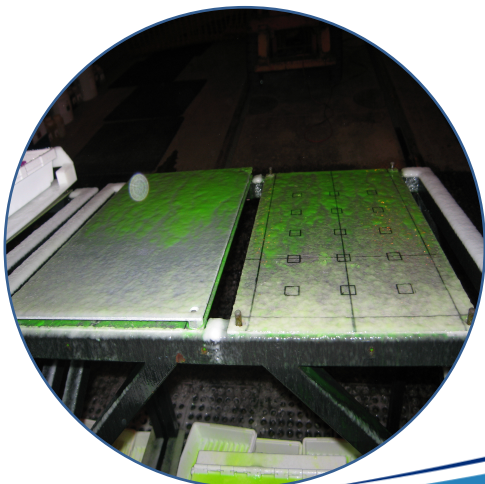
TP 15275E

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)



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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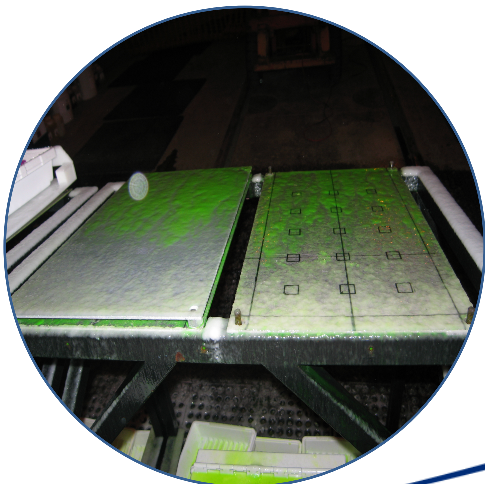

By:

Marco Ruggi

Prepared by:

APS Aviation Inc.

October 2014
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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:	Marco Ruggi, Eng., M.B.A. Project Leader	July 28, 2017 Date
Reviewed by:	John D'Avirro, Eng. Director, Aviation Services	July 28, 2017 Date
Approved by:	** John Detombe Chief Engineer, Defence and Security ADGA Group Consultants Inc.	Date

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

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

A broader test plan was developed and conducted during the winter of 2011-12. Testing 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.

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, 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 contamination due to fluid runoff. The use of coatings on the vertical surfaces (i.e. vertical

stabilizer, winglets, fuselage, etc.) could provide added protection from adherence of contamination.

Preliminary work done simulating aerodynamically quiet areas in aircraft also indicated potential benefits to using ice phobic coatings. These coatings typically repel fluids, causing residual fluid to bead in concentrated areas rather than smear across the surface. This may in turn result in less fluid residues, and future testing should attempt to investigate this further.

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. Nonetheless, one manufacturer has demonstrated continual improvement in the coatings submitted for testing indicating that these coatings can potentially evolve to be complementary to de/anti-icing 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.

The following are potential areas for future research:

- Wind tunnel testing with a thin, high-performance wing model to investigate coating performance during ground icing conditions with and without fluid;
- Investigate effect of weathered coatings on fluid endurance times;
- Investigate performance of high and low end fluid viscosities on coated surfaces;
- Investigate potential use of coatings in areas prone to icing but where de/anti-icing protection is limited, or not available (e.g. flap leading edges retracted section, vertical stabilizer, and controls in aerodynamically quiet areas);
- Further evaluation of the potential application of ice phobic products in aerodynamically quiet areas and areas near drain holes to reduce gel residues;
- Evaluation of newly developed coatings; and
- Research to support development of the new SAE AIR document.

SOMMAIRE

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

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

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

Un plan d'essais plus vaste a été élaboré et exécuté au cours de l'hiver 2011-2012. Les essais 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.

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, 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 résultats prometteurs ont été observés sur les surfaces verticales, qui sont susceptibles d'être contaminées plus tôt en raison de l'écoulement du liquide. 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. Généralement, ces revêtements repoussent les liquides, ce qui provoque la formation en zones concentrées de gouttelettes de liquide résiduel plutôt que de l'étaler sur toute la surface. En conséquence, cela pourrait réduire le liquide résiduel, une possibilité que les essais futurs devraient tenter d'examiner davantage.

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. Néanmoins, un fabricant a démontré une amélioration constante des revêtements soumis aux essais, ce qui indique que ces revêtements pourraient évoluer et compléter les liquides de dégivrage et d'antigivrage.

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 :

- Mener des essais en soufflerie avec un modèle d'aile mince de haute performance, pour examiner le rendement du revêtement dans des conditions de givrage au sol, avec ou sans liquide;
- Étudier l'effet de revêtements éprouvés sur l'endurance des liquides;
- Examiner la performance des liquides de basse et de haute viscosité sur des surfaces revêtues;
- 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 la section rentrée des bords d'attaque des volets, le stabilisateur vertical et les contrôles des zones à l'abri d'écoulement aérodynamique);

- Évaluer davantage la possibilité d'appliquer des produits glaciophobes dans les zones à l'abri d'écoulement aérodynamique et les zones proches des trous de drainage, afin de réduire les résidus de gel;
- Évaluer les revêtements nouvellement élaborés; et
- Mener des recherches en appui au développement du nouveau document SAE AIR.

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GLOSSARY

APS	APS Aviation Inc.
CEF	Climatic Engineering Facility
EG	Ethylene Glycol
FAA	Federal Aviation Administration
HOT	Holdover Time
MSC	Meteorological Service of Canada
NRC	National Research Council Canada
OAT	Outside Air Temperature
PG	Propylene Glycol
PIWT	Propulsion and Icing Wind Tunnel
SAE	Society of Automotive Engineers, Inc.
TC	Transport Canada
TDC	Transportation Development Centre
ZD	Freezing Drizzle
ZF	Freezing Fog
ZR	Freezing Rain

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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 2 of 4.

1.1 Background

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

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

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

A broader test plan was developed and conducted during the winter of 2011-12. Testing 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.

1.2 Objective

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

Seven 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. **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;
3. **Adherence Tests:** Evaluate potential to delay the onset of adherence on bare surfaces treated with ice phobic products during freezing precipitation conditions;
4. **Vertical Stabilizer Tests:** Evaluate the endurance time performances of vertical surfaces treated with an ice phobic coating;

5. **Wind Tunnel Tests of Streamline Posts:** Evaluate the performance of the ice phobic coatings on streamline posts following repeated applications of glycol and potential residue formations;
6. **Fluid Drainage Tests from Aerodynamically Quiet Areas in Aircraft:** Investigate potential application of ice phobic products in aerodynamically quiet areas in aircraft to reduce residues by evaluating ability to facilitate fluid drainage; and
7. **Overnight Ice Tests:** Investigate potential benefits of having ice phobic products prevent ice formation on aircraft critical surfaces.

In addition, a significant amount of work was done in developing a new Society of Automotive Engineers (SAE) Aerospace Information Report (AIR) 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 2011-12;

b) Section 3 summarizes the results from endurance time testing conducted during the winter of 2011-12;

c) Section 4 summarizes the results from the fluid wetting and fluid thickness testing conducted during the winter of 2011-12;

d) Section 5 summarizes the results from the adherence testing conducted during the winter of 2011-12;

e) Section 6 summarizes the results from the vertical stabilizer testing conducted during the winter of 2011-12;

f) Section 7 summarizes the results from the wind tunnel testing of streamline posts conducted during the winter of 2011-12;

g) Section 8 summarizes the results from the fluid drainage testing from aerodynamically quiet areas in aircraft conducted during the winter of 2011-12;

h) Section 9 summarizes the results from the overnight ice testing conducted during the winter of 2011-12;

i) Section 10 summarizes the activities regarding the development of the SAE AIR being developed for evaluating the interaction of de/anti-icing fluids with aircraft after-market coating;

j) Section 11 presents the conclusions; and

k) Section 12 presents the recommendations.

2. METHODOLOGY

This section describes the overall approach, test parameters and experimental procedures followed during the 2011-12 projects.

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 9001:2000 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.

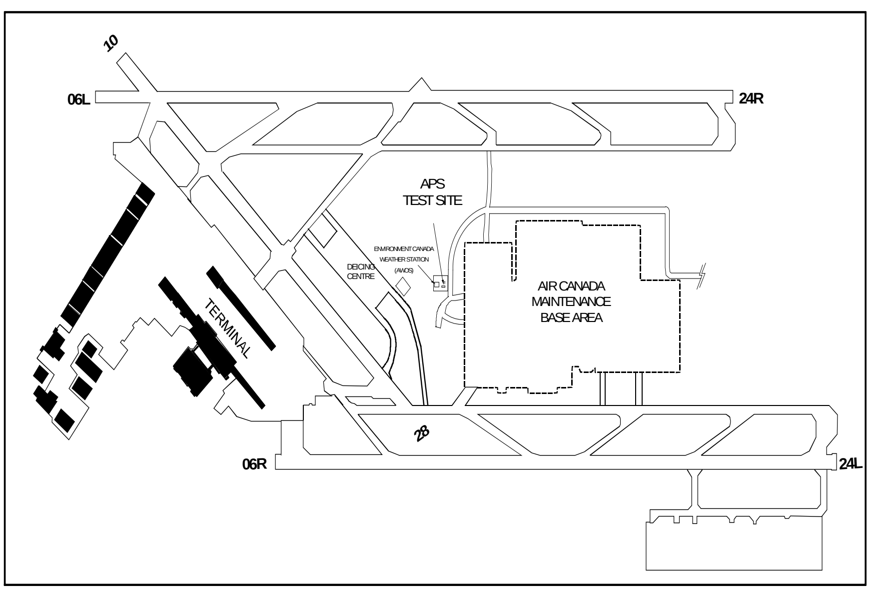

Figure 2.1: Plan View of APS Montreal-Trudeau Airport Test Site

2.2 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.

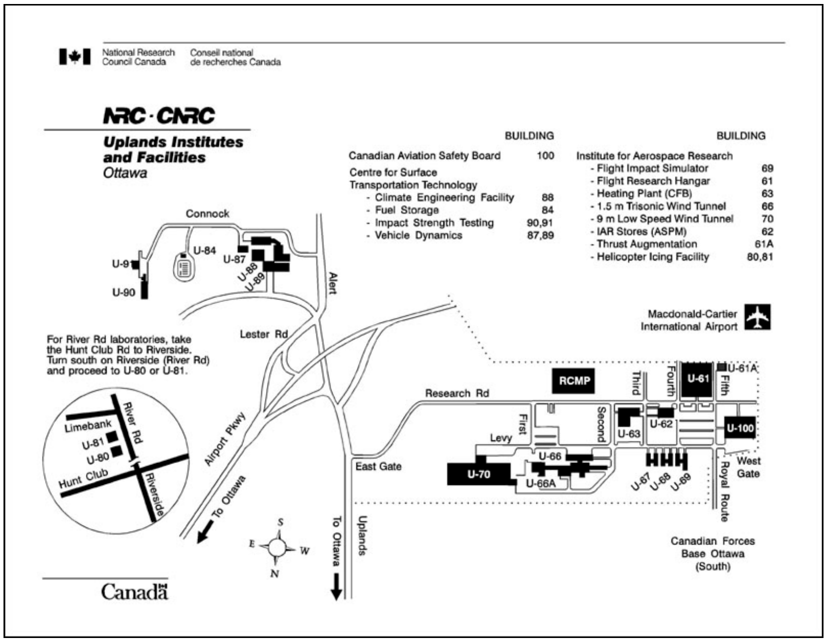

Figure 2.2: Schematic of NRC Uplands Campus

2.2.1 NRC Open Circuit Wind Tunnel Test Site

The 2011-12 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 contacting the fan. The fan is normally driven electrically but high-speed operation 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.

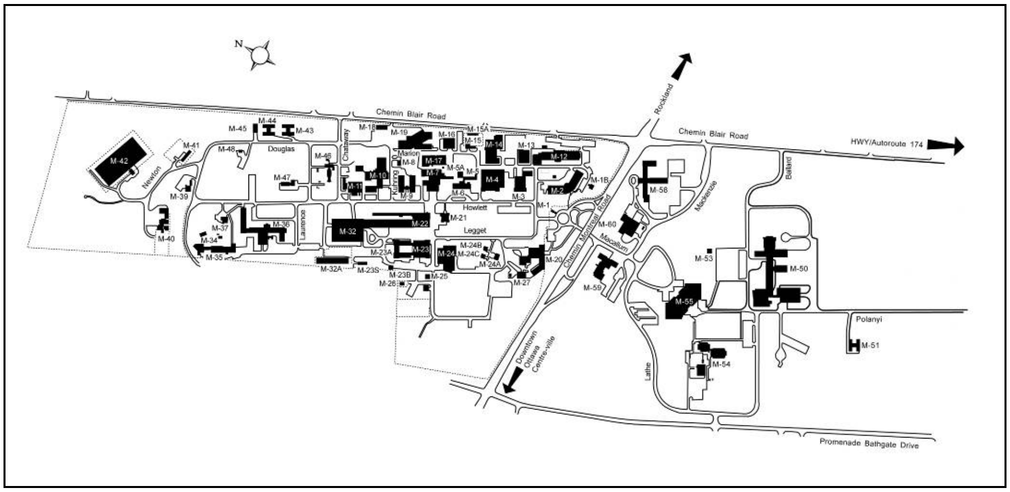

Figure 2.3: Schematic of NRC Montreal Road Campus

2.3 Materials Tested

2.3.1 Ice Phobic Products

To investigate the effects of ice phobic treated aluminum surfaces on de/anti-icing fluid performance, three products were evaluated during the winter of 2011-12. The choices in materials were made based on availability and 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 the 2011-12 testing year results are described in this report.

2.3.2 Flat Pate 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 To Date and Reference Codes

Testing Year	APS Reference Code	Manufacturer Code	Product Applied Code
2009-10	I-PH A	Manufacturer A	Product 1
2009-10	I-PH B1	Manufacturer B	Product 1
2009-10	I-PH B2	Manufacturer B	Product 2
2009-10	I-PH B3	Manufacturer B	Product 3
2009-10	I-PH B4	Manufacturer B	Product 4
2009-10	I-PH B5	Manufacturer B	Product 5
2010-11	I-PH B3	Manufacturer B	Product 3
2010-11	I-PH B7	Manufacturer B	Product 6
2010-11	I-PH B8	Manufacturer B	Product 7
2010-11	I-PH B9	Manufacturer B	Product 8
2010-11	I-PH B10	Manufacturer B	Product 9
2010-11	I-PH C1	Manufacturer C	Product 1
2010-11	I-PH C2	Manufacturer C	Product 1
2011-12	I-PH B3	Manufacturer B	Product 3
2011-12	I-PH B11	Manufacturer B	Product 9
2011-12	I-PH C2	Manufacturer C	Product 1

Table 2.2: List of Flat Plate Baseline Surfaces Tested

APS Reference Code	Material	Treatment Used
Baseline	2024-T3 Aluminum	Not Treated
Polished	2024-T3 Aluminum	Sanded using fine grit paper and then polished using "Jacksonlea" buffing compound and buffing wheel
Painted	2024-T3 Aluminum	Primed and painted white using aircraft grade paint

2.4 Test Methodology

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

2.4.1 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 (see document *Test Requirements for Simulated Freezing Precipitation Flat Plate Testing*). 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.

2.4.2 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 (see document *Test Requirements for Simulated Freezing Precipitation Flat Plate Testing*). 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.

2.4.3 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 De-Icing 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* (3). 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 15 minutes. Due to the thin fluid layer, fluid thickness was not an appropriate evaluation method. Details of this procedure are included in Appendix B.

2.4.4 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, and the time for the ice to adhere were recorded. The adhesion was verified using the “APS Adherence Tester” which has been 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.

2.4.5 Description of Vertical Stabilizer Testing Procedure

Due to the early contamination 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 Montreal-Trudeau Airport in Montreal. Standard endurance time test and rate collection protocol were followed during the execution of these tests. Type I and 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 C.

2.4.6 Description of Wind Tunnel Testing Procedure

Treating the wing surface with ice phobic products was not feasible without interfering or affecting other high priority wind tunnel testing activities in 2011-12. To minimize the impact on the other wind tunnel testing being conducted, two identical stream line posts (typically used to mount pitot sensors in the wind tunnel) were re-surfaced with sheet aluminum, one of which was coated with the I-PH B3 product, and one which was left untreated. These streamline posts were positioned on the bottom of the scaffolding system, which when stowed was located downstream during a typical test, and subject to spent fluid spray from the fluid being sheared off the main wing section and blown downstream.

The objective was to gather observational data regarding the performance of the coating following repeated exposure to glycol and wind shear forces, and to identify potential residue formations. To do so, the wind tunnel was run with fluids as per the testing schedule. The stream line posts were exposed to fluid spray but were not cleaned in between tests. When possible, at the beginning and end of each day, the performances of the treated and un-treated sections of the wing were compared. Details of this procedure are included in Appendix D.

2.4.7 Description of Fluid Drainage Testing Procedure

Aerodynamically quiet areas were simulated using stainless steel cup containers, both coated and uncoated, with a drain hole drilled into the bottom. Containers were filled with Type I, II or III fluid and then left to drip out. Containers were weighed dry, and at several time intervals during drainage. Each coated container's performance was compared to the different products and to the baseline uncoated container. Details of this procedure are included in Appendix B.

2.4.8 Description of Overnight Ice Testing Procedure

To investigate the potential benefits of having ice phobic products prevent ice formation on critical surface, two test plates (one coated and one uncoated) were exposed to freezing precipitation. The coated surface accretion was compared to the non-coated surface accretion. When possible, surfaces were examined at the end of each test day, or once significant ice had formed. Details of this procedure are included in Appendix B.

2.5 Data Forms

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

2.6 Equipment

The test equipment for standard HOT testing and typical wind tunnel testing was used to conduct the ice phobic product evaluation. Subsections 2.6.1 to 2.6.4 briefly describe some of the equipment used.

2.6.1 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 NRC specifically for the conduct of these tests following extensive consultations with an airframe manufacturer to ensure a representative super-critical design.

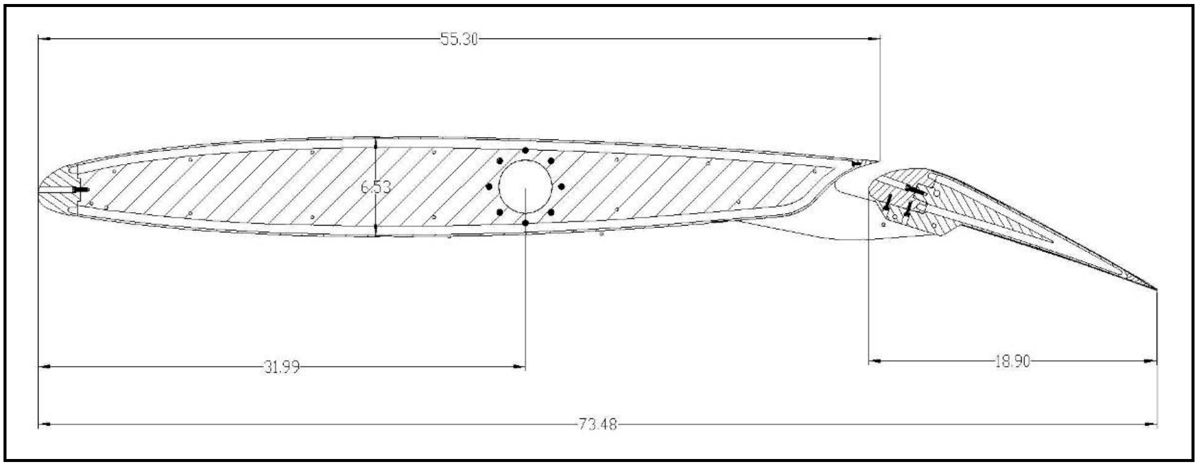

Figure 2.4: Wing Section

2.6.2 Test Plate 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.

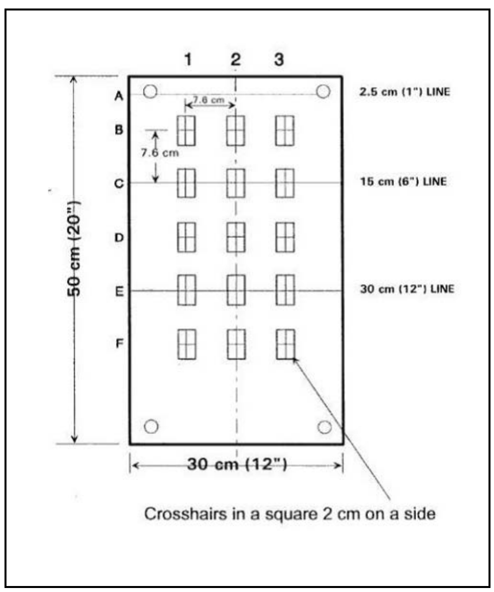

Figure 2.5: Schematic of Standard Holdover Time Test Plate

2.6.3 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.

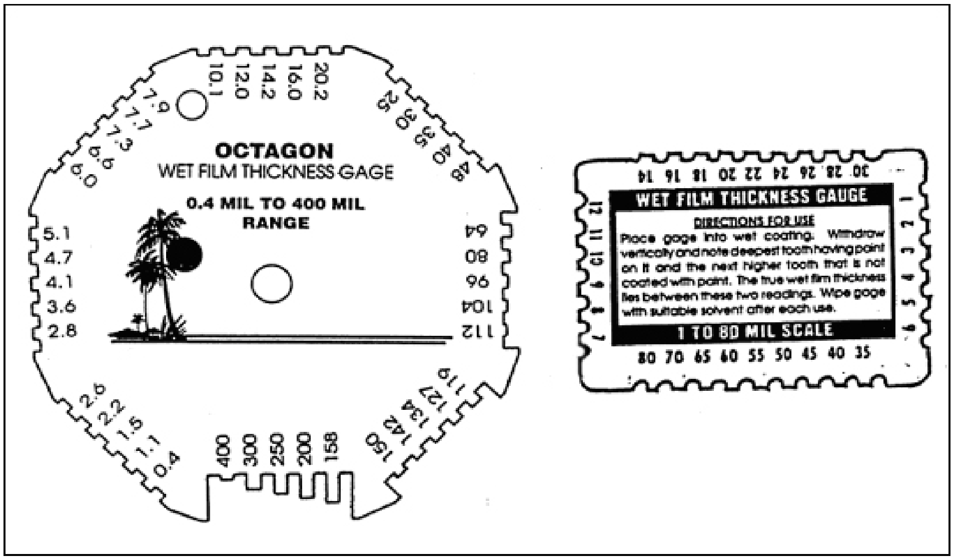

Figure 2.6: Wet Film Thickness Gauges

2.6.4 Brixometer

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

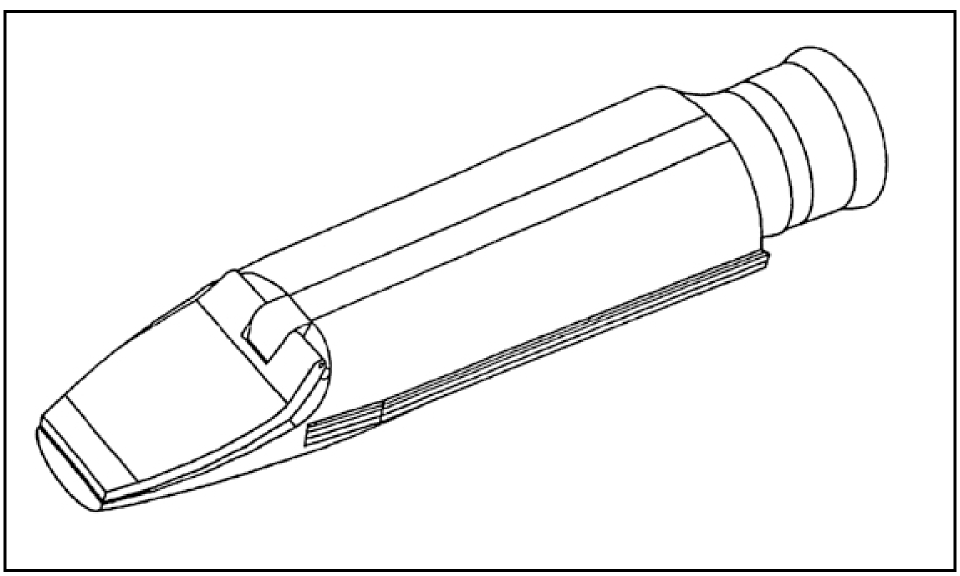

Figure 2.7: Hand-Held Brixometer

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Photo 2.1: APS Test Site - View from Test Pad

Photo 2.2: Pad 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

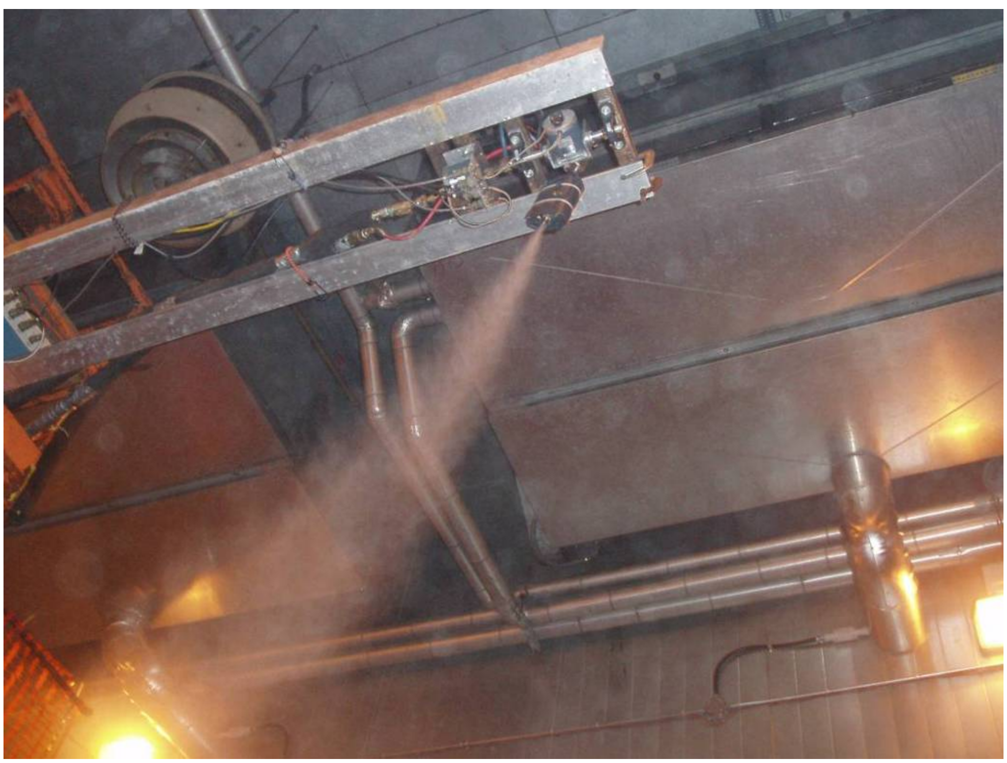


Photo 2.5: Outside View of NRC Wind Tunnel Facility

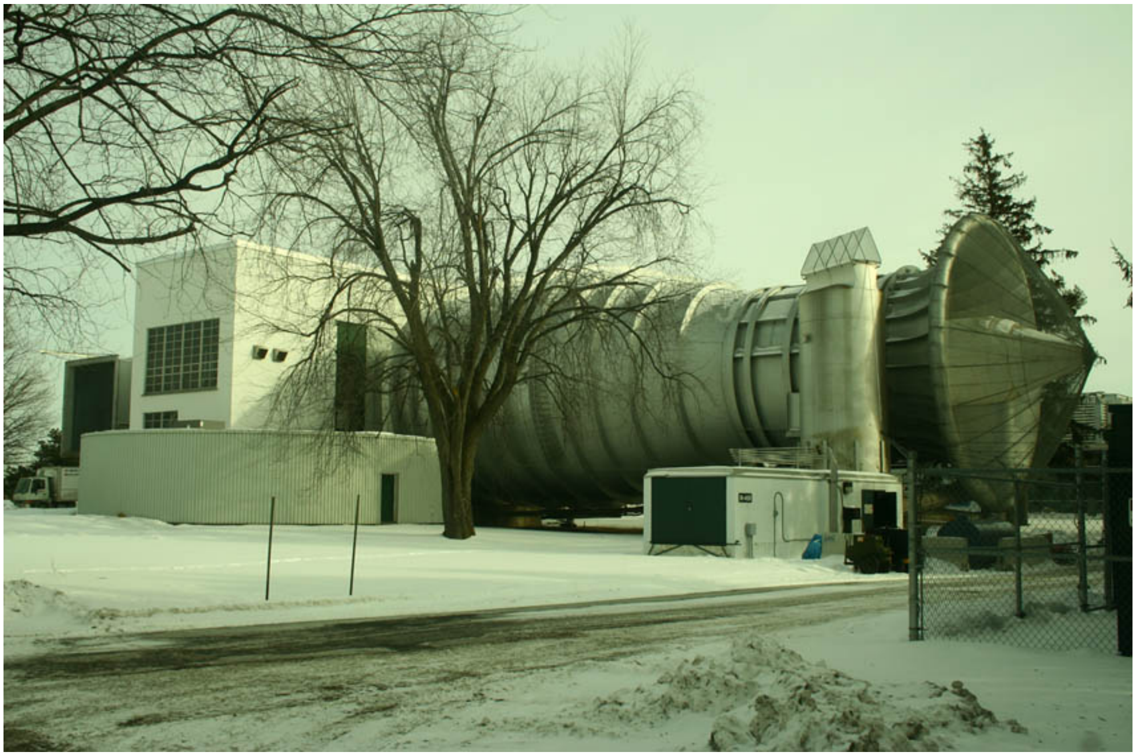
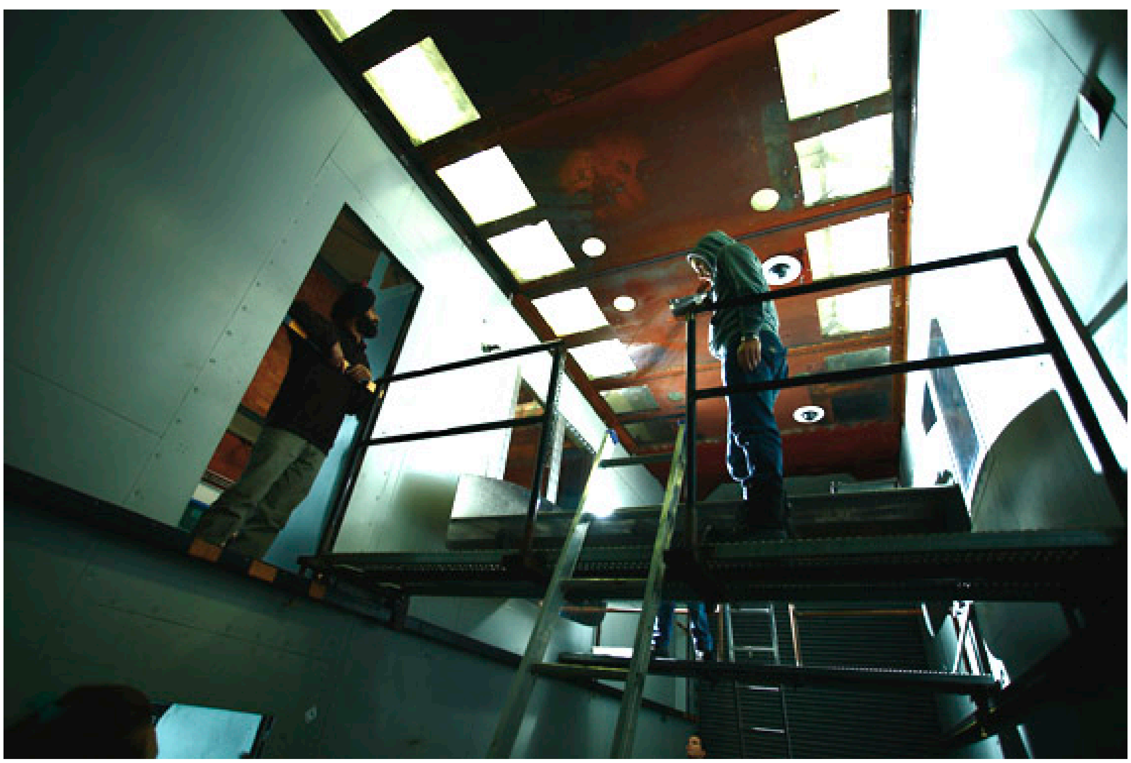


Photo 2.6: Inside View of NRC Wind Tunnel Test Section



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3. ENDURANCE TIME TESTING DATA AND RESULTS

In this section, the endurance time testing data collected during the winter of 2011-12 is analysed and discussed. The treated surfaces were evaluated against the baseline plate to investigate potential adverse effects on fluid HOT's when applied to surfaces treated with ice phobic products. Testing was conducted with the new I-PH B11 coated test plate, and the previously tested I-PH C2 coated test plate.

