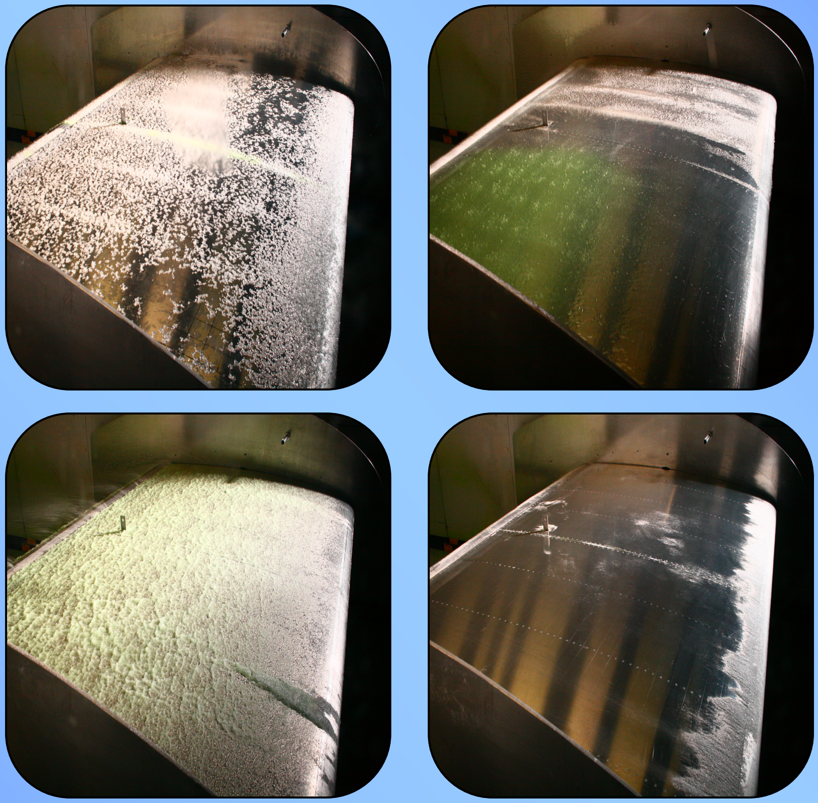
TP 15057E

Exploratory Wind Tunnel Aerodynamic Research

Examination of Contaminated Anti-Icing Fluid Flow-Off Characteristics

Winter 2009-10



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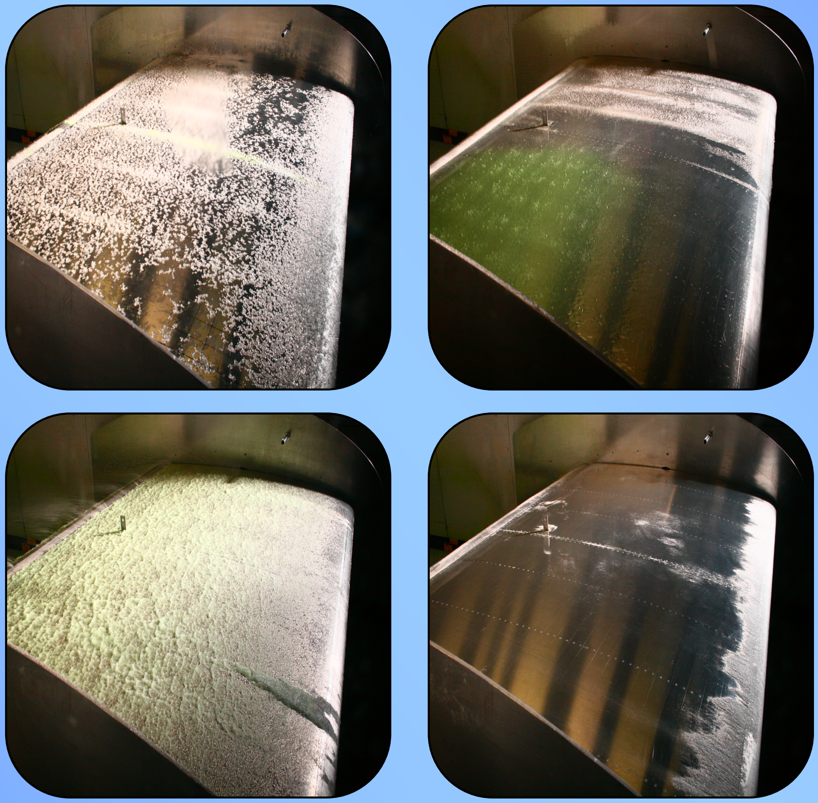

by

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PREFACE

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

- To develop holdover time data for all newly-qualified de/anti-icing fluids; and update and maintain the website for the holdover time guidelines;
- To evaluate weather data from previous winters that can have an impact on the format of the holdover time guidelines;
- To develop Type I holdover times for composite surfaces; and evaluate first-step rule for use with composite surfaces;
- To conduct general and exploratory de/anti-icing research;
- To conduct endurance time tests simulating vertical stabilizer anti-icing;
- To conduct endurance time tests in simulated snow pellet conditions;
- To conduct endurance time tests with a snow machine in an attempt to refine the current test protocol;
- To conduct endurance time tests in heavy snow conditions;
- To support Federal Aviation Administration and Transport Canada in the development of an advisory circular for the implementation of a holdover time determination system;
- To evaluate the use of sensors in determining active frost conditions;
- To initiate research for development of ice detection capabilities for departing aircraft at the runway threshold;
- To evaluate frost holdover times for use during cold-soaked wing frost conditions;
- To update the regression coefficient report with the newly-qualified de/anti-icing fluids;
- To conduct endurance time tests on surfaces treated with ice phobic products;
- To evaluate holdover times for anti-icing in a hangar;
- To conduct research at the National Research Council Canada wind tunnel to further develop and expand ice pellet allowance times; and
- To conduct various aerodynamic research activities at the National Research Council Canada wind tunnel.

The research activities of the program conducted on behalf of Transport Canada during the winter of 2009-10 are documented in eight reports. The titles of the reports are as follows:

- TP 15050E Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2009-10 Winter;
- TP 15051E Winter Weather Impact on Holdover Time Table Format (1995-2010);

• TP 15052E	Development of Type I Fluid Holdover Times for Use on Aircraft with Composite Surfaces;
• TP 15053E	Aircraft Ground Icing General Research Activities During the 2009-10 Winter;
• TP 15054E	Regression Coefficients and Equations Used to Develop the Winter 2010-11 Aircraft Ground Deicing Holdover Time Tables;
• TP 15055E	Emerging De/Anti-Icing Technology: Evaluation of Ice Phobic Products for Potential Use in Aircraft Operations;
• TP 15056E	Holdover Times Related to Aircraft Hangar Operations; and
• TP 15057E	Exploratory Wind Tunnel Aerodynamic Research Examination of Contaminated Anti-Icing Fluid Flow-Off Characteristics Winter 2009-10.

In addition, the following interim report is being prepared:

- *Wind Tunnel Research to Support the Development of Ice Pellet Allowance Time Tables, Winter 2009-10.*

This report, TP 15057E, has the following objective:

- To conduct various aerodynamic research activities at the National Research Council Canada wind tunnel.

This objective was met by conducting a series of full-scale tests using a supercritical wing section mounted in the National Research Council Canada open-circuit wind tunnel to examine the flow-off properties of anti-icing fluids contaminated with various forms of simulated freezing precipitation to investigate several recent industry operational concerns; this work was completed in conjunction with the ice pellet research being conducted at the National Research Council Canada Propulsion Icing Wind Tunnel.

PROGRAM ACKNOWLEDGEMENTS

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

APS Aviation Inc. would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data. This includes the following people: Stephanie Bendickson, Michael Chaput, John D'Avirro, Peter Dawson, Jesse Dybka, Benjamin Guthrie, Michael Hawdur, Eric Perocchio, Michelle Pineau, Marco Ruggi, David Smith, James Smyth, Robert ter Beek, Joey Tiano, David Youssef and Victoria Zoitakis.

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

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The author of this report would like to acknowledge and thank Angelo Boccanfuso (Transport Canada) and Warren Underwood (Federal Aviation Administration) whose individual specializations played a critical role in directing the experiments. The author would also like to acknowledge and thank the staff of the National Research Council Canada Open-Circuit Propulsion Icing Wind Tunnel for their diligence and commitment in providing support for the conduct of the experiments, as well as ABAX, Clariant, Dow, Kilfrost, and Octagon for their support in providing fluid samples required for this project, and Bombardier Aerospace for providing guidance in the design of the wing model.

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

16. Abstract

This objective was met by conducting a series of full-scale tests using the National Research Council Canada (NRC) open-circuit wind tunnel to examine the flow-off properties of anti-icing fluids contaminated with various forms of simulated freezing precipitation to investigate several recent industry operational concerns; this work was completed in conjunction with the ice pellet research being conducted at the NRC Propulsion Icing Wind Tunnel.

- Type III Ice Pellet Allowance Times: A viscosity issue was discovered with the Type III 1000 L fluid tote sample received for testing, therefore the data collected was dismissed and testing with the Type III fluid was stopped. A new quality control protocol was put into place by APS to prevent this occurrence during future tests.
- Effects of Wing Surface Roughness: The aerodynamic performance improved as the wing section became increasingly clean, however, the stall angle data demonstrated results that were counter-intuitive, whereby the wing seemed to stall at a higher angle when contaminated as compared to the clean wing.
- Effects of a Contaminated Flap: A contaminated flap section can have significant impacts on aerodynamic performance. The most severe lift losses were observed when the leading edge section and stagnation point of the flap was contaminated.
- Effect of Applying Excessive Amounts of Anti-Icing Fluid: The lift data for both comparative tests were comparable indicating no aerodynamic difference between a standard application, and an excessive application of anti-icing fluid.
- Low Speed Ramp Testing: The results indicated that the aerodynamic performance will significantly improve as the speed is increased.
- Light Freezing Rain Mixed with Moderate Snow Conditions: The Type I fluid results indicated that the added snow contamination (compared to light freezing rain alone) significantly affected the aerodynamic performance when the wing section was severely contaminated.
- Effects of Snow on an Un-Protected Wing: The results from this testing indicated that a takeoff with dry loose snow on the wings may be feasible at colder temperatures, however, it is not recommended at warmer temperatures where the risk of melting and refreezing is high.
- Degraded Anti-Icing Fluid Performance Following Contamination with Runway Deicing Fluid: The degradation effect of runway deicer fluid on anti-icing fluid protection time was more apparent following the Type IV application when higher concentrations of runway deicer fluid were used.
- Heavy Snow: The results obtained using Type III, Type IV EG, and Type IV PG fluid indicated that using half the moderate snow HOT for heavy snow conditions could be a viable approach for providing guidance in heavy snow conditions.
- Future Testing: In order to ensure fluid quality for large shipments (i.e. large 1000 L fluid totes) during future wind tunnel tests, it is recommended that fluid sampling for viscosity testing should be done before testing begins by extracting fluid from several layers in the tote, i.e. the bottom, the top, and the middle. Additional research should be conducted to continue the work related to Type III Ice Pellet Allowance Times, Effects of Surface Roughness, Low Speed Ramp Testing, Light Freezing Rain Mixed with Moderate Snow Conditions, Effects of Snow on an Un-Protected Wing, Degraded Anti-Icing Fluid Performance Following Contamination with Runway Deicing Fluid, and Heavy Snow.

17. Key Words

Ice Pellet, Allowance Time, High Speed Rotation, Low Speed Rotation, Fluid Adherence, Fluid Flow-Off, Wind Tunnel, Surface Roughness, Contaminated Flap, Excessive Anti-Icing Application, Light Freezing Rain Mixed With Moderate Snow, Snow on an Un-Protected Wing, Runway Deicing Fluid, Heavy Snow

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Plusieurs rapports de recherche sur des essais de technologies de dégivrage et d'antigivrage ont été produits au cours des hivers précédents pour le compte de Transports Canada. Ils sont disponibles auprès du Centre de développement des transports. Plusieurs rapports ont été rédigés dans le cadre du programme de recherche de cet hiver. Leur objet apparaît à l'avant-propos. Les travaux décrits dans ce rapport ont été en partie coparrainés par la Federal Aviation Administration.

16. Résumé

Cet objectif a été atteint en réalisant une série d'essais pleine grandeur dans la soufflerie à circuit ouvert du Conseil national de recherches Canada (CNRC) visant à examiner les propriétés de ruissellement de liquides d'antigivrage contaminés par diverses formes de précipitations givrantes simulées dans le but d'étudier de récentes préoccupations opérationnelles du secteur. Les travaux ont été réalisés en même temps que la recherche sur les granules de glace menée dans la soufflerie de givrage à propulsion du CNRC.

- Marges de tolérance pour les liquides de type III dans des conditions de granules de glace : un problème de viscosité a été constaté dans l'échantillon de 1 000 L de liquide de type III reçu pour les essais ; les données recueillies ont donc été rejetées et les essais sur le liquide de type III ont été interrompus. APS a mis en place un nouveau protocole de contrôle de la qualité afin de prévenir ce problème pour les prochains essais.
- Effets de la rugosité de la surface de l'aile : la performance aérodynamique s'améliorait à mesure que la section d'aile devenait plus propre ; toutefois, les données sur l'angle de décrochage ont généré des résultats allant à l'encontre du sens commun, selon lesquels l'aile contaminée semblait décrocher à un angle plus élevé que l'aile propre.
- Effets d'un volet contaminé : la contamination d'une section de volet peut avoir une incidence considérable sur la performance aérodynamique. Les pertes de portance les plus importantes ont été observées en présence de contamination sur le bord d'attaque et le point d'arrêt du volet.
- Effet de l'application de quantités excessives de liquide d'antigivrage : les données de portance issues des deux essais comparatifs étaient comparables et n'indiquaient aucune différence sur le plan aérodynamique entre une application standard et une application excessive de liquide d'antigivrage.
- Essais avec accélération à basse vitesse : les résultats ont indiqué que la performance aérodynamique s'améliore grandement à mesure que la vitesse augmente.
- Conditions mixtes de pluie verglaçante légère et de neige modérée : les résultats obtenus avec le liquide de type I indiquaient que la présence d'une contamination par la neige (comparativement aux conditions de pluie verglaçante légère seulement) avait une grande incidence sur la performance aérodynamique lorsque la section d'aile était fortement contaminée.
- Effets de la neige sur une aile non protégée : les résultats de ces essais ont démontré qu'un aéronef dont les ailes sont recouvertes de neige folle sèche peut décoller à basse température ; le décollage n'est toutefois pas recommandé à des températures plus chaudes, où le risque de fonte et de regel est élevé.
- Performance du liquide d'antigivrage dégradé à la suite d'une contamination par du liquide de dégivrage de piste : l'effet de dégradation du liquide de dégivrage de piste sur la durée de protection du liquide d'antigivrage était plus évident après l'application de liquide de type IV lorsque des concentrations plus élevées de liquide de dégivrage de piste étaient utilisées.
- Neige lourde : selon les résultats obtenus avec les liquides de type III, les liquides à base d'éthylène glycol de type IV et les liquides à base de propylène glycol de type IV, il serait possible de diviser par deux la durée d'efficacité dans des conditions de neige modérée pour orienter l'approche dans des conditions de neige lourde.
- Essais futurs : afin d'assurer la qualité des liquides dans les envois d'envergure (comme les réservoirs de 1 000 L) pour les futurs essais en soufflerie, il est recommandé de mesurer la viscosité du liquide avant le début des essais en prélevant des échantillons dans différentes couches du réservoir, c'est-à-dire dans la partie du bas, dans la partie du haut et au milieu. D'autres recherches devraient être effectuées afin de poursuivre les travaux sur les marges de tolérance pour les liquides de type III dans des conditions de granules de glace, les effets de la rugosité de surface, les essais avec accélération à basse vitesse, les conditions mixtes de pluie verglaçante légère et de neige modérée, les effets de la neige sur une aile non protégée, la performance du liquide d'antigivrage dégradé à la suite d'une contamination par du liquide de dégivrage de piste et la neige lourde.

17. Mots clés

Granule de glace, marge de tolérance, rotation à haute vitesse, rotation à basse vitesse, adhérence de liquide, écoulement de liquide, soufflerie, rugosité de surface, volet contaminé, application de quantités excessives de liquide d'antigivrage, conditions mixtes de pluie verglaçante légère et de neige modérée, neige sur une aile non protégée, liquide de dégivrage de piste, neige lourde

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EXECUTIVE SUMMARY

Background

Under contract to the Transportation Development Centre (TDC), with financial support from the Federal Aviation Administration (FAA), APS Aviation Inc. (APS) has undertaken research activities to further advance aircraft ground de/anti-icing technology. APS conducted a series of full-scale tests in the National Research Council Canada (NRC) 3 m x 6 m Open-Circuit Propulsion Icing Wind Tunnel (PIWT) to determine the flow-off characteristics of anti-icing fluid with and without simulated frozen precipitation contamination

As a result of the large fixed costs associated with the aerodynamic research, and to benefit from economies of scale, Transport Canada (TC) and the FAA opted to conduct a series of preliminary tests to investigate several recent industry operational concerns; this work was completed in conjunction with the ice pellet research being conducted at the NRC PIWT, details of which are described in an interim report, which was provided to TC and the FAA. A final report is expected to be published once the research is completed in a future winter.

Objectives

A preliminary test plan was developed for the winter of 2009-10. Testing was conducted with and without contamination. Research was conducted to satisfy the following objectives:

- Development of Ice Pellet Allowance Times for Use with Type III Fluid;
- Examination of the aerodynamic effects of surface roughness on aerodynamic performance;
- Examination of the aerodynamic effects of a contaminated flap on aerodynamic performance;
- Examination of the aerodynamic effects following application of excessive amounts of Type IV fluid;
- Expansion of current low speed ramp aerodynamic acceptance test parameters (67 knot rotation versus 80 knots versus 100 knots);
- Inclusion of mixed light rain or light freezing rain and snow conditions into the holdover time (HOT) guidelines;
- Examination of the aerodynamic effects of snow on an unprotected wing;

- Examination of the aerodynamic effects of anti-icing fluid contaminated with runway deicer fluid; and
- Examination of the aerodynamic effects of heavily contaminated anti-icing fluid subjected to artificial snow conditions.

An additional test was conducted to evaluate the use of ice phobic products for potential use in aircraft operations, however the details of this test have been included in a separate TC report, TP 15055E*, Emerging De/Anti-Icing Technology: Evaluation of Ice Phobic Products for Potential Use in Aircraft Operations* (1).

The wing section used for testing was a generic high-performance commuter airfoil, referred to as "supercritical." This wing section was constructed by the NRC specifically for the conduct of these tests following extensive consultations with an airframe manufacturer to ensure a representative supercritical design.

Conclusions

Type III Ice Pellet Allowance Times

Early on in the testing period, a viscosity issue was discovered with the Type III 1000 L fluid tote sample received for testing. Replacement fluid could not be obtained in time therefore the data collected was dismissed and testing with the Type III fluid was stopped. As a result, a new quality control protocol was put into place by APS concerning fluid received in large totes in order to prevent this occurrence during future tests.

Effects of Wing Surface Roughness

The lift loss data collected indicated that the aerodynamic performance improved as the wing section became increasingly clean, however, the stall angle data demonstrated results that were counter-intuitive, whereby the wing seemed to stall at a higher angle when contaminated as compared to the clean wing. This observation is of particular importance if future testing is to explore stall margin rather than lift loss.

Effects of a Contaminated Flap

The results of this testing indicated that a contaminated flap section can have significant impacts on aerodynamic performance; results indicated up to a 28 percent lift loss as compared to the dry wing with a heavily contaminated flap. The most severe lift losses were observed when the leading edge and the stagnation point of the flap was contaminated.

Effect of Applying Excessive Amounts of Anti-Icing Fluid

The fluid thickness results indicated slightly greater fluid thickness on the trailing edge following an excessive anti-icing fluid application, however differences in residual fluid at the end of the test were minimal. The lift data for both comparative tests were comparable indicating no aerodynamic difference between a standard application and an excessive application of anti-icing fluid.

Low Speed Ramp Testing

Visually, more fluid was observed to shear off the wing prior to the time of rotation during the 100 knots rotation speed as compared to the 65, and 80 knots rotation speed tests; this was also confirmed by the fluid thickness measurements taken following the end of each test run. The results indicated that the aerodynamic performance will significantly improve as the speed is increased.

Light Freezing Rain Mixed with Moderate Snow Conditions

The Type I fluid results indicated that the added snow contamination (compared to light freezing rain alone) significantly affected the aerodynamic performance when the wing section was severely contaminated; lift losses increased from 2.7 percent to 15.8 percent with the presence of snow as compared to light freezing rain alone. Additional testing is required to support these results due to procedural limitations.

Effects of Snow on an Unprotected Wing

The results from this testing indicated that a takeoff with dry loose snow on the wings may be feasible at colder temperatures, however, it is not recommended at warmer temperatures where the risk of melting and refreezing is high. It may be difficult to identify adhered contamination on a snow-covered wing (due to hot spots, high moisture, or residual fluid), therefore, de/anti-icing may still be recommended as the best practice in order to ensure safe operations.

Degraded Anti-Icing Fluid Performance Following Contamination with Runway Deicing Fluid

The results of this testing indicated that the effect of runway deicer fluid was visually more apparent following the Type IV application when higher concentrations of runway deicer fluid were used. All three tests demonstrated significant differences between the protection time of fluid contaminated with runway deicer fluid and the baseline fluid; adhered contamination was not removed during the takeoff run.

Heavy Snow

The results obtained using the three different types of fluid (Type III, Type IV EG, and Type IV PG) indicated that using half the moderate snow HOT for heavy snow conditions could be a viable approach for providing guidance in heavy snow conditions. In all cases, the visual and aerodynamic performance was comparable for the moderate snow test, and the heavy snow test with half the exposure time.

Recommendations

Fluid Quality Assurance

When fluid is shipped in large 1000 L totes, fluid sampling for viscosity testing should be done before testing begins by extracting fluid from several layers in the tote, i.e. the bottom, the top, and the middle.

Type III Ice Pellet Allowance Times

It is recommended that testing continue during the winter of 2010-11 with a fluid sample that has been verified to be within the acceptable specification for Type III fluids.

Effects of Surface Roughness

Additional testing should be conducted with the supercritical wing with different types of contamination to further investigate the correlation between lift loss and stall angle.

Low Speed Ramp Testing

Additional testing is recommended to investigate the effect of contamination during low speed ramp test profiles.

Light Freezing Rain Mixed with Moderate Snow Conditions

It is recommended that additional testing be conducted with thickened Type II/III/IV, fluids less prone to adhesion, in order to substantiate the preliminary results obtained with Type I fluid.

Effects of Snow on an Unprotected Wing

Additional testing should be conducted to identify a threshold temperature at which departures with snow on an unprotected wing can be considered acceptable.

Degraded Anti-Icing Fluid Performance Following Contamination with Runway Deicing Fluid

It is recommended that operational data be collected in order to determine a representative amount of runway deicer fluid that could potentially be blown up onto a wing upon landing on a wet runway and during taxi to the runway. Further testing could be done on flat plates (as a less costly alternative) in order to determine the impact on fluid HOTs.

Heavy Snow

Additional testing using the comparative methodology (heavy snow versus moderate snow) should be conducted with different fluids and at different temperatures in order to generate a thorough data set to support this recommendation. Testing with propylene glycol fluids is of particular importance as results have indicated that these fluids are more prone to lift losses at colder temperatures. Consideration should be given to conducting some flat plate testing in the artificial snow machine in order to reduce associated testing costs.

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SOMMAIRE

Contexte

Dans le cadre d'un contrat avec le Centre de développement des transports (CDT) et avec l'appui financier de la Federal Aviation Administration (FAA), APS Aviation Inc. (APS) a entrepris des activités de recherche visant à faire progresser les technologies associées au dégivrage et à l'antigivrage d'aéronefs au sol. APS a mené une série d'essais pleine grandeur dans la soufflerie de givrage à propulsion et à circuit ouvert de 3 m sur 6 m du Conseil national de recherches Canada (CNRC) afin de déterminer les caractéristiques de ruissellement du liquide d'antigivrage avec et sans contamination par des précipitations gelées simulées.

En raison des importants coûts fixes associés à la recherche aérodynamique et pour profiter des économies d'échelle, Transports Canada (TC) et la FAA ont décidé de mener une série d'essais préliminaires afin d'étudier plusieurs préoccupations opérationnelles récentes du secteur. Ces travaux ont été réalisés en même temps que la recherche sur les granules de glace menée dans la soufflerie de givrage à propulsion du CNRC, dont les détails figurent dans un rapport provisoire, lequel a été transmis à TC et à la FAA. Une version définitive devrait être publiée une fois la recherche terminée, dans un hiver à venir.

Objectifs

Un plan d'essais préliminaires a été élaboré pour l'hiver 2009-2010. Les essais ont été effectués avec et sans contamination. Des recherches ont été menées pour répondre aux objectifs suivants :

- Développement des marges de tolérance dans des conditions de granules de glace à utiliser avec les liquides de type III ;
- Examen des effets aérodynamiques de la rugosité des surfaces sur la performance aérodynamique ;
- Examen des effets aérodynamiques de la contamination d'un volet sur la performance aérodynamique ;
- Examen des effets aérodynamiques de l'application de quantités excessives de liquide de type IV ;
- Élargissement des paramètres actuels des essais d'acceptabilité aérodynamique à basse vitesse (rotation de 67 nœuds par rapport à 80 nœuds par rapport à 100 nœuds) ;
- Ajout des conditions mixtes de pluie légère ou de pluie verglaçante légère et de neige aux lignes directrices sur les durées d'efficacité ;

- Examen des effets aérodynamiques de la neige sur une aile non protégée ;
- Examen des effets aérodynamiques d'un liquide d'antigivrage contaminé par du liquide de dégivrage de piste ; et
- Examen des effets aérodynamiques d'un liquide d'antigivrage fortement contaminé dans des conditions de neige simulées.

Un essai supplémentaire a été réalisé dans le but d'évaluer l'utilisation potentielle de produits glaciophobes dans l'exploitation d'aéronefs. Les détails de cet essai ont été inclus dans un rapport distinct de TC, TP 15055E, *Emerging De/Anti-Icing Technology: Evaluation of Ice Phobic Products for Potential Use in Aircraft Operations* (1).

La section d'aile utilisée pour les essais consistait en un profil générique haute performance d'un avion de transport régional, qualifié de « supercritique ». Le CNRC a construit cette section d'aile précisément pour les essais après avoir mené de vastes consultations auprès d'un avionneur de façon à assurer une conception supercritique représentative.

Conclusions

Marges de tolérance pour les liquides de type III dans des conditions de granules de glace

Dès le début de la période d'essai, un problème de viscosité a été constaté dans l'échantillon de 1 000 L de liquide de type III reçu. Étant donné l'impossibilité d'obtenir du liquide de rechange à temps, les données recueillies ont été rejetées et les essais sur le liquide de type III ont été interrompus. APS a par la suite mis en place un nouveau protocole de contrôle de la qualité des liquides reçus dans de grands réservoirs afin de prévenir ce problème pour les prochains essais.

Effets de la rugosité de la surface de l'aile

Les données recueillies sur la perte de portance ont indiqué que la performance aérodynamique s'améliorait à mesure que la section d'aile devenait plus propre ; toutefois, les données sur l'angle de décrochage ont généré des résultats allant à l'encontre du sens commun, selon lesquels l'aile contaminée semblait décrocher à un angle plus élevé que l'aile propre. Cette observation revêt une importance particulière si de futurs essais devaient explorer les marges de décrochage plutôt que la perte de portance.

Effets d'un volet contaminé

Les résultats de ces essais ont indiqué que la contamination d'une section de volet peut avoir une incidence importante sur la performance aérodynamique. En effet, les résultats ont démontré une perte de portance allant jusqu'à 28 pour cent pour le volet fortement contaminé par rapport à l'aile sèche. Les pertes de portance les plus importantes ont été observées en présence de contamination sur le bord d'attaque et le point d'arrêt du volet.

Effet de l'application de quantités excessives de liquide d'antigivrage

Les résultats relatifs à l'épaisseur du liquide ont indiqué une épaisseur légèrement supérieure sur le bord de fuite à la suite d'une application excessive de liquide d'antigivrage ; les différences sur le plan du liquide résiduel à la fin de l'essai étaient toutefois minimes. Les données de portance issues des deux essais comparatifs étaient comparables et n'indiquaient aucune différence sur le plan aérodynamique entre une application standard et une application excessive de liquide d'antigivrage.

Essais avec accélération à basse vitesse

Visuellement, une quantité plus importante de liquide a été cisaillée sur l'aile avant la rotation durant l'essai à une vitesse de rotation de 100 nœuds, comparativement aux essais menés à des vitesses de rotation de 65 et de 80 nœuds. Cette observation a également été confirmée par la mesure de l'épaisseur du liquide prise à la fin de chaque essai. Les résultats ont indiqué que la performance aérodynamique s'améliore grandement à mesure que la vitesse augmente.

Conditions mixtes de pluie verglaçante légère et de neige modérée

Les résultats obtenus avec le liquide de type I indiquaient que la présence d'une contamination par la neige (comparativement aux conditions de pluie verglaçante légère seulement) avait une grande incidence sur la performance aérodynamique lorsque la section d'aile était fortement contaminée. Les pertes de portance ont augmenté en présence de neige par rapport aux conditions de pluie verglaçante légère seulement, passant de 2,7 pour cent à 15,8 pour cent. Des essais supplémentaires sont requis pour étayer ces résultats en raison des restrictions en matière de procédure.

Effets de la neige sur une aile non protégée

Les résultats de ces essais ont démontré qu'un aéronef dont les ailes sont recouvertes de neige folle sèche peut décoller à basse température ; le décollage n'est toutefois pas recommandé à des températures plus chaudes, où le risque de fonte et de regel est élevé. Il pourrait être difficile de détecter l'adhérence de contaminants sur une aile couverte de neige (en raison de points chauds, d'une forte humidité ou de liquide résiduel). Par conséquent, il se peut que le dégivrage et l'antigivrage soient toujours recommandés comme pratiques exemplaires afin d'assurer des manœuvres sécuritaires.

Performance du liquide d'antigivrage dégradé à la suite d'une contamination par du liquide de dégivrage de piste

Les résultats de ces essais ont indiqué que l'effet du liquide de dégivrage de piste était visuellement plus évident après l'application de liquide de type IV lorsque des concentrations plus élevées de liquide de dégivrage de piste étaient utilisées. Les trois essais ont fait état de différences considérables entre la durée de protection du liquide contaminé par du liquide de dégivrage de piste et celle du liquide de référence. La contamination ayant adhéré aux surfaces n'a pas été éliminée durant la course de décollage.

Neige lourde

Selon les résultats obtenus avec les trois types de liquides différents (type III, type IV EG et type IV PG), il serait possible de diviser par deux la durée d'efficacité dans des conditions de neige modérée pour orienter l'approche dans des conditions de neige lourde. Dans tous les cas, la performance visuelle et aérodynamique était comparable durant l'essai avec neige modérée et celui avec neige lourde à une durée d'exposition deux fois moins grande.

Recommandations

Assurance de la qualité des liquides

Lorsque du liquide est expédié dans de grands réservoirs de 1 000 L, sa viscosité devrait être mesurée avant le début des essais en prélevant des échantillons dans différentes couches du réservoir, c'est-à-dire dans la partie du bas, dans la partie du haut et au milieu.

Marges de tolérance pour les liquides de type III dans des conditions de granules de glace

Les essais devraient être poursuivis à l'hiver 2010-2011 avec un échantillon de liquide concordant avec les spécifications acceptables pour les liquides de type III.

Effets de la rugosité de la surface de l’aile

Des essais supplémentaires devraient être réalisés sur l’aile supercritique avec différents types de contamination afin d’examiner davantage la corrélation entre la diminution de portance et l’angle de décrochage.

Essai d’accélération à basse vitesse

Il est recommandé d’effectuer d’autres essais afin d’étudier l’effet de la contamination durant les profils d’accélération à basse vitesse.

Conditions mixtes de pluie verglaçante légère et de neige modérée

Des essais supplémentaires devraient être réalisés avec des liquides de type II, III et IV épaissis, qui sont moins susceptibles d’adhérer aux surfaces, afin d’étayer les résultats préliminaires obtenus avec le liquide de type I.

Effets de la neige sur une aile non protégée

Des essais supplémentaires devraient être réalisés afin de déterminer une température seuil à laquelle le décollage d’aéronefs dont les ailes non protégées sont recouvertes de neige est jugé acceptable.

Performance du liquide d’antigivrage dégradé à la suite d’une contamination par du liquide de dégivrage de piste

Des données opérationnelles devraient être recueillies afin de déterminer la quantité représentative de liquide de dégivrage de piste qui pourrait être projeté sur une aile lors d’un atterrissage sur une piste mouillée et durant la circulation au sol vers la piste. D’autres essais pourraient être réalisés sur des plaques planes (une solution moins coûteuse) afin de déterminer l’incidence sur la durée d’efficacité des liquides.

Neige lourde

Des essais comparant les conditions de neige lourde et de neige modérée devraient être réalisés avec différents liquides et à différentes températures afin de générer un ensemble de données exhaustif visant à étayer cette recommandation. Il est tout particulièrement important de tester les liquides à base de propylène glycol, puisque les résultats ont indiqué que ceux-ci sont plus susceptibles d’entraîner une perte de portance à basse température. Des essais sur des plaques planes dans des machines de neige simulée devraient être envisagés afin de réduire les coûts associés.

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GLOSSARY

APS	APS Aviation Inc.
CFD	Computational Fluid Dynamics
EASA	European Union Aviation Safety Agency
FAA	Federal Aviation Administration
HOT	Holdover Time
IATA	International Air Transport Association
MSC	Meteorological Service of Canada
NASA	National Aeronautics and Space Administration
NRC	National Research Council Canada
OAT	Outside Air Temperature
PIWT	3 m x 6 m Open-Circuit Propulsion Icing Wind Tunnel
RTD	Resistance Temperature Detector
SAE	SAE International
TC	Transport Canada
TDC	Transportation Development Centre

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1. INTRODUCTION

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

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

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

1.1 Background

Due to the recent industry requirement for guidance material for aircraft operations in mixed precipitation conditions with ice pellets, APS conducted a series of plate tests and full-scale tests in the NRC 3 m x 6 m Open-Circuit Propulsion Icing Wind Tunnel (PIWT) and with a Falcon 20 aircraft. This ongoing research was conducted during the winters of 2005-06 to 2009-10 to determine the flow-off characteristics of anti-icing fluid contaminated with mixed conditions including ice pellets and to substantiate and possibly expand the newly developed ice pellet allowance times.

As a result of the large fixed costs associated with the aerodynamic research, and to benefit from economies of scale, TC and the FAA opted to conduct a series of preliminary tests to investigate several recent industry operational concerns; this work was completed in conjunction with the ice pellet research being conducted at the NRC PIWT.

1.2 Program Objectives

APS conducted a series of preliminary tests during the winter of 2009-10 to investigate several recent industry concerns. Aerodynamic research focused on the fluid flow-off properties of contaminated and uncontaminated fluid simulating different operational scenarios. Aerodynamic testing was conducted in conjunction with the ice pellet allowance time research program.

A preliminary test plan was developed for the winter of 2009-10. Testing was conducted with and without contamination. Research was conducted to satisfy the following objectives:

- Development of Ice Pellet Allowance Times for Use with Type III Fluid;
- Examination of the aerodynamic effects of surface roughness on aerodynamic performance;
- Examination of the aerodynamic effects of a contaminated flap on aerodynamic performance;
- Examination of the aerodynamic effects following application of excessive amounts of Type IV fluid;
- Expansion of current low-speed ramp aerodynamic acceptance test parameters (67 knot rotation versus 80 knots versus 100 knots);
- Inclusion of mixed light rain or light freezing rain and snow conditions into the holdover time (HOT) guidelines;
- Examination of the aerodynamic effects of snow on an unprotected wing;
- Examination of the aerodynamic effects of anti-icing fluid contaminated with runway deicer fluid; and
- Examination of the aerodynamic effects of heavily contaminated anti-icing fluid subjected to artificial snow conditions.

The results from this work are reported in Sections 4 to 12 of this report. An additional test was conducted to evaluate the use of ice phobic products for potential use in aircraft operations; however, the details of this test have been included in TC report, TP 15055E*, Emerging De/Anti-Icing Technology: Evaluation of Ice Phobic Products for Potential Use in Aircraft Operations* (1). The work statement for these tests is provided in Appendix A.

1.3 Overview of 2009-10 Testing

Full-scale testing during the winter of 2009-10 was conducted using the NRC PIWT. The primary testing conducted aimed at validating the current allowance times for use with newer generation aircraft with supercritical wing designs.

In addition, some preliminary work was conducted as a lower priority to address current industry concerns. These secondary research objectives have been outlined in Subsection 1.2, and the details of this work are described in this report. Table 1.1 demonstrates the groupings for the global set of tests conducted at the wind tunnel during the winter of 2009-10. Tests listed in groups #4 and #5 are described in this report (some baseline tests from groups #2 and #3 are also referenced). Table 1.2 demonstrates in greater detail the groupings for the secondary R&D objective tests.

Table 1.1: Summary of 2009-10 Wind Tunnel Tests by Objective

1. Ice Pellet Allowance Times (Total Runs: 51) 0, 5, 9, 10, 11, 10A, 10B, 13, 14, 15, 16, 20, 21, 22, 23, 24, 26, 26A, 28, 28A, 44, 47, 48, 49, 56, 56A, 57, 57A, 58, 59, 63, 65, 66, 67, 68, 69, 71, 72, 73, 74, 77, 78, 79, 80, 81, 82, 94, 95, 96, 97, 98	**4. Type III Allowance Times (Total Runs: 7)** 31, 33, 35, 36, 41, 42, 43
2. Dry (Total Runs: 3) 2, 3, 46	**5. Research & Development (Total Runs: 33)** 6, 6A, 6B, 6C, 7, 37, 38, 39, 40, 45, 45A, 45B, 50, 51, 52, 52A, 61, 62, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 99, 102, 103, 104
3. Fluid Only (Total Runs: 24) 1, 4, 8, 12, 17, 18, 18A, 19, 25, 27, 29, 30, 32, 34, 53, 54, 55, 60, 64, 70, 75, 76, 100, 101	**Total Number of Runs: 118**

Table 1.2: Summary of 2009-10 Secondary R&D Objectives

Research & Development Objectives	Run #
Type III Allowance Times	31, 33, 35, 36, 41, 42, 43
Effect Double Fluid Quantity	7
Heavy Snow	37, 38, 39, 40, 83, 84, 85, 86, 87,88, 90, 91, 92
Surface Roughness	45, 45A, 45B
Dry Snow with No Fluid	51, 52, 52A, 89
Anti-Icing Fluid Contaminated with Runway Deicer	50, 93, 104
65 vs. 80 Knots Rotation	61, 62
Flap Contamination Examination	6, 6A, 6B, 6C
Evaluation of Ice Phobic Products	99
Mixed Light Freezing Rain and Snow	102, 103
TOTAL R&D RUNS: 40	

1.4 Report Format

The following list provides short descriptions of subsequent sections of this report:

a) Section 2 describes the methodology used in testing, as well as equipment and personnel requirements necessary to carry out testing;

b) Section 3 describes data collected during the full-scale testing conducted;

c) Section 4 describes the data, results, and observations for the ice pellet allowance time testing using Type III fluid;

d) Section 5 describes the data, results, and observations regarding the effects of surface roughness on aerodynamic performance;

e) Section 6 describes the data, results, and observations regarding the effects of a contaminated flap on aerodynamic performance;

f) Section 7 describes the data, results, and observations regarding the aerodynamic effects following application of excessive amounts of Type IV fluid;

g) Section 8 describes the data, results, and observations regarding low-speed ramp testing (67 knot rotation versus 80 knots versus 100 knots);

h) Section 9 describes the data, results, and observations regarding mixed light rain or light freezing rain and snow conditions testing;

i) Section 10 describes the data, results, and observations regarding the aerodynamic effects of snow on an unprotected wing;

j) Section 11 describes the data, results, and observations regarding the aerodynamic effects of anti-icing fluid contaminated with runway deicer fluid;

k) Section 12 describes the data, results, and observations regarding the heavy snow testing;

l) Section 13 presents a summary of the conclusions and observations; and

m) Section 14 lists the recommendations for future testing.

It should be noted that an additional test was conducted as part of this project to evaluate the use of ice phobic products for potential use in aircraft operations; however, the details of this test have been included in TP 15055E (1).

2. METHODOLOGY

This section describes the test methodology and equipment specific to the full-scale aerodynamic tests conducted at the NRC PIWT, as well as general testing methodology and equipment.

2.1 Wind Tunnel Test Site

The 2009-10 PIWT tests were performed at the NRC Aerospace Facilities, Building M-46, at the NRC Montreal Road campus, located in Ottawa, Canada. Figure 2.1 provides a schematic of the NRC Montreal Road campus showing the location of the NRC PIWT. Photo 2.1 shows an outside view of the wind tunnel test facility. Photo 2.2 shows an inside view of the wind tunnel test section. The open-circuit layout, with a fan at entry, permits contaminants associated with the test articles (such as heat or de/anti-icing fluid) to discharge directly, without recirculating 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 operations 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.

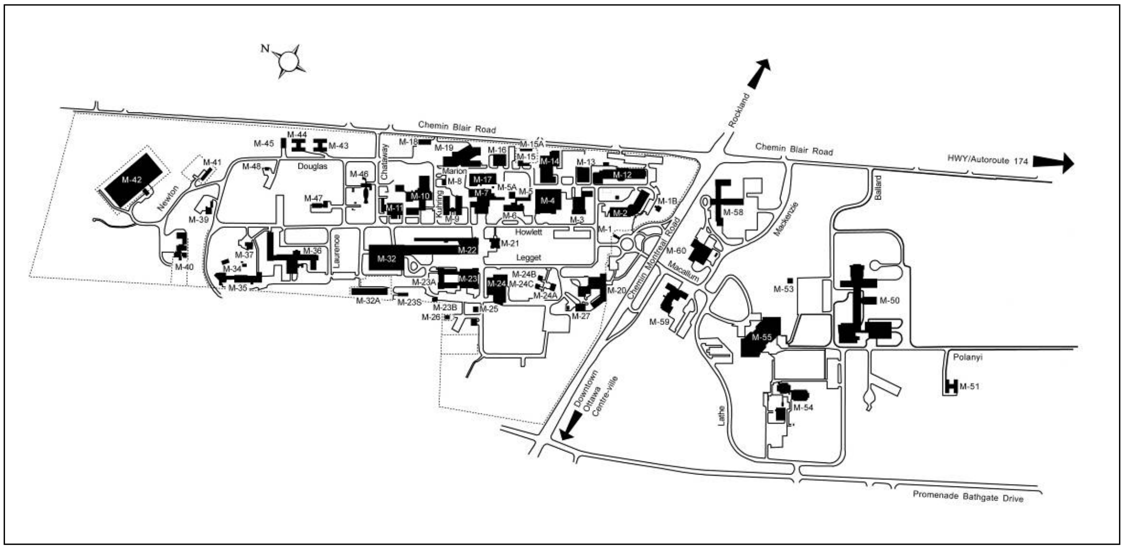


Figure 2.1: Schematic of NRC Montreal Road Campus

2.2 Test Schedule

Testing was conducted over a period of five weeks starting January 5, 2010 and ending February 3, 2010. Two days were dedicated to setup and calibration prior to the start of the actual testing. Testing was conducted during 20 days over the five-week period; testing days were selected based on weather. Table 2.1 presents the calendar of wind tunnel tests performed in 2009-10. It should be noted that the tests listed comprise all the tests conducted, including the tests not pertaining to the ice pellet allowance time objectives. At the beginning of each test day, a plan was developed that included the list of tests (taken from the global test plan) to be completed based on the weather conditions and testing priorities. This daily plan was discussed, approved, and modified (if necessary) by TC, the FAA, and APS.

Table 2.1: Calendar of Tests

Date	Number of Test Runs	Test Numbers
5-Jan-10	Setup	n/a
6-Jan-10	Precip. Calib.	n/a
7-Jan-10	3	0, 1, 2
11-Jan-10	5	3, 4, 5, 6, 6A
12-Jan-10	4	6B, 6C, 7, 8
13-Jan-10	6	9, 10, 10A, 10B, 11, 12
14-Jan-10	8	13, 14, 15, 16, 17, 18, 18A, 19
20-Jan-10	4	20, 21, 22, 23
21-Jan-10	9	24, 25, 26, 26A, 27, 28, 28A, 29, 30
22-Jan-10	9	31, 32, 33, 34, 35, 36, 37, 38, 39
23-Jan-10	9	40, 41, 42, 43, 44, 45, 45A, 45B, 46
24-Jan-10	4	47, 48, 49, 50
27-Jan-10	10	51, 52, 52A, 53, 54, 55, 56, 56A, 57, 57A
28-Jan-10	7	58, 59, 60, 61, 62, 63, 64
29-Jan-10	10	65, 66, 67, 68, 69, 70, 71, 72, 73, 74
30-Jan-10	8	75, 76, 77, 78, 79, 80. 81, 82
31-Jan-10	2	83, 84
1-Feb-10	8	85, 86, 87, 88, 89, 90, 91, 92
2-Feb-10	6	93, 94, 95, 96, 97, 98
3-Feb-10	6	99, 100, 101, 102, 103, 104

2.3 Wind Tunnel Procedure

To satisfy the program objective, simulated takeoff and climb-out tests were performed with the supercritical wing section, and different parameters, including fluid thickness, wing temperature, and fluid freezing point, were recorded at designated times during the tests. The supercritical wing section was constructed by the NRC specifically to conduct these tests following extensive consultations with an airframe manufacturer to ensure a representative supercritical design was used.

The typical procedure for each test is outlined below.

a) The wing section was treated with anti-icing fluid, poured in a one-step operation (no Type I fluid was used during the tests).

b) Contamination, in the form of simulated ice pellets, freezing rain, and snow, was applied to the wing section. Test parameters were measured at the beginning and end of the exposure to contamination.

c) At the end of the contamination period, the tunnel was cleared of all equipment and scaffolding.

The wind tunnel was subsequently operated through a simulated takeoff and climb-out test. The behaviour of the fluid during takeoff and climb-out was recorded with digital high-speed still cameras. In addition, windows overlooking the wing section allowed observers to document the fluid elimination performance in real-time.

The procedure for the wind tunnel tests is included in Appendix B. The procedure includes details regarding the test objectives, test plan, procedure and methodology, and pertinent information and documentation.

2.4 Analysis Methodology

A standardized approach to analysing each of the tests included in this report was not possible due to the different test methodologies and objectives. The basic parameters typically analysed have been included in this section. Additional details regarding the analysis methodology used can also be found in Sections 4 and 5 of the TC report, TP 15232E, *Wind Tunnel Trials to Examine Anti-Icing Fluid Flow-Off Characteristics and to Support the Development of Ice Pellet Allowance Times, Winters 2009-10 to 2012-13* (Vol. 2) (2).

