): ____________ Fluid Application Method: POUR

ICE PELLETS APPLICATION (if applicable)

Actual start time: ____________ Actual End Time: ____________

Rate of Ice Pellets Applied (g/dm²/h): ____________ Ice Pellets Size (mm): 1.4 - 4.0 mm

Exposure Time: ____________

Total IP Required per Dispenser: ____________

FREEZING RAIN/DRIZZLE APPLICATION (if applicable)

Actual start time: ____________ Actual End Time: ____________

Rate of Precipitation Applied (g/dm²/h): ____________ Droplet Size (mm): ____________

Exposure Time: ____________ Needle: ____________

Flow: ____________

Pressure ____________

SNOW APPLICATION (if applicable)

Actual start time: ____________ Actual End Time: ____________

Rate of Snow Applied (g/dm²/h): ____________ Snow Size (mm): <1.4 mm

Exposure Time: ____________ Method: ☐ Dispenser ☐ Sieve

Total SN Required per Dispenser: ____________

COMMENTS ____________

MEASUREMENTS BY: ____________ HANDWRITTEN BY: ____________

ATTACHMENT XVIII – Wing Temperature, Fluid Thickness and Fluid Brix Form

Date: ______________________________ Run: ____________________

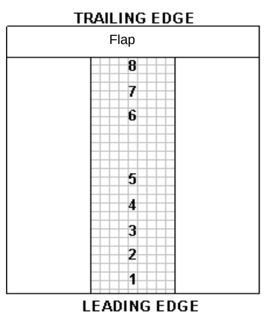
WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
T2				
T5				
TU				
Time:				

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2			
8			
Flap			
Time:			

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2			
3			
4			
5			
6			
7			
8			
Flap			
Time:			

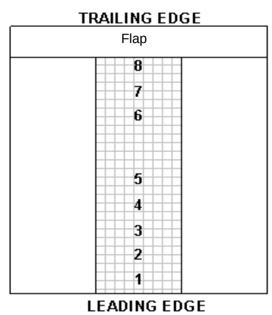
Fluid Film <1 After Takeoff Run: ☐ YES ☐ NO

Wing and Plate Condition
After the Takeoff Run
Time: ___________

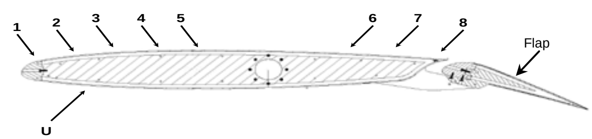


Comments:______________________
____
____
____
____

Wing and Plate Condition
Before the Takeoff Run
Time: ___________



Comments:______________________
____
____
____
____



Wing Position 1: Approximately 10 cm up from the leading edge stagnation point;

Wing Position 2, 3, 4, 5: At equal distances (approximately 15 cm) along the wing chord;

Wing Position 6: Approximately 30 cm from trailing edge;

Wing Position 7: Approximately 15 cm from trailing edge;

Wing Position 8: Approximately 2.5 cm from trailing edge; and

Wing Position 9: Midway up the flap

Underside: Approximately 40 cm up from the leading edge stagnation point.

Note: In an attempt to optimize timing of tests, shaded box measurements can be ommitted with approval of the project coordinator

General Comments: ______________________________
____
____
____

OBSERVER: ______________________________

ASSISTED BY: ______________________________

ATTACHMENT XIX – Example Ice Pellet Dispensing Form

WING TRAILING EDGE

8 ft = 24.4 dm

6 ft = 18.3 dm

DISPENSOR #3								DISPENSOR #4							
1 ←	1ft	→ 2 ←	1ft	→ 3 ←	1ft	→ 4		1 ←	1ft	→ 2 ←	1ft	→ 3 ←	1ft	→ 4	
14.9	16.5	18.2	17.4	18.5	17.6	18.5	17.6	18.5	17.6	18.5	17.6	17.2	17.2	16.3	13.3
20.3	24.1	26.2	26.4	27.3	26.9	27.5	26.9	27.5	26.9	27.5	26.9	26.9	25.8	24.2	18.6
20.3	25.4	27.4	28.7	29.0	29.4	29.0	29.4	29.0	29.4	29.0	29.3	28.3	27.7	24.4	19.3
19.1	23.8	25.6	25.6	29.2	29.6	29.3	29.6	29.3	29.6	29.3	29.5	28.6	27.4	24.3	19.2
18.8	23.5	27.2	27.9	29.4	28.8	29.5	28.8	29.5	28.8	29.5	28.8	28.7	26.8	24.1	18.5
18.4	24.0	26.9	28.7	29.0	29.6	29.1	29.6	29.1	29.6	29.1	29.4	28.4	27.2	23.5	18.5
18.5	23.5	27.2	28.4	29.4	29.1	29.6	29.1	29.6	29.1	29.6	29.0	28.7	26.9	24.0	18.4
18.5	24.1	26.8	28.7	28.8	29.5	28.8	29.5	28.8	29.5	28.8	29.4	27.9	27.2	23.5	18.8
19.2	24.3	27.4	28.6	29.5	29.3	29.6	29.3	29.6	29.3	29.6	29.2	25.6	25.6	23.8	19.1
19.3	24.4	27.7	28.3	29.3	29.0	29.4	29.0	29.4	29.0	29.4	29.0	28.7	27.4	25.4	20.3
18.6	24.2	25.8	26.9	26.9	27.5	26.9	27.5	26.9	27.5	26.9	27.3	26.4	26.2	24.1	20.3
13.3	16.3	17.2	17.2	17.6	18.5	17.6	18.5	17.6	18.5	17.6	18.5	17.4	18.2	16.5	14.9
	4 ←	1ft	→ 3 ←	1ft	→ 2 ←	1ft	→ 1		4 ←	1ft	→ 3 ←	1ft	→ 2 ←	1ft	→ 1
	DISPENSOR #2								DISPENSOR #1						

WING LEADING EDGE

Precipitation Type	IP

Date	

Run #	

Field to be manipulated

Target Rate	**25**	**g/dm²/h**
Duration	**5**	**minutes**

Footprint Rate	25	g/dm²/h
Stdev of Rate (+/-)	5	g/dm²/h

IP needed per 5min

In each position	81	g
In each Dispensor	323	g

IP needed for entire test

Total amount of IP in Each Dispensor	323	g
Total Amount IP Needed for Entire Test	1291	g

1. Enter "Date" and "Run #".
2. Manipulate desired "Target Rate" for test event.
3. Manipulate desired "Duration" for test event.
4. Prepare "Total Amount of IP Needed for Entire Test" in grams.
5. Prepare 4 boxes for "Total Amount of IP in Each Dispensor" in grams. **(Each Dispensor must be emptied at 5-minute intervals.)**
6. Dictate amount of IP needed "In each Position" in grams. **(Each Position must be emptied at approximately 1-minute intervals.)**
7. Once a Position is emptied of its contents (1-minute intervals), move the Dispensor 1-foot to the left.
8. Once a Dispensor has complested its cycle at Position #4, start next cycle at Position #4 and move 1-Foot to the right at (1-minute intervals). (e.g: Position #1 -> Pos #2 -> Pos #3 -> Pos #4 -> Pos #4 -> Pos #3 -> Pos #2 -> Pos #1 -> Pos #1...)

NOTE:

- Leading Edge (LE): Centre Pole of the Dispensor Stands must be 1-foot (12 inches) from the Leading Edge (LE)

-Trailing Edge (TE): Centre Pole of the Dispensor Stands must be 10-inches from the Trailing Edge (TE) Flap.

- Height of the Stand must be 4-feet from bottom of the dispensor

ATTACHMENT XX – Example Snow Dispensing Form

WING TRAILING EDGE

← 8 ft = 24.4 dm →

6 ft = 18.3 dm

DISPENSOR #3								DISPENSOR #4							
1 ←	1ft	→ 2 ←	1ft	→ 3 ←	1ft	→ 4		1 ←	1ft	→ 2 ←	1ft	→ 3 ←	1ft	→ 4	
23.1	24.8	27.2	25.5	27.4	25.5	27.4	25.5	27.4	25.5	27.4	25.5	27.4	25.4	26.6	19.7
27.1	35.5	34.9	36.7	35.1	36.7	35.1	36.7	35.1	36.7	35.1	36.7	35.0	36.3	33.9	29.8
24.6	39.4	36.4	41.4	36.8	41.5	36.8	41.5	36.8	41.5	36.8	41.5	36.7	41.1	35.5	35.2
14.4	26.3	25.3	28.6	25.7	28.7	25.7	28.7	25.7	28.7	25.7	28.7	25.6	28.4	24.7	24.3
8.8	15.2	16.4	17.4	17.0	17.6	17.2	17.6	17.2	17.6	17.2	17.6	17.0	17.2	15.9	14.2
6.1	9.4	10.6	11.2	11.1	11.4	11.2	11.4	11.2	11.4	11.2	11.3	11.0	10.9	9.8	7.9
7.9	9.8	10.9	11.0	11.3	11.2	11.4	11.2	11.4	11.2	11.4	11.1	11.2	10.6	9.4	6.1
14.2	15.9	17.2	17.0	17.6	17.2	17.6	17.2	17.6	17.2	17.6	17.0	17.4	16.4	15.2	8.8
24.3	24.7	28.4	25.6	28.7	25.7	28.7	25.7	28.7	25.7	28.7	25.7	28.6	25.3	26.3	14.4
35.2	35.5	41.1	36.7	41.5	36.8	41.5	36.8	41.5	36.8	41.5	36.8	41.4	36.4	39.4	24.6
29.8	33.9	36.3	35.0	36.7	35.1	36.7	35.1	36.7	35.1	36.7	35.1	36.7	34.9	35.5	27.1
19.7	26.6	25.4	27.4	25.5	27.4	25.5	27.4	25.5	27.4	25.5	27.4	25.5	27.2	24.8	23.1
	4 ←	1ft	→ 3 ←	1ft	→ 2 ←	1ft	→ 1		4 ←	1ft	→ 3 ←	1ft	→ 2 ←	1ft	→ 1
	DISPENSOR #2								DISPENSOR #1						

WING LEADING EDGE

Precipitation Type	Snow

Date	

Run #	

* ***Field to be manipulated***

Target Rate	**25**	**g/dm²/h**
Duration	**5**	**minutes**

Footprint Rate	25	g/dm²/h
Stdev of Rate	10	g/dm²/h

Snow needed per 5 minutes

In each position	84	76	g
In each Dispensor	336	305	g

Snow needed for entire test

In each Dispensor	336	305	g
Total Amount Snow Needed for Entire Test	1344	1222	g

1. Enter "Date" and "Run #".
2. Manipulate desired "Target Rate" for test event.
3. Manipulate desired "Duration" for test event.
4. Prepare "Total Amount of Snow Needed for Entire Test" in grams.
5. Prepare 4 boxes for "Total Amount of Snow in Each Dispensor" in grams. **(Each Dispensor must be emptied at 5-minute intervals.)**
6. Dictate amount of Snow needed "In each Position" in grams. **(Each Position must be emptied at approximately 1-minute intervals.)**
7. Once a Position is emptied of its contents (1-minute intervals), move the Dispensor 1-foot to the left.
8. Once a Dispensor has complested its cycle at Position #4, start next cycle at Position #4 and move 1-Foot to the right at (1-minute intervals).