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 NRC CEF and at the P.E.T. airport site during the winter of 2011-12. The log presented in Table 3.1 and Table 3.2 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.

The column headings are generally self-explanatory, supported with the following comments:

- Condition column entry is: type of precipitation, ambient temperature in °C, rate of precipitation in g/dm²/h; and
- Fluid Dilution column entry for Type I fluid indicates that the fluid is diluted to the 10 degree buffer (10°B) relative to ambient temperature, and states the Brix value.

Table 3.1: Log of Simulated Precipitation Endurance Time Tests

Test #	Condition	Fluid Brand	Fluid Dilution	Test Surface	Start Time	End Time	Total Time (min)	Brix @ 5 min (°)	Brix @ Fail (°)	Thick @ 5 min (mm)	Thick @ Fail (mm)	Comments
PH1	ZR, -10, 13	Octagon Octaflo EF	10°B (B=27.0)	Baseline	17:48:45	17:56	7.3	n/a	n/a	n/a	n/a	std fail
PH2	ZR, -10, 13	Octagon Octaflo EF	10°B (B=27.0)	I-PH B11	17:50	18:00	10.0	n/a	n/a	n/a	n/a	30% bare @17:52 no adh. 100% bare at 17:58. Fail only if seeding with pencil
PH3	ZR, -10, 13	Octagon Octaflo EF	10°B (B=27.0)	I-PH C2	17:50:45	17:58:30	7.7	n/a	n/a	n/a	n/a	30% bare @17:56. Adhered ice present onbottom of plate after fail
PH4	ZR, -10, 13	C2	75/25	Baseline	16:45:30	17:30	44.5	n/a	n/a	2.7	n/a	
PH5	ZR, -10, 13	C2	75/25	I-PH B11	17:13:30	17:43:30	30.0	n/a	n/a	1.8	n/a	no adh. Re-pour due to diff in thickness and ET. Same results.
PH6	ZD, -10, 13	C2	100/0	Baseline	20:19:16	20:52:31	33.3	34.5	26	1.7	1.5	no adherence
PH7	ZD, -10, 13	C2	100/0	I-PH B11	20:21	20:50	29.0	34.25	17	1.5	0.4	no adherence
PH8	ZR, -10, 25	Dow UCAR EG106	100/0	Baseline	14:33	15:34	61.0	29	12.5	3.1	n/a	Adherence >3" line
PH9	ZR, -10, 25	Dow UCAR EG106	100/0	I-PH B11	14:33:30	15:36	62.5	28.5	12.5	2.9	n/a	Similar adherence to baseline
PH10	ZD, -3, 5	Dow UCAR ADF (EG)	10°B (B=17.6)	Baseline	13:53:45	14:05	11.3	n/a	n/a	n/a	n/a	Standard failure
PH11	ZD, -3, 5	Dow UCAR ADF (EG)	10°B (B=17.6)	I-PH B11	13:54:25	14:12	17.6	n/a	n/a	n/a	n/a	100% bare @ 13:57, <5% ice @14:10. Plate iced up only if seeded
PH12	ZD, -3, 5	Dow UCAR ADF (EG)	10°B (B=17.6)	I-PH C2	14:12:45	14:28	15.3	n/a	n/a	n/a	n/a	Random spots of ice on plate
PH13	ZD, -3, 5	Octagon Octaflo EF	10°B (B=21.25)	Baseline	14:32:30	14:46	13.5	n/a	n/a	n/a	n/a	Standard failure
PH14	ZD, -3, 5	Octagon Octaflo EF	10°B (B=21.25)	I-PH B11	14:33:30	15:00	26.5	n/a	n/a	n/a	n/a	100% bare @ 14:39. No ice until lifted and dropped plate on edge @ 15:00 simulating taxi shaking
PH15	ZD, -3, 5	Octagon Octaflo EF	10°B (B=21.25)	I-PH C2	14:47:33	15:05	17.5	n/a	n/a	n/a	n/a	Bare on top, ice on bottom portion of plate at failure
PH16	ZD, -3, 13	C2	50/50	Baseline	17:00:22	17:29:30	29.1	17.5	7	1.1	n/a	Standard failure
PH17	ZD, -3, 13	C2	50/50	I-PH B11	16:59:20	17:14:30	15.2	16	3	0.4	n/a	10% bare @ 17:09. Ice formed primarily on bottom
PH18	ZD, -3, 13	Dow UCAR ADF (EG)	10°B (B=17.6)	Baseline	17:37:20	17:45	7.7	n/a	n/a	n/a	n/a	Standard failure
PH19	ZD, -3, 13	Dow UCAR ADF (EG)	10°B (B=17.6)	I-PH B11	17:09:40	17:35	25.3	n/a	n/a	n/a	n/a	100% bare @ 17:22. No ice until lifted and dropped plate on edge @ 17:35 simulating taxi shaking
PH20	ZD, -3, 13	Dow UCAR ADF (EG)	10°B (B=17.6)	I-PH C2	17:47	18:00	13.0	n/a	n/a	n/a	n/a	Random spots of ice on plate and mostly on bottom. Bare spots on plate.

n/a indicates that data was not calculated, or not collected.

Table 3.2: Log of Natural Snow Endurance Time Tests

Run #	Date	Fluid / Dilution	Surface	Start Time (min)	End Time (min)	Endurance Time (min)	OAT (°C)	Precip. Rate (g/dm²/h)	Wind Speed (km/h)	Thickness @ 5 min (mm)	Brix @ Fail (º)	Notes
1	February-21-12	2031, 75/25	Baseline	23:47:00	no fail	n/a	0.5	n/a	0	n/a	n/a	no fail. Snow stopped @ 23:54
	February-21-12	2031, 75/25	I-PH C2	23:47:18	no fail	n/a	0.5	n/a	0	n/a	n/a	
2	February-27-12	2031, 75/25	Baseline	14:45:23	15:09:00	23.6	-5.1	4.6	20	0.3	10.5	
	February-27-12	2031, 75/25	I-PH C2	14:45:49	15:12:00	26.2	-5.1	4.5	20	0.3	10	
3	March-01-12	2031, 100/0	Baseline	06:29:40	06:52:30	22.8	-5.2	8.6	33	0.4	10.5	
	March-01-12	2031, 100/0	I-PH C2	06:30:20	06:54:00	23.7	-5.2	8.6	33	0.4	10	
4	March-01-12	2031, 75/25	Baseline	08:32:40	08:48:00	15.3	-5.0	13.4	32	n/a	7.5	
	March-01-12	2031, 75/25	I-PH C2	08:33:00	08:45:00	12.0	-5.0	14.0	32	n/a	n/a	
5	March-01-12	2031, 100/0	Baseline	10:42:30	10:57:40	15.2	-4.7	16.8	32	n/a	10.5	
	March-01-12	2031, 100/0	I-PH C2	10:43:10	10:57:20	14.2	-4.7	16.8	32	n/a	9.5	
6	March-03-12	ABC-S+, 75/25	Baseline	01:25:26	02:19:00	53.6	1.2	18.9	19	2.5	4	
	March-03-12	ABC-S+, 75/25	I-PH C2	01:25:06	02:24:47	59.7	1.2	19.0	19	1.8	4	
7	March-03-12	AD-49, 100/0	Baseline	02:56:32	no fail	n/a	-0.3	n/a	22	1.2	n/a	
	March-03-12	AD-49, 100/0	I-PH C2	02:56:29	no fail	n/a	-0.3	n/a	22	1.2	n/a	

n/a indicates that data was not calculated, or not collected.

3.2 Data Analysis

The endurance time testing results were separated into three groups to provide a general summary of the results. Testing was conducted in simulated freezing precipitation conditions with the exception of the Type IV testing with the I-PH C2 coating, which was done in natural snow conditions. Figure 3.1 to Figure 3.4 demonstrate the results obtained. The four test groupings are as follows:

- Type I Testing with I-PH B11 Coating;
- Type I Testing with I-PH C2 Coating;
- Type IV Testing with I-PH B11 Coating; and
- Type IV Testing with I-PH C2 Coating (Natural Snow Tests).

The Type I endurance time results in Figure 3.1, indicated that the ice protection time for the tests conducted with the I-PH B11 coated plate were longer when compared to the standard baseline test (see Photo 3.1). It should be noted that the typical Type I fluid failure call was not applicable; fluid failure would normally be called when 1/3 of the plate was not wetted, but because the coating delayed the onset of freezing, failure was called when 1/3 of the plate showed signs of frozen contamination or ice. This method of failure call was applied to both plates to isolate the effect of the coating on failure time. In all of these cases the coated plate had to be seeded in order to begin forming ice. During each test with the ice phobic coatings, fluid wetting issues were observed. Results indicate the time when more than 30 percent of the plate was not wetted by a dashed line and an arrow. In the case of Type I fluid tests, the heat in the plate provided some protection against freezing contamination. In addition, the hydrophobic properties of the coating delayed freezing on the unprotected surface. Due to the latter factor, the ice protection time on the coated surfaces was generally longer as compared to the baseline test.

The Type I endurance time results in Figure 3.2 were slightly different, however, these tests still indicated that the ice protection time for the tests conducted with the I-PH C2 coated plate were longer as compared to the standard baseline test. In all four cases tested, the coating did delay the onset of adherence. However, only the first test demonstrated fluid wetting issues. The I-PH C2 coating did not require seeding in order to generate ice formations. The surface may have been less hydrophobic as compared to the I-PH B11 coated surface.

The Type IV endurance time results in Figure 3.3 indicate that the protection time for the tests conducted with the new I-PH B11 coating demonstrated some reductions with the 75/25 and 50/50 fluid. However, these results were comparable when testing the 100/0 fluid (see Photo 3.2). This difference is likely due to low viscosity of the diluted fluids, which makes it easier to slide off the coated test plate. The reductions in protection time for dilutions have been seen previously with other ice phobic coatings tested in the past. Compared to the Type I tests, the hydrophobic nature of the coating does not add to the protection time because the ice forms in the thin fluid layer of Type IV fluid as compared to on the bare plate surface for the Type I tests.

The Type IV results shown in Figure 3.4 indicated that the fluid endurance times were comparable on the I-PH C2 coated and baseline plate. The measured endurance time was slightly shorter on the I-PH C2 coated plate during two of the five tests. These results indicated that the coating did not tend to shed the fluid.

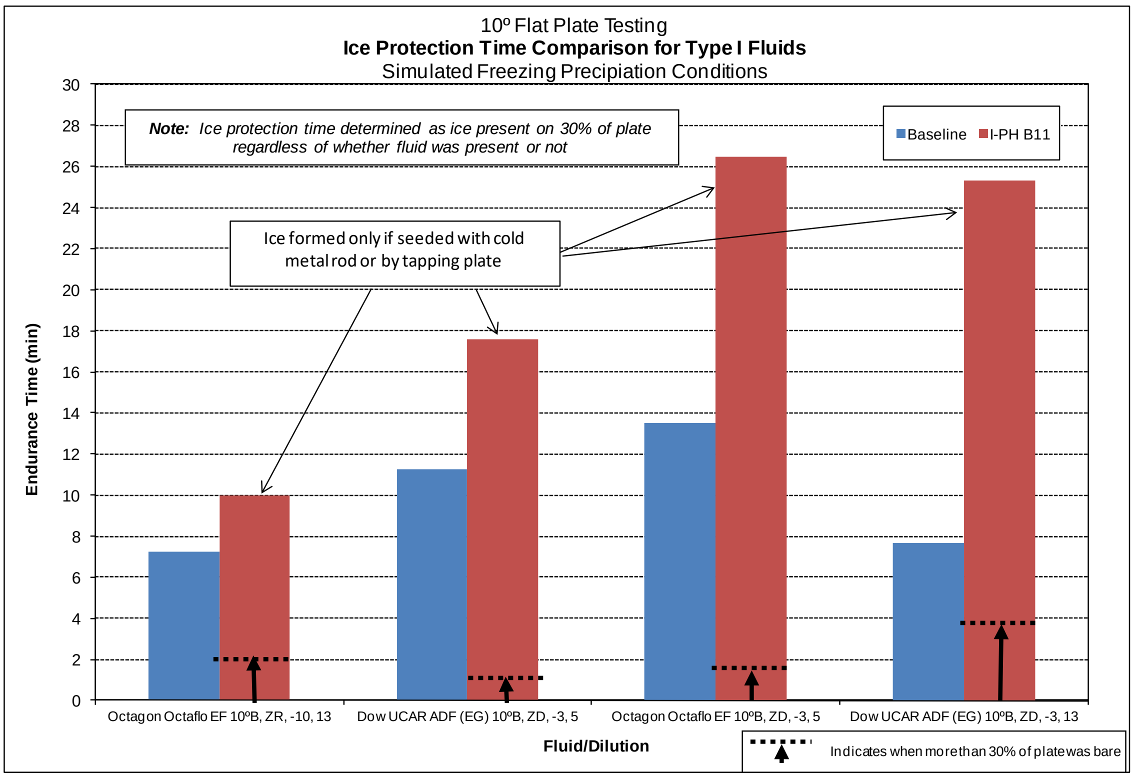

Figure 3.1: Type I Testing with I-PH B11 Coating - Endurance Time Results

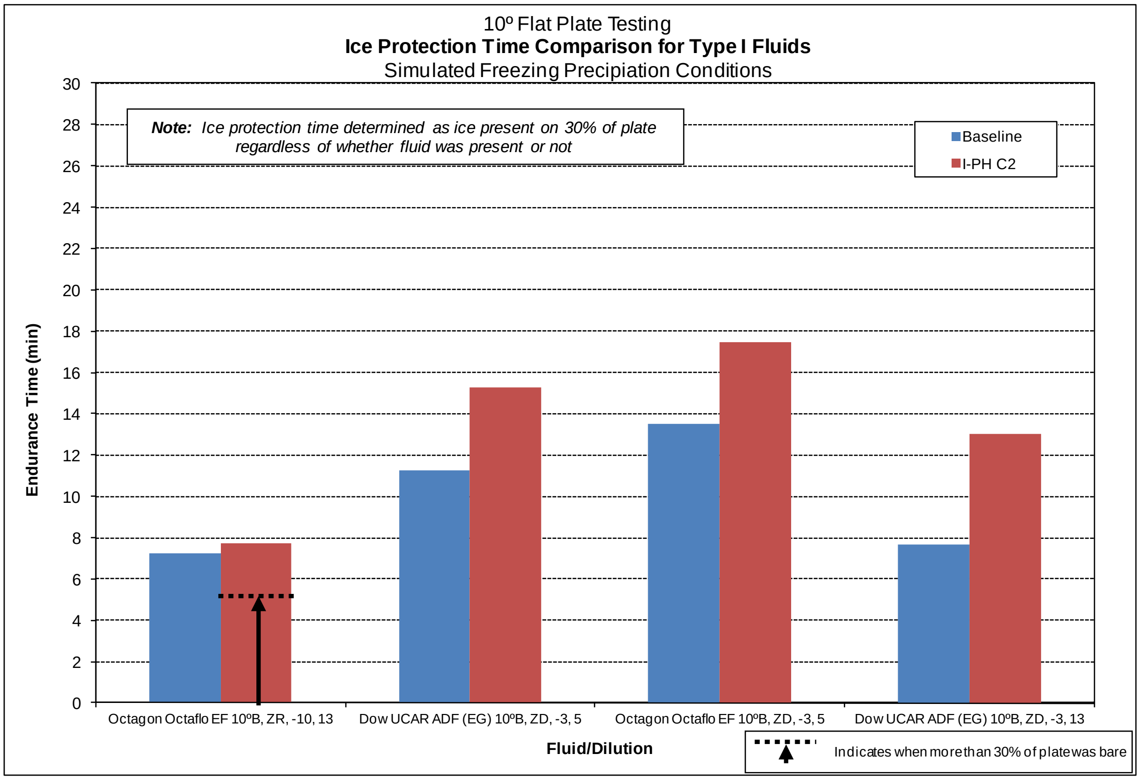

Figure 3.2: Type I Testing with I-PH C2 Coating - Endurance Time Results

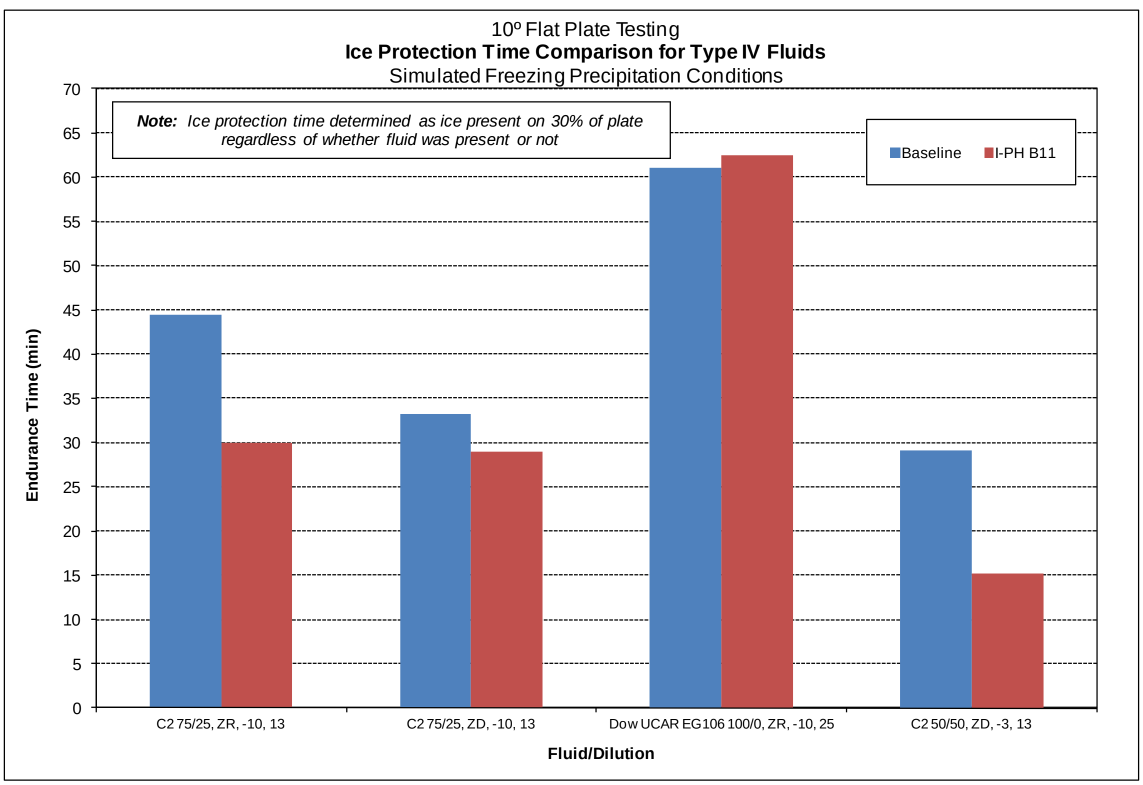

Figure 3.3: Type IV Testing with I-PH B11 Coating - Endurance Time Results

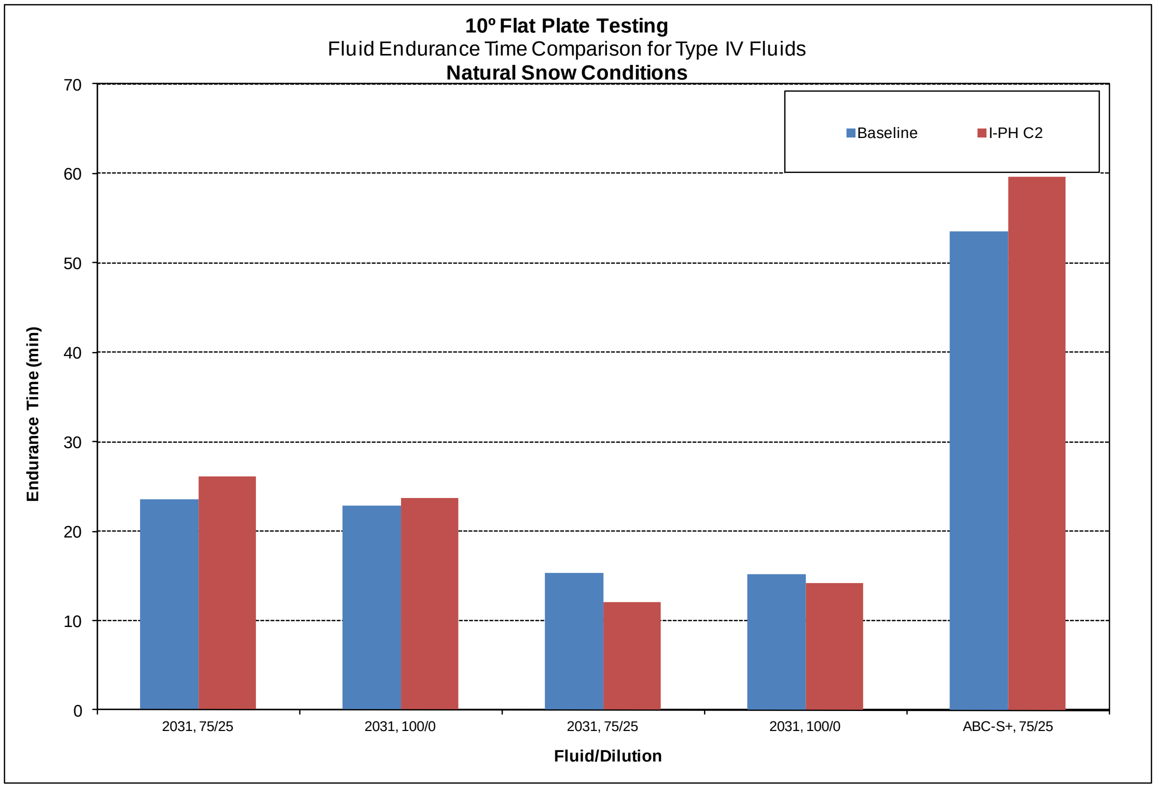

Figure 3.4: Type IV Testing with I-PH C2 Coating – Natural Snow Endurance Time Results

3.3 General Observations

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

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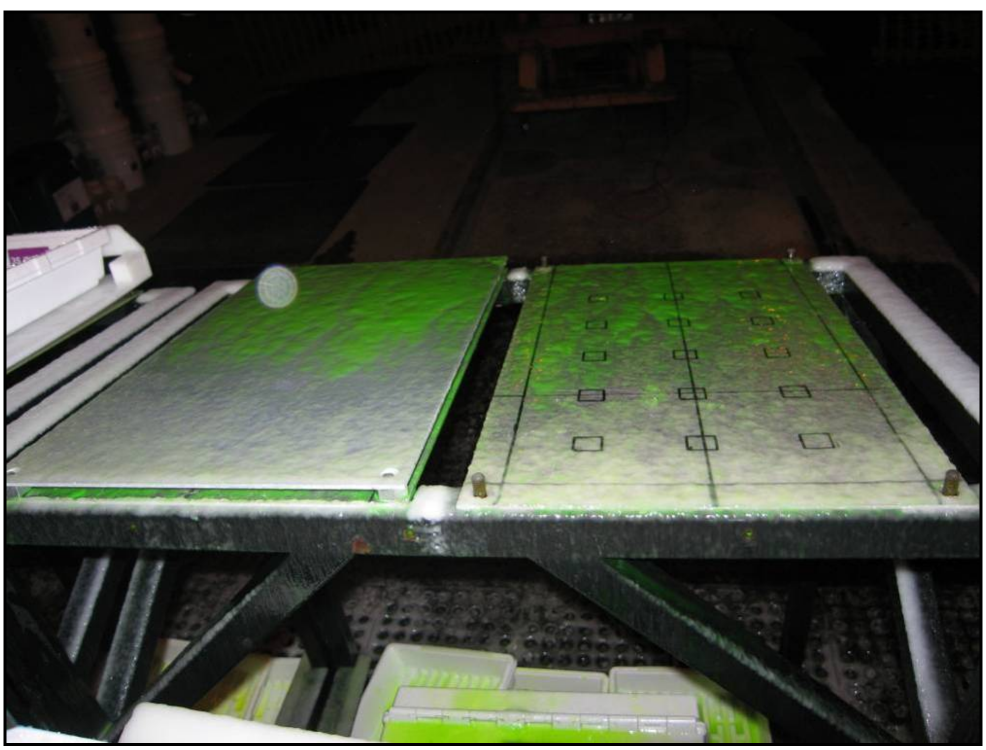
Photo 3.1: Baseline, I-PH B11, and I-PH C2 Plates at Time of Baseline Type I Fluid Failure (Test # PH1, PH2, PH3)

Photo 3.2: I-PH B11, and Baseline Plate at Time of Type IV 100/0 Fluid Failure (Test # PH8, PH9)



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4. FLUID WETTING AND FLUID THICKNESS TESTING DATA AND RESULTS

In this section, the fluid thickness testing data collected during the winter of 2011-12 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 in light freezing rain at the NRC CEF, as this is considered a worst case scenario with regard to adhesion to surfaces. Fluid thickness was measured for the Type IV fluid test (fluid wetting was not necessary as it typically remains fully wetted). Fluid wetting was measured for Type I fluids because fluid thickness is not representative (thickness is usually in the range from 0 to 1 mm for all Type I fluids) and because wetting issues are more apparent due to the lack of fluid thickeners.

4.1 Log of Fluid Wetting and Fluid Thickness 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 2011-12. 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 Type I Fluid Thickness Tests Conducted

Test #	Fluid Type	Fluid Dilution	Test Surface	% Wet @ 2 min	% Wet @ 5 min	% Wet @ 15 min	% Wet @ 30 min	Thick (mm) @ 2 min	Thick (mm) @ 5 min	Thick (mm) @ 15 min	Thick (mm) @ 30 min
PH-TH1	Type I EG - D	10°B	Baseline	100%	100%	100%	-	-	-	-	-
PH-TH2	Type I EG - D	10°B	I-PH B11	50%	<5%	<1%	-	-	-	-	-
PH-TH4	Type I EG - D	STD MIX	Baseline	100%	100%	100%	100%	-	-	-	-
PH-TH5	Type I EG - D	STD MIX	I-PH B11	95%	70%	15%	<1%	-	-	-	-
PH-TH7	Type IV PG - A	100/0	Baseline	-	-	-	-	1.5	1.2	1	0.8
PH-TH8	Type IV PG - A	100/0	I-PH B11	-	-	-	-	1.5	1.1	0.7	0.5

Note: All tests conducted at OAT -3ºC

4.2 Test Summary

These fluid thickness and wetting results are limited in that they have evaluated only a sample of the fluids currently available, and serve only to provide an initial indication of performance.

The Type I wetting tests indicated potential wetting problems with the ice phobic coated test surfaces. Wetting issues were observed 2 minutes 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, generating equal or longer protection times. This is further explained in Section 5.

The Type IV fluid thickness test demonstrated some degradation in fluid thickness 5 minutes after application. Although the plate remained fully wetted and evenly coated during the test, some reduction in fluid thickness was observed. Large reductions in fluid thickness may result in adverse impacts on fluid endurance times.

4.3 General observations

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

5. ADHERENCE TESTING DATA AND RESULTS

In this section, the adherence testing data collected during the winter of 2011-12 is analysed and discussed. The coated surface was evaluated against the baseline plate based on the potential to delay the onset of adherence when exposed to simulated freezing contamination. The plates were bare of fluid and at ambient temperature. Testing was conducted in light freezing rain, as this is considered to be a worst case scenario with regard to adhesion to surfaces.

5.1 Log of Adherence Tests Conducted

To facilitate the accessibility of the data collected, a log was created for the tests conducted by APS at NRC CEF during the winter of 2011-12. The log presented in Table 5.1 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 5.1: Log of Adherence Tests Conducted

Test #	Precip. Type	Temp (°C)	Precip. Rate (g/dm²/h)	Test Surface	Time: 30% Ice Coverage	Time: 100% Ice Coverage	Comments
PH-AD1	ZR	-10	13	Baseline Plate	1 min	2.5 min	30% ice at 1 min, 100% at 2.5 min
PH-AD2	ZR	-10	13	I-PH B11	n/a	4.5 min	After 2.5 min beads of water present but no ice unless probed. At 4.5 min seeding and tapping resulted in ice on 100% of plate

5.2 Test Summary

During the comparative test run, the baseline aluminum plate demonstrated signs of ice and adherence following 1 minute of exposure to freezing rain. The baseline aluminum plate was completely covered in ice following 2.5 minutes of exposure.

In the case of the ice phobic coated plate, super cooled beads of water were present on the surface of the plate, however, they were not freezing or adhering to the surface when left undisturbed. This was also the case at the 2.5 minute mark when the baseline plate was completely covered with ice (Photo 5.1). Small patches of ice did form when beads of water grew very large and eventually slid down the plate, causing small streaks of ice. After 4.5 minutes, the plate was lifted and tapped on its side at which point the beads of water slid and caused ice streaks which covered the entire plate (Photo 5.2).

At the end of the first test run, the contamination was removed using a handheld scraper. It was observed that the coating made it easier to remove the adhered contamination compared to the baseline plate.

5.3 General Observations

When left undisturbed, the coated surface was able to delay the onset of adherence and ice formation, as compared to the baseline test plate. In addition, the removal of the contamination was easier on the 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. Aerodynamic research to investigate the effects is recommended.

Similar trends were seen with other coatings from the same manufacturer.