2.4.1 Visual Contamination Ratings

The wind tunnel was equipped with observation windows overlooking the wing section. During each of the tests conducted, visual contamination ratings were determined by three observers: one observer from the FAA and two observers from APS. The level of contamination present on the leading edge and trailing edge of the wing, as well as on the flap, was quantified using a scale of one-to-five, with five being the worst-case scenario; partial numbers were sometimes assigned when cases were also marginally above or below a specific rating. These observations were taken three times during each test: at the start of the test (just prior to the wind tunnel ramp-up), at the time of rotation, and at the end of the test. The values assigned by the three observers were then averaged and used for comparative analysis. See below a description of the rating system used.

Visual Contamination Ratings (1 to 5):

1) Contamination not very visible, fluid still clean;
2) Contamination visible, but lots of fluid still present;
3) Contamination visible, spots of bridging contamination;
4) Contamination visible, lots of dry bridging present; and
5) Contamination visible, adherence of contamination.

It should be noted that the visual contamination ratings were subjective due to the various conditions tested; it was not feasible to develop rating descriptions that were applicable to all conditions. The descriptions were primarily used as an aid for determining the numerical visual contamination rating. Having the same three observers for all the tests provided a level of consistency in the rating system that allowed for a more accurate comparison system.

The visual contamination ratings were evaluated based on pre-determined criteria; less than or equal to three on the leading and trailing edge, less than or equal to four on the flap at the start of the test, and equal to one on the leading edge at the time of rotation were considered acceptable. Ratings higher than these indicated potential fluid contamination or fluid flow-off issues; these results were supported by the lift coefficient data collected.

2.4.2 Lift Coefficient Data

The NRC collected various parameters during each of the wind tunnel test runs. The data was collected at a rate of 250 samples per second. Parameters such as lift force, normal force, drag force, wind speed, and pitch angle were collected and used to calculate the lift, normal, and drag coefficients. For the purpose of the tests conducted, the lift coefficient was primarily used as the evaluation criteria when analysing the fluid flow-off performance during the tests. Typically, the lift coefficient varied from 0.6 to 1.7 depending on the wing angle of attack, which ranged from -2° to 8°. The calculated lift coefficient at the 6° and 8°rotation angles was typically evaluated against the dry wing average data. Lift losses below five percent compared to the dry wing were considered acceptable, and lift losses from five percent to eight percent were considered marginal; additional work is being done to correlate these lift losses to the aerodynamic fluid certification results. The lift coefficient data collected as part of the "ice pellet allowance time" research has been included in Appendix C.

The lift coefficient is a non-dimensional measure of the lifting efficiency of an airfoil and is not a function of air speed. As a result, the lift generated during a dry wing scenario for a low-speed and high-speed test run should generate similar lift coefficient profiles. During the fluid tests, variations in air speed could potentially cause variations in the lift data collected; fluid shearing is a function of the air speed, and this would be demonstrated in the data. Therefore, when comparing lift coefficient data under similar conditions, differences as a result of air speed variations would only be apparent during the fluid cases and not the dry wing cases.

2.4.3 Sequence of When Test Parameters Were Recorded

Figure 2.2 demonstrates the lift coefficient data collected during an example test run. The x-axis shows the time in seconds as of the start of the test; rotation begins at approximately 28 seconds, the wing rotates to a maximum angle of 8°in approximately 3.7 seconds, and then it is rotated back to 4 degrees over a period of approximately 16 seconds. The y-axis indicates the calculated lift coefficient. The visual observations of the condition of the wing were recorded at the start of the test (time = 0), just before the start of rotation (time = 28 sec.), at the end of the rotation (time = 32 sec.), and at the end of the test (time = 60 sec.). The lift coefficient data used to calculate lift losses compared to the baseline test (typically the dry wing case) was measured at the 8° angle of rotation.

2.5 Test Sequence

The length of each test (from start of setup to end of last measurement) varied largely due to the length of exposure to precipitation (if applicable). Time required for setup and teardown as well as preparing and configuring the aircraft stayed relatively the same from test to test. Figure 2.3 demonstrates a sample timeline for a typical wind tunnel test. It should be noted that a precipitation exposure time of 30 minutes was used for demonstration purposes; this time varied for each test depending on the objective.

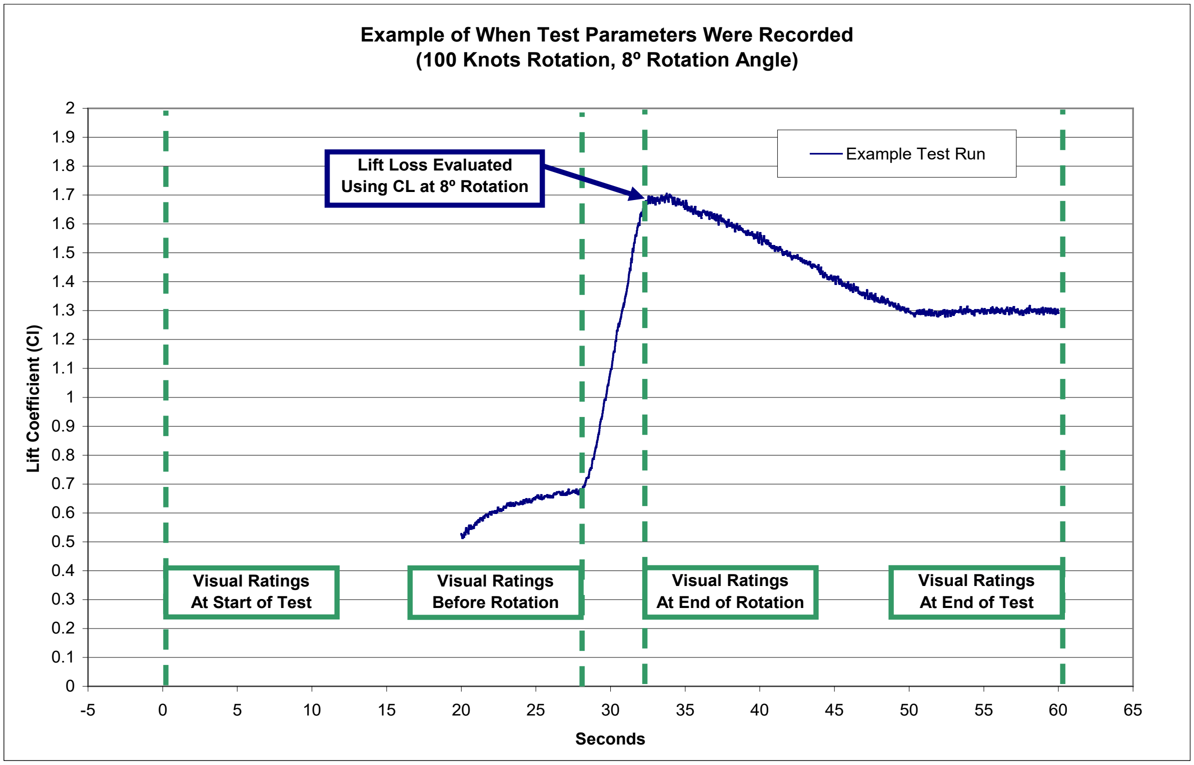


Figure 2.2: Example of When Test Parameters Were Recorded

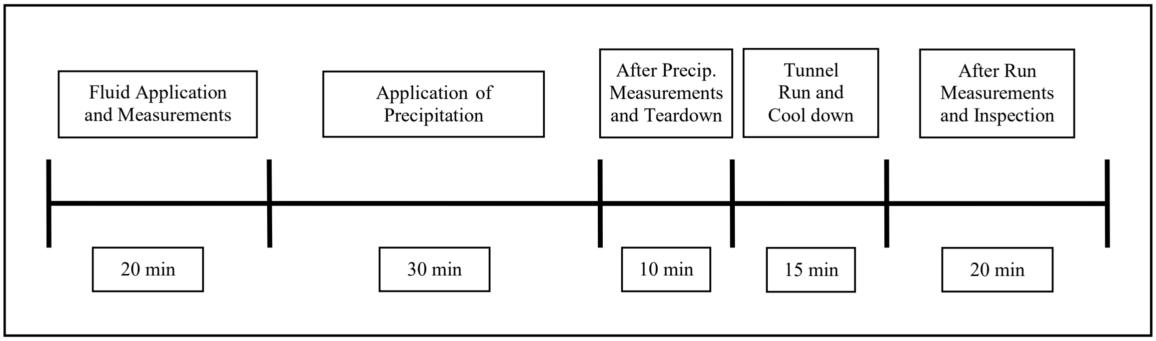


Figure 2.3: Typical Wind Tunnel Test Timeline

2.6 Wind Tunnel

The experiments were performed in the NRC PIWT. This facility is an open-circuit wind tunnel with a fan at the entry, drawing air from and exhausting to the outdoors; this design is ideal for de/anti-icing tests as it prevents contaminants from recirculating within the tunnel. This design also permits sub-freezing air to be drawn in during the Ottawa winter, thereby providing test section temperatures appropriate for these experiments. The test section is 3 m (10 ft.) wide by 6 m (20 ft.) high by

12 m (40 ft.) long, with a maximum wind speed of 78 knots when using the electrical turbine drive, and with a maximum wind speed of 100 knots when using the gas turbine drive. Scaffolding was constructed to allow access to the wing section, which facilitated the application of fluids and the subsequent inspection and cleaning of the airfoil.

2.6.1 Generic High-Performance "Supercritical" Commuter Airfoil

The wing section used for testing was a generic high-performance commuter airfoil, also referred to as "supercritical." This wing section was constructed by the NRC specifically to conduct these tests following extensive consultations with an airframe manufacturer to ensure a representative supercritical design. The original wing design was representative of an outboard section and did not include a flap; the flap was later added at the request of TC, the FAA, and APS. A computational fluid dynamics (CFD) analysis of the modified wing section was conducted by the airframe manufacturer, and it was confirmed that the wing section provided a good representation of a flapped section of an operational supercritical wing. Photo 2.3 shows the wing section used for testing.

2.6.2 Generic "Supercritical" Wing Design Characteristics

A cross-sectional view of the supercritical wing section used for testing has been included in Figure 2.4; the dimensions indicated are in meters. Some of the pertinent dimensions of the wing section are:

a) Chord length not including flap: 1.4 m (4.6 ft.); and
b) Width: 2.4 m (8 ft.).

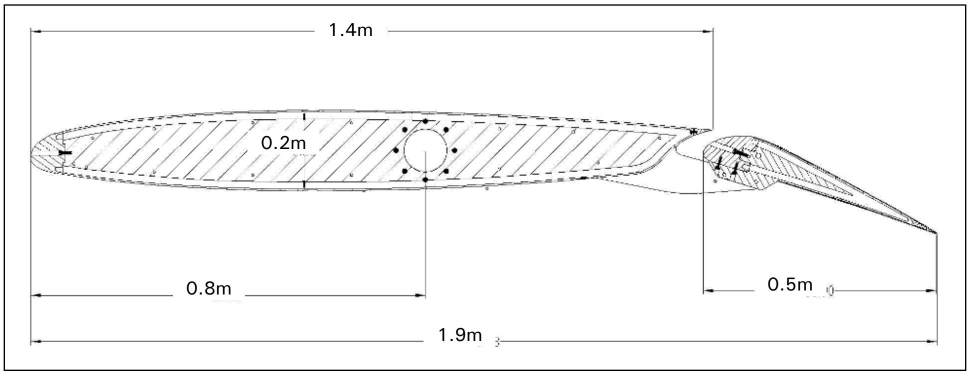


Figure 2.4: Generic "Supercritical" Wing Section

An analysis of the wing section model was conducted by the airframe manufacturer to determine the typical rest position of this type of wing section. It was determined that on a typical commuter aircraft, this section of wing would typically be pitched forward by 2º when sitting on the ground. As a result, the NRC ensured the rest position of the wing model was set to -2º for each test.

The wing section was fitted with a hinged flap. The flap position was fixed at 20º and was not intended to be changed during testing. The top surface of the flap wing section had a steeper angle; a flap setting of 20º created close to a 26º slope on the top surface of the flap (with the wing pitched forward by 2º). As testing progressed, the ability to change the flap setting from 0º to 20º was necessary; contrary to a nested flap, which is typically protected during precipitation, a hinged flap is always exposed, and results indicated earlier failures due to the shallower angle of the hinged flap. Modifications were made by the NRC to allow the flap setting to alternate between 0º and 20º for the fluid application and contamination periods; however, all takeoff simulations were conducted with the flap set to 20º. No moveable devices were available on the wing section. Detailed coordinates for this airfoil are included in Appendix D.

End plates were installed on the wing section to eliminate the “wall effects” from the wind tunnel walls and to provide a better aerodynamic flow above the test area. Figure 2.5 demonstrates the end plates installed on the supercritical wing section (note: the wing section is depicted without the top wing skin).

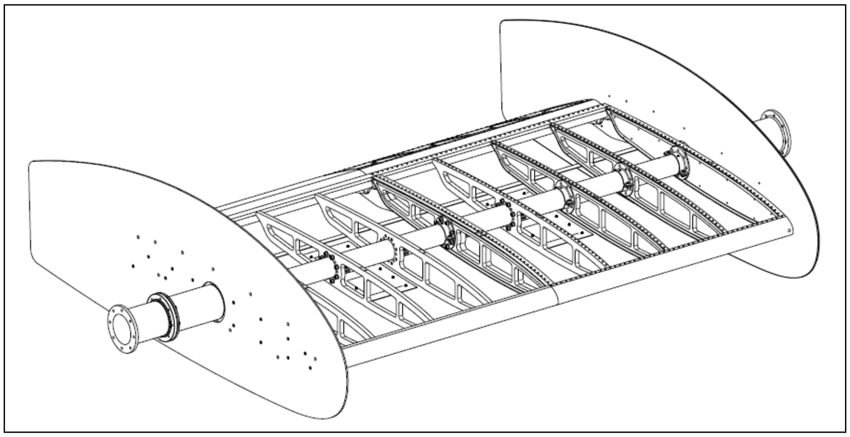


Figure 2.5: End Plates Installed on Supercritical Wing Section

2.6.3 Wind Tunnel Measurement Capabilities

The supercritical wing section was supported on either side by 2-axis weigh scales capable of measuring drag and lift forces generated on the wing section. The lift data collected for each test described in this report has been plotted as a function of time and is included in Appendix C. The wing section was attached to servo-systems capable of pitching the wing section to a static angle or generating dynamic movements. The servo-system was programmed to simulate pitch angles during takeoff and climb-out based on operational aircraft flight profiles.

The wing section was also equipped with eight Resistance Temperature Detectors (RTDs); these were installed by NRC personnel to record the skin temperature on the leading edge (LE), mid chord (MID), trailing edge (TE), and under wing (UND). RTDs were placed along a chord 0.5 m (1.5 fee) in pairs to the left and to the right of the wing centreline. The following are the locations of the RTDs:

- RTD LE located approximately 25 cm from the leading edge (as measured along wing skin curvature);
- RTD MID located approximately 70 cm from the leading edge (as measured along wing skin curvature);
- RTD TE located approximately 30 cm from the trailing edge (as measured along wing skin curvature); and
- RTD UND located approximately 45 cm from the leading edge.

Figure 2.6 demonstrates the general location of the RTDs. These RTDs were primarily used to monitor the skin temperature in real-time through the NRC data display system, and measurements were recorded by APS personnel as described in Subsection 2.16.

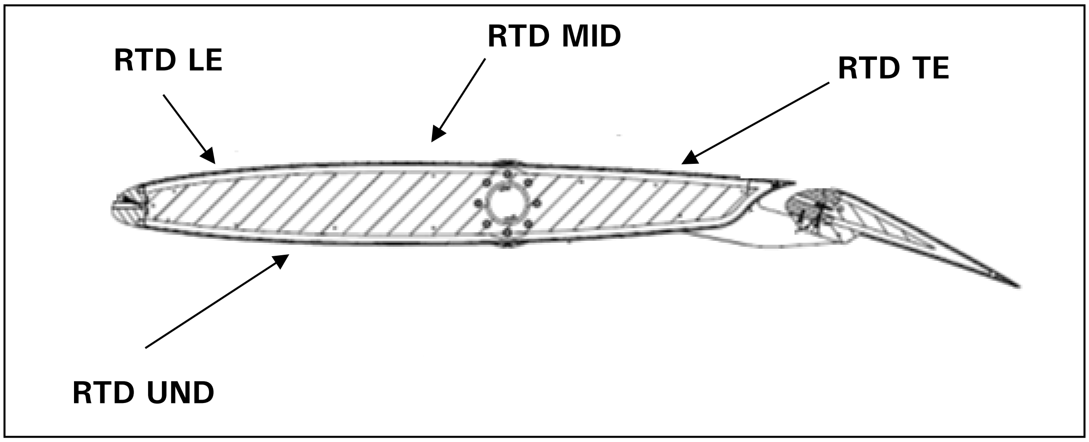


Figure 2.6: Location of RTDs Installed Inside Supercritical Wing

The wind tunnel was also equipped with sensors recording the following parameters:

- Ambient temperature inside the tunnel;
- Outside air temperature;
- Air pressure;
- Wind speed; and
- Relative humidity.

2.6.4 Test Area Grid

Prior to the testing, APS personnel used markers to draw a grid on the wing upper surface (excluding the flap). Each grid cell measured 5.1 cm x 5.1 cm (2 in. x 2 in.) with the cell axis positioned perpendicular and parallel to the leading edge (see Photo 2.4). The grid section was 2.4 m (8 ft.), which covered the entire wing section. The grid markings began approximately 10.1 cm (4 in.) aft of the leading edge stagnation point and were continued along the length of the main chord; grid markings were not drawn on the flap section. The grid was used to facilitate observations of the fluid shearing off the wing and the movement of ice pellets during takeoff. Additional notes can be found in Appendix E.

2.7 Equipment

A considerable amount of test equipment was required to perform these tests. Key items are described in the following sections; a full list of equipment is provided in the test procedure, which is included in Appendix B.

2.8 Simulated Precipitation

2.8.1 Ice Pellets

In a previous analysis of natural ice pellet events, the diameter of ice pellets was measured. It was found that ice pellets generally ranged from 1 mm to 3 mm. During moderate to heavy ice pellet conditions, the diameter of the ice pellets measured up to 5 mm. Based on this observation, ice pellets were produced with diameters ranging from 1.4 mm to 4.0 mm to represent the most common ice pellet sizes observed during natural events.

The ice pellets were manufactured inside a refrigerated truck (see Photo 2.5). Cubes of ice were crushed and passed through calibrated sieves (see Photo 2.6) to obtain the required ice pellet size range. Hand-held motorized dispensers were used to dispense the ice pellets. The ice pellets were applied to the leading and trailing edges of the wing at the same time.

2.8.2 Snow

Snow was produced using the same method for producing ice pellets. The snow used consisted of small ice crystals measuring less than 1.4 mm in diameter. Previous testing conducted by APS investigated the dissolving properties of the artificial snow versus natural snow. The artificial snow was selected as an appropriate substitute for natural snow.

The snow was manufactured inside a refrigerated truck. Cubes of ice were crushed and passed through calibrated sieves to obtain the required snow size range. Hand-held motorized dispensers were used to dispense the snow. The snow was applied to the leading and trailing edges of the wing at the same time. During some tests, sieves were used to dispense the snow over the wing.

2.8.3 Freezing Rain/Rain

The same sprayer head and scanner used for HOT testing at the NRC Climatic Engineering Facility (CEF) was employed for testing. The sprayer system uses compressed air and distilled water to produce freezing rain. The temperature of the water is controlled and is kept just above freezing temperature in order to produce freezing rain. To produce rain, the temperature of the water is raised until the precipitation no longer freezes on the test surfaces.

2.9 Simulated Precipitation Related Equipment

2.9.1 Ice Pellet and Snow Dispenser

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

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

These tests were conducted using 121 collection pans, each measuring 15 cm x 15 cm, over an area 3.4 m x 3.4 m. Pre-measured amounts of IP/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.

Using the results from these calibration tests, it was determined that the most appropriate distribution for the wind tunnel tests would be attained by using four dispensers (two on the leading edge and two on the trailing edge) and by moving them through a cycle of four positions 0.3 m (1 ft.) apart; this essentially simulated sixteen dispensers positioned 0.3 m (1 ft.) apart along the leading and trailing edge of the wing.

Dispensing was done by placing known quantities of simulated ice pellets or snow into the dispensing bucket and allowing the dispenser to completely empty the contents over a set period of time (usually 1 minute). After the dispensing bucket was emptied, the dispenser was shifted over to the next of four positions per dispenser. The dispensers were re-filled every minute for the duration of the test (see Photo 2.7). The calculated efficiencies were accounted for when weighing the required amounts of ice pellets and snow. Details regarding the distribution pattern can be found in Attachments XI and XII of the wind tunnel procedure found in Appendix B.

Towards the end of the testing period (Test #83 and later), the methodology for dispensing snow was modified. Snow was dispensed manually by sifting snow directly onto the wing using calibrated sieves. This method was found to be more efficient, and it provided a more even application for cases where higher intensity snow precipitation rates were required. Consideration will be given to potentially using this methodology for future testing in 2010-11.

2.9.2 Freezing Rain Sprayer

Simulated freezing rain was generated by the NRC freezing rain sprayer system. The same sprayer head and scanner used for HOT testing at the NRC CEF was employed for testing. The sprayer system uses compressed air and distilled water to produce freezing rain. Two hypodermic needles are mounted onto a sprayer head whose movement is controlled by a 2-axis scanner. Approximately 2 seconds are required for the sprayer to disperse across the 2.4m (8ft.) width of the wing. The spray pattern is an “S” shape form, and a total of 54 seconds is required to complete a full cycle. Two full cycles are required to completely cover the wing (the second cycle is offset to generate a more even distribution). The freezing rain sprayer is shown in Photo 2.8.

2.10 Definition of Precipitation Rates

When simulating precipitation rates for full-scale and plate testing, the rate limits defined for standard HOT testing were referenced. Figure 2.7 demonstrates the HOT testing rate precipitation breakdown.

HOT testing protocol for ice pellets does not currently exist. As a result, ice pellet precipitation rate limits were based on the freezing rain rate breakdown. The following precipitation rates were used for the full-scale and flat plate testing conducted during the winter of 2009-10:

• Light Ice Pellets:	13-25 g/dm²/h;
• Moderate Ice Pellets:	25-75 g/dm²/h;
• Light Freezing Rain:	13-25 g/dm²/h;
• Freezing Drizzle (Heavy):	5-13 g/dm²/h;
• Light Rain:	13-25 g/dm²/h;
• Moderate Rain:	25-75 g/dm²/h;
• Light Snow:	4-10 g/dm²/h; and
• Moderate Snow	10-25 g/dm²/h.

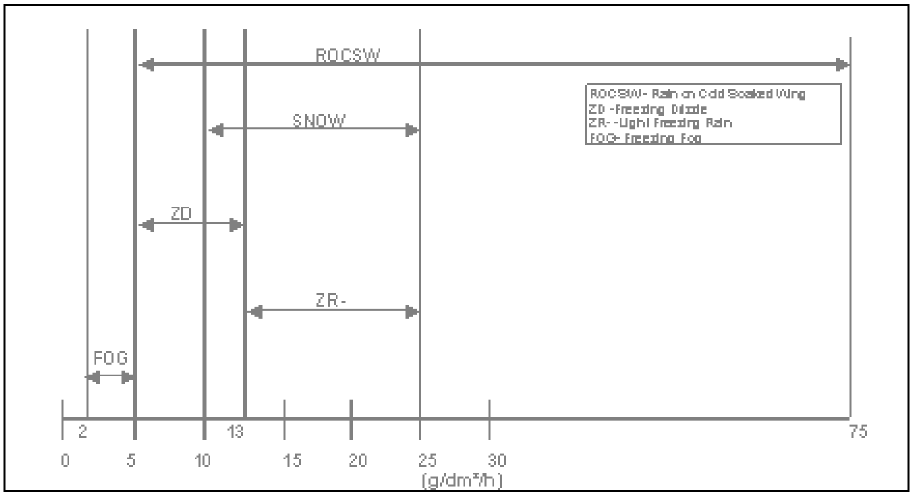


Figure 2.7: Precipitation Rate Breakdown

2.11 Video and Photo Equipment

Two Canon Digital Rebel XT digital still cameras were used to obtain high-speed, high-resolution photographs of the testing. The 8 mega-pixel resolution cameras are capable of taking up to three pictures per second in continuous shooting mode. Early in the testing, the cameras were fitted with an intervalometer and the frames were set at one per second; this reduced the storage size required for the photos while still providing sufficient detail of the fluid flow-off. The cameras were fitted with 18-55 mm lenses.

To create a consistent and stable setup for the cameras, APS mounted the cameras in the observation window overlooking the wing section. The flashes, operated through radio triggering sensors, were positioned in the opposing observation window; this created a shadow effect that could be used to measure and calculate the magnitude of the fluid waves and protruding contamination. An additional observation window was installed during the winter of 2010-11 directly overlooking the wing; the purpose was to allow observers to get a close look at the wing without interfering with the camera setup. Photos 2.9 and 2.10 demonstrate the camera setup used for the testing period.

The cameras were positioned to obtain a wide-angle view of the leading edge and a close-up view of the trailing edge. In comparison to the 2006-07 and 2008-09 camera test setups, the positioning of the cameras was modified slightly due to the end plates installed on the wing and the wing geometry, both of which affected the camera view. During the 2006-07 tests, the cameras' primary focus was on the starboard section of the wing, whereas during the 2008-09 and 2009-10 tests, the primary focus point was on the center section of the wing; this was due to the restricted view points resulting from the changes in the wing setup. The trailing edge lens was also changed from a 105 mm macro lens (2006-07) to an 18-55 mm lens (2008-09 and 2009-10), as the primary focus point had been moved further away from the camera. Additional information regarding the camera setup used can be found in Appendix E.

In addition, a professional photographer used a digital still camera to take pictures of the test setup and all phases of the test from both inside and outside the test section.

2.12 Additional Photos Taken During Precipitation Phase

Digital cameras fitted with intervalometers were used for taking pictures during the precipitation phase. The cameras were set to trigger every minute and, during shorter tests, at shorter intervals as required. These photos proved to be useful for demonstrating the progression of contamination, as well as for reviewing and comparing tests. This protocol should be continued for future testing.

2.13 Type II/III/IV Fluid Application Equipment

The Type II/III/IV fluids were stored outside the wind tunnel and were kept at ambient temperature. The fluids were poured rather than sprayed so that application would not change the fluid viscosity. This methodology was appropriate given the relatively small test area of the wing section and the goal of minimizing the amount of fluid flowing off the wing.

Type II/III/IV fluids were generally received in 20 L containers; however, during the 2009-10 testing, some select fluids were received in large 1000 L totes. The fluids were applied to the wing section by using smaller 2 L containers (see Photo 2.11). Approximately 16 L to 20 L of fluid were applied to the wing section for each test; less fluid was required for the less viscous Type II and III fluids. Due to the flat top surface of the supercritical wing, the thickened fluid did not easily settle and flow on the top surface. The wing was therefore tilted forward (by approximately 10 degrees) for 1 minute following the end of fluid application to allow the fluid to spread out evenly over the top surface of the wing.

2.14 Waste Fluid Collection

Using a relatively small test area and applying the fluids by pouring minimized the amount of fluid falling off the wing. APS personnel used a vacuum to collect the fluid that would drip onto the tunnel floor prior to each test. The NRC also fitted the wind tunnel with appropriate drainage tubes to collect spent fluid. At the end of the testing period, the services of Safety-Kleen were employed to safely dispose of the waste glycol fluid.

2.15 Personnel

NRC personnel operated the wind tunnel. Five APS staff members were required to conduct the tests, and four additional persons from Ottawa were hired to manufacture and dispense ice pellets as well as to help with general setup tasks. A professional photographer was retained to record digital images of the test setup and test runs. Representatives from the TDC and the FAA provided direction in testing and participated as observers. Photo 2.12 shows a portion of the 2009-10 research team (due to scheduling, not all participants were available for the photo).

2.16 Measurement of Test Parameters

2.16.1 Measurement Locations

For each test, the fluid thickness, skin temperature, and fluid Brix were measured at eight locations along the center chord. Measurements were taken during four stages of a typical test:

a) Before fluid application;
b) After fluid application;
c) After application of contamination; and
d) After the simulated takeoff test.

The locations designated for measurement, identified in Figure 2.8, were the following:

- Wing Position 1: Approximately 10 cm up from the leading edge stagnation point;
- Wing Position 2: Approximately 25 cm up from the leading edge stagnation point;
- Wing Position 3: Approximately 40 cm up from the leading edge stagnation point;
- Wing Position 4: Approximately 55 cm up from the leading edge stagnation point;
- Wing Position 5: Approximately 70 cm up from the leading edge stagnation point;
- Wing Position 6: Approximately 30 cm from the trailing edge;
- Wing Position 7: Approximately 15 cm from the trailing edge;
- Wing Position 8: Approximately 2.5 cm from the trailing edge;
- Wing Position 9: Midway up the flap; and
- Underside: Approximately 40 cm up from the leading edge stagnation point.

The wing positions were measured along the curvature of the wing.

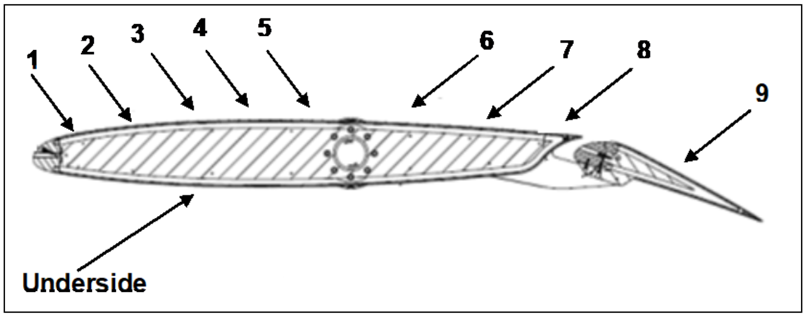


Figure 2.8: Measurement Locations Along Chord of Supercritical Wing Section

2.16.2 Fluid Thickness

Fluid thickness was measured using wet film thickness gauges at three stages of a typical test:

a) After fluid application;
b) After application of contamination; and
c) After the simulated takeoff test.

The locations designated for fluid thickness measurements, identified in Figure 2.8, were the following:

- Wing Position 1: Approximately 10 cm up from the leading edge stagnation point;
- Wing Position 2: Approximately 25 cm up from the leading edge stagnation point;
- Wing Position 3: Approximately 40 cm up from the leading edge stagnation point;
- Wing Position 4: Approximately 55 cm up from the leading edge stagnation point;
- Wing Position 5: Approximately 70 cm up from the leading edge stagnation point;
- Wing Position 6: Approximately 30 cm from the trailing edge;
- Wing Position 7: Approximately 15 cm from the trailing edge;
- Wing Position 8: Approximately 2.5 cm from the trailing edge;
- Wing Position 9: Midway up the flap; and
- Underside: Approximately 40 cm up from the leading edge stagnation point.

The wing positions were measured along the curvature of the wing. Photo 2.13 shows the fluid thickness gauges used for the testing.

In some cases, fluid thickness measurements were omitted if the data collected was repetitive or not critical to the test objective, with the aim of streamlining and accelerating the testing process; these instances have been denoted with “N/A” in the respective data tables.

2.16.3 Wing Skin Temperature

Initially, wing temperatures were measured using a hand-held temperature probe at three locations during four stages of a typical test:

a) Before fluid application;
b) After fluid application;
c) After application of contamination; and
d) After the simulated takeoff test.

The locations designated for skin temperature measurements, identified in Figure 2.8, were the following:

- Wing Position 2: Approximately 25 cm up from the leading edge stagnation point;
- Wing Position 5: Approximately 70 cm up from the leading edge stagnation point; and
- Underside: Approximately 40 cm up from the leading edge stagnation point.

The wing positions were measured along the curvature of the wing. Photo 2.14 shows the skin temperature probe used for the testing.

It should be noted that early on in the testing, the hand-held measurements were compared to the NRC-monitored data from the RTDs located inside the wing (see Subsection 2.6.3). The average of the temperatures recorded by the pairs of RTDs denoted by RTD LE, RTD MID, and RTD UND were comparable to the manual measurements taken by APS using a hand-held temperature probe on positions 2, 5, and Underside, respectively. Therefore, early on, the manual measurements were replaced by the data logged by the NRC (APS recorded an instantaneous average value from the NRC data at the required intervals for analysis purposes). The average instantaneous temperatures indicated by the three pairs of RTDs (located to the left and right of the centreline) were recorded for each of the three locations where APS typically measured skin temperature.

Early on in the testing, when manual skin temperature measurements were being taken, fluid thickness measurements were omitted in some cases if the data collected was repetitive or not critical to the test objective, with the aim of streamlining and accelerating the testing process; these instances have been denoted with “N/A” in the respective data tables.

2.16.4 Fluid Brix

Fluid Brix was measured using hand-held refractometers at three stages of a typical test:

a) After fluid application;
b) After application of contamination; and
c) After the simulated takeoff test.

The locations designated for fluid Brix measurements, identified in Figure 2.8, were the following:

- Wing Position 2: Approximately 25 cm up from the leading edge stagnation point; and
- Wing Position 5: Approximately 70 cm up from the leading edge stagnation point.

The wing positions were measured along the curvature of the wing. Photo 2.15 shows the hand-held Brixometer used for the testing.

In some cases, fluid Brix measurements were omitted if the data collected was repetitive or not critical to the test objective, with the aim of streamlining and accelerating the testing process; these instances have been denoted with “N/A” in the respective data tables.

2.17 Data Forms

Several different forms were used to facilitate the documentation of the various data collected in the wind tunnel tests. These forms include:

a) General Form;
b) Wing Temperature, Fluid Thickness and Fluid Brix Form;
c) Ice Pellet and Snow Dispensing Forms;
d) Sprayer Calibration Form;

e) Visual Evaluation Rating Form;
f) Condition of Wing and Plate Form;
g) Fluid Receipt Form; and
h) Log of Fluid Sample Bottles.

Copies of these forms are provided in the test procedure, which is included in Appendix B.

2.18 General Methodology

This section describes equipment and general information used for the wind tunnel tests.

2.18.1 Refractometer

Fluid freezing points were measured using a hand-held Misco 10431VP refractometer with a Brix scale. The freezing points of the various fluid samples were determined using the conversion curve or table provided to APS by the fluid manufacturer. The following tables contain the fluid freezing points for the various fluids tested and the relevant conversion data:

- Table 2.2 - Kilfrost ABC-S Plus;
- Table 2.3 - Clariant MP III 2031 ECO;
- Table 2.4 - Octagon Octaflo Type I;
- Table 2.5 - Clariant MPIV Launch; and
- Table 2.6 - Brix to Refractive Index Conversion Table.

Figure 2.9 illustrates the fluid freezing points for the Dow EG 106 fluid.

2.18.2 Temperature Sensor

Wing skin temperature and fluid temperature were measured using a Wahl digital heat-probe thermometer Model 392Vxc. A surface temperature probe was used for wing skin temperature measurements (except in later tests when wing-mounted RTDs were used), and an immersion probe was used for measuring and monitoring fluid temperatures.

Table 2.2: Freezing Point vs. Brix of Aqueous Solutions of Kilfrost ABC-S Plus

Conc. (% vol)	BRIX (20°C)	Freezing Point (20°C)	RI (20°C)	Conc. (% vol)	BRIX (20°C)	Freezing Point (20°C)	RI (20°C)	Conc. (% vol)	BRIX (20°C)	Freezing Point (20°C)	RI (20°C)
20%	8.20	1.345	-3.4	**50%**	**18.90**	**1.362**	**-10.6**	80%	29.40	1.380	-23.1
21%	8.59	1.345	-3.6	51%	19.26	1.363	-11.1	81%	29.73	1.380	-23.7
22%	8.98	1.346	-3.8	52%	19.62	1.364	-11.6	82%	30.06	1.381	-24.2
23%	9.37	1.346	-4.0	53%	19.98	1.364	-12.0	83%	30.36	1.382	-24.8
24%	9.76	1.347	-4.2	54%	20.34	1.365	-12.4	84%	30.72	1.382	-25.4
25%	10.15	1.348	-4.4	55%	20.70	1.365	-12.8	85%	31.05	1.383	-26.0
26%	10.54	1.348	-4.6	56%	21.06	1.366	-13.1	86%	31.38	1.383	-26.7
27%	10.93	1.349	-4.9	57%	21.42	1.366	-13.4	87%	31.71	1.384	-27.3
28%	11.32	1.349	-5.1	58%	21.78	1.367	-13.8	88%	32.04	1.384	-28.0
29%	11.71	1.350	-5.3	59%	22.14	1.368	-14.1	89%	32.37	1.385	-28.6
30%	12.10	1.351	-5.5	60%	22.50	1.368	-14.5	90%	32.70	1.386	-29.3
31%	12.43	1.351	-5.8	61%	22.85	1.369	-14.9	91%	33.02	1.386	-30.1
32%	12.76	1.352	-6.0	62%	23.20	1.369	-15.2	92%	33.34	1.387	-30.8
33%	13.09	1.352	-6.3	63%	23.55	1.370	-15.7	93%	33.66	1.387	-31.5
34%	13.42	1.353	-6.5	64%	23.90	1.371	-16.0	94%	33.98	1.388	-32.2
35%	13.75	1.354	-6.8	65%	24.25	1.371	-16.4	95%	34.30	1.389	-33.0
36%	14.08	1.354	-7.0	66%	24.60	1.372	-16.8	96%	34.62	1.389	-33.8
37%	14.41	1.355	-7.3	67%	24.95	1.372	-17.2	97%	34.94	1.390	-34.6
38%	14.74	1.355	-7.6	68%	25.30	1.373	-17.6	98%	35.26	1.391	-35.4
39%	15.07	1.356	-7.9	69%	25.65	1.373	-18.0	99%	35.58	1.391	-36.2
40%	15.40	1.356	-8.1	70%	26.00	1.374	-18.4	**100%**	**35.90**	**1.392**	**-37.0**
41%	15.75	1.357	-8.4	71%	26.34	1.375	-18.9				
42%	16.10	1.358	-8.7	72%	26.68	1.375	-19.3				
43%	16.45	1.358	-9.0	73%	27.02	1.376	-20.0				
44%	16.80	1.359	-9.3	74%	27.36	1.376	-20.7				
45%	17.15	1.359	-9.5	**75%**	**27.70**	**1.377**	**-21.4**				
46%	17.50	1.360	-9.8	76%	28.04	1.378	-21.7				
47%	17.85	1.361	-10.0	77%	28.38	1.379	-22.0				
48%	18.20	1.361	-10.2	78%	28.72	1.379	-22.3				
49%	18.55	1.362	-10.4	79%	29.06	1.379	-22.6				

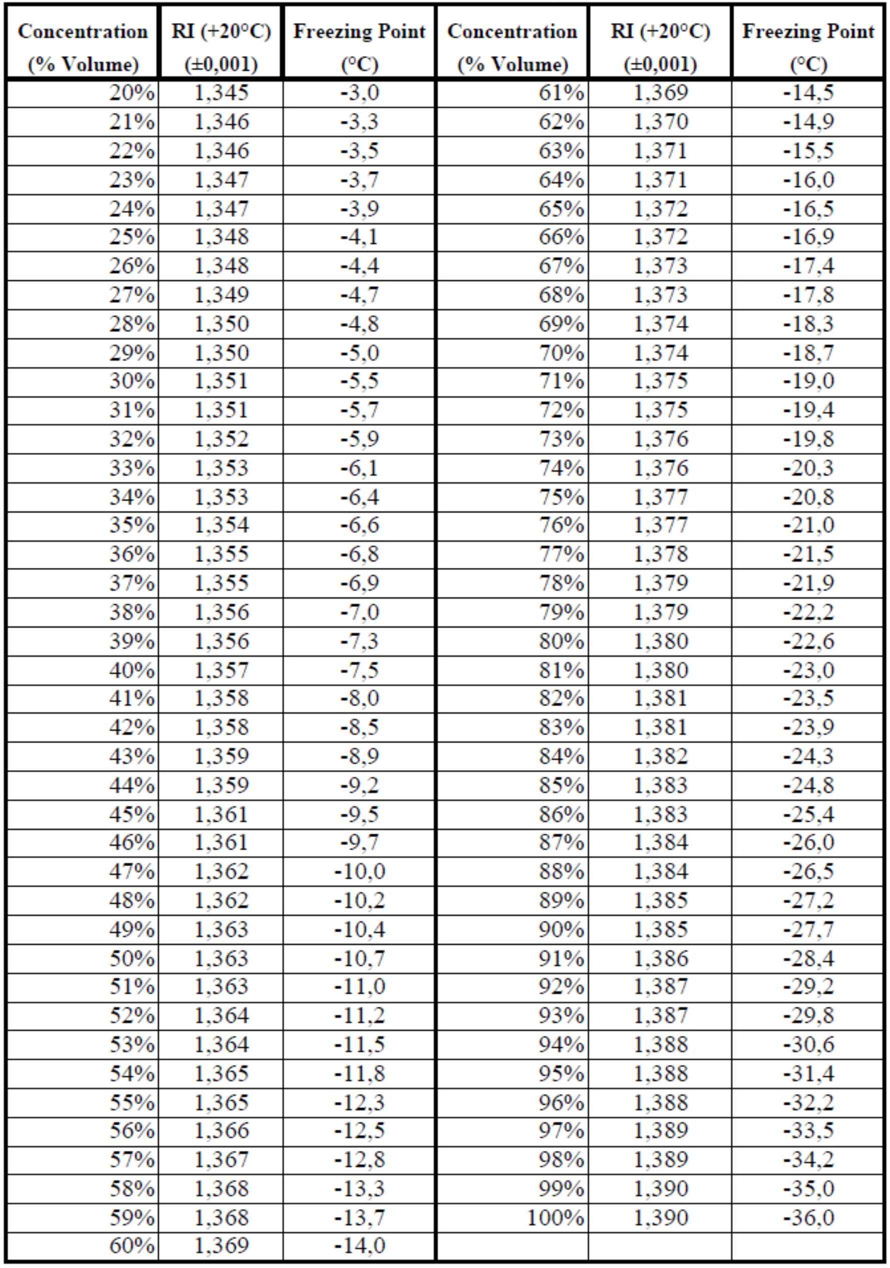
Table 2.3: Dilution Chart for Clariant MP III 2031 ECO

DILUTION (v/v) Safewing: Water	**BRIX** MISCO 10431 VP	**FREEZING POINT**
100: 0	34.3 to 36.0	-31 to -34
95: 5	33.4	-29
90: 10	31.8	-26
85: 15	30.2	-23
80: 20	28.8	-21
75: 25	27.2	-18
70: 30	25.4	-16
65: 35	24.0	-14
60: 40	22.2	-12
55: 45	20.4	-11
50: 50	18.8	-10

Table 2.4: Dilution Chart for Octagon Octaflo Type I

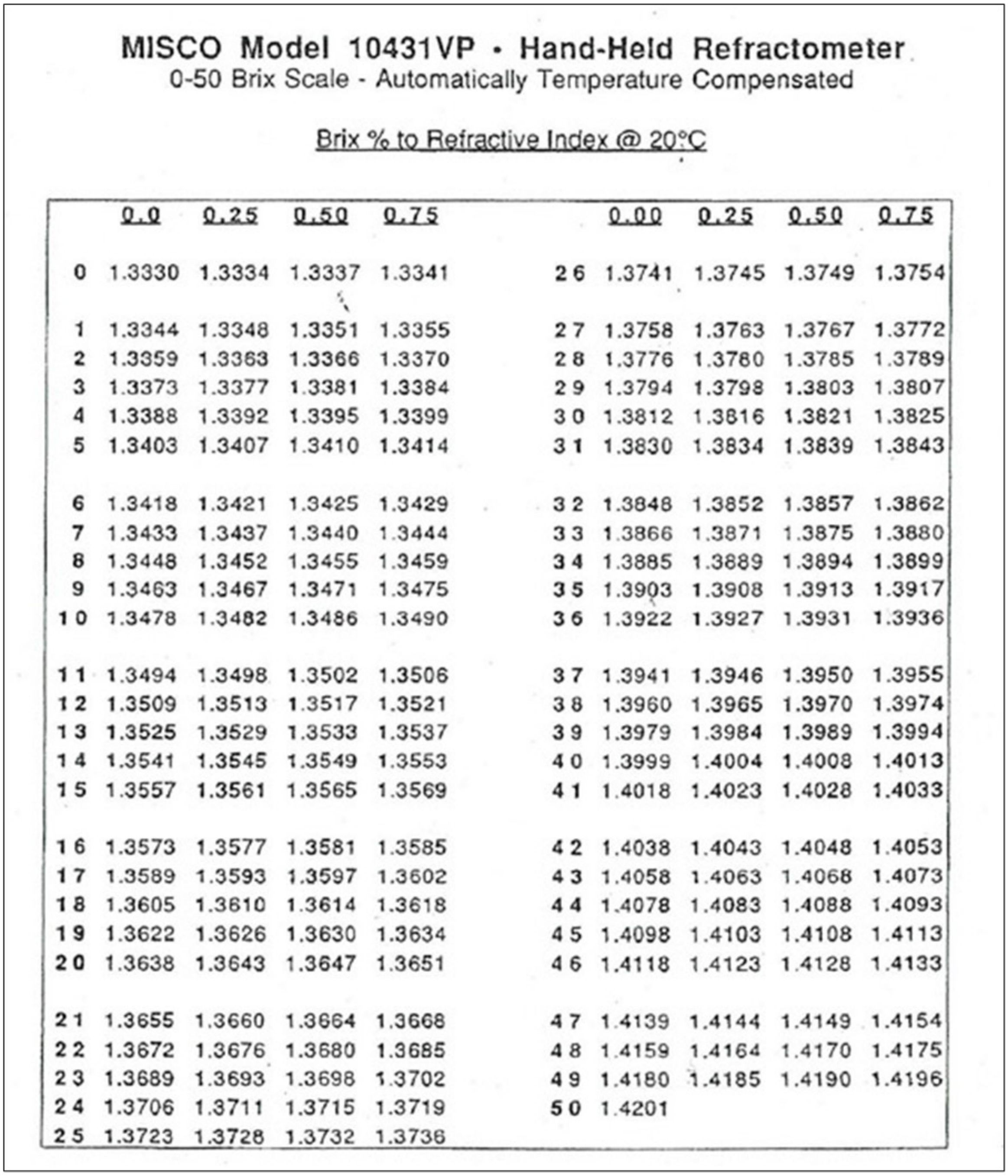
Dilution (Fluid/Water)	**Refractive Index**	**Brix**	**Freezing Point**
100/0	1.425	52.25	N/A
65/35	1.398	39.00	-54°C
60/40	1.394	37.00	-40°C
56/44	N/A	34.25	-35°C
55/45	1.389	34.25	-34°C
50/50	1.384	31.5	-28°C
45/55	1.378	28.5	-22°C
42/58	N/A	26.75	-20°C
40/60	1.374	26.00	-19°C
35/65	1.369	23.00	-15°C
32/68	N/A	21.50	-13°C
30/70	1.364	20.00	-11°C
28/72	N/A	18.50	-9°C
25/75	1.358	16.50	-8°C
20/80	1.352	12.75	-6°C
10/90	1.343	6.75	-4°C