(e.g. Position #1 -> Pos #2 -> Pos #3 -> Pos #4 -> Pos #4 -> Pos #3 -> Pos #2 -> Pos #1 -> Pos #1...)

NOTE:

- Leading Edge (LE): Centre Pole of the Dispensor Stands must be 1-foot (12 inches) from the Leading Edge (LE)

-Trailing Edge (TE): Centre Pole of the Dispensor Stands must be 10-inches from the Trailing Edge (TE) Flap. The use of Dispensor Stand Extention is needed.

- Height of the Stand must be 4-feet from bottom of the dispensor

ATTACHMENT XXI – Example Snow Dispensing Form

Precipitation Type	Sifted Snow

Date	

Run #	

* ***Field to be manipulated***

Target Rate	**25**	**g/dm²/h**
Duration	**5**	**minutes**

Footprint Rate	25	g/dm²/h
Stdev of Rate	10	g/dm²/h

Snow needed per 5 minutes

In each position	66
In each Dispensor	265

Snow needed for entire test

In each Dispensor	265
Total Amount Snow Needed for Entire Test	1062

1. Enter "Run #".
2. Manipulate desired "Target Rate" for test event.
3. Manipulate desired "Duration" for test event.
4. Prepare "Total Amount of Snow Needed for Entire Test" in grams.
5. Prepare 4 boxes for "Total Amount of Snow in Each Dispensor" in grams. **(Each Dispensor must be emptied at 5-minute intervals.)**
6. Dictate amount of Snow needed "In each Position" in grams. **(Each Position must be emptied at approximately 1-minute intervals.)**
7. Once a Position is emptied of its contents (1-minute intervals), move the Dispensor 1-foot to the left.
8. Once a Dispensor has complested its cycle at Position #4, start next cycle at Position #4 and move 1-Foot to the right at (1-minute intervals).
(e.g: Position #1 -> Pos #2 -> Pos #3 -> Pos #4 -> Pos #4 -> Pos #3 -> Pos #2 -> Pos #1 -> Pos #1...)

NOTE:

- Leading Edge (LE): Centre Pole of the Dispensor Stands must be 1-foot (12 inches) from the Leading Edge (LE)

-Trailing Edge (TE): Centre Pole of the Dispensor Stands must be 10-inches from the Trailing Edge (TE) Flap.

- Height of the Stand must be 4-feet from bottom of the dispensor

- Since dispensing is done using a sieve, the percentage of snow loss is reduced. This efficiency is estimated at 90%, as per visual analysis in 2009-10.

ATTACHMENT XXII – Visual Evaluation Rating Form

VISUAL EVALUATION RATING OF CONDITION OF WING

Date: ____________________ Run Number: _______

Ratings:
1 - Contamination not very visible, fluid still clean.
2 - Contamination is visible, but lots of fluid still present
3 - Contamination visible, spots of bridging contamination
4 - Contamination visible, lots of dry bridging present
5 - Contamiantion visible, adherence of contamination

Before Take-off Run

Area	Visual Severity Rating (1-5)
Leading Edge	
Trailing Edge	
Flap	

At Rotation

Area	Visual Severity Rating (1-5)
Leading Edge	
Trailing Edge	
Flap	

Expected Lift Loss (%)

After Take-off Run

Area	Visual Severity Rating (1-5)
Leading Edge	
Trailing Edge	
Flap	

Additional Observations:

OBSERVER: ____________________

ATTACHMENT XXIII – Fluid Receipt Form

(Consider using electronic auto-fill format)

SECTION A - SITE

☐ **HOT SAMPLE** ☐ **RESEARCH/OTHER SAMPLE**

Receiving Location: ______________________ **Date of Receiving:** ______________________

Manufacturer: __________________ **Fluid Name:** ______________________ **Fluid Type:** _______

Date of Production: ______________________ **Batch #:** ______________________

Fluid Dilution:	_______	_______	_______
Fluid Quantity:	___ x ___ L = _____ L	___ x ___ L = _____ L	___ x ___ L = _____ L
APS Measured BRIX:	_______	_______	_______

Note any additional information included on fluid containers:

Received by: ______________________
(PRINT NAME)
on: ______________________
(DATE)

SECTION B - OFFICE

Fluid Code Assigned: 100/0 _______ 75/25 _______ 50/50 _______ Type I _______

Viscosity Information Received:[1]	☐	**Viscosity Measured:**[1]	☐
WSET Sample Sent to AMIL:	☐	**WSET Result Received:**	☐
FFP Curves Received:[2]	☐		

[1] Type II/III/IV fluids only

[2] Type I fluids only

ATTACHMENT XXIV – Log of Fluid Sample Bottles

Date of Extraction	Fluid and Dilution	Batch #	Sample Source (i.e. drum)	Falling Ball Fluid Temp (°C)	Falling Ball Time (sec)	Comments

ATTACHMENT XXV – Procedure: Stall Warning Sensor

Background

Airfoil performance monitors (APM) are being developed and can be installed on any airfoil on an aircraft, including the tail. An APM is designed to measure the airflow over the wing, which reveals how well the wing is working. As a wing becomes contaminated, the APM should measure the changing or turbulent airflow and resulting lift generated by the wing. The APM is designed to alert the crew if the airflow degrades below a configurable threshold, giving the crew time to correct a potential stall before it happens. It was recommended that testing be conducted with a Canadian developed APM to support the development of the technology and aid in evaluating the potential for use in ground icing operations and to investigate whether or not the use of fluids with the systems would potentially obstruct the pressure ports which are critical to the systems operation.

Objective

To provide a testing platform to the manufacturer and allow them to evaluate the ability of the airfoil performance monitor to properly identify stall with and without icing conditions during aircraft ground operations with de/anti-icing fluid applications.

Methodology

- Conduct dry wing baseline testing with and without the installation to understand any potential aerodynamic influences the sensor may have;
- With the sensor installed, conduct dry wing tests to stall;
- Repeat tests with fluid only to stall;
- Evaluate ability of the APM to measure stall and compare to the stall observed through the aerodynamic data collected; and
- Evaluate the use of the APM unit with fluids.

Test Plan

Four tests are anticipated.

ATTACHMENT XXVI – Procedure: Heavy Snow

Background

As a direct result of the ice pellet research conducted, the use of HOTs for determining the protection time provided by anti-icing fluids was questioned. The focus has turned towards "aerodynamic failure" which can be defined as a significant lift loss resulting from contaminated anti-icing fluid. Heavy snow conditions have been selected for this study for two reasons. First, snow conditions account for the most significant portion of de-icing operations globally. Secondly, there has been a recent industry interest for holdover time for heavy snow conditions. Preliminary aerodynamic testing was conducted during the winters of 2006-07 and 2008-2011.

Objective

To investigate the fluid aerodynamic flow-off characteristics of anti-icing fluid contaminated with simulated heavy snow versus moderate snow.

Methodology

The general methodology to be used during these tests is in accordance with the methodologies used for typical snow condition tests conducted in the wind tunnel.

- For a chosen fluid, conduct a test simulating moderate snow conditions (rate of 25 g/dm²/h) for an exposure time derived from the HOT table based on the tunnel temperature at the time of the test;
- Record lift data, visual observations, and manually collected data;
- Conduct two comparative tests simulating heavy snow conditions (rate of 50 g/dm²/h or higher) for the same exposure time used during the moderate snow test;
    - o NOTE: previous testing has indicated that using half, to ¾ of the moderate snow HOT generates similar end conditions, whereas using the full moderate HOT for heavy snow conditions generates a more sever fluid failure which behaves worse aerodynamically. ;
- Record lift data, visual observations, and manually collected data;
- Compare the heavy snow results to the moderate snow results. If the heavy snow results are worse, repeat the heavy snow test with a

reduced exposure time, if the results are better, repeat the heavy snow test with an increased exposure time;

- Repeat until similar lift data, and visual observations are achieved for both heavy snow and moderate snow; and
- Document the percentage of the moderate snow HOT that is acceptable for heavy snow conditions.

Test Plan

Two to four comparative tests are anticipated. See previous reports for suggested test plan.

ATTACHMENT XXVII– Procedure: Heavy Contamination

Background

Previous testing in the wind tunnel demonstrated that although very heavy ice pellet and/or snow contamination was applied to a fluid covered wing section, significant lift losses were not apparent. The initial testing indicated that after a certain level of contamination, the dry loose ice pellets or snow no longer absorb into the fluid and easily fly off during the acceleration. The protection is due to a thin layer of fluid present underneath the contamination that prevents adherence. Questions of which point the lift losses become detrimental have been raised.

Objective

To continue previous research investigating heavy contamination effects on fluid flow off.

Methodology

The general methodology to be used during these tests is in accordance with the methodologies used for typical ice pellet tests conducted in the wind tunnel.

- For a chosen fluid, conduct a test simulating ice pellets, snow, or freezing rain, for an exposure time far exceeding the recommended HOT or allowance time;
- Record lift data, visual observations, and manually collected data; and
- Compare aerodynamic performance results to fluid only or fluid and contamination tests at the same temperature.

Test Plan

One to four tests are anticipated. Previous work should be referenced to identify starting levels of heavy contamination.

ATTACHMENT XXVIII – Procedure: Wind Tunnel Test Section Cooling

Background

Recent wind tunnel research has been limited by the ambient temperature in wind tunnel test section; in sunny conditions, the radiation will raise the temperature in the test section making testing difficult. To mitigate this effect, testing is often conducted overnight, however in some cases, even body heat from people working in the test area (specifically during long precipitation exposure tests) can affect the temperature. A new cooling system has been installed by the NRC to mitigate the effects of the radiation warming as well as from the heat generated by the personnel working in the test section. It was recommended that testing be conducted to evaluate the effects of the new cooling system on the test results.

Objective

To evaluate the effect of the cooling system on the aerodynamic test results produced.