Photo 5.1: Baseline and Coated Test Plate @ 2.5 minutes

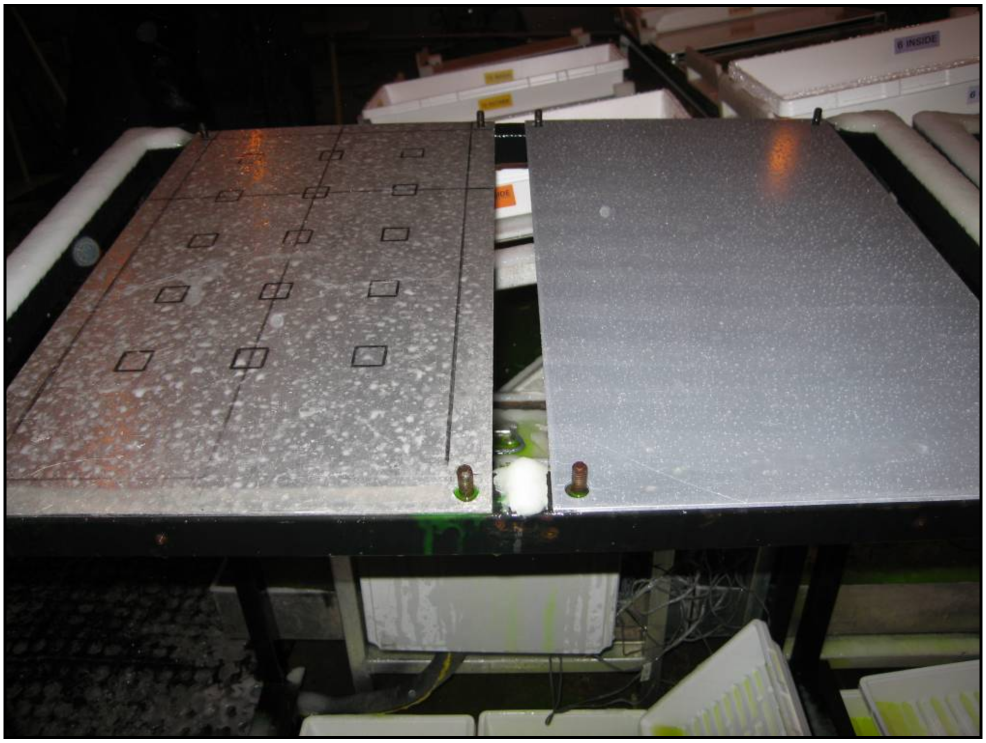

Photo 5.2: Baseline and Coated Test Plate @ 4.5 minutes

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6. VERTICAL STABILIZER TESTING DATA AND RESULTS

In this section, the vertical stabilizer testing data collected during the winter of 2011-12 is analysed and discussed. Due to the early contamination 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 a vertical plate which was coated with an ice phobic coating, and the performance was compared to a baseline vertical plate which was not coated (see Photo 6.1).

6.1 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 2011-12. The log presented in Table 6.1 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. These tests were conducted in natural snow.

Table 6.1: Log of Vertical Stabilizer Endurance Time Tests

Run #	Date	Fluid/Dilution	Surface	Start Time (min)	End Time (min)	Endurance Time (min)	EC OAT (°C)	Precip. Rate (g/dm²/h)	EC Wind Speed (km/h)	Brix @ Fail	Notes
1	January-17-12	ABC-S+, 100/0	Baseline	15:20:22	15:40:00	19.6	-3.7	14.3	24	7	Look same at fail
	January-17-12	ABC-S+, 100/0	I-PH B3	15:22:42	15:40:00	17.3	-3.7	14.0	24	7.5	
2	January-26-12	Type IV?, 100/0?	Baseline	22:29:20	22:54:00	24.7	-5.3	6.2	22	n/a	Fluid not documented. Assume Type IV PG 100/0
	January-26-12	Type IV?, 100/0?	I-PH B3	22:29:45	22:57:05	27.3	-5.3	6.3	22	n/a	
3	January-26-12	AD-49, 100/0	Baseline	23:27:17	23:58:00	30.7	-5.8	6.0	22	n/a	same fluid as AA testing
	January-26-12	AD-49, 100/0	I-PH B3	23:27:44	00:00:45	33.0	-5.8	6.0	22	n/a	
4	February-27-12	ABC-S+, 75/25	Baseline	14:52:10	15:52:00	59.8	-5.1	1.9	20	12	
	February-27-12	ABC-S+, 75/25	I-PH B3	14:52:55	15:53:45	60.8	-5.1	1.9	20	13.5	
5	March-01-12	ABC-S+, 75/25	Baseline	07:27:30	07:43:00	15.5	-4.9	6.5	30	7.5	
	March-01-12	ABC-S+, 75/25	I-PH B3	07:26:50	07:43:00	16.2	-4.9	6.5	30	8.25	
6	March-03-12	ABC-S+, 75/25	Baseline	01:24:05	01:54:35	30.5	1.2	17.3	19	2	
	March-03-12	ABC-S+, 75/25	I-PH B3	01:24:50	01:56:15	31.4	1.2	17.7	19	3	
7	March-03-12	AD-49, 100/0	Baseline	02:57:05	no fail	n/a	-0.3	n/a	22	n/a	no fail, snow stopped
	March-03-12	AD-49, 100/0	I-PH B3	02:57:59	no fail	n/a	-0.3	n/a	22	n/a	

n/a indicates that data was not calculated, or not collected.

6.2 Data Analysis

Figure 6.1 demonstrates the results obtained. In general, the fluid endurance time measured on the vertical coated surface was comparable to the baseline vertical surface. Of the six tests conducted, only the first test indicated a reduction in endurance time on the coated test plate as compared to the baseline. During the other five tests, the coated plate demonstrated slightly longer endurance times. As testing was conducted with Type IV fluids only, no adherence was observed.

A special ad hoc test was completed to compare a vertical stabilizer set at 80° to that of a vertical stabilizer set at 90°. The results indicated little to no difference in endurance times between these two setups.

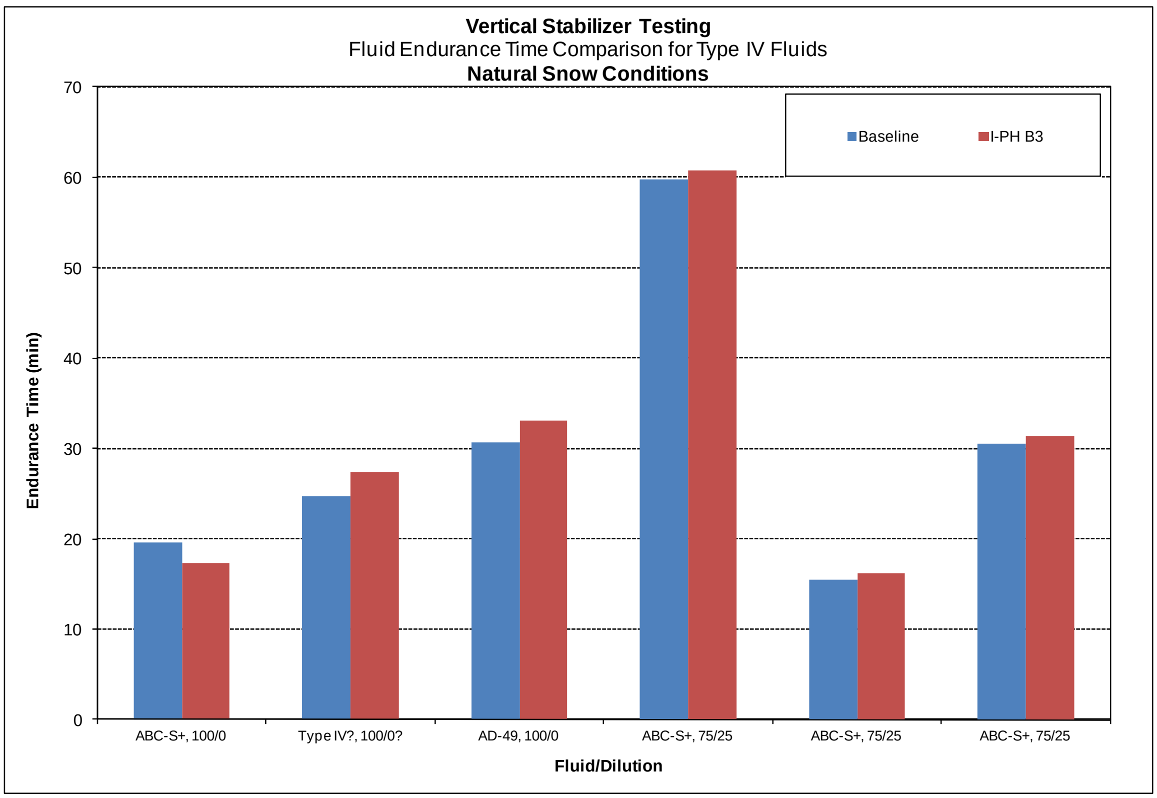

Figure 6.1: Type IV Testing with I-PH B3 Coating – Vertical Stabilizer Endurance Time Results

6.3 General Observations

The Type IV results indicated generally slightly longer endurance times for the vertical coated surface. As testing was conducted with Type IV fluids only, no adherence was observed. Future testing should focus on the use of Type I fluid on vertical surfaces, as in these cases, the ice phobic coating may have more benefits.

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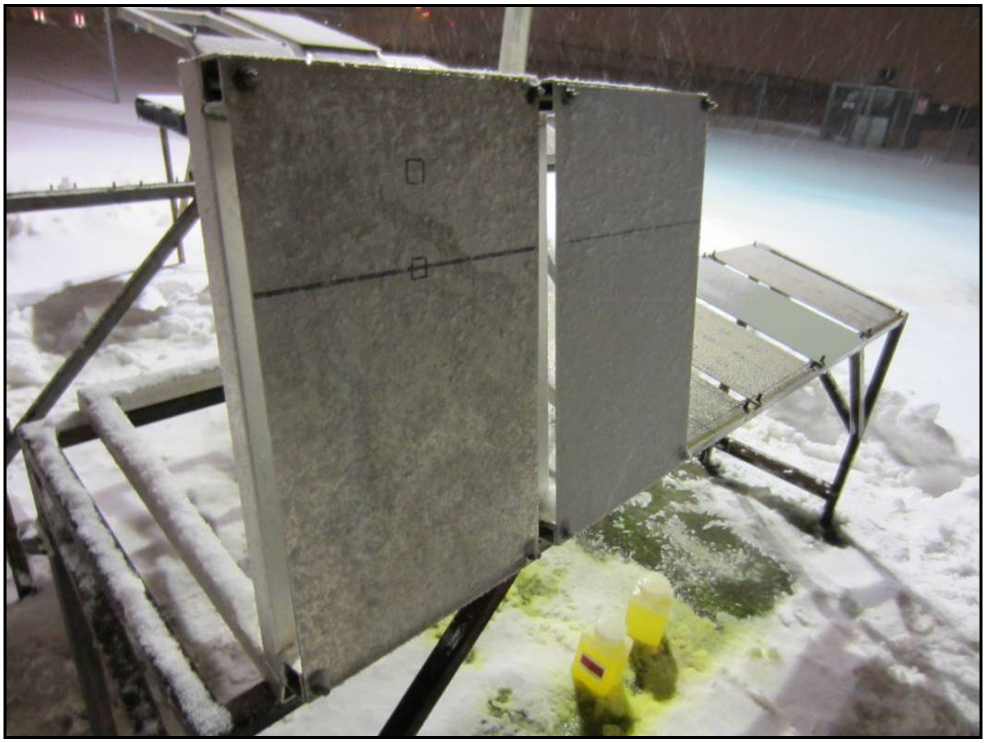
Photo 6.1: Outdoor Testing Setup



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7. WIND TUNNEL TESTING OF STREAMLINE POSTS

In this section, the wind tunnel testing data collected during the winter of 2011-12 is analysed and discussed. Due to procedural limitations, it was not possible to have the ice phobic coatings applied to the airfoil. Instead, two identical stream line posts, used for mounting pitot sensors in the wind tunnel, were re-surfaced with aluminum sheeting, one of which was coated with ice phobic product I-PH B11 and the other which was left untreated. The streamline posts were positioned on the underside of the leading edge scaffolding, which when stowed during the wind tunnel takeoff runs was located behind the wing section and was subjected to glycol spray and mist. The objective was to evaluate the performance of ice phobic coatings in reducing residue formations following repeated applications of glycol.

7.1 Test Summary

The coated and uncoated streamline posts (Photo 7.1) were installed on the scaffolding on January 29, 2012 until the end of the wind tunnel testing on February 2, 2012 (Photo 7.2). During that period, over seventy wind tunnel tests were conducted, nearly fifty of which were with deicing fluid, anti-icing fluid, windshield washer fluid, or pre-stone fluid. The streamline posts were inspected daily for residues but were left relatively undisturbed and were not cleaned between tests.

At the start of the second day of testing (following eleven anti-icing fluid tests the previous day and an overnight dry-out period), a wet fluid film was present on both test surfaces. Longer narrower streaks were seen on the coated surface, whereas a wider thinner smeared layer was present on the uncoated surface. However, no dry residue was present on either surface (Photo 7.3 and Photo 7.4).

At the end of the second day of testing (following eleven tests with windshield washer fluid and prestone fluid), similar amounts of wet fluid film were present on both surfaces (Photo 7.5 and Photo 7.6). The wet fluid film was left to dry out overnight.

At the start of the third day of testing, some dry-out occurred and the coated surface had a slightly greater residual fluid thickness as compared to the uncoated surface (0.05 mm vs. 0.03 mm on the highest peaks). Visually, the uncoated surface seemed to have a very thin film layer, whereas the coated surface seemed to have more isolated areas with fluid film (Photo 7.7 and Photo 7.8).

As testing progressed, no other significant findings were observed. Photo 7.9 and Photo 7.10 show the condition of the streamline posts at the end of the last day of testing.

7.2 General Observations

The coated surface appeared to have fluid in isolated areas whereas the uncoated surface was generally completely covered in a thin fluid film. The hydrophobic properties of the ice phobic coating may be repelling some of the fluid and causing the generally "streaky" fluid film coverage, which may in turn effect and possibly reduce fluid residue formation. However, this has yet to be investigated.

Photo 7.1: Streamline Post (with aluminum sheeting and without coating)

Photo 7.2: Positioning of Streamline Post (second streamline post not shown)

Photo 7.3: Coated Streamline Post – Start of Day 2

Photo 7.4: Uncoated Streamline Post – Start of Day 2

Photo 7.5: Coated Streamline Post – End of Day 2

Photo 7.6: Uncoated Streamline Post – End of Day 2

Photo 7.7: Coated Streamline Post – Start of Day 3

Photo 7.8: Uncoated Streamline Post – End of Day 3

Photo 7.9: Coated Streamline Post – End of Day 5

Photo 7.10: Uncoated Streamline Post – End of Day 5

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8. FLUID DRAINAGE FROM AERODYNAMICALLY QUIET AREAS IN AIRCRAFT

In this section, the fluid drainage testing data collected during the winter of 2011-12 is analysed and discussed. The objective was to investigate potential application of ice phobic products in aerodynamically quiet areas.

For the purpose of these tests, aerodynamically quiet areas in aircraft were simulated using stainless steel cups, both coated and uncoated, with a drain hole drilled or punched into the bottom. Three different drain holes were evaluated: a small hole (Photo 8.1), a large hole (Photo 8.2) and a narrow slit (Photo 8.3). The cups were filled with Type I, II or III fluid and left to drip out on a matrix board (Photo 8.4). The containers were weighed dry (at the start of the test), at 1 hour, at 5 hours, and after 4 days (Photo 8.5). The coated cup performance is compared to uncoated cup for each specific fluid type.

8.1 Log of Fluid Drainage 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 2011-12. The log presented in Table 8.1 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 8.1: Log of Fluid Drainage Tests Conducted

Test #	Fluid Name	Fluid Type	Fluid Dilution	DRAIN HOLE TYPE	Test Surface Treatment*	Intial Cup Dry Weight (g)	1hr Weight (g)	5hr Weight (g)	4 Day Weight (g)	Delta (g) 1hr	Delta (g) 5hr	Delta (g) 4 days
PH-D1	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.0)	SMALL HOLE	Baseline	17	17.5	17.5	17.1	0.5	0.5	0.1
PH-D2	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.0)	SMALL HOLE	I-PH B2	17.2	17.7	17.5	17.4	0.5	0.3	0.2
PH-D3	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.0)	SMALL HOLE	I-PH B4	19.5	19.9	19.7	19.5	0.4	0.2	0
PH-D4	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.0)	SMALL HOLE	I-PH A	17.8	18	18	17.6	0.2	0.2	-0.2
PH-D5	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.0)	SMALL HOLE	Baseline	18.2	18.5	18.5	18.2	0.3	0.3	0
PH-D6	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.0)	SMALL HOLE	I-PH B2	18.1	18.8	18.6	18.2	0.7	0.5	0.1
PH-D7	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.0)	SMALL HOLE	I-PH B4	18.3	18.7	18.7	18.2	0.4	0.4	-0.1
PH-D8	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.0)	SMALL HOLE	I-PH A	16.6	17.1	17	16.7	0.5	0.4	0.1
PH-D9	Clariant 2031	TYPE III PG	100/0	SMALL HOLE	Baseline	17.2	17.9	17.8	17.5	0.7	0.6	0.3
PH-D10	Clariant 2031	TYPE III PG	100/0	SMALL HOLE	I-PH B2	20.6	21.2	20.9	20.7	0.6	0.3	0.1
PH-D11	Clariant 2031	TYPE III PG	100/0	SMALL HOLE	I-PH B4	19.5	20.3	20	19.6	0.8	0.5	0.1
PH-D12	Clariant 2031	TYPE III PG	100/0	SMALL HOLE	I-PH A	18.3	18.8	18.6	18.4	0.5	0.3	0.1
PH-D13	Kilfrost ABC-S Plus	Type IV PG	100/0	SMALL HOLE	Baseline	18.3	19.9	19.4	18.4	1.6	1.1	0.1
PH-D14	Kilfrost ABC-S Plus	Type IV PG	100/0	SMALL HOLE	I-PH B2	18.5	19.3	19	18.5	0.8	0.5	0
PH-D15	Kilfrost ABC-S Plus	Type IV PG	100/0	SMALL HOLE	I-PH B4	18.1	18.8	18.4	18.4	0.7	0.3	0.3
PH-D16	Kilfrost ABC-S Plus	Type IV PG	100/0	SMALL HOLE	I-PH A	17.8	19.2	18.7	17.8	1.4	0.9	0
PH-D17	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.0)	LARGE HOLE	Baseline	18.6	18.6	18.5	18.6	0	-0.1	0
PH-D18	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.0)	LARGE HOLE	I-PH B2	17.8	17.8	17.6	17.8	0	-0.2	0
PH-D19	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.0)	LARGE HOLE	I-PH B4	19.3	19.4	19.4	19.3	0.1	0.1	0
PH-D20	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.0)	LARGE HOLE	I-PH A	19	19	19.1	19	0	0.1	0
PH-D21	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.0)	LARGE HOLE	Baseline	16.1	16.1	16.1	16.1	0	0	0
PH-D22	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.0)	LARGE HOLE	I-PH B2	20	20.5	20.3	20.2	0.5	0.3	0.2
PH-D23	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.0)	LARGE HOLE	I-PH B4	19.3	19.5	19.3	19.3	0.2	0	0
PH-D24	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.0)	LARGE HOLE	I-PH A	20.2	20.8	20.5	20.5	0.6	0.3	0.3
PH-D25	Clariant 2031	TYPE III PG	100/0	LARGE HOLE	Baseline	18.9	19.5	19.3	19	0.6	0.4	0.1
PH-D26	Clariant 2031	TYPE III PG	100/0	LARGE HOLE	I-PH B2	17.3	17.6	17.4	17.3	0.3	0.1	0
PH-D27	Clariant 2031	TYPE III PG	100/0	LARGE HOLE	I-PH B4	21.5	21.9	21.9	21.7	0.4	0.4	0.2
PH-D28	Clariant 2031	TYPE III PG	100/0	LARGE HOLE	I-PH A	19.7	20.5	20.5	20	0.8	0.8	0.3

Table 8.1: Log of Fluid Drainage Tests Conducted (cont'd)

Test #	Fluid Name	Fluid Type	Fluid Dilution	DRAIN HOLE TYPE	Test Surface Treatment*	Intial Cup Dry Weight (g)	1hr Weight (g)	5hr Weight (g)	4 Day Weight (g)	Delta (g) 1hr	Delta (g) 5hr	Delta (g) 4 days
PH-D29	Kilfrost ABC-S Plus	Type IV PG	100/0	LARGE HOLE	Baseline	18	19.4	19	18.3	1.4	1	0.3
PH-D30	Kilfrost ABC-S Plus	Type IV PG	100/0	LARGE HOLE	I-PH B2	18.3	18.7	18.7	18.4	0.4	0.4	0.1
PH-D31	Kilfrost ABC-S Plus	Type IV PG	100/0	LARGE HOLE	I-PH B4	18.9	19.6	19.5	19.2	0.7	0.6	0.3
PH-D32	Kilfrost ABC-S Plus	Type IV PG	100/0	LARGE HOLE	I-PH A	19.1	20.5	20.4	19.9	1.4	1.3	0.8
PH-D33	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.0)	NARROW SLIT	Baseline	18.1	18.5	18.4	18.1	0.4	0.3	0
PH-D34	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.0)	NARROW SLIT	I-PH B2	18.7	18.8	18.7	18.6	0.1	0	-0.1
PH-D35	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.0)	NARROW SLIT	I-PH B4	20.4	20.4	20.4	20.3	0	0	-0.1
PH-D36	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.0)	NARROW SLIT	I-PH A	20.5	20.9	20.8	20.3	0.4	0.3	-0.2
PH-D37	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.0)	NARROW SLIT	Baseline	17.9	18.2	18	18	0.3	0.1	0.1
PH-D38	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.0)	NARROW SLIT	I-PH B2	17.5	17.5	17.5	17.6	0	0	0.1
PH-D39	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.0)	NARROW SLIT	I-PH B4	21.7	21.9	21.9	21.8	0.2	0.2	0.1
PH-D40	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.0)	NARROW SLIT	I-PH A	18.7	19.2	19.2	19	0.5	0.5	0.3
PH-D41	Clariant 2031	TYPE III PG	100/0	NARROW SLIT	Baseline	18.3	18.6	18.6	18.4	0.3	0.3	0.1
PH-D42	Clariant 2031	TYPE III PG	100/0	NARROW SLIT	I-PH B2	19.3	19.7	19.6	19.5	0.4	0.3	0.2
PH-D43	Clariant 2031	TYPE III PG	100/0	NARROW SLIT	I-PH B4	20.3	20.3	20.3	20.1	0	0	-0.2
PH-D44	Clariant 2031	TYPE III PG	100/0	NARROW SLIT	I-PH A	21	21.2	21.2	20.9	0.2	0.2	-0.1
PH-D45	Kilfrost ABC-S Plus	Type IV PG	100/0	NARROW SLIT	Baseline	18.6	19.9	19.5	18.6	1.3	0.9	0
PH-D46	Kilfrost ABC-S Plus	Type IV PG	100/0	NARROW SLIT	I-PH B2	16.9	17.4	17.1	16.9	0.5	0.2	0
PH-D47	Kilfrost ABC-S Plus	Type IV PG	100/0	NARROW SLIT	I-PH B4	19.1	19.4	19.5	19	0.3	0.4	-0.1
PH-D48	Kilfrost ABC-S Plus	Type IV PG	100/0	NARROW SLIT	I-PH A	20.7	21.7	21.2	20.6	1	0.5	-0.1

OAT was -3ºC at start but varied from -3ºC to -10ºC based on HOT testing conducted in conjunction.

Type I fluid was applied at room temperature (20ºC) wheras Type III and IV fluid was applied at OAT (-3ºC)

8.2 Test Summary

8.2.1 General

This testing was preliminary and primarily done as a scoping study. As such the test procedure could be further improved for future tests. One of the challenges of this exercise was recording the very small residual amounts of fluid in the chamber where constant air circulation interfered with the weigh scale accuracy (see setup Photo 8.6). For future tests, a weigh scale with a higher accuracy and an enclosed chamber should be used, or alternatively, use larger cups with multiple holes to collect larger residual fluid samples and reduce experimental error. For this reason, the observations discussed below are based primarily on visual observations taken during the test.

Photos of the cups at 5 hours, and after 4 days are shown in Photo 8.7 and Photo 8.8. It should be noted that the cup number shown in the photo corresponds to the number portion of the "Test #" in Table 8.1.

8.2.2 Small Hole vs. Large Hole vs. Small Slit

The large hole allowed more fluid to flow through, therefore less remained in cup after initial filling. The small hole and small slit behaved similarly, likely due to similar size in openings. In all cases, very little fluid remained shortly after start of test.

8.2.3 Type I vs. Type III vs Type II

There was no significant difference in how the Type I 10º buffer fluid behaved compared to the Type I standard mix fluid. The Type II and III fluid however appeared to generate larger residual fluid in the cups compared to the Type I fluid. Visually, it appeared the Type III fluid may have generated greater residual fluid compared to the Type II fluid.

8.2.4 Baseline vs. I-PH B2 vs. I-PH B4 vs. I-PH A

The baseline uncoated cup always demonstrated a smooth coating of residual fluid, even with Type I fluids. Although fluid may have puddled in certain areas, a small film was always still present on walls of cup.

The I-PH B2 and I-PH B4 coated cups behaved similarly. The coating's hydrophobic properties seemed to shed fluid from the walls leaving much less film (if any). However, these coatings demonstrated larger puddles and beads of fluid in the bottom of cup as compared to baseline; again, likely due to the hydrophobic coating. In general, the I-PH B2 and I-PH B4 coated cups had glycol film and fluid spread over a smaller area as compared to the baseline test after several hours of drainage.

The I-PH A coated cup seemed to have minimal effects on fluid drainage. The coating may have helped, but was not visually striking. The appearance was not very different from the baseline test.

8.3 General Observations

Procedural limitations put greater confidence in visual observations rather than measured delta weight data analysis. Based on visual observation, the cups coated with I-PH B2 and I-PH B4 appeared to have fluid in isolated areas whereas the baseline and the I-PH A coated cup were generally completely covered in a thin fluid film. The hydrophobic properties of the I-PH B2 and I-PH B4 coating may be repelling some of the fluid and causing the fluid to puddle in isolated areas, which may in turn effect and possibly reduce fluid residue formation. However, this has yet to be investigated.

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Photo 8.1: Small Hole in Stainless Steel Cup

Photo 8.2: Large Hole in Stainless Steel Cup

Photo 8.3: Small Slit in Stainless Steel Cup

Photo 8.4: Matrix of Filled Cups Left to Drip Out Fluid

Photo 8.5: Weigh Scale and Stand for Weighing Cups

Photo 8.6: General Setup

Photo 8.7: Matrix of Draining Cups After 5 Hours

Photo 8.8: Matrix of Draining Cups After 4 Days

9. OVERNIGHT ICE TESTING DATA AND RESULTS

In this section, the overnight ice testing data collected during the winter of 2011-12 is analysed and discussed. The objective was to investigate the potential of ice phobic products to prevent ice formation on critical surfaces. To do so, two test plates (one coated with I-PH B3 and one uncoated) were exposed to freezing precipitation in the NRC chamber. No anti-icing fluid was applied. The plates were left undisturbed during the testing periods, in the outer perimeter of the spray zone. The plates were exposed to precipitation during four testing days, and the coated surface accretion was compared to the non-coated surface accretion. Surfaces were examined at least once a day.

9.1 Video Documentation and Commentary

As testing was primarily based on visual observations, a log was not created. Instead, video documentation and commentary of each of the inspections was recorded. Videos were taken on:

- March 22, 2012 at 6 pm;
- March 23, 2012 at 12 pm;
- March 23, 2012 at 6 pm (two videos);
- March 26, 2012 at 12 pm;
- March 27, 2012 at 1 pm (two videos); and
- March 28, 2012 at 1 pm (photo only).

The commentary and observations are summarized in the following section.

9.2 Test Summary

Early on during testing, the plates were exposed to freezing rain and freezing drizzle. The testing demonstrated that early on (towards the end of the first day of testing), larger and longer icicles would form on the bottom of the ice phobic coated plate (see Photo 9.1). This phenomenon was likely due to the hydrophobic properties of the plate trying to shed the super-cooled precipitation. In fact, the coated plate still had some bare spots where ice still had not completely formed, whereas the baseline plate was completely frozen over.

By day two of testing, the plates began to look similar as more and more ice formed on the surfaces of both plates. The bare spots on the coated surface also eventually filled up with ice as well.

At the end of the second day of testing, the top 15 cm of the plate were scraped clean (see Photo 9.2). The coated plate required less effort as compared to the baseline to remove the frozen ice but it still required a significant amount of effort.

During the third and fourth day, the plates were exposed to freezing fog. During these tests the condition of the plates seemed similar, and the coated surface was not effective at preventing the freezing fog from forming on the surface of the plate (see Photo 9.3).

At the end of day five (see Photo 9.4), the ice was once again scraped from both plates and again the coated plate required less effort as compared to the baseline to remove the frozen ice, but it still required a significant amount of effort.

9.3 General Observations

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

Photo 9.1: Day 1 @ 6pm – Baseline and Coated Plate

Photo 9.2: Day 2 @ 6pm – Baseline and Coated Plate After Top 15 cm of Plate Scraped Clean

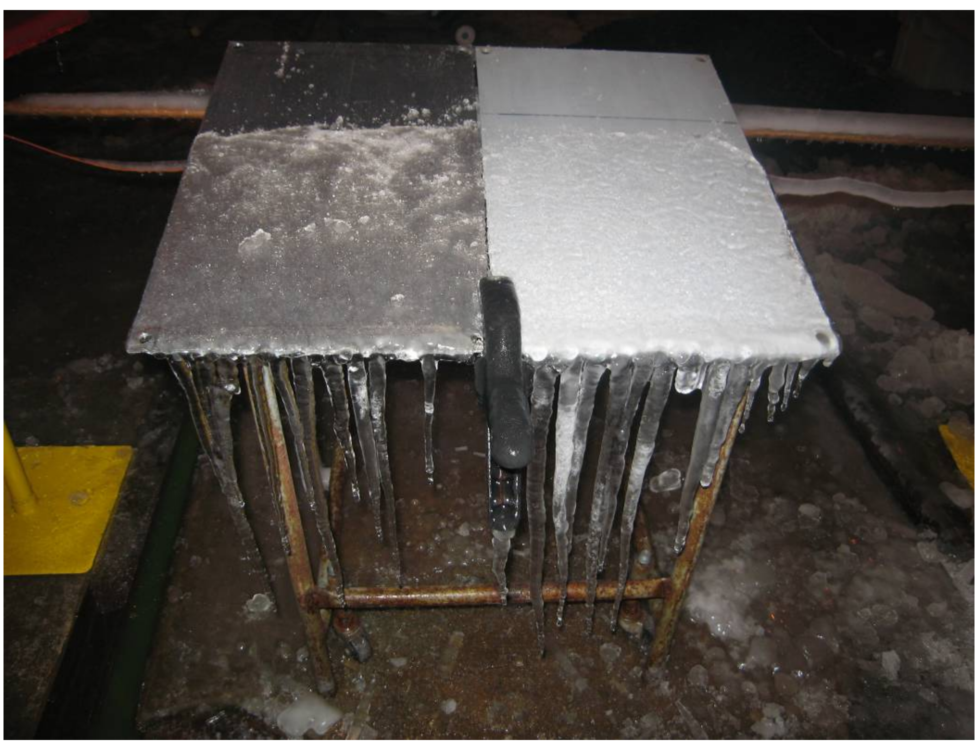

Photo 9.3: Day 3 @ 12pm – Baseline and Coated Plate After Top 30 cm of Plate Squeegeed Clean (Not Scraped)

Photo 9.4: Day 5 @ 1pm – Baseline and Coated Plate After Top 30 cm of Plate Scraped Clean

10. DEVELOPMENT OF SAE AIR DOCUMENT

In this section, the activities related to the development of a 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.