Table 2.5: Dilution Chart for Clariant MPIV Launch



Concentration (% Volume)	RI (+20°C) (±0,001)	Freezing Point (°C)	Concentration (% Volume)	RI (+20°C) (±0,001)	Freezing Point (°C)
20%	1,345	-3,0	61%	1,369	-14,5
21%	1,346	-3,3	62%	1,370	-14,9
22%	1,346	-3,5	63%	1,371	-15,5
23%	1,347	-3,7	64%	1,371	-16,0
24%	1,347	-3,9	65%	1,372	-16,5
25%	1,348	-4,1	66%	1,372	-16,9
26%	1,348	-4,4	67%	1,373	-17,4
27%	1,349	-4,7	68%	1,373	-17,8
28%	1,350	-4,8	69%	1,374	-18,3
29%	1,350	-5,0	70%	1,374	-18,7
30%	1,351	-5,5	71%	1,375	-19,0
31%	1,351	-5,7	72%	1,375	-19,4
32%	1,352	-5,9	73%	1,376	-19,8
33%	1,353	-6,1	74%	1,376	-20,3
34%	1,353	-6,4	75%	1,377	-20,8
35%	1,354	-6,6	76%	1,377	-21,0
36%	1,355	-6,8	77%	1,378	-21,5
37%	1,355	-6,9	78%	1,379	-21,9
38%	1,356	-7,0	79%	1,379	-22,2
39%	1,356	-7,3	80%	1,380	-22,6
40%	1,357	-7,5	81%	1,380	-23,0
41%	1,358	-8,0	82%	1,381	-23,5
42%	1,358	-8,5	83%	1,381	-23,9
43%	1,359	-8,9	84%	1,382	-24,3
44%	1,359	-9,2	85%	1,383	-24,8
45%	1,361	-9,5	86%	1,383	-25,4
46%	1,361	-9,7	87%	1,384	-26,0
47%	1,362	-10,0	88%	1,384	-26,5
48%	1,362	-10,2	89%	1,385	-27,2
49%	1,363	-10,4	90%	1,385	-27,7
50%	1,363	-10,7	91%	1,386	-28,4
51%	1,363	-11,0	92%	1,387	-29,2
52%	1,364	-11,2	93%	1,387	-29,8
53%	1,364	-11,5	94%	1,388	-30,6
54%	1,365	-11,8	95%	1,388	-31,4
55%	1,365	-12,3	96%	1,388	-32,2
56%	1,366	-12,5	97%	1,389	-33,5
57%	1,367	-12,8	98%	1,389	-34,2
58%	1,368	-13,3	99%	1,390	-35,0
59%	1,368	-13,7	100%	1,390	-36,0
60%	1,369	-14,0			

Table 2.6: Brix to Refractive Index Conversion Chart



MISCO Model 10431VP • Hand-Held Refractometer

0-50 Brix Scale - Automatically Temperature Compensated

Brix % to Refractive Index @ 20°C

	0.0	0.25	0.50	0.75		0.00	0.25	0.50	0.75
0	1.3330	1.3334	1.3337	1.3341	26	1.3741	1.3745	1.3749	1.3754
1	1.3344	1.3348	1.3351	1.3355	27	1.3758	1.3763	1.3767	1.3772
2	1.3359	1.3363	1.3366	1.3370	28	1.3776	1.3780	1.3785	1.3789
3	1.3373	1.3377	1.3381	1.3384	29	1.3794	1.3798	1.3803	1.3807
4	1.3388	1.3392	1.3395	1.3399	30	1.3812	1.3816	1.3821	1.3825
5	1.3403	1.3407	1.3410	1.3414	31	1.3830	1.3834	1.3839	1.3843
6	1.3418	1.3421	1.3425	1.3429	32	1.3848	1.3852	1.3857	1.3862
7	1.3433	1.3437	1.3440	1.3444	33	1.3866	1.3871	1.3875	1.3880
8	1.3448	1.3452	1.3455	1.3459	34	1.3885	1.3889	1.3894	1.3899
9	1.3463	1.3467	1.3471	1.3475	35	1.3903	1.3908	1.3913	1.3917
10	1.3478	1.3482	1.3486	1.3490	36	1.3922	1.3927	1.3931	1.3936
11	1.3494	1.3498	1.3502	1.3506	37	1.3941	1.3946	1.3950	1.3955
12	1.3509	1.3513	1.3517	1.3521	38	1.3960	1.3965	1.3970	1.3974
13	1.3525	1.3529	1.3533	1.3537	39	1.3979	1.3984	1.3989	1.3994
14	1.3541	1.3545	1.3549	1.3553	40	1.3999	1.4004	1.4008	1.4013
15	1.3557	1.3561	1.3565	1.3569	41	1.4018	1.4023	1.4028	1.4033
16	1.3573	1.3577	1.3581	1.3585	42	1.4038	1.4043	1.4048	1.4053
17	1.3589	1.3593	1.3597	1.3602	43	1.4058	1.4063	1.4068	1.4073
18	1.3605	1.3610	1.3614	1.3618	44	1.4078	1.4083	1.4088	1.4093
19	1.3622	1.3626	1.3630	1.3634	45	1.4098	1.4103	1.4108	1.4113
20	1.3638	1.3643	1.3647	1.3651	46	1.4118	1.4123	1.4128	1.4133
21	1.3655	1.3660	1.3664	1.3668	47	1.4139	1.4144	1.4149	1.4154
22	1.3672	1.3676	1.3680	1.3685	48	1.4159	1.4164	1.4170	1.4175
23	1.3689	1.3693	1.3698	1.3702	49	1.4180	1.4185	1.4190	1.4196
24	1.3706	1.3711	1.3715	1.3719	50	1.4201			
25	1.3723	1.3728	1.3732	1.3736					

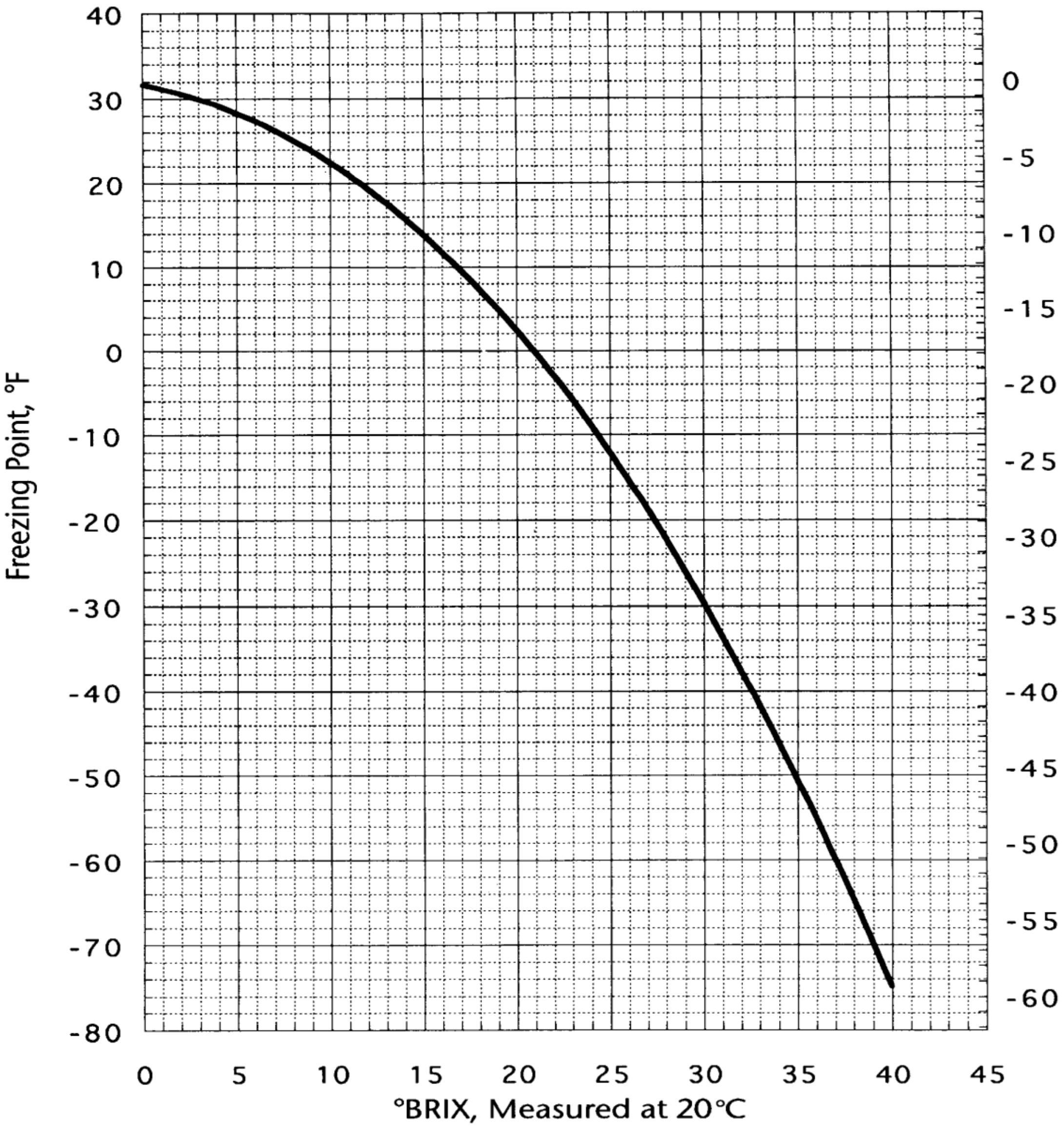
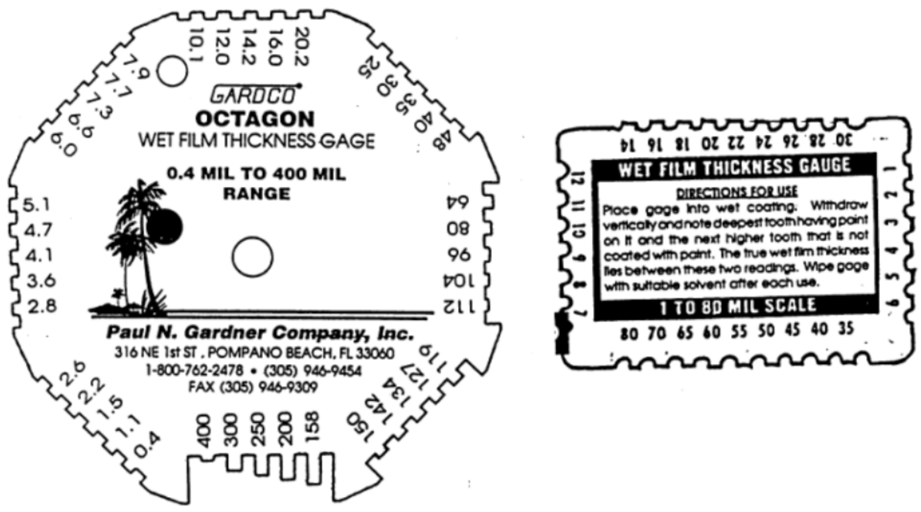


Figure 2.9: Freezing Point vs. Brix of Aqueous Solutions of Dow EG106

2.18.3 Thickness Gauges

Wet film thickness gauges, shown in Figure 2.10 and Photo 2.13, were used to measure fluid film thickness. These gauges were selected because they provide an adequate range of thicknesses (0.1 mm to 10.2 mm) for Type I/II/III/IV fluids. The rectangular gauge shown in Figure 2.10 has a finer scale and was used in some cases when the fluid film was thinner (toward the end of a test). The observer recorded a thickness value (in mils), as read directly from the thickness gauge. The recorded value was the last wetted tooth of the thickness gauge; however, the true thickness lies between the last wetted tooth and the next un-wetted tooth. A thickness conversion table (shown in Table 2.7) was used to convert the recorded thickness values into the corrected thickness values.



Place gage into wet coating. Withdraw vertically and note deepest tooth having paint on it and the next higher tooth that is not coated with paint. The true wet film thickness lies between these two readings. Wipe gage with suitable solvent after each use.

Figure 2.10: Thickness Gauges

2.18.4 Viscometer

Viscosity measurements were carried out using a Brookfield viscometer (Model DV-1+, shown in Photo 2.16) fitted with a recirculating fluid bath and small sample adapter.

On-site measurements were initially done with the Stony Brook PDVdi-120 Falling Ball Viscometer (Photo 2.17) to obtain a preliminary verification of the fluid integrity; falling ball tests are much faster and more convenient to perform as compared to tests with the Brookfield viscometer.

Table 2.7: Film Thickness Conversion Table

RECTANGULAR GAUGE			OCTAGON GAUGE		
Reading*	Calculated Thickness		Reading*	Calculated Thickness	
(mil)	(mil)	(mm)	(mil)	(mil)	(mm)
			0.4	0.8	0.0
1.0	1.5	0.0	1.1	1.3	0.0
			1.5	1.9	0.0
2.0	2.5	0.1	2.2	2.4	0.1
			2.6	2.7	0.1
3.0	3.5	0.1	2.8	3.2	0.1
			3.6	3.9	0.1
4.0	4.5	0.1	4.1	4.4	0.1
			4.7	4.9	0.1
5.0	5.5	0.1	5.1	5.6	0.1
6.0	6.4	0.2	6.0	6.4	0.2
			6.6	7.0	0.2
7.0	7.5	0.2	7.3	7.5	0.2
8.0	8.5	0.2	7.7	7.8	0.2
9.0	9.5	0.2	7.9	9.0	0.2
10	11	0.3	10	11	0.3
11	12	0.3			
12	13	0.3	12	13	0.3
14	15	0.4	14	15	0.4
16	18	0.4	16	18	0.4
18	19	0.5			
20	21	0.5	20	23	0.6
22	23	0.6			
24	25	0.6	25	28	0.7
26	27	0.7			
28	29	0.7			
30	33	0.8	30	33	0.8
35	38	1.0	35	38	1.0
40	43	1.1	40	43	1.1
45	48	1.2			
50	53	1.3	48	56	1.4
55	58	1.5			
60	63	1.6			
65	68	1.7	64	80	2.0
70	75	1.9			
80	88	2.2	80	88	2.2
			96	100	2.5
			104	108	2.7
			112	116	2.9
			119	123	3.1
			127	131	3.3
			134	138	3.5
			142	146	3.7
			150	154	3.9
			158	179	4.5
			200	225	5.7
			250	275	7.0
			300	350	8.9
			400	400	10.2

* Reading of last wetted tooth.

2.18.5 Fluids

Five fluids were used during the wind tunnel tests conducted during the winter of 2009-10. The fluid used for testing was at mid-production viscosity. The viscosity of the fluids received was measured using the Stony Brook PDVdi-120 Falling Ball Viscometer to ensure the fluid was within the fluid manufacturer production specifications and comparable to previous samples received. In previous years, the viscosity was measured using the Brookfield viscometer and the Stony Brook PDVdi-120 Falling Ball Viscometer. Samples received in 2009-10 were only verified using the falling ball method due to similarities in results obtained; no measurements were taken for the Type I fluid tested. The pertinent characteristics of these fluids are given in Table 2.8.

Table 2.8: Test Fluids

	Falling Ball Results 2008-09				Falling Ball Results 2009-10			
Fluid Name	**Batch #**	**Brix**	**Temp (°C)**	**Time (sec.)**	**Batch #**	**Brix**	**Temp (°C)**	**Time (sec.)**
Dow UCAR EG106	VK0601GKDR	33	22.5	49	WH0601GKDR	31.6	22.7	49
		33	22.5	45		31.6	22.7	46
	XA2201GKI6	32.9	22.7	39		31.5	23	50
		32.9	22.6	39				
Kilfrost ABC-S PLUS	K01212009IV	36.5	22.9	25	P/22/12/09	35.8	22.3	25
	K01212009IV	36.5	22.9	26		35.8	22.3	27
Clariant MP IV Launch	C15012009IV	35.1	23.6	30	USHA024295	35.7	22.6	30
	C02192009IV	35.5	23.7	26		35.7	22.6	31
		35.5	23.9	27				
Clariant MP III 2031	C15012009III	35.4	24.7	3	USHA024443	35.5	22.9	9
		35.4	24.7	3		35.5	22.9	9
	C02192009III	35.7	23.6	3				<1
		35.7	23.7	3				<1
Octagon Octaflo *	Not Used in 2008-09				WL-102009	N/A	N/A	N/A

* Note: Brix and viscosity measurments are not taken for Type I fluids in concentrate formulation

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Photo 2.1: Outside View of NRC Wind Tunnel Facility

Photo 2.2: Inside View of NRC Wind Tunnel Test Section

Photo 2.3: Supercritical Wing Section Used for Testing

Photo 2.4: Grid Markings on Supercritical Wing Section

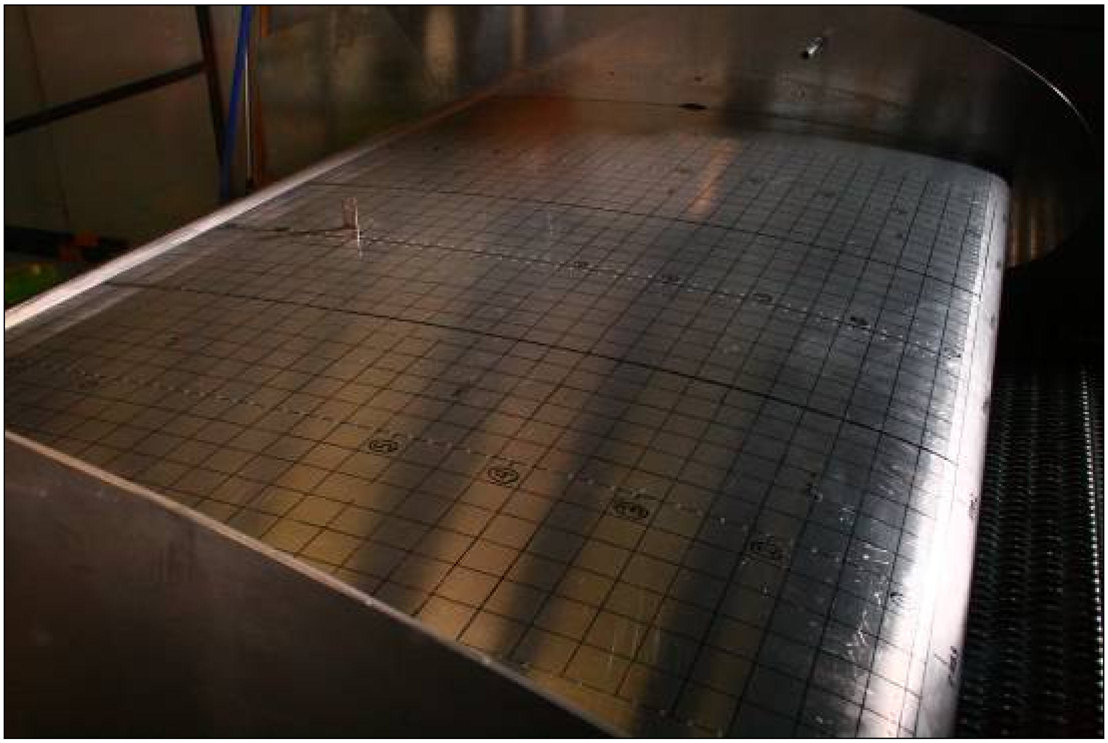

Photo 2.5: Refrigerated Truck Used for Manufacturing Ice Pellets

Photo 2.6: Calibrated Sieves Used to Obtain Desired Size Distribution

Photo 2.7: Ice Pellet Dispensers Operated by APS Personnel

Photo 2.8: Ceiling-Mounted Freezing Rain Sprayer

Photo 2.9: Wind Tunnel Setup for Flashes

Photo 2.10: Wind Tunnel Setup for Digital Cameras

Photo 2.11: Fluid Pour Containers

Photo 2.12: 2009-10 Research Team

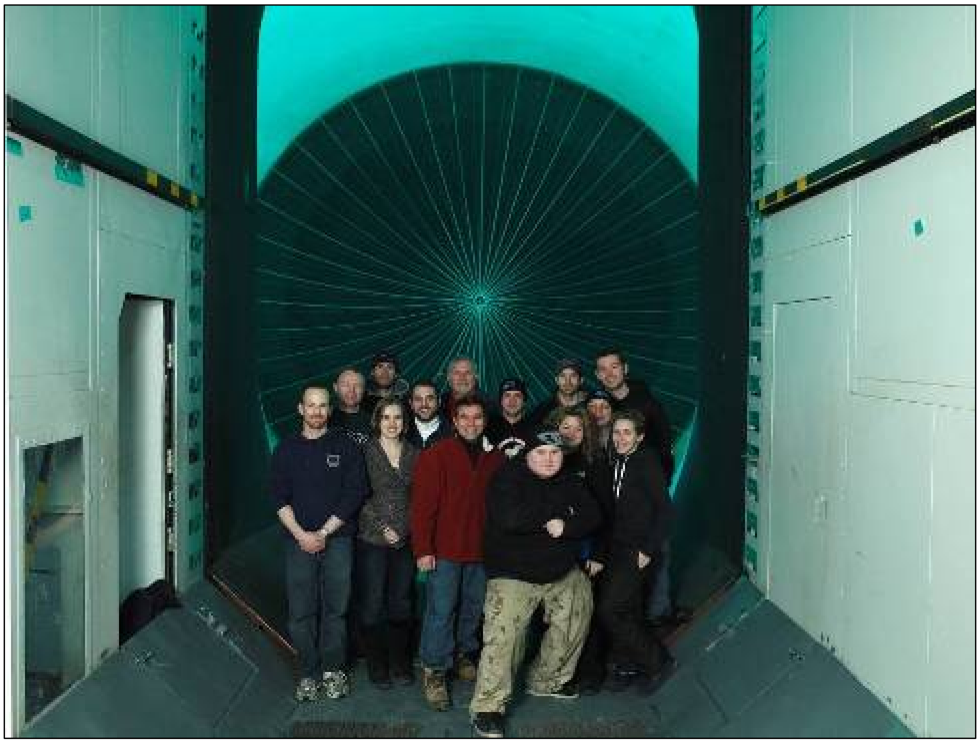

Photo 2.13: Wet Film Thickness Gauges

Photo 2.14: Hand-Held Temperature Probe

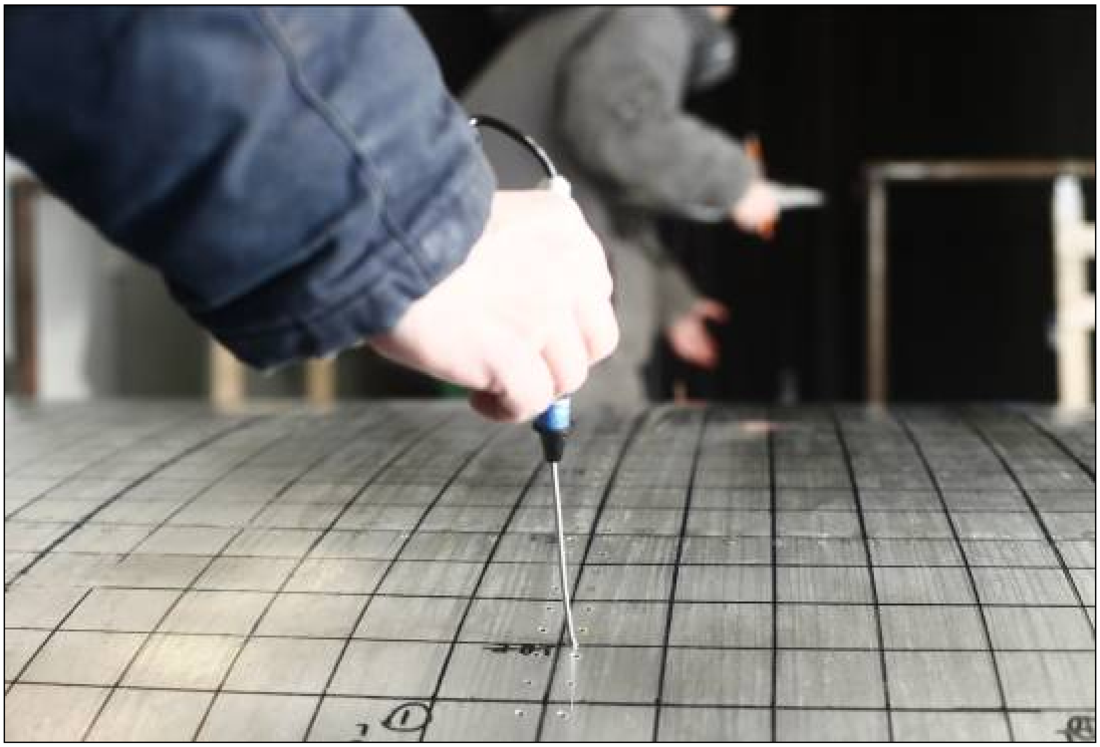

Photo 2.15: Hand-Held Brixometer (Misco 10431VP)

Photo 2.16: Brookfield Digital Viscometer Model DV-1+

Photo 2.17: Stony Brook PDVdi-120 Falling Ball Viscometer

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3. FULL-SCALE DATA COLLECTED

3.1 Test Log

A calendar of the tests conducted during the winter of 2009-10 can be found in Table 2.1. A detailed log of the tests conducted in the NRC PIWT is shown in Table 3.1; only data pertaining to the test objectives described in this report are included (see Table 1.2 for additional details). Table 3.1 provides relevant information for each of the tests, as well as final values used for the data analysis. Each column contains data specific to one test. The following is a brief description of the column headings for Table 3.1.

Run #:	Exclusive number identifying each test run.
Objective:	Main objective of the test.
Test Condition:	Description of the simulated conditions for the test.
Fluid:	Aircraft anti-icing fluid used during the test.
Rotation Angle:	Maximum angle of rotation obtained during simulated takeoff run; began testing with a max 8° rotation angle and increased to 20° as testing progressed.
Flap Angle:	Positioning of the flap during the precipitation period; either 0° (retracted) or 20° (extended). *Note: Flap was always extended at 20° during the takeoff run.*
Date:	Date when the test was conducted.
Precipitation End Time:	End time of the application of precipitation, recorded in local time.
Tunnel Start Time:	Start of the simulated takeoff run, recorded in local time.
OAT Before Test (°C):	Outside air temperature recorded just before the start of the simulated takeoff test, measured in degrees Celsius. *Note: Not an important parameter, as "Tunnel Temp. Before Test" was used as actual test temperature for analysis.*

Tunnel Temp. Before Test (ºC):	Static tunnel ambient temperature recorded just before the start of the simulated takeoff test, measured in degrees Celsius. *Note: This parameter was used as the actual test temperature for analysis.*
Avg. Wing Temp. Before Test (ºC):	Average of the wing skin temperature measurements just before the start of the simulated takeoff test, recorded in degrees Celsius.
Precipitation Rate (Type: [g/dm²/h]):	Simulated freezing precipitation rate (or combination of different precipitation rates). "N/A" indicates that no precipitation was applied.
Exposure Time:	Simulated precipitation period, recorded in minutes.

The visual contamination ratings are described below. Visual contamination ratings were typically reported as the average of the three observer ratings and rounded to the nearest decimal. The visual contamination ratings system is further described in Subsection 2.4.1.

Visual Contamination Rating Before Takeoff (LE, TE, Flap):	Visual contamination rating determined before the start of the simulated takeoff: 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 - Contamination visible, adherence of contamination.
Visual Contamination Rating at Rotation (LE, TE, Flap):	Visual contamination rating determined at the time of rotation: 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 - Contamination visible, adherence of contamination.
Visual Contamination Rating After Takeoff (LE, TE, Flap):	Visual contamination rating determined at the end of the test: 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 - Contamination visible, adherence of contamination.
CL at 0° Before Rotation:	Calculated lift coefficient at the 0° wing angle position just prior to the start of the rotation; data provided by the NRC.
CL at 8° During Rotation:	Calculated lift coefficient at the 8° wing rotation angle position; data provided by the NRC.
CL at 4° Following End of Rotation:	Calculated lift coefficient at the 4° wing rotation angle position attained at the end of the rotation cycle; data provided by the NRC.
% Lift Loss:	Percentage lift loss calculated based on the comparison of the 8° lift coefficient during the test run versus the dry wing average lift coefficient (calculated to be 1.7213).

Table 3.1: Wind Tunnel Test Log

Run #	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip.End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipiation Rate (g/dm²/h)	Exposure Time (min)	Visual Contamination Rating Before Takeoff (LE, TE, Flap)	Visual Contamination Rating at Rotation (LE, TE, Flap)	Visual Contamination Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	Cl at 6° During Rotation	Cl at 8°	CL at 4° Following End of Rotation	% Lift Loss (8°Cl vs Dry Cl AVG =1.7213)
1	Baseline	Fluid Only	ABC-S Plus	8	20	7-Jan-10	N/A	13:42	-6.6	-5.7	-4.6		-	1, 1, 1	1, 1, 1	1, 1, 1	0.695	1.463	1.635	1.266766	5.01
2	Baseline	Dry Wing	No Fluid	8	20	7-Jan-10	N/A	0.6	-6.5	-4.9	N/A		-	-, -, -	-, -, -	-, -, -	0.75	1.536992	1.698	1.303	1.35
3	Baseline	Dry Wing	No Fluid	14	20	11-Jan-10	N/A	N/A	-7.1	N/A	N/A		-	-, -, -	-, -, -	-, -, -	0.748	1.52	1.732	1.293	-0.62
4	Baseline	Fluid Only	ABC-S Plus	14	20	11-Jan-10	N/A	9:59	-6.4	-6.6	-5.4		-	1, 1, 1	1, 1, 1	1, 1, 1	0.653	1.456	1.652	1.278	4.03
6	Flap Failure	IP/ZR	N/A	20	20	11-Jan-10	12:14	12:29	-4.5	-4.2	N/A	IP:23, ZR:28 Applied by Hand	20	1, 1, 5	1, 1, 5	1, 1, 5	0.425	1.086	1.255	-	27.09
6A	Flap Failure	IP/ZR	N/A	12	20	11-Jan-10	N/A	12:37	-4.7	-4.6	N/A		-	-, -, -	-, -, -	-, -, -	0.412	1.061	1.2355	0.883	28.22
6B	Flap Failure	IP/ZR	N/A	13	20	12-Jan-10	15:21	15:29	-11	-10.3	N/A	IP:13, ZR:11 Applied by Hand	20	1, 1, 5	1, 1, 5	1, 1, 5	0.534	1.261	1.443	1.054	16.17
6C	Flap Failure	Applied in Previous Run (6B)	N/A	13	20	12-Jan-10	N/A	16:04	-11.6	-10.3	N/A		-	1, 1, 5	1, 1, 5	1, 1, 5	0.723	1.503	1.715	1.271	0.37
7	Double Fluid	Fluid Only	ABC-S Plus	13	20	12-Jan-10	N/A	17:08	-12	-9.7	-9.1		-	1, 1, 1	1, 1, 1	1, 1, 1	0.689	1.449	1.668	1.273	3.10
8	Baseline	Fluid Only	ABC-S Plus	13	20	12-Jan-10	N/A	18:09	-11.8	-8.8	-7.9		-	1, 1, 1	1, 1, 1	1, 1, 1	0.683	1.461	1.668	1.271	3.10
12	Baseline	Fluid Only	ABC-S Plus	13	20	13-Jan-10	N/A	16:46	-10.4	-5.9	-5.8		-	1, 1, 1	1, 1, 1	1, 1, 1	0.656	1.454	1.66	1.263	3.56
17	Baseline	Fluid Only	ABC-S Plus	8	20	14-Jan-10	N/A	11:11	-8.4	-3.9	-4.4		-	1, 1, 1	1, 1, 1	1, 1, 1	0.653	1.448	1.636	1.262	4.96
18	Baseline	Fluid Only	ABC-S Plus	12	20	14-Jan-10	N/A	12:32	-2	-2.5	-3.5		-	1, 1, 1	1, 1, 1	1, 1, 1	0.659	Data Loss	Data Loss	Data Loss	-
18A	Baseline	Fluid Only	ABC-S Plus	8	20	14-Jan-10	N/A	14:46	-5.7	-1.8	-2.9		-	1, 1, 1	1, 1, 1	1, 1, 1	0.721	1.501	1.692	1.31	1.70
19	Baseline	Fluid Only	ABC-S Plus	8	20	14-Jan-10	N/A	15:13	-5.7	-2.1	N/A		-	1, 1, 1	1, 1, 1	1, 1, 1	0.745	1.536	1.741	1.324	-1.14

Table 3.1: Wind Tunnel Test Log (cont'd)

Run #	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip .End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipiation Rate (g/dm^2/h)	Exposure Time (min)	Visual Contamination Rating Before Takeoff (LE, TE, Flap)	Visual Contamination Rating at Rotation (LE, TE, Flap)	Visual Contamination Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	Cl at 6° During Rotation	Cl at 8°	CL at 4° Following End of Rotation	% Lift Loss (8°Cl vs Dry Cl AVG =1.7213)
25	Baseline	Fluid Only	EG 106	8	20	21-Jan-10	N/A	2:05	-5.9	-4	-3.4		-	1, 1, 1	1, 1, 1	1, 1, 1	0.715	1.516	1.687	1.284	1.99
27	Baseline	Fluid Only	ABC-S Plus	6	20	21-Jan-10	N/A	5:37	-6.2	-3.5	-3.7		-	1, 1, 1	1, 1, 1	1, 1, 1	0.655	1.423	-	1.254	-
29	Baseline	Fluid Only	Launch	8	20	21-Jan-10	N/A	22:25	-8.5	-4.8	-3.9		-	1, 1, 1	1, 1, 1	1, 1, 1	0.643	1.448	1.636	1.291	4.96
30	Baseline	Fluid Only	Launch	6	20	21-Jan-10	N/A	22:56	-8.8	-6.8	-5.2		-	1, 1, 1	1, 1, 1	1, 1, 1	0.64	1.409	-	1.252	-
31	Type III IP High Speed	IP-	2031 - Cold	8	20	22-Jan-10	1:23	1:28	-9	-7	-6.8	IP:25	10	2.2, 2, 3	1, 2, 2.2	1, 1, 1.7	0.633	1.422	1.591	1.256	7.57
32	Type III IP High Speed	Fluid Only	2031 - Cold	8	20	22-Jan-10	N/A	2:24	-9.5	-6.7	-5.8		-	1, 1, 1	1, 1, 1	1, 1, 1	0.668	1.457	1.633	1.259	5.13
33	Type III IP High Speed	IP-	2031 - Hot	8	20	22-Jan-10	3:03	3:09	-10.4	-5.4	3.7	IP:25	10	2, 2, 2.8	1, 1, 1.7	1, 1, 1	0.668	1.435	1.644	1.255	4.49
34	Type III IP High Speed	Fluid Only	2031 - Hot	8	20	22-Jan-10	N/A	3:45	-9.3	-5.4	16.2		-	1, 1, 1	1, 1, 1	1, 1, 1	0.686	1.466	1.652	1.265	4.03
35	Type III IP High Speed	IP- / SN-	2031 - Cold	8	20	22-Jan-10	4:35	4:42	-9.3	-6.2	-7	IP:25, SN:10	10	2, 2.2, 3	1, 2, 2	1, 1, 1.1	0.64	1.42	1.626	1.25	5.54
36	Type III IP High Speed	IP- / SN-	2031 - Hot	8	20	22-Jan-10	5:23	5:29	-9.1	-4.6	0.5	IP:25, SN:10	10	2.2, 2.2, 3.1	1.3, 1.1, 1.7	1.2, 1, 1	0.665	1.448	1.634	1.253	5.07
37	Heavy Snow	S	2031 - Cold	8	20	22-Jan-10	21:43	21:53	-5.6	-0.9	-1.3	SN:25	10	2, 2, 3	1, 1, 1.5	1, 1, 1	0.66	1.455	1.64	1.261	4.72
38	Heavy Snow	S++	2031 - Cold	8	20	22-Jan-10	22:52	22:55	-5.6	-2.5	-3	SN:50	5	1.7, 1.7, 3	1, 1, 2	1, 1, 1	0.666	1.445	1.638	1.256	4.84
39	Heavy Snow	S++	2031 - Cold	8	20	22-Jan-10	23:37	23:48	-8.1	-2.9	-4.6	SN:50	7.5	3, 2.7, 3	1, 1.2, 1.5	1, 1, 1	0.646	1.432	1.633	1.252	5.13
40	Heavy Snow	S++	2031 - Cold	8	20	23-Jan-10	1:21	1:27	-9.3	-3.1	-7.4	SN:50	15	4, 2, 4	1.5, 2.3, 3.8	1.2, 1.7, 3.8	0.614	1.39	1.594	1.235	7.40
41	Type III IP High Speed	IP-	2031 - Cold	8	20	23-Jan-10	2:36	2:43	-9	-6.1	-8.6	IP:25	20	2.3, 2.3, 3	1, 1.25, 1.3	1, 1, 1	0.691	1.468	1.666	1.27	3.21

Table 3.1: Wind Tunnel Test Log (cont'd)

Run #	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip .End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipiation Rate (g/dm²/h)	Exposure Time (min)	Visual Contamination Rating Before Takeoff (LE, TE, Flap)	Visual Contamination Rating at Rotation (LE, TE, Flap)	Visual Contamination Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	Cl at 6° During Rotation	Cl at 8°	CL at 4° Following End of Rotation	% Lift Loss (8°Cl vs Dry Cl AVG =1.7213)
42	Type III IP High Speed	IP-	2031 - Hot	8	20	23-Jan-10	3:30	3:35	-10.4	-5.8	-4.1	IP:25	20	2.3, 2.3, 2.7	1.2, 1.7, 2	1.3, 1.2, 1.2	0.658	1.446	1.633	1.254	5.13
43	Type III IP High Speed	IP-	2031 - Cold	8	20	23-Jan-10	5:05	5:11	-9.3	-7.7	-8.1	IP:25	10	3.7, 4, 4	1, 1, 1	1, 1, 1	0.712	1.491	1.686	1.267	2.05
45	Roughness	IP/R Applied in Test 44	EG 106 Applied in Test 44	13	20	23-Jan-10	N/A	21:54	-8	-6	N/A	IP:25, R:75	-	5, 5, 5	5, 5, 5	5, 5, 5	0.38	1.077	1.246	0.9	27.61
45A	Roughness	IP/R Applied in Test 44	EG 106 Applied in Test 44	15	20	23-Jan-10	N/A	22:10	-8.3	-6.1	N/A	IP:25, R:75	-	-, -, -	-, -, -	-, -, -	0.403	1.13	1.278	0.902	25.75
45B	Roughness	IP/R Applied in Test 44	EG 106 Applied in Test 44	15	20	23-Jan-10	N/A	22:41	-8.5	-4.1	N/A	IP:25, R:75	-	-, -, -	-, -, -	-, -, -	0.435	1.122	1.31	1.029	23.89
46	Baseline	Dry Wing	No Fluid	15	20	23-Jan-10	N/A	23:13	-8.6	-3.5	N/A		-	-, -, -	-, -, -	-, -, -	0.718	1.496	1.713	1.276	0.48
50	Runway Deicier	ZR	Safeway + Launch	8	20	24-Jan-10	5:36	5:37	-8.8	-0.6	-0.8	ZR:25	53	P: 2, 1, 4.7 SB: 1.7, 1.7, 3.3	P: 3.7, 3.7, 3.7 SB: 2.3, 2.3, 2.3	P: 5, 5, 5 SB: 1, 1, 1.3	0.667	1.452	1.643	1.242	4.55
51	SN w/ No Fluid	Snow	Dry - Warm Wing	8	20	27-Jan-10	2:41	2:54	-1.5	-0.5	-0.4	SN: 25	20	4.5, 4.5, 4.5	4.8, 4.8, 4.8	4.8, 4.8, 4.8	0.42	1.176	1.341	0.958	22.09
52	SN w/ No Fluid	Same as Test 41 + Rain	Dry - Warm Wing	8	20	27-Jan-20	3:36	3:41	-2.1	-0.2	-0.4	ZR: 25	24	5, 5, 5	5, 5, 5	5, 5, 5	0.451	1.204	1.369	0.976	20.47
52A	SN w/ No Fluid	Same as Test 52	Dry - Warm Wing	15	20	27-Jan-10	N/A	3:44	-2.2	-2	N/A	N/A	N/A	5, 5, 5	5, 5, 5	5, 5, 5	0.451	1.185	1.398	0.976	18.78
53	Baseline	Snow	Dry - Cold Wing	8	20	27-Jan-10	N/A	4:25	-2.7	-1.9	-0.3	SN:50	Approx. 7	1, 1, 1	1, 1, 1	1, 1, 1	0.648	1.441	1.654	1.275	3.91
54	Baseline	Fluid Only	Launch	8	20	27-Jan-10	N/A	4:57	-3.6	-2.2	-0.8		-	1, 1, 1	1, 1, 1	1, 1, 1	0.69	1.462	1.66	1.282	3.56
55	Baseline	Fluid Only	EG 106	8	20	27-Jan-10	N/A	5:34	-4.2	-2.6	-0.9		-	1, 1, 1	1, 1, 1	1, 1, 1	0.704	1.498	1.689	1.282	1.88
60	Baseline	Fluid Only	Launch	8	20	28-Jan-10	N/A	5:04	-4.9	-2.8	-1.9		-	1, 1, 1	1, 1, 1	1, 1, 1	0.665	1.465	1.642	1.273	4.61

Table 3.1: Wind Tunnel Test Log (cont'd)

Run #	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0º, 20º)	Date	Precip .End Time	Tunnel Start Time	OAT Before Test (ºC)	Tunnel Temp. Before Test (ºC)	AVG Wing Temp. Before Test (ºC)	Precipiation Rate (g/dm²/h)	Exposure Time (min)	Visual Contamination Rating Before Takeoff (LE, TE, Flap)	Visual Contamination Rating at Rotation (LE, TE, Flap)	Visual Contamination Rating After Takeoff (LE, TE, Flap)	CL at -2º Before Rotation	Cl at 6º During Rotation	Cl at 8º	CL at 4º Following End of Rotation	% Lift Loss (8ºCl vs Dry Cl AVG =1.7213)
61	65 vs 80	Fluid Only	Launch	8	20	28-Jan-10	N/A	5:37	-5.1	-2.3	-2.2		-	1, 1, 1	1, 1, 1	1, 1, 1	0.538	1.385	1.575	1.254	8.50
62	65 vs 80	Fluid Only	Launch	8	20	28-Jan-10	N/A	6:06	-5.7	-3.4	-2.4		-	1, 1, 1	1, 1, 1	1, 1, 1	0.601	1.384	1.555	1.242	9.66
64	Baseline	Fluid Only	ABC-S Plus	8	20	28-Jan-10	N/A	22:45	-15	-13.4	-11.3		-	1, 1, 1	1, 1, 1	1, 1, 1	0.629	1.425	1.634	1.275	5.07
70	Baseline	Fluid Only	Launch	8	20	29-Jan-10	N/A	6:43	-20.9	-17.9	-15.8		-	1, 1, 1	1, 1, 1	1, 1, 1	0.627	1.396	1.625	1.272	5.59
75	Baseline	Fluid Only	EG 106	8	20	30-Jan-10	N/A	0:40	-22.3	-18.1	-16.9		-	1, 1, 1	1, 1, 1	1, 1, 1	0.655	1.424	1.651	1.274	4.08
76	Baseline	Fluid Only	ABC-S Plus	8	20	30-Jan-10	N/A	1:13	-22.6	-17.9	-17.3		-	1, 1, 1	1, 1, 1	1, 1, 1	0.643	1.41	1.62	1.258	5.89
83	Heavy Snow	S	EG 106	8	20	31-Jan-10	22:40	22:44	-6.2	-4.2	-7	SN:25	40	2.4, 2.2, 4	1, 1.2, 1.3	1, 1, 1.3	0.695	1.498	1.693	1.292	1.64
84	Heavy Snow	S++	EG 106	8	20	31-Jan-10	23:50	23:54	-7.5	-6.2	-9.5	SN:50	30	3, 2.3, 4	1, 1.7, 1.9	1, 1.2, 1	0.66	1.506	1.683	1.29	2.23
85	Heavy Snow	S++	EG 106	8	20	1-Feb-10	0:43	0:46	-8.8	-6.8	-10.8	SN:50	20	2.6, 2.3, 4	1, 1.5, 1.9	1, 1, 1	0.694	1.498	1.697	1.308	1.41
86	Heavy Snow	S	ABC-S Plus	8	20	1-Feb-10	3:05	3:08	-13.2	-8.5	-11.5	SN:25	60	3.7, 2.9, 4	1.5, 2.2, 3.5	1.2, 1.8, 3	0.494	1.311	1.512	1.192	12.16
87	Heavy Snow	S++	ABC-S Plus	8	20	1-Feb-10	4:15	4:18	-15	-11.6	-14.3	SN:50	30	3.7, 2.9, 4	1.7, 2.2, 3.2	1.2, 1.8, 2.3	0.512	1.305	1.5	1.192	12.86
88	Heavy Snow	S++	ABC-S Plus	8	20	1-Feb-10	5:08	5:13	-15.8	-12.6	-14	SN:50	10	2, 2, 2.8	1.5, 2, 2	1.3, 1.5, 1.5	0.579	1.399	1.574	1.229	8.56
89	SN w/ No Fluid	None	Dry - Cold Wing	8	20	1-Feb-10	5:55	6:03	-16.5	-12.7	N/A	SN:50	Approx. 7	4, 4, 4	3.6, 1, 3.5	3.7, 1, 3.5	0.689	1.491	1.652	1.275	4.03
90	Heavy Snow	S++	ABC-S Plus	8	20	1-Feb-10	21:37	21:43	-9.8	-2.2	-8.3	SN:50	10	2.3, 2.2, 2.2	1.1, 1.5, 1.7	1, 1, 1	0.602	1.442	1.619	1.273	5.94
91	Heavy Snow	S++	ABC-S Plus	8	20	1-Feb-10	22:48	22:52	-10.8	-3.8	-11	SN:50	30	2.8, 2.7, 3.7	1.5, 2.2, 2.7	1, 1.8, 2.3	0.556	1.388	1.576	1.239	8.44

Table 3.1: Wind Tunnel Test Log (cont'd)

Run #	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip .End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipiation Rate (g/dm²/h)	Exposure Time (min)	Visual Contamination Rating Before Takeoff (LE, TE, Flap)	Visual Contamination Rating at Rotation (LE, TE, Flap)	Visual Contamination Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	Cl at 6° During Rotation	Cl at 8°	CL at 4° Following End of Rotation	% Lift Loss (8°Cl vs Dry Cl AVG =1.7213)
92	Heavy Snow	S	ABC-S Plus	8	20	1-Feb-10	0:29	0:33	-12.4	-4.7	-10.3	SN:25	60	2.5, 2.3, 3.8	1.5, 2, 2.7	1, 1.7, 1.8	0.553	1.39	1.577	1.228	8.38
93	Runway Deicier	ZR	Safeway + ABC-S Plus	8	20	2-Feb-10	3:05	3:07	-12.6	-1.4	-3.3	ZR:25-50	96	P: 4.5, 4.5, 5 SB: 1, 1, 5	P:5, 5, 5 SB: 2.3, 1, 5	P: 5, 5, 5 SB: 2.5, 1.2, 5	0.671	1.454	1.623	1.222	5.71
100	Baseline	Fluid Only	EG 106	8	20	3-Feb-10	N/A	2:37	-11.9	-6.3	-8.2		-	1, 1, 1	1, 1, 1	1, 1, 1	0.698	1.5	1.682	1.296	2.28
101	Baseline	Fluid Only	Launch	8	20	3-Feb-10	N/A	3:01	-11.9	-7.6	-8.4		-	1, 1, 1	1, 1, 1	1, 1, 1	0.629	1.447	1.636	1.274	4.96
102	LZR / SN	LZR / SN	Type I Octaflo	8	20	3-Feb-10	3:31	3:42	-11.8	-5.5	-1.3	SN:25, ZR:25	4	3.3, 3.3, 4.3	5, 5, 5	5, 5, 5	0.555	1.291	1.449	1.102	15.82
103	LZR / SN	LZR	Type I Octaflo	8	20	3-Feb-10	4:17	4:24	-11.9	-4.6	-3.7	ZR:25	8	5, 4.7, 5	5, 5, 5	5, 5, 5	0.7	1.491	1.675	1.265	2.69
104	Runway Deicier	ZR	Safeway + ABC-S Plus	8	20	3-Feb-10	6:21	6:23	-11.8	-1.8	-2.1	ZR:25	83	P: 5, 5, 5 SB:1, 1, 5	P: 5, 5, 5 SB:1.8, 1.3, 4.3	P: 5, 5, 5 SB: 1.8, 1.2, 3.8	0.629	1.387	1.576	1.181	8.44

4. TYPE III ALLOWANCE TIMES

Previous ice pellet allowance time testing (2007-08 and 2008-09) has investigated the possibility of expanding the current ice pellet allowance times for low rotation speed aircraft. However, Type IV anti-icing fluid is not recommended by the fluid manufacturers for use on low rotation speed aircraft. Some airframe manufacturers have approved the use of Type IV fluid on their low rotation speed aircraft; however, they have imposed speed penalties to compensate for the poor fluid flow-off at low speeds. The Clariant Type III fluid was specifically designed as an anti-icing fluid for low rotation speed aircraft, but it is also readily used for high-speed aircraft. It was therefore recommended to investigate the performance of the Type III fluid during the low-speed as well as high-speed rotation test runs.