Methodology

- Conduct a fluid only test without the cooling system. Have personnel standing on scaffolding for 20-minutes following fluid application to generate extra heat prior to running the wind tunnel;
- Conduct a second comparative fluid only test with the cooling system. Have personnel standing on scaffolding for 20-minutes following fluid application to generate extra heat prior to running the wind tunnel;
- Conduct a third comparative test at a suitable ambient temperature where the expected test area temperature with the cooling system is equal to the test area temperature of the test conducted without the cooling system.
- Compare aerodynamic performance results.

EXAMPLE OF COMPARATIVE DATA TO BE COLLECTED

Test #	Cooling System Status	OAT ºC	Test Area Temp ºC	Lift Loss %
1	Off	-18	-14	6.3
2	On	-18	-17	7.5
3	On	-15*	-14	5.7

* to be selected based on efficiency of cooling system based on test #2

Test Plan

Three tests at a minimum are expected.

ATTACHMENT XXIX- Procedure: Effect of Fluid Viscosity

Background

Testing was previously conducted to evaluate the aerodynamic effects of fluid viscosity on flow-off. To do so, comparative testing was conducted with both mid-production fluid (used for ice pellet allowance time testing) and with lowest on-wing viscosity fluid (LOWV) (used for holdover time testing). Testing was conducted with the thin high performance airfoil in fluid only conditions. Additional testing was recommended to further substantiate the testing results.

Objective

To continue previous research evaluating the effect of fluid viscosity on aerodynamics.

Methodology

For each comparative test set, a baseline mid-production test should be conducted, and immediately followed by a lowest on-wing viscosity test of the same fluid type. Testing should be done with fluid only and fluid and contamination.

Test Plan

Two to four tests are anticipated.

ATTACHMENT XXX – Procedure: Fluid and Contamination at LOUT

Background

Recent changes to the frost HOT guidance material allowing fluids to be used to the LOUT have raised concerns about whether or not this is an appropriate practice. In frost the major concern was the effect of radiation cooling and how it could affect the LOUT, however the concern also includes contamination at LOUT. This issue was also raised from the AWG for the ice pellet testing which allows fluids to be used to LOUT: will the added ice pellet contamination at the LOUT not bust BLDT? It was recommended that some testing be conducted at the fluid LOUT to investigate how contamination can affect the aerodynamic performance of the fluid.

Objective

To investigate the fluid aerodynamic flow-off characteristics of anti-icing fluid with contamination at the LOUT.

Methodology

The general methodology to be used during these tests is in accordance with the methodologies used for typical ice pellet tests conducted in the wind tunnel.

- For a chosen fluid, conduct a test simulating ice pellets, snow, freezing fog, or frost, for an exposure time derived from the HOT table at the fluid LOUT;
- Record lift data, visual observations, and manually collected data;
- Conduct a fluid only baseline test at the same temperature (at LOUT); and
- Compare the aerodynamic performance.

Test Plan

Four or more tests are anticipated at a minimum. If LOUT temperatures for neat fluids are not likely to occur, investigate the possibility of using diluted fluids to obtain a higher LOUT.

ATTACHMENT XXXI – Procedure: Small Hail

Background

Reports from primarily Asian operators have indicated that small hail can occur frequently during winter operations. The small hail will generally occur above freezing conditions; however no guidance for operating in the conditions is currently available. Questions have been raised as to whether the ice pellet allowance times can be used due to similarity in precipitation type. Although this concern has only been raised by Asian operators, it can be assumed that similar conditions can be expected by North American operators. WMO defines small hail as snow pellets encapsulated by ice, a precipitation halfway between graupel and hail.

Objective

To investigate the fluid aerodynamic flow-off characteristics of anti-icing fluid with contamination with small hail and to compare the results to ice pellets.

Methodology

The general methodology to be used during these tests is in accordance with the methodologies used for typical ice pellet tests conducted in the wind tunnel.

- For a chosen fluid, conduct a test simulating small hail for an exposure time derived from the current ice pellet allowance time table as a starting point;
- Record lift data, visual observations, and manually collected data;
- Conduct a fluid only baseline test at the same temperature; and
- Compare the aerodynamic performance.

Test Plan

One to four tests are anticipated. A meteorologist should be consulted prior to the conduct to narrow down the exact conditions and temperatures at which small hail will occur, as well as to obtain the desired small hail diameter.

ATTACHMENT XXXII – Procedure: Frost Simulation in the Wind Tunnel

Background

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. Frost is an area of research that has yet to be fully explored. Discussions regarding the aerodynamic effects of frost have been raised, and the possibility of doing wind tunnel testing has been considered. It was recommended that initial testing be performed to investigate whether it would be feasible to simulate frost conditions in the PIWT.

Objective

To investigate the feasibility of simulating frost conditions in the PIWT.

Methodology

This work is exploratory, so no exact procedure exists. It is recommended that the frost generating parameters be explored to try and stimulate frost accretion. This can be done by causing a negative temperature differential between the wing and the ambient air i.e. air is warmer than skin. A more specific methodology may be determined on site following a brain-storm with onsite technicians.

Test Plan

One or two tests is anticipated.

ATTACHMENT XXXIII – Procedure: Flaps/Slats Testing to Support YMX Tests

Background

Flaps/slats testing has been conducted with the support of UPS during the winters of 2011-12 and 2012-13, and is scheduled to continue during the winter of 2013-14. The initial results have indicated that extended configurations can result in earlier fluid failure on the flap and slats as compared to the main section of the wing. It was recommended that testing in the wind tunnel be conducted to evaluate how significant the aerodynamic penalties would be from having failed fluid in these isolated areas.

Objective

To investigate the aerodynamic performance degradation associated with failed fluid on flaps and slats.

Methodology

The general methodology to be used during these tests is in accordance with the methodologies used for typical snow condition tests conducted in the wind tunnel.

- For a chosen fluid, conduct a test simulating moderate snow conditions (rate of 25 $g/dm^2/h$) for an exposure time derived from the HOT table based on the tunnel temperature at the time of the test;
- Simulate early fluid failure on the fixed leading edge by applying higher rates of contamination on this area (record additional amounts);
- The flap is a hinged flap, so will be subject to early failure by design;
- Record lift data, visual observations, and manually collected data;
- Conduct a fluid only baseline test at the same temperature;
- Compare the aerodynamic performance; and
- Consideration should be given to conducting Type I tests.

Test Plan

Two to four comparative tests are anticipated.

ATTACHMENT XXXIV – Procedure: Mixed HOT Conditions

Background

As the accuracy of meteorological reporting continues to improve, there has been a need to provide improved guidance material during these transitional periods of mixed precipitation. During the winter of 2008-09, guidance material was developed for operations during light snow mixed with light rain conditions. As a result of this work, there was industry interest in guidance material for operations during light freezing rain and moderate snow conditions as well as other mixed conditions. The objective of these tests is to collect data to determine if the current HOT guidelines can be expanded to include other operational mixed conditions which may be of current interest to industry.

Objective

To investigate if the current HOT guidelines can be expanded to include mixed conditions i.e. light freezing rain and moderate snow conditions.

Methodology

The general methodology to be used during these tests is in accordance with the methodologies used for precipitation tests conducted in the wind tunnel.

- For a chosen fluid, conduct a test simulating mixed conditions for an exposure time derived from the HOT table based on relative condition;
- Record lift data, visual observations, and manually collected data;
- Conduct a fluid only baseline test at the same temperature; or
- Conduct a test with an existing relative HOT condition to evaluate the severity of the condition;
- Compare the aerodynamic performance; and
- If the mixed condition results are severe, repeat the test with a reduced exposure time, if the results are good, repeat the test with a increased exposure time.

Test Plan

Two to four comparative tests are anticipated.

ATTACHMENT XXXV – Procedure: Snow on an Un-Protected Wing

Background

In colder northern operations, it is common for aircraft to depart with "loose, dry, un-adhered snow" on present on their wing sections. Although it is assumed most or all of this contamination will be removed at the time of rotation, it is unknown whether a certain level of contamination will reduce aerodynamic performance. Preliminary testing has demonstrated fluid seepage from the airfoil can lead to snow diluting and adhering to the airfoil during rotation; this effect has yet to be substantiated will operational data. During the winter of 2011-12, a video was leaked on the internet of an eastern European aircraft taking off with significant amounts of snow on the wing. As a result, additional wind tunnel testing was conducted during the winter of 2011-12. It was recommended that additional testing investigate the aerodynamic performance of a wing section contaminated with dry, un-adhered snow versus wet or humid snow.

Objective

To investigate the aerodynamic performance of a wing section contaminated with dry, un-adhered snow versus wet or humid snow.

Methodology

The general methodology to be used during these tests is in accordance with the methodologies used for typical snow condition tests conducted in the wind tunnel.

- Ensure the wing section and tunnel temperature are well below freezing (-5ºC and below);
- Ensure the wing section is clean, dry, and free of any forms of contamination;
- Apply loose, dry snow contamination to the wing section;
- Record lift data, visual observations, and manually collected data; and
- Compare the results to baseline fluid only and dry wing test results.

Test Plan

One to four comparative tests are anticipated.

ATTACHMENT XXXVI – Procedure: Feasibility of Ice Pellet Testing at Higher Speeds

Background

Historically, the ice pellet allowance time testing conducted in the wind tunnel simulated typical aircraft rotation of 100 knots, and more recently some limited work at 115 knots. As a result of some of the higher lift losses observed at colder temperatures with PG fluids applied to a thin high performance airfoil, it was recommended that higher speed testing be conducted to verify if the limitations in the allowance times would need to be applied to commercial aircraft with rotation speeds well above 115 knots. It was recommended that 130-150 knots be targeted, however modifications to the wind tunnel may be required as those higher speeds may increase stress on the wind tunnel engine and other structural systems.

Objective

To investigate the feasibility of conducting ice pellet testing at higher speeds of 130-150 knots.

Methodology

This work is exploratory, so no exact procedure exists. A more specific methodology may be determined on site following a brain-storm with onsite technicians. It is expected that a series of tests may be conducted to try and achieve speeds above 115 knots without rotating the wing model.

Test Plan

One or two tests are anticipated, however more tests may be required based on the results.

ATTACHMENT XXXVII – Procedure: Windshield Washer Used as Type I Deicer

Background

Based on recent industry reports, it has become apparent that in more remote airports or with general aviation aircraft with smaller operations, aircraft deicing is not being conducted with SAE aircraft ground deicing Type I fluid, but rather with off-the-shelf windshield washer fluid. Although the basic chemistry of the windshield washer fluid may be similar, questions regarding the fluid freeze point, holdover time, aerodynamics, and material compatibility have been raised. It was recommended that some preliminary testing be conducted to investigate fluid flow off in the wind tunnel with and without contamination. Limited test was conducted during the winter of 2011-12. It was recommended that testing should continue if necessary based on operational needs.