10.1 Background Leading to the Development of the SAE AIR

There is currently no standardized approach for evaluating aircraft after-market coatings with respect to fluid HOT's. Although limited research has been conducted by TC and FAA over the last three years, a minimum set of evaluation criteria has 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.

10.2 Overview of the Working Group Activities to Date

General email discussions were held between November 2011 and March 2012. In March 2012, APS Aviation Inc. developed a draft version of an SAE AIR which would serve as the basis and starting point. A start-up teleconference was held with a sub-group (which consisted of approximately 10 selected members) on March 30th, 2012. The objective was to review document and agree on the general direction of the document before going to the group at large. Following this discussion, an initial teleconference with the whole work group was held on April 13th, 2012 with the purpose of reviewing the document and receiving feedback from the group. Changes were made to the document, and an in-person working group meeting was scheduled on May 9th, 2012 in Prague during the SAE G-12. During this meeting, there was general discussion regarding the overall direction of the document. It was agreed that APS would make additional changes to the document based on the feedback received.

Since the May 9th 2012 meeting, the document has been updated and working group members have been solicited to provide missing or lacking sections of the AIR. The next in-person meeting is scheduled for November 2012 during the next SAE G-12 meeting in Montreal. It is anticipated that a completed draft will be available for balloting by January 2013.

10.3 Principle Focus of Draft AIR

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

The principle focus of AIR document is the impact coatings have on aircraft ground de/anti-icing fluid. This is addressed in two main sections 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
  - To evaluate how coatings influence fluid flow-off; and
  - 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 it was felt by the workgroup that the development of an SAE AIR would be faster than the development of an ARP; also the AIR could eventually be changed to an ARP once performance criteria were developed.

10.4 General Comments and Observations

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.

11. OBSERVATIONS AND CONCLUSIONS

The observations and conclusions drawn from the tests performed during the winter of 2011-12 are described in this section.

11.1 General Comments Regarding 2011-12 Testing

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

11.2 Fluid Endurance Time Testing

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

11.3 Fluid Wetting and Fluid Thickness Testing

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

11.4 Adherence Testing

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

Some concern remains with the ice formation on the coated surface. The coated surface typically results in bumpier, higher contact angle ice formations. Aerodynamic research to investigate the effects is recommended.

Similar trends were seen with other coatings from the same manufacturer.

11.5 Vertical Stabilizer Testing

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

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

11.6 Wind Tunnel Testing of Streamline Posts

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

11.7 Fluid Drainage Testing from Aerodynamically Quiet Areas in Aircraft

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

11.8 Overnight Ice Testing

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

11.9 Development of SAE AIR

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 an in-person meeting in conjunction with the SAE G-12 meetings.

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12. RECOMMENDATIONS

The following recommendations were compiled following the testing conducted during the winter of 2011-12 as well as industry feedback regarding the results obtained.

12.1 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.

Preliminary work done simulating aerodynamically quiet areas in aircraft also indicated potential benefits to using ice phobic coatings. These coatings typically repel fluids causing residual fluid to bead in concentrated areas rather than smear across a surface. This may in turn result in less fluid residues, and future testing should investigate this further.

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. Nonetheless, one manufacturer has demonstrated continual improvement in the coatings submitted for testing indicating that these coatings can potentially evolve to be complementary to de/anti-icing 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.

12.2 Future Research and Activities

The following are potential areas for future research:

- Conduct wind tunnel testing with a thin, high performance wing model to investigate coating performance during ground icing conditions with and without fluid;
- Investigate effect of weathered coatings on fluid endurance times;

- Investigate performance of high and low end fluid viscosities on coated surfaces;
- Investigate potential use of coatings in areas prone to icing but where de/anti-icing protection is limited, or not available (e.g. flap leading edges (retracted section, vertical stabilizer, and controls in quiet areas);
- Perform further evaluation of the potential application of ice phobic products in quiet areas and areas near drain holes to reduce gel residues; Conduct evaluation of newly developed coatings; and
- Conduct research to support development of the new SAE AIR document.

12.3 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, an SAE specification is being 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. 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 2011-12

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

7. DETAILED STATEMENT OF PREPARATORY WORK

(Contract T-8200-088510/001/MTB)

7.3 Investigation of the Effects of De/Anti-Icing Fluids Ice Phobic Technologies to Reduce Aircraft Icing in Northern Operations

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

a) A discussion with the manufacturer of ice phobic materials will be required to determine potential research areas of interest. 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, flap leading edges, quiet areas, fan blades and cowlings, as well as runways and deicing pads etc.; and

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.

7.3.2 Vertical Stabilizer Anti-Icing and Use of Ice Phobics

a) Review (and modify if necessary) methodology and procedure for simulating vertical stabilizer anti-icing with and without ice phobic treated surfaces.

3. DETAILED WORK DESCRIPTION

(Contract T8125-110167/001/TOR)

3.3 Investigation of the Effects of De/Anti-Icing Fluids Ice Phobic Technologies to Reduce Aircraft Icing in Northern Operations

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.

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

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) Conduct limited wind tunnel testing to investigate fluid and contamination flow-off behaviour (this testing has not currently been budgeted as part of this project). It is anticipated that testing will be conducted in conjunction with the Ice Pellet Allowance Time testing;

e) Analyze data and results; and

f) Prepare a test report of the findings.

3.3.2 Development of SAE ARP for Evaluation of Aircraft Coatings (Ice Phobic)

g) Develop preliminary list of minimum evaluation criteria for testing aircraft ice phobic coatings with respect to de/anti-icing fluid performance;

h) Organize work group consisting of regulators, manufacturers, airlines, and industry members;

i) Review and make changes to preliminary ARP document; and

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

3.3.2 Vertical Stabilizer Anti-Icing and Use of Ice Phobics

a) 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;

b) Analyze data and results;

c) Develop alternatives for potential guidance material for anti-icing vertical stabilizer surfaces;

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

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

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APPENDIX B

PROCEDURE:
OVERALL PROGRAM OF TESTS AT NRC, MARCH 2012

CM2265.001 (11-12)

OVERALL PROGRAM OF TESTS AT NRC, MARCH 2012

Winter 2011-12

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: for Stephanie Bendickson

Reviewed by: John D'Avirro

APS Aviation Inc.

March 20, 2012
Final Version 1.0

OVERALL PROGRAM OF TESTS AT NRC, MARCH 2012

Winter 2011-12

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 21-28, 2012.

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 2012 NRC test session are listed in this section. Each project has been given a shortened name (shown in brackets following full title) which will be used in subsequent sections of this document.

The test procedures for several projects are provided in separate detailed documents. These documents are referenced in the appropriate subsection and listed in Section 9.

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 stands that will be used for each project are noted below.

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 I, Type II, Type III and Type IV tests, as described below.

Type I Tests: Tests will be conducted with a new non-glycol Type I fluid over the entire range of freezing precipitation conditions encompassed by the

Type I HOT tables, including aluminum and composite surfaces. This fluid is ready-to-use and therefore will not be diluted. It should be noted that Type I fluids are not tested in freezing rain at -3ºC because the latent heat of freezing in calm test conditions produces artificially long endurance times. The fluid will be tested under fluid code “F1”.

Type II Tests: A new Type II fluid will be tested over the entire range of freezing precipitation conditions encompassed by the Type II HOT tables. The fluid will be tested under fluid code “C2”.

Type III Tests: Tests will be conducted with a commercial Type III fluid using the Type I test protocol. The main difference in this protocol and the Type II/III/IV protocol (which was used in the original tests with this fluid) is that fluids are applied at 20°C rather than at ambient air temperature. Tests will be conducted over the entire range of freezing precipitation conditions encompassed by the Type III HOT table. The fluid will be tested under fluid code “C3”.

Type III Supplemental Tests: Several sets of supplemental Type III endurance times will be conducted with the Type III fluid coded “C3”:

- Composite Surface Tests: Limited tests (5) will be conducted on composite surfaces to gather preliminary data to determine if heated Type III endurance times are reduced on composite surfaces.
- Ambient Fluid Application Temperature Tests: Limited tests (10) will be conducted with fluid applied at ambient temperature to compare endurance times of the 2012 fluid sample to those obtained with the original endurance time testing sample (tested in 2004).

Type IV Tests: A new Type IV fluid will be tested over the entire range of freezing precipitation conditions encompassed by the Type IV HOT tables. The fluid will be tested under fluid code “T4”.

The procedure for conducting endurance time tests is given in the document *Test Requirements for Simulated Freezing Precipitation Flat Plate Testing* (1). The test stands should be situated in the cold chamber as per the measurements provided in Figure 2. The cold soak boxes should be prepared using the procedure provided in Attachment 1.

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

2.2 Thickness of New Fluids (Fluid Thickness)

The objective of these tests is to measure the thickness of all new de/anti-icing fluids (listed in Subsection 2.1) 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* (2) and can be found in Transport Canada Report TP 13991E, Appendix I. It should be noted that Type I/III tests will be conducted with fluid at 20°C and Type II/IV tests will be conducted with fluid at ambient temperature (-3°C).

The test plan for Fluid Thickness tests is given in Table 2. The tests will be conducted at the small end of the chamber outside of the spray area.

2.3 Inspection Immediately Prior to Takeoff (5 Minute Rule)

Current guidance stipulates aircraft surfaces must be inspected within five minutes of beginning the takeoff roll. If it is not possible to take-off within five minutes, the aircraft must return to de/anti-ice again. The objective of this project is to evaluate the appropriateness of this guidance by evaluating the condition of a test plate five minutes after fluid failure is called.

This project will be carried out by conducting additional observations on a selection of the new fluid endurance time tests (see Section 2.1), including Type I, II, III and IV tests. No separate tests are scheduled for this project and it has no formal procedure. However, the following points are of importance:

- The comments column in the New Fluid ETs test plan (Table 1) indicates which tests require additional observations for this project;
- After fluid failure is recorded for the selected tests, the test plates 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 (using the ET test data form); and
- Testing will be conducted in the following conditions:
    - Freezing Rain, -3°C, 13 and 25 g/dm^2/h;
    - Freezing Rain, -6°C, 13 and 25 g/dm^2/h;
    - Freezing Rain, -10°C, 25 g/dm^2/h;
    - Freezing Drizzle, -3°C, 5 g/dm^2/h; and
    - Freezing Fog, -3°C, 2 g/dm^2/h.

As tests are being conducted as part of the New Fluid ETs project, no additional test plan is required for this project.

2.4 Effect of Ice Phobic Products on Fluid Holdover Times (Ice Phobic)

This project has four objectives as described below.

1. New Product Testing: Investigate new ice phobic products. Investigation of the new ice phobic products will include three types of testing:
    - Endurance time testing: comparative testing with Type I and II fluids in a subset of holdover time conditions (inline with previous test plans);
    - Fluid thickness/wetting tests; and
    - Ice adherence/accumulation tests.

2. Type I Fluid Failure on Ice Phobic Surface: Investigate previous concerns regarding Type I fluid not wetting ice phobic surfaces but ice not forming due to contact angle. Will include comparative Type I tests in freezing drizzle and light freezing rain.

3. Drainage Characteristics in Quiet Areas: Investigate potential application of ice phobic products in quiet areas.
    - Quiet areas to be simulated using aluminum containers (cube type cups) with a drain hole drilled into the bottom;
    - Containers will be coated and un-coated and will be filled with Type I, II or III fluid and left to drip out;
    - Containers will be weighed dry, and at several time intervals during drainage, i.e. 10-min, 30-min, 60-min, etc.;
    - Coated performance will be compared to un-coated; and
    - Tests will be conducted outside spray area.

4. Overnight Ice: Investigate potential benefits of having ice phobic products prevent ice formation on critical surfaces.
    - Parts of HOT test stand which are notorious for accreting large amounts of ice (while only being exposed to minimal amounts of fluid) will be treated with ice phobic products;
    - Coated surface accretion will be compared to non-coated accretion;
    - Surfaces will be examined at the end of each test day, or once significant ice has formed and needs to be removed for holdover time testing purposes; and
    - These tests will be done inside the spray area, but do not require plate positions.

The test plans for Ice Phobic tests are given in Table 3 (new product endurance time tests and Type I fluid failure tests), Table 4 (new product thickness tests), Table 5 (new product adherence tests) and Table 6 (drainage tests). There is no test plan required for the overnight ice tests.

The endurance time and adherence tests will be conducted on the main and/or side stand. The thickness and drainage tests will be conducted at the small end of the chamber outside of the spray area.

2.5 Endurance Times on Deployed Flaps (Deployed Flaps)

The objective of this project is to evaluate the endurance time performance of anti -icing fluids on wing surfaces with deployed flaps. Previous testing has been conducted with both nested and non-nested flat plate testing. More recently, full scale testing to correlate simulated plates with actual wing failure has identified non- nested flaps to have reduced holdover times. Limited testing with Type I and Type III fluids is being carried out at this test session to supplement previously collected indoor data.

The procedure for the conduct of these tests is provided in the document *Evaluation of Endurance Times on Deployed Flaps* (3). 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). In addition to failure time, fluid thickness and Brix will be taken as detailed in the test plan.

The test plan for Deployed Flaps tests is given in Table 7. The tests will be conducted on the main and/or side stand.

2.6 Evaluation of Windshield Washer Fluids Used for Frost De/Anti-Icing (Windshield Washer Fluids)

Because frost often has the appearance of being a minor contamination, it does not offer the same obvious signal of danger as other types of contamination. However, the irregular and rough accretion patterns of frost can result in a significant loss of lift on critical aircraft surfaces. The current frost holdover times have been evaluated and substantiated for use during natural active frost conditions, but it is not known if these holdover times can be applied to commercial windshield washer fluids. Transport Canada has indicated that General Aviation users apply these products to remove frost before flight in active frost.

The objective of this project is to approximate how much protection these fluids provide and if additional guidance is necessary for their use for this purpose. Preliminary tests have been completed in the NRC PIWT and at the APS test site in Montreal. The project authority suggested “piggy-backing” additional tests onto the March 2012 NRC test session.

Freezing fog conditions will be used to simulate frost at the NRC because frost is not easily generated in the NRC cold chamber. Tests will be conducted in three climatic conditions: freezing fog at a rate of 2 $g/dm^2/h$ at ambient temperatures of -3, -14 and -25°C. The tests may be conducted at 5 $g/dm^2/h$ if scheduling issues arise.

Each climatic condition will include 3 sets of tests:

- Set 1 [in spray zone]: HOT test of clean plate;
- Set 2 [in spray zone]: HOT test of iced plate (do not scrape ZF); and
- Set 3 [outside spray zone]: Deicing only of iced plate (do not scrape ZF). Will measure refreezing if applicable.

Each test set will consist of 3 test plates:

- Plate 1: Baseline Type I 10º Buffer;
- Plate 2: WWF 1 Green; and
- Plate 3: WWF 2 Yellow.

Tests will be carried out using standard endurance time test protocols, including 1 litre of test fluid applied at 20ºC.

The test plan for Windshield Washer Fluid tests is given in Table 8. The non-spray tests will be conducted at the small end of the chamber outside of the spray area. The spray tests will be conducted on the main stand.

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); and
- Rates Team: SB, YOW1.

2. Fluid Thickness:
   - Manager: MR (runs tests, takes measurements); and
   - Assistant: YOW2 (records measurements).
3. 5 Minute Rule Tests (run in conjunction with New Fluid ET tests):
   - Manager: JD (records failure 5 minutes after test);
   - Assistant: VZ (tracks timing, records measurements); and
   - Rates Team: SB, YOW1.
4. Ice Phobic:
   - Manager: MR (runs tests, takes measurements);
   - Assistant: YOW2 (records measurements, assists as needed); and
   - Rates Team: SB, YOW1.
5. Deployed Flaps:
   - Manager: MR (runs tests, takes measurements);
   - Assistant: YOW2 (records measurements); and
   - Rates Team: SB, YOW1.
6. Windshield Washer:
   - Manager: MR (runs tests, takes measurements);
   - Assistant: YOW2 (records measurements); and
   - Rates Team: SB, YOW1.

The Rates Team will consist of:

- Rate Manager: SB (runs rate station); and
- Rate Assistant: YOW1 (runs pans, refills fluids).

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

- Box Prep Manager: MR; and
- Box Prep Assistants: VZ, YOW2.

In addition, personnel will be designated responsible for:

- Equipment: MR/JD;
- Pre-test Setup: MR/JD;

- Data Form Manager: VZ;
- HOT Data Management: SB; and
- Fluid Management: SB/VZ.

4. FLUIDS

The required fluids and fluid quantities are shown in Table 9. Type I fluids will be diluted prior to testing using the dilution tables provided in Table 10.

5. EQUIPMENT

Table 11 provides a list of the equipment required.

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); and
   - Rate Management Form (Figure 4).

2. Fluid Thickness:
   - Fluid Thickness Data Form (Figure 5).

3. 5 Minute Rule:
   - No data forms required; observations recorded on New Fluid ET endurance time data forms.

4. Ice Phobic:
   - Ice Phobic End Condition Data Form (Figure 6);
   - Ice Phobic Thickness Data Form (Figure 7);
   - Overnight Ice Stand Inspection Data Form (Figure 8); and
   - Ice Phobic Drainage Data Form (Figure 9).

5. Deployed Flaps:
   - Freezing Precipitation Endurance Time Data Form (Figure 3).

6. Windshield Wiper Fluids:
    - Freezing Precipitation Endurance Time Data Form (Figure 3).

7. PRE–TEST SET–UP ACTIVITIES

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

1. Mark plates and boxes. (MR);
2. Check rate pans: check quantity, check for holes, and check all pans are properly labelled (PG);
3. Ensure plates and boxes are equipped with operational and verified thermistors (MR);
4. Determine number of loggers required (loggers on stands already) (MR);
5. Prepare PC for logging plate temperatures (MR);
6. Ensure fluids are prepared in advance according to Table 9 (MR/JD);
7. Prepare labels for pour containers (SB);
8. Clean and label 1 litre pour containers (MR/JD);
9. Check laptops (2) work for rate station (MR);
10. Rent cube van (VZ);
11. Book hotel (VZ);
12. Update and print chamber settings file – time permitting (DY);
13. Print data forms and procedures (SB/PG); and
14. Print chamber condition sheets (SB/PG).

The following items should be purchased prior to arrival at the NRC:

1. Blue towels;
2. White gloves;
3. Scrapers x5; and
4. Rubber squeegees x10.

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. Test Requirements For Simulated Freezing Precipitation Flat Plate Testing, Version 1.0, January 15, 2004.
2. Experimental Program to Establish Film Thickness Profiles for De-Icing and Anti-Icing Fluids on Flat Plates, Version 1.0, April 3, 2002.
3. Evaluation of Endurance Times on Deployed Flaps, Final Version 1.0, January 25, 2012.

FIGURE 1: TEST SCHEDULE

	Mon Mar-19	Tue Mar-20	Wed Mar-21	Thurs Mar-22	Fri Mar-23	Mon Mar-26	Tues Mar-27	Wed Mar-28	Thu Mar-29
9:00	Rent Cube Van + Packup Test Site	Drive to YOW	ZD, -10, 5 FLAPS	ZR, -6, 25 5 MIN	ZD, -3, 13 PH-ET	ZF, -25, 5	ZF, -10, 5	ZF, -6, 2	Drive to YUL + Unpack + Return Cube Van
9:30									
10:00				ZR, -6, 13 5 MIN				ZF, -6, 5	
10:30						ZF, -25, 2 WWF	ZF, -10, 2		
11:00								Warm to -3	
11:30			ZR, -10, 25 5 MIN PH-ET	ZD, -6, 5	ZR, -3, 25 5 MIN			ZF, -3, 5 FLAPS DRAINAGE	
12:00						Warm to -14	Warm to -3		
12:30				Warm to -3			ZF, -3, 2 5 MIN WWF DRAINAGE		
13:00		Setup at NRC		ZD, -3, 5 5 MIN FLAPS PH-ET		ZF, -14, 2 WWF			
13:30			ZR, -10, 13 PH-ET PH-AD		Warm to +1				
14:00					CSW, 1, 5				
14:30									
15:00									
15:30						ZF, -14, 5			
16:00			ZD, -10, 13 FLAPS PH-ET					Pack up	
16:30				ZR, -3, 13 5 MIN ET-THICK PH-THICK					
17:00					CSW, 1, 75				
17:30									
18:00			ZD, -6, 13						
18:30									
19:00									

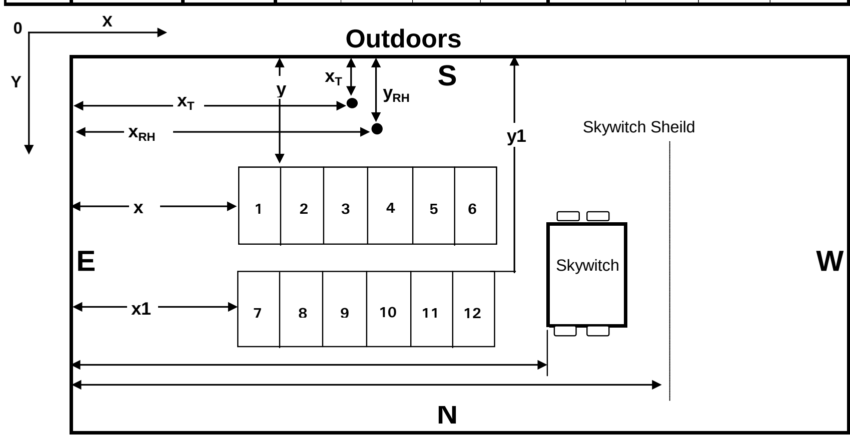
Holdover Time Fluids

- All Fluid Types (blue)
- Type II, III, IV (green)
- Type II, IV (yellow)
- Type I, III only (pink)
- Type I only (orange)

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; and

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

TABLE 1: ENDURANCE TIME TEST PLAN

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid Code	Fluid Dilution (%)	Test Surface	Comments
1	Freezing Fog	-25	2	C2	100	Al. Plate	
2	Freezing Fog	-25	2	C2	100	Al. Plate	
3	Freezing Fog	-25	2	T4	100	Al. Plate	
4	Freezing Fog	-25	2	T4	100	Al. Plate	
5	Freezing Fog	-25	2	C3	100	Al. Plate	
6	Freezing Fog	-25	2	C3	100	Al. Plate	
7	Freezing Fog	-25	2	F1	Conc.	Al. Plate	
8	Freezing Fog	-25	2	F1	Conc.	Al. Plate	
9	Freezing Fog	-25	2	F1	Conc.	Comp. Plate	
10	Freezing Fog	-25	2	F1	Conc.	Comp. Plate	
11	Freezing Fog	-25	5	C2	100	Al. Plate	
12	Freezing Fog	-25	5	C2	100	Al. Plate	
13	Freezing Fog	-25	5	T4	100	Al. Plate	
14	Freezing Fog	-25	5	T4	100	Al. Plate	
15	Freezing Fog	-25	5	C3	100	Al. Plate	
16	Freezing Fog	-25	5	C3	100	Al. Plate	
17	Freezing Fog	-25	5	F1	Conc.	Al. Plate	
18	Freezing Fog	-25	5	F1	Conc.	Al. Plate	
19	Freezing Fog	-25	5	F1	Conc.	Comp. Plate	
20	Freezing Fog	-25	5	F1	Conc.	Comp. Plate	
21	Freezing Fog	-14	2	C2	100	Al. Plate	
22	Freezing Fog	-14	2	C2	100	Al. Plate	
23	Freezing Fog	-14	2	T4	100	Al. Plate	
24	Freezing Fog	-14	2	T4	100	Al. Plate	
25	Freezing Fog	-14	2	C2	75	Al. Plate	
26	Freezing Fog	-14	2	C2	75	Al. Plate	
27	Freezing Fog	-14	2	T4	75	Al. Plate	
28	Freezing Fog	-14	2	T4	75	Al. Plate	
29	Freezing Fog	-14	5	C2	100	Al. Plate	
30	Freezing Fog	-14	5	C2	100	Al. Plate	
31	Freezing Fog	-14	5	T4	100	Al. Plate	
32	Freezing Fog	-14	5	T4	100	Al. Plate	
33	Freezing Fog	-14	5	C2	75	Al. Plate	
34	Freezing Fog	-14	5	C2	75	Al. Plate	
35	Freezing Fog	-14	5	T4	75	Al. Plate	
36	Freezing Fog	-14	5	T4	75	Al. Plate	
37	Freezing Fog	-10	2	C3	100	Al. Plate	
38	Freezing Fog	-10	2	C3	100	Al. Plate	
39	Freezing Fog	-10	2	C3	75	Al. Plate	
40	Freezing Fog	-10	2	C3	75	Al. Plate	
CD40	Freezing Fog	-10	2	C3	75	Al. Plate	Fluid @ OAT
CP40	Freezing Fog	-10	2	C3	75	Comp. Plate	
41	Freezing Fog	-10	2	F1	Conc.	Al. Plate	
42	Freezing Fog	-10	2	F1	Conc.	Al. Plate	
43	Freezing Fog	-10	2	F1	Conc.	Comp. Plate	
44	Freezing Fog	-10	2	F1	Conc.	Comp. Plate	
45	Freezing Fog	-10	5	C3	100	Al. Plate	
46	Freezing Fog	-10	5	C3	100	Al. Plate	

TABLE 1: ENDURANCE TIME TEST PLAN (CONT'D)

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid Code	Fluid Dilution (%)	Test Surface	Comments
47	Freezing Fog	-10	5	C3	75	Al. Plate	
48	Freezing Fog	-10	5	C3	75	Al. Plate	
49	Freezing Fog	-10	5	F1	Conc.	Al. Plate	
50	Freezing Fog	-10	5	F1	Conc.	Al. Plate	
51	Freezing Fog	-10	5	F1	Conc.	Comp. Plate	
52	Freezing Fog	-10	5	F1	Conc.	Comp. Plate	
53	Freezing Fog	-6	2	F1	Conc.	Al. Plate	
54	Freezing Fog	-6	2	F1	Conc.	Al. Plate	
55	Freezing Fog	-6	2	F1	Conc.	Comp. Plate	
56	Freezing Fog	-6	2	F1	Conc.	Comp. Plate	
57	Freezing Fog	-6	5	F1	Conc.	Al. Plate	
58	Freezing Fog	-6	5	F1	Conc.	Al. Plate	
59	Freezing Fog	-6	5	F1	Conc.	Comp. Plate	
60	Freezing Fog	-6	5	F1	Conc.	Comp. Plate	
61	Freezing Fog	-3	2	C2	100	Al. Plate	5 min failure
62	Freezing Fog	-3	2	C2	100	Al. Plate	
63	Freezing Fog	-3	2	T4	100	Al. Plate	5 min failure
64	Freezing Fog	-3	2	T4	100	Al. Plate	
65	Freezing Fog	-3	2	C2	75	Al. Plate	5 min failure
66	Freezing Fog	-3	2	C2	75	Al. Plate	
67	Freezing Fog	-3	2	T4	75	Al. Plate	5 min failure
68	Freezing Fog	-3	2	T4	75	Al. Plate	
69	Freezing Fog	-3	2	C2	50	Al. Plate	5 min failure
70	Freezing Fog	-3	2	C2	50	Al. Plate	
71	Freezing Fog	-3	2	T4	50	Al. Plate	5 min failure
72	Freezing Fog	-3	2	T4	50	Al. Plate	
73	Freezing Fog	-3	2	C3	100	Al. Plate	5 min failure
74	Freezing Fog	-3	2	C3	100	Al. Plate	
75	Freezing Fog	-3	2	C3	75	Al. Plate	5 min failure
76	Freezing Fog	-3	2	C3	75	Al. Plate	
77	Freezing Fog	-3	2	C3	50	Al. Plate	5 min failure
78	Freezing Fog	-3	2	C3	50	Al. Plate	
79	Freezing Fog	-3	2	F1	Conc.	Al. Plate	5 min failure
80	Freezing Fog	-3	2	F1	Conc.	Al. Plate	
81	Freezing Fog	-3	2	F1	Conc.	Comp. Plate	5 min failure
82	Freezing Fog	-3	2	F1	Conc.	Comp. Plate	
83	Freezing Fog	-3	5	C2	100	Al. Plate	
84	Freezing Fog	-3	5	C2	100	Al. Plate	
85	Freezing Fog	-3	5	T4	100	Al. Plate	
86	Freezing Fog	-3	5	T4	100	Al. Plate	
87	Freezing Fog	-3	5	C2	75	Al. Plate	
88	Freezing Fog	-3	5	C2	75	Al. Plate	
89	Freezing Fog	-3	5	T4	75	Al. Plate	
90	Freezing Fog	-3	5	T4	75	Al. Plate	
91	Freezing Fog	-3	5	C2	50	Al. Plate	
92	Freezing Fog	-3	5	C2	50	Al. Plate	
93	Freezing Fog	-3	5	T4	50	Al. Plate	
94	Freezing Fog	-3	5	T4	50	Al. Plate	

TABLE 1: ENDURANCE TIME TEST PLAN (CONT'D)