Preliminary work was conducted during the winter of 2007-08 with the Falcon 20 aircraft and the T-33 aircraft to investigate the fluid flow-off performance of uncontaminated and contaminated Type III fluids; contamination comprised mixed conditions with ice pellets [see TC report, TP 14871E, *Research for Further Development of Ice Pellet Allowance Times: Aircraft Trials to Examine Anti-Icing Fluid Flow-Off Characteristics Winter 2007-08* (3). The results obtained with the Type III fluid demonstrated better fluid flow-off when compared to Type IV fluids at low rotation speeds; however, a significant amount of Type III fluid was still present at the end of the low-speed test runs.

More extensive testing was conducted during the winter of 2008-09 at the NRC PIWT [see TC report, TP 14935E, *Research for Further Development of Ice Pellet Allowance Times: Wind Tunnel Trials to Examine Anti-Icing Fluid Flow-Off Characteristics Winter 2008-09* (4)]. Based on the testing conducted during the winter of 2008-09, preliminary Type III allowance times were developed to allow greater flexibility to Type III fluid users. However, because low-speed allowance time testing with Type III fluid was conducted as a secondary objective during the winter of 2008-09, only a limited amount of data was collected. The preliminary results indicated a good potential for the use of Type III fluid during ice pellet conditions, but based on the limitations of the data collected, it was recommended that the preliminary Type III allowance time table not be published in the HOT Guidelines for the winter of 2009-10. Further testing was recommended for the winter of 2009-10.

This section provides an overview of the Winter 2009-10 testing conducted to further develop allowance times for Type III fluids. Testing was conducted in simulated precipitation conditions. The parameters for each test are detailed, and a description of the data collected during each test is provided.

NOTE: This data for Winter 2009-10 was dismissed due to fluid viscosity issues; the fluid was not representative (see Subsection 4.3 for details). The log presented is *strictly for record-keeping purposes, and therefore the data should NOT be used as support for the future development of Type III allowance times.*

4.1 General Methodology

The methodology used during these tests was in accordance with the methodologies described in Section 2. The selected intensity and exposure time of the ice pellet precipitation were based on the current allowance times (and reduced accordingly) for mixed conditions with ice pellets.

4.2 Overview of Tests

A summary of the Type III ice pellet allowance time tests conducted in the wind tunnel is shown in Table 4.1. The table 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. A more detailed test log of all conditions tested using the wind tunnel is provided in Subsection 3.1. The following is a brief description of the column headings for Table 4.1.

Test #:	Exclusive number identifying each test.
Date:	Date when the test was conducted.
Fluid:	Aircraft deicing fluid specified by product name; all fluids were in the “neat” 100/0 dilution.
Associated Baseline Run:	The associated fluid only baseline run based on fluid selection.
Condition:	Simulated precipitation condition.
Precipitation Rate (g/dm²/h):	Simulated freezing precipitation rate (or combination of different precipitation rates). “N/A” indicates that no precipitation was applied.
Precip. Time (min.):	Total time of exposure to simulated precipitation.
Tunnel Temp. at Start of Test (°C):	The tunnel ambient temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.

Avg. Wing Temp. Before Test (°C):	Average of the wing skin temperature measurements just before the start of the simulated takeoff test, recorded in degrees Celsius.
Visual Contamination Rating Before Takeoff (LE, TE, Flap):	Visual contamination rating determined before the start of the simulated takeoff: 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 - Contamination visible, adherence of contamination.
Visual Contamination Rating at Rotation (LE, TE, Flap):	Visual contamination rating determined at the time of rotation: 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 - Contamination visible, adherence of contamination.
CL at 8° During Rotation:	Calculated lift coefficient at the 8° wing rotation angle position; data provided by the NRC.
% Lift Loss:	Percentage lift loss calculated based on the comparison of the 8° lift coefficient during the test run versus the dry wing average lift coefficient (calculated to be 1.7213).

Table 4.1: Summary of 2009-10 Type III Ice Pellet Allowance Time Testing

Test No.	Date	Fluid	Associated Baseline Run	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° Rotation	% Lift Loss	Comments
31	22-Jan-10	2031 - Cold	32	IP-	IP:25	10	-7	-6.8	2.2, 2, 3	1, 2, 2.2	1.591	7.57	DATA NOT VALID DUE TO VISCOSITY ISSUE
32	22-Jan-10	2031 - Cold	N/A	Fluid Only	N/A	N/A	-6.7	-5.8	1, 1, 1	1, 1, 1	1.633	5.13	DATA NOT VALID DUE TO VISCOSITY ISSUE
33	22-Jan-10	2031 - Hot	34	IP-	IP:25	10	-5.4	3.7	2, 2, 2.8	1, 1, 1.7	1.644	4.49	DATA NOT VALID DUE TO VISCOSITY ISSUE
34	22-Jan-10	2031 - Hot	N/A	Fluid Only	N/A	N/A	-5.4	16.2	1, 1, 1	1, 1, 1	1.652	4.03	DATA NOT VALID DUE TO VISCOSITY ISSUE
35	22-Jan-10	2031 - Cold	32	IP- / SN-	IP:25, SN:10	10	-6.2	-7	2, 2.2, 3	1, 2, 2	1.626	5.54	DATA NOT VALID DUE TO VISCOSITY ISSUE
36	22-Jan-10	2031 - Hot	34	IP- / SN-	IP:25, SN:10	10	-4.6	0.5	2.2, 2.2, 3.1	1.3, 1.1, 1.7	1.634	5.07	DATA NOT VALID DUE TO VISCOSITY ISSUE
41	23-Jan-10	2031 - Cold	32	IP-	IP:25	20	-6.1	-8.6	2.3, 2.3, 3	1, 1.25, 1.3	1.666	3.21	DATA NOT VALID DUE TO VISCOSITY ISSUE
42	23-Jan-10	2031 - Hot	34	IP-	IP:25	20	-5.8	-4.1	2.3, 2.3, 2.7	1.2, 1.7, 2	1.633	5.13	DATA NOT VALID DUE TO VISCOSITY ISSUE
43	23-Jan-10	2031 - Cold	32	IP-	IP:25	10	-7.7	-8.1	3.7, 4, 4	1, 1, 1	1.686	2.05	DATA NOT VALID DUE TO VISCOSITY ISSUE

4.3 Data Collected

The data collected (9 test runs) as part of the Type III allowance time testing has not been included in this report as the fluid used was deemed not representative. However, the data collected is still available; the completed data forms are stored in the APS archives.

4.4 Issues with 2009-10 Type III Fluid Sample

The Type III fluid sample received for the winter of 2009-10 was packaged, stored, and shipped in a 1000 L tote. Fluid samples used for testing were extracted from the bottom of the tote using the built-in spigot. During the early testing, it was observed that the Type III fluid was sitting thicker on the wing than is typically seen. As testing progressed, the viscosity of the fluid being extracted from the tote changed from very viscous to very low viscosity.

As a result of this, several discussions were held with the fluid manufacturer due to the potential operational implications, as well as due to the implications on the progression of the test plan. It was concluded that the thickener used in the Type III formulation had separated and settled to the bottom of the tote, resulting in a very viscous fluid at the bottom (the early samples extracted) and a much less viscous fluid on the top (which was extracted once all the viscous fluid had been extracted).

Immediately after the issue was determined, numerous verification checks of the fluid were performed by APS; samples were retained, and duplicates were also sent to the fluid manufacturer for their confirmation of viscosity. The samples that were sent were extracted from the top and bottom of the tote. A verification of the fluid viscosity using the Stony Brook portable viscometer indicated that the fluid was indeed more viscous at the bottom. Four comparative measurements were taken of the upper and lower samples; these measurements showed that the lower samples took about 10 times longer than the upper samples for the ball to descend (this confirmed the problem).

The manufacturer specified that this may have been a storage or cross-contamination issue and that this isolated incident was not a reason for alarm concerning current aircraft operations using this type of fluid. However, due to the short timeframe of testing and the time required to obtain a new Type III fluid sample, it was decided by the test team and the fluid manufacturer that testing with Type III fluid would not continue for the winter of 2009-10 and that the data collected for ice pellet allowance time testing would be discarded as it was not representative (some comparative testing data collected for other objectives still had some validity, and these are described in other sections of this report).

This incident had large financial implications due to the high cost of testing in the wind tunnel; testing conducted was not valid and was dismissed. As a result, a new protocol was put into place by APS concerning fluid received in large totes. Future fluid sampling for viscosity testing will be done by extracting fluid from several layers in the tote (i.e., the bottom, the top, and the middle). This will ensure that any future instances where fluid may have separated or may have been contaminated will be identified early on and will minimize the financial impact on the testing performed.

It is recommended that Type III ice pellet allowance time testing continue during the winter of 2010-11 with a fluid sample that has been verified to be within the acceptable specifications for Type III fluids.

5. EFFECTS OF WING SURFACE ROUGHNESS

The current generation of “regional jet” aircraft was developed with supercritical wing designs. Some of these aircraft require strict maintenance procedures to ensure a polished leading edge, as minimal amounts of contamination (in the form of bugs, et cetera) can result in severe aerodynamic penalties. The same requirement applies for the removal of contamination in the form of frozen precipitation.

Previous preliminary wind tunnel testing during the winter of 2006-07 was conducted using a NACA 23012 wing section. This type of airfoil is less susceptible to aerodynamic penalties resulting from contamination (as is also the case with large commuter jet type airfoils). Testing in the wind tunnel with a non-supercritical airfoil demonstrated that although contamination was present on the wing section, significant lift losses were not apparent. Lift losses were incurred upon application of anti-icing fluid (when compared to a bare wing); however, the presence of contamination, whether adhered or not, did not generate significant lift losses when compared to the uncontaminated fluid. Although the presence of adhered contamination may be hazardous with regards to control surfaces, the impact of the different surface roughness types on the overall aerodynamic performance of the wing needs to be further investigated.

Testing was continued during the winter of 2008-09 with a National Aeronautics and Space Administration (NASA) LS(1)-0417 wing section. Similar to the 2006-07 results, although contamination was present on the wing section, significant lift losses were not generally apparent. Larger lift losses were typically observed when contamination was applied directly to the leading edge stagnation point and adhered. The results also indicated that as the angle of rotation increased, the effects of the contamination were more prominent, and the difference in the lift coefficient data was consequently increased.

It was recommended that some preliminary work be conducted with a supercritical wing to investigate the effects of various types of adhered frozen contamination on the aerodynamic performance of the airfoil and, more specifically, the potential for an early wing stall as a result of a contaminated wing section. This section of the report provides an overview of each test conducted as part of the test program to evaluate the effects of wing surface roughness on aerodynamic performance.

5.1 General Methodology

The following is a brief summary of the methodology used for this testing:

- Ensure OAT is below -5°C to ensure cold-adhered contamination;

- Begin the application of precipitation (a combination of ice pellets, light freezing rain, and snow) for a pre-determined amount of time;
- Run wind tunnel tests and collect lift loss data;
- Compare results to typical dry wing results conducted at similar temperatures (and fluid only or contaminated fluid results if necessary);
- Increase or reduce level of contamination to determine wing sensitivity and resulting lift losses; and
- Document amount and type of contamination used.

It should be noted that during the 2009-10 tests, only three tests were conducted, and the contamination was not applied directly to a dry wing. Tests #45, #45A, and #45B were conducted using the adhered contamination that remained following Test #44; due to the severe contamination present following Test #44, it was deemed acceptable and representative for the purpose of these tests.

5.2 Overview of Tests

A summary of the effect of surface roughness tests conducted in the wind tunnel is shown in Table 5.1. The table 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. A more detailed test log of all conditions tested using the wind tunnel is provided in Subsection 3.1. The following is a brief description of the column headings for Table 5.1.

Test #:	Exclusive number identifying each test.
Date:	Date when the test was conducted.
Fluid:	Aircraft deicing fluid specified by product name; all fluids were in the “neat” 100/0 dilution.
Associated Baseline Run:	The associated fluid only baseline run based on fluid selection.
Condition:	Simulated precipitation condition.
Precipitation Rate (g/dm^2/h):	Simulated freezing precipitation rate (or combination of different precipitation rates). “N/A” indicates that no precipitation was applied.
Precip. Time (min.):	Total time of exposure to simulated precipitation.

Tunnel Temp. at Start of Test (ºC):	The tunnel ambient temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.
Avg. Wing Temp. Before Test (ºC):	Average of the wing skin temperature measurements just before the start of the simulated takeoff test, recorded in degrees Celsius.
Visual Contamination Rating Before Takeoff (LE, TE, Flap):	Visual contamination rating determined before the start of the simulated takeoff: 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 - Contamination visible, adherence of contamination.
Visual Contamination Rating at Rotation (LE, TE, Flap):	Visual contamination rating determined at the time of rotation: 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 - Contamination visible, adherence of contamination.
CL at 8º During Rotation:	Calculated lift coefficient at the 8º wing rotation angle position; data provided by the NRC.
% Lift Loss:	Percentage lift loss calculated based on the comparison of the 8º lift coefficient during the test run versus the dry wing average lift coefficient (calculated to be 1.7213).

Table 5.1: Summary of 2009-10 Effect of Surface Roughness Testing

Test No.	Date	Fluid	Associated Baseline Run	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° Rotation	% Lift Loss	Comments
45	23-Jan-10	EG 106 Applied in Test 44	46	IP/R Applied in Test 44	IP:25, R:75	40	-6	N/A	5, 5, 5	5, 5, 5	1.246	27.61	Repeat of Test #44 with 13° Rotation
45A	23-Jan-10	EG 106 Applied in Test 44	46	IP/R Applied in Test 44	IP:25, R:75	40	-6.1	N/A	5, 5, 5	5, 5, 5	1.278	25.75	Repeat of Test #44 with 15° Rotation
45B	23-Jan-10	EG 106 Applied in Test 44	46	IP/R Applied in Test 44	IP:25, R:75	40	-4.1	N/A	5, 5, 5	5, 5, 5	1.31	23.89	8 inches of Cont. removed from leading edge. 15° Rotation
46	23-Jan-10	No Fluid	N/A	Dry Wing	N/A	N/A	-3.5	N/A	-, -, -	-, -, -	1.713	0.48	

5.3 Data Collected

5.3.1 Fluid Thickness Data

No fluid thickness measurements were collected because there was no fluid applied to the wing surface for the tests conducted.

5.3.2 Skin Temperature Data

The wing surface was covered in ice; therefore, no skin temperature measurements were recorded during the tests.

5.3.3 Fluid Brix Data

No fluid Brix measurements were collected because there was no fluid applied to the wing surface for the tests conducted.

5.4 Photos

High-speed digital photography of each test was taken. For each test, wide-angle photos were taken of the leading edge, and close-up photos were taken of the trailing edge. For each of the tests, photo summaries have been compiled comprising four stages:

- Start of test;
- Before Rotation (just before the wing began to pitch);
- End of Rotation (end of the rotation cycle when the wing position is returned to four degrees); and
- End of test.

Photos 5.1 to 5.12 show the photo summaries of the tests conducted. A complete set of photos will be provided to the TDC in electronic format.

5.5 Summary of Test Results

The objective of the testing was to identify the effect of contamination on stall angle and on lift loss. Three back-to-back tests were conducted with a severely contaminated wing (adhered ice pellet and rain contamination). During Test #45, the wing was rotated to a maximum angle of 13º; however, no appreciable stall was observed. The test was repeated (Test #45A) but with a 15° max rotation angle. During this test, the wing section experienced a stall at an angle of attack of approximately 13.8°. The test was once again repeated; however, the first 20 cm (8 in.) of the leading were cleaned of any adhered contamination. During this test (Test #45B), the wing section experienced a stall at a shallower angle of attack of approximately 13.6°. To get a baseline, the wing section was completely cleaned of any contamination, and the 15° max rotation test run was conducted. During this test (Test #46), the wing section experienced a stall at the lowest angle of attack of approximately 12.4°. The lift losses for all four tests were calculated based on the 8° CL and were compared to Test #46, which was considered to be the baseline for this series of tests. Table 5.2 summarizes the test results. Figure 5.1 demonstrates the three lift coefficient curves for Tests #45A, #45B, and #46; it should be noted that the increase in CL during Test #45B at approximately 60 seconds is due to a large section of frozen contamination being shed during the test, which improved performance.

The lift loss data collected indicated that the aerodynamic performance at 8° rotation improved as the wing section became increasingly clean from Tests #45A, to #45B, and to #46, respectively. However, the stall angle data demonstrated results that were counterintuitive, whereby the wing seemed to stall at a higher angle when contaminated compared to the clean wing. It is not uncommon in aerodynamics for added surface roughness to delay stall on airfoils. Depending on the degree of roughness, added contamination can delay the stall angle by promoting the turbulent boundary layer on the airfoil. However, this benefit will typically be accompanied by a drag penalty (due to added skin friction) and a lower lift coefficient. This observation is of particular importance if future testing is to explore stall margin rather than lift loss. Additional testing is recommended to further investigate this phenomenon, and to understand its potential impact on aircraft operations.

Table 5.2: Comparison of Lift and Stall Angle Data

Test #	Condition	Max Rotation Angle (º)	8º CL	% LL at 8º (Test #46 Baseline)	Stall Angle (º)
45	Fully Contaminated	13	1.246	27.3%	No appreciable stall at 13º
45A	Fully Contaminated	15	1.278	25.4%	13.77
45B	LE Clean / Contaminated	15	1.31	23.5%	13.61
46	Clean Wing	15	1.713	-	12.35

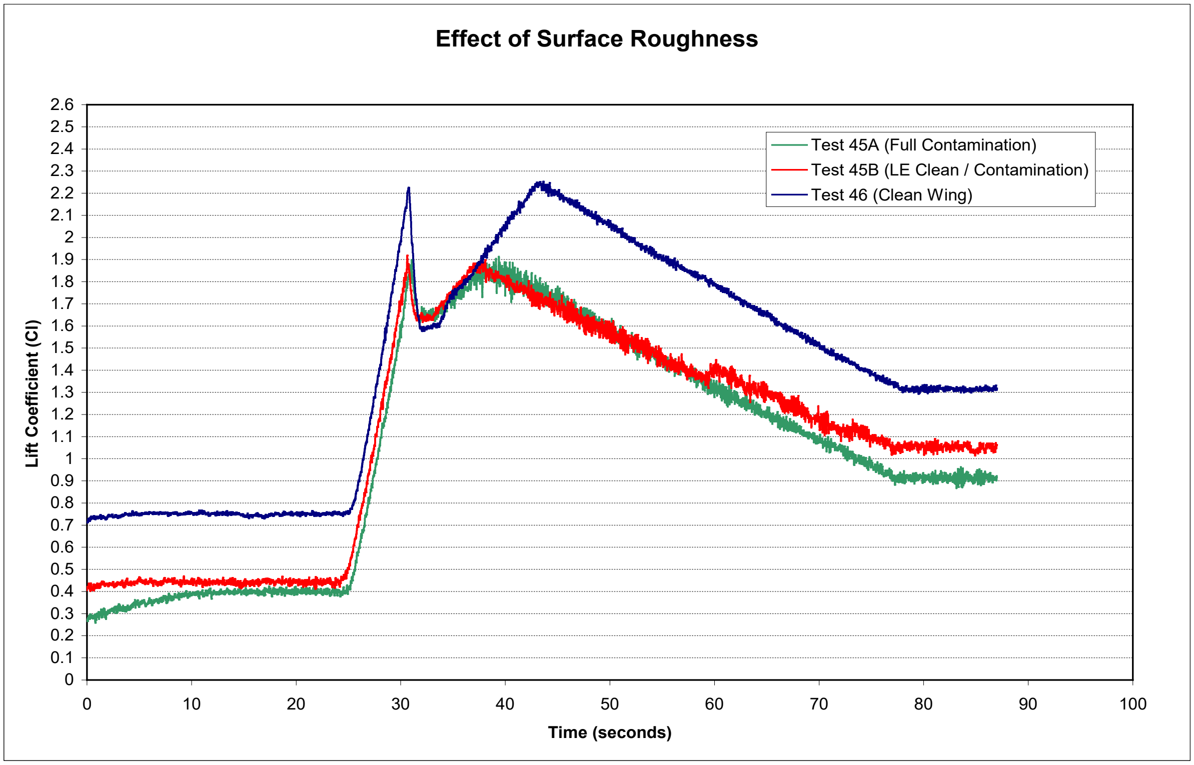

Figure 5.1: Comparison of Lift Coefficient Data — Effect of Surface Roughness Tests

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Photo 5.1: Test #45 – Start of Test

Test #45
EG106, IP+R 25+75 g/dm²/h, 40 min
-6°C, 13° Rotation
Visual Contamination Rating (5,5,5)
Start of Test

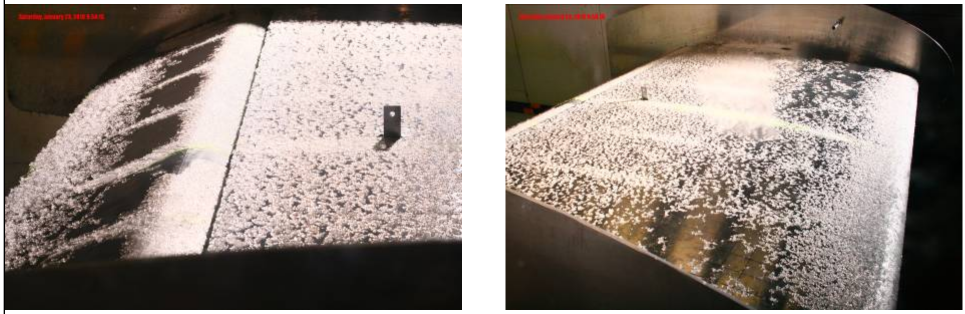


Photo 5.2: Test #45 – Before Rotation

Test #45
EG106, IP+R 25+75 g/dm²/h, 40 min
-6°C, 13° Rotation
Visual Contamination Rating (5,5,5)
Before Rotation

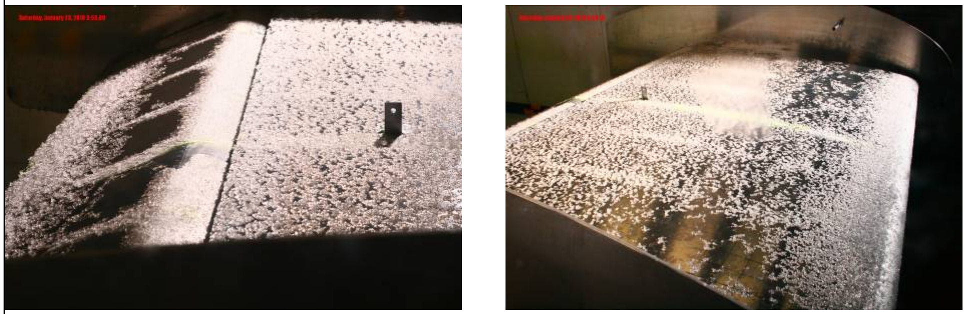
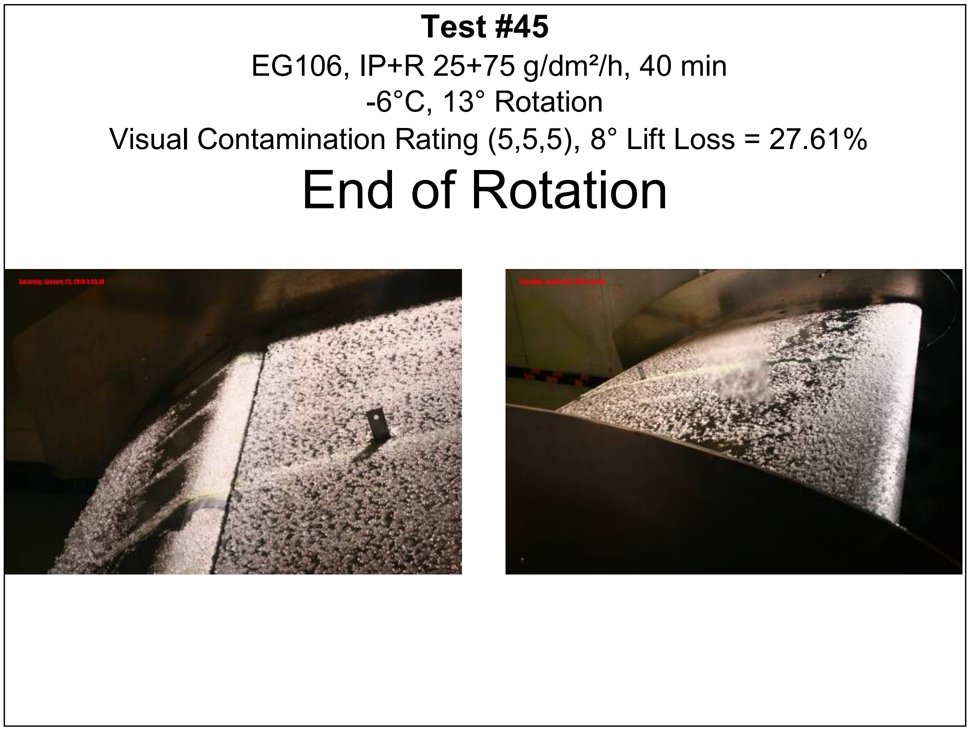


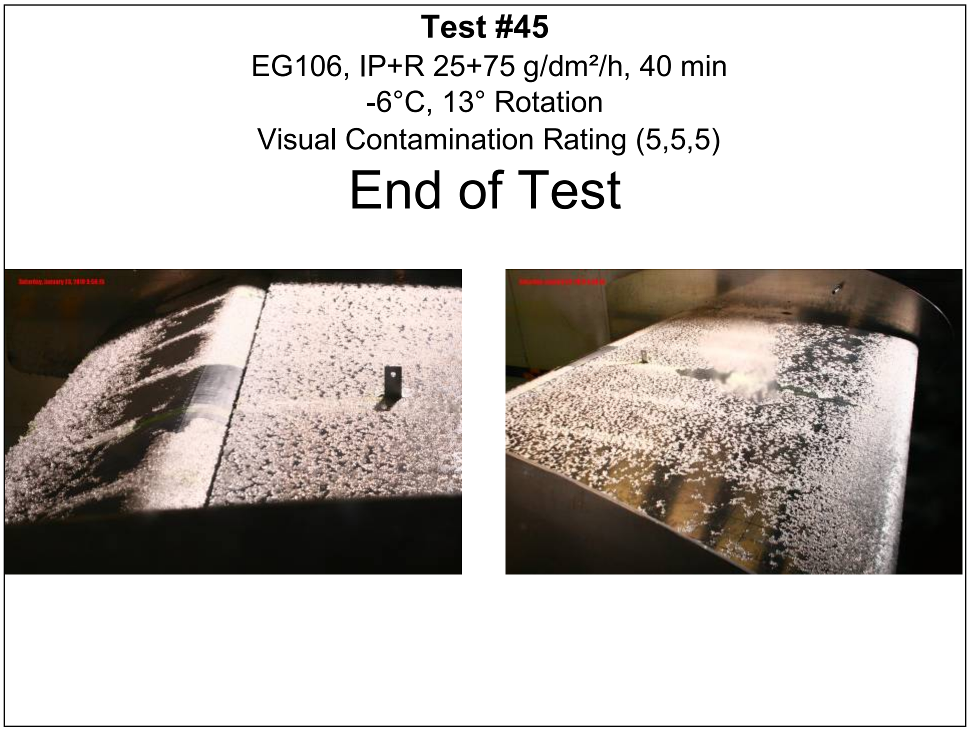
Photo 5.3: Test #45 – End of Rotation



Test #45
EG106, IP+R 25+75 g/dm²/h, 40 min
-6°C, 13° Rotation
Visual Contamination Rating (5,5,5), 8° Lift Loss = 27.61%

End of Rotation

Photo 5.4: Test #45 – End of Test



Test #45
EG106, IP+R 25+75 g/dm²/h, 40 min
-6°C, 13° Rotation
Visual Contamination Rating (5,5,5)

End of Test

Photo 5.5: Test #45A – Start of Test

Test #45A
EG106, IP+R 25+75 g/dm²/h, 40 min (Applied In Run #44)
-6°C, 15° Rotation
Visual Contamination Rating Same as Run 45 (5,5,5)

Start of Test

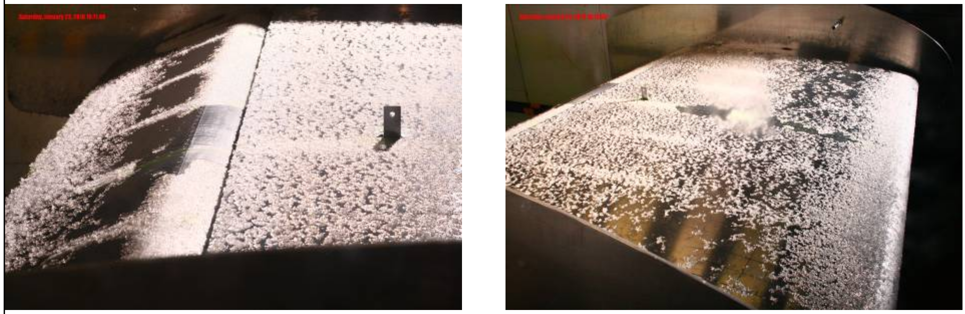


Photo 5.6: Test #45A – Before Rotation

Test #45A
EG106, IP+R 25+75 g/dm²/h, 40 min (Applied In Run #44)
-6°C, 15° Rotation
Visual Contamination Rating Same as Run 45 (5,5,5)

Before Rotation

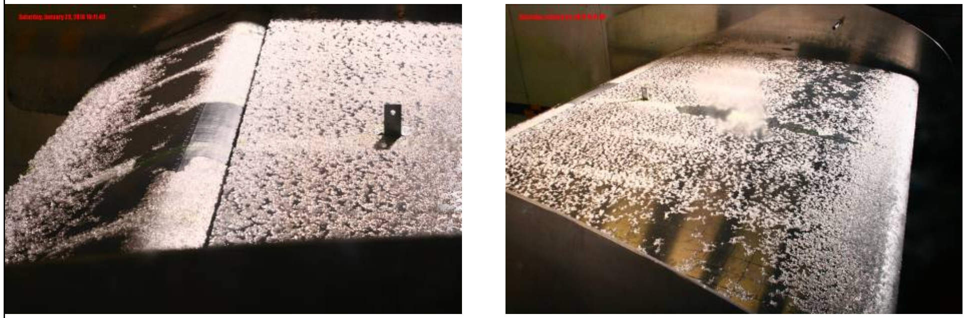


Photo 5.7: Test #45A – End of Rotation

Test #45A
EG106, IP+R 25+75 g/dm²/h, 40 min (Applied In Run #44)
-6°C, 15° Rotation,
Visual Contamination Rating Same as Run 45 (5,5,5)
8° Lift Loss = 25.75%

End of Rotation

Photo 5.8: Test #45A – End of Test

Test #45A
EG106, IP+R 25+75 g/dm²/h, 40 min (Applied In Run #44)
-6°C, 15° Rotation
Visual Contamination Rating Same as Run 45 (5,5,5)

End of Test

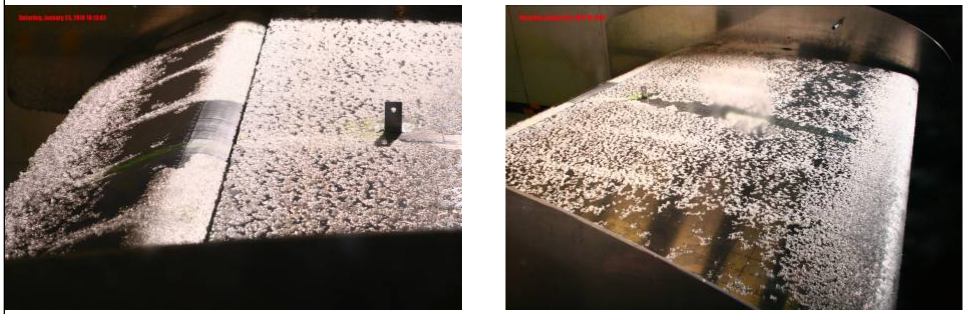
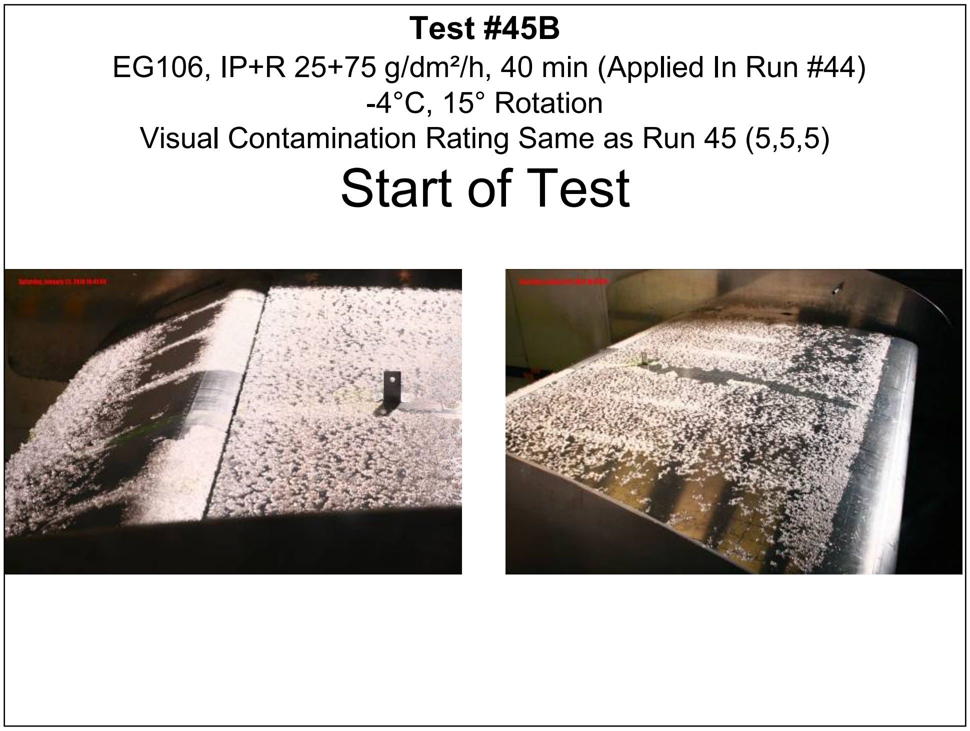
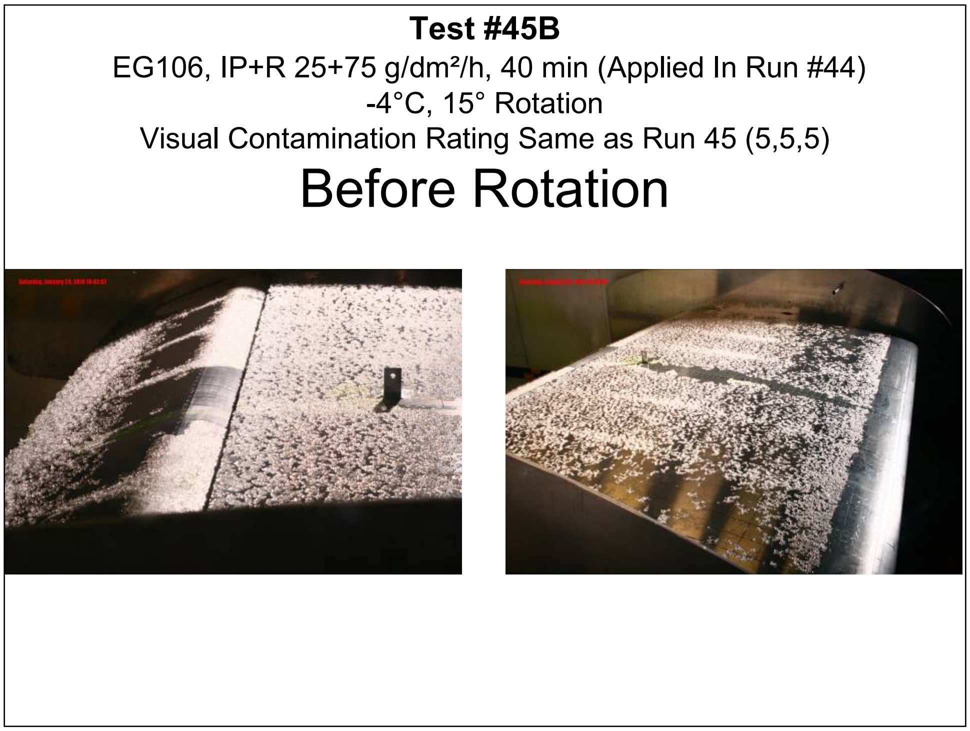


Photo 5.9: Test #45B – Start of Test



Test #45B
EG106, IP+R 25+75 g/dm²/h, 40 min (Applied In Run #44)
-4°C, 15° Rotation
Visual Contamination Rating Same as Run 45 (5,5,5)
Start of Test

Photo 5.10: Test #45B – Before Rotation



Test #45B
EG106, IP+R 25+75 g/dm²/h, 40 min (Applied In Run #44)
-4°C, 15° Rotation
Visual Contamination Rating Same as Run 45 (5,5,5)
Before Rotation

Photo 5.11: Test #45B – End of Rotation

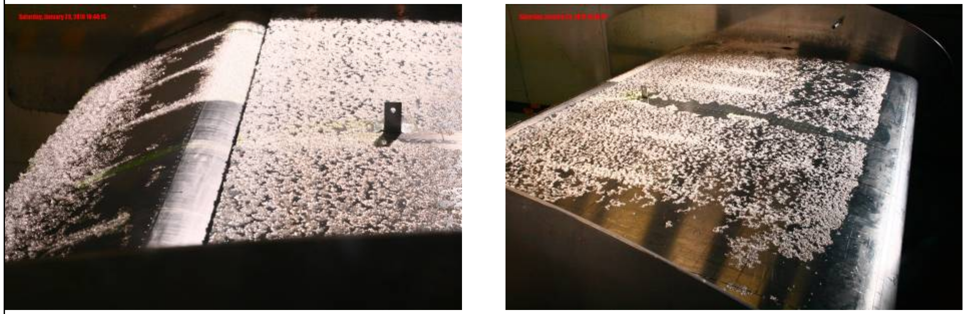
Test #45B
EG106, IP+R 25+75 g/dm²/h, 40 min (Applied In Run #44)
-4°C, 15° Rotation,
Visual Contamination Rating Same as Run 45 (5,5,5)
8° Lift Loss = 23.89%

End of Rotation

Photo 5.12: Test #45B – End of Test

Test #45B
EG106, IP+R 25+75 g/dm²/h, 40 min (Applied In Run #44)
-4°C, 15° Rotation
Visual Contamination Rating Same as Run 45 (5,5,5)

End of Test



6. EFFECTS OF A CONTAMINATED FLAP

Testing during the winter of 2009-10 was conducted with a generic supercritical wing model. Early on in the testing, it was apparent that the wing model was more sensitive to lift losses compared to the previous non-supercritical wing models used during 2006-07 and 2008-09. In addition, the 2009-10 wing section had a hinged flap that is exposed to precipitation in both the extended and retracted configuration as compared to a nested flap (the 2008-09 wing model), which is protected from the elements when retracted. In order to better understand the aerodynamic behaviour of the wing when contaminated, several tests were conducted with adhered contamination on the wing section (see Section 5). In order to understand the effects of a contaminated flap, it was recommended that testing be conducted with varying levels of adhered contamination on the flap section. The purpose was to identify how much of the lift losses observed could be attributed to a contaminated flap.

6.1 General Methodology

The following is a brief summary of the methodology used for this testing:

- Ensure the wing section is clean and dry;
- Ensure OAT is below -5ºC to ensure cold-adhered contamination;
- Begin the application of precipitation (a combination of ice pellets, light freezing rain, and snow) for a pre-determined amount of time to the flap section;
- Run wind tunnel tests and collect lift loss data;
- Compare results to typical dry wing results conducted at similar temperatures (fluid only and contaminated fluid results if necessary);
- Increase or reduce level of contamination to determine wing sensitivity and resulting lift losses; and
- Document amount and type of contamination used.

It should be noted that contamination was applied by hand to the flap section and to the flap leading edge stagnation point, as it was believed that this would have the greatest impact on aerodynamic performance. The contamination was then removed systematically to investigate the aerodynamic impact.

6.2 Overview of Tests

A summary of the effect of contaminated flap tests conducted in the wind tunnel is shown in Table 6.1. The table 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. A more detailed test log of all conditions tested using the wind tunnel is provided in Subsection 3.1. The following is a brief description of the column headings for Table 6.1.

Test #:	Exclusive number identifying each test.
Date:	Date when the test was conducted.
Fluid:	Aircraft deicing fluid specified by product name; all fluids were in the "neat" 100/0 dilution.
Associated Baseline Run:	The associated fluid only baseline run based on fluid selection.
Condition:	Simulated precipitation condition.
Precipitation Rate (g/dm²/h):	Simulated freezing precipitation rate (or combination of different precipitation rates). "N/A" indicates that no precipitation was applied.
Precip. Time (min.):	Total time of exposure to simulated precipitation.
Tunnel Temp. at Start of Test (°C):	The tunnel ambient temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.
Avg. Wing Temp. Before Test (°C):	Average of the wing skin temperature measurements just before the start of the simulated takeoff test, recorded in degrees Celsius.
Visual Contamination Rating Before Takeoff (LE, TE, Flap):	Visual contamination rating determined before the start of the simulated takeoff: 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 - Contamination visible, adherence of contamination.
Visual Contamination Rating at Rotation (LE, TE, Flap):	Visual contamination rating determined at the time of rotation: 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 - Contamination visible, adherence of contamination.
CL at 8° During Rotation:	Calculated lift coefficient at the 8° wing rotation angle position; data provided by the NRC.
% Lift Loss:	Percentage lift loss calculated based on the comparison of the 8° lift coefficient during the test run versus the dry wing average lift coefficient (calculated to be 1.7213).

Table 6.1: Summary of 2009-10 Effect of Contaminated Flap Testing

Test No.	Date	Fluid	Associated Baseline Run	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° Rotation	% Lift Loss	Comments
6	11-Jan-10	N/A	Dry Wing	IP/ZR	IP:23, ZR:28 Applied by Hand	20	-4.2	N/A	1, 1, 5	1, 1, 5	1.255	27.09	Target of 16° Rotation, Got 20° (Malfunction). All Flap Contaminated.
6A	11-Jan-10	N/A	Dry Wing	IP/ZR	Contamination present from previous test	-	-4.6	N/A	-, -, -	-, -, -	1.2355	28.22	Repeat of Test #6 with 12° Rotation
6B	12-Jan-10	N/A	Dry Wing	IP/ZR	IP:13, ZR:11 Applied by Hand	20	-10.3	N/A	1, 1, 5	1, 1, 5	1.443	16.17	No Contamination On Stagnation point, 13° Rotation.
6C	12-Jan-10	N/A	Dry Wing	IP/ZR	Contamination present from previous test	-	-10.3	N/A	1, 1, 5	1, 1, 5	1.715	0.37	No contamination on leading half of flap. 13° Rotation.

6.3 Data Collected

6.3.1 Fluid Thickness Data

No fluid thickness measurements were collected because there was no fluid applied to the wing surface for the tests conducted.

6.3.2 Skin Temperature Data

The wing flap surface was covered in ice and measurements on the main wing section were not critical; therefore, no skin temperature measurements were recorded during the tests.

6.3.3 Fluid Brix Data

No fluid Brix measurements were collected because there was no fluid applied to the wing surface for the tests conducted.