Objective

To evaluate the holdover time and aerodynamic effects windshield washer fluid when used a substitute for an aircraft ground deicing Type I fluid.

Methodology

- Purchase various formulations of windshield washer fluid with varying freeze points;
- Apply fluid heated to 20ºC using a garden sprayer;
- Expose to simulated freezing contamination (snow, freezing rain, or ice pellets). The exposure time is to be determined based on Type I fluid HOT's (45 minutes at a rate of 0.3 g/dm^2/h);
- Document condition of the wing;
- Run the wind tunnel and collect data; and
- Compare results to baseline uncontaminated windshield washer tests and potentially with standard Type I tests.

Test Plan

No testing is planned unless indicated otherwise by TC.

ATTACHMENT XXXVIII – Procedure: Effect of Fluid Seepage on Dry Wing Performance

Background

Preliminary observations have indicated that fluid seepage from the airfoil can lead to lift losses and other aerodynamic impacts. This is especially of concern after a long series of fluid tests followed by a baseline dry wing test. It was recommended that testing investigate the aerodynamic impacts of residual fluid seepage on the airfoil performance.

Objective

To investigate the aerodynamic impacts of residual fluid seepage on the airfoil performance.

Methodology

The general methodology to be used during these tests is in accordance with the methodologies used for typical tests conducted in the wind tunnel.

- To be conducted following a long series of fluid and/or contamination tests;
- Ensure the wing section is clean, dry, and free of any forms of contamination;
- Record lift data, visual observations, and manually collected data;
- Compare results to the first dry wing test of the season;
- Re-clean the wing using a wet-vac or other alternative method to try and remove any residual fluid;
- Record lift data, visual observations, and manually collected data; and
- Compare the results.

Test Plan

One to three comparative tests are anticipated.

ATTACHMENT XXXIX – Procedure: 2nd Wave of Fluid during Rotation

Background

Previous wind tunnel testing has shown that during a simulated take-off roll following de/anti-icing, fluid will shear off the wing section; however a small amount of fluid can remain trapped along the leading edge at the stagnation point. This "trapped" fluid begins to flow over the wing only once the wing is rotated; the stagnation point shifts below the leading edge, and the "trapped" fluid begins to shear off as a second wave. Previous testing was simulated in a static model using strips of speed tape and cork tape strategically located on the leading edge of the wing section (along the span where the separation bubble will typically occur). A separate set of dynamic tests simulated the second wave with actual anti-icing fluid; sheared fluid prior to rotation was left only in select areas either below or above the stagnation point and then the flow was observed during a typical rotation. The results showed the stalling characteristics of the wing with fluid (or fluid with contamination) appear to be driven by secondary wave effects near the leading edge; these effects are difficult to interpret on the two-dimensional model relative to a fully three-dimensional wing and should not be used in developing allowance times. Additional testing may be useful to better understand this effect.

Objective

To investigate the aerodynamic effects of the second wave of fluid flow during rotation.

Methodology

- Simulate the 2nd wave of fluid using strips of tape applied at specific areas at different thicknesses on the wing, or with fluid; and
- Compare the different results.

Test Plan

One to four tests are anticipated.

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APPENDIX F

AEROSPACE INFORMATION REPORT

SAE Aerospace An SAE International Group	AEROSPACE INFORMATION REPORT	AIR 6232	Final Version 1.3
		Issued: July 8, 2013 Revised: N/A	

AIRCRAFT SURFACE COATING INTERACTION WITH
AIRCRAFT DEICING/ANTI-ICING FLUIDS

RATIONALE

This SAE Aerospace Information Report (AIR) provides a description of screening methods for verifying whether aircraft surface coatings have adverse effects on aircraft deicing/anti-icing fluid performance as published in the holdover time guidelines. The surface coatings include thin film coatings, typically less than 1 mil (0.0254 millimeters) thick and sometimes called paint sealants or protectants, as well as bulk coatings that are typically greater than 2 mils (0.0508 millimeters) thick. Although recommended performance criteria have been outlined, ultimately, the interpretation of the test results outlined in this document will be left to the discretion of the aircraft operator.

FOREWORD

Aircraft operators rely on the use of SAE AMS 1424 and/or SAE AMS 1428 deicing/anti-icing fluids during winter operations to provide a limited period of protection against frozen or freezing precipitation while the aircraft is on the ground. Methods of protection of aircraft surfaces with these fluids are described in ARP 4737. The protection time can be estimated using fluid-specific holdover time guidelines that are published by the Federal Aviation Administration (FAA) and Transport Canada (TC). Holdover time values for deicing/anti-icing fluids are derived from standard endurance time testing procedures that are described in SAE ARP 5945 and SAE ARP 5485. The aerodynamic performance of deicing/anti-icing fluids is evaluated according to the procedure described in SAE AS 5900.

Recently, aircraft operators have expressed interest in the use of after-market coatings on aircraft surfaces for various purposes, including appearance enhancement, fuel savings, and ice shedding. The coatings may be designed to have hydrophilic or hydrophobic properties, and therefore, the interaction of these coatings with SAE AMS 1424 and/or SAE AMS 1428 deicing/anti-icing fluids and their associated holdover times is unclear. Since aircraft coatings may affect fluid wetting capability and resulting fluid thickness, they could affect a fluid’s holdover time protection. Therefore, the interaction of aircraft surface coatings and aircraft deicing/anti-icing fluids should be -evaluated with respect to holdover time performance and aerodynamic performance. In addition, test methods are available to help characterize the various aircraft surface coating properties, including durability, hardness, weathering, effect on aerodynamic drag, ice adhesion, ice accumulation, contact angle, and thermal conductivity. This AIR 6232 provides test methods which can serve as screening indicators for compatibility and additional test methods which can be used to characterize the different coatings.

1. SCOPE

This SAE Aerospace Information Report (AIR) provides descriptions of test methods for determining if an aircraft surface coating of any thickness has adverse effects on aircraft deicing/anti-icing fluids with respect to fluid holdover time performance and aerodynamic performance.

Although not the primary mandate of the G-12 Aircraft Ground Deicing Committee, this document also provides descriptions of suggested test methods for evaluating aircraft surface coatings with respect to durability, hardness, weathering, aerodynamic drag, ice adhesion, ice accumulation, contact angle, and thermal conductivity. These additional tests can provide informational data for characterizing the coatings and may be useful to operators when evaluating the coatings.

1.1 Purpose

To provide a reference method for evaluating the interaction of aircraft surface coatings with respect to aircraft deicing/anti-icing fluid holdover time performance and aerodynamic performance.

To provide additional informational test methods that can be used for characterizing the aircraft surface coatings.

1.2 Definitions and Abbreviations

- ADVANCING CONTACT ANGLE: The advancing angle is the largest possible contact angle attained by the drop during volume addition before the motion of the contact line. Similarly, it is the maximum angle attained by the advancing front on an inclined surface before the motion of the contact line;
- AERODYNAMIC ACCEPTANCE TEST: A performance test required under §3.2.5 of AMS 1428 and defined in AS 5900;
- AIRCRAFT SURFACE COATING: A coating applied to an aircraft surface with properties that may be icephobic, hydrophobic, super-hydrophobic, or hydrophilic. This term as used in the document is not intended to refer to surface finishes that have been qualified by the original equipment manufacturer;
- BOUNDARY LAYER DISPLACEMENT THICKNESS (BLDT): The measured displacement of the air flow over a surface. The increase in BLDT over the flat plate surface caused by the fluid flow-off during the AS 5900 aerodynamic acceptance is directly related to loss of lift during takeoff;
- BUFFER: The difference between OAT and the freezing point of the fluids used;
- CASSIE STATE: When the liquid of a drop does not fill the voids in the solid on which it sits and the voids remain filled with air, resulting in a hydrophobic condition, the opposite of Wenzel State;
- CONTACT ANGLE: The angle, conventionally measured relative to the liquid-air and liquid-sold interfaces, quantifying the wettability of a solid surface by a liquid;
- CONTACT ANGLE HYSTERESIS: The difference between the advancing and receding contact angles;
- ENDURANCE TIME: Time that a fluid can endure defined and controlled temperature and precipitation conditions before visual failure. Endurance time tests are defined in ARP 5485 and ARP 5945;
- FAA: United States Department of Transportation, Federal Aviation Administration.
- HOLDOVER TIME (HOT): Starting from the time of initial application of an anti-icing fluid, the time that the fluid is expected to provide protection of an aircraft against freezing or frozen precipitation;
- HOLDOVER TIME GUIDELINE: A table giving the holdover time for various precipitation conditions and temperatures, with cautions and notes, giving guidance to ground

deicing/anti-icing crews and pilots. The "holdover time guideline" is also often referred to as the "holdover time table";

- HYDROPHILIC SURFACE: A surface producing a contact angle of $\theta < 90°$;
- HYDROPHOBIC SURFACE: A surface producing a contact angle of $\theta > 90°$;
- ICEPHOBIC SURFACE: A surface producing a reduction in ice adhesion;
- LOWEST ON-WING VISCOSITY (LOWV): Lowest viscosity of a fluid for which the applicable holdover time table can be used;
- LOWEST OPERATIONAL USE TEMPERATURE (LOUT): The lowest temperature at which a Type I/II/III/IV fluid can be used on an aircraft, generally recognized as the higher of:
    a. the lowest temperature at which it meets the aerodynamics acceptance test (AS 5900) for a given type of aircraft; or
    b. the freezing point of the fluid plus the freezing point buffer of 7 °C for Type II/III/IV fluids, or 10 °C for Type I fluids.
- MAXIMUM ON-WING VISCOSITY (MOWV): Maximum viscosity of a fluid which is still aerodynamically acceptable;
- OAT: Outside Air Temperature;
- RECEDING CONTACT ANGLE: The receding angle is smallest possible angle which can be measured when liquid is removed from the drop. Similarly, it is the minimum angle attained by the receding front on an inclined surface before the motion of the contact line;
- ROLL-OFF ANGLE; The tilt angle of a surface relative to horizontal at which the water drop starts to slide on the surface and varies between 0 and 90 degrees. Also called sliding angle;
- SLIDING ANGLE: The tilt angle at which the water drop starts to slide on the surface and varies between 0 and 90 degrees. Also called roll-off angle;
- STANDARD ALUMINUM TEST PLATE: Aluminum test plate surface used for endurance time testing of Type I and Type II/III/IV fluids in accordance with ARP 5945 and ARP 5485;
- SUPER-HYDROPHOBIC SURFACE: A surface producing a static contact angle of $\theta > 150°$ and a roll-off angle of less than 10º;
- TREATED SURFACE: A surface that has been treated with an aircraft surface coating of any thickness;
- UNTREATED SURFACE: A surface in its original condition from the airplane manufacturer, or a surface that has been painted with a coating qualified by the manufacturer for use on that surface, that has not been treated with an aircraft surface coating; and
- WENZEL STATE: When the liquid of a drop fills the voids in the solid on which it sits, the opposite of Cassie State.