Test #	Precipitation Type	Temp (°C)	Precip. Rate ($g/dm^2/h$)	Fluid Code	Fluid Dilution (%)	Test Surface	Comments
95	Freezing Fog	-3	5	C3	100	Al. Plate	
96	Freezing Fog	-3	5	C3	100	Al. Plate	
97	Freezing Fog	-3	5	C3	75	Al. Plate	
98	Freezing Fog	-3	5	C3	75	Al. Plate	
99	Freezing Fog	-3	5	C3	50	Al. Plate	
100	Freezing Fog	-3	5	C3	50	Al. Plate	
CD100	Freezing Fog	-3	5	C3	50	Al. Plate	Fluid @ OAT
101	Freezing Fog	-3	5	F1	Conc.	Al. Plate	
102	Freezing Fog	-3	5	F1	Conc.	Al. Plate	
103	Freezing Fog	-3	5	F1	Conc.	Comp. Plate	
104	Freezing Fog	-3	5	F1	Conc.	Comp. Plate	
105	Light Freezing Rain	-10	13	C2	100	Al. Plate	
106	Light Freezing Rain	-10	13	C2	100	Al. Plate	
107	Light Freezing Rain	-10	13	T4	100	Al. Plate	
108	Light Freezing Rain	-10	13	T4	100	Al. Plate	
109	Light Freezing Rain	-10	13	C2	75	Al. Plate	
110	Light Freezing Rain	-10	13	C2	75	Al. Plate	
111	Light Freezing Rain	-10	13	T4	75	Al. Plate	
112	Light Freezing Rain	-10	13	T4	75	Al. Plate	
113	Light Freezing Rain	-10	13	C3	100	Al. Plate	
114	Light Freezing Rain	-10	13	C3	100	Al. Plate	
CD114	Light Freezing Rain	-10	13	C3	100	Al. Plate	Fluid @ OAT
115	Light Freezing Rain	-10	13	C3	75	Al. Plate	
116	Light Freezing Rain	-10	13	C3	75	Al. Plate	
117	Light Freezing Rain	-10	13	F1	Conc.	Al. Plate	
118	Light Freezing Rain	-10	13	F1	Conc.	Al. Plate	
119	Light Freezing Rain	-10	13	F1	Conc.	Comp. Plate	
120	Light Freezing Rain	-10	13	F1	Conc.	Comp. Plate	
121	Light Freezing Rain	-10	25	C2	100	Al. Plate	5 min failure
122	Light Freezing Rain	-10	25	C2	100	Al. Plate	
123	Light Freezing Rain	-10	25	T4	100	Al. Plate	5 min failure
124	Light Freezing Rain	-10	25	T4	100	Al. Plate	
125	Light Freezing Rain	-10	25	C2	75	Al. Plate	5 min failure
126	Light Freezing Rain	-10	25	C2	75	Al. Plate	
127	Light Freezing Rain	-10	25	T4	75	Al. Plate	5 min failure
128	Light Freezing Rain	-10	25	T4	75	Al. Plate	
129	Light Freezing Rain	-10	25	C3	100	Al. Plate	5 min failure
130	Light Freezing Rain	-10	25	C3	100	Al. Plate	
131	Light Freezing Rain	-10	25	C3	75	Al. Plate	5 min failure
132	Light Freezing Rain	-10	25	C3	75	Al. Plate	
CD132	Light Freezing Rain	-10	25	C3	75	Al. Plate	Fluid @ OAT
133	Light Freezing Rain	-10	25	F1	Conc.	Al. Plate	5 min failure
134	Light Freezing Rain	-10	25	F1	Conc.	Al. Plate	
135	Light Freezing Rain	-10	25	F1	Conc.	Comp. Plate	5 min failure
136	Light Freezing Rain	-10	25	F1	Conc.	Comp. Plate	
137	Light Freezing Rain	-6	13	F1	Conc.	Al. Plate	5 min failure
138	Light Freezing Rain	-6	13	F1	Conc.	Al. Plate	
139	Light Freezing Rain	-6	13	F1	Conc.	Comp. Plate	5 min failure

TABLE 1: ENDURANCE TIME TEST PLAN (CONT'D)

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid Code	Fluid Dilution (%)	Test Surface	Comments
140	Light Freezing Rain	-6	13	F1	Conc.	Comp. Plate	
141	Light Freezing Rain	-6	25	F1	Conc.	Al. Plate	5 min failure
142	Light Freezing Rain	-6	25	F1	Conc.	Al. Plate	
143	Light Freezing Rain	-6	25	F1	Conc.	Comp. Plate	5 min failure
144	Light Freezing Rain	-6	25	F1	Conc.	Comp. Plate	
145	Light Freezing Rain	-3	13	C2	100	Al. Plate	5 min failure
146	Light Freezing Rain	-3	13	C2	100	Al. Plate	
147	Light Freezing Rain	-3	13	T4	100	Al. Plate	5 min failure
148	Light Freezing Rain	-3	13	T4	100	Al. Plate	
149	Light Freezing Rain	-3	13	C2	75	Al. Plate	5 min failure
150	Light Freezing Rain	-3	13	C2	75	Al. Plate	
151	Light Freezing Rain	-3	13	T4	75	Al. Plate	5 min failure
152	Light Freezing Rain	-3	13	T4	75	Al. Plate	
153	Light Freezing Rain	-3	13	C2	50	Al. Plate	5 min failure
154	Light Freezing Rain	-3	13	C2	50	Al. Plate	
155	Light Freezing Rain	-3	13	T4	50	Al. Plate	5 min failure
156	Light Freezing Rain	-3	13	T4	50	Al. Plate	
157	Light Freezing Rain	-3	13	C3	100	Al. Plate	5 min failure
158	Light Freezing Rain	-3	13	C3	100	Al. Plate	
159	Light Freezing Rain	-3	13	C3	75	Al. Plate	5 min failure
160	Light Freezing Rain	-3	13	C3	75	Al. Plate	
CD160	Light Freezing Rain	-3	13	C3	75	Al. Plate	Fluid @ OAT
CP160	Light Freezing Rain	-3	13	C3	75	Comp. Plate	
161	Light Freezing Rain	-3	13	C3	50	Al. Plate	5 min failure
162	Light Freezing Rain	-3	13	C3	50	Al. Plate	
163	Light Freezing Rain	-3	25	C2	100	Al. Plate	5 min failure
164	Light Freezing Rain	-3	25	C2	100	Al. Plate	
165	Light Freezing Rain	-3	25	T4	100	Al. Plate	5 min failure
166	Light Freezing Rain	-3	25	T4	100	Al. Plate	
167	Light Freezing Rain	-3	25	C2	75	Al. Plate	5 min failure
168	Light Freezing Rain	-3	25	C2	75	Al. Plate	
169	Light Freezing Rain	-3	25	T4	75	Al. Plate	5 min failure
170	Light Freezing Rain	-3	25	T4	75	Al. Plate	
171	Light Freezing Rain	-3	25	C2	50	Al. Plate	5 min failure
172	Light Freezing Rain	-3	25	C2	50	Al. Plate	
173	Light Freezing Rain	-3	25	T4	50	Al. Plate	5 min failure
174	Light Freezing Rain	-3	25	T4	50	Al. Plate	
175	Light Freezing Rain	-3	25	C3	100	Al. Plate	5 min failure
176	Light Freezing Rain	-3	25	C3	100	Al. Plate	
CD176	Light Freezing Rain	-3	25	C3	100	Al. Plate	Fluid @ OAT
CP176	Light Freezing Rain	-3	25	C3	100	Comp. Plate	
177	Light Freezing Rain	-3	25	C3	75	Al. Plate	5 min failure
178	Light Freezing Rain	-3	25	C3	75	Al. Plate	
179	Light Freezing Rain	-3	25	C3	50	Al. Plate	5 min failure
180	Light Freezing Rain	-3	25	C3	50	Al. Plate	
181	Freezing Drizzle	-10	5	C2	100	Al. Plate	
182	Freezing Drizzle	-10	5	C2	100	Al. Plate	
183	Freezing Drizzle	-10	5	T4	100	Al. Plate	

TABLE 1: ENDURANCE TIME TEST PLAN (CONT'D)

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid Code	Fluid Dilution (%)	Test Surface	Comments
184	Freezing Drizzle	-10	5	T4	100	Al. Plate	
185	Freezing Drizzle	-10	5	C2	75	Al. Plate	
186	Freezing Drizzle	-10	5	C2	75	Al. Plate	
187	Freezing Drizzle	-10	5	T4	75	Al. Plate	
188	Freezing Drizzle	-10	5	T4	75	Al. Plate	
189	Freezing Drizzle	-10	5	C3	100	Al. Plate	
190	Freezing Drizzle	-10	5	C3	100	Al. Plate	
CD190	Freezing Drizzle	-10	5	C3	100	Al. Plate	Fluid @ OAT
CP190	Freezing Drizzle	-10	5	C3	100	Comp. Plate	
191	Freezing Drizzle	-10	5	C3	75	Al. Plate	
192	Freezing Drizzle	-10	5	C3	75	Al. Plate	
193	Freezing Drizzle	-10	5	F1	Conc.	Al. Plate	
194	Freezing Drizzle	-10	5	F1	Conc.	Al. Plate	
195	Freezing Drizzle	-10	5	F1	Conc.	Comp. Plate	
196	Freezing Drizzle	-10	5	F1	Conc.	Comp. Plate	
197	Freezing Drizzle	-10	13	C2	100	Al. Plate	
198	Freezing Drizzle	-10	13	C2	100	Al. Plate	
199	Freezing Drizzle	-10	13	T4	100	Al. Plate	
200	Freezing Drizzle	-10	13	T4	100	Al. Plate	
201	Freezing Drizzle	-10	13	C2	75	Al. Plate	
202	Freezing Drizzle	-10	13	C2	75	Al. Plate	
203	Freezing Drizzle	-10	13	T4	75	Al. Plate	
204	Freezing Drizzle	-10	13	T4	75	Al. Plate	
205	Freezing Drizzle	-10	13	C3	100	Al. Plate	
206	Freezing Drizzle	-10	13	C3	100	Al. Plate	
CD206	Freezing Drizzle	-10	13	C3	100	Al. Plate	Fluid @ OAT
207	Freezing Drizzle	-10	13	C3	75	Al. Plate	
208	Freezing Drizzle	-10	13	C3	75	Al. Plate	
209	Freezing Drizzle	-10	13	F1	Conc.	Al. Plate	
210	Freezing Drizzle	-10	13	F1	Conc.	Al. Plate	
211	Freezing Drizzle	-10	13	F1	Conc.	Comp. Plate	
212	Freezing Drizzle	-10	13	F1	Conc.	Comp. Plate	
213	Freezing Drizzle	-6	5	F1	Conc.	Al. Plate	
214	Freezing Drizzle	-6	5	F1	Conc.	Al. Plate	
215	Freezing Drizzle	-6	5	F1	Conc.	Comp. Plate	
216	Freezing Drizzle	-6	5	F1	Conc.	Comp. Plate	
217	Freezing Drizzle	-6	13	F1	Conc.	Al. Plate	
218	Freezing Drizzle	-6	13	F1	Conc.	Al. Plate	
219	Freezing Drizzle	-6	13	F1	Conc.	Comp. Plate	
220	Freezing Drizzle	-6	13	F1	Conc.	Comp. Plate	
221	Freezing Drizzle	-3	5	C2	100	Al. Plate	5 min failure
222	Freezing Drizzle	-3	5	C2	100	Al. Plate	
223	Freezing Drizzle	-3	5	T4	100	Al. Plate	5 min failure
224	Freezing Drizzle	-3	5	T4	100	Al. Plate	
225	Freezing Drizzle	-3	5	C2	75	Al. Plate	5 min failure
226	Freezing Drizzle	-3	5	C2	75	Al. Plate	
227	Freezing Drizzle	-3	5	T4	75	Al. Plate	5 min failure
228	Freezing Drizzle	-3	5	T4	75	Al. Plate	

TABLE 1: ENDURANCE TIME TEST PLAN (CONT'D)

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid Code	Fluid Dilution (%)	Test Surface	Comments
229	Freezing Drizzle	-3	5	C2	50	Al. Plate	5 min failure
230	Freezing Drizzle	-3	5	C2	50	Al. Plate	
231	Freezing Drizzle	-3	5	T4	50	Al. Plate	5 min failure
232	Freezing Drizzle	-3	5	T4	50	Al. Plate	
233	Freezing Drizzle	-3	5	C3	100	Al. Plate	5 min failure
234	Freezing Drizzle	-3	5	C3	100	Al. Plate	
235	Freezing Drizzle	-3	5	C3	75	Al. Plate	5 min failure
236	Freezing Drizzle	-3	5	C3	75	Al. Plate	
CD236	Freezing Drizzle	-3	5	C3	75	Al. Plate	Fluid @ OAT
237	Freezing Drizzle	-3	5	C3	50	Al. Plate	5 min failure
238	Freezing Drizzle	-3	5	C3	50	Al. Plate	
239	Freezing Drizzle	-3	5	F1	Conc.	Al. Plate	5 min failure
240	Freezing Drizzle	-3	5	F1	Conc.	Al. Plate	
241	Freezing Drizzle	-3	5	F1	Conc.	Comp. Plate	5 min failure
242	Freezing Drizzle	-3	5	F1	Conc.	Comp. Plate	
243	Freezing Drizzle	-3	13	C2	100	Al. Plate	
244	Freezing Drizzle	-3	13	C2	100	Al. Plate	
245	Freezing Drizzle	-3	13	T4	100	Al. Plate	
246	Freezing Drizzle	-3	13	T4	100	Al. Plate	
247	Freezing Drizzle	-3	13	C2	75	Al. Plate	
248	Freezing Drizzle	-3	13	C2	75	Al. Plate	
249	Freezing Drizzle	-3	13	T4	75	Al. Plate	
250	Freezing Drizzle	-3	13	T4	75	Al. Plate	
251	Freezing Drizzle	-3	13	C2	50	Al. Plate	
252	Freezing Drizzle	-3	13	C2	50	Al. Plate	
253	Freezing Drizzle	-3	13	T4	50	Al. Plate	
254	Freezing Drizzle	-3	13	T4	50	Al. Plate	
255	Freezing Drizzle	-3	13	C3	100	Al. Plate	
256	Freezing Drizzle	-3	13	C3	100	Al. Plate	
257	Freezing Drizzle	-3	13	C3	75	Al. Plate	
258	Freezing Drizzle	-3	13	C3	75	Al. Plate	
259	Freezing Drizzle	-3	13	C3	50	Al. Plate	
260	Freezing Drizzle	-3	13	C3	50	Al. Plate	
CD260	Freezing Drizzle	-3	13	C3	50	Al. Plate	Fluid @ OAT
CP260	Freezing Drizzle	-3	13	C3	50	Comp. Plate	
261	Freezing Drizzle	-3	13	F1	Conc.	Al. Plate	
262	Freezing Drizzle	-3	13	F1	Conc.	Al. Plate	
263	Freezing Drizzle	-3	13	F1	Conc.	Comp. Plate	
264	Freezing Drizzle	-3	13	F1	Conc.	Comp. Plate	
265	Cold Soak Box	1	5	C2	100	Al. Box	
266	Cold Soak Box	1	5	C2	100	Al. Box	
267	Cold Soak Box	1	5	T4	100	Al. Box	
268	Cold Soak Box	1	5	T4	100	Al. Box	
269	Cold Soak Box	1	5	C2	75	Al. Box	
270	Cold Soak Box	1	5	C2	75	Al. Box	
271	Cold Soak Box	1	5	T4	75	Al. Box	
272	Cold Soak Box	1	5	T4	75	Al. Box	
273	Cold Soak Box	1	5	C3	100	Al. Box	

TABLE 1: ENDURANCE TIME TEST PLAN (CONT'D)

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid Code	Fluid Dilution (%)	Test Surface	Comments
274	Cold Soak Box	1	5	C3	100	Al. Box	
275	Cold Soak Box	1	5	C3	75	Al. Box	
276	Cold Soak Box	1	5	C3	75	Al. Box	
277	Cold Soak Box	1	5	F1	Conc.	Al. Box	
278	Cold Soak Box	1	5	F1	Conc.	Al. Box	
279	Cold Soak Box	1	5	F1	Conc.	Comp. Box	
280	Cold Soak Box	1	5	F1	Conc.	Comp. Box	
281	Cold Soak Box	1	75	C2	100	Al. Box	
282	Cold Soak Box	1	75	C2	100	Al. Box	
283	Cold Soak Box	1	75	T4	100	Al. Box	
284	Cold Soak Box	1	75	T4	100	Al. Box	
285	Cold Soak Box	1	75	C2	75	Al. Box	
286	Cold Soak Box	1	75	C2	75	Al. Box	
287	Cold Soak Box	1	75	T4	75	Al. Box	
288	Cold Soak Box	1	75	T4	75	Al. Box	
289	Cold Soak Box	1	75	C3	100	Al. Box	
290	Cold Soak Box	1	75	C3	100	Al. Box	
291	Cold Soak Box	1	75	C3	75	Al. Box	
292	Cold Soak Box	1	75	C3	75	Al. Box	
293	Cold Soak Box	1	75	F1	Conc.	Al. Box	
294	Cold Soak Box	1	75	F1	Conc.	Al. Box	
295	Cold Soak Box	1	75	F1	Conc.	Comp. Box	
296	Cold Soak Box	1	75	F1	Conc.	Comp. Box	

TABLE 2: FLUID THICKNESS TEST PLAN

Test #	Fluid Code	Fluid Dilution	Fluid Temp	Test Surface	Ambient Air Temp
TH1	F1	concentrate	20°C	Al. Plate	-3°C
TH2	F1	concentrate	20°C	Al. Plate	-3°C
TH3	C2	100/0	-3°C	Al. Plate	-3°C
TH4	C2	100/0	-3°C	Al. Plate	-3°C
TH5	C2	75/25	-3°C	Al. Plate	-3°C
TH6	C2	75/25	-3°C	Al. Plate	-3°C
TH7	C2	50/50	-3°C	Al. Plate	-3°C
TH8	C2	50/50	-3°C	Al. Plate	-3°C
TH9	C3 WARM	100/0	20°C	Al. Plate	-3°C
TH10	C3 WARM	100/0	20°C	Al. Plate	-3°C
TH11	C3 WARM	75/25	20°C	Al. Plate	-3°C
TH12	C3 WARM	75/25	20°C	Al. Plate	-3°C
TH13	C3 WARM	50/50	20°C	Al. Plate	-3°C
TH14	C3 WARM	50/50	20°C	Al. Plate	-3°C
TH15	T4	100/0	-3°C	Al. Plate	-3°C
TH16	T4	100/0	-3°C	Al. Plate	-3°C
TH17	T4	75/25	-3°C	Al. Plate	-3°C
TH18	T4	75/25	-3°C	Al. Plate	-3°C
TH19	T4	50/50	-3°C	Al. Plate	-3°C
TH20	T4	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; and
- If the results for one fluid vary by more than 10% repeat the two tests and disregard the highest and lowest values.

TABLE 3: ICE PHOBIC ENDURANCE TIME TEST PLAN

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid Code	Fluid Dilution	Test Surface	Comments
PH1	Light Freezing Rain	-10	13 (25)	Octagon Octaflo EF	10°B (B=27.0)	Baseline	1 L at 20°C, Brix/thick t=5 min + fail, temp
PH2	Light Freezing Rain	-10	13 (25)	Octagon Octaflo EF	10°B (B=27.0)	MFR B 11	1 L at 20°C, Brix/thick t=5 min + fail, temp
PH3	Light Freezing Rain	-10	13 (25)	Octagon Octaflo EF	10°B (B=27.0)	AA C2 (Optional)	1 L at 20°C, Brix/thick t=5 min + fail, temp
PH4	Light Freezing Rain	-10	13 (25)	C2	75/25	Baseline	Brix/thick t=5 min and failure
PH5	Light Freezing Rain	-10	13 (25)	C2	75/25	MFR B 11	Brix/thick t=5 min and failure
PH6	Freezing Drizzle	-10	13 (5)	C2	100/0	Baseline	Brix/thick t=5 min and failure
PH7	Freezing Drizzle	-10	13 (5)	C2	100/0	MFR B 11	Brix/thick t=5 min and failure
PH8	Light Freezing Rain	-10	25 (13)	Dow UCAR EG106	100/0	Baseline	Brix/thick t=5 min and failure
PH9	Light Freezing Rain	-10	25 (13)	Dow UCAR EG106	100/0	MFR B 11	Brix/thick t=5 min and failure
PH10	Freezing Drizzle	-3	5 (13)	Dow UCAR ADF (EG)	10°B (B=17.6)	Baseline	1 L at 20°C, Brix/thick t=5 min + fail, temp
PH11	Freezing Drizzle	-3	5 (13)	Dow UCAR ADF (EG)	10°B (B=17.6)	MFR B 11	2 L at 20°C, Brix/thick t=5 min + fail, temp
PH12	Freezing Drizzle	-3	5 (13)	Dow UCAR ADF (EG)	10°B (B=17.6)	AA C2 (Optional)	3 L at 20°C, Brix/thick t=5 min + fail, temp
PH13	Freezing Drizzle	-3	5 (13)	Octagon Octaflo EF	10°B (B=21.25)	Baseline	4 L at 20°C, Brix/thick t=5 min + fail, temp
PH14	Freezing Drizzle	-3	5 (13)	Octagon Octaflo EF	10°B (B=21.25)	MFR B 11	5 L at 20°C, Brix/thick t=5 min + fail, temp
PH15	Freezing Drizzle	-3	5 (13)	Octagon Octaflo EF	10°B (B=21.25)	AA C2 (Optional)	6 L at 20°C, Brix/thick t=5 min + fail, temp
PH16	Freezing Drizzle	-3	13 (5)	C2	50/50	Baseline	Brix/thick t=5 min and failure
PH17	Freezing Drizzle	-3	13 (5)	C2	50/50	MFR B 11	Brix/thick t=5 min and failure
PH18	Freezing Drizzle	-3	13 (5)	Dow UCAR ADF (EG)	10°B (B=17.6)	Baseline	7 L at 20°C, Brix/thick t=5 min + fail, temp
PH19	Freezing Drizzle	-3	13 (5)	Dow UCAR ADF (EG)	10°B (B=17.6)	MFR B 11	8 L at 20°C, Brix/thick t=5 min + fail, temp
PH20	Freezing Drizzle	-3	13 (5)	Dow UCAR ADF (EG)	10°B (B=17.6)	AA C2 (Optional)	9 L at 20°C, Brix/thick t=5 min + fail, temp

TABLE 4: ICE PHOBIC THICKNESS TEST PLAN

Test #	Fluid Name/Code	Fluid Type	Fluid Dilution	Fluid Temp	Test Surface*	Ambient Air Temp
PH-TH1	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	+20°C	Baseline	-3°C
PH-TH2	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	+20°C	MFR B 11	-3°C
PH-TH3	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	+20°C	Baseline	-3°C
PH-TH4	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	+20°C	MFR B 11	-3°C
PH-TH5	C2	Type II PG	100/0	-3°C	Baseline	-3°C
PH-TH6	C2	Type II PG	100/0	-3°C	MFR B 11	-3°C

* Baseline = Standard aluminum test plate; Mfr B = Mfr B Ice Phobic treated test plate

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

TABLE 5: ICE PHOBIC ADHERENCE TEST PLAN

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid Code	Fluid Dilution	Test Surface	Comments
PH-AD1	Light Freezing Rain	-10	13	No fluid	n/a	Standard Plate	Measure adherence
PH-AD2	Light Freezing Rain	-10	13	No fluid	n/a	MFR B 11	Measure adherence

TABLE 6: ICE PHOBIC DRAINAGE TEST PLAN

Test #	Fluid Name	Fluid Type	Fluid Dilution	DRAIN HOLE TYPE	Test Surface Treatment*	Ambient Air Temp
PH-D1	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	CIRCULAR	Baseline	-3°C
PH-D2	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	CIRCULAR	MFR B 2	-3°C
PH-D3	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	CIRCULAR	MFR B 4	-3°C
PH-D4	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	CIRCULAR	MFR A	-3°C
PH-D5	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	CIRCULAR	Baseline	-3°C
PH-D6	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	CIRCULAR	MFR B 2	-3°C
PH-D7	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	CIRCULAR	MFR B 4	-3°C
PH-D8	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	CIRCULAR	MFR A	-3°C
PH-D9	C3 WARM	TYPE III PG	100/0	CIRCULAR	Baseline	-3°C
PH-D10	C3 WARM	TYPE III PG	100/0	CIRCULAR	MFR B 2	-3°C
PH-D11	C3 WARM	TYPE III PG	100/0	CIRCULAR	MFR B 4	-3°C
PH-D12	C3 WARM	TYPE III PG	100/0	CIRCULAR	MFR A	-3°C
PH-D13	C2	Type II PG	100/0	CIRCULAR	Baseline	-3°C
PH-D14	C2	Type II PG	100/0	CIRCULAR	MFR B 2	-3°C
PH-D15	C2	Type II PG	100/0	CIRCULAR	MFR B 4	-3°C
PH-D16	C2	Type II PG	100/0	CIRCULAR	MFR A	-3°C
PH-D17	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	OVAL	Baseline	-3°C
PH-D18	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	OVAL	MFR B 2	-3°C
PH-D19	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	OVAL	MFR B 4	-3°C
PH-D20	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	OVAL	MFR A	-3°C
PH-D21	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	OVAL	Baseline	-3°C
PH-D22	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	OVAL	MFR B 2	-3°C
PH-D23	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	OVAL	MFR B 4	-3°C
PH-D24	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	OVAL	MFR A	-3°C
PH-D25	C3 WARM	TYPE III PG	100/0	OVAL	Baseline	-3°C
PH-D26	C3 WARM	TYPE III PG	100/0	OVAL	MFR B 2	-3°C
PH-D27	C3 WARM	TYPE III PG	100/0	OVAL	MFR B 4	-3°C
PH-D28	C3 WARM	TYPE III PG	100/0	OVAL	MFR A	-3°C
PH-D29	C2	Type II PG	100/0	OVAL	Baseline	-3°C
PH-D30	C2	Type II PG	100/0	OVAL	MFR B 2	-3°C
PH-D31	C2	Type II PG	100/0	OVAL	MFR B 4	-3°C
PH-D32	C2	Type II PG	100/0	OVAL	MFR A	-3°C
PH-D33	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	NARROW SLIT	Baseline	-3°C
PH-D34	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	NARROW SLIT	MFR B 2	-3°C
PH-D35	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	NARROW SLIT	MFR B 4	-3°C
PH-D36	Dow UCAR ADF (EG)	Type I EG	10°B (B=17.6)	NARROW SLIT	MFR A	-3°C
PH-D37	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	NARROW SLIT	Baseline	-3°C
PH-D38	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	NARROW SLIT	MFR B 2	-3°C
PH-D39	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	NARROW SLIT	MFR B 4	-3°C
PH-D40	Dow UCAR ADF (EG)	Type I EG	FFP=-35°C (B=30.5)	NARROW SLIT	MFR A	-3°C
PH-D41	C3 WARM	TYPE III PG	100/0	NARROW SLIT	Baseline	-3°C
PH-D42	C3 WARM	TYPE III PG	100/0	NARROW SLIT	MFR B 2	-3°C
PH-D43	C3 WARM	TYPE III PG	100/0	NARROW SLIT	MFR B 4	-3°C
PH-D44	C3 WARM	TYPE III PG	100/0	NARROW SLIT	MFR A	-3°C
PH-D45	C2	Type II PG	100/0	NARROW SLIT	Baseline	-3°C
PH-D46	C2	Type II PG	100/0	NARROW SLIT	MFR B 2	-3°C
PH-D47	C2	Type II PG	100/0	NARROW SLIT	MFR B 4	-3°C
PH-D48	C2	Type II PG	100/0	NARROW SLIT	MFR A	-3°C

Procedure: Measure weight at 15, 30, 45, 60, 90, 120 minutes etc. after pouring

TABLE 7: DEPLOYED FLAPS TEST PLAN

Test #	Precipitation Type	Temp (°C)	Precip. Rate ($g/dm^2/h$)	Fluid Code	Fluid Dilution (%)	Test Surface	Comments
DF1	Freezing Drizzle	-3	5	C3 WARM	100/0	Plate (10°)	Thickness at 5 mins, Brix at failure
DF2	Freezing Drizzle	-3	5	C3 WARM	100/0	Plate (20°)	Thickness at 5 mins, Brix at failure
DF3	Freezing Drizzle	-3	5	C3 WARM	100/0	Plate (35°)	Thickness at 5 mins, Brix at failure
DF4	Freezing Drizzle	-10	5	C3 WARM	75/25	Plate (10°)	Brix/thickness every 15 mins
DF5	Freezing Drizzle	-10	5	C3 WARM	75/25	Plate (20°)	Brix/thickness every 15 mins
DF6	Freezing Drizzle	-10	5	C3 WARM	75/25	Plate (35°)	Brix/thickness every 15 mins
DF7	Freezing Drizzle	-10	13	F1	Concentrate	Plate (10°)	Thickness at 5 mins, Brix at failure
DF8	Freezing Drizzle	-10	13	F1	Concentrate	Plate (20°)	Thickness at 5 mins, Brix at failure
DF9	Freezing Drizzle	-10	13	F1	Concentrate	Plate (35°)	Thickness at 5 mins, Brix at failure
DF10	Freezing Fog	-3	5	C3 WARM	50/50	Plate (10°)	Thickness at 5 mins, Brix at failure
DF11	Freezing Fog	-3	5	C3 WARM	50/50	Plate (20°)	Thickness at 5 mins, Brix at failure
DF12	Freezing Fog	-3	5	C3 WARM	50/50	Plate (35°)	Thickness at 5 mins, Brix at failure

TABLE 8: WINDSHIELD WASHER FLUIDS TEST PLAN

Test #	Precipitation Type	Temp (°C)	Precip. Rate ($g/dm^2/h$)	Fluid Name/Code	Fluid Dilution (%)	Test Surface	Comments
WW1	Freezing Fog	-3	2	Octagon Octaflo EF	10° Buf	Clean Plate	Apply 1 L @ 20°C
WW2	Freezing Fog	-3	2	WWF 1 Green	n/a	Clean Plate	Apply 1 L @ 20°C
WW3	Freezing Fog	-3	2	WWF 2 Yellow	n/a	Clean Plate	Apply 1 L @ 20°C
WW4	Freezing Fog	-3	2	Octagon Octaflo EF	10° Buf	Iced Plate Under Spray	Apply 1 L @ 20°C
WW5	Freezing Fog	-3	2	WWF 1 Green	n/a	Iced Plate Under Spray	Apply 1 L @ 20°C
WW6	Freezing Fog	-3	2	WWF 2 Yellow	n/a	Iced Plate Under Spray	Apply 1 L @ 20°C
WW7	Freezing Fog	-3	2	Octagon Octaflo EF	10° Buf	Iced Plate Outside Spray	Apply 1 L @ 20°C
WW8	Freezing Fog	-3	2	WWF 1 Green	n/a	Iced Plate Outside Spray	Apply 1 L @ 20°C
WW9	Freezing Fog	-3	2	WWF 2 Yellow	n/a	Iced Plate Outside Spray	Apply 1 L @ 20°C
WW10	Freezing Fog	-14	2	Octagon Octaflo EF	10° Buf	Clean Plate	Apply 1 L @ 20°C
WW11	Freezing Fog	-14	2	WWF 1 Green	n/a	Clean Plate	Apply 1 L @ 20°C
WW12	Freezing Fog	-14	2	WWF 2 Yellow	n/a	Clean Plate	Apply 1 L @ 20°C
WW13	Freezing Fog	-14	2	Octagon Octaflo EF	10° Buf	Iced Plate Under Spray	Apply 1 L @ 20°C
WW14	Freezing Fog	-14	2	WWF 1 Green	n/a	Iced Plate Under Spray	Apply 1 L @ 20°C
WW15	Freezing Fog	-14	2	WWF 2 Yellow	n/a	Iced Plate Under Spray	Apply 1 L @ 20°C
WW16	Freezing Fog	-14	2	Octagon Octaflo EF	10° Buf	Iced Plate Outside Spray	Apply 1 L @ 20°C
WW17	Freezing Fog	-14	2	WWF 1 Green	n/a	Iced Plate Outside Spray	Apply 1 L @ 20°C
WW18	Freezing Fog	-14	2	WWF 2 Yellow	n/a	Iced Plate Outside Spray	Apply 1 L @ 20°C
WW19	Freezing Fog	-25	2	Octagon Octaflo EF	10° Buf	Clean Plate	Apply 1 L @ 20°C
WW20	Freezing Fog	-25	2	WWF 1 Green	n/a	Clean Plate	Apply 1 L @ 20°C
WW21	Freezing Fog	-25	2	WWF 2 Yellow	n/a	Clean Plate	Apply 1 L @ 20°C
WW22	Freezing Fog	-25	2	Octagon Octaflo EF	10° Buf	Iced Plate Under Spray	Apply 1 L @ 20°C
WW23	Freezing Fog	-25	2	WWF 1 Green	n/a	Iced Plate Under Spray	Apply 1 L @ 20°C
WW24	Freezing Fog	-25	2	WWF 2 Yellow	n/a	Iced Plate Under Spray	Apply 1 L @ 20°C
WW25	Freezing Fog	-25	2	Octagon Octaflo EF	10° Buf	Iced Plate Outside Spray	Apply 1 L @ 20°C
WW26	Freezing Fog	-25	2	WWF 1 Green	n/a	Iced Plate Outside Spray	Apply 1 L @ 20°C
WW27	Freezing Fog	-25	2	WWF 2 Yellow	n/a	Iced Plate Outside Spray	Apply 1 L @ 20°C

Notes:

- Consider doing duplicate runs with backpack sprayer in 1 or 2 of the 9 sets; and
- If necessary, tests can be run at a rate of 5 $g/dm^2/h$.