6.4 Photos

High-speed digital photography of each test was taken. For each test, wide-angle photos were taken of the leading edge, and close-up photos were taken of the trailing edge. For each of the tests, photo summaries have been compiled comprising four stages:

- Start of test;
- Before Rotation (just before the wing began to pitch);
- End of Rotation (end of the rotation cycle when the wing position is returned to four degrees); and
- End of test.

Photos 6.1 to 6.16 show the photo summaries of the tests conducted. A complete set of photos will be provided to the TDC in electronic format.

6.5 Summary of Test Results

The objective of the testing was to identify the effect of a contaminated flap on lift loss. Four back-to-back tests were conducted with a severely contaminated flap section (adhered ice pellet and rain contamination); however, the main wing section remained clean during the tests. Some contamination was applied by hand to ensure a proper application around the flap stagnation point.

During Test #6, the wing was rotated to a maximum angle of 16º; however, due to a malfunction in the system, the wing rotated to close to 20º. Although the data collected was accurate, the test was repeated to ensure appropriate results. The test was repeated (Test #6A), however, with a 12º max rotation angle. During this test, the wing section experienced significant lift losses: 28 percent lift loss compared to the dry wing case.

The test was once again repeated (Test #6B). Here, the first 10 cm (4 in.) of the leading edge of the flap were cleaned of any adhered contamination. During this test, the wing section experienced less lift loss; however, the lift losses were still severe: 16 percent lift loss compared to the dry wing case.

For the last test (Test #6C), the leading half of the flap (approximately 25 cm) was cleaned of any adhered contamination. During this test, the wing section experienced a significant improvement in lift loss: lift losses were minimal (0.4 percent) compared to the dry wing case.

The results of this testing indicated that a contaminated flap section can have significant impact on aerodynamic performance. The most severe lift losses were observed when the leading edge section and stagnation point of the flap were contaminated.

Some additional work was conducted to investigate the aerodynamic improvement resulting from having the flap up versus down during taxi following anti-icing; this work is described in TP 15232E (Vol. 2) (2). The results of the work included in the interim report are consistent with the results observed during this testing, indicating that a contaminated flap can have significant adverse effects on aerodynamic performance.

Photo 6.1: Test #6 – Start of Test

Test #6
IP+ZR 23+28 g/dm²/h, 20 min
-4°C, 20° Rotation
Visual Contamination Rating (1,1,5)
Start of Test

Photo 6.2: Test #6 – Before Rotation

Test #6
IP+ZR 23+28 g/dm²/h, 20 min
-4°C, 20° Rotation
Visual Contamination Rating (1,1,5)
Before Rotation

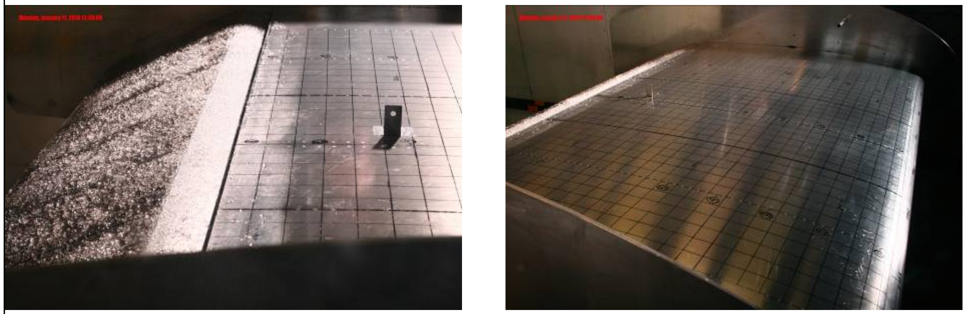
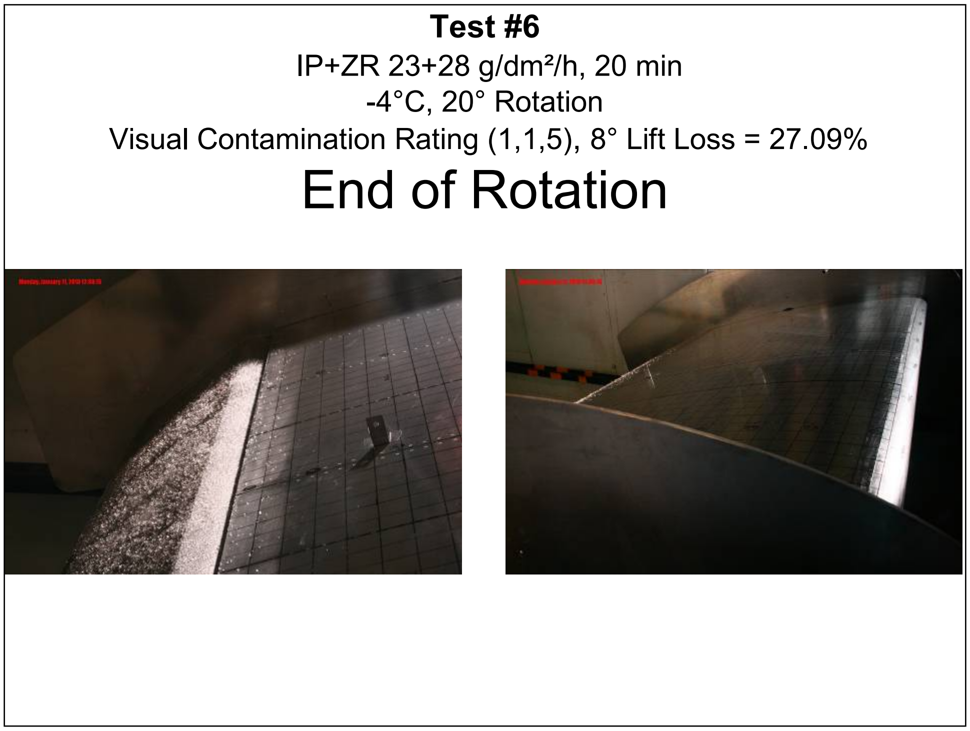
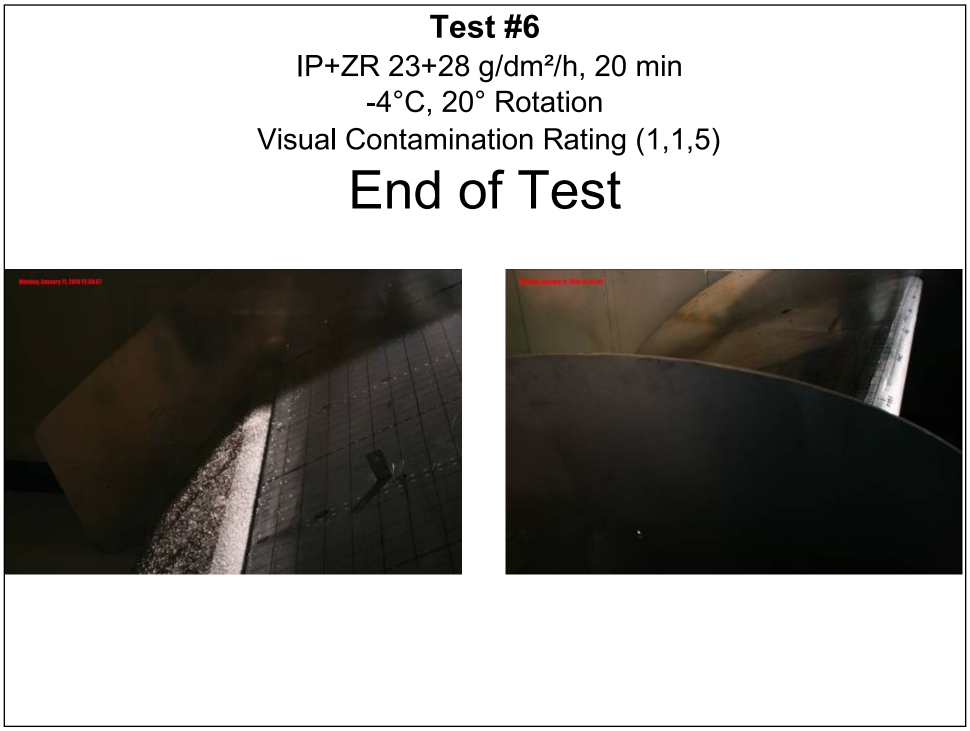


Photo 6.3: Test #6 – End of Rotation



Test #6
IP+ZR 23+28 g/dm²/h, 20 min
-4°C, 20° Rotation
Visual Contamination Rating (1,1,5), 8° Lift Loss = 27.09%
End of Rotation

Photo 6.4: Test #6 – End of Test



Test #6
IP+ZR 23+28 g/dm²/h, 20 min
-4°C, 20° Rotation
Visual Contamination Rating (1,1,5)
End of Test

Photo 6.5: Test #6A – Start of Test

No Photo Documentation Available

Photo 6.6: Test #6A – Before Rotation

No Photo Documentation Available

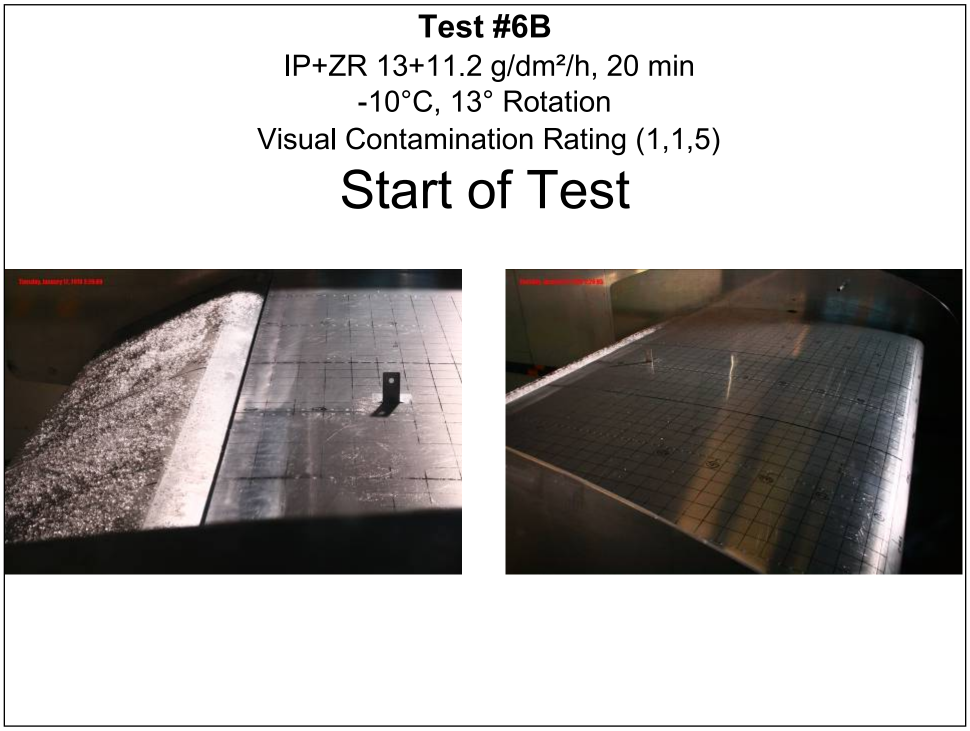
Photo 6.7: Test #6A – End of Rotation

No Photo Documentation Available

Photo 6.8: Test #6A – End of Test

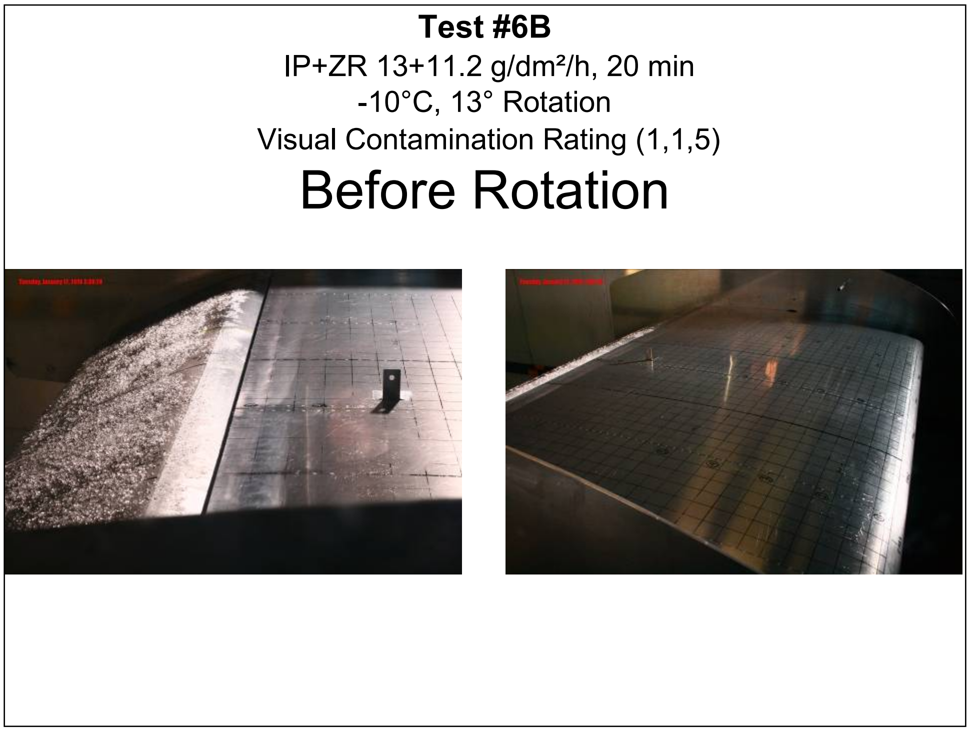
No Photo Documentation Available

Photo 6.9: Test #6B – Start of Test



Test #6B
IP+ZR 13+11.2 g/dm²/h, 20 min
-10°C, 13° Rotation
Visual Contamination Rating (1,1,5)
Start of Test

Photo 6.10: Test #6B – Before Rotation



Test #6B
IP+ZR 13+11.2 g/dm²/h, 20 min
-10°C, 13° Rotation
Visual Contamination Rating (1,1,5)
Before Rotation

Photo 6.11: Test #6B – End of Rotation

Test #6B

IP+ZR 13+11.2 g/dm²/h, 20 min
-10°C, 13° Rotation
Visual Contamination Rating (1,1,5), 8° Lift Loss = 16.17%

End of Rotation

Photo 6.12: Test #6B – End of Test

Test #6B

IP+ZR 13+11.2 g/dm²/h, 20 min
-10°C, 13° Rotation
Visual Contamination Rating (1,1,5)

End of Test

Photo 6.13: Test #6C – Start of Test

Test #6C
IP+ZR 13+11.2 g/dm²/h, 20 min (Applied In Run #6B)
-10°C, 13° Rotation
Visual Contamination Rating (1,1,5)
Start of Test

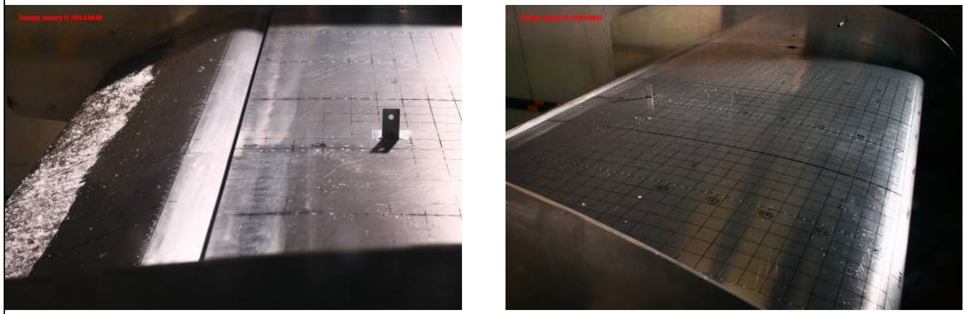


Photo 6.14: Test #6C – Before Rotation

Test #6C
IP+ZR 13+11.2 g/dm²/h, 20 min (Applied In Run #6B)
-10°C, 13° Rotation
Visual Contamination Rating (1,1,5)
Before Rotation

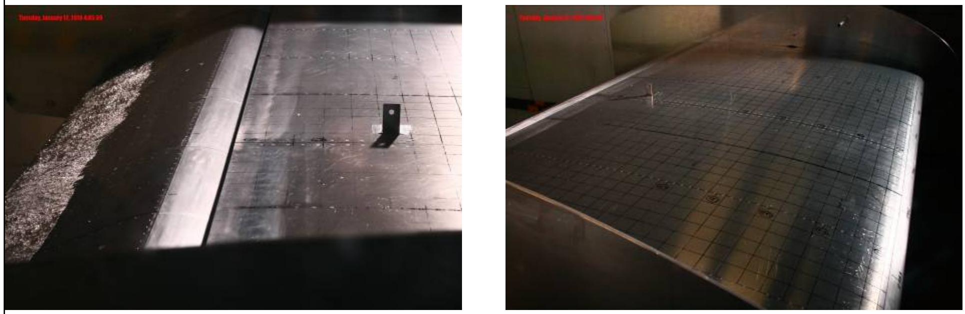
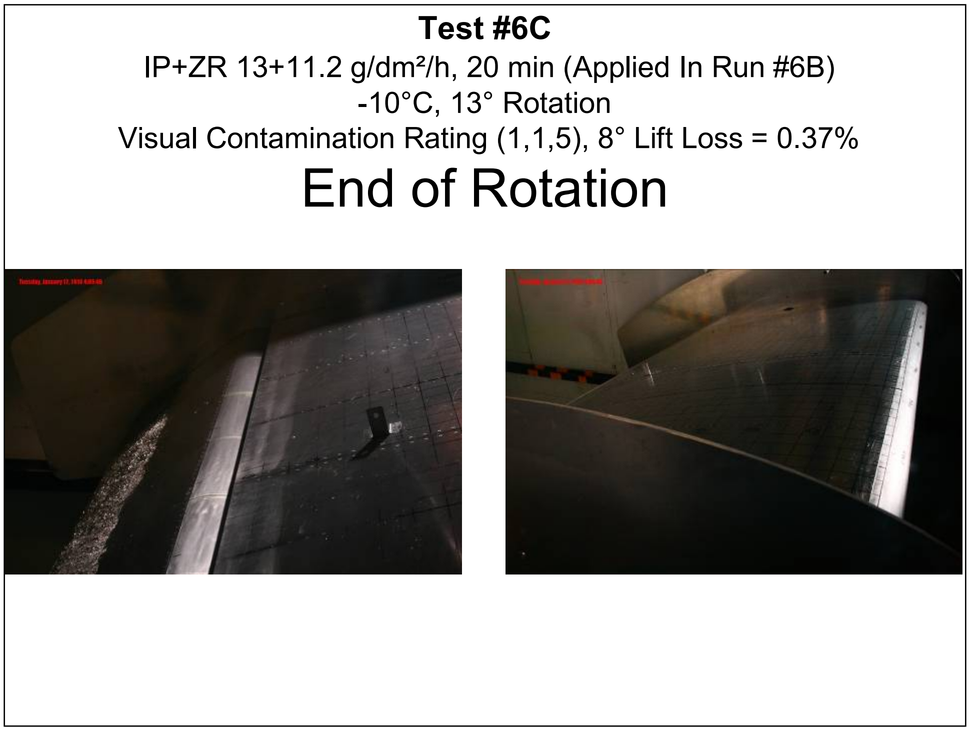
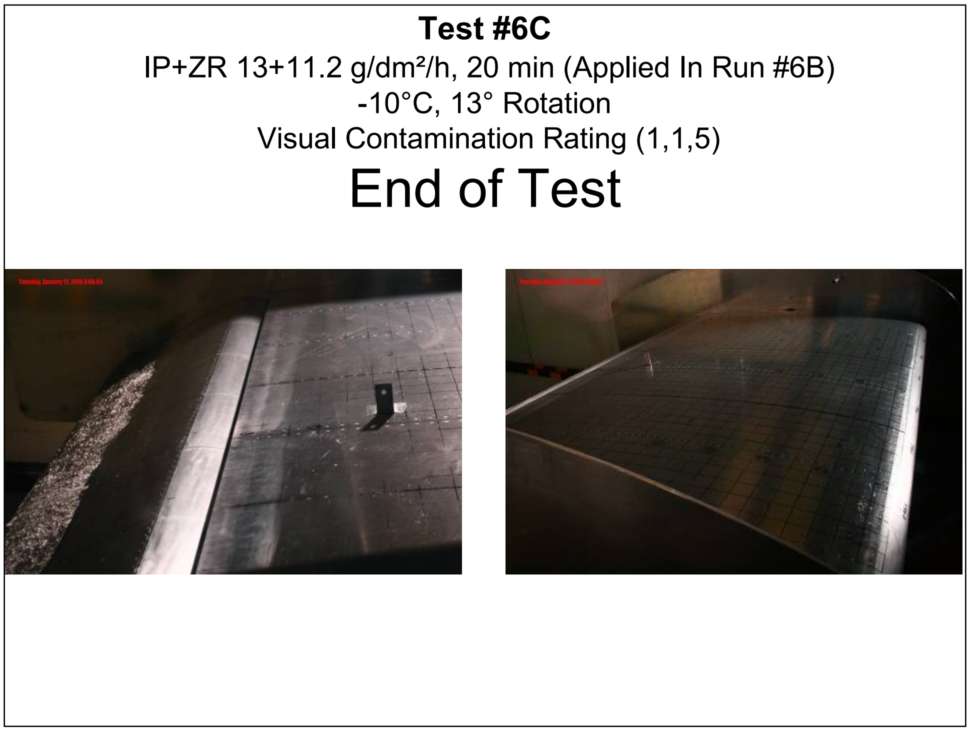


Photo 6.15: Test #6C – End of Rotation



Test #6C
IP+ZR 13+11.2 g/dm²/h, 20 min (Applied In Run #6B)
-10°C, 13° Rotation
Visual Contamination Rating (1,1,5), 8° Lift Loss = 0.37%
End of Rotation

Photo 6.16: Test #6C – End of Test



Test #6C
IP+ZR 13+11.2 g/dm²/h, 20 min (Applied In Run #6B)
-10°C, 13° Rotation
Visual Contamination Rating (1,1,5)
End of Test

7. EFFECTS OF APPLYING EXCESSIVE AMOUNTS OF ANTI-ICING FLUID

During the 2009-10 wind tunnel testing, it was observed that fluid applied to the supercritical wing section would not flow-off as readily compared to previous wing sections tested. The geometry of the supercritical wing produced a relatively flat top surface aft of the leading edge. As a result of this, fluid applied to the wing would generally sit thicker compared to previous testing conducted with wings with shallower top surface angles. Due to this phenomenon, it was recommended that testing be conducted to investigate the effects of having applied excessive amounts of anti-icing fluid. The purpose was to identify if the aerodynamic performance of the wing would be changed if greater amounts of fluid were applied and whether the fluid would collect on the top surface and increase lift losses.

7.1 General Methodology

The methodology used during these tests was in accordance with the methodologies described in Section 2. The comparative testing was done using a typical fluid application (approximately 18 L to 20 L applied to the wing) versus an excessive fluid application (approximately 40 L applied to the wing). No contamination was applied during these tests.

7.2 Overview of Tests

A summary of the excessive application of anti-icing fluid tests conducted in the wind tunnel is shown in Table 7.1. The table 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. A more detailed test log of all conditions tested using the wind tunnel is provided in Subsection 3.1. The following is a brief description of the column headings for Table 7.1.

Test #:	Exclusive number identifying each test.
Date:	Date when the test was conducted.
Fluid:	Aircraft deicing fluid specified by product name; all fluids were in the “neat” 100/0 dilution.
Associated Baseline Run:	The associated fluid only baseline run based on fluid selection.
Condition:	Simulated precipitation condition.

Precipitation Rate (g/dm^2/h):	Simulated freezing precipitation rate (or combination of different precipitation rates). "N/A" indicates that no precipitation was applied.
Precip. Time (min.):	Total time of exposure to simulated precipitation.
Tunnel Temp. at Start of Test (°C):	The tunnel ambient temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.
Avg. Wing Temp. Before Test (°C):	Average of the wing skin temperature measurements just before the start of the simulated takeoff test, recorded in degrees Celsius.
Visual Contamination Rating Before Takeoff (LE, TE, Flap):	Visual contamination rating determined before the start of the simulated takeoff: 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 - Contamination visible, adherence of contamination.
Visual Contamination Rating at Rotation (LE, TE, Flap):	Visual contamination rating determined at the time of rotation: 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 - Contamination visible, adherence of contamination.

CL at 8º During Rotation:	Calculated lift coefficient at the 8º wing rotation angle position; data provided by the NRC.
% Lift Loss:	Percentage lift loss calculated based on the comparison of the 8º lift coefficient during the test run versus the dry wing average lift coefficient (calculated to be 1.7213).

Table 7.1: Summary of 2009-10 Excessive Application of Anti-Icing Fluid Testing

Test No.	Date	Fluid	Associated Baseline Run	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° Rotation	% Lift Loss	Comments
7	12-Jan-10	ABC-S Plus	8	Fluid Only	N//A	N//A	-9.7	-9.1	1, 1, 1	1, 1, 1	1.668	3.10	Double fluid quantity applied (approx 40L)
8	12-Jan-10	ABC-S Plus	N/A	Fluid Only	N//A	N//A	-8.8	-7.9	1, 1, 1	1, 1, 1	1.668	3.10	Standard application (approx 20L)

7.3 Data Collected

7.3.1 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Subsection 2.16.2. Fluid thickness measurements were recorded at the following intervals:

- After fluid application;
- After application of contamination; and
- After the simulated takeoff test.

Tables 7.2 to 7.3 show the fluid thickness measurements collected during the contaminated fluid tests.

Table 7.2: Test #7 Fluid Thickness Data

Test 7: Fluid Only, ABC-S Plus, Tunnel OAT -9.7°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.5	N/A	0.0
2	2.2	N/A	0.2
3	3.1	N/A	0.1
4	4.5	N/A	0.1
5	5.7	N/A	0.2
6	5.7	N/A	0.2
7	7.0	N/A	0.2
8	5.7	N/A	0.2
Flap	1.0	N/A	0.1

Table 7.3: Test #8 Fluid Thickness Data

Test 8: Fluid Only, ABC-S Plus, Tunnel OAT -8.8°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.3	N/A	0.0
2	2.2	N/A	0.1
3	3.1	N/A	0.2
4	4.5	N/A	0.2
5	5.7	N/A	0.2
6	4.5	N/A	0.2
7	4.5	N/A	0.2
8	3.3	N/A	0.2
Flap	1.0	N/A	0.2

7.3.2 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Subsection 2.16.3. Skin temperature measurements were recorded at the following intervals:

- Before fluid application;
- After fluid application;
- After application of contamination; and
- After the simulated takeoff test.

Tables 7.4 to 7.5 show the wing temperature measurements recorded during the contaminated fluid tests.

Table 7.4: Test #7 Wing Skin Temperature Data

Test 7: Fluid Only, ABC-S Plus, Tunnel OAT -9.7°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	N/A	-8.7	N/A	-7.7
T5	N/A	-9.2	N/A	-7.3
TU	N/A	-9.4	N/A	-8.7

Table 7.5: Test #8 Wing Skin Temperature Data

Test 8: Fluid Only, ABC-S Plus, Tunnel OAT -8.8°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-7.3	-8.0	N/A	-7.5
T5	-7.2	-7.7	N/A	-6.5
TU	-8.3	-8.1	N/A	-7.9

7.3.3 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Subsection 2.16.4. Fluid Brix measurements were recorded at the following intervals:

- After fluid application;
- After application of contamination; and
- After the simulated takeoff test.

Tables 7.6 to 7.7 show the fluid Brix measurements collected during the contaminated fluid tests.

Table 7.6: Test #7 Fluid Brix Data

Test 7: Fluid Only, ABC-S Plus, Tunnel OAT -9.7°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	N/A	N/A	N/A
8	N/A	N/A	N/A

Table 7.7: Test #8 Fluid Brix Data

Test 8: Fluid Only, ABC-S Plus, Tunnel OAT -8.8°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.25	N/A	38.25
8	37	N/A	38.25

7.4 Photos

High-speed digital photography of each test was taken. For each test, wide-angle photos were taken of the leading edge, and close-up photos were taken of the trailing edge. For each of the tests, photo summaries have been compiled comprising four stages:

- Start of test;
- Before Rotation (just before the wing began to pitch);
- End of Rotation (end of the rotation cycle when the wing position is returned to four degrees); and
- End of test.

Photos 7.1 to 7.8 show the photo summaries of the tests conducted (photos have been arranged so as to demonstrate a comparison at each stage of the test). A complete set of photos will be provided to the TDC in electronic format.

7.5 Summary of Test Results

The geometry of the supercritical wing produced a relatively flat top surface aft of the leading edge. As a result of this, fluid applied to the wing would generally sit thicker compared to previous testing conducted with wings with shallower top surface angles. Figure 7.1 demonstrates a simplified comparison of the wing top surface angles for the different wing models tested.

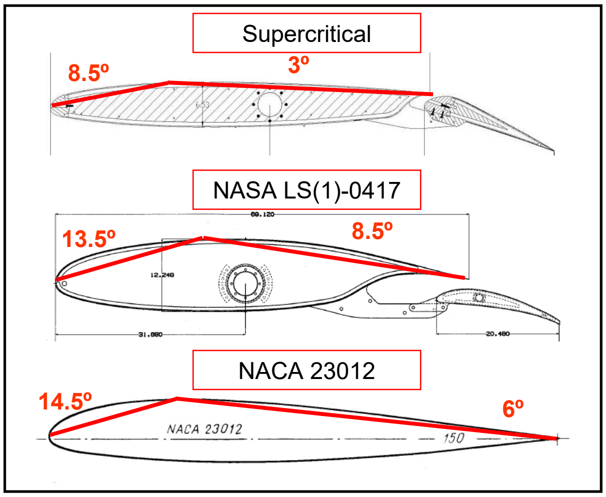


Figure 7.1: Comparison of Wing Top Surface Angles

The objective of the comparative testing was to investigate potential negative aerodynamic effects associated with applying excessive amounts of anti-icing fluid to a wing. Two comparative tests were conducted: Test #7, which used twice the typical amount of fluid (approximately 40 L), and the baseline Test #8, which used a typical fluid application (approximately 20 L).

The fluid thickness results indicated that following the fluid application (approximately 5 minutes later), the differences in fluid thickness were not significant on the leading edge of the wing section; however, increased fluid thickness was observed on the trailing edge of Test #7 compared to Test #8. At the end of the tests, the differences in residual fluid thickness were minimal (<0.1 mm) for both tests. Table 7.8 demonstrates the results obtained; the circled values indicate locations where the fluid thickness was greater.

The lift coefficient data collected supported the fluid thickness results taken after the test, whereby the aerodynamic performance was equivalent for both tests; both Tests #7 and #8 had 3.1 percent lift loss at the 8° CL when compared to the dry wing case.

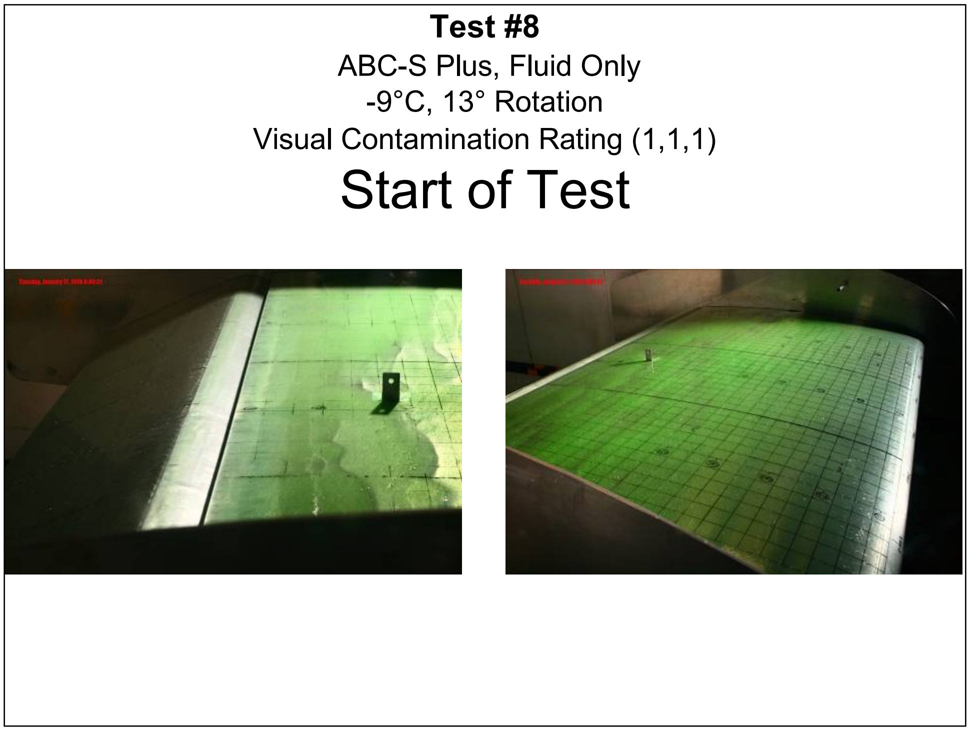
The latter observations were of specific importance to the 2009-10 testing due to the flat surface of the wing section, which seemed to generate thicker fluid layers. The results from this comparative testing indicated that the fluid will settle shortly after application, and any differences in fluid thickness should not significantly affect the aerodynamic results.

From an operational perspective, reports of improper or inadequate application of anti-icing fluid have caused concerns, and recent research has indicated reduced fluid protection times as a result of inadequate fluid application. This research indicates that applying excessive amounts of fluid, although unnecessary, may be aerodynamically safer than applying not enough fluid.

Table 7.8: Comparison of Fluid Thickness

Wing Position	Fluid Thickness (mm)			
	After Fluid Application		After Takeoff Test	
	Test #7 (2x Fluid)	Test #8 (STD Fluid)	Test #7 (2x Fluid)	Test #8 (STD Fluid)
1	1.5	1.3	0	0
2	2.2	2.2	0.2	0.1
3	3.1	3.1	0.1	0.2
4	4.5	4.5	0.1	0.2
5	5.7	5.7	0.2	0.2
6	5.7	4.5	0.2	0.2
7	7	4.5	0.2	0.2
8	5.7	3.3	0.2	0.2
Flap	1	1	0.1	0.2

Photo 7.1: Test #8 – Start of Test



Test #8

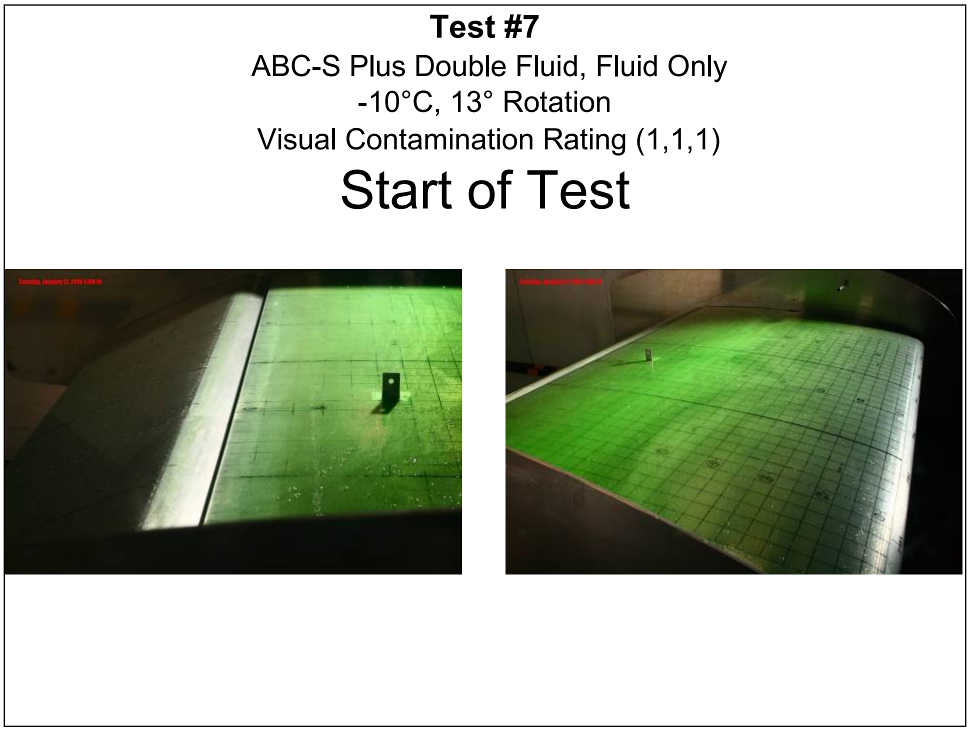
ABC-S Plus, Fluid Only

-9°C, 13° Rotation

Visual Contamination Rating (1,1,1)

Start of Test

Photo 7.2: Test #7 – Start of Test



Test #7

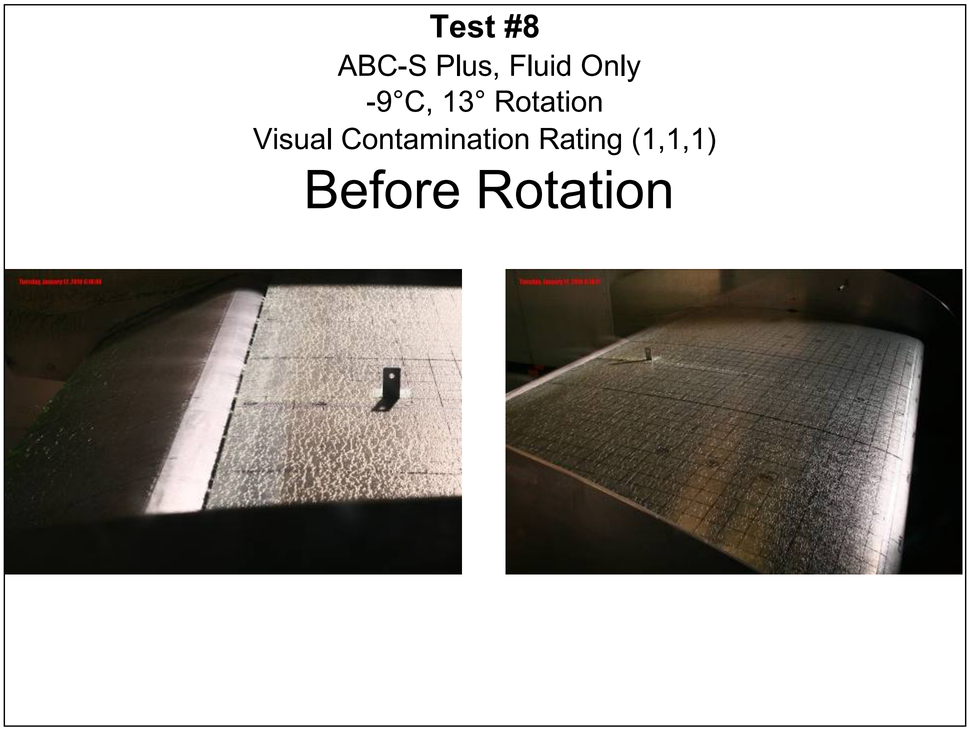
ABC-S Plus Double Fluid, Fluid Only

-10°C, 13° Rotation

Visual Contamination Rating (1,1,1)

Start of Test

Photo 7.3: Test #8 – Before Rotation



Test #8

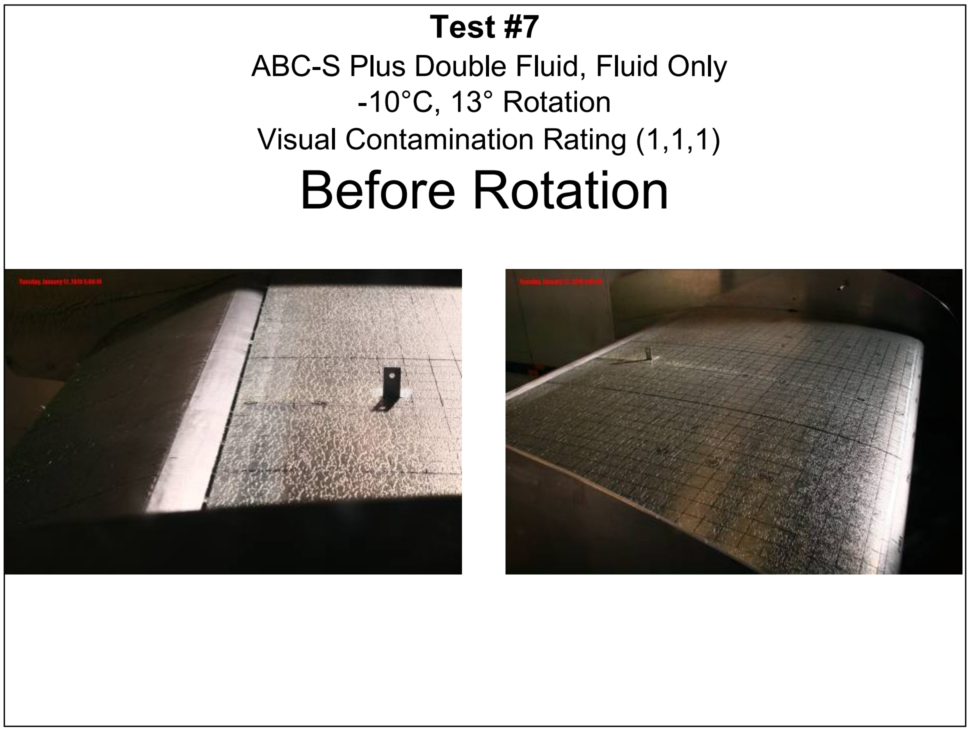
ABC-S Plus, Fluid Only

-9°C, 13° Rotation

Visual Contamination Rating (1,1,1)

Before Rotation

Photo 7.4: Test #7 – Before Rotation



Test #7

ABC-S Plus Double Fluid, Fluid Only

-10°C, 13° Rotation

Visual Contamination Rating (1,1,1)

Before Rotation

Photo 7.5: Test #8 – End of Rotation

Test #8
ABC-S Plus, Fluid Only
-9°C, 13° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 3.10%
End of Rotation

Photo 7.6: Test #7 – End of Rotation

Test #7
ABC-S Plus Double Fluid, Fluid Only
-10°C, 13° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 3.10%
End of Rotation

Photo 7.7: Test #8 – End of Test

Test #8
ABC-S Plus, Fluid Only
-9°C, 13° Rotation
Visual Contamination Rating (1,1,1)
End of Test

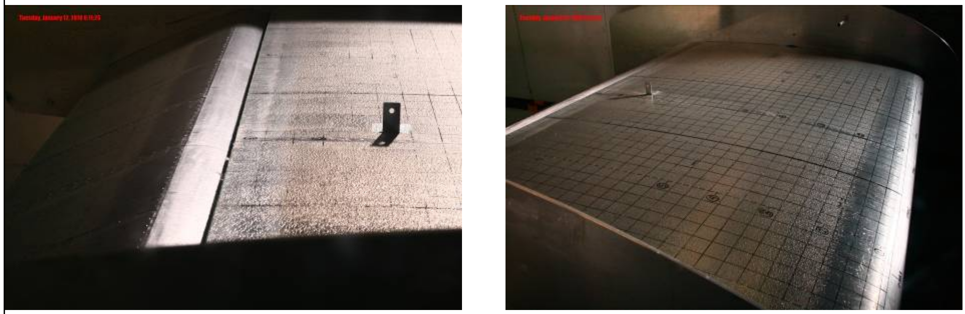
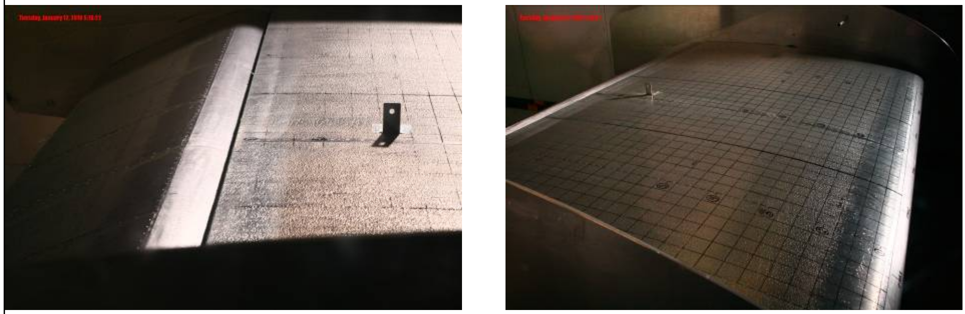


Photo 7.8: Test #7 – End of Test

Test #7
ABC-S Plus Double Fluid, Fluid Only
-10°C, 13° Rotation
Visual Contamination Rating (1,1,1)
End of Test



8. LOW-SPEED RAMP TESTING

Type IV anti-icing fluid is not recommended by the fluid manufacturers for use on low rotation speed aircraft. Some airframe manufacturers have approved the use of Type IV fluid on their low rotation speed turboprop aircraft; however, they have imposed speed penalties to compensate for the poor fluid flow-off at low speeds. The current low-speed aerodynamic acceptance test for anti-icing fluids simulates a rotation speed of 67 knots; this takeoff profile was developed based on older generation low-speed aircraft. In recent years, the newer generation low-speed aircraft have rotation speeds closer to 80-85 knots. As a result, the SAE International (SAE) aerodynamic working group has been working to modify the aerodynamic acceptance test criteria to include a revised low-speed profile, which is more representative of current operational aircraft.

Previous work conducted in the NRC wind tunnel during the winter of 2008-09 indicated that increasing the aerodynamic acceptance test speed profile from the 67 knot rotation to the 80+ knot rotation could potentially provide better aerodynamic results for Type IV fluids, and potentially allow Type IV fluids to be certified for low-speed aircraft. It should be noted that those tests were conducted with no contamination; therefore, fluid elimination could potentially be hampered with the presence of solid or adhered contamination. It was recommended that this work be continued with a supercritical wing section to validate the results obtained for newer generation aircraft.

8.1 General Methodology

The methodology used during these tests was in accordance with the methodologies described in Section 2. The tests conducted were with fluid only (no contamination).

For consistency throughout the report, the format of Tables 8.1 to 8.10 has not been modified to account for the fluid only tests. Since there is no contamination for this series of tests, the visual contamination ratings listed in the table are a “1” indicating no visible contamination. For post-contamination fluid thickness and Brix information, “N/A” is listed in the tables, as this does not apply to the test.

8.2 Overview of Tests

A summary of the low-speed ramp tests conducted in the wind tunnel is shown in Table 8.1. The table 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. A more detailed test log of all conditions tested using the wind tunnel is provided in Subsection 3.1. The following is a brief description of the column headings for Table 8.1.