2. APPLICABLE DOCUMENTS

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

AIR 6130-2011 — Cadmium Plate Cyclic Corrosion Test

AMS 1424 — Deicing/Anti-icing Fluid, Aircraft, SAE Type I

AMS 1428 — Fluid, Aircraft Deicing/Anti-icing, Non-Newtonian (Pseudoplastic), SAE Types II, III, and IV

AMS 1650 — Polish, Aircraft Metal

AMS 3095 — Paint, Gloss, Airline Exterior System

AMS-C-83231A — Coatings, Polyurethane, Rain Erosion Resistant for Exterior Aircraft and Missile Plastic Parts

ARP 4737 — Aircraft Deicing/Anti-Icing Methods

ARP 5485 — Endurance Time Tests for Aircraft Deicing/Anti-icing Fluids SAE Type II, III, and IV

ARP 5945 — Endurance Time Tests for Aircraft Deicing/Anti-icing Fluids SAE Type I

AS 5900 — Standard Test Method for Aerodynamic Acceptance for SAE AMS 1424 and SAE AMS 1428 Aircraft Deicing/Anti-icing Fluids

2.2 FAA Publications

Available from the Federal Aviation Administration at http://www.faa.gov/.

- Official FAA Holdover Time Tables Winter 20XX-20XX. (New document published for each winter. Always use the latest issue; search for “FAA Holdover Time”.)
- FAA-Approved Deicing Program Updates, Winter 20XX-20XX. (New document published for each winter. Always use the latest issue; search for “FAA-Approved Deicing Program”.)

2.3 Transport Canada Publications

Available from Transport Canada, Civil Aviation Directorate, Standards Branch, 330 Sparks Street, Ottawa, Ontario, K1A 0N5, Canada and at http://www.tc.gc.ca/eng/civilaviation/standards/commerce-holdovertime-menu-1877.htm.

- Transport Canada Holdover Time Guidelines Winter 20XX-20XX. (New document published for each winter. Always use the latest issue).
- Guidelines for Aircraft Ground Icing Operations. TP14052E, April 2005.
- Aircraft Ground De/Anti-Icing Fluid Holdover Time and Endurance Time Testing Program for the 2001-02 Winter. TP13991E, December 2002.

2.4 Other Publications

Goldhammer, Mark I., and Plendl, Bruce R., “Surface Coatings and Drag Reduction,” *AERO* magazine, The Boeing Company, edition Q1, 2013.

AIMS 09-00-002	Evaluation of Maintenance Materials, Airbus
AIP 94, 133109-1	Nonwetting of Impinging Droplets on Textured Surfaces
AIP 97, 234102	Frost Formation and Ice Adhesion on Superhydrophobic Surfaces
APS 106, 036102	Rapid Deceleration-Driven Wetting Transition during Pendant Drop Deposition on Superhydrophobic Surfaces
ASTM C518 – 10	Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus
ASTM D5930-01	Standard Test Method for Thermal Conductivity of Plastics by Means of a Transient Line-Source Technique
ASTM E1225-04	Standard Test Method for Thermal Conductivity of Solids by Means of the Guarded-Comparative-Longitudinal Heat Flow Technique
ASTM F483	Standard Practice for Total Immersion Corrosion Test for Aircraft Maintenance Chemicals
ASTM F484	Standard Test Method for Stress Crazing of Acrylic Plastics in Contact with Liquid or Semi-Liquid Compounds
ASTM F502	Standard Test Method for Effects of Cleaning and Chemical Maintenance Materials on Painted Aircraft Surfaces
ASTM F519-93	Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating/Coating Processes and Service Environments
ASTM F1110	Standard Test Method for Sandwich Corrosion Test
D6-17487	Evaluation of Airplane Maintenance Materials, Boeing
ISO 8301	Thermal insulation -- Determination of steady-state thermal resistance and related properties -- Heat flow meter apparatus"
ISO 11507	Paints and varnishes -- Exposure of coatings to artificial weathering -- Exposure to fluorescent UV lamps and water
ISO 22007-2:2008	Plastics -- Determination of thermal conductivity and thermal diffusivity -- Part 2: Transient plane heat source (hot disc) method"
ISO 22007-3:2008	Plastics -- Determination of thermal conductivity and thermal diffusivity -- Part 3: Temperature wave analysis method"
ISO 22007-4:2008	Plastics -- Determination of thermal conductivity and thermal diffusivity -- Part 4: Laser flash method

3. COMPARATIVE FLUID ENDURANCE TIME TESTS

Tests should be conducted with SAE AMS 1424 Type I fluids and SAE AMS 1428 Type II/III/IV fluids to compare the endurance times of fluids applied to aluminum test plate surfaces treated with the aircraft surface coating to the endurance times of the same fluids applied to an untreated standard aluminum test plate (and as an optional test, a freshly painted aluminum test plate which serves as reference tool). If the coating being tested will typically be applied to painted surfaces, consideration should be given to conducting testing using painted, untreated and treated test plates.

Comparative endurance time testing should be conducted according to the procedures described in ARP 5945 and ARP 5485.

3.1 Fluid Selection

The aircraft operator or coating manufacturer should determine the fluid brands to be tested. The following are recommended criteria for selecting the fluids for the comparative endurance time testing:

- Minimum of two SAE AMS 1424 Type I fluids. Consideration should be given to testing both an ethylene-glycol and a propylene-glycol fluid diluted to a 10ºC freezing point buffer, and possibly also the standard mix. A non-glycol formulation may also be considered depending on the expected operations.
- Minimum of two SAE AMS 1428 Type II/III/IV fluids. Consideration should be given to testing both an ethylene-glycol and a propylene-glycol fluid at 100/0 fluid/water dilution (also referred to as undiluted or “neat”), and possibly also at 75/25 and 50/50 dilutions. A non-glycol formulation may also be considered depending on the expected operations. Fluid viscosity should be within the production range specified by the fluid manufacturer that meets on-wing viscosity limits.

3.2 Test Surfaces

The following is a description of the test surfaces that should used for the comparative endurance time testing:

- Standard Aluminum Test Plate (Baseline Surface)
  - Material Aluminum alloy AMS 4037 or 4041
  - Test plate dimensions 500 mm long x 300 mm wide x 3.2 mm thick
  - Angle 10.0° ± 0.2°
  - Average surface roughness: Ra ≤ 0.5 µm
- Treated Test Plate
  - Same material and construction as the “Standard Aluminum Test Plate” described above, however, treated using aircraft surface coating according to coating manufacturer specifications.
- Painted Test Plate (Optional)
  - Same material and construction as the “Standard Aluminum Test Plate” described above, however, painted using representative aircraft grade primer and paint according to AMS 3095 specifications.

Note: In the case of outdoor natural snow testing with Type I fluid, the test surface is considered as the upper plate surface of the empty aluminum box described in ARP 5945.

3.3 Precipitation Conditions for Holdover Time Evaluation

Comparative endurance time testing will evaluate the fluid performance on a treated test plate versus a standard aluminum test plate, and in some cases versus a painted test plate. Testing in each of the holdover time precipitation conditions described in ARP 5945 and ARP 5485 with each of the selected fluids is not practical in most cases. For that reason, Table 1 provides a suggested minimum set of precipitation conditions for comparative testing. All possible testing conditions have been included in Table 1 for planning purposes, with a minimum suggested set of precipitation conditions for comparative testing indicated by "X". When selecting conditions, the objective is to try to obtain a broad range of temperatures and precipitation rates.

Natural snow tests have been specified with ranges of air temperature and icing intensity; as testing is conducted outdoors, conditions may vary depending on weather. In the event that natural snow testing is not possible, consideration can be given to conducting artificial snow testing.

A recommended set of frost tests has been included in Table 1 which may be modified in future revisions of this document to reflect new frost testing procedures being developed for inclusion in ARP 5945 and ARP 5485.

TABLE 1 – Matrix of Suggested HOT Testing Conditions for Comparative Testing

Precipitation Type	Precipitation ID.	Air temperature, °C	Icing intensity, $g/dm^2/h$	Type I Fluid A	Type I Fluid B	Type II/III/IV Fluid C	Type II/III/IV Fluid D
Frost	FROST - A	>-3	<0.3	X*		X*	
	FROST - B	-3 to -14	<0.3	X	X	X	X
	FROST - C	-14 to -25	<0.3	X		X	
Freezing Fog	FOG-A	-3 ± 0.5	2.0 ± 0.2				
	FOG-B	-3 ± 0.5	5.0 ± 0.2	X*		X*	
	FOG-S	-6 ± 0.5	2.0 ± 0.2				
	FOG-T	-6 ± 0.5	5.0 ± 0.2				
	FOG-C	-14 ± 0.5	2.0 ± 0.2				
	FOG-D	-14 ± 0.5	5.0 ± 0.2				
	FOG-E	-25 ± 1	2.0 ± 0.2	X		X	
	FOG-F	-25 ± 1	5.0 ± 0.2				
Freezing Drizzle	ZL-A	-3 ± 0.5	5 ± 0.2				
	ZL-B	-3 ± 0.5	13 ± 0.5	X		X*	X
	ZL-S	-6 ± 0.5	5 ± 0.2				
	ZL-T	-6 ± 0.5	13 ± 0.5				
	ZL-C	-10 ± 0.5	5 ± 0.2		X*	X*	
	ZL-D	-10 ± 0.5	13 ± 0.5			X	X
Light Freezing Rain	LZR-A	-3 ± 0.5	13 ± 0.5	X*	X	X*	
	LZR-B	-3 ± 0.5	25 ± 1.0			X	X
	LZR-S	-6 ± 0.5	13 ± 0.5				
	LZR-T	-6 ± 0.5	25 ± 1.0				
	LZR-C	-10 ± 0.5	13 ± 0.5				
	LZR-D	-10 ± 0.5	25 ± 1.0	X		X	X*
Rain on Cold Soaked Wing	RCSW-A	1 ± 0.5	5.0 ± 0.4				
	RCSW-B	1 ± 0.5	75.0 ± 3.0				
Natural Snow	SNW-K	>-3	2 to 10				
	SNW-L	>-3	10 to 25	X	X	X	X
	SNW-M	-3 to -6	2 to 10	X*	X	X*	X
	SNW-N	-3 to -6	10 to 25				
	SNW-O	-6 to -10	2 to 10	X		X	
	SNW-P	-6 to -10	10 to 25	X	X	X	X
	SNW-Q	-10 to -14	2 to 10				
	SNW-R	-10 to -14	10 to 25				
	SNW-S	-14 to -25	2 to 10				
	SNW-T	-14 to -25	10 to 25				

X = Comparative Fluid Endurance Time Test on: 1. Standard Aluminum Test Plate and 2. Treated Test Plate
X* = Comparative Fluid Endurance Time Test on: 1. Standard Aluminum Test Plate, 2. Treated Test Plate, and 3. Painted Test Plate

3.4 Fluid Thickness and Fluid Wetting Tests

Comparative testing should be conducted using the same protocol used to characterize the fluid thickness decay profile of fluids submitted for endurance time testing. The procedure is entitled, “Experimental Program to Establish Film Thickness Profiles for De-Icing and Anti-Icing Fluids on Flat Plates”, and can be found in Transport Canada Report TP 13991E, Appendix I. The procedure specifies that fluid thickness measurements be made at the 15 cm line of a 10º inclined test plate at 2, 5, 15, and 30 minutes following fluid application. In the case of Type I fluids, fluid wetting should be evaluated rather than fluid thickness. These tests should not be conducted under precipitation. Table 2 suggests a minimum set of tests for comparative fluid thickness and wetting. Consideration should be given to expanding this matrix to include other dilutions if used by the aircraft operator.