TABLE 9: LIST OF FLUIDS

Fluid	Fluid Code	Batch #	Fluid Temp	Fluid Dil or Brix (FFP)	Litres Required per Project							Total Litres	Pour Bottles	Notes
					ET	TH	IP-ET	IP-TH	IP-D	DF	WW			
Clariant Safewing 2031	C3 WARM	TV512	20°C	100	34	2	-	-	5	3	-	**44**	**8**	
Clariant Safewing 2031	C3 WARM	TV512	20°C	75	30	2	-	-	-	3	-	**35**	**8**	
Clariant Safewing 2031	C3 WARM	TV512	20°C	50	13	2	-	-	-	3	-	**18**	**8**	
Clariant Safewing 2031	C3 COLD	TV512	OAT	100	4	-	-	-	-	-	-	**4**	**4**	*
Clariant Safewing 2031	C3 COLD	TV512	OAT	75	4	-	-	-	-	-	-	**4**	**4**	*
Clariant Safewing 2031	C3 COLD	TV512	OAT	50	2	-	-	-	-	-	-	**2**	**2**	*
Clariant Flight Plus	C2	TV513	OAT	100	32	2	2	2	5	-	-	**43**	**8**	
Clariant Flight Plus	C2	TV513	OAT	75	28	2	2	-	-	-	-	**32**	**8**	
Clariant Flight Plus	C2	TV513	OAT	50	12	2	2	-	-	-	-	**16**	**8**	
TBD	T4	TBD	OAT	100	32	2	-	-	-	-	-	**34**	**8**	
TBD	T4	TBD	OAT	75	28	2	-	-	-	-	-	**30**	**8**	
TBD	T4	TBD	OAT	50	12	2	-	-	-	-	-	**14**	**8**	
Dow EG106	n/a	WT.11.12.EG106	OAT	100	-	-	2	-	-	-	-	**2**	**2**	*
Hokkaido Fever Snow	F1	11/11/2011	20°C	Concentrate	80	2	-	2	-	3	-	**87**	**8**	
Octagon Octaflo EF	n/a	WL102009	20°C	21.25 (-13°C)	-	-	15	-	-	-	3	**18**	**3**	
Octagon Octaflo EF	n/a	WL102009	20°C	27.0 (-20°C)	-	-	3	-	-	-	-	**3**	**3**	**
Octagon Octaflo EF	n/a	WL102009	20°C	29.5 (-24°C)	-	-	-	-	-	-	3	**3**	**3**	**
Octagon Octaflo EF	n/a	WL102009	20°C	34.5 (-35°C)	-	-	-	-	-	-	3	**3**	**3**	**
Dow UCAR EG	n/a	Aeromag 2009 or 2011	20°C	17.6 (-13°C)	-	-	30	2	5	-	-	**37**	**4**	
Dow UCAR EG	n/a		20°C	30.5 (-35°C)	-	-		-	5	-	-	**5**	**0**	***
All Fluids					**311**	**20**	**56**	**6**	**20**	**12**	**9**	**434**	**108**	

Warm Storage Fluid

Cold Storage Fluid

Notes:

*Fluid requirements met by fluid brought in pour containers, no larger containers need to be brought;
**Fluid requirements met by fluid brought in pour containers, consider bringing 5L concentrate in large container for spare (label made); and
***Pack 5 L in one jug, no pour containers needed as all fluid for drainage project.

Attention: WARM and COLD labels should go on ALL pour and large C3 containers

TABLE 10: 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
-35	-25	50.3	30.5	2.0	2.0

TABLE 11: EQUIPMENT LIST

HOT, 5 MIN, PH-ET,THICKNESS AND PH-TH PROJECTS

EQUIPMENT	LOCATION
1L Pour containers (see separate list)	Site
20L/gas jug for PH-ET tests	Site
Barrel Opener	Site
Boards for cold-soak test x13	Site
Brixometer x 3	Site
Close circuit TV camera for rates	Site
Cold-soak boxes (all in good condition)	Site
Collection pans for stands (one per stand)	Site
Composite Boxes x2	Site
Composite Plates x2	Site
Electrical Extension Cords x2	Site
Empty 20 L cont. for -30C CSW fluid	Site
Fluids (see Table 7)	Site
Funnels x 4	Site
Gloves - yellow	Site
Hard Water (1x18L)	Site
Hard water chemicals	Site
Ice Phobic Plates x2	Site
Inclinometer (yellow level) x 2	Site
Isopropyl x 15	Site
Large digital clock x 2	Site
Marker for Waste x 2	Site
Measuring Cups (various sizes)	Site
Memory Card Reader	Site
Mixing buckets for Type I fluids	Site
Nuts to separate plates x 100	Site
Plate covers x 16	Site
Plates: 12 w/logging +15 w/o logging	Site
Printer & Ink Cartridge	Site
Protective clothing x 4	Site
Scrapers x 10 (Buy 5)	Buy/Site
Shelving unit x 1	Site
Shop Vac + Sump Pump + Tubing	Site
Speed tape	Site
Tape measure (yellow + small)	Site
Temperature probes: immersion x 2	Site
Temperature probes: surface x 2	Site
Test Stand Shims (poker chips)	Site
Test Stands: 2 x 6-position (main stand)	Site
Test Stands: 3 position (side stand)	Site
Test Stands: 6 position (for small end)	Site
Thermistor Kit/blue USB/black RS232/box	Site
Thickness Gauges x 4 (both types)	Site
Vise grip (large) for containers	Site
Walkie Talkies x 4	Site
Weigh Scale x 2 (sartorius) + wiring	Site
White boards for water run-off	Site
Yellow Carrying Cases x2	Site
Yellow Ice Pic	Site
Scrapers x 10 (Buy 5)	Buy/Site

EQUIPMENT	LOCATION
Gloves - cotton	Buy
Paper Towels (lots)	Buy
Rubber squeegees x 10	Buy
Cold-soak box filling stand	NRC
Cold-soak fluid pump	NRC
Fluid for cold-soak boxes (barrel)	NRC
Rubber Mats	NRC
Tote for Waste Fluid	NRC
Accordian Folder	Office
Camera Suitcase Pack	Office
Chamber Settings	Office
Clipboards x 10	Office
Data Forms (on water phobic paper)	Office
Envelopes (9x12) x box	Office
Hard Drive with Current Project folder	Office
Mouse for Rate Station	Office
MR camera x 1 (has video capability)	Office
One Temp Logger Laptop (MR)	Office
Paper for printer (1 pack)	Office
Pencils (sharpened) + pens + markers	Office
Precipitation Rate Pans x 100	Office
Rate computer x2	Office
Test Procedures x 2 (1 sided)	Office
Waterproof paper (100 sheets)	Office

WWF PROJECT

EQUIPMENT	LOCATION
WWF 1 Green x 9 L	Site
WWF 2 Yellow x 9 L	Site

DEPLOYED FLAPS PROJECT

EQUIPMENT	LOCATION
20° Stand x1	Site
35° Stand x1	Site

PH-ADHERENCE PROJECT

EQUIPMENT	LOCATION
Adhesion probe	Site

PH-DRAINAGE PROJECT

EQUIPMENT	LOCATION
Drainage containers - uncoated	Buy (MR)
Drainage containers - coated	Buy (MR)
Measuring cups/containers	Buy (MR)

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	1st or 2nd Rate	PAN #	TAB	TIME OUT	1st or 2nd Rate

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

FIGURE 5: 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 #:		Plate: **V** Run #:		Plate: **W** Run #:		Plate: **X** Run #:		Plate: **Y** Run #:		Plate: **Z** Run #:	
Fluid:		Fluid:		Fluid:		Fluid:		Fluid:		Fluid:	
Application Time:		Application Time:		Application Time:		Application Time:		Application Time:		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:

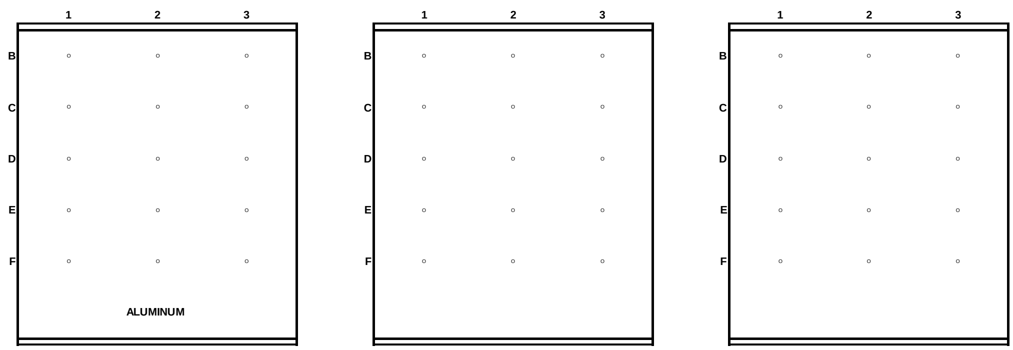
- The quantity of fluid that will be poured for each test is 1.0 L;
- Measurements should be made at the 15-cm line at the time of fluid application, and after 2, 5, 15 and 30 minutes; and
- If the results for one fluid vary by more than 10% repeat the two tests and disregard the highest and lowest values.

FIGURE 6: ICE PHOBIC END CONDITION DATA FORM

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

PLATE #			
SURFACE	Aluminum		
FLUID NAME			
TIME OF FLUID APPLICATION			
TIME OF FLUID FAILURE			

DESCRIBE ADHESION AND DRAW FAILURE AT TIME OF PLATE 1 FAILURE



BRIX MEASUREMENTS (TIME / BRIX)

5 MIN	/	**5 MIN**	/	**5 MIN**	/
END	/	**END**	/	**END**	/
AT P1 FAIL	/	**AT P1 FAIL**	/	**AT P1 FAIL**	/

THICKNESS MEASUREMENTS (TIME / THICKNESS)

5 MIN	/	**5 MIN**	/	**5 MIN**	/
END	/	**END**	/	**END**	/
AT P1 FAIL	/	**AT P1 FAIL**	/	**AT P1 FAIL**	/

ADDITIONAL COMMENTS

ALUMINUM		

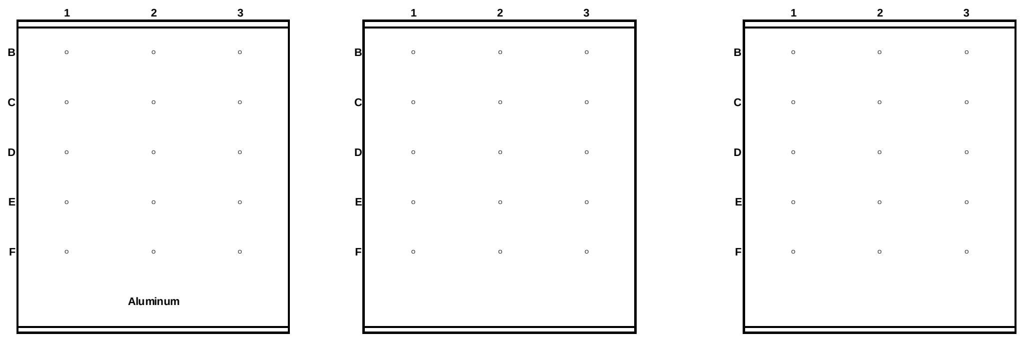
check if there are more notes on the other side ☐

PERFORMED BY: ____________ **WRITTEN BY:** ____________

FIGURE 7: ICE PHOBIC THICKNESS DATA FORM

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

PLATE #			
SURFACE	Aluminum		
FLUID NAME			
TIME OF FLUID APPLICATION			



THICKNESS MEASUREMENTS (mil)

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

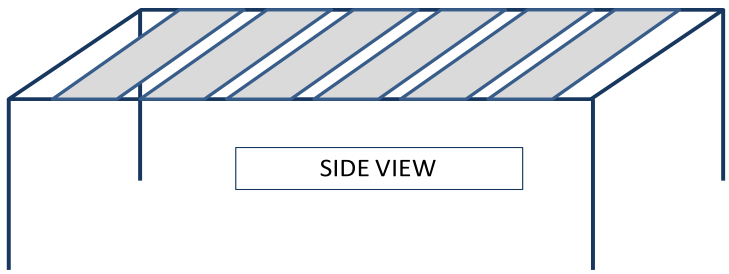
PERFORMED BY: ______________________ WRITTEN BY: ______________________

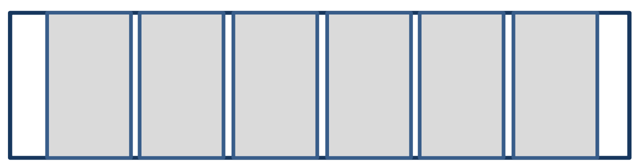
FIGURE 8: OVERNIGHT ICE STAND INSPECTION DATA FORM

FORM FOR OVERNIGHT ICE (STAND INSPECTION)

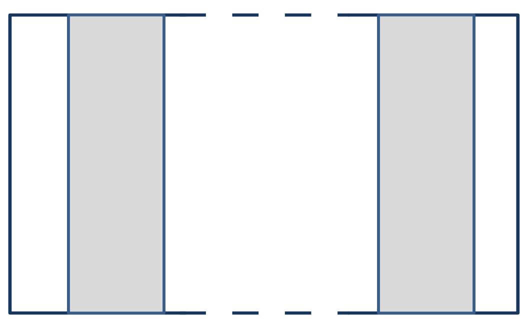
LOCATION: NRC	CONDITION:	DATE:	TIME:	STAND#:

DESCRIBE ADHESION AND DRAW ICE ON DIAGRAMS





TOP VIEW



ZOOM VIEW

ADDITIONAL COMMENTS ______________________________

check if there are more notes on the other side ☐

PERFORMED BY: ____________________ **WRITTEN BY:** ____________________

FIGURE 9: ICE PHOBIC DRAINAGE DATA FORM

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

PAN #	____	____	____
DRAIN HOLE TYPE	____	____	____
FLUID NAME	____	____	____
FLUID QUANTITY	____	____	____
TIME OF FLUID APPLICATION	____	____	____

TOP VIEW OF PAN

DRAW DRAIN HOLE AND DESCRIBE GEL FORMATIONS

THICKNESS MEASUREMENTS (mil)

Time	WEIGHT	Time	WEIGHT	Time	WEIGHT

ADDITIONAL COMMENTS ____

PERFORMED BY: ____ **WRITTEN BY:** ____

FIGURE 10: 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

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APPENDIX C

PROCEDURE:
ADDENDUM TO PROCEDURE:
EVALUATION OF ENDURANCE TIME PERFORMANCE ON VERTICAL SURFACES – VERTICAL SURFACES TREATED WITH ICE PHOBIC COATINGS

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.

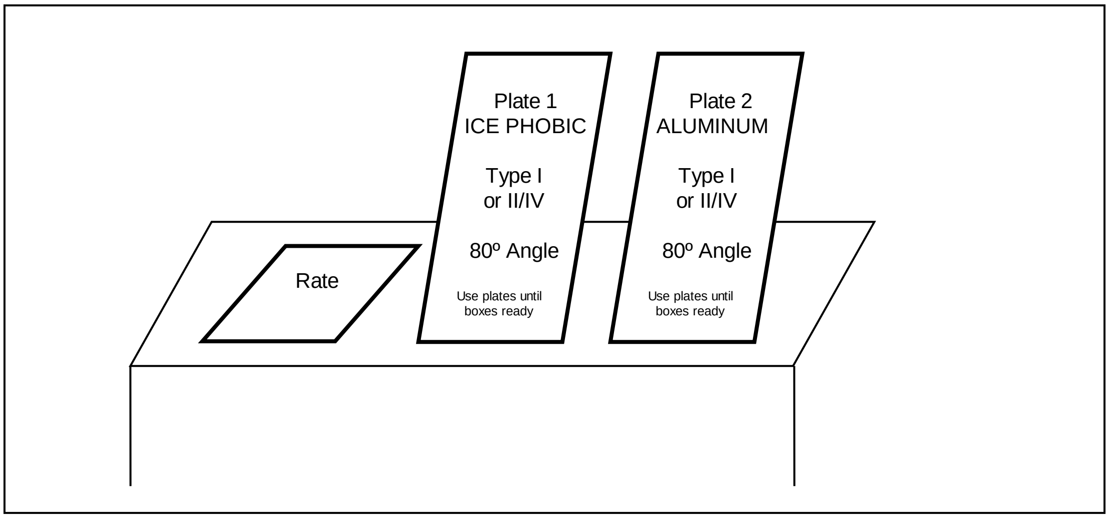

Figure 3.1: New General Setup

APPENDIX D

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

CM2265.001

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

Winter 2011-12

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Marco Ruggi

Reviewed by: John D'Avirro

APS Aviation Inc.

January 13, 2012
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 results. With the support and under direction of NASA, a large series of test runs are anticipated to better understand the performance characteristics of the wind tunnel and airfoil. Some limited fluid tests will also be conducted, however will be of lower priority.

2. OBJECTIVES

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

- Thoroughly survey the clean wing performance through pitch pause, angle sweeps, and stall runs, and verify repeatability;
- Perform oil flow visualization to better understand boundary layer separation and uniformity of flow;
- Install boundary layer trips to establish wing sensitivity;
- Conduct fluid testing with and without contamination to evaluate repeatability of results;
- Install larger end plates to evaluate potential 3D effects; and
- Obtain additional fluid data in all dilations to correlate the lift losses observed in the NRC PIWT with the fluid aerodynamic acceptance test protocol (5.24% LL).

See Attachment I for further details.

As lower priority objectives, testing may be conducted to investigate the following:

- o Heavy Snow;
- o Snow on an Un-Protected Wing;
- o Ice Phobic Coatings;
- o Heavily Contaminated Vertical Stabilizer;
- o Type I Spot Deicing during CSW Frost;
- o Light and Very Light Snow HOT's;
- o Windshield Washer Used as a Type I Deicer; and
- o Effect of fluid seepage on dry wing performance.

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.

Three weeks of testing have been scheduled for the conduct of these tests. The start date for testing is currently scheduled for January 16th and testing will continue until February 3rd (see Figure 2.2).

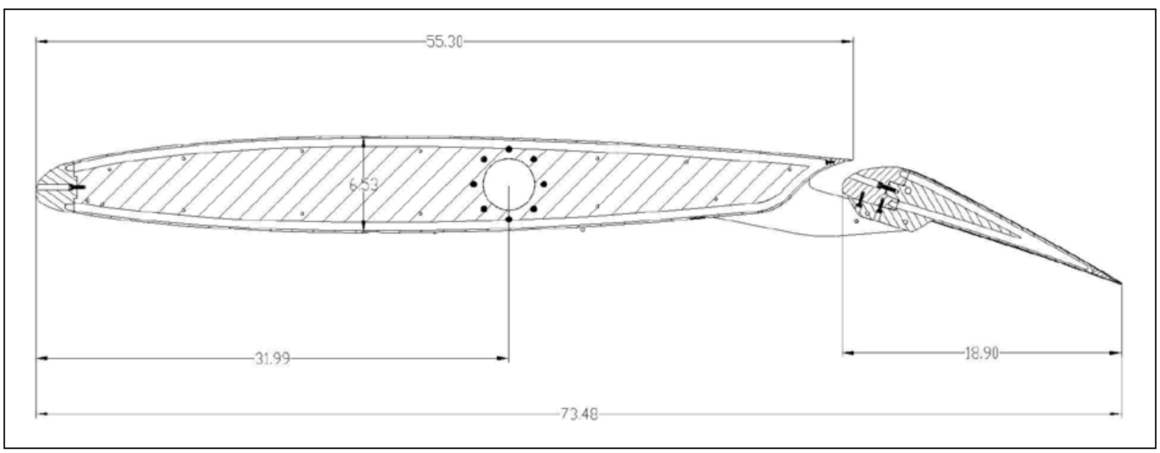

Figure 2.1: Super-Critical Wing Section

Figure 2.2: Test Calendar

Week	Monday	Tuesday	Wednesday	Thursday	Friday
1	**Setup & Clean Wing Any Temp** Pitch-pause AoA sweeps Stall Discrepency *APS: MR, BG, JS, JD, DY, VZ, JsD (4 hrs)*	**Oil Flow Visualization Any Temp** Doc. boudary Layer Doc. Separation Boundary Layer Rake *APS: MR, BG, JS*	**Boundary Layer Trips Any Temp** Roughness (sand paper) Simulated frost Establish sensitivity *APS: MR, BG, JS*	**Boundary Layer Trips (cont'd) Any Temp** Roughness (sand paper) Simulated frost Establish sensitivity APS: MR, BG, JS	**Fluid testing With and without ice pellets** Temp = available temp Conditions to be tested: fluid Repeats of past cases for continuity, C_L Max, BLDT Fluids-Launch, EG106,ABC S+ 2 runs each = 6 runs *APS: MR, BG, JS, YOWx2, JD, DY, VZ*
	12 TESTS	**12 TESTS**	**6 TESTS**	**6 TESTS**	**17 TESTS**
2	**Fluid testing With and without ice pellets** Temp = available temp Conditions to be tested: IP Repeats of past cases for continuity, C_L Max, BLDT Fluids-Launch, EG106,ABC S+ 2 runs each = 6 runs Additional runs TBD *APS: MR, BG, JS, YOWx2, JD, DY, VZ*	**Remove Standard End Plates, Install Large End Plates** **NRC - ALL DAY INSTALLATION** *No APS*	**LARGE END PLATE TESTS Clean Wing Any Temp** Pitch-pause AoA sweeps Stall Discrepency *APS: MR, BG, JS, JsD (4 hrs)*	**LARGE END PLATE TESTS Oil Flow Visualization Any Temp** Doc. boudary Layer Doc. Separation Boundary Layer Rake *APS: MR, BG, JS*	**LARGE END PLATE TESTS Boundary Layer Trips Any Temp** Roughness (sand paper) Simulated frost Establish sensitivity *APS: MR, BG, JS*
	19 TESTS		**12 TESTS**	**12 TESTS**	**12 TESTS**
Fluid-test Leads: FAA & APS (night time)					
3	**LARGE END PLATE TESTS Fluid testing With and without ice pellets** Temp = available temp Conditions to be tested; fluid Repeats of cases from week 1, Fri *APS: MR, BG, JS, YOWx2, JD, DY, VZ*	**LARGE END PLATE TESTS Fluid testing With and without ice pellets** Temp = available temp Conditions to be tested:IP Repeats of cases from week 2, Mon *APS: MR, BG, JS, YOWx2, JD, DY, VZ*	**LARGE END PLATE TESTS Fluid testing** <-15ºC Add to BLDT data New & 2010-11 Fluid 75/25 & 100/0 BLDT Fluid Seapage ***Warren & John revise if and as necessessary*** *APS: MR, BG, JS, YOWx2, JD, DY, VZ*	**LARGE END PLATE TESTS Fluid testing** <-15ºC Add to BLDT data New & 2010-11 Fluid 75/25 & 100/0 BLDT Fluid Seapage ***Warren & John revise if and as necessessary*** *APS: MR, BG, JS, YOWx2, DY, VZ*	**LARGE END PLATE TESTS OTHER FLUID TESTS: <0ºC S++,–V-Stab, Frost Spot Deicing, Snow no Fluid** TC R&D ITEMS <0ºC, S- & S--, Ice Phobic Vanes, Windshield Washer Fluid ***Warren & John revise if and as necessessary*** *APS: MR, BG, JS, YOWx2, DY, VZ* **(TEARDOWN)**
	13 TESTS	**8 TESTS**	**9 TESTS**	**6 TESTS**	**14 TESTS**
4				**NRC Flow Survey** No Charge and No APS/TC/FAA Involvement	
Aug	**NACA 23012 Wing Model Calibration (see NRC email Nov 2011)** Will likely be done after NRC restructuring, however pending approval by NRC				

Part 1: days 1-4
Dry airfoil with standard end plates

Part 2: days 5-6
Airfoil with fluids, uncontaminated and contaminated with ice pellets, with standard end plates. Repeats of past cases.

Part 3: day 7
Change from standard to large end plates.

Part 4: days 8-10
Dry airfoil with large end plates.

Part 5: days 11-12
Airfoil with fluids, uncontaminated and contaminated with ice pellets, with large end plates. Repeats of cases from Part 2.

Part 6: days 13-15
Other testing with fluids, uncontaminated and contaminated

Notes:

1.) The first two weeks of the test entry are aero-testing. This will be lead by NASA - Andy Broeren and Sam Lee, and NRC - Katherine Clark. They will be supported by FAA - Warren Underwood and Tom Bond, and staff from APS.
2.) The third week will be fluids testing and will be lead by FAA - Warren Underwood and TC in collaboration with APS. NRC will support the testing. NASA will not be available.
3.) Current start date is set for Monday January 16th. Three weeks of testing are planned.
4.) Test days are placeholders and can be adjusted: first prirority is the aerodynamic testing, second priority is the fluids testing. The fluids testing will be done in the third week if the aerodynamic test matrix is completed. The conditions and daily test schedule can be modified based on temperature or other test considerations.
5.) 1800L of fluid ordered 600L EG106, 400L Launch & 800L ABC-S+
6.) Calibration model PIWT tests tentatively in August 2012. Support for this test will be from NRC, NASA, FAA, and APS.

Test Runs With Fluids – to be run on small end plate (days 5 and 6) and large end plate (days 11 and 12) configurations.

Fluids to be used, all Type IV:
Clariant Safewing MPIV Launch- PG
Dow EG106 (EG106) – EG
Kilfrost ABC S+ - PG

Runs with fluid only: (days 5&6 – small end plates – and 11&12 – large end plates)
1)Clariant Launch @100Kt
2)Repeat 1
3) Clariant Launch @100Kt with moderate IP for 15min.
4) Repeat 3
5)EG106 @100Kt
6)Repeat 5
7) Dow EG106 @100Kt with moderate IP for 30min.
8) Repeat 7
9)ABC S+ @100Kt
10)Repeat 9
11) Kilfrost ABC S+ @100Kt with moderate IP for 15min.
12) Repeat 11

This should not take 2 full days. Additional runs TBD.

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 II to V present the generic holdover time guidelines for Type I and 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 VI.

The calendar shown in Table 2.1 presents each of the major test objectives, however 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 3.1.

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.