Test #:	Exclusive number identifying each test.
Date:	Date when the test was conducted.
Fluid:	Aircraft deicing fluid specified by product name; all fluids were in the "neat" 100/0 dilution.
Associated Baseline Run:	The associated fluid only baseline run based on fluid selection.
Condition:	Simulated precipitation condition.
Precipitation Rate (g/dm²/h):	Simulated freezing precipitation rate (or combination of different precipitation rates). "N/A" indicates that no precipitation was applied.
Precip. Time (min.):	Total time of exposure to simulated precipitation.
Tunnel Temp. at Start of Test (°C):	The tunnel ambient temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.
Avg. Wing Temp. Before Test (°C):	Average of the wing skin temperature measurements just before the start of the simulated takeoff test, recorded in degrees Celsius.
Visual Contamination Rating Before Takeoff (LE, TE, Flap):	Visual contamination rating determined before the start of the simulated takeoff: 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 - Contamination visible, adherence of contamination.

Visual Contamination Rating at Rotation (LE, TE, Flap):	Visual contamination rating determined at the time of rotation: 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 - Contamination visible, adherence of contamination.
CL at 8° During Rotation:	Calculated lift coefficient at the 8° wing rotation angle position; data provided by the NRC.
% Lift Loss:	Percentage lift loss calculated based on the comparison of the 8° lift coefficient during the test run versus the dry wing average lift coefficient (calculated to be 1.7213).

Table 8.1: Summary of 2009-10 Low-Speed Ramp Testing

Test No.	Date	Fluid	Associated Baseline Run	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° Rotation	% Lift Loss	Comments
60	28-Jan-10	Launch	N/A	Fluid Only	N/A	N/A	-2.8	-1.9	1, 1, 1	1, 1, 1	1.642	4.61	100 Knots Rotation
61	28-Jan-10	Launch	60	Fluid Only	N/A	N/A	-2.3	-2.2	1, 1, 1	1, 1, 1	1.575	8.50	80 Knots Rotation
62	28-Jan-10	Launch	60	Fluid Only	N/A	N/A	-3.4	-2.4	1, 1, 1	1, 1, 1	1.555	9.66	65 Knots Rotation

8.3 Data Collected

8.3.1 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Subsection 2.16.2. Fluid thickness measurements were recorded at the following intervals:

- After fluid application;
- After application of contamination; and
- After the simulated takeoff test.

Tables 8.2 to 8.4 show the fluid thickness measurements collected during the contaminated fluid tests.

Table 8.2: Test #60 Fluid Thickness Data

Test 60: Launch, Fluid Only, Tunnel OAT -2.8°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.2	N/A	0.0
2	0.1	N/A	0.1
3	2.2	N/A	0.1
4	2.5	N/A	0.1
5	2.5	N/A	0.2
6	2.7	N/A	0.1
7	2.5	N/A	0.2
8	2.2	N/A	0.2
Flap	0.7	N/A	0.0

Table 8.3: Test #61 Fluid Thickness Data

Test 61: Launch, Fluid Only, Tunnel OAT -2.3°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.3	N/A	0.0
2	1.6	N/A	0.0
3	2.2	N/A	0.1
4	2.5	N/A	0.2
5	2.7	N/A	0.1
6	2.9	N/A	0.2
7	2.7	N/A	0.2
8	2.2	N/A	0.2
Flap	1.0	N/A	0.0

Table 8.4: Test #62 Fluid Thickness Data

Test 62: Launch, Fluid Only, Tunnel OAT -3.4°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.6	N/A	0.0
2	1.8	N/A	0.2
3	2.2	N/A	0.2
4	2.7	N/A	0.3
5	2.9	N/A	0.3
6	2.9	N/A	0.3
7	2.5	N/A	0.3
8	2.2	N/A	0.3
Flap	1.0	N/A	0.2

8.3.2 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Subsection 2.16.3. Skin temperature measurements were recorded at the following intervals:

- Before fluid application;
- After fluid application;
- After application of contamination; and
- After the simulated takeoff test.

Tables 8.5 to 8.7 show the wing temperature measurements recorded during the contaminated fluid tests.

Table 8.5: Test #60 Wing Skin Temperature Data

Test 60: Launch, Fluid Only, Tunnel OAT -2.8°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3	-1.8	N/A	-3.9
T5	-2.2	-1.6	N/A	-4.3
TU	-3.1	-2.4	N/A	-4.4

Table 8.6: Test #61 Wing Skin Temperature Data

Test 61: Launch, Fluid Only, Tunnel OAT -2.3°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-2.1	-2.1	N/A	-3.5
T5	-1.4	-2.1	N/A	-3.4
TU	-2.8	-2.4	N/A	-3.8

Table 8.7: Test #62 Wing Skin Temperature Data

Test 62: Launch, Fluid Only, Tunnel OAT -3.4°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.5	-2.1	N/A	-4.6
T5	-3.4	-2.2	N/A	-4.5
TU	-3.8	-3.0	N/A	-4.5

8.3.3 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Subsection 2.16.4. Fluid Brix measurements were recorded at the following intervals:

- After fluid application;
- After application of contamination; and
- After the simulated takeoff test.

Tables 8.8 to 8.10 show the fluid Brix measurements collected during the contaminated fluid tests.

Table 8.8: Test #60 Fluid Brix Data

Test 60: Launch, Fluid Only, Tunnel OAT -2.8°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.00	N/A	41.00
8	36.75	N/A	39.25

Table 8.9: Test #61 Fluid Brix Data

Test 61: Launch, Fluid Only, Tunnel OAT -2.3°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.75	N/A	39.75
8	37.00	N/A	38.50

Table 8.10: Test #62 Fluid Brix Data

Test 62: Launch, Fluid Only, Tunnel OAT -3.4°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.25	N/A	37.75
8	37.00	N/A	37.50

8.4 Photos

High-speed digital photography of each test was taken. For each test, wide-angle photos were taken of the leading edge, and close-up photos were taken of the trailing edge. For each of the tests, photo summaries have been compiled comprising four stages:

- Start of test;
- Before Rotation (just before the wing began to pitch);
- End of Rotation (end of the rotation cycle when the wing position is returned to four degrees); and
- End of test.

Photos 8.1 to 8.16 show the photo summaries of the tests conducted. A complete set of photos will be provided to the TDC in electronic format.

8.5 Summary of Test Results

The lift coefficient data collected during the three comparative tests indicated that the wing performance improved as the rotation speed was increased. The calculated lift loss at 8° rotation was 4.6 percent, 8.5 percent, and 9.7 percent for the 100, 80, and 65 knots rotation speed tests, respectively. Figure 8.1 demonstrates a comparison of the lift coefficient data during the three tests conducted.

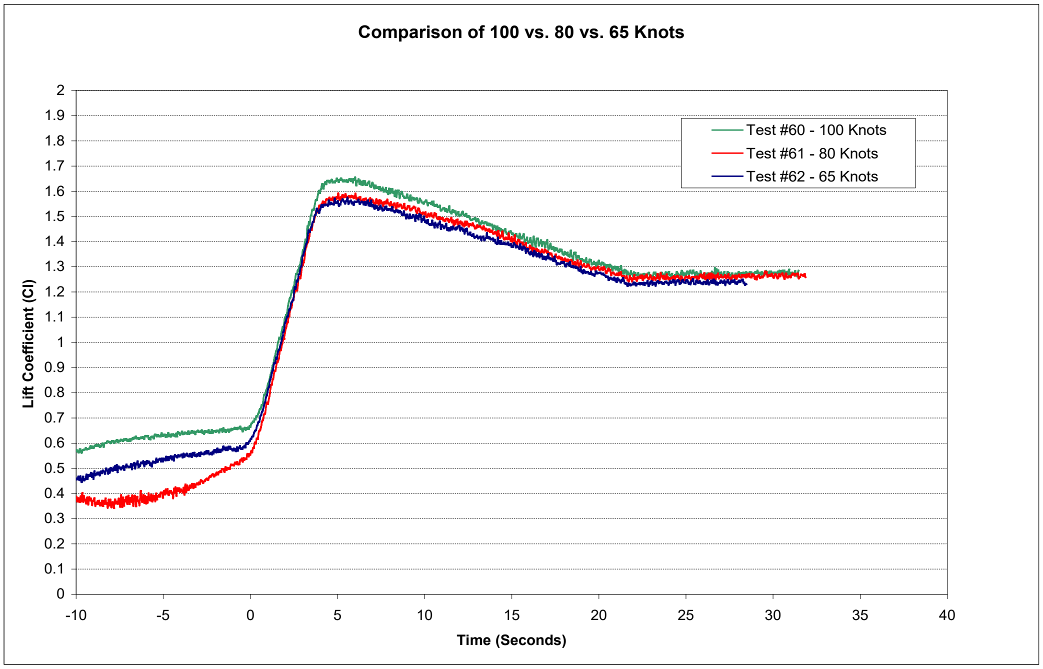


Figure 8.1: Comparison of Lift Coefficient Data for 100 vs. 80 vs. 65 Knots Fluid Only Tests

Visually, more fluid was observed to shear off the wing prior to rotation during the 100 knots rotation speed test compared to the 65 and 80 knots rotation speed tests. The lift coefficient values prior to rotation reflect this, with the higher speed tests producing higher lift coefficients.

This was confirmed by the fluid thickness measurements taken following the end of each test run demonstrated in Table 8.11. The cases when fluid thickness was greater compared to the 100 knots test are circled and bolded. The data supported the visual observations wherein the fluid thickness at the end of the test was greater during the 80 and 65 knots tests.

The results indicated that the aerodynamic performance will significantly improve as the speed is increased. This should be taken into consideration when developing a new low-speed fluid certification standard.

Table 8.11: Comparison of Fluid Thickness Measurements After Takeoff Test for 100 vs. 80 vs. 65 Knots Fluid Only Tests

Wing Position	Fluid Thickness (mm)		
	After Takeoff Test		
	Test #60 (100 Knots)	Test #61 (80 Knots)	Test #62 (65 Knots)
1	0	0	0
2	0.1	0	**0.2**
3	0.1	0.1	**0.2**
4	0.1	**0.2**	**0.3**
5	0.2	0.1	**0.3**
6	0.1	**0.2**	**0.3**
7	0.2	0.2	**0.3**
8	0.2	0.2	**0.3**
Flap	0	0	**0.2**

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Photo 8.1: Test #60 – Start of Test

Test #60
Launch, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

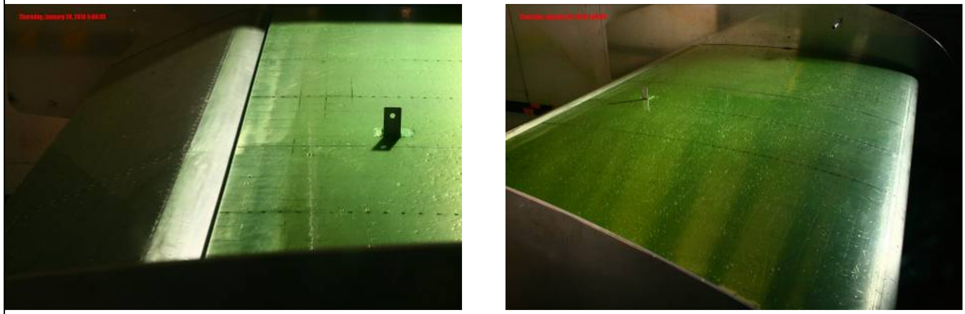


Photo 8.2: Test #61 – Start of Test

Test #61
Launch, Fluid Only
-2°C, 8° Rotation, 80 Kts
Visual Contamination Rating (1,1,1)
Start of Test

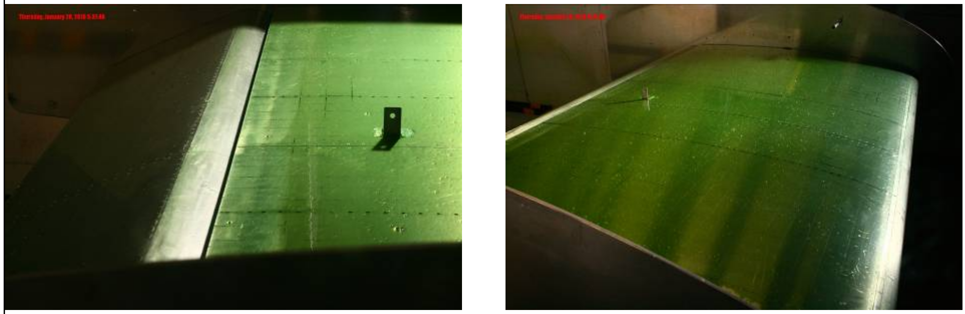


Photo 8.3: Test #60 – Before Rotation

Test #60
Launch, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

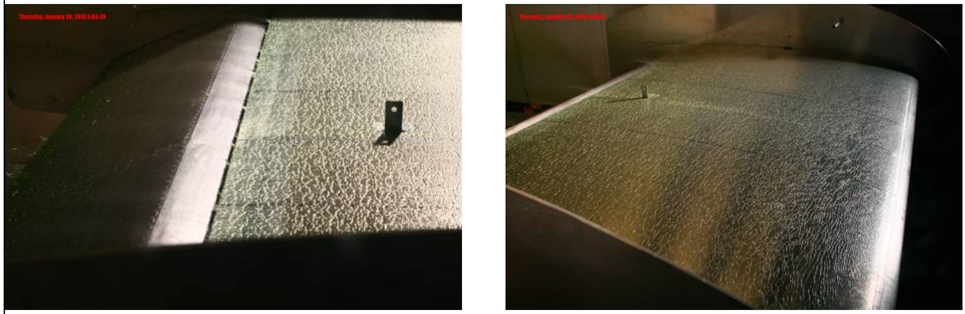


Photo 8.4: Test #61 – Before Rotation

Test #61
Launch, Fluid Only
-2°C, 8° Rotation, 80 Kts
Visual Contamination Rating (1,1,1)
Before Rotation

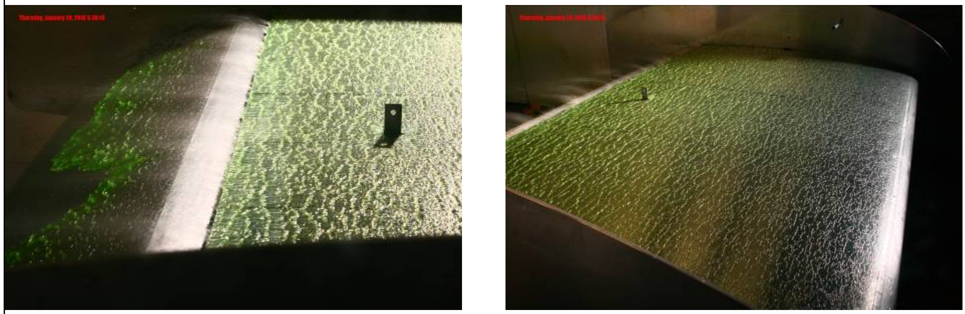
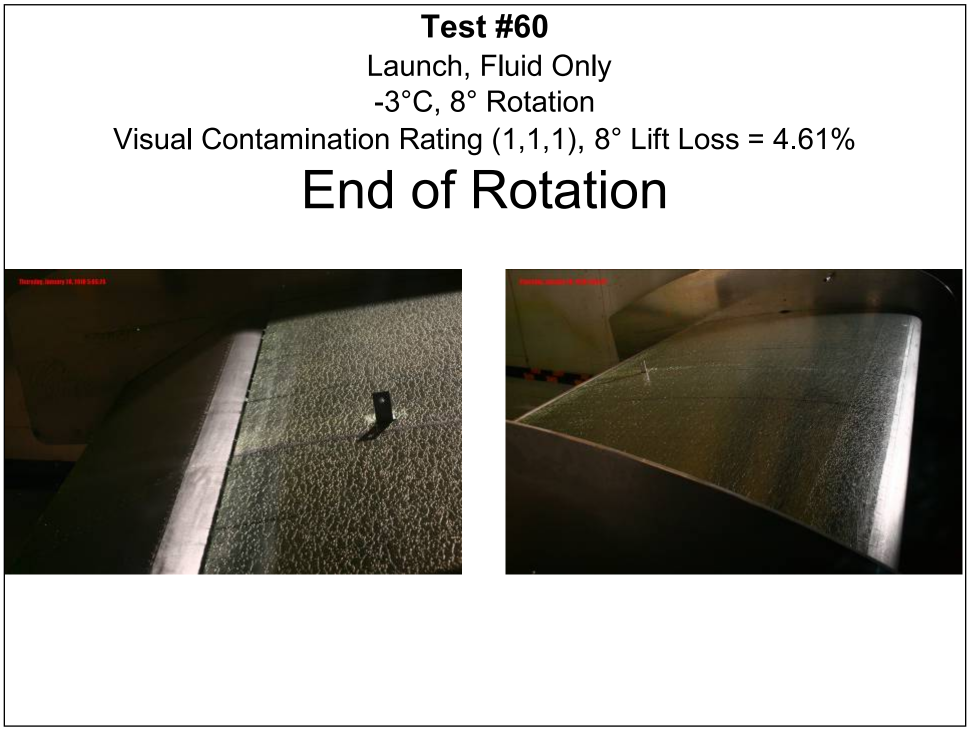


Photo 8.5: Test #60 – End of Rotation



Test #60

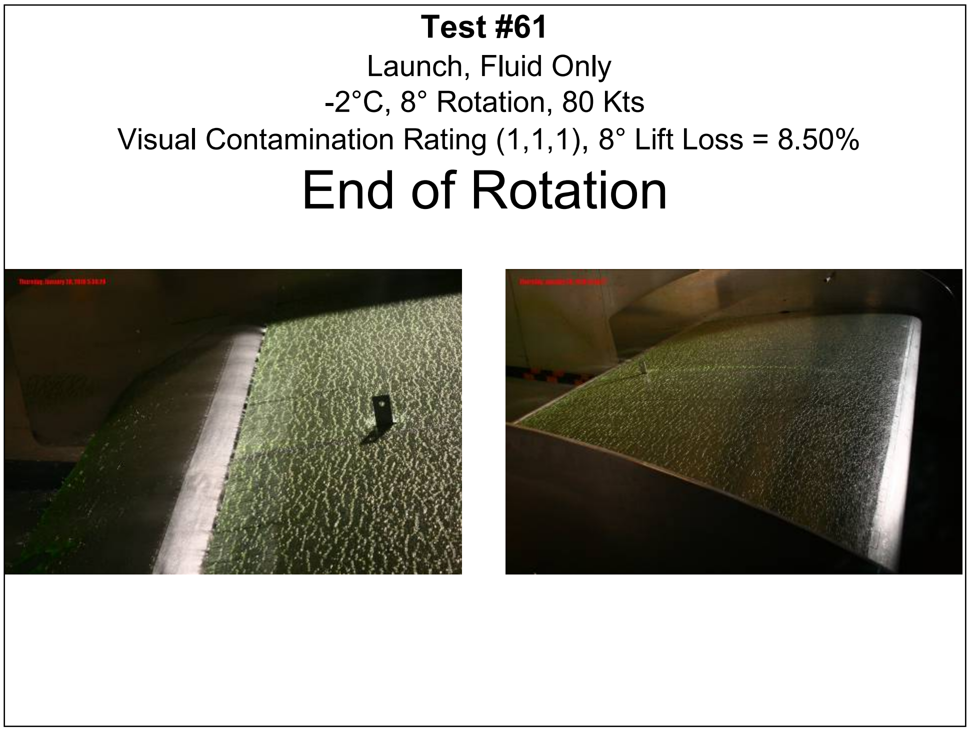
Launch, Fluid Only

-3°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 4.61%

End of Rotation

Photo 8.6: Test #61 – End of Rotation



Test #61

Launch, Fluid Only

-2°C, 8° Rotation, 80 Kts

Visual Contamination Rating (1,1,1), 8° Lift Loss = 8.50%

End of Rotation

Photo 8.7: Test #60 – End of Test

Test #60
Launch, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

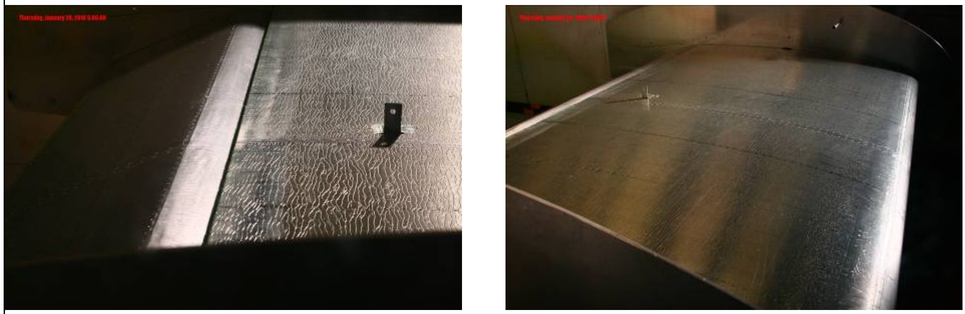


Photo 8.8: Test #61 – End of Test

Test #61
Launch, Fluid Only
-2°C, 8° Rotation, 80 Kts
Visual Contamination Rating (1,1,1)
End of Test

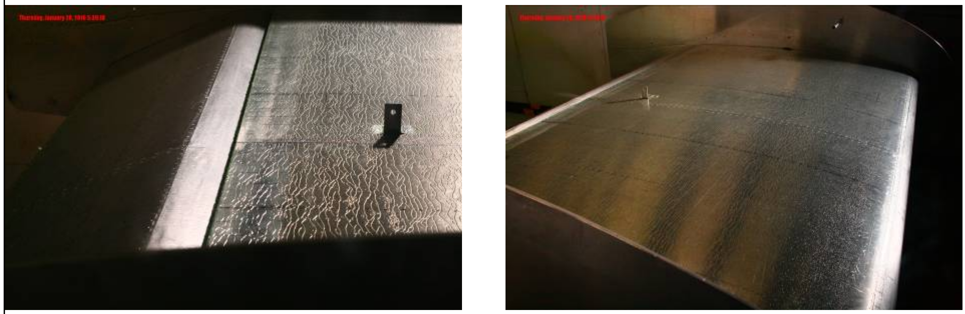
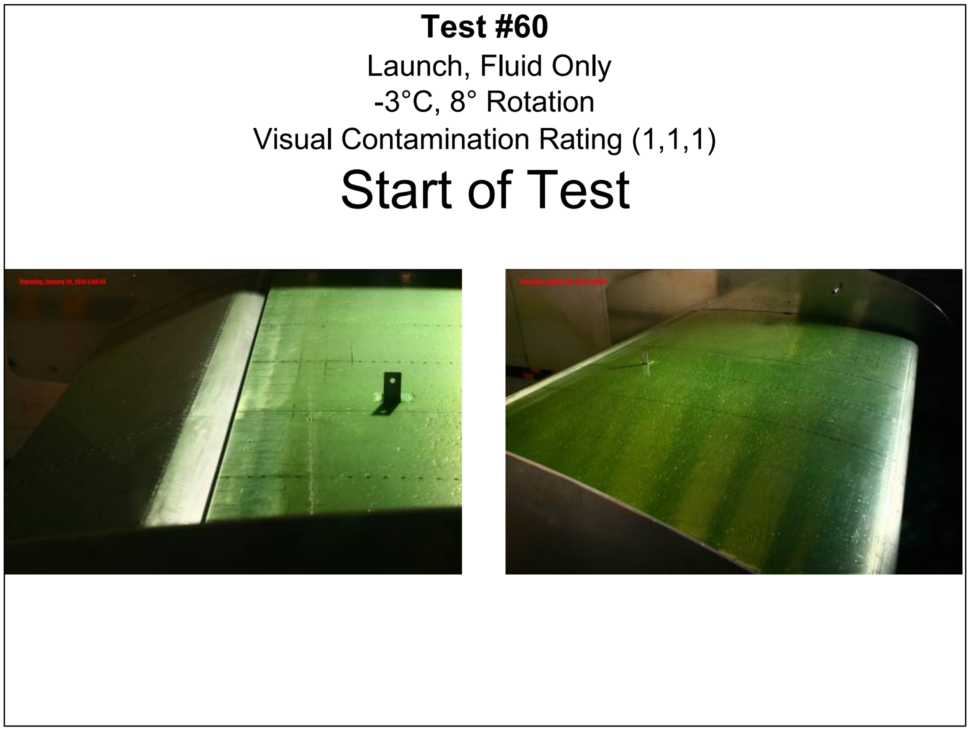
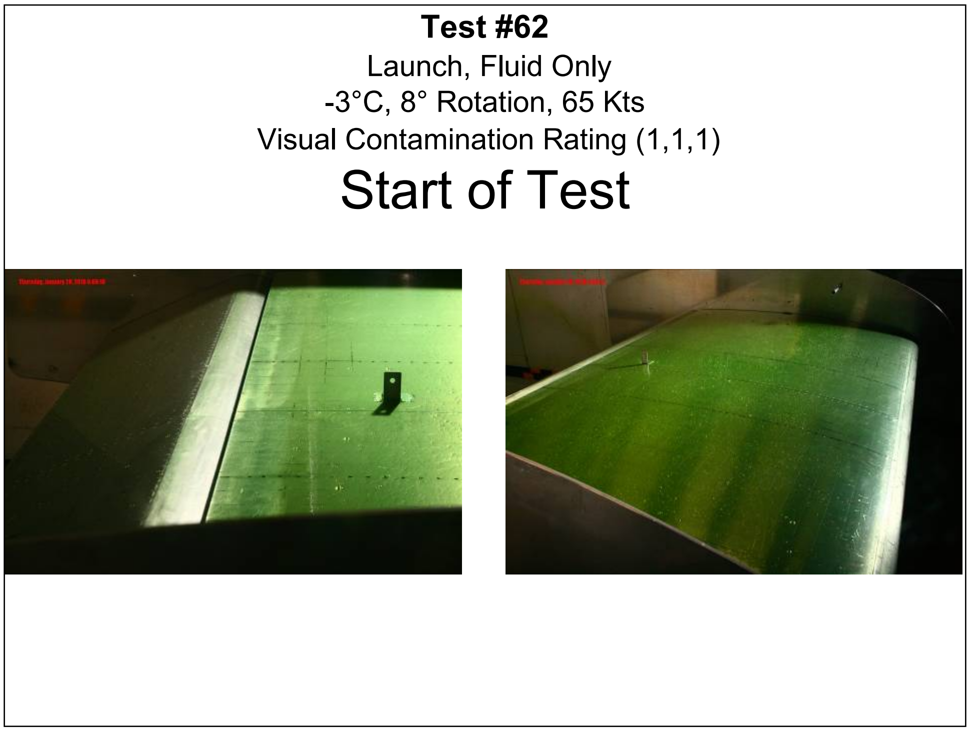


Photo 8.9: Test #60 – Start of Test



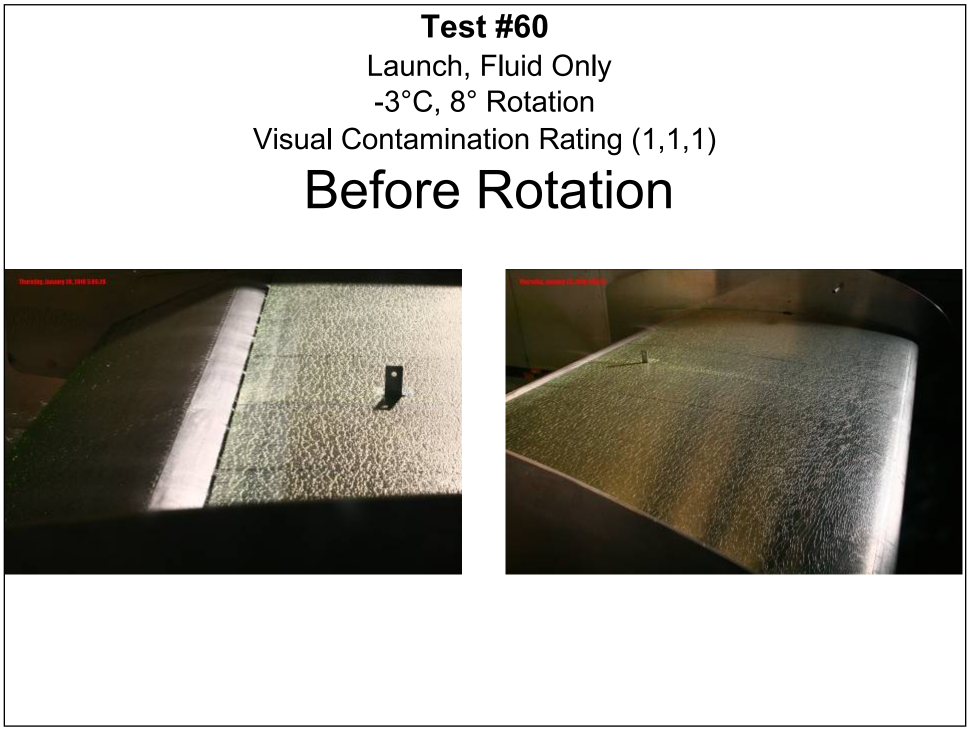
Test #60
Launch, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

Photo 8.10: Test #62 – Start of Test



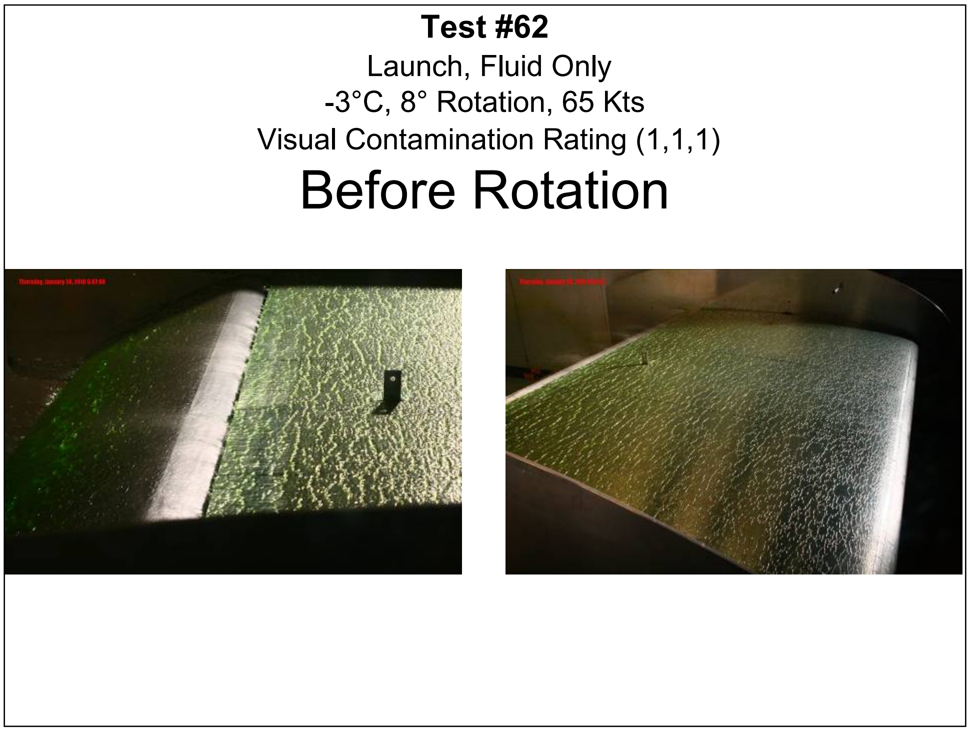
Test #62
Launch, Fluid Only
-3°C, 8° Rotation, 65 Kts
Visual Contamination Rating (1,1,1)
Start of Test

Photo 8.11: Test #60 – Before Rotation



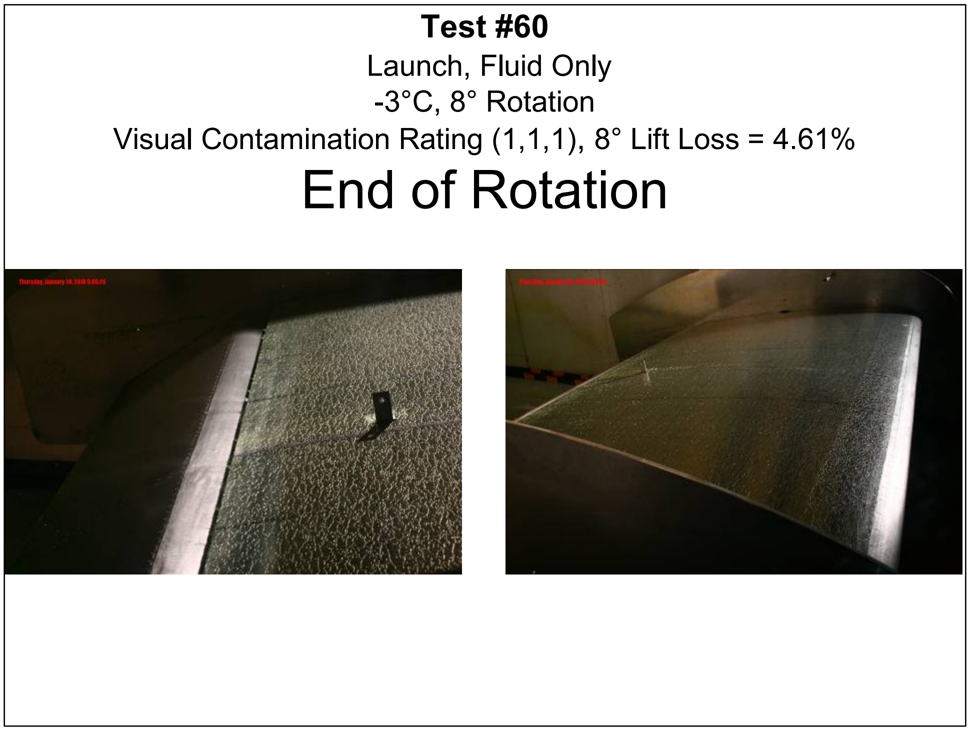
Test #60
Launch, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

Photo 8.12: Test #62 – Before Rotation



Test #62
Launch, Fluid Only
-3°C, 8° Rotation, 65 Kts
Visual Contamination Rating (1,1,1)
Before Rotation

Photo 8.13: Test #60 – End of Rotation



Test #60

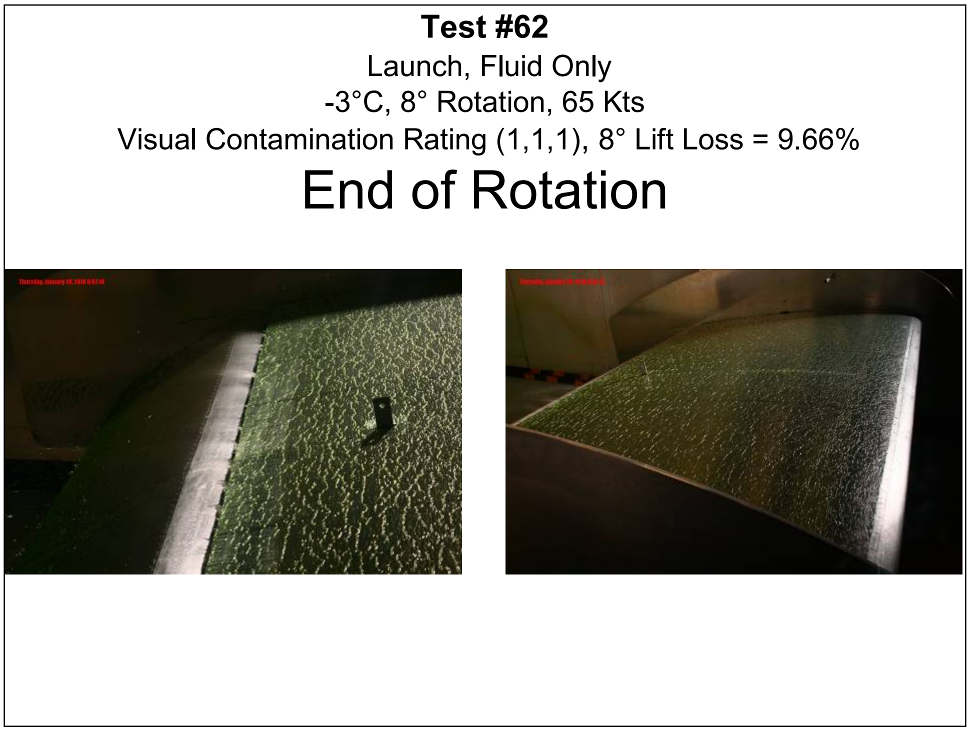
Launch, Fluid Only

-3°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 4.61%

End of Rotation

Photo 8.14: Test #62 – End of Rotation



Test #62

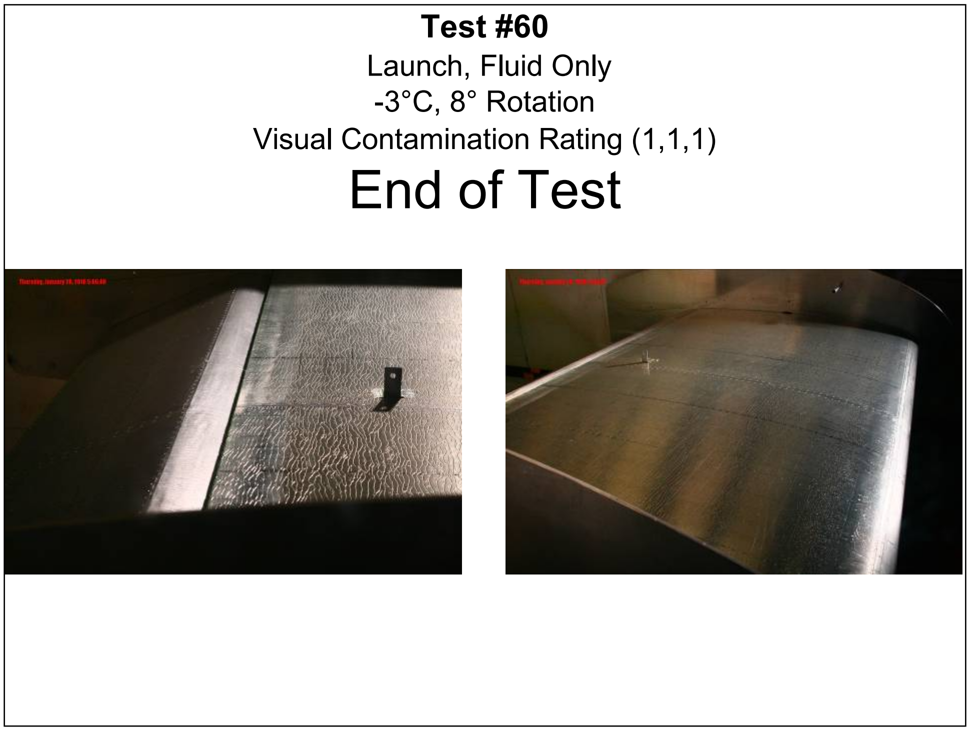
Launch, Fluid Only

-3°C, 8° Rotation, 65 Kts

Visual Contamination Rating (1,1,1), 8° Lift Loss = 9.66%

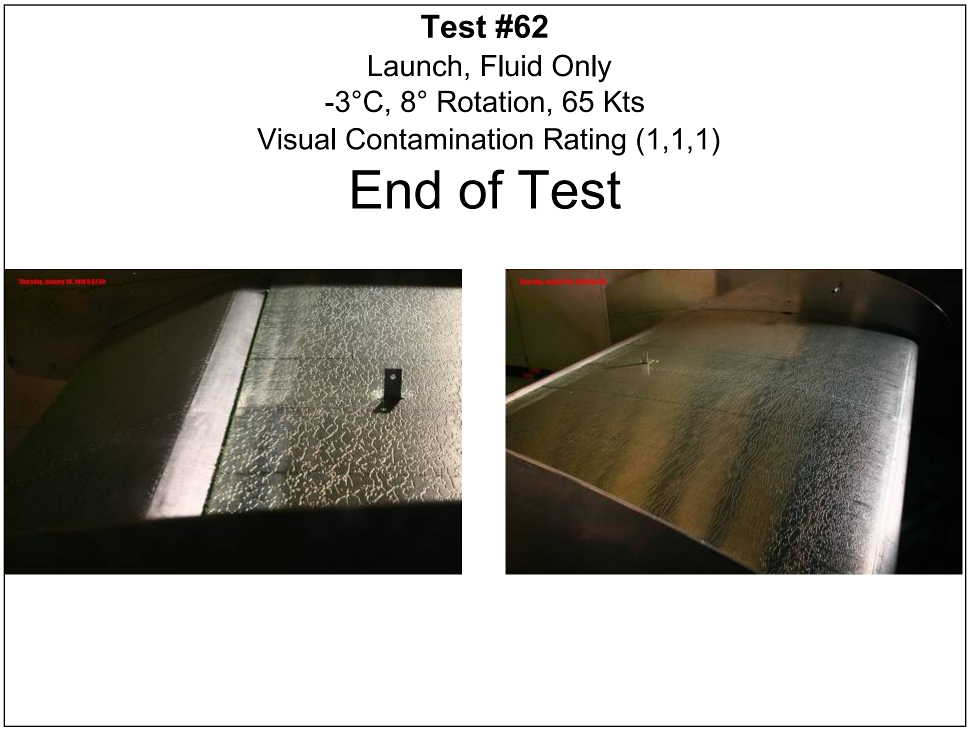
End of Rotation

Photo 8.15: Test #60 – End of Test



Test #60
Launch, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

Photo 8.16: Test #62 – End of Test



Test #62
Launch, Fluid Only
-3°C, 8° Rotation, 65 Kts
Visual Contamination Rating (1,1,1)
End of Test

9. LIGHT FREEZING RAIN MIXED WITH MODERATE SNOW CONDITIONS

Transitional precipitation periods often include a mix of multiple precipitation types. Although these periods are generally short, on many occasions these transitional periods can last several hours, especially at warmer temperatures. The accuracy of meteorological reporting continues to improve; in addition, HOT Determination Systems designers will require appropriate guidance to provide accurate HOTs during mixed precipitation conditions. As a result, there has been a recent industry need to provide improved guidance material during these transitional periods of mixed precipitation.

Previous flat plate testing was conducted in light rain mixed with light snow conditions, and guidance material was issued by both TC and the FAA. As a result of this work, there was industry interest in guidance material for operations during light freezing rain and moderate snow conditions. Light freezing rain mixed with moderate snow was selected as this condition is a typical transitional condition that occurs at warmer temperatures during aircraft deicing operations. The purpose was to obtain preliminary data regarding the aerodynamic effects of this mixed precipitation condition to determine if the current HOT Guidelines can be expanded to include conditions of light freezing rain mixed with moderate snow.

9.1 General Methodology

The methodology used during these tests was in accordance with the methodologies described in Section 2; however, the Type I fluid application differed from the typical application whereby the fluid was warm (room temperature) and 10 L were applied (less fluid was required to properly cover the wing). The length of exposure time was based on the current Type I HOTs for light freezing rain and moderate snow.

9.2 Overview of Tests

A summary of the light freezing rain mixed with moderate snow tests conducted in the wind tunnel is shown in Table 9.1. The table 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. A more detailed test log of all conditions tested using the wind tunnel is provided in Subsection 3.1. The following is a brief description of the column headings for Table 9.1.

Test #: Exclusive number identifying each test.

Date: Date when the test was conducted.

Fluid: Aircraft deicing fluid specified by product name; all fluids were in the “neat” 100/0 dilution.

Associated Baseline Run: The associated fluid only baseline run based on fluid selection.

Condition: Simulated precipitation condition.

Precipitation Rate (g/dm^2/h): Simulated freezing precipitation rate (or combination of different precipitation rates). ”N/A” indicates that no precipitation was applied.

Precip. Time (min.): Total time of exposure to simulated precipitation.

Tunnel Temp. at Start of Test (°C): The tunnel ambient temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.

Avg. Wing Temp. Before Test (°C): Average of the wing skin temperature measurements just before the start of the simulated takeoff test, recorded in degrees Celsius.

Visual Contamination Rating Before Takeoff (LE, TE, Flap): Visual contamination rating determined before the start of the simulated takeoff:

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 - Contamination visible, adherence of contamination.

Visual Contamination Rating at Rotation (LE, TE, Flap):	Visual contamination rating determined at the time of rotation: 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 - Contamination visible, adherence of contamination.
CL at 8° During Rotation:	Calculated lift coefficient at the 8° wing rotation angle position; data provided by the NRC.
% Lift Loss:	Percentage lift loss calculated based on the comparison of the 8° lift coefficient during the test run versus the dry wing average lift coefficient (calculated to be 1.7213).

Table 9.1: Summary of 2009-10 Light Freezing Rain Mixed with Moderate Snow Testing

Test No.	Date	Fluid	Associated Baseline Run	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° Rotation	% Lift Loss	Comments
102	3-Feb-10	Type I Octaflo	103	LZR / SN	SN:25, ZR:25	4	-5.5	-1.3	3.3, 3.3, 4.3	5, 5, 5	1.449	15.82	N/A
103	3-Feb-10	Type I Octaflo		LZR	ZR:25	8	-4.6	-3.7	5, 4.7, 5	5, 5, 5	1.675	2.69	N/A

9.3 Data Collected

9.3.1 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Subsection 2.16.2. Fluid thickness measurements were recorded at the following intervals:

- After fluid application;
- After application of contamination; and
- After the simulated takeoff test.

Tables 9.2 to 9.3 show the fluid thickness measurements collected during the contaminated fluid tests.

Table 9.2: Test #102 Fluid Thickness Data

Test 102: Octaflo, LZR/SN, Tunnel OAT -5.5°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	0.1	slush	0.0
2	0.2	slush	0.0
3	0.3	slush	0.0
4	0.4	slush	0.0
5	0.4	slush	0.0
6	0.3	slush	0.0
7	0.3	slush	0.0
8	0.2	slush	0.0
Flap	0.0	slush	0.0

Table 9.3: Test #103 Fluid Thickness Data

Test 103: Octaflo, ZR, Tunnel OAT -4.6°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	0.3	0.4	0.0
2	0.4	0.1	0.0
3	0.4	0.1	0.0
4	0.4	0.2	0.0
5	0.4	0.2	0.0
6	0.3	0.1	0.0
7	0.4	0.2	0.0
8	0.4	0.3	0.0
Flap	0.1	0.1	0.0

9.3.2 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Subsection 2.16.3. Skin temperature measurements were recorded at the following intervals:

- Before fluid application;
- After fluid application;
- After application of contamination; and
- After the simulated takeoff test.

Tables 9.4 to 9.5 show the wing temperature measurements recorded during the contaminated fluid tests.

Table 9.4: Test #102 Wing Skin Temperature Data

Test 102: Octaflo, LZR/SN, Tunnel OAT -5.5°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-8.3	+1.0	-5.2	-9.9
T5	-7.7	+1.5	-5.6	-9.7
TU	-8.6	-6.5	-5.4	-9.1

Table 9.5: Test #103 Wing Skin Temperature Data

Test 103: Octaflo, ZR, Tunnel OAT -4.6°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-7.0	-1.4	-3.5	-8.5
T5	-6.4	-1.3	-3.0	-8.2
TU	-6.8	-6.0	-4.6	-8.6

9.3.3 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Subsection 2.16.4. Fluid Brix measurements were recorded at the following intervals:

- After fluid application;
- After application of contamination; and
- After the simulated takeoff test.