TABLE 2 – Selected Fluid Thickness and Wetting Testing Conditions for Comparative Testing

Test ID	Fluid	Fluid Dilution	Air Temperature, °C	Test Plates
TH1	Type I B	10° Buffer	-3°C	Standard and Treated
TH2	Type I A	10° Buffer	-3°C	Standard, Treated, and Painted
TH3	Type I A	Standard Mix (50/50)	-3°C	Standard and Treated
TH4	Type II/III/IV C	100/0	-3°C	Standard and Treated
TH5	Type II/III/IV D	100/0	-3°C	Standard and Treated

3.5 Interpretation of Test Results

The comparative endurance time tests will provide a good indication of fluid endurance time performance when applied to aircraft surfaces treated with coatings. The interpretation of the test results, and ultimately the decision to use the coating on aircraft, is the responsibility of the aircraft operator.

3.6 Testing Organization

As of the date of publication of the AIR, the following organization is known to provide testing for anti-icing fluids. This is not an endorsement by SAE for this organization but simply to facilitate the location of laboratories for those seeking testing. Please enquire directly with the organization for a full list of testing available.

APS Aviation Inc., 6700, chemin de la Côte-de-Liesse, Suite 105, Saint-Laurent, Quebec, H4T 2B5, Canada; 514-878-4388, www.adga.ca/aps.

4. COMPARATIVE FLUID AERODYNAMIC TESTS

Aircraft surface coatings may influence the fluid flow-off behavior. These coatings may result in flow-off improvement, or they may cause adverse effects on aerodynamic performance. For this reason, it is suggested that testing be conducted to evaluate the impact of aircraft surface coatings on fluid flow-off characteristics. Tests should be conducted with SAE AMS 1424 Type I fluids and SAE AMS 1428 Type II/III/IV fluids. The purpose is to compare the aerodynamic test results of a fluid applied on top of an aircraft surface coating to those of the same fluid without the coating. The basis of the comparative test methodology should be the fluid aerodynamic acceptance test AS 5900.

4.1 Fluid Selection

The fluid selection should be in accordance with Section 3.1.

4.2 Test Surfaces

The following is a description of the test surfaces that should be used for the comparative aerodynamic testing:

- Standard Test Duct Floor (Baseline Surface)
  - Plexiglas
  - Test duct floor dimensions 1600 mm long x 302 mm wide
  - Horizontal
  - Surface shall be hydraulically smooth, resulting in a dry boundary layer displacement thickness (BLDT) ≤ 3.0 mm at duct end at 65 m/s ± 5 m/s, or a dry BLDT ≤ 3.3 mm at duct end at 35 m/s ± 3 m/s.
- Aluminum Test Plate
  - Material Aluminum alloy 2024-T3
  - Test plate dimensions 1600 mm long x 302 mm wide x 1.6 mm thick
  - Horizontal
  - Surface finish Average surface roughness: Ra ≤ 30 µm
  - Plate fixed over the standard test duct floor with double-sided tape 0.17mm thick
- Treated Test Plate
  - Same material and construction as the ‘‘Aluminum Test Plate’’ described above, however,
  - Treated using aircraft surface coating according to manufacturer specifications.

Note: If the coating being tested will typically be applied to painted surfaces, consideration should be given to conducting testing using painted untreated and treated test plates.

4.3 Test Conditions

Full testing of the fluids according to AS 5900 with both treated and untreated test duct floor/plates is not practical in most cases. At a minimum, it is recommended that comparative testing be conducted with each selected fluid in accordance with AS 5900, at one data point, run three times, using the neat fluid. The one data point shall represent the lowest temperature ±1 °C (2 °F) at which the fluids met the aerodynamic performance requirements with the standard test duct floor.

4.4 Interpretation of Test Results

The comparative fluid aerodynamic tests will provide a good indication of fluid aerodynamic performance when applied to aircraft surfaces treated with coatings. The interpretation of the test results, and ultimately the decision to use the coating or paint on aircraft, is the responsibility of the aircraft operator.

4.5 Testing Organization

As of the date of publication of the AIR, the following organization is known to provide testing for anti-icing fluids. This is not an endorsement by SAE for this organization but simply to facilitate the location of laboratories for those seeking testing. Please enquire directly with the organization for a full list of testing available.

Anti-icing Materials International Laboratory (AMIL), 555, boulevard de l'Université, Chicoutimi, Québec,
G7H 2B1, Canada; 418-545-2918. www.uqac.ca/amil.

5. ADDITIONAL INFORMATIONAL TEST METHODS

The following describe test methodologies that may be used to conduct testing to help characterize aircraft surface coatings. These tests are outside of the scope of the SAE G-12 Aircraft Ground Deicing Committee but are provided here for reference purposes. The interpretation of these tests results, and ultimately the decision to use the coating on aircraft, is the responsibility of the aircraft operator.

5.1 Aircraft Surface Coating Compatibility and Integrity Tests

Aircraft surface coatings should be tested for: compatibility with airplane surfaces; durability, hardness and weathering; exposure to deicing/anti-icing fluids; and compatibility with other fluids. Tests should be run on both treated and untreated surfaces. Treated surfaces should preferably show no additional degradation. Consideration should be given to conducting additional comparative endurance time testing and fluid aerodynamic acceptance testing with weathered treated surfaces if dramatic changes in coating properties are experienced following the compatibility and integrity tests.

5.1.1 Compatibility with Airplane Surfaces

Tests should include those conducted for evaluation of airplane maintenance waxes and polishes, as well as exterior cleaners (if a pre-clean step is required), per industrial standards, such as SAE AMS 1526, SAE AMS 1650, or per requirements of commercial aircraft manufacturers, such as Boeing D6-17487 and Airbus AIMS 09-00-002.

These tests can include, but might not be limited to: sandwich corrosion in accordance with ASTM F1110, acrylic and polycarbonate crazing in accordance with ASTM F484, paint softening in accordance with ASTM F502, hydrogen embrittlement in accordance with ASTM F519, and total immersion tests in accordance with ASTM F483.

These tests are intended to ensure that the surface coatings are not detrimental to airplane surfaces. They are not intended to judge performance.

5.1.2 Durability, Hardness, and Weathering

Tests should be conducted on treated and untreated, unpainted and painted panels, as applicable, in accordance with AMS 3095 for the following properties: gloss, initial color, adhesion, impact-reverse, flexibility, water, and fluid resistance. Note that the requirement for AMS 3095 properties, such as 60° gloss greater than 90 units and color, might not be applicable, but failures of other property requirements should be further investigated with careful interpretation.

Tests should be conducted on treated and untreated, unpainted and painted panels, as applicable, in accordance with AMS 3095 for artificial weathering, except that the exposure time should be adjusted to the anticipated treatment lifetime. The 1000-hour exposure specified in AMS 3095 is assumed to be a 5-year lifetime. Example: if the treatment is expected to last one year, then the exposure time should be 200 hours.

Tests should be conducted on treated and untreated, unpainted and painted, ice centrifuge adhesion test sample beams, as applicable, in accordance with Section 5.3.1 after artificial weathering (UV exposure) in accordance with AMS 3095, except that the exposure time should be adjusted to the anticipated treatment lifetime. The 1000-hour exposure specified in AMS 3095 is assumed to be a 5-year lifetime. Example: If the treatment is expected to last one year, then the exposure time should be 200 hours. Compare ice adhesion for the exposed beams to that for the unexposed beams.

For treatments applied to the leading edge of aircraft surfaces, the rain erosion test from SAE AMS-C-83231A “Coatings, Polyurethane, Rain Erosion Resistant for Exterior Aircraft and Missile Plastic Parts”, section 4.9.15.2, should be considered as a relative evaluation of coating longevity.

5.1.3 Exposure to Deicing/Anti-Icing Fluids

The following tests should be conducted with AMS 1424 Type I fluid and AMS 1428 Type II/III/IV fluid on treated and untreated, unpainted and painted panels (see Section 3.1 for guidelines on fluid selection). The fluid, when heated to 149 °F ± 4 (65 °C ± 2) and applied to a surface having an initial surface temperature of 72 °F ± 2 (22 °C ± 1), shall not produce any streaking, discoloration, or blistering of the treated panel. For treated, painted panels, the fluid should not decrease paint film hardness by more than two pencil hardness numbers from either the untreated, unexposed panel value or the treated, unexposed panel value when determined in accordance with ASTM F 502.

5.1.4 Immersion Tests for Compatibility Screening

Airline operators and manufacturers need to understand any possible deleterious effects and interactions that might arise from the use of coatings on aircraft surfaces. Any such interactions can be caused by direct contact with the aircraft surface or possibly through complex interactions in combination with fluids commonly encountered during the service life of an aircraft.

Immersion tests can help as a screening tool in order to highlight potential incompatibilities on pristine surfaces. Such tests, however, are by no means a guarantee of in-service performance as they fail to account for in-service wear and tear from abrasion, variances in operator application techniques, and other such variables.