Table 3.1: Proposed Test Plan

Test Plan #	Day	Objective	Priority	Test Condition	Rotation Angle	Ramp (s/kts)	Target OAT (ºC)	Fluid	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Exposure Time
P001	1	Clean Wing	1	None	8	100	any	none	-	-	-
P002	1	Clean Wing	1	None	8	80	any	none	-	-	-
P003	1	Clean Wing	1	None	stall	80	any	none	-	-	-
P004	1	Clean Wing	1	None	stall	80	any	none	-	-	-
P005	1	Clean Wing	1	None	stall	80	any	none	-	-	-
P006	1	Clean Wing	1	None	stall -4 to stall +4	80	any	none	-	-	-
P007	1	Clean Wing	1	None	8	100	any	none	-	-	-
P008	1	Clean Wing	1	None	8	80	any	none	-	-	-
P009	1	Clean Wing	1	None	stall	80	any	none	-	-	-
P010	1	Clean Wing	1	None	stall	80	any	none	-	-	-
P011	1	Clean Wing	1	None	stall	80	any	none	-	-	-
P012	1	Clean Wing	1	None	stall -4 to stall +4	80	any	none	-	-	-
P013	2	Oil Flow Visualization	1	Oil	8	80	any	none	-	-	-
P014	2	Oil Flow Visualization	1	Oil	4 or 6	80	any	none	-	-	-
P015	2	Oil Flow Visualization	1	Oil	stall	80	any	none	-	-	-
P016	2	Oil Flow Visualization	1	Oil	stall-1	80	any	none	-	-	-
P017	2	Oil Flow Visualization	1	Oil	stall-2	80	any	none	-	-	-
P018	2	Oil Flow Visualization	1	Oil	stall-4	80	any	none	-	-	-
P019	2	Oil Flow Visualization	1	Oil	stall-8	80	any	none	-	-	-
P020	2	Oil Flow Visualization	1	Oil	TBD	TBD	TBD	none	-	-	-
P021	2	Oil Flow Visualization	1	Oil	TBD	TBD	TBD	none	-	-	-
P022	2	Oil Flow Visualization	1	Oil	TBD	TBD	TBD	none	-	-	-
P023	2	Oil Flow Visualization	1	Oil	TBD	TBD	TBD	none	-	-	-
P024	2	Oil Flow Visualization	1	Oil	TBD	TBD	TBD	none	-	-	-
P025	3	Roughness (Trips)	1	40-grit	stall	80	same as P013	none	-	-	-
P026	3	Roughness (Trips)	1	40-grit	stall -4 to stall +4	80	same as P016	none	-	-	-
P027	3	Roughness (Trips)	1	150-grit	stall	80	same as P013	none	-	-	-
P028	3	Roughness (Trips)	1	150-grit	stall -4 to stall +4	80	same as P016	none	-	-	-
P029	3	Roughness (Trips)	1	80-grit	stall	80	same as P013	none	-	-	-
P030	3	Roughness (Trips)	1	80-grit	stall -4 to stall +4	80	same as P016	none	-	-	-
P031	4	Roughness (Trips)	1	Full Wing Grit	stall	80	same as P013	none	-	-	-
P032	4	Roughness (Trips)	1	Full Wing Grit	stall -4 to stall +4	80	same as P016	none	-	-	-
P033	4	Roughness (Trips)	1	Grit (-30% grit on LE)	stall	80	same as P013	none	-	-	-
P034	4	Roughness (Trips)	1	Grit (-30% grit on LE)	stall -4 to stall +4	80	same as P016	none	-	-	-
P035	4	Roughness (Trips)	1	Grit (-60% grit on LE)	stall	80	same as P013	none	-	-	-
P036	4	Roughness (Trips)	1	Grit (-60% grit on LE)	stall -4 to stall +4	80	same as P016	none	-	-	-
P037	6	Fluid Tests - Repeatibility	1	Fluid Only	8	100	-12 to -13	ABC-S Plus (100)	-	-	-
P038	6	Fluid Tests - Repeatibility	2	Fluid Only	8	100	-12 to -13	ABC-S Plus (100)	-	-	-
P039	5	Fluid Tests - Repeatibility	1	Fluid Only	8	100	-15 to -18	EG 106 (100)	-	-	-
P040	5	Fluid Tests - Repeatibility	2	Fluid Only	8	100	-15 to -18	EG 106 (100)	-	-	-

Table 3.1 (cont'd): Proposed Test Plan

Test Plan #	Day	Objective	Priority	Test Condition	Rotation Angle	Ramp (s/kts)	Target OAT (ºC)	Fluid	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Exposure Time
P041	5	Fluid Tests - Repeatibility	1	Fluid Only	8	100	-3 to -5	Launch (100)	-	-	-
P042	5	Fluid Tests - Repeatibility	2	Fluid Only	8	100	-3 to -5	Launch (100)	-	-	-
P043	5	Fluid Tests - Repeatibility	1	IP-	8	100	-11 to -13	EG 106 (100)	25	-	30
P044	5	Fluid Tests - Repeatibility	2	IP-	8	100	-11 to -13	EG 106 (100)	25	-	30
P045	5	Fluid Tests - Repeatibility	1	IP Mod	8	100	-4 to -6	Launch (100)	75	-	25
P046	5	Fluid Tests - Repeatibility	2	IP Mod	8	100	-4 to -6	Launch (100)	75	-	25
P047	6	Fluid Tests - Repeatibility	1	IP Mod	8	100	-13 to -15	ABC-S Plus (100)	75	-	10
P048	6	Fluid Tests - Repeatibility	2	IP Mod	8	100	-13 to -15	ABC-S Plus (100)	75	-	10
P049	6	Fluid Tests - New BLDT	2	Fluid Only	8	100	below -25	ABC-S Plus (100)	-	-	-
P050	6	Fluid Tests - New BLDT	2	Fluid Only	8	100	below -25	ABC-S Plus (100)	-	-	-
P051	6	Fluid Tests - New BLDT	2	Fluid Only	8	100	below -25	ABC-S Plus (100)	-	-	-
P052	6	Fluid Tests - New BLDT	2	Fluid Only	8	100	below -20	ABC-S Plus (75)	-	-	-
P053	6	Fluid Tests - New BLDT	2	Fluid Only	8	100	below -20	ABC-S Plus (75)	-	-	-
P054	6	Fluid Tests - New BLDT	2	Fluid Only	8	100	below -20	ABC-S Plus (75)	-	-	-
P055	6	Fluid Tests - New BLDT	2	Fluid Only	8	100	below -25	EG 106 (100)	-	-	-
P056	6	Fluid Tests - New BLDT	2	Fluid Only	8	100	below -25	EG 106 (100)	-	-	-
P057	6	Fluid Tests - New BLDT	2	Fluid Only	8	100	below -25	EG 106 (100)	-	-	-
P058	5	Fluid Tests - New BLDT	1	Fluid Only	8	100	below -25	Launch (100)	-	-	-
P059	5	Fluid Tests - New BLDT	2	Fluid Only	8	100	below -25	Launch (100)	-	-	-
P060	5	Fluid Tests - New BLDT	2	Fluid Only	8	100	below -25	Launch (100)	-	-	-
P061	6	Fluid Tests - New BLDT	1	Fluid Only	8	100	-15 to -21	Launch (75)	-	-	-
P062	6	Fluid Tests - New BLDT	2	Fluid Only	8	100	-15 to -21	Launch (75)	-	-	-
P063	6	Fluid Tests - New BLDT	2	Fluid Only	8	100	-15 to -21	Launch (75)	-	-	-
P064	6	Fluid Tests - Data at Stall	2	Fluid Only	8	100	-12 to -13	ABC-S Plus (100)	-	-	-
P065	5	Fluid Tests - Data at Stall	2	Fluid Only	8	100	-15 to -18	EG 106 (100)	-	-	-
P066	5	Fluid Tests - Data at Stall	2	Fluid Only	8	100	-3 to -5	Launch (100)	-	-	-
P067	5	Fluid Tests - Data at Stall	2	IP-	8	100	-11 to -13	EG 106 (100)	25	-	30
P068	5	Fluid Tests - Data at Stall	2	IP Mod	8	100	-4 to -6	Launch (100)	75	-	25
P069	6	Fluid Tests - Data at Stall	2	IP Mod	8	100	-13 to -15	ABC-S Plus (100)	75	-	10
P070	6	Fluid Tests - Clean LE	2	Fluid Only	8	100	-12 to -13	ABC-S Plus (100)	-	-	-
P071	5	Fluid Tests - Clean LE	2	Fluid Only	8	100	-15 to -18	EG 106 (100)	-	-	-
P072	5	Fluid Tests - Clean LE	2	Fluid Only	8	100	-3 to -5	Launch (100)	-	-	-
P073	8	END PLATES - Clean Wing	1	None	8	100	any	none	-	-	-
P074	8	END PLATES - Clean Wing	1	None	8	80	any	none	-	-	-
P075	8	END PLATES - Clean Wing	1	None	stall	80	any	none	-	-	-
P076	8	END PLATES - Clean Wing	1	None	stall	80	any	none	-	-	-
P077	8	END PLATES - Clean Wing	1	None	stall	80	any	none	-	-	-
P078	8	END PLATES - Clean Wing	1	None	stall -4 to stall +4	80	any	none	-	-	-
P079	8	END PLATES - Clean Wing	1	None	8	100	any	none	-	-	-
P080	8	END PLATES - Clean Wing	1	None	8	80	any	none	-	-	-

Table 3.1 (cont'd): Proposed Test Plan

Test Plan #	Day	Objective	Priority	Test Condition	Rotation Angle	Ramp (s/kts)	Target OAT (ºC)	Fluid	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Exposure Time
P081	8	END PLATES - Clean Wing	1	None	stall	80	any	none	-	-	-
P082	8	END PLATES - Clean Wing	1	None	stall	80	any	none	-	-	-
P083	8	END PLATES - Clean Wing	1	None	stall	80	any	none	-	-	-
P084	8	END PLATES - Clean Wing	1	None	stall -4 to stall +4	80	any	none	-	-	-
P085	9	END PLATES - Oil Flow Vis	1	Oil	8	80	any	none	-	-	-
P086	9	END PLATES - Oil Flow Vis	1	Oil	4 or 6	80	any	none	-	-	-
P087	9	END PLATES - Oil Flow Vis	1	Oil	stall	80	any	none	-	-	-
P088	9	END PLATES - Oil Flow Vis	1	Oil	stall-1	80	any	none	-	-	-
P089	9	END PLATES - Oil Flow Vis	1	Oil	stall-2	80	any	none	-	-	-
P090	9	END PLATES - Oil Flow Vis	1	Oil	stall-4	80	any	none	-	-	-
P091	9	END PLATES - Oil Flow Vis	1	Oil	stall-8	80	any	none	-	-	-
P092	9	END PLATES - Oil Flow Vis	1	Oil	TBD	TBD	TBD	none	-	-	-
P093	9	END PLATES - Oil Flow Vis	1	Oil	TBD	TBD	TBD	none	-	-	-
P094	9	END PLATES - Oil Flow Vis	1	Oil	TBD	TBD	TBD	none	-	-	-
P095	9	END PLATES - Oil Flow Vis	1	Oil	TBD	TBD	TBD	none	-	-	-
P096	9	END PLATES - Oil Flow Vis	1	Oil	TBD	TBD	TBD	none	-	-	-
P097	10	END PLATES - Rough(Trips)	1	40-grit	stall	80	same as P013	none	-	-	-
P098	10	END PLATES - Rough(Trips)	2	40-grit	stall -4 to stall +4	80	same as P016	none	-	-	-
P099	10	END PLATES - Rough(Trips)	1	150-grit	stall	80	same as P013	none	-	-	-
P100	10	END PLATES - Rough(Trips)	2	150-grit	stall -4 to stall +4	80	same as P016	none	-	-	-
P101	10	END PLATES - Rough(Trips)	1	80-grit	stall	80	same as P013	none	-	-	-
P102	10	END PLATES - Rough(Trips)	2	80-grit	stall -4 to stall +4	80	same as P016	none	-	-	-
P103	10	END PLATES - Rough(Trips)	1	Full Wing Grit	stall	80	same as P013	none	-	-	-
P104	10	END PLATES - Rough(Trips)	2	Full Wing Grit	stall -4 to stall +4	80	same as P016	none	-	-	-
P105	10	END PLATES - Rough(Trips)	1	Grit (-30% grit on LE)	stall	80	same as P013	none	-	-	-
P106	10	END PLATES - Rough(Trips)	2	Grit (-30% grit on LE)	stall -4 to stall +4	80	same as P016	none	-	-	-
P107	10	END PLATES - Rough(Trips)	1	Grit (-60% grit on LE)	stall	80	same as P013	none	-	-	-
P108	10	END PLATES - Rough(Trips)	2	Grit (-60% grit on LE)	stall -4 to stall +4	80	same as P016	none	-	-	-
P109	12	END PLATES - Fluid Tests - Repeatibility	1	Fluid Only	8	100	-12 to -13	ABC-S Plus (100)	-	-	-
P110	12	END PLATES - Fluid Tests - Repeatibility	2	Fluid Only	8	100	-12 to -13	ABC-S Plus (100)	-	-	-
P111	11	END PLATES - Fluid Tests - Repeatibility	1	Fluid Only	8	100	-15 to -18	EG 106 (100)	-	-	-
P112	11	END PLATES - Fluid Tests - Repeatibility	2	Fluid Only	8	100	-15 to -18	EG 106 (100)	-	-	-
P113	11	END PLATES - Fluid Tests - Repeatibility	1	Fluid Only	8	100	-3 to -5	Launch (100)	-	-	-
P114	11	END PLATES - Fluid Tests - Repeatibility	2	Fluid Only	8	100	-3 to -5	Launch (100)	-	-	-
P115	11	END PLATES - Fluid Tests - Repeatibility	1	IP-	8	100	-11 to -13	EG 106 (100)	25	-	30
P116	11	END PLATES - Fluid Tests - Repeatibility	2	IP-	8	100	-11 to -13	EG 106 (100)	25	-	30
P117	11	END PLATES - Fluid Tests - Repeatibility	1	IP Mod	8	100	-4 to -6	Launch (100)	75	-	25
P118	11	END PLATES - Fluid Tests - Repeatibility	2	IP Mod	8	100	-4 to -6	Launch (100)	75	-	25
P119	12	END PLATES - Fluid Tests - Repeatibility	1	IP Mod	8	100	-13 to -15	ABC-S Plus (100)	75	-	10
P120	12	END PLATES - Fluid Tests - Repeatibility	2	IP Mod	8	100	-13 to -15	ABC-S Plus (100)	75	-	10

Table 3.1 (cont'd): Proposed Test Plan

Test Plan #	Day	Objective	Priority	Test Condition	Rotation Angle	Ramp (s/kts)	Target OAT (ºC)	Fluid	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Exposure Time
P121	13	END PLATES - Fluid Tests - New BLDT	1	Fluid Only	8	100	below -25	ABC-S Plus (100)	-	-	-
P122	13	END PLATES - Fluid Tests - New BLDT	2	Fluid Only	8	100	below -25	ABC-S Plus (100)	-	-	-
P123	13	END PLATES - Fluid Tests - New BLDT	2	Fluid Only	8	100	below -25	ABC-S Plus (100)	-	-	-
P124	14	END PLATES - Fluid Tests - New BLDT	1	Fluid Only	8	100	-15 to -21	ABC-S Plus (75)	-	-	-
P125	14	END PLATES - Fluid Tests - New BLDT	2	Fluid Only	8	100	-15 to -21	ABC-S Plus (75)	-	-	-
P126	14	END PLATES - Fluid Tests - New BLDT	2	Fluid Only	8	100	-15 to -21	ABC-S Plus (75)	-	-	-
P127	14	END PLATES - Fluid Tests - New BLDT	1	Fluid Only	8	100	below -25	EG 106 (100)	-	-	-
P128	14	END PLATES - Fluid Tests - New BLDT	2	Fluid Only	8	100	below -25	EG 106 (100)	-	-	-
P129	14	END PLATES - Fluid Tests - New BLDT	2	Fluid Only	8	100	below -25	EG 106 (100)	-	-	-
P130	13	END PLATES - Fluid Tests - New BLDT	1	Fluid Only	8	100	below -25	Launch (100)	-	-	-
P131	13	END PLATES - Fluid Tests - New BLDT	2	Fluid Only	8	100	below -25	Launch (100)	-	-	-
P132	13	END PLATES - Fluid Tests - New BLDT	2	Fluid Only	8	100	below -25	Launch (100)	-	-	-
P133	13	END PLATES - Fluid Tests - New BLDT	1	Fluid Only	8	100	-15 to -21	Launch (75)	-	-	-
P134	13	END PLATES - Fluid Tests - New BLDT	2	Fluid Only	8	100	-15 to -21	Launch (75)	-	-	-
P135	13	END PLATES - Fluid Tests - New BLDT	2	Fluid Only	8	100	-15 to -21	Launch (75)	-	-	-
P136	12	END PLATES - Fluid Tests - Data at Stall	1	Fluid Only	8	100	-12 to -13	ABC-S Plus (100)	-	-	-
P137	12	END PLATES - Fluid Tests - Data at Stall	1	Fluid Only	8	100	-15 to -18	EG 106 (100)	-	-	-
P138	11	END PLATES - Fluid Tests - Data at Stall	1	Fluid Only	8	100	-3 to -5	Launch (100)	-	-	-
P139	11	END PLATES - Fluid Tests - Data at Stall	1	IP-	8	100	-11 to -13	EG 106 (100)	25	-	30
P140	11	END PLATES - Fluid Tests - Data at Stall	1	IP Mod	8	100	-4 to -6	Launch (100)	75	-	25
P141	12	END PLATES - Fluid Tests - Data at Stall	1	IP Mod	8	100	-13 to -15	ABC-S Plus (100)	75	-	10
P142	12	END PLATES - Fluid Tests - Clean LE	1	Fluid Only	8	100	-12 to -13	ABC-S Plus (100)	-	-	-
P143	11	END PLATES - Fluid Tests - Clean LE	1	Fluid Only	8	100	-15 to -18	EG 106 (100)	-	-	-
P144	11	END PLATES - Fluid Tests - Clean LE	1	Fluid Only	8	100	-3 to -5	Launch (100)	-	-	-
P145	15	Other Dry Tests: SN w/ No Fluid	3	none	8	100	any	Dry - Cold Wing	See details in procedure		
P146	15	Other Dry Tests: SN w/ No Fluid	3	None	8	100	any	Dry - Warm Wing	See details in procedure		
P147	15	TC R&D - S- & S--	1	S--	8	100	above -3	ABC-S Plus (50)	-	3	See details in procedure
P148	15	TC R&D - S- & S--	1	Mod S (Baseline)	8	100	above -3	ABC-S Plus (50)	-	25	See details in procedure
P149	15	TC R&D - S- & S--	1	Fluid Only (Baseline)	8	100	above -3	ABC-S Plus (50)	-	-	-
P150	15	TC R&D: I-PH VANES	1	None	8	100	any	See Details in Procedure			
P151	15	Other Fluid Tests: V-Stab	3	S++	8	100	any	See Details in Procedure			
P152	15	Other Fluid Tests: Frost Spot Deicing	3	Frost	8	100	any	See Details in Procedure			
P153	15	Windshield Washer Fluid	1	Fluid Only	8	100	any	Type I	-	-	-
P154	15	Windshield Washer Fluid	1	Fluid Only	8	100	any	Windshield Washer Fluid	-	-	-
P155	15	Windshield Washer Fluid	1	Frost	8	100	any	Windshield Washer Fluid	-	0.3	45
P156	15	Other Fluid Tests: S++	2	S	8	100	any	See Details in Procedure	-	25	See HOT
P157	15	Other Fluid Tests: S++	2	S++	8	100	any	See Details in Procedure	-	50	1/2 of HOT
P158	15	Other Fluid Tests: S++	2	S++	8	100	any	See Details in Procedure	-	50	3/4 of HOT

4. PRE-TEST SETUP

The following describes the activities to be performed prior to the conduct of any tests:

- Co-ordinate with NRC wind tunnel personnel;
- Co-ordinate with APS photographer;
- Conduct dry photography test of old vs. new camera positioning;
- Document new final camera and flash locations;
- Arrange for hotel accommodations for APS personnel;
- Ensure availability of de/anti-icing fluid (shipped directly to NRC);
- Conduct falling ball tests on received fluids;
- Collect fluid samples for viscosity verification at APS office;
- Arrange personnel travel to Ottawa;
- Ensure proper functioning of ice pellet dispenser equipment;
- Ensure proper functioning of freezing rain sprayer equipment (not applicable);
- Mark wing data collection locations and draw grid on the wing (not applicable). Refer to Feasibility report for diagrams;
- Prepare and arrange for transport of equipment to Ottawa;
- Co-ordinate fabrication of ice pellets/snow/snow pellets; and
- Arrange for storage of ice pellets/snow/snow pellets.

The task list for setup and testing is included as Attachment VII.

5. DATA FORMS

The following data forms are required for the January – February 2012 wind tunnel tests:

- Attachment VIII - General Form/Calibration;
- Attachment IX – General Form;
- Attachment X – Wing Temperature, Fluid Thickness and Fluid Brix Measurements and Condition of Wing and Plate Form;
- Attachment XI, XII and XIII – Ice Pellet, Snow and Sifted Snow Dispensing Forms;
- Attachment XIV – Visual Evaluation Rating Form;
- Attachment XV – Fluid Receipt Form (Generic form used by APS; will be used for this project as appropriate); and
- Attachment XVI – 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. For the majority of the tunnel surveying and calibration (FAA initiative tests), only the general form will be filled out for record keeping purposes, and the electronic data log will be updated accordingly.

6.1 Initial Test Conditions Survey

- Record ambient conditions of the test (Attachment VIII/IX); and
- Record wing temperature (Attachment X).

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 IX);
- Record fluid application quantities (Attachment IX);
- 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 X);
- Record wing temperature (Attachment X);
- Measure fluid Brix value (Attachment X); and
- Photograph and videotape the appearance of the fluid on the wing.

Note: At the request of TC/FAA, a standard aluminum test plate will 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 XI and XII 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 XIII.

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 IX). Any comments regarding dispensing activities should be documented directly on the form.

6.4 Prior to Engines-On Wind Tunnel Test

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

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 consider 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/videotape 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 XIV); 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 X);
- Measure fluid Brix value (Attachment X);
- Record wing temperatures (Attachment X);
- Observe and record the status of the fluid/contamination (Attachment X);
- Fill out visual evaluation rating form (Attachment XIV);
- 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 XV) 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 XVI). 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 services of Safety-Kleen (or other glycol recovery service) 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 2008-09. 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
8:00:00	START OF TEST. ALL EQUIPMENT READY.
8:00:00	- Record test conditions.
8:05:00	- Prepare wing for fluid application (clean wing, etc).
8:15:00	- Measure wing temperature. - Ensure clean wing for fluid application
8:20:00	- Pour fluid over test area.
8:30:00	- Measure Brix, thickness, wing temperature. - Photograph test area.
8:35:00	- Apply contamination over test area. (i.e. 30 min)
9:05:00	- Measure Brix, thickness, wing temperature. - Photograph test area.
9:10:00	- Clear area and start wind tunnel
9:25:00	- Wind tunnel stopped
9:35:00	- Measure Brix, thickness, wing temperature. - Photograph test area. - Record test observations
9:45:00	END OF TEST

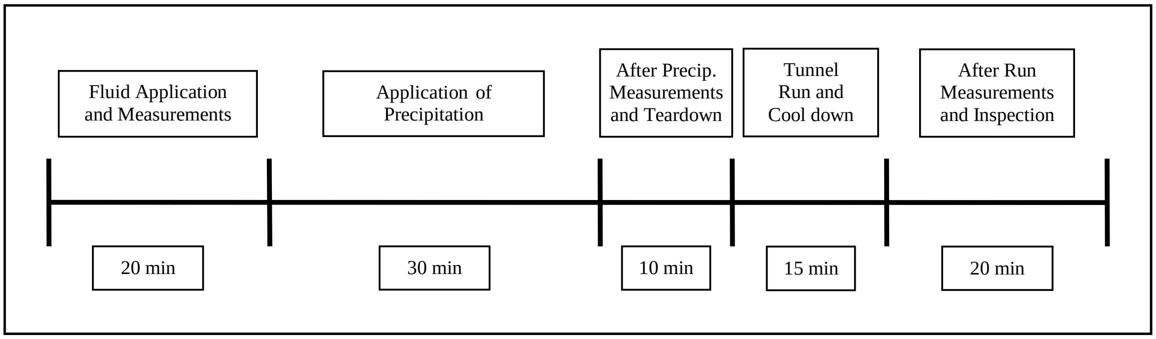

Figure 6.1: Typical Wind Tunnel Run Timeline

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:

- Heavy Snow (Attachment XVII);
- Snow on an Un-Protected Wing (Attachment XVIII);
- Ice Phobic Coatings (Attachment XIX);
- Heavily Contaminated Vertical Stabilizer (Attachment XX);
- Type I Spot Deicing during CSW Frost (Attachment XXI);
- Light and Very Light Snow HOT's (Attachment XXII); and
- Windshield Washer Used as a Type I Deicer (Attachment XXIII).

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 indicated in parentheses above. 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 Equipment		***Ice Pellets Fabrication Equipment***	
Large and small tape measure		Refrigerated Truck	
Fluids (ORDER and SHIP to Ottawa)		Ice pellets Styrofoam containers x20	
Horse and tap for fluid barrel x 2		Ice bags	
Funnels		Ice bags storage freezer	
Sample bottles for viscosity measurement x10		Blenders x6+	
Squeegees		Ice pellets sieves	
Isopropyl x24		Folding tables	
Gloves, paper towel (lots)		Measuring cups (1L and smaller)	
Extension cords		Wooden Spoons	
Clipboards, pencils, wing markers for sample locations and solvent		Rubber Mats	
Large Clock x1			
Walkie Talkies x8		***Freezing Rain Equipment***	
Envelopes and labels		NRC Freezing rain sprayer (not required)	
Previous 05-06 to 10-11 F20/WT reports		APS PC equipped with rate station software	
Grid Section + Location docs		White plastic rate pans (100)	
Large Sharpies for Grid Section		Wooden boards for rate pans (x8)	
Projector for laptop		Rubber suction cup feet for wooden boards	
YOW employee contracts		Sartorius Weigh Scale x1 + NCAR Scale x 1	
Blow Horns x4		Black Shelving Unit (or plastic)	
Stop Watches x4			
Calculators x3			
Scissors			
Exacto Knives x2			
APS Laptops x5			
Camera Equipment			
Digital still cameras x4 (with lenses, chargers, batteries, etc)			
Flashes and tripods			
Memory card reader			
Test Equipment			
Test Procedures, data forms, printer paper			
Electronic copy of the whole wind tunnel procedure folder, incl all forms and working docs (maybe Falcon too).			
Hard Drive (3 x New)			
Test Plate			
Speed tape (large and small)			
Thickness Gauges			
Temperature Probe x 2 and spare batteries			
Brixometers X4			
Adherence Probes (Oral B) x4 with tips and charger			
Fluid pouring jugs x40 (10 per fluid + extra)			
Ice pellets dispersers x6			
Stands for ice pellets dispensing devices x6			
Ice Pellet control wires and boxes (all)			
Ice pellet box supports for railing x4			
Hot Plate x3 and Large Pots with rubber handles			
Watmans Paper and conversion charts			
Long Ruler for marking wing x2			
Small 90º aluminum ruler for wing			
20L containers x12 (DY order from YUL)			
hard water chemicals			
Thermometer for Reefer Truck			
Poster board (8"x3") for flap section			

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 Manufacturer	Fluid Name	Type	2011-12 Quantity Ordered (Planned) (L)
Dow Chemical Company	EG106	IV	600 (400)
Kilfrost Limited	ABC-S PLUS	IV	800 (580)
Clariant Produkte	Launch	IV	400 (520)
		Total	1800

3600 L Ordered For 2009-10 Testing (18 Days)

3200 L Ordered For 2010-11 Testing (15 Days)

1800 L to be Ordered For 2011-12 Testing (7 of 15 days will be fluid testing)

9. PERSONNEL

Four APS staff members are required for the tests at the NRC wind tunnel. Three additional persons 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. The level of personnel has been reduced from previous test campaigns due to budgetary constraints.

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

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;
- 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;
- Appropriate footwear and 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 – AERODYNAMIC CHARACTERIZATION OF THIN, HIGH-PERFORMANCE WING IN THE NRC PIWT TEST PLAN AND RATIONALE FOR WINTER 2012 CAMPAIGN

FAA/TC/APS/NRC/NASA Test Team

Version 1.0
25 November 2011

Overall Goal and Desired Results

Determine the baseline aerodynamic characteristics of the current model configuration—thin, high-performance wing. Improve our understanding and general applicability of the fluids and contamination tested on this wing model configuration.

1. Angle of Attack Sweeps

Objective and Rationale: verify fixed rotation rate method for acquiring wing performance data from force balance, particularly with regard to repeatability in maximum lift ($C_{L,max}$) and stall angle (α_{stall}). Note that we should also be reducing, plotting and analyzing pitching-moment and drag data from the force balance -assuming that these are deemed reliable.

1.1 Perform standard speed ramp profile and rotation to α = 8 deg. and hold. V = 100 kts. Compare C_L, C_M and C_D versus α results to data from previous test campaigns.
1.2 Perform standard speed ramp profile and rotation to α = 8 deg., and hold. V = 80 kts. Compare CL, CM and CD to data from 1.1.
1.3 Perform standard speed ramp profile and rotation to α = 8 deg., and hold, then continue rotation through stall. V = 80 kts. Compare CL, CM and CD to data from 1.1 and 1.2.
1.4 Perform standard speed ramp profile and rotation through stall. V = 80 kts. Compare CL, CM and CD to data from 1.1, 1.2 and 1.3.
1.5 Set V = 80 kts and measure performance data from α = -4 deg. to αstall+ 4 deg. in one degree increments (pitch & pause mode), then take data for decreasing angle of attack also at one degree increments. Note that the V = 80 kts should be maintained as the angle and blockages increase. Compare CL, CM and CD.
1.6 Perform repeat runs of 1.1 – 1.5 as time allows during the remainder of the test campaign.

2. Surface-oil Flow Visualization

Objective and Rationale: document the flow patterns on the surface of the wing for select angles of attack leading up to stall, specifically looking for evidence of spanwise variation, boundary-layer transition and separation to determine the stall type of the wing (e.g., leading-edge stall vs. trailing-edge stall.). Knowledge of the baseline wing flow patterns will help determine the general applicability of the fluids testing results.

Preparations: clean the upper surface of the wing and flap, develop and apply two strips of tape in the chordwise direction marking the %-chord on the model from leading edge to trailing edge. Locate oil with appropriate dye or color for good visibility under normal light. Apply oil to entire upper surface of the wing using a paint roller (foam (sponge) roller preferred, but fiber roller with short nap may also work).

General Procedure: roll oil to uniform coverage and photograph. Set desired angle of attack and set tunnel speed (probably 80 kts to correspond to 1.5). Observe flow of oil on the surface and shut down tunnel when steady state is achieved. Take photographs to document features. Re-distribute oil on the surface with roller to prepare for next run.

2.1 Perform flow viz run at $\alpha = 8$ deg. since this is the angle of interest for fluids evaluation. Repeat as many times as needed to get high-quality images.

2.2 Depending upon extend of separation and spanwise flow, it may be necessary to perform flow viz run at a lower angle (say 4 or 6 deg.). For example, if spanwise flow is noted at $\alpha = 8$ deg., then it may be useful to document the angle of attack at which the spanwise flow is mitigated.

2.3 Perform flow viz runs at incremental angles of attack leading up to stall. For example, if CL,max occurs at $\alpha = \alpha stall = 20$ deg. Then a suggested matrix is $\alpha = 12, 16, 18, 19$ and 20. This will characterize the surface flow leading to stall and hence determine the stall type.

2.4 Based upon results of flow visualization, define and conduct test matrix for boundary-layer rake data acquisition.

3. Surface Roughness Tests

Objective and Rationale: determine the wing sensitivity to various sizes and configurations of roughness and simulated frost. Knowledge of wing sensitivity to roughness and roughness extent may help determine the general applicability of the fluids effects.

Preparations: need to develop suitable methods for applying and removing roughness in cold environment without damaging the wing surface.

3.1 Apply 40-grit sandpaper (*k/c* = 0.00023) roughness to leading edge from *x/c* = 0.08 on the upper surface to *x/c* = 0.08 on the lower surface. Acquire performance data through stall according to 1.4 or 1.5 or both.

3.2 Assuming that the performance effects from 3.1 are significant apply 150-grit sandpaper (k/c = 0.000050) roughness to leading edge from x/c = 0.08 on the upper surface to x/c = 0.08 on the lower surface. Acquire performance data through stall according to 1.4 or 1.5 or both.

3.3 If a larger variation in performance is observed between 3.1 and 3.2 consider applying 80-grit sandpaper (k/c = 0.00010) roughness to leading edge from x/c = 0.08 on the upper surface to x/c = 0.08 on the lower surface. Acquire performance data through stall according to 1.4 or 1.5 or both.

3.4 Based upon the results from 3.1 to 3.2 select one of the roughness sizes for an study of upper surface frost. Cover the entire upper surface of the wing with roughness and acquire performance data through stall according to 1.4 or 1.5 or both.

3.5 After running 3.4 remove the roughness from the first 30% of chord, leaving the aft 70% covered with roughness and acquire performance data through stall according to 1.4 or 1.5 or both.

3.6 After running 3.5 remove the roughness from the first 60% of chord, leaving the aft 40% covered with roughness and acquire performance data through stall according to 1.4 or 1.5 or both.

4. Tests with Uncontaminated and Contaminated Fluids

Objective and Rationale: gather data to show year-to-year repeatability for selected fluid and fluid+contamination cases; gather new data for uncontaminated fluid cases to add to BLDT correlation (suggested to use 75/25 mixture to obtain data closer to AAT failure limit at warmer temperatures). Also, look at acquiring fluid and fluid+contamination data at stall.

4.1 Select cases for uncontaminated fluid repeat runs (temperature dependent).

4.2 Select cases for fluid+contamination repeat runs (temperature dependent).

4.3 Select cases for uncontaminated fluid runs to add to BLDT correlation (e.g., 75/25 fluid) (temperature dependent).

4.4 Repeat runs from 4.1 and 4.2, but rotating model through stall, with usual hold at $\alpha = 8$ deg.

4.5 Repeat runs from 4.1 and 4.2, but rotating model through stall, without hold at α = 8 deg.

4.6 If possible, apply fluid to only the aft portion of the wing, leaving the leading edge clean and conduct usual ramp and rotation as in 4.1 and 4.2 (temperature dependent).

5. Tests with New Endplates

Objective and Rationale: determine if larger endplates result in reduced 3D surface flow effects and less spanwise variation. Also, show that fluid and fluid+contamination effects observed at α = 8 deg. are similar to that previously observed with the original endplates.