Tables 9.6 to 9.7 show the fluid Brix measurements collected during the contaminated fluid tests.

Table 9.6: Test #102 Fluid Brix Data

Test 102: Octaflo, LZR/SN, Tunnel OAT -5.5°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	31.50	13.00	N/A
8	31.50	13.00	12.00

Table 9.7: Test #103 Fluid Brix Data

Test 103: Octaflo, ZR, Tunnel OAT -4.6°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	31.50	10.50	11.50
8	N/A	10.50	N/A

9.4 Photos

High-speed digital photography of each test was taken. For each test, wide-angle photos were taken of the leading edge, and close-up photos were taken of the trailing edge. For each of the tests, photo summaries have been compiled comprising four stages:

- Start of test;
- Before Rotation (just before the wing began to pitch);
- End of Rotation (end of the rotation cycle when the wing position is returned to four degrees); and
- End of test.

Photos 9.1 to 9.8 show the photo summaries of the tests conducted. A complete set of photos will be provided to the TDC in electronic format.

9.5 Summary of Test Results

A Type I fluid test was conducted in mixed light freezing rain and moderate snow (Test #102), and a comparison test (Test #103) was conducted in light freezing rain alone. During Test #102, a 4-minute exposure time was selected based on the current Type I fluid HOT for light freezing rain in conditions of -3°C to -6°C. Due to the severe level of contamination observed in Test #102, the comparison Test #103 was conducted with an exposure time of 8 minutes to obtain a comparable amount of contamination and to avoid simulating the HOT, which is 4 minutes in this condition. Each test experienced a total precipitation amount of approximately 3.3 g/dm².

During Test #102, the visual contamination ratings were just beyond the acceptable level of “3” on the leading and trailing edge, and “4” on the flap. As the wind tunnel accelerated, some of the contamination present began to freeze and was not eliminated by the time of rotation; the flap was completely covered with frozen contamination. The aerodynamic performance was significantly reduced; a lift loss of 15.8 percent compared to the dry wing was recorded.

During Test #103, spots of adhered contamination were observed on the wing section at the end of the precipitation period. As the wind tunnel accelerated, the fluid and contamination present began to freeze and were not eliminated by the time of rotation; the whole wing section was frozen. Due to the freezing rain contamination, which is inherently smooth, the aerodynamic performance was not significantly affected; a lift loss of 2.7 percent compared to the dry wing was recorded.

The results indicated that the added snow contamination (compared to light freezing rain alone) significantly affected the aerodynamic performance when the wing section was severely contaminated. It is recommended that additional testing be conducted with thickened Type II/III/IV fluids, less prone to adhesion, in order to substantiate these results. In addition, the temperature differential between the inside tunnel and the cold air being blown through the tunnel during the ramp-up may have promoted the formation of ice and adherence, causing more severe lift losses than may typically be expected; Type I fluids will be more susceptible to this effect compared to thickened fluids.

Photo 9.1: Test #103 – Start of Test

Test #103
Octaflo, Light ZR 25 g/dm²/h, 8 min
-5°C, 8° Rotation
Visual Contamination Rating (5,4.7,5)
Start of Test

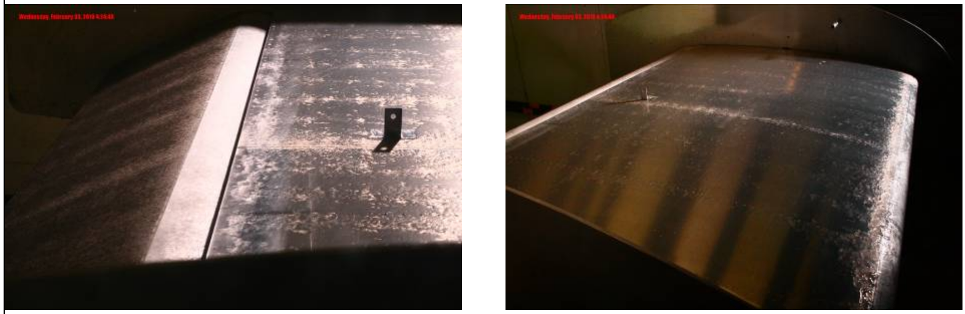
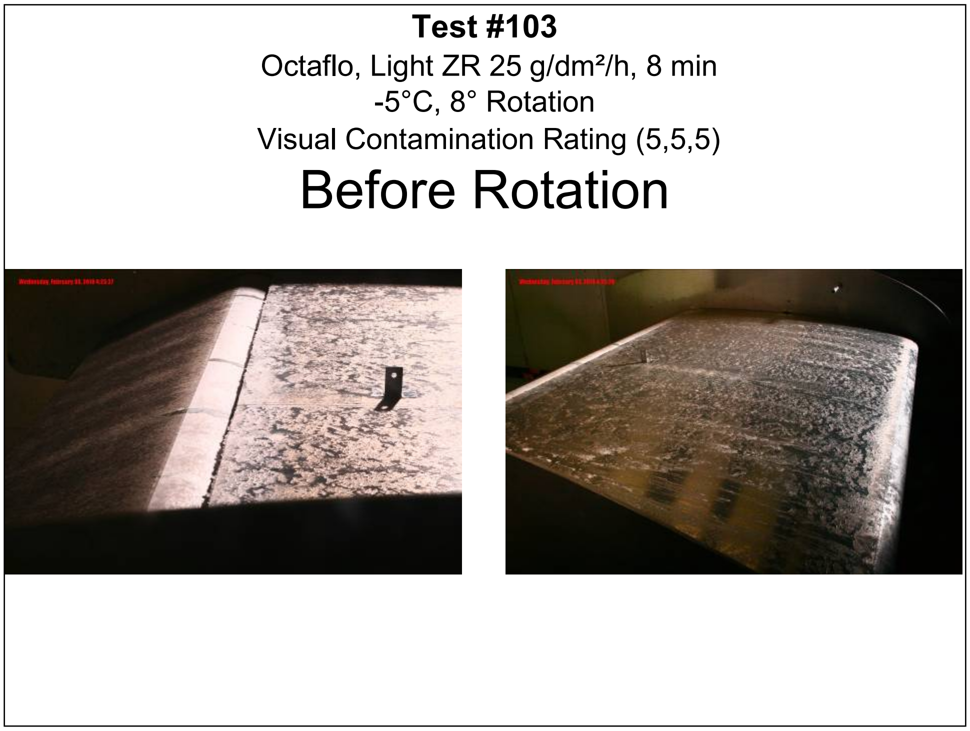


Photo 9.2: Test #102 – Start of Test

Test #102
Octaflo, SN + Light ZR 25+25 g/dm²/h, 4 min
-5.5°C, 8° Rotation
Visual Contamination Rating (3.3,3.3,4.3)
Start of Test

Photo 9.3: Test #103 – Before Rotation



Test #103

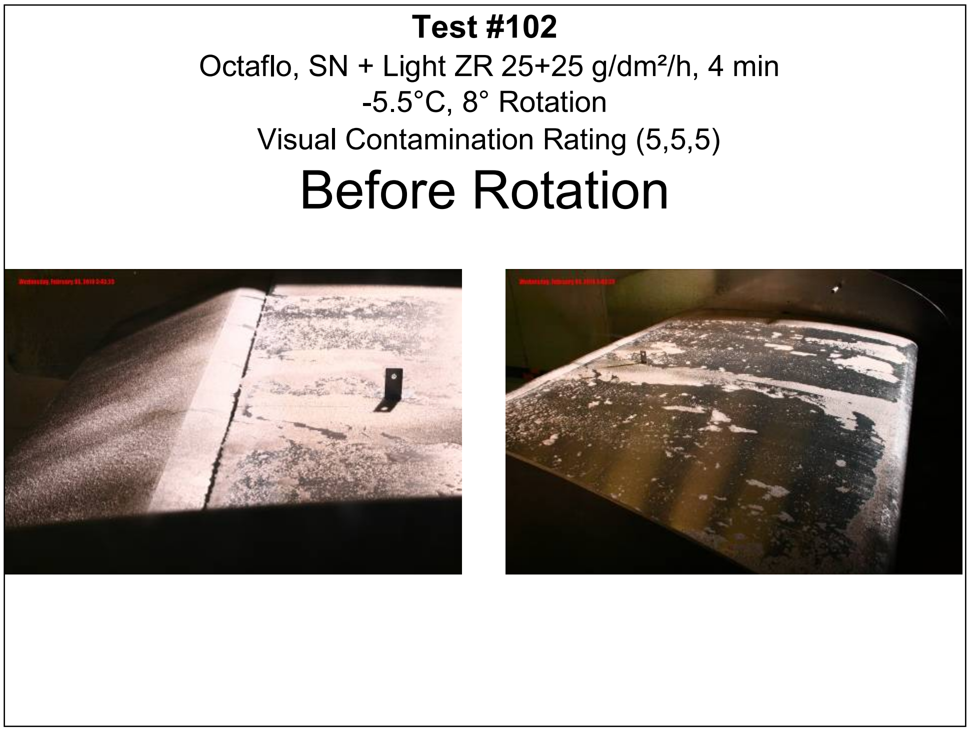
Octaflo, Light ZR 25 g/dm²/h, 8 min

-5°C, 8° Rotation

Visual Contamination Rating (5,5,5)

Before Rotation

Photo 9.4: Test #102 – Before Rotation



Test #102

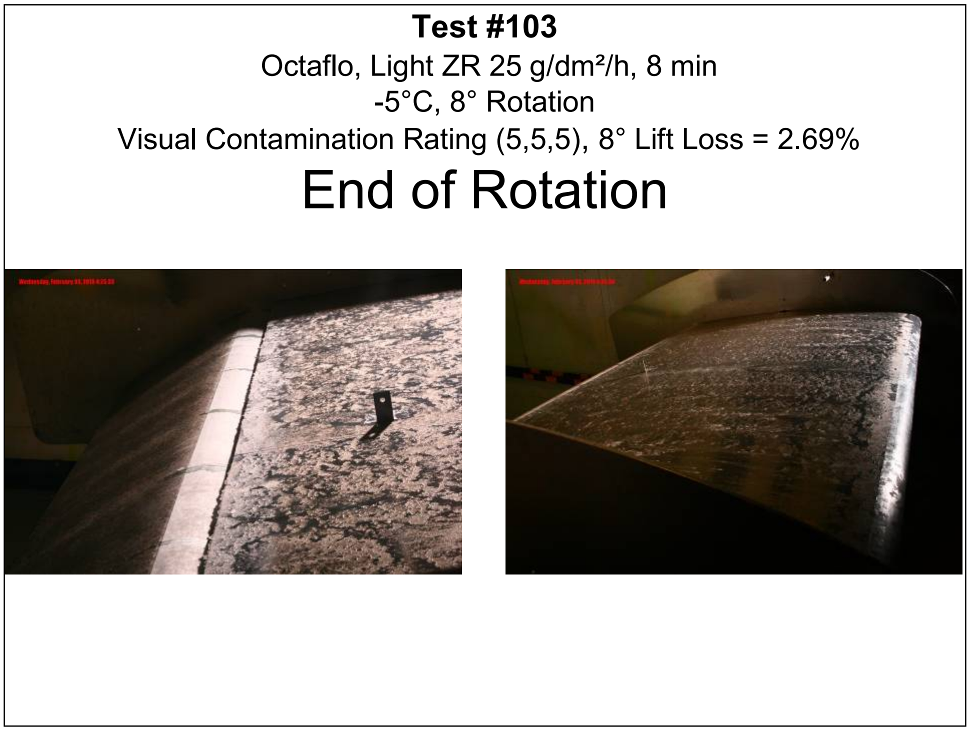
Octaflo, SN + Light ZR 25+25 g/dm²/h, 4 min

-5.5°C, 8° Rotation

Visual Contamination Rating (5,5,5)

Before Rotation

Photo 9.5: Test #103 – End of Rotation



Test #103

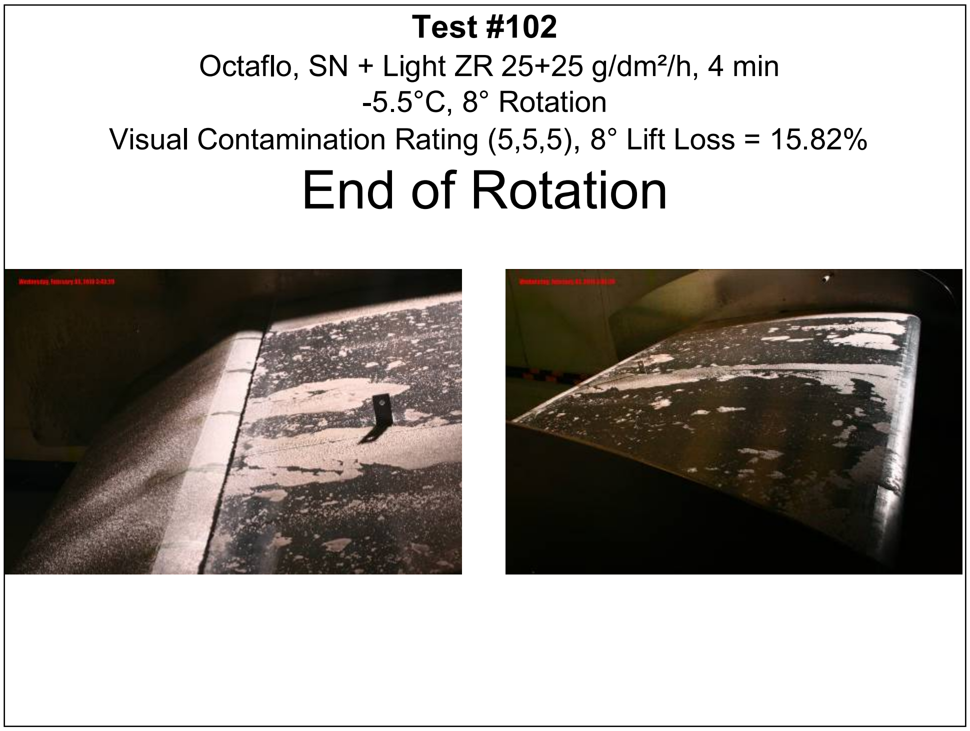
Octaflo, Light ZR 25 g/dm²/h, 8 min

-5°C, 8° Rotation

Visual Contamination Rating (5,5,5), 8° Lift Loss = 2.69%

End of Rotation

Photo 9.6: Test #102 – End of Rotation



Test #102

Octaflo, SN + Light ZR 25+25 g/dm²/h, 4 min

-5.5°C, 8° Rotation

Visual Contamination Rating (5,5,5), 8° Lift Loss = 15.82%

End of Rotation

Photo 9.7: Test #103 – End of Test

Test #103
Octaflo, Light ZR 25 g/dm²/h, 8 min
-5°C, 8° Rotation
Visual Contamination Rating (5,5,5)
End of Test

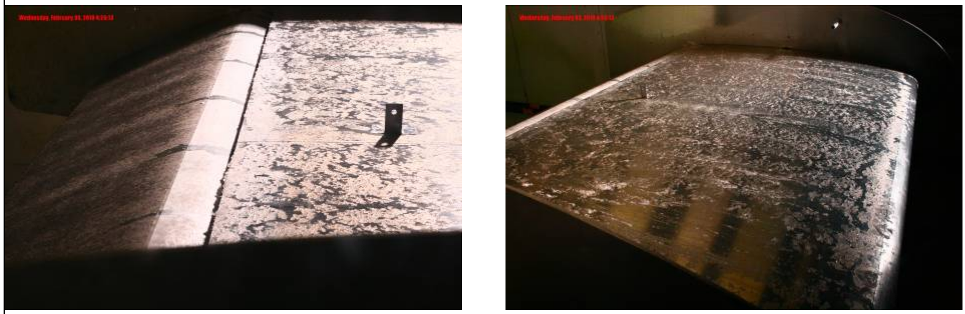
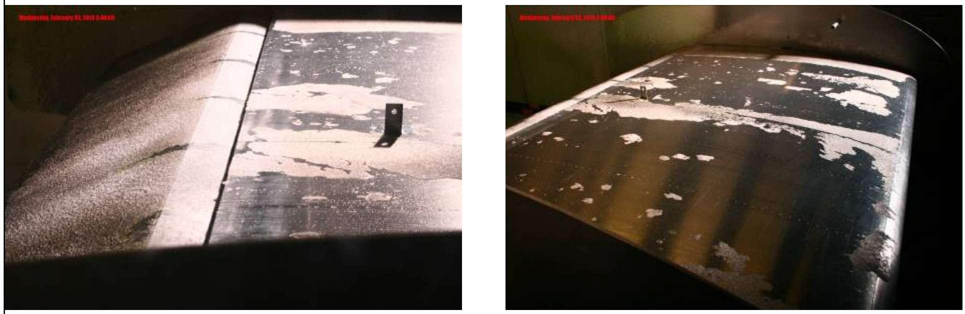


Photo 9.8: Test #102 – End of Test

Test #102
Octaflo, SN + Light ZR 25+25 g/dm²/h, 4 min
-5.5°C, 8° Rotation
Visual Contamination Rating (5,5,5)
End of Test



10. EFFECTS OF SNOW ON AN UNPROTECTED WING

In colder northern operations, it is believed to be common for aircraft to depart with loose, dry, un-adhered snow present on their wing sections. Although it is assumed that most or all of this contamination will be removed at the time of rotation, it is unknown whether a certain level of residual contamination will reduce aerodynamic performance. It was recommended that wind tunnel testing be conducted to investigate the aerodynamic performance of a wing section contaminated with dry, unadhered snow.

10.1 General Methodology

The methodology used during these tests was in accordance with the methodologies described in Section 2. However, no de/anti-icing fluid protection was applied to the wing section; the wing was clean and dry at the start of the test. Snow was applied to the wing until a visually severe level of contamination was observed, at which point the wind tunnel was run to collect aerodynamic data.

10.2 Overview of Tests

A summary of the effects of snow on an unprotected wing tests conducted in the wind tunnel is shown in Table 10.1. The table 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. A more detailed test log of all conditions tested using the wind tunnel is provided in Subsection 3.1. The following is a brief description of the column headings for Table 10.1.

Test #:	Exclusive number identifying each test.
Date:	Date when the test was conducted.
Fluid:	Aircraft deicing fluid specified by product name; all fluids were in the “neat” 100/0 dilution.
Associated Baseline Run:	The associated fluid only baseline run based on fluid selection.
Condition:	Simulated precipitation condition.

Precipitation Rate (g/dm²/h):	Simulated freezing precipitation rate (or combination of different precipitation rates). "N/A" indicates that no precipitation was applied.
Precip. Time (min.):	Total time of exposure to simulated precipitation.
Tunnel Temp. at Start of Test (°C):	The tunnel ambient temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.
Avg. Wing Temp. Before Test (°C):	Average of the wing skin temperature measurements just before the start of the simulated takeoff test, recorded in degrees Celsius.
Visual Contamination Rating Before Takeoff (LE, TE, Flap):	Visual contamination rating determined before the start of the simulated takeoff: 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 - Contamination visible, adherence of contamination.
Visual Contamination Rating at Rotation (LE, TE, Flap):	Visual contamination rating determined at the time of rotation: 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 - Contamination visible, adherence of contamination.

CL at 8º During Rotation:	Calculated lift coefficient at the 8º wing rotation angle position; data provided by the NRC.
% Lift Loss:	Percentage lift loss calculated based on the comparison of the 8º lift coefficient during the test run versus the dry wing average lift coefficient (calculated to be 1.7213).

Table 10.1: Summary of 2009-10 Effects of Snow on an Unprotected Wing Testing

Test No.	Date	Fluid	Associated Baseline Run	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° Rotation	% Lift Loss	Comments
51	27-Jan-10	Dry - Warm Wing	Dry Wing	Snow	SN: 25	20	-0.5	-0.4	4.5, 4.5, 4.5	4.8, 4.8, 4.8	1.341	22.09	Target OAT 0°
52	27-Jan-20	Dry - Warm Wing	Dry Wing	Same as Test 51 + Rain	R: 100	24	-0.2	-0.4	5, 5, 5	5, 5, 5	1.369	20.47	Rain Applied On Top Of Residual Snow from Test #51
52A	27-Jan-10	Dry - Warm Wing	Dry Wing	Same as Test 52	N/A	N/A	-2	N/A	5, 5, 5	5, 5, 5	1.398	18.78	Same As Run 52 But With 15° Rot. Angle
89	1-Feb-10	Dry - Cold Wing	Dry Wing	Snow	SN:50	Approx. 7	-12.7	N/A	4, 4, 4	3.6, 1, 3.5	1.652	4.03	N/A

10.3 Data Collected

10.3.1 Fluid Thickness Data

No fluid thickness measurements were collected because there was no fluid applied to the wing surface for the tests conducted.

10.3.2 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Subsection 2.16.3. Skin temperature measurements were recorded at the following intervals:

- Before fluid application;
- After fluid application;
- After application of contamination; and
- After the simulated takeoff test.

Tables 10.2 to 10.5 show the wing temperature measurements recorded during the contaminated fluid tests.

Table 10.2: Test #51 Wing Skin Temperature Data

Test 51: No Fluid, SN, Tunnel OAT -0.5°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-0.4	N/A	-0.4	-0.9
T5	-0.2	N/A	-0.5	-0.6
TU	-0.1	N/A	-0.2	-0.5

Table 10.3: Test #52 Wing Skin Temperature Data

Test 52: No Fluid, SN/R, Tunnel OAT -0.2°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-0.5	N/A	-0.3	N/A
T5	-0.5	N/A	-0.4	N/A
TU	-0.6	N/A	-0.4	N/A

Table 10.4: Test #52A Wing Skin Temperature Data

Test 52A: No Fluid, SN/R, Tunnel OAT -2.0°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	N/A	N/A	N/A	-0.3
T5	N/A	N/A	N/A	-0.4
TU	N/A	N/A	N/A	-1.1

Table 10.5: Test #89 Wing Skin Temperature Data

Test 89: No Fluid, S++, Tunnel OAT -12.7°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-13.4	N/A	N/A	N/A
T5	-13.1	N/A	N/A	N/A
TU	-13.4	N/A	N/A	N/A

10.3.3 Fluid Brix Data

No fluid Brix measurements were collected because there was no fluid applied to the wing surface for the tests conducted.

10.4 Photos

High-speed digital photography of each test was taken. For each test, wide-angle photos were taken of the leading edge, and close-up photos were taken of the trailing edge. For each of the tests, photo summaries have been compiled comprising four stages:

- Start of test;
- Before Rotation (just before the wing began to pitch);
- End of Rotation (end of the rotation cycle when the wing position is returned to four degrees); and
- End of test.

Photos 10.1 to 10.16 show the photo summaries of the tests conducted. A complete set of photos will be provided to the TDC in electronic format.

10.5 Summary of Test Results

Testing was conducted at near 0°C and at colder temperatures (-13°C) to identify the potential risks associated with aircraft taking off with dry snow present on the wing. Test #51 was conducted just below 0°C, and snow was applied until the wing section was completely covered. The amount of snow applied was equivalent to a 20-minute exposure to moderate snow; this generated a layer of snow 0.5 cm to 1 cm thick. During the simulated takeoff run, no contamination had been removed by the time of rotation, and as a result, significant lift losses were recorded: 22 percent compared to the dry wing. It was concluded that the high moisture content close to 0°C and the colder air being blown through the tunnel during the simulated takeoff likely froze the layer of snow together and made it difficult to shear off.

Immediately following, it was decided that rain be applied over the wing section to simulate a case where the operator would not deice the aircraft and a transitional period of rain occurred just before takeoff (Test #52). The rain seemed to form a thin ice crust on the wing section, which seemed to slightly improve the aerodynamic performance; however, lift losses were still significant (20.5 percent compared to the dry wing), and no contamination was removed at the time of rotation.

Test #52A was a repeat of #52; however, the wing was rotated to 15° to identify the stall angle of the wing. The data indicated that the wing began to stall at approximately 12.9° rotation, and the recorded lift loss at 8° rotation was 18.8 percent compared to the dry wing, similar to run #52. Due to the adhered contamination present due to the temperature being close to 0°C, and the resulting large lift losses, it was recommended that testing be conducted at a colder temperature when moisture content would be lower, and it would be possible to ensure dry, loose, un-adhered snow.

Test #89 was conducted at approximately -13°C. Slightly less snow was applied during this test compared to Test #51; the layer of snow on the wing measured between 0.3 cm and 0.5 cm. At the time of rotation, most of the dry snow had been removed with the exception of the leading edge and the flap; it was concluded that some residual anti-icing fluid may have seeped from the joints in the skin and caused some melting, which refroze during the wind tunnel run. The lift losses observed were acceptable at 4 percent compared to the dry wing.

The results from this testing indicated that a takeoff with dry, loose snow on the wings may be feasible at colder temperatures; however, it is not recommended at warmer temperatures where the risk of melting and refreezing is high. In addition, it may be difficult to identify adhered contamination on a snow-covered wing (due to hot spots, high moisture, or residual fluid); therefore, de/anti-icing may still be the best practice in order to ensure safe operations. More testing is necessary at colder temperatures to ensure that there is no melting and refreezing of contamination.

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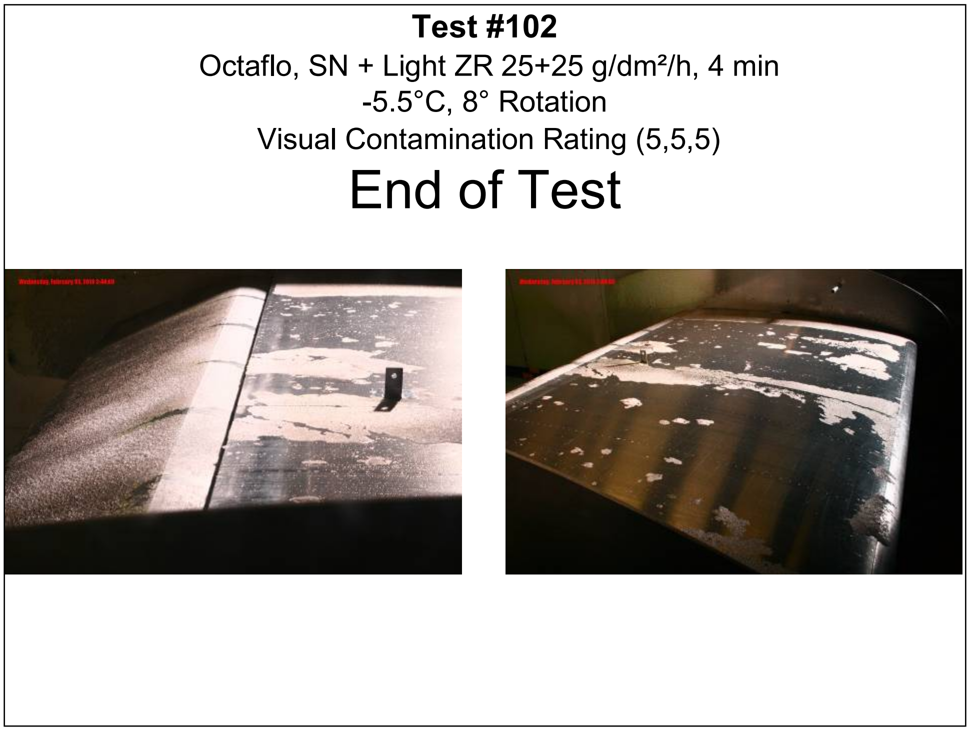
Photo 10.1: Test #51 – Start of Test



Test #102

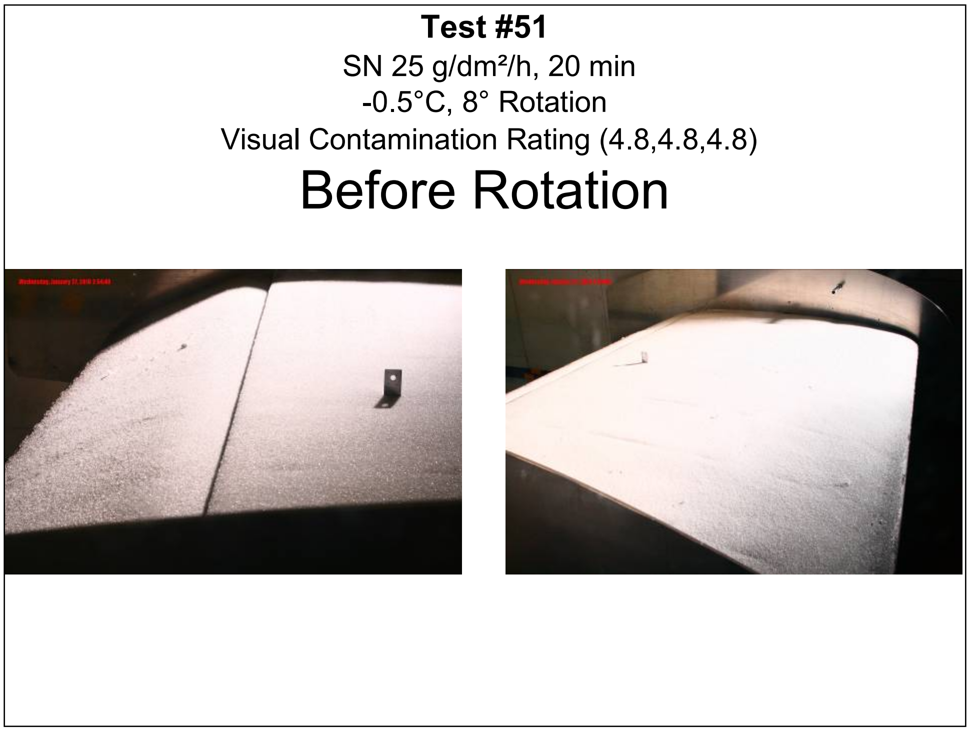
Octaflo, SN + Light ZR 25+25 g/dm²/h, 4 min

-5.5°C, 8° Rotation

Visual Contamination Rating (5,5,5)

End of Test

Photo 10.2: Test #51 – Before Rotation



Test #51

SN 25 g/dm²/h, 20 min

-0.5°C, 8° Rotation

Visual Contamination Rating (4.8,4.8,4.8)

Before Rotation

Photo 10.3: Test #51 – End of Rotation

Test #51
SN 25 g/dm²/h, 20 min
-0.5°C, 8° Rotation
Visual Contamination Rating (4.8,4.8,4.8), 8° Lift Loss = 22.09%

End of Rotation

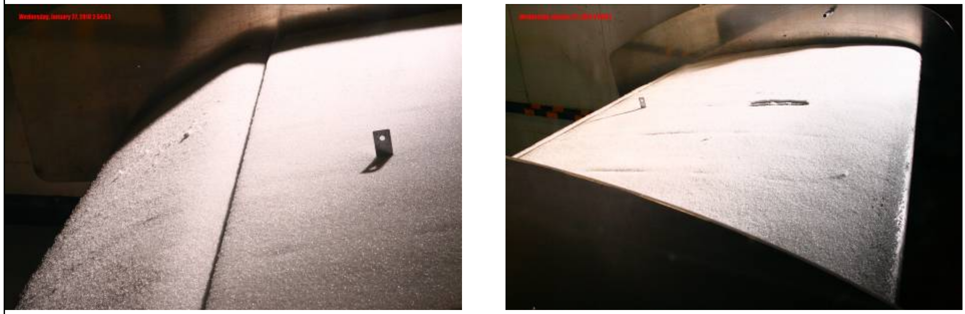


Photo 10.4: Test #51 – End of Test

Test #51
SN 25 g/dm²/h, 20 min
-0.5°C, 8° Rotation
Visual Contamination Rating (4.8,4.8,4.8)

End of Test

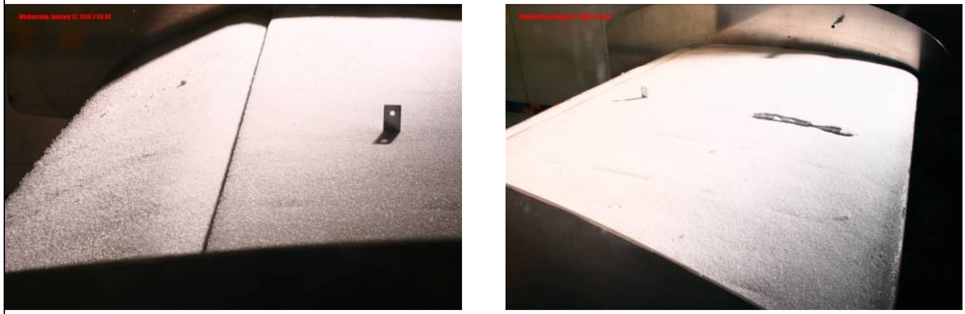


Photo 10.5: Test #52 – Start of Test

Test #52
SN + R 25 + 100 g/dm²/h (SN Applied In Run #51), 24 min
0°C, 8° Rotation
Visual Contamination Rating (5,5,5)

Start of Test

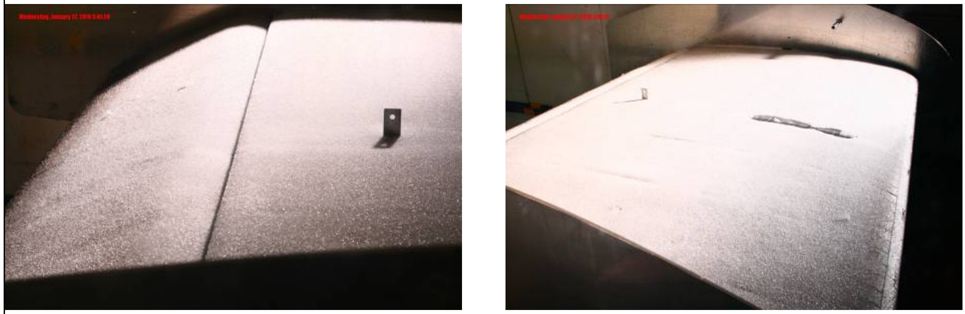


Photo 10.6: Test #52 – Before Rotation

Test #52
SN + R 25 + 100 g/dm²/h (SN Applied In Run #51), 24 min
0°C, 8° Rotation
Visual Contamination Rating (5,5,5)

Before Rotation

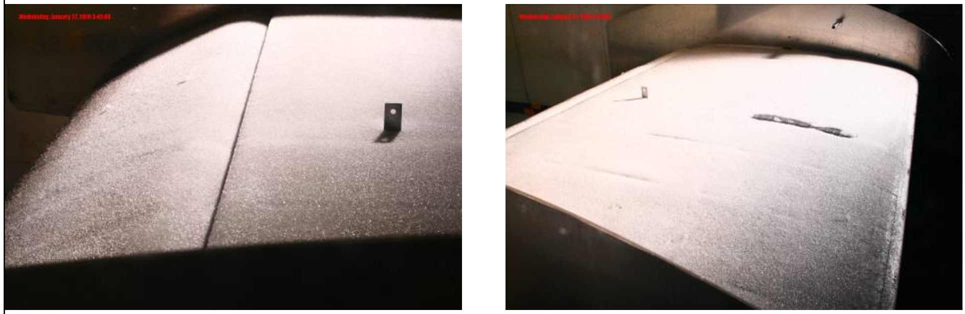
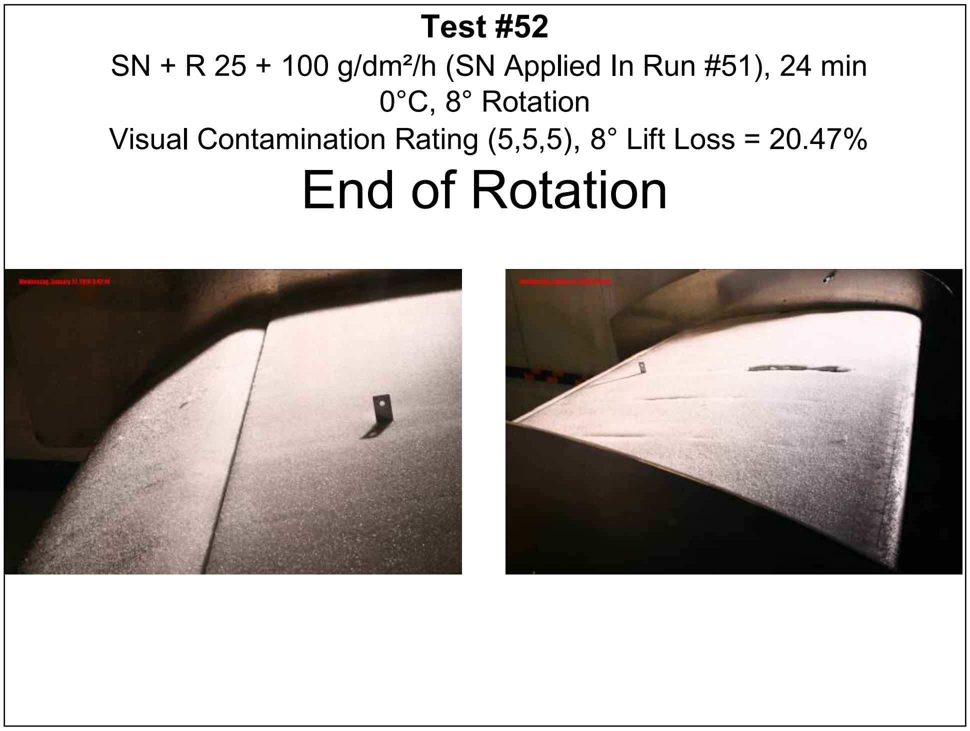
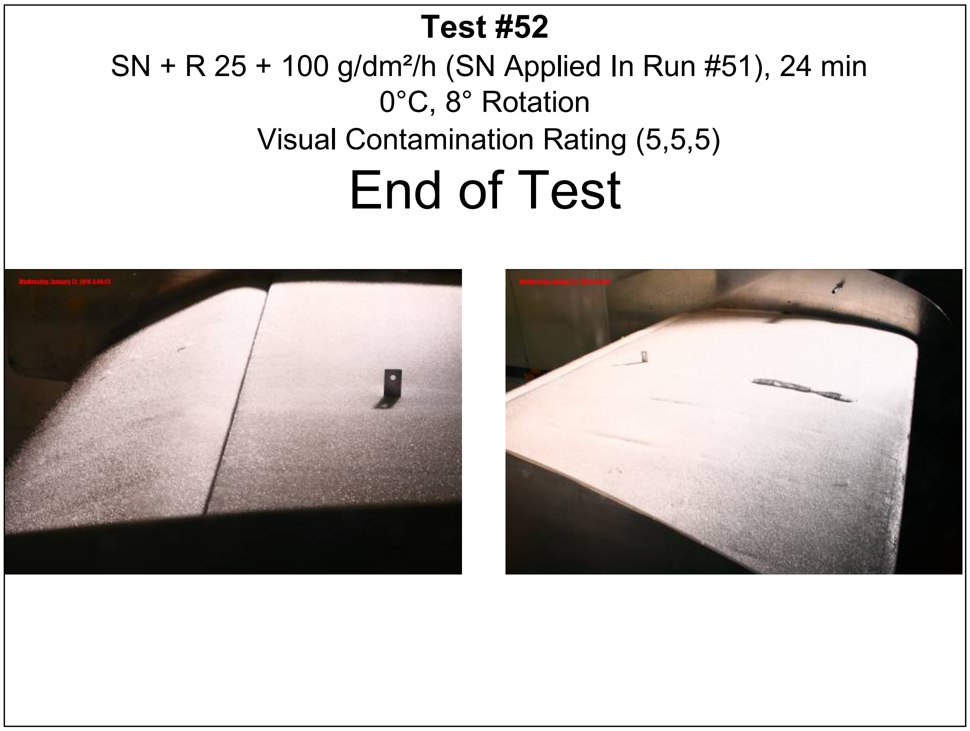


Photo 10.7: Test #52 – End of Rotation



Test #52
SN + R 25 + 100 g/dm²/h (SN Applied In Run #51), 24 min
0°C, 8° Rotation
Visual Contamination Rating (5,5,5), 8° Lift Loss = 20.47%
End of Rotation

Photo 10.8: Test #52 – End of Test



Test #52
SN + R 25 + 100 g/dm²/h (SN Applied In Run #51), 24 min
0°C, 8° Rotation
Visual Contamination Rating (5,5,5)
End of Test

Photo 10.9: Test #52A – Start of Test

Test #52A
SN + R 25 + 100 g/dm²/h, 20 min (Applied In Run #52)
-2°C, 15° Rotation
Visual Contamination Rating (5,5,5)
Start of Test

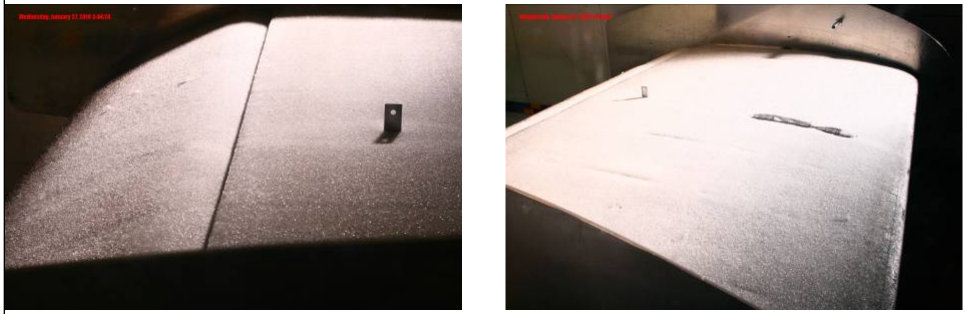


Photo 10.10: Test #52A – Before Rotation

Test #52A
SN + R 25 + 100 g/dm²/h, 20 min (Applied In Run #52)
-2°C, 15° Rotation
Visual Contamination Rating (5,5,5)
Before Rotation

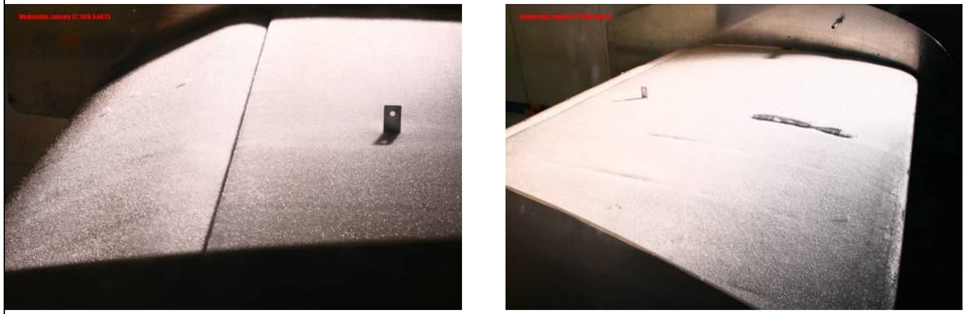


Photo 10.11: Test #52A – End of Rotation

Test #52A
SN + R 25 + 100 g/dm²/h, 20 min (Applied In Run #52)
-2°C, 15° Rotation
Visual Contamination Rating (5,5,5), 8° Lift Loss = 18.78%

End of Rotation

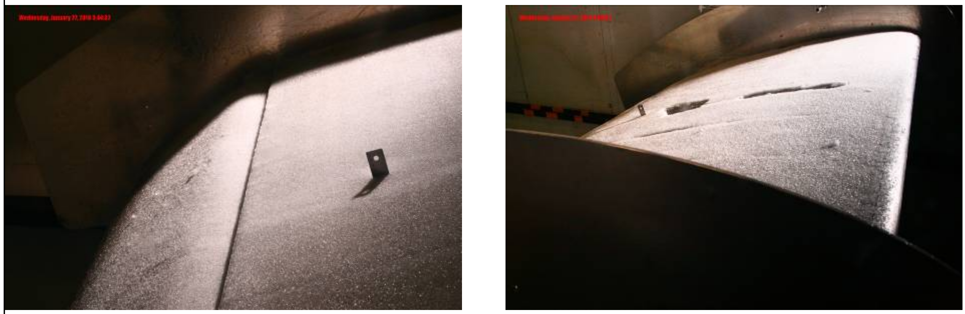


Photo 10.12: Test #52A – End of Test

Test #52A
SN + R 25 + 100 g/dm²/h, 20 min (Applied In Run #52)
-2°C, 15° Rotation
Visual Contamination Rating (5,5,5)

End of Test

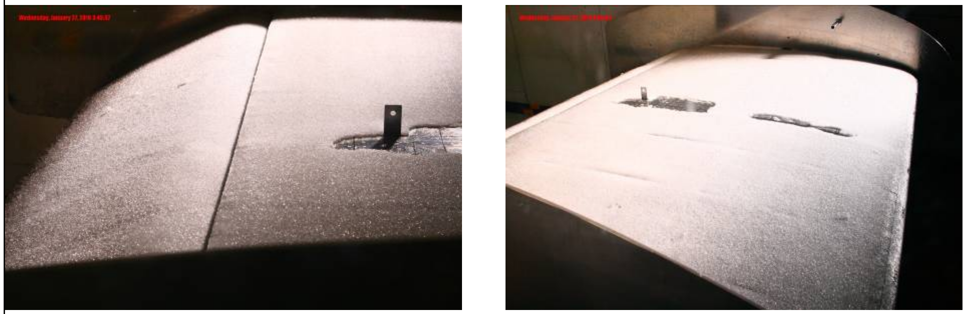


Photo 10.13: Test #89 – Start of Test

Test #89
SN 50 g/dm²/h, 7 min
-13°C, 8° Rotation
Visual Contamination Rating (4,4,4)
Start of Test

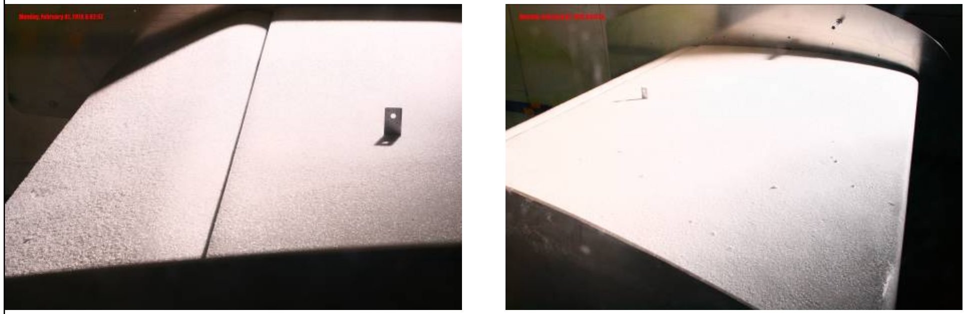
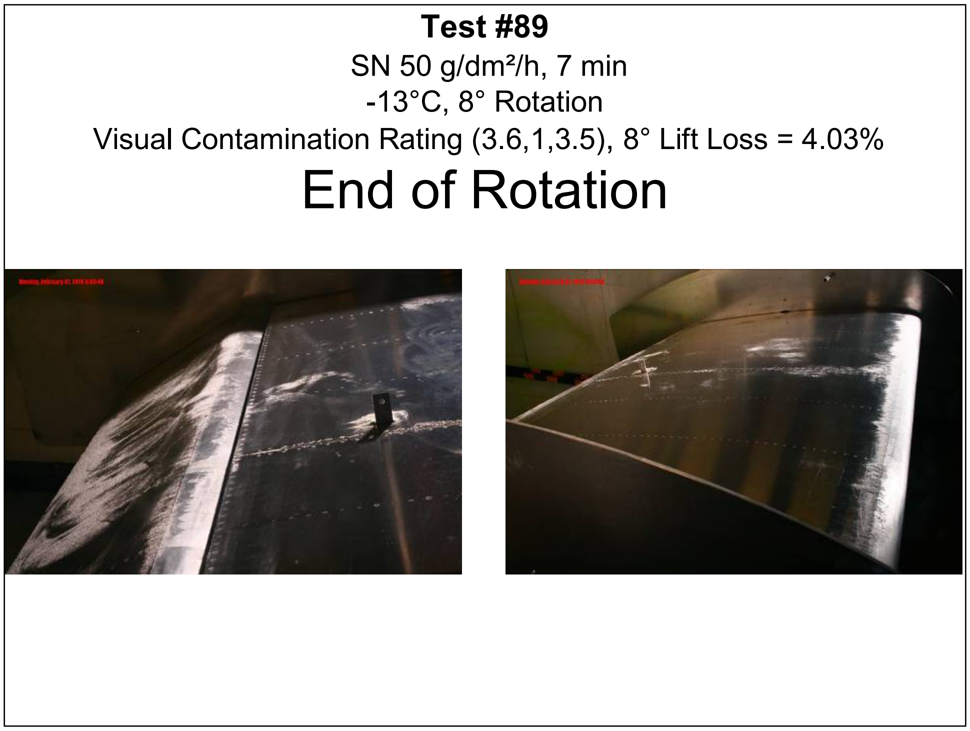


Photo 10.14: Test #89 – Before Rotation

Test #89
SN 50 g/dm²/h, 7 min
-13°C, 8° Rotation
Visual Contamination Rating (3.6,1,3.5)
Before Rotation

Photo 10.15: Test #89 – End of Rotation



Test #89

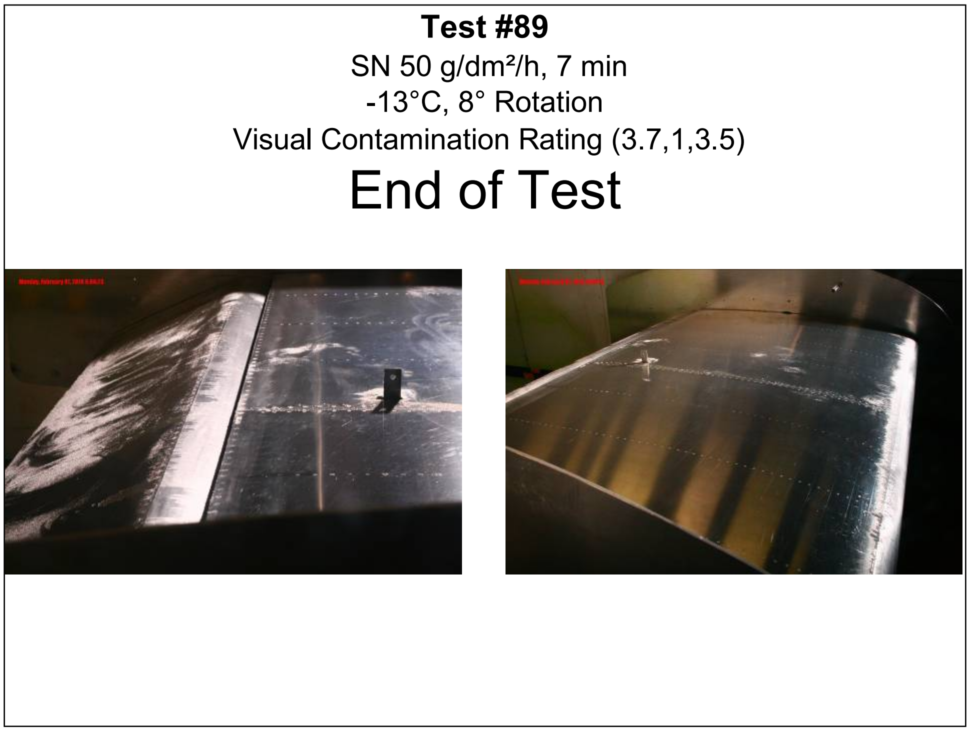
SN 50 g/dm²/h, 7 min

-13°C, 8° Rotation

Visual Contamination Rating (3.6,1,3.5), 8° Lift Loss = 4.03%

End of Rotation

Photo 10.16: Test #89 – End of Test



Test #89

SN 50 g/dm²/h, 7 min

-13°C, 8° Rotation

Visual Contamination Rating (3.7,1,3.5)

End of Test

11. DEGRADED ANTI-ICING FLUID PERFORMANCE FOLLOWING CONTAMINATION WITH RUNWAY DEICING FLUID

Recent operational reports have indicated a significant degradation effect of thickened anti-icing fluids as a result of cross-contamination with runway deicing fluids. This is especially of concern for landings on a wet runway with reverse thrusters followed by preventative anti-icing applications. It was recommended that full-scale testing be conducted in the wind tunnel to obtain preliminary data to identify the aerodynamic impact of degraded anti-icing fluid flow-off following contamination.