As a guide in evaluating product suitability, consideration should be given to:

- Surfaces affected (treated or untreated, aluminum or composite, etc.)
- Exposure to various fluids that may be encountered by the treated surface:
    - Hydraulic fluid (an applicable test is in AMS 3095)
    - Aircraft deicing/anti-icing fluids and runway deicing/anti-icing fluids (or solids if applicable); a relevant test is discussed in section 5.1.3
    - Detergents
    - Fuel
- Suitable exposure scenarios including potential photo, ultraviolet, ozonization, acid rain, or oxidation effects (some applicable tests can be found in ISO 11507)
- Pre- and post- immersion performance tests

A number of aircraft manufacturer and SAE materials specifications reference ASTM F483, which can be used as a basis for developing a total-immersion test for the above fluids. A cyclical immersion protocol is detailed in SAE AIR 6130-2011, which can be used as a basis for testing when a cyclical exposure scenario is required.

5.2 Aerodynamic Drag Evaluation Test

5.2.1 Background Information about Aircraft Drag

The total drag of an aircraft is often broken down into several components such as induced drag and profile drag. The manufacturers of some coatings have claimed that their products reduce aircraft drag. To verify or evaluate this claimed benefit, it is important to understand how aircraft drag reduction could be achieved by application of a surface coating. In most cases, it is anticipated that the mechanism by which a drag reduction would be achieved is by reducing the profile drag via a reduction of the skin friction drag.

5.2.2 Drag Evaluation Considerations

- Well-established fluid dynamics theory says that if a surface is rough, then the skin friction, and therefore the drag, will be higher than for a smooth surface. By making a rough surface smoother, the skin friction drag will be reduced. However, if a surface is already ”hydrodynamically smooth”, as aircraft surfaces should be, further smoothing will not yield any drag-reduction benefits for a turbulent boundary layer.
- Some coatings could cause a drag increase. For example, coatings intended to have hydrophobic properties via micro-textured surfaces have some inherent surface roughness that, if not hydrodynamically smooth, could adversely affect skin friction drag.
- The drag effects of a coating could be evaluated using 2D or 3D aircraft model wind tunnel testing. This approach could utilize a generic model to provide a general indication of the effect of a coating, or the effect on a specific aircraft model could be evaluated.
- Comparative testing could also be conducted using a flat-plate wind tunnel test, with the plate both treated and untreated under the same conditions. For this approach, comparative changes to fluid flow-off properties, such as ∆BLDT, could give an indication of the drag effects.
- Wind tunnel testing for drag evaluation introduces issues that should be considered, such as:
  - There will be Reynolds number differences between the real aircraft and the sub-scale model or flat-test plates, which affects the skin friction drag that the sub-scale model will experience. This affects the total drag and could affect the incremental effect of a coating.
  - Some of the claimed drag benefits due to coatings could potentially be realized due to restoring the integrity of a worn painted finish to that of a freshly painted surface. Overall, the combination of Reynolds number effects and this surface texture scaling will lead to difficulties in interpreting any measured drag benefits.
  - Wind tunnel flow and measurement devices may mask the ability to determine the effects of a coating.
  - Sub-scale wind tunnel testing results may not be representative of the full-scale effect, however if significant drag effects are indicated from wind tunnel testing, consideration should be given to evaluation on a real aircraft and/or consultation with the aircraft manufacturer.
- Testing a coating on a real aircraft will avoid many of the difficulties described above. However, accurate drag measurements via flight testing are challenging, and therefore small differences will likely not be measureable.

Additional information on surface coatings and drag reduction has also been published in The Boeing Company’s *AERO* magazine referenced in Section 2.4. .

5.3 Ice Adhesion Test

The following are two different test procedures for evaluating ice adhesion.

5.3.1 Centrifuge Ice Adhesion Test

The Centrifuge Adhesion Test consists of a two-step procedure. In the first step, the extremity of small aluminum sample beams, treated and untreated, accrete ice in either a cold room or an icing wind tunnel (testing may also be considered with painted treated and untreated sample beams). In the second step, the ice adhesion is measured by rotating the iced beams in a centrifuge at an accelerating rate until the ice detaches; the adhesion stress from the centrifugal force is calculated using detachment speed, the mass of the ice accreted on the extremity of the beam prior to the test, and the beam length. The Adhesion Reduction Factor can then be calculated using the adhesion stress measured on the treated beam compared to the untreated beam. Figure 1 demonstrates an example of the centrifuge ice adhesion test apparatus.

FIGURE 1

5.3.2 Zero-Degree Cone Test

The zero-degree cone test is used to measure the adhesive strength of ice to a substrate treated with a layer of icephobic material or other coating. The test apparatus consists of two concentric cones (referred to as a pile and mold) bonded together with ice. The cones are typically metallic (aluminum or stainless steel); however, cones can also be made from composites or other non-metallic materials. Figure 2 demonstrates an example of the zero-degree cone test apparatus.

Three piles are treated with a representative layer of an icephobic material or other coating. Each pile is then placed in a concentric mold and the mold is filled with ASTM Type II water. The mold is then placed in a -10 ± 2°C freezer for 48 ± 2 hours. The load required to push the pile through the ice is subsequently measured using a tensile tester equipped with an environmental chamber that maintains a -10 ± 2°C environment throughout the test. The nominal shear stress can be calculated by dividing the measured load by the surface area of the ice/pile interface. Consideration may be given to conducting this test at other freezing temperatures, i.e., -20ºC or colder.

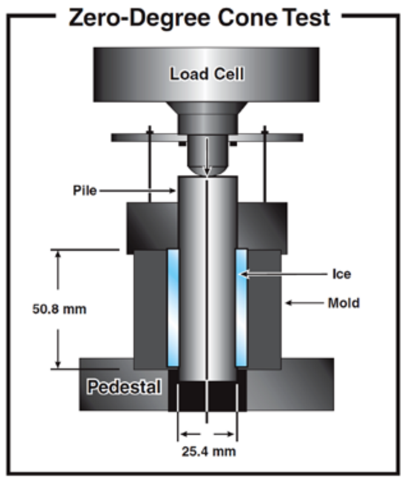

FIGURE 2

5.4 Ice Accumulation

The following are two different test procedures for evaluating ice accumulation.

5.4.1 Static Ice Accumulation

This test determines the reduction in the mass accumulation of ice when icephobic treated samples, positioned horizontally and at 45° and 80° from the horizontal, are exposed to freezing precipitation. The mass of ice accumulated on the icephobic samples are compared to that of bare samples at the same angles. This test can be run at different temperatures and under different precipitation types.

5.4.2 In-Flight Ice Accretion

Comparative testing should be performed in an icing wind tunnel with a treated and untreated model under the same conditions. The location, shape, thickness, surface quality, and any other noted characteristics of the accreted ice should be well documented (good-quality photographs are recommended) for comparing the treated and untreated results. Consideration may also be given to testing models with a heated leading edge, as well as a painted treated and untreated model.

Tests with generic models may provide a general indication of a coating's potential to provide icephobic results (reduced ice accretion). However, generic-model test results should not be assumed to be directly applicable to specific aircraft (e.g., model geometry, configuration details, etc.). Note that this type of testing provides comparative results between treated and untreated ice accretion. Flight test results may vary from icing tunnel test results due to several variables, such as differences in the actual icing conditions, flight conditions, scale and modeling effects, etc.

The ice accretions generated could then be evaluated for aerodynamic effects in an aerodynamic wind tunnel or in flight.

5.5 Contact Angle (CA), Contact Angle Hysteresis (CAH), and Roll-Off Angle (ROA)

Measure the contact angle (CA) of water on the surface using small drop volumes, smaller than ~10μL (to avoid distortion due to gravity). If the CA > 90°, the surface can be considered hydrophobic;

and when CA < 90, the surface can be considered hydrophilic. Note that hydrophobicity or super-hydrophobicity *does not* imply icephobicity as described below.

Measure the advancing contact angle (ACA) and receding contact angle (RCA) on the treated substrate. The ACA and RCA can be measured by the volume addition and removal methods, respectively. Another method involved uses a tilt stage. Tilting the surface and measuring the contact angles at the advancing and receding fronts before the drop slides, yields ACA and RCA. The difference between ACA and RCA is Contact Angle Hysteresis (CAH). A low RCA of water could indicate high adhesion strength of ice to the surface.

Measure roll-off angle (ROA) of a 10μL water droplet on the surface by using a tilt stage which varies between 0 and 90 degrees. An ROA~ 0 degrees indicates superior slippery properties and low CAH. Such surfaces could result in low ice adhesion provided the droplet does not impale into surface textures (Wenzel state) while freezing (which is possible due to various reasons such as dynamic impact or frost). An ROA close to 90 degrees indicates high drop adhesion, and consequently large ice adhesion.

5.6 Droplet Impact Resistance

Dynamic pressures generated under droplet impact are significantly higher than the static pressures and can cause droplets to transition from the non-wetting (Cassie) state to the wetting (Wenzel) state (see Deng, et.al., Appl. Phys. Lett., AIP 94, 133109-1, 2009; Kwon, et.al., Phys. Rev. Lett, APS 106, 036102, 2011). These dynamic wetting pressures are referred to as water hammer pressure and Bernoulli pressure. Textured hydrophobic surfaces (e.g., super-hydrophobic surfaces) resist wetting by generating anti-wetting capillary pressures. When the wetting pressures exceed the anti-wetting pressures, droplet transition into the wetting state (Wenzel) occurs. Once the transition occurs, ice accretion will dramatically increase. These are illustrated in the Figures 3 and 4 below.

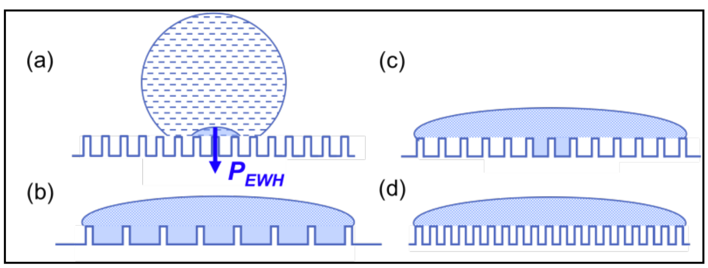

FIGURE 3

Figure 3 (adapted from Figure 1 of Deng, et.al., Appl. Phys. Lett., AIP 94, 133109-1, 2009): Relative magnitude of the wetting and anti-wetting pressures decides the wetting states of impinging droplets:

a) P_{EWH} the effective water hammer pressure is generated during the contact stage as the droplet impinges on the textured surface. P_D is the dynamic Bernoulli pressure and P_C is the anti-wetting capillary pressure.

b) Total wetting state ($P_{EWH} > P_D > P_C$) as water penetrates in both contact and spreading stage.

c) Partial wetting state ($P_{EWH} > P_C > P_D$) as water penetrates only during contact stage.

d) Total non-wetting state ($P_C > P_{EWH} > P_D$) as the structure resist wetting in both stages.