Probably need to repeat a subset of all tests in 1-4 above. Of course this depends upon how the data compare to the original configuration as they are acquired.

ATTACHMENT II – Generic Type I Holdover Time Table

Transport Canada Holdover Time Guidelines **Winter 2011-2012**

TABLE 1-A

SAE TYPE I FLUID HOLDOVER GUIDELINES ON ALUMINUM WING SURFACES FOR WINTER 2011-2012[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

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

NOTES

1 Type I Fluid / Water Mixture is 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.**

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

Transport Canada Holdover Time Guidelines **Winter 2011-2012**

TABLE 4-D-E106

DOW CHEMICAL TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2011-2012[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	Snow, Snow Grains or Snow Pellets[3]	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	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	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	0:15 – 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 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 IV – Kilfrost ABC-S Plus Type IV Holdover Time Table

TABLE 4-K-ABC-S+

KILFROST TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2011-2012[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**	**Snow, Snow Grains or Snow Pellets[3]**	**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	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	0:45 – 1:15	1:00 – 1:20	0:30 – 0:50	0:10 – 1:20	
		50/50	0:30 – 0:55	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	1:00 – 1:45	0:25 – 1:35[7]	0:20 – 0:30[7]		
		75/25	0:45 – 1:50	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	0:15 – 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 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 V – Clariant Safewing MP IV Launch Type IV Holdover Time Table

TABLE 4-C-LAUNCH

CLARIANT TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2011-2012[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	Snow, Snow Grains or Snow Pellets[3]	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing[5]	Other[6]
-3 and above	27 and above	100/0	4:00 – 4:00	1:05 – 1:45	1:30 – 2:00	1:00 – 1:40	0:15 – 1:40	
		75/25	3:40 – 4:00	1:00 – 1:45	1:40 – 2:00	0:45 – 1:15	0:10 – 1:45	
		50/50	1:25 – 2:45	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	0:50 – 1:20	0:35 – 1:40[7]	0:25 – 0:45[7]		
		75/25	0:40 – 1:20	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	0:15 – 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 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 VI– Ice Pellet Allowance Time Table

Transport Canada Holdover Time Guidelines **Winter 2011-2012**

TABLE 11

ICE PELLET ALLOWANCE TIMES FOR WINTER 2011-2012

<table>
<tr><th></th><th>OAT -5°C and above</th><th>OAT less than -5°C to -10°C</th><th>OAT less than -10°C</th></tr>
<tr><td>Light Ice Pellets</td><td>50 minutes</td><td>30 minutes</td><td>30 minutes[1]</td></tr>
<tr><td>Moderate Ice Pellets</td><td>25 minutes[2]</td><td>10 minutes</td><td>10 minutes[1]</td></tr>
<tr><td>Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle</td><td>25 minutes</td><td>10 minutes</td><td rowspan="6">Caution: No allowance times currently exist</td></tr>
<tr><td>Light Ice Pellets Mixed with Light Freezing Rain</td><td>25 minutes</td><td>10 minutes</td></tr>
<tr><td>Light Ice Pellets Mixed with Light Rain</td><td>25 minutes[3]</td><td rowspan="2"></td></tr>
<tr><td>Light Ice Pellets Mixed with Moderate Rain</td><td>25 minutes[4]</td></tr>
<tr><td>Light Ice Pellets Mixed with Light Snow</td><td>25 minutes</td><td>15 minutes</td></tr>
<tr><td>Light Ice Pellets Mixed with Moderate Snow</td><td>10 minutes</td><td></td></tr>
</table>

NOTES

1. 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).
2. Allowance time is 15 minutes for propylene glycol (PG) fluids, or when the fluid type is unknown.
3. No allowance times exist in this condition for temperatures below 0°C; consider use of light ice pellets mixed with light freezing rain.
4. No allowance times exist in this condition for temperatures below 0°C.

ATTACHMENT VII – 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 personnel travel to Ottawa;	VZ	
6	Hire YOW personnel	VZ	
7	Complete contract for YOW personnel	VZ/PG	
8	Co-ordinate with APS photographer	MR	
9	Ensure availability of freezing rain sprayer equipment;	MR	
10	Prepare and Arrange Office Materials for YOW	VZ	
11	Prepare Data forms and procedure	VZ	
12	Prepare Test Log (See JD with it)	VZ	
13	Finalize and complete list of equipment/materials required	MR	
14	Prepare and Arrange Site Equipment for YOW	MR/DY	
15	Ensure proper functioning of ice pellet dispenser equipment;	MR/VZ	
16	Review IP/ZR/SN dispersal techniques and location	VZ/MR	
17	Update IP Rate File (if necessary)	VZ/MR	
18	Arrange for freezer storage of ice pellets/snow/snow pellets.	VZ	
19	Check weather prior to establishing test dates	MR	
20	Arrange for pallets to lift up 1000L totes (if applicable)	MR	
21	Purchase new 20 L containers (as necessary)	DY	
22	Complete purchase list and shopping	VZ	
	Monday Jan 16		
23	Pack and leave YUL for YOW on Jan 16th	APS	
24	Safety Briefing & Training (APS/YOW)	MR	
25	Unload Truck and organize equipement in lower, middle, or office area	APS	
26	Verify and Organize Fluid Recieved (labels and fluid receipt forms)	DY/JS	
27	Transfer Fluids from 1000 L Totes to 20 L containers	DY/JS	
28	Collect fluid samples for viscosity and falling ball verification at APS office	DY/VZ	
29	Confirm ice and freezer delivery	DY	
30	Setup general office and testing equipment	VZ	
31	Setup Projector	VZ	
32	Setup Printer	VZ	
33	Setup rate station	DY	
34	Setup IP/SN manufacturing material in reefer truck	JS	
35	Test and prepare IP dispensing equipment	JS	
36	Train IP making personnel (ongoing)	JS/YOW	
37	Co-ordinate fabrication of ice pellets/snow	VZ/JS	
38	IP/SN/ZR Calibration (if necessary)	DY/VZ/MR	
39	Start IP manufacturing	JS	
40	Mark wing (only if requested);	VZ	
41	Setup Still and Video Cameras same as 2010-11	BG/JsD	
42	Verify 2010-11 vs 2011-12 photo and video angles, resolution, etc	BG/JsD/MR	
43	Document new final camera and flash locations	BG/JsD	
44	General safety briefing and update on testing	APS/NRC/YOW	
45	Dry Run of tests with APS and NRC (if necessary)	APS/NRC	
46	Start Testing	APS/NRC	
	Each Testing Day		
47	Check with NRC the status of the testing site, tunnel, weather etc	MR	
48	Deicide personnel requirements for following day for 24hr notice	MR/WU	
49	Prepare equipment and fluid to be used for test	DY	
50	Manufacture ice pellets	JS/YOW	
51	Prepare photography equipment	BG	
52	Prepare data forms for test	VZ	
53	Conduct tests based on test plan	APS	
54	Modify test plan based on results obtained	WU/JD/MR	
55	Update ice pellet, snow, raw ice, and fluid Inventory (end of day)	VZ/JS	
56	Update Test Log and Test Plan (ongoing and end of day)	VZ	

ATTACHMENT VIII – General Form/ Calibration

GENERAL FORM (EVERY CALIBRATION TEST)

DATE: ______________________ RUN # (Plan #): ______________

OJECTIVE: ☐ Angle of Attack Sweeps ☐ Surface-oil Flow Visualization ☐ Surface Roughness Tests

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

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

WIND TUNNEL START TIME: __________ ROTATION ANGLE: __________

WIND TUNNEL END TIME: __________ PROJECTED SPEED (S/KTS): __________

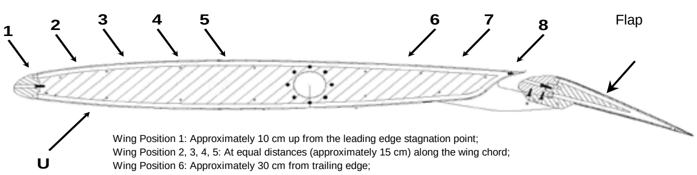
FLAP SETTING (20°, 0°): __________

OIL APPLIED: Y / N OIL DETAILS: ______________________

☐ Full Wing ☐ Partial Wing (describe) ______________________

GRIT APPLIED: Y / N GRIL DETAILS: ______________________

☐ Full Wing ☐ Partial Wing (describe) ______________________

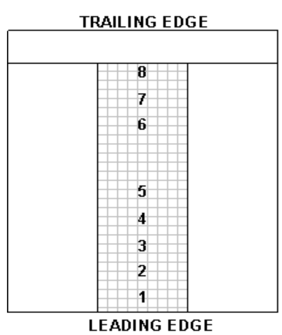


Wing Position 1: Approximately 10 cm up from the leading edge stagnation point;
Wing Position 2, 3, 4, 5: At equal distances (approximately 15 cm) along the wing chord;
Wing Position 6: Approximately 30 cm from trailing edge;
Wing Position 7: Approximately 15 cm from trailing edge;
Wing Position 8: Approximately 2.5 cm from trailing edge;
Wing Position 9: Midway up the flap; and
Underside: Approximately 40 cm up from the leading edge stagnation point.

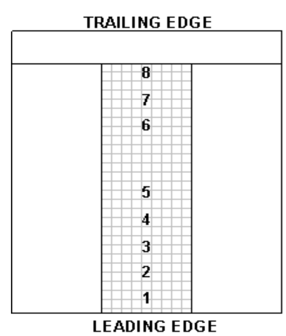
☐ Small Endplates

☐ Large Endplates

Before the Takeoff Run



After the Takeoff Run



COMMENTS :

HANDWRITTEN BY:

☐ Check if further details are available behind this sheet

ATTACHMENT IX – 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°): ____________

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/dm^2/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/dm^2/h): ____________ Droplet Size (mm): ____________

Exposure Time: ____________ Needle: ____________

Flow: ____________

Pressure ____________

SNOW APPLICATION (if applicable)

Actual start time: ____________ Actual End Time: ____________

Rate of Snow Applied (g/dm^2/h): ____________ Snow Size (mm): <1.4 mm

Exposure Time: ____________ Method: ☐ Dispenser ☐ Sieve

Total SN Required per Dispenser: ____________

COMMENTS

MEASUREMENTS BY: ____________ **HANDWRITTEN BY:** ____________

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

Date: ______________________________ Run: ____________________

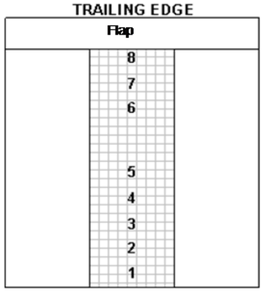
WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
T2				
T5				
TU				
Time:				

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:			

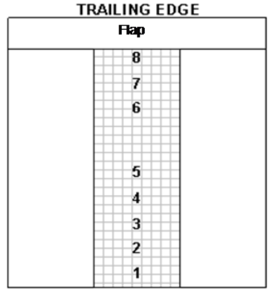
Fluid Film <1 After Takeoff Run: ☐ YES ☐ NO

Wing and Plate Condition
After the Takeoff Run
Time: ___________

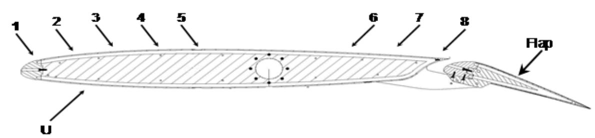


Comments: ____________________

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 XI – Example Ice Pellet Dispensing Form

WING TRAILING EDGE

8 ft = 24.4 dm (width); 6 ft = 18.3 dm (height)

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 XII – 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	g
In each Dispensor	336	g

Snow needed for entire test

In each Dispensor	336	g
Total Amount Snow Needed for Entire Test	1344	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 completed 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 XIII – 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 XIV – 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 XV – Fluid Receipt Form

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 XVI – Log of Fluid Sample Bottles

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

ATTACHMENT XVII – 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 2008-11.

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.

ATTACHMENT XVIII – 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. Full-scale testing is required to investigate the aerodynamic performance of a wing section contaminated with dry, un-adhered snow.

Objective

To investigate the aerodynamic performance of a wing section contaminated with dry, un-adhered 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 (-5°C 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 XIX – Procedure: Ice Phobic Coatings

Background

There has been a recent industry interest in the use of ice phobic coatings to protect aircraft critical surfaces. Currently, some non-commercial operators are using ice phobic coatings on the aircraft radome and other aircraft surfaces. Previous work was conducted during the winter of 2009-10 with a severely contaminated wing section. It was recommended that application of these materials on different parts of the wing surface be investigated i.e. wing and flap leading edge, quiet areas, etc. It was recommended that testing be continued to investigate the protective properties of these coatings in precipitation conditions, and to verify the compatibility of these products with glycol de/anti-icing fluids.

Due to procedural limitations, it was not possible to have the ice phobic coatings applied to the airfoil. Instead, the ice phobic coating will be applied to one of the vertical turning vanes at the back end of the wind tunnel.

Objective

To gather observational data regarding the performance of the coatings following repeated applications of glycol and potential residue formations.

Methodology

The vertical turning vanes at the back end of the tunnel (which are essentially vertical airfoils) are approximately 20ft tall and with a 5ft chord. The intent is to coat the lower half of a vane with an ice phobic coating which results in 2 x 10ft X 5ft sections, or about 100ft² of coated surface. These vanes are typically covered in glycol and residues by the end of the wind tunnel testing period, therefore, by having one of the vanes coated may provide some observational indication into how the coatings behave with repeated applications of glycol and potential residue formations.

- One vane should be treated with the ice phobic coating as per the manufacturer specification. The other vanes should be left untreated;
- Run wind tunnel with fluids as per schedule;
- DO NOT CLEAN VANES IN BETWEEN TEST RUNS; and
- At the end of the testing period, the performance of the treated and un-treated sections of the wing should be compared.

Test Plan

Ongoing and independent of wind tunnel test plan.

ATTACHMENT XX – Procedure: Heavily Contaminated Vertical Stabilizer (Testing Feasibility)

Background

Preliminary flat plate testing has indicated that fluid endurance times can be significantly reduced on vertical surfaces, primarily due to fluid flow off and increased "catch-factor" resulting from high winds. The preliminary endurance time testing indicated that during snow conditions, a vertical surface failure is similar to a heavy snow condition due to the increased "catch-factor". It was recommended that preliminary testing be conducted on the current wing section to investigate the lift losses associated, which could then be translated to a vertical stabilizer.

Objective

To investigate the aerodynamic effects of a heavily contaminated vertical stabilizer.

Methodology

- Conduct a heavy snow test on the upper surface of the wing;
- Once the contamination is complete, apply a generous coating of the same anti-icing fluid to the underside of the wing;
- Run the wind tunnel to obtain aerodynamic data;
- Repeat test with un-contaminated fluid on both the upper and underside of the wing; and
- Document results and develop methodology to translate the results to a vertical surface to simulate un-even contamination due to cross winds.

Test Plan

Testing should be limited due to the preliminary nature of the procedure. If results are promising, investigate feasibility of using a vertical stabilizer wing section for future wind tunnel testing.

ATTACHMENT XXI – Procedure: Type I Spot Deicing during CSW Frost Conditions

Background

The fundamental difference between both types of frost is how the wing skin temperature is cooled below ambient: radiation cooling versus conduction cooling. During natural active frost, the wing skin temperature will be cooled below ambient temperature as a result of radiation cooling from the cold clear sky. During cold soak wing conditions, however, the wing skin temperature is cooled and maintained at a temperature below ambient as a result of conduction cooling from the cold fluid stored inside the wing; either the aircraft was refueled with cold fuel, or following a flight, the wing and fluid will be cold soaked. Full-scale data is recommended to investigate the aerodynamic effects of CSW frost on a deiced airfoil protected with Type I fluid.

Objective

To investigate the aerodynamic effects of CSW frost on a deiced airfoil protected with Type I fluid.

Methodology

- Dilute Type I fluid to a 0ºC buffer with respect to the wing skin temperature (to simulate CSW);
- Apply fluid heated to 60ºC to wing section;
- Wait 45 minutes (the Type I HOT in frost) or until fluid fails;
- Run the wind tunnel and collect data; and
- Compare results to baseline uncontaminated Type I tests.

Test Plan

One to two tests are anticipated.

ATTACHMENT XXII – Procedure: Light and Very Light Snow HOT's

Background

Holdover time determination systems have been developed to provide greater accuracy for determining rate of precipitation and allowing for a better use of the holdover time tables. Some recent discussion has been raised about HOT's for light and very light snow with respect to the fluid condition at the end of the several hour holdover time and potential concerns with fluid dripping off and thinning out. It was recommended that some preliminary testing be conducted in the wind tunnel to see how the fluid fails on an airfoil and to investigate the resulting aerodynamic effects.

Objective

To investigate the potential light and very light snow HOT's failure patterns and the respective effects on aerodynamic performance.

Methodology

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

- For a chosen fluid (ABC-S Plus suggested), conduct a test simulating very light snow conditions for an exposure time (72 minutes for rate of 3 $g/dm^2/h$) derived from the fluid specific HOT regression equations;
- Evaluate the condition of fluid and any potential dry-out or thinning of fluid at end of exposure period; and
- Record lift data, visual observations, and manually collected data.

Test Plan

One to four comparative tests are anticipated for comparison to a baseline condition. The baseline should either be fluid only (50/50) or moderate snow, or both.

ATTACHMENT XXIII – 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.

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

One to four tests are anticipated.

APPENDIX E

SAE AIR: AIRCRAFT AFTER-MARKET SURFACE COATING INTERACTION WITH GROUND DEICING/ ANTI-ICING FLUIDS – AIR DRAFT 1.5

SAE Aerospace An SAE International Group	**AEROSPACE INFORMATION REPORT**	**AIR Draft 1.5**	
		Issued Revised	

AIRCRAFT AFTER-MARKET SURFACE COATING INTERACTION WITH GROUND DEICING / ANTI-ICING FLUIDS

RATIONALE

This SAE Aerospace Information Report (AIR) provides a description of screening methods for verifying if aircraft after-market wing surface coatings have adverse effects on aircraft ground deicing/anti-icing fluid performance as published in the holdover time guidelines. 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 FAA and Transport Canada. Holdover time values for deicing / anti-icing fluids are derived from endurance time testing standard procedures 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 hydro-philic or hydro-phobic 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 guidelines is unclear. A fluid’s holdover time may be partly related to the thickness of the anti-icing fluid; however, after-market coatings may affect fluid wetting capability and resulting fluid thickness, thus potentially affecting fluid holdover time protection. There exists a need to evaluate the interaction of aircraft after-market wing surface coatings with ground deicing/anti-icing fluids with respect to holdover time performance and potential implications for aerodynamic performance. In addition, test methods are available to help characterize the various aircraft after-market wing surface coating properties, including durability, hardness, weathering, effect on aerodynamic drag, ice adhesion, ice accumulation, contact angle, and thermal conductivity. This AIR XXXX 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 after-market wing surface coating has adverse effects on ground deicing/anti-icing fluids with respect to fluid holdover time performance and aerodynamic performance.

Although not the primary mandate of the G-12 Ground Deicing Committee, this document also provides descriptions of suggested test methods for evaluating aircraft after-market 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 after-market wing surface coatings with respect to ground deicing / anti-icing fluid holdover time performance and aerodynamic performance.

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

1.2 Definitions and Abbreviations

- AERODYNAMIC ACCEPTANCE TEST: a performance test required under §3.2.5 of AMS1428 and defined in AS5900.
- AIRCRAFT AFTER-MARKET SURFACE COATING: a coating applied to an aircraft surface with properties that may be Ice-phobic, Hydro-phobic, Super hydro-phobic, or Hydro-philic.
- ENDURANCE TIME: time that a fluid can endure defined and controlled temperature and precipitation conditions before visual failure. Endurance time tests are defined in ARP5485 and ARP 5945.
- FAA: United States Department of Transportation, Federal Aviation Administration.
- HOLDOVER TIME (HOT): time a fluid is expected to provide protection of an aircraft against freezing or frozen precipitation from the initial application of fluid.
- 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 "holdover time table".
- HYDROPHILIC SURFACE: Producing a surface contact angle of $\theta < 90°$.
- HYDROPHOBIC SURFACE: Producing a surface contact angle of $\theta > 90°$.
- ICE-PHOBIC SURFACE: A surface offering reduction in ice adhesion and designed specifically for anti-ice applications.
- LOWEST ON-WING VISCOSITY (LOWV): viscosity reported by the laboratory performing the testing under §3.1.3 of ARP5485. The LOWV is published with the specific holdover time guideline for that fluid. Fluids having an on-wing viscosity less than the LOWV cannot be used with holdover time guidelines. The LOWV must be equal to or below the lower viscosity limit of the deicing/anti-icing fluid as specified in the sales or technical brochure.
- LOWEST OPERATIONAL USE TEMPERATURE (LOUT): the lowest operational use temperature of a Type II/III/IV fluid is generally recognized as the higher of:
    a. the lowest temperature at which it meets the aerodynamics acceptance test (AS5900) for a given type of aircraft or
    b. the freezing point of the fluid plus the freezing point buffer of 7 °C (about 13 °F).
- MAXIMUM ON-WING VISCOSITY (MOWV): see AMS1428 high viscosity. Fluids having a viscosity higher than the MOWV must not be used.
- OAT: Outside Air Temperature.
- 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 5845.
- SUPERHYDROPHOBIC SURFACE: Producing a surface contact angle of $\theta > 150°$ and a roll-off angle less than 10º.

2. APPLICABLE DOCUMENTS

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications s9hall 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.

AMS1424 Deicing/Anti-icing Fluid, Aircraft, SAE Type I

AMS1428 Fluid, Aircraft Deicing/Anti-icing, Non-Newtonian (Pseudoplastic), SAE Types II, III, and IV

ARP5485 Endurance Time Tests for Aircraft Deicing/Anti-icing Fluids SAE Type II, III, and IV

ARP5945 Endurance Time Tests for Aircraft Deicing/Anti-icing Fluids SAE Type I

AS5900 Standard Test Method for Aerodynamic Acceptance for SAE AMS1424 and SAE AMS1428 Aircraft Deicing/Anti-icing Fluids

AMS 3095 Paint, Gloss, Airline Exterior System

2.2 FAA Publications

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

- FAA Holdover Time Guidelines. (These are published every winter. Always use the latest issue; search for "FAA Holdover Time".)
- FAA-Approved Deicing Program Updates, Winter 20XX-20XX. (These are published every 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. (These are published every 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.

3. COMPARATIVE FLUID ENDURANCE TIME TEST (Marco to Expand as Required)

Tests will be conducted with Type I and Type II/III/IV fluids to compare the endurance times of fluids applied to aluminum test plate surfaces treated with the aircraft after-market surface coating to the endurance times of the same fluids applied to a standard aluminum test plate (and in some limited cases a freshly painted aluminum test plate which serves as reference tool).

ARP 5945 and ARP 5485 will be the basis of the comparative endurance time test methodology. The endurance time testing will be conducted according to the procedures described in ARP 5945 and ARP 5485.

3.1 Fluid Selection

The aircraft operator shall determine the fluid brands to be selected. The following are recommended criteria for selecting the fluids for the comparative endurance time testing:

- Minimum of two Type II/III/IV AMS 1428 fluids that are selected by the aircraft operator or the coating manufacturer. Consideration should be given to testing both an ethylene-glycol and propylene-glycol based fluid in 100/0 dilution, and possibly also at 75/25 and 50/50 dilutions, or a non-glycol formulation, depending on the operator. Fluid should be within the production range specified by the fluid manufacturer.
- Minimum of two Type I AMS 1424 fluids that are used by the aircraft operator. Consideration should be given to testing both an ethylene-glycol and propylene-glycol based fluid diluted to a 10ºC freezing point buffer, and possibly also the standard mix, or a non-glycol formulation, depending on the operator.

3.2 Test Surfaces

The following is a description of the test surfaces to be 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°
  - Surface finish 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 after-market 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 plate represents the upper 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; therefore, Table 1 suggests a minimum set of precipitation conditions for comparative testing. When selecting conditions, the objective is to try to obtain a broader 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 Selected HOT Testing Conditions for Comparative Testing

Precipitation Type	Precipitation ID.	Air temperature, °C	Icing intensity, g/dm2/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*			
	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			
	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 carried out using the same protocol used to measure fluid thickness of new endurance time fluids. 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. 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, Treated
TH2	Type I A	10°Buffer	-3°C	Standard, Treated, and Painted
TH3	Type I A	Standard Mix (50/50)	-3°C	Standard, Treated
TH4	Type II/III/IV C	100/0	-3°C	Standard, Treated
TH5	Type II/III/IV D	100/0	-3°C	Standard, 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 after-market 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 Laboratory

As of the date of publication of the AIR the following laboratory is known to provide testing for anti-icing fluids. This is not an endorsement by SAE for this laboratory but simply to facilitate the finding of laboratories for those seeking testing. Please enquire directly with the laboratory 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 ACCPETANCE TEST (Eric to Expand as Required)

Aircraft after-market surface coatings may influence the fluid flow-off behavior during takeoff. 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 after-market surface coatings on fluid flow-off characteristics. Tests should be conducted with Type I and Type II/III/IV fluids. The purpose of these tests is to compare the aerodynamic acceptance results with the aircraft after-market surface coating to those of the same fluid without the coating. AS 5900 will be the basis of the comparative fluid aerodynamic acceptance test methodology.

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) OR JUST ALUMINUM AND TREATED???
  - Plexiglas
  - Test duct floor dimensions 1600 mm long x 302 mm wide
  - Horizontal
  - Surface shall be hydraulically smooth, resulting in a dry 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. OR Reference to AS5900 section 3.1.3 a and b?
- 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 ≤ X µm
  - Plate fixed over the standard test duct floor with X tape
- Treated Test Plate
  - Same material and construction as the ''Aluminum Test Plate'' described above, however,
  - Treated using aircraft after-market surface coating according to coating manufacturer specifications.
- Painted Test Plate (Optional)
  - Same material and construction as the ''Aluminum Test Plate'' described above, however,
  - Painted using representative aircraft grade primer and paint according to coating manufacturer specifications.

4.3 Test Conditions

Full testing of the fluids according to AS 5900 with both treated and un-treated test duct floor/plates is not practical. At a minimum, it is recommended that comparative testing be conducted with each selected fluid in accordance with AS5900, at one data point, three runs, using the neat fluid. The test shall repeat 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 acceptance tests will provide a good indication of fluid aerodynamic performance when applied to aircraft surfaces treated with after-market coatings. The interpretation of the test results, and ultimately the decision to use the coating on aircraft, is the responsibility of the aircraft operator.

4.5 Testing Laboratory

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

Anti-icing Materials International Laboratory (AMIL), 555, boulevard de l'Université, Chicoutimi, Québec,

G7H 2B1, Canada; 418 545-5011 ext. 2406. www.uqac.ca/amil

5. ADDITIONAL INFORMATIONAL TEST METHODS (Brian, Eric, Mark, Yvan and others to Expand as Required)

The following describe test methodologies that may be used to conduct testing to help characterize aircraft surface after-market coatings. These tests are outside of the scope of the 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 Durability, Hardness, and Weathering

Aircraft after-market surface coatings should be tested for durability, hardness, and weathering from exposure to wear, heat, humidity, and ultraviolet light. Consideration should be given to conducting additional comparative endurance time testing and fluid aerodynamic acceptance testing with weathered surfaces if dramatic changes in coating properties are experienced.

5.2 Aerodynamic Drag Evaluation Test

Use an aerodynamic balance to measure drag forces on a representative model in an icing wind tunnel. Comparative testing should evaluate the model both treated and un-treated under the same conditions. Testing should record and evaluate the drag coefficient. Conditions to be tested are the following: Elaborate conditions???

- Dry Condition (no icing)
  - -20°C and -5°C for 10, 20 and 30 minutes
- Icing with 0.4 LWC
  - -20°C and -5°C for 10, 20 and 30 minutes

5.3 Ice Adhesion Test

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

5.3.1 Centrifuge Ice Adhesion Test

Accrete ice in the form of freezing precipitation under controlled conditions. Form small ice coupons on a substrate and on aluminum. Centrifuge the substrate and measure the force required to separate the ice from the substrate through adhesive failure and compare with aluminum coupons.

5.3.2 Zero-Degree Cone Test

Ice is grown in a gap between two concentric, cylindrical surfaces. The force required to push the inner cylinder out of the ice collar is measured to determine the adhesive strength of the ice to the coating. Samples are frozen at -10 ºC for 48 hours and the nominal shear stress for ice release is calculated from the measured maximum load divided by the surface area of the coated pin/ice interface.

5.4 Ice Accumulation

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

5.4.1 Static Ice Accumulation

Accrete ice in the form of freezing precipitation under controlled conditions. Form small ice coupons on a substrate positioned at 0, 45 and 80° from the horizontal. Measure and evaluate the amount of accreted ice on the substrate.

5.4.2 Dynamic Ice Accumulation

Use a representative model airfoil in an icing wind tunnel. Comparative testing should evaluate an un-treated aluminum airfoil and treated aluminum airfoil under the same conditions. Testing should evaluate the amount and shape of ice accreted on the airfoil and the drag increase in function of accumulation time. Conditions to be tested are the following:

- Icing with 0.4 g/m³ LWC at -20°C and -5°C for 10, 20 and 30 minutes

5.5 Contact Angle

Measure the contact angle of a coating to identify whether a coating is Ice phobic, Hydrophobic, or Hydrophilic. Hydrophobic does not necessarily mean Ice Phobic. The following are definitions of contact angle:

- $\theta < 90°$hydrophilic surface
- $\theta > 90°$hydrophobic surface
- $\theta > 150°$superhydrophobic surface

5.6 Rolling Angle

NEED TO DEVELOP TEXT

(Rolling Angle or Sliding Angle or Contact Angle Hysteresis. REF Callies an al, Microfabricated textured surfaces for super-hydrophobicity investigations)

5.7 Frost Endurance Test

NEED TO DEVELOP TEXT

(Ability of coating to prevent frost formation)

5.8 Thermal Conductivity

NEED TO DEVELOP TEXT

A suggestion by Yvan Chabot: Measure and assess the coating thermal conductivity. The coating may influence heat transfer in a deicing or anti-icing scenario, potentially impacting the fluid holdover times (either positively or negatively)

5.9 Cyclical Immersion Test

NEED TO DEVELOP TEXT

A suggestion by Mark Nagy: consider a compatibility test between the coating and ADFs, possibly a cyclical immersion test which could use parameters such as change in coating hardness, contact angle, ice adhesion etc. before and after ADF exposure.

5.10 Testing Laboratories

As of the date of publication of the AIR the following laboratories are known to provide testing for aircraft after-market coatings. This is not an endorsement by SAE for these laboratories but simply a list to facilitate the finding of laboratories 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; 418 545-5011 ext. 2406. www.uqac.ca/amil

Scientific Material International, 12219 SW 131st Avenue, Miami, Florida, USA 33186-6401; 305-971-7047; www.smiinc.com

6. NOTES

6.1 Keywords

Aircraft After-Market Coating, Ice Phobic, Hydrophobic, Hydrophilic, Endurance Time, Holdover, Aircraft, Surface, Frost, Ice, Freezing, Rain, Drizzle, Fog, Cold Soaked Wing, Snow.

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