11.1 General Methodology

The following is a brief summary of the methodology used for this testing:

- Clean and dry wing before the start of test;
- Section wing in half: baseline side and degraded fluid side;
- Treat the degraded fluid side with a spray of diluted runway deicer fluid. The runway deicer fluid applied will be potassium acetate based in liquid form and was diluted with water when required. The fluid is applied as a light misting using a spray bottle;
- Apply anti-icing fluid to the whole wing (both baseline and degraded fluid side). Fluid to be applied approximately 5 minutes following the application of runway deicer fluid;
- Expose wing section to simulated light freezing rain at a rate of 25 g/dm²/h. Time of exposure should be selected based on OAT and fluid specific HOTs;
- Run wind tunnel and collect data; and
- Repeat test and reduce or increase amount of runway deicer fluid applied.

During these tests, the aerodynamic data collected has little relevance due to the variation in contamination resulting from the different fluid applications on each half of the wing.

11.2 Overview of Tests

A summary of the anti-icing fluid contaminated with runway deicer tests conducted in the wind tunnel is shown in Table 11.1. The table 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. A more detailed test log of all conditions tested using the wind tunnel is provided in Subsection 3.1. The following is a brief description of the column headings for Table 11.1.

Test #:	Exclusive number identifying each test.
Date:	Date when the test was conducted.
Fluid:	Aircraft deicing fluid specified by product name; all fluids were in the "neat" 100/0 dilution.
Associated Baseline Run:	The associated fluid only baseline run based on fluid selection.
Condition:	Simulated precipitation condition.
Precipitation Rate (g/dm²/h):	Simulated freezing precipitation rate (or combination of different precipitation rates). "N/A" indicates that no precipitation was applied.
Precip. Time (min.):	Total time of exposure to simulated precipitation.
Tunnel Temp. at Start of Test (°C):	The tunnel ambient temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.
Avg. Wing Temp. Before Test (°C):	Average of the wing skin temperature measurements just before the start of the simulated takeoff test, recorded in degrees Celsius.
Visual Contamination Rating Before Takeoff (LE, TE, Flap):	Visual contamination rating determined before the start of the simulated takeoff: 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 - Contamination visible, adherence of contamination.

Visual Contamination Rating at Rotation (LE, TE, Flap):	Visual contamination rating determined at the time of rotation: 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 - Contamination visible, adherence of contamination.
CL at 8° During Rotation:	Calculated lift coefficient at the 8° wing rotation angle position; data provided by the NRC.
% Lift Loss:	Percentage lift loss calculated based on the comparison of the 8° lift coefficient during the test run versus the dry wing average lift coefficient (calculated to be 1.7213).

Table 11.1: Summary of 2009-10 Anti-Icing Fluid Contaminated with Runway Deicer Testing

Test No.	Date	Fluid	Associated Baseline Run	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° Rotation	% Lift Loss	Comments
50	24-Jan-10	Safeway + Launch	N/A	ZR	ZR:25	53	-0.6	-0.8	P: 2, 1, 4.7 SB:1.7, 1.7, 3.3	P: 3.7, 3.7, 3.7 SB:2.3, 2.3, 2.3	1.643	4.55	0.2g/dm² of 100% RWD applied to PORT side prior to anti-icing
93	2-Feb-10	Safeway + ABC-S Plus	N/A	ZR	ZR:25-50	96	-1.4	-3.3	P: 4.5, 4.5, 5 SB: 1, 1, 5	P: 5, 5, 5 SB: 2.3, 1, 5	1.623	5.71	0.2g/dm² of 5% RWD applied to PORT side prior to anti-icing
104	3-Feb-10	Safeway + ABC-S Plus	N/A	ZR	ZR:25	83	-1.8	-2.1	P: 5, 5, 5 SB:1, 1, 5	P: 5, 5, 5 SB:1.8, 1.3, 4.3	1.576	8.44	0.2g/dm² of 50% RWD applied to PORT side prior to anti-icing

11.3 Data Collected

11.3.1 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Subsection 2.16.2. Fluid thickness measurements were recorded at the following intervals:

- After fluid application;
- After application of contamination; and
- After the simulated takeoff test.

Tables 11.2 to 11.4 show the fluid thickness measurements collected during the contaminated fluid tests.

Table 11.2: Test #50 Fluid Thickness Data

Test 50: Safeway KA & Launch, ZR, Tunnel OAT -0.6°C			
FLUID THICKNESS PORT (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	0.5	N/A	N/A
2	0.7	N/A	N/A
3	0.8	N/A	N/A
4	0.8	N/A	N/A
5	0.7	N/A	N/A
6	0.6	N/A	N/A
7	0.6	N/A	N/A
8	0.7	N/A	N/A
Flap	N/A	N/A	N/A

Test 50: Launch, ZR, Tunnel OAT -0.6°C			
FLUID THICKNESS STBD (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.5	N/A	N/A
2	2.2	N/A	N/A
3	2.5	N/A	N/A
4	3.1	N/A	N/A
5	3.3	N/A	N/A
6	3.5	N/A	N/A
7	3.3	N/A	N/A
8	2.2	N/A	N/A
Flap	N/A	N/A	N/A

Table 11.3: Test #93 Fluid Thickness Data

Test 93: Safeway KA & ABC-S+, ZR, Tunnel OAT -1.4°C			
FLUID THICKNESS PORT (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.0	0.5	N/A
2	1.2	0.4	N/A
3	1.6	0.3	N/A
4	1.8	0.4	N/A
5	1.7	0.4	N/A
6	2.2	0.6	N/A
7	1.8	0.5	N/A
8	1.8	0.6	N/A
Flap	0.8	N/A	N/A

Test 93: ABC-S Plus, ZR, Tunnel OAT -1.4°C			
FLUID THICKNESS STBD (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.1	0.5	0.0
2	1.6	0.6	0.0
3	2.7	0.8	0.0
4	3.1	2.5	0.0
5	3.3	2.5	0.0
6	3.3	0.3	0.2
7	3.1	0.2	0.2
8	2.9	0.5	0.2
Flap	1.0	N/A	0.1

Table 11.4: Test #104 Fluid Thickness Data

Test 104: Safeway KA & ABC-S+, ZR, Tunnel OAT -1.8°C			
FLUID THICKNESS PORT (mm)			
Wing Position	After Fluid Application	After Precip, Application	After Takeoff Test
1	0.6	slush	slush
2	1.0	slush	slush
3	0.8	slush	slush
4	1.3	slush	slush
5	1.0	slush	slush
6	1.0	slush	slush
7	1.5	slush	slush
8	1.5	slush	slush
Flap	0.5	slush	slush

Test 104: ABC-S Plus, ZR, Tunnel OAT -1.8°C			
FLUID THICKNESS STBD (mm)			
Wing Position	After Fluid Application	After Precip, Application	After Takeoff Test
1	1.8	0.5	0.0
2	2.7	0.6	0.0
3	3.3	1.7	0.0
4	3.9	2.2	0.0
5	4.5	3.5	0.0
6	4.5	4.5	0.3
7	4.5	3.5	0.3
8	4.5	1.4	0.2
Flap	1.3	slush	0.2

11.3.2 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Subsection 2.16.3. Skin temperature measurements were recorded at the following intervals:

- Before fluid application;
- After fluid application;
- After application of contamination; and
- After the simulated takeoff test.

Tables 11.5 to 11.7 show the wing temperature measurements recorded during the contaminated fluid tests.

Table 11.5: Test #50 Wing Skin Temperature Data

Test 50: Safeway KA & Launch, ZR, Tunnel OAT -0.6°C				
WING TEMPERATURE PORT (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-4.6	-3.6	-	-5.2
T5	-4.6	-3.7	-	-4.7
TU	-5.5	-4.0	-	-11.6

Test 50: Launch, ZR, Tunnel OAT -0.6°C				
WING TEMPERATURE STBD (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-4.6	-3.6	-0.4	-5.2
T5	-4.6	-3.7	-0.4	-4.7
TU	-5.5	-4.0	-1.7	-11.6

Table 11.6: Test #93 Wing Skin Temperature Data

Test 93: Safeway KA & ABC-S+, ZR, Tunnel OAT -1.4°C				
WING TEMPERATURE PORT (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-7.5	-8.2	-2.0	-7.2
T5	-7.1	-8.4	-1.8	-6.5
TU	-8.5	-8.2	-6.0	-8.3

Test 93: ABC-S Plus, ZR, Tunnel OAT -1.4°C				
WING TEMPERATURE STBD (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-7.5	-8.2	-2.0	-7.2
T5	-7.1	-8.4	-1.8	-6.5
TU	-8.5	-8.2	-6.0	-8.3

Table 11.7: Test #104 Wing Skin Temperature Data

Test 104: Safeway KA & ABC-S+, ZR, Tunnel OAT -1.8°C				
WING TEMPERATURE PORT (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T3	-8.5	-5.6	-1.3	-9.2
T5	-8.2	-5.3	-1.1	-9.4
TU	-8.6	-6.5	-4.0	-8.9

Test 104: ABC-S Plus, ZR, Tunnel OAT -1.8°C				
WING TEMPERATURE STBD (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T3	-8.5	-5.6	-1.3	-9.2
T5	-8.2	-5.3	-1.1	-9.4
TU	-8.6	-6.5	-4.0	-8.9

11.3.3 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Subsection 2.16.4. Fluid Brix measurements were recorded at the following intervals:

- After fluid application;
- After application of contamination; and
- After the simulated takeoff test.

Tables 11.8 to 11.10 show the fluid Brix measurements collected during the contaminated fluid tests.

Table 11.8: Test #50 Fluid Brix Data

Test 50: Safeway KA & Launch, ZR, Tunnel OAT -0.6°C			
FLUID BRIX PORT (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.00	5.50	N/A
8	N/A	N/A	N/A

Test 50: Launch, ZR, Tunnel OAT -0.6°C			
FLUID BRIX STBD (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.25	25.00	N/A
8	N/A	N/A	N/A

Table 11.9: Test #93 Fluid Brix Data

Test 93: Safeway KA & ABC-S+, ZR, Tunnel OAT -1.4°C			
FLUID BRIX PORT (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.5	6.75	7.00
8	36.75	8.50	10.50

Test 93: ABC-S Plus, ZR, Tunnel OAT -1.4°C			
FLUID BRIX STBD (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.25	13.00	16.50
8	36.75	12.25	25.75

Table 11.10: Test #104 Fluid Brix Data

Test 104: Safeway KA & ABC-S+, ZR, Tunnel OAT -1.8°C			
FLUID BRIX PORT (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Test
2	38.50	N/A	N/A
8	49.25	N/A	N/A

Test 104: ABC-S Plus, ZR, Tunnel OAT -1.8°C			
FLUID BRIX STBD (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Test
2	29.00	14.00	22.25
8	29.25	24.50	24.25

11.4 Photos

High-speed digital photography of each test was taken. For each test, wide-angle photos were taken of the leading edge, and close-up photos were taken of the trailing edge. For each of the tests, photo summaries have been compiled comprising five stages:

- After Fluid application;
- Start of test;
- Before Rotation (just before the wing began to pitch);
- End of Rotation (end of the rotation cycle when the wing position is returned to four degrees); and
- End of test.

Photos 11.1 to 11.15 show the photo summaries of the tests conducted. A complete set of photos will be provided to the TDC in electronic format.

11.5 Summary of Test Results

During Test #50, significant fluid degradation was visually apparent following application of Type IV fluid on the section contaminated with undiluted (100 percent) runway deicer fluid. The visual observation was also supported by the fluid thickness measurements taken after the fluid application; the average of the fluid thickness measurements on the degraded section were approximately 74 percent lower compared to the baseline test. At the end of the contamination period, minimal adherence was present for both sections; the temperature in the tunnel was close to 0°C. During the takeoff run, the section with runway deicer fluid showed frozen contamination at the time of rotation; the diluted fluid froze as cold air was blown during wind tunnel run.

During Test #93, no significant visual differences in the appearance of the Type IV fluid were observed following the application on the section contaminated with runway deicer fluid diluted to 5 percent. The fluid thickness measurements, however, indicated a 40 percent reduction in the average fluid thickness on the degraded side compared to the baseline side. Although this reduction was not visually apparent, it was still significant. At the end of the precipitation period, the section contaminated with runway deicer fluid showed significant signs of fluid adherence on all parts of the wing section, whereas the baseline section showed minimal adherence, primarily on the flap. At the time of rotation, both sections had adhered contamination present; however, the section contaminated with RWD fluid had significantly more adhered contamination compared to the baseline section.

During Test #104, significant fluid degradation was visually apparent following application of Type IV fluid on the section contaminated with runway deicer fluid diluted to 50 percent. The visual observation was also supported by the fluid thickness measurements taken after the fluid application; the average of the fluid thickness measurements on the degraded section were approximately 70 percent lower compared to the baseline test. At the end of precipitation period, the section contaminated with runway deicer fluid showed significant signs of fluid adherence, whereas the baseline section showed minimal adherence, primarily on the flap. At the time of rotation, both sections had adhered contamination present; however, the section contaminated with runway deicer fluid had significantly more adhered contamination compared to the baseline section; the baseline section was primarily covered in slush with minimal adherence.

The results of this testing indicated that the effect of runway deicer fluid was visually more apparent following the Type IV application when higher concentrations of runway deicer were used; contamination with 100 percent runway deicer showed almost instant degradation of Type IV fluid, while contamination with 5 percent runway deicer showed little visual difference initially. All three tests demonstrated significant differences between the protection time of fluid contaminated with runway deicer fluid and the baseline section.

The fluid contaminated with runway deicer demonstrated earlier and more severe signs of fluid adherence, and the adhered contamination was not removed at the time of rotation.

This and other work was presented in May 2010 at the Residues Working Group meeting held in Berlin. Following the meeting, a letter was issued on behalf of the Residues Working Group to International Air Transport Association (IATA), European Union Aviation Safety Agency (EASA), TC, and the FAA to inform the industry of the potential safety issue; the letter also specified that the issue related to pre-treatment operations with thickened fluid only. The intent was to have the regulators distribute the letter to operators, airports, and service providers, or incorporate the contents of the letter into the regulators' appropriate guidance material. As a result of this, EASA issued a Safety Information Bulletin (#2010-26, issued September 14, 2010) directed at all aircraft operators warning of the potential safety issues involved with cross-contamination of anti-icing fluid and runway deicer fluid. TC and the FAA indicated that they also intend to include guidance material in the next revision of the HOT Guidelines.

Photo 11.1: Test #50 – After Fluid Application

Test #50
Safeway + Launch, ZR 25 g/dm²/h, 53 min
-1°C, 8° Rotation
After Fluid Application

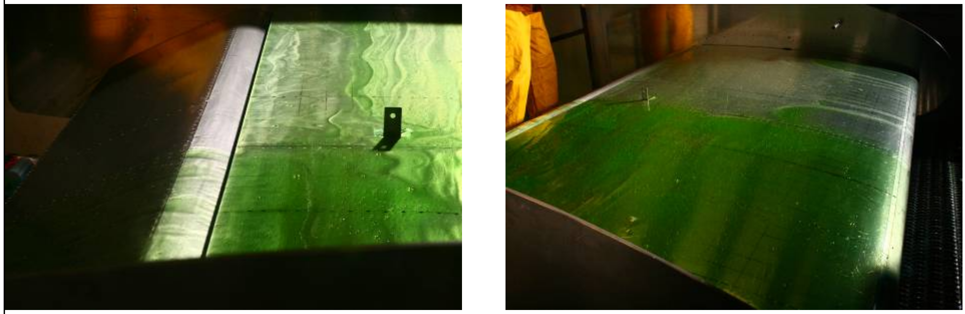


Photo 11.2: Test #50 – Start of Test

Test #50
Safeway + Launch, ZR 25 g/dm²/h, 53 min
-1°C, 8° Rotation
Start of Test

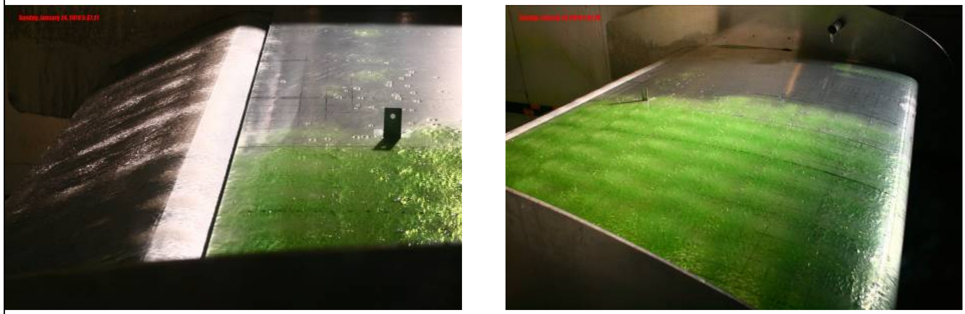
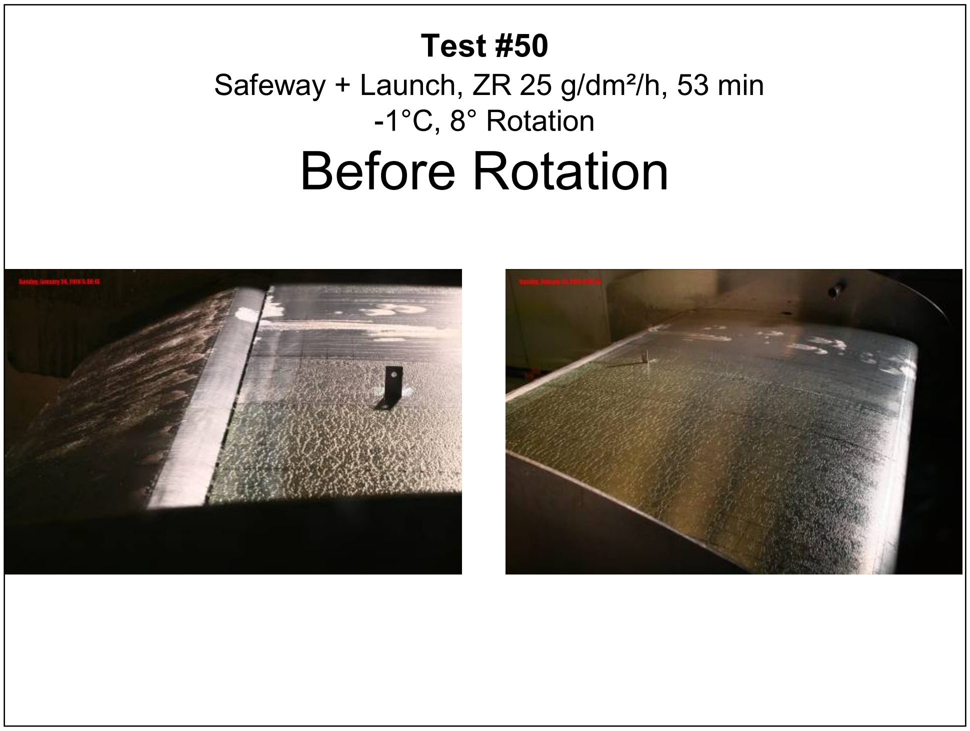


Photo 11.3: Test #50 – Before Rotation

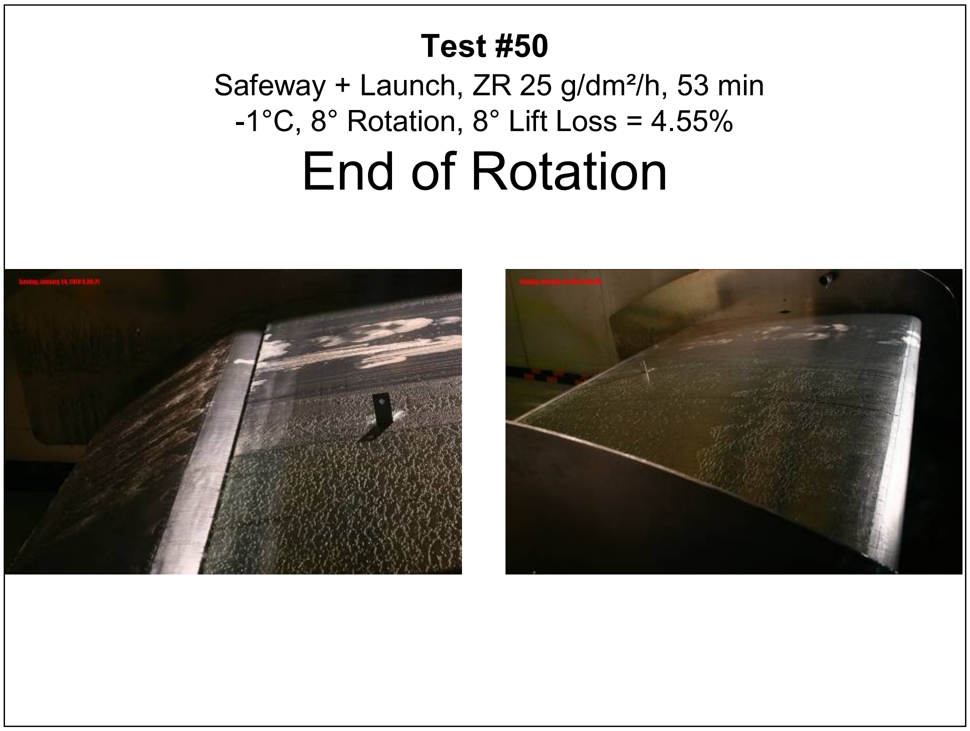


Test #50

Safeway + Launch, ZR 25 g/dm²/h, 53 min
-1°C, 8° Rotation

Before Rotation

Photo 11.4: Test #50 – End of Rotation



Test #50

Safeway + Launch, ZR 25 g/dm²/h, 53 min
-1°C, 8° Rotation, 8° Lift Loss = 4.55%

End of Rotation

Photo 11.5: Test #50 – End of Test

Test #50

Safeway + Launch, ZR 25 g/dm²/h, 53 min

-1°C, 8° Rotation

End of Test

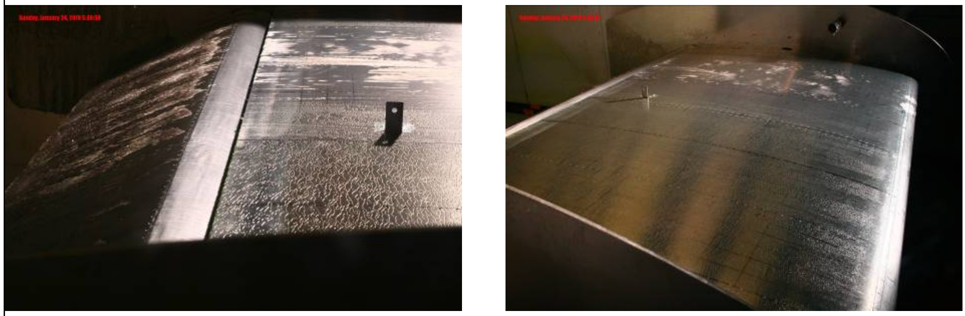


Photo 11.6: Test #93 – After Fluid Application

Test #93

Safeway + ABC-S Plus, ZR 25-50 g/dm²/h, 96 min

-1°C, 8° Rotation

After Fluid Application

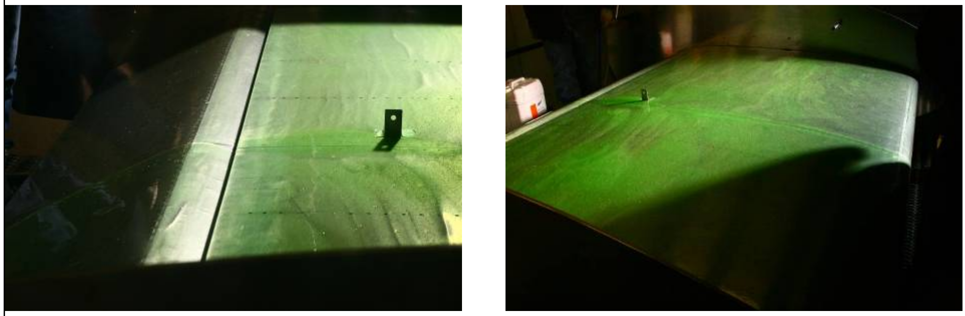
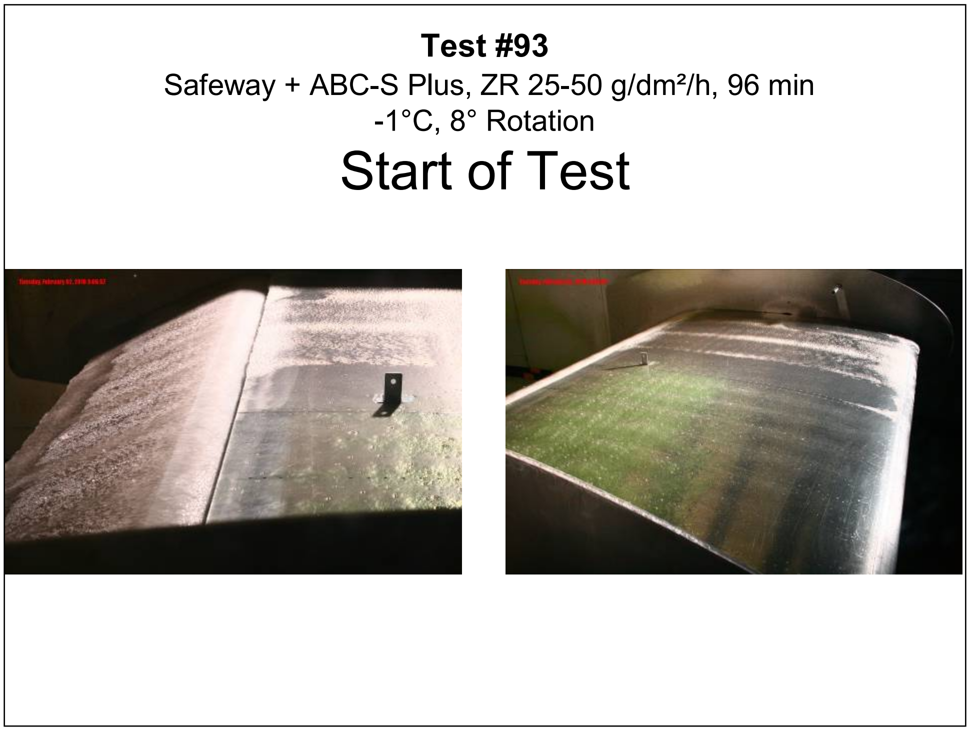


Photo 11.7: Test #93 – Start of Test



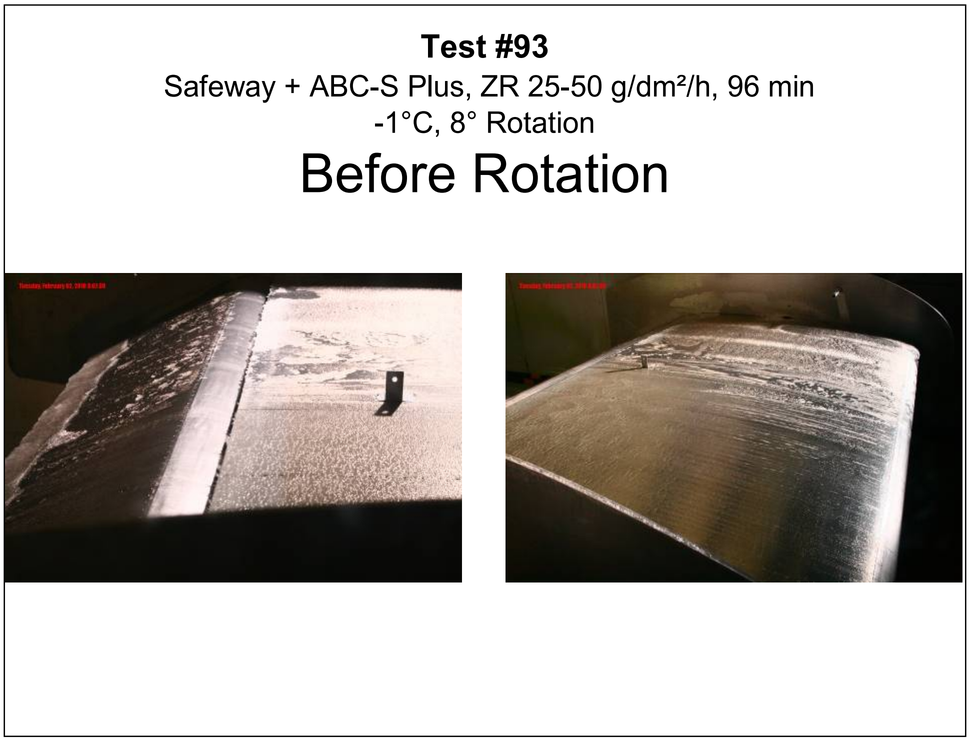
Test #93

Safeway + ABC-S Plus, ZR 25-50 g/dm²/h, 96 min

-1°C, 8° Rotation

Start of Test

Photo 11.8: Test #93 – Before Rotation



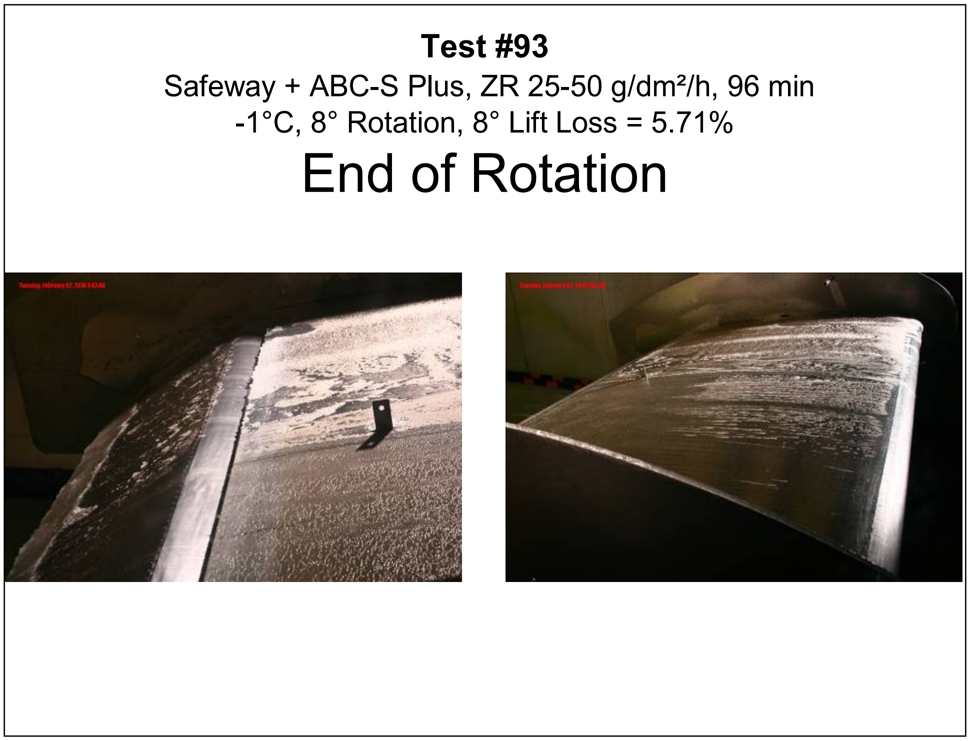
Test #93

Safeway + ABC-S Plus, ZR 25-50 g/dm²/h, 96 min

-1°C, 8° Rotation

Before Rotation

Photo 11.9: Test #93 – End of Rotation



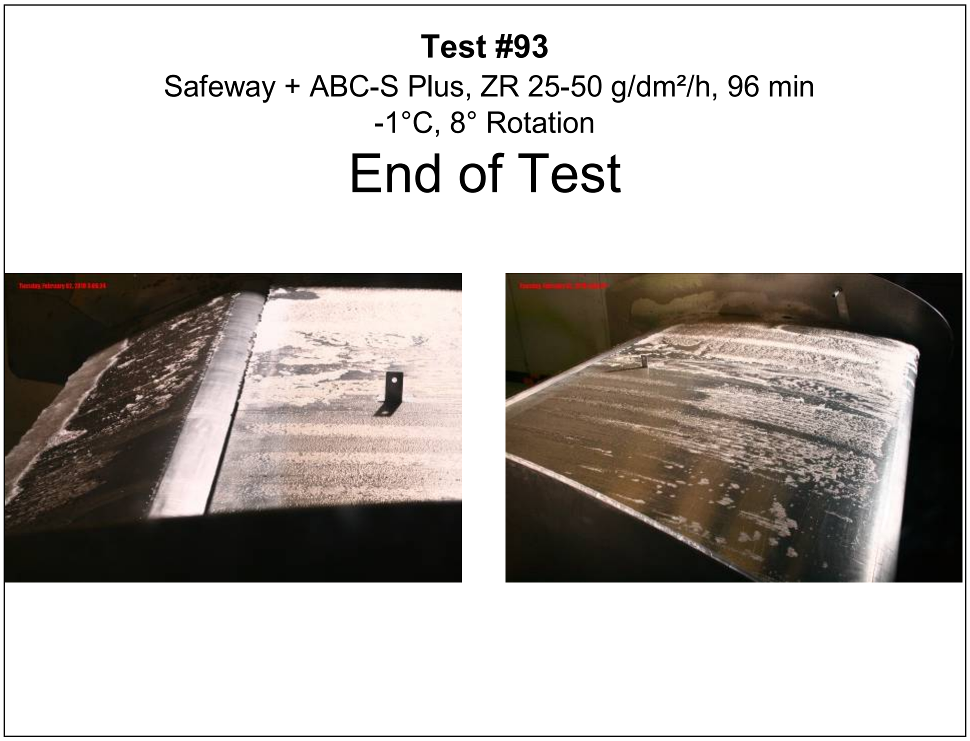
Test #93

Safeway + ABC-S Plus, ZR 25-50 g/dm²/h, 96 min

-1°C, 8° Rotation, 8° Lift Loss = 5.71%

End of Rotation

Photo 11.10: Test #93 – End of Test



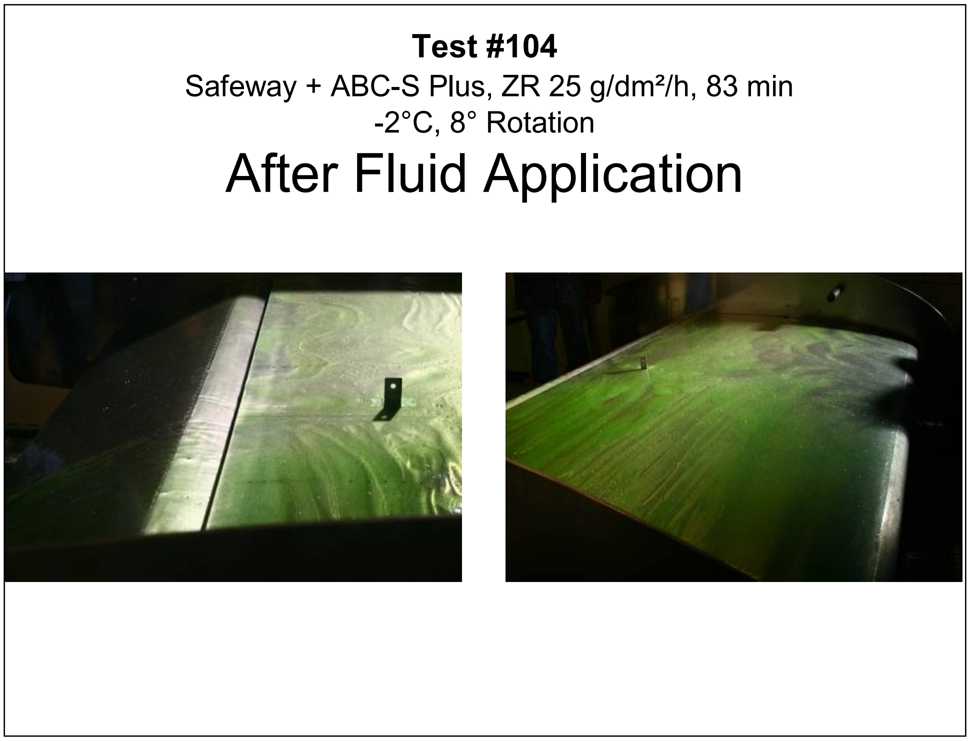
Test #93

Safeway + ABC-S Plus, ZR 25-50 g/dm²/h, 96 min

-1°C, 8° Rotation

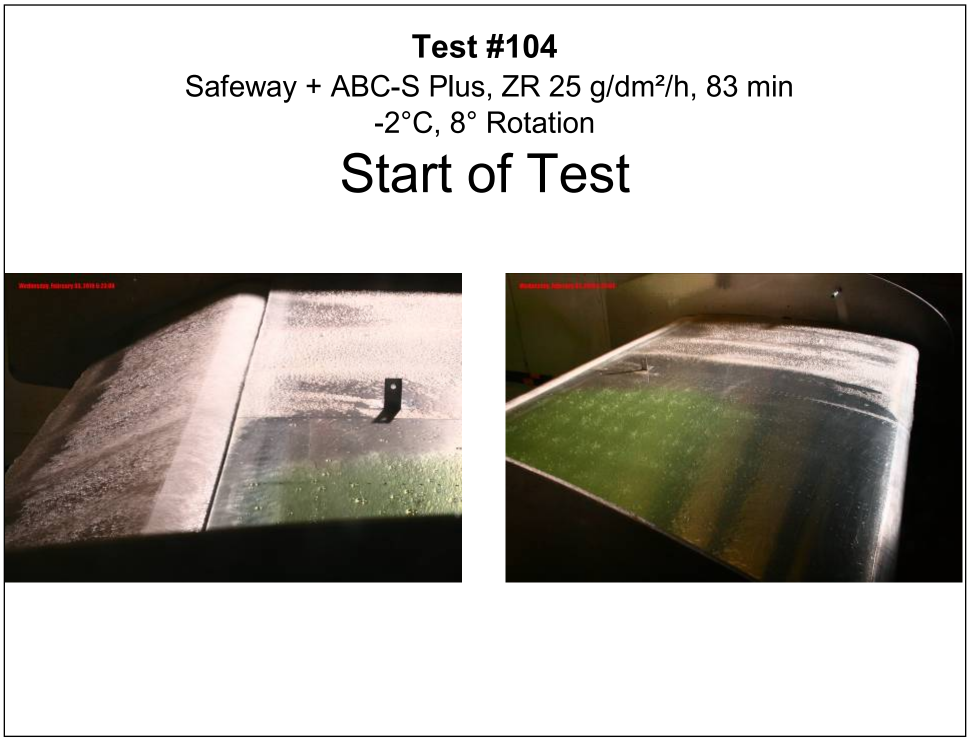
End of Test

Photo 11.11: Test #104 – After Fluid Application



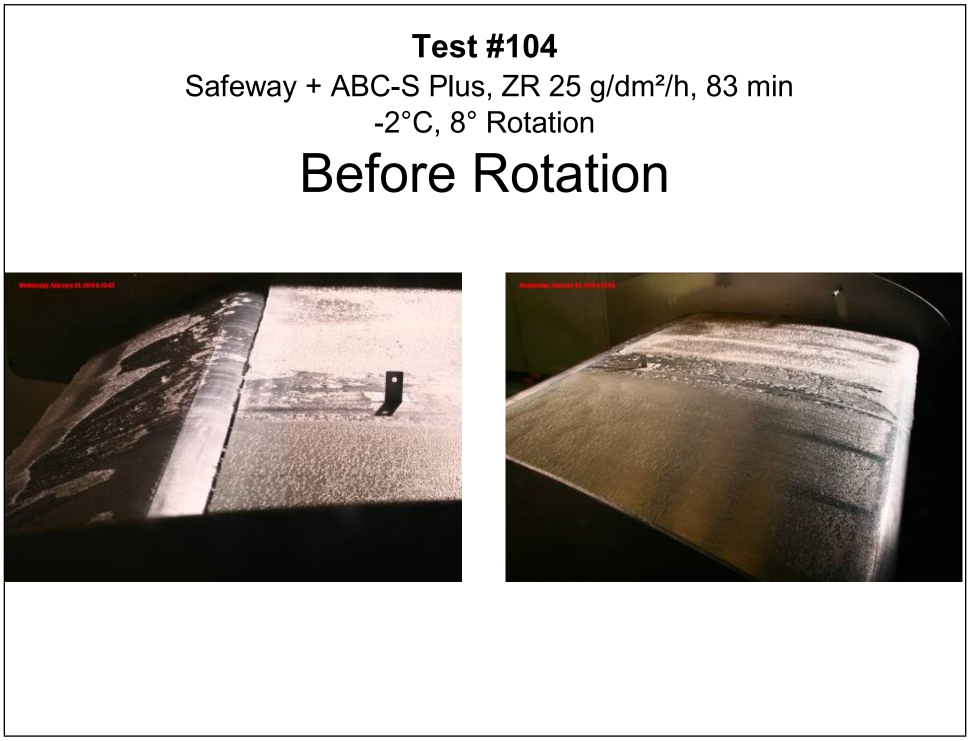
Test #104
Safeway + ABC-S Plus, ZR 25 g/dm²/h, 83 min
-2°C, 8° Rotation
After Fluid Application

Photo 11.12: Test #104 – Start of Test



Test #104
Safeway + ABC-S Plus, ZR 25 g/dm²/h, 83 min
-2°C, 8° Rotation
Start of Test