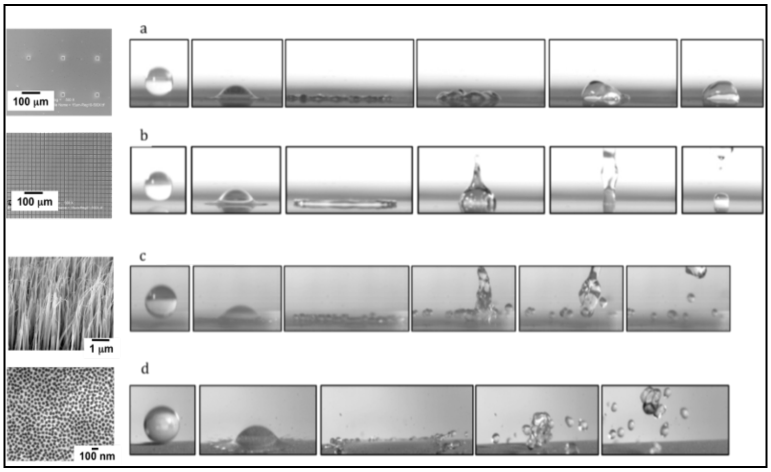

FIGURE 4

Figure 4 (adapted from Deng, et.al., Appl. Phys. Lett., AIP 94, 133109-1, 2009): Dynamic interactions of 1 mm diameter droplets with a variety of surfaces captured using a high-speed camera:

(a) Micro-textured surface consisting of 15 µm posts spaced apart by 150 µm – droplet does not recoil and impales into texture. Such structures will increase ice accretion.

(b) Partial drop recoil on micro-textured surface consisting of 15 µm posts spaced apart by 5 µm; such small impaled regions will over time lead to enhanced ice accretion.

(c) Complete drop recoil on 100nm dendritic structures.

(d) Complete drop recoil on metal-oxide nanoporous surface with ~38 nm pores.

Conduct droplet impact experiments on the treated substrate to characterize the dynamic wetting resistance of the substrate. Ideally, the impact experiments should be conducted with typical drop sizes and impact speeds experienced under field conditions, i.e., at large Weber numbers.

5.7 Frost Endurance Test

Frost is formed either via deposition of water vapor directly into ice or via condensation of water droplets followed by freezing. These occur as a result of either convective or radiation cooling of the surface. When meteorological conditions cause either to occur, surface textures and coatings can become covered with a layer of frost, which then makes the surface hydrophilic and results in increased ice adhesion and ice accretion (e.g., Varanasi, et.al., Appl. Phys. Lett., AIP 97, 234102, 2010). This phenomenon poses a significant limitation to the use of super-hydrophobic coatings in icephobic applications, and hence, hydrophobic does not necessarily imply icephobic properties (see Varanasi, et.al., Appl. Phys. Lett., AIP 97, 234102, 2010). Figure 5 and Figure 6 below illustrate these effects.

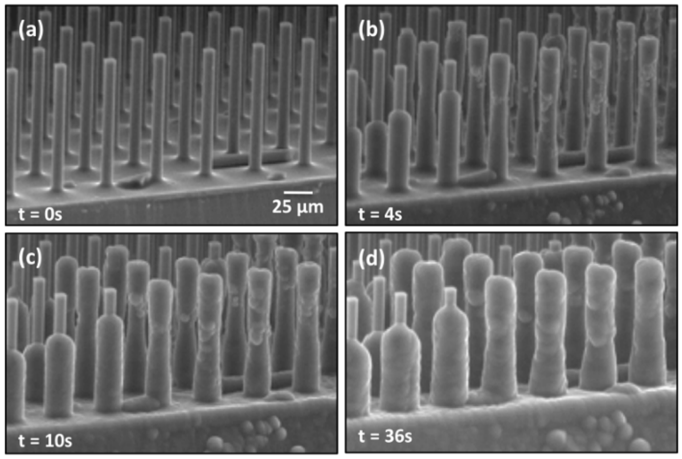

FIGURE 5

Figure 5 (adapted from Varanasi, et.al., Appl. Phys. Lett., AIP 97, 234102, 2010): environmental scanning electron microscope (ESEM) images of frost formation on a super-hydrophobic surface comprising of an array of hydrophobic square posts.

(a) Dry surface.

[(b)-(d)] Snapshot images of frost formation on the surface. The intrinsic water contact angle of the hydrophobic coating on the posts is ~110º. The surface is maintained at a temperature -13ºC by means of a cold stage accessory of the ESEM. At the beginning of the experiment the chamber pressure is maintained ~ 100 Pa, well below the saturation pressure to ensure a dry surface. The vapor pressure in the chamber is then slowly increased until frost nucleation is observed. Frost nucleation and growth occurs without any particular spatial preference on all of the available area including post tops, sidewalls and valleys due to the uniform intrinsic wettability of the surface.

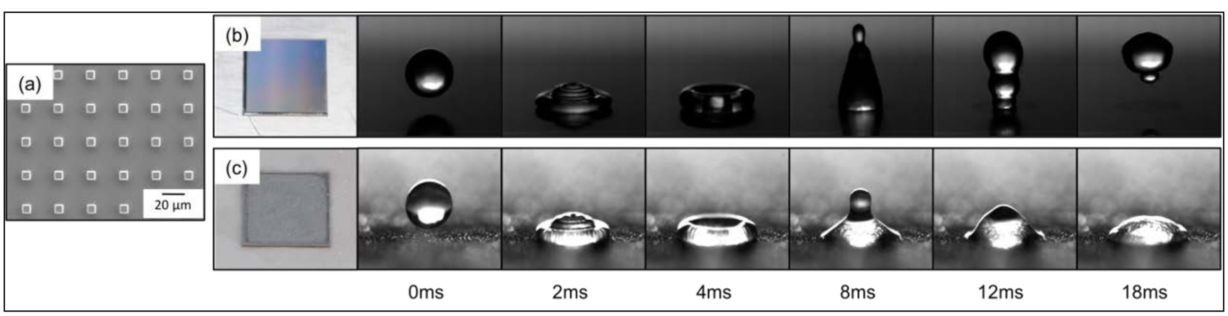

FIGURE 6

Figure 6 (adapted from Varanasi, et.al., Appl. Phys. Lett., AIP 97, 234102, 2010): Droplet impact measurements on dry and frosted super-hydrophobic surface conducted using droplets of 1mm radius impacting the surface at velocity ~ 0.7 m/s

(a) Top view ESEM image of the representative Si silicone post array surface.

(b) Photograph of the dry surface along with sequential high-speed video images of droplet impact. As expected, droplet recoils from the surface, as the anti-wetting capillary pressure is greater than the dynamic wetting pressures.

(c) Photograph of the frosted surface along with sequential high-speed video images of droplet impact. Frost alters the wetting properties of the surface, making the surface hydrophilic, and causing Cassie-to-Wenzel wetting transition of the impacting drop and subsequent pinning to the surface.

The following battery of tests, ranging from simple to complex, is recommended to fully quantify the performance of the coating under frost. For the following testing, consider a saturated water vapor environment with substrate sub-cooling that promote direct deposition or condensation followed by freezing. For example, if the environment is not pure water vapor, consider high relative humidity (>90%) and substrate temperature below the freezing point. The pressure can be altered to promote condensation or deposition. Under these conditions, the following should be performed:

a) Visual inspections of frost build up.
b) Measure contact angle to ascertain the hydrophobicity of the surface. Because of the presence of nucleated water or ice in the textures, the surface could display hydrophilic behavior. Such a surface could be compromised.
c) Conduct ROA angle measurements. If the SLA increases from the dry surface, then frost-induced impalement is occurring and the surface is compromised.
d) Droplet impact experiments to ascertain the hydrophobic drop shedding properties. If shedding is arrested, then surface could be compromised.
e) Ice adhesion testing under frosting conditions. Due to interlocking, the adhesion testing under frost conditions should be higher than for the smooth surface of identical surface chemistry. Increase in adhesion strength could indicate frost-induced adhesion and potential loss of coating functionality.

5.8 Thermal Conductivity

Consider testing a sample, representative of the aircraft surface, treated with the surface coating to assess its overall thermal conductivity or heat transfer properties. The thermal conductivity of a material, k (W/m -K) is the property of a material's ability to conduct heat. The normal conductivities of typical aluminum or composite aircraft surfaces may be modified due to the addition of a coating between the skin and the heated fluid or contamination.

Additionally, thermal conductivity of materials are temperature dependent. Surface coatings and heated fluids, in combination with various forms of precipitation and temperatures, may lead to modified anti-icing fluid performance and holdover times.

Various methods exist for determining thermal conductivity of substrates. The following are some standards that may be useful to assess:

i. ASTM Standard C518 - 10, "Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus"
ii. ASTM Standard E1225-04, "Standard Test Method for Thermal Conductivity of Solids by Means of the Guarded-Comparative-Longitudinal Heat Flow Technique"
iii. ASTM Standard D5930-01, "Standard Test Method for Thermal Conductivity of Plastics by Means of a Transient Line-Source Technique"
iv. ISO 8301, "Thermal insulation -- Determination of steady-state thermal resistance and related properties -- Heat flow meter apparatus"
v. ISO 22007-2:2008 "Plastics -- Determination of thermal conductivity and thermal diffusivity -- Part 2: Transient plane heat source (hot disc) method"

vi. ISO 22007-3:2008 "Plastics -- Determination of thermal conductivity and thermal diffusivity -- Part 3: Temperature wave analysis method"

vii. ISO 22007-4:2008 "Plastics -- Determination of thermal conductivity and thermal diffusivity -- Part 4: Laser flash method"

5.9 Testing Organizations

As of the date of publication of the AIR the following organizations are known to provide testing for aircraft coatings. This is not an endorsement by SAE for these laboratories but simply a list to facilitate the location of organizations for those seeking testing. Please enquire directly with the laboratories for a full list of testing available.

Anti-icing Materials International Laboratory (AMIL), 555, boulevard de l'Université, Chicoutimi, Québec, G7H 2B1, Canada; 418-545-2918. www.uqac.ca/amil .

APS Aviation Inc., 6700, chemin de la Côte-de-Liesse, Suite 105, Saint-Laurent, Quebec, H4T 2B5, Canada; 514-878-4388, www.adga.ca/aps.

Scientific Material International, 12219 SW 131st Avenue, Miami, Florida, USA 33186-6401; 305-971-7047; www.smiinc.com .

6. NOTES

6.1 Keywords

Aircraft Coating, Icephobic, Hydrophobic, Hydrophilic, Endurance Time, Holdover, Aircraft, Surface, Frost, Ice, Freezing, Rain, Drizzle, Fog, Cold Soaked Wing, Snow.

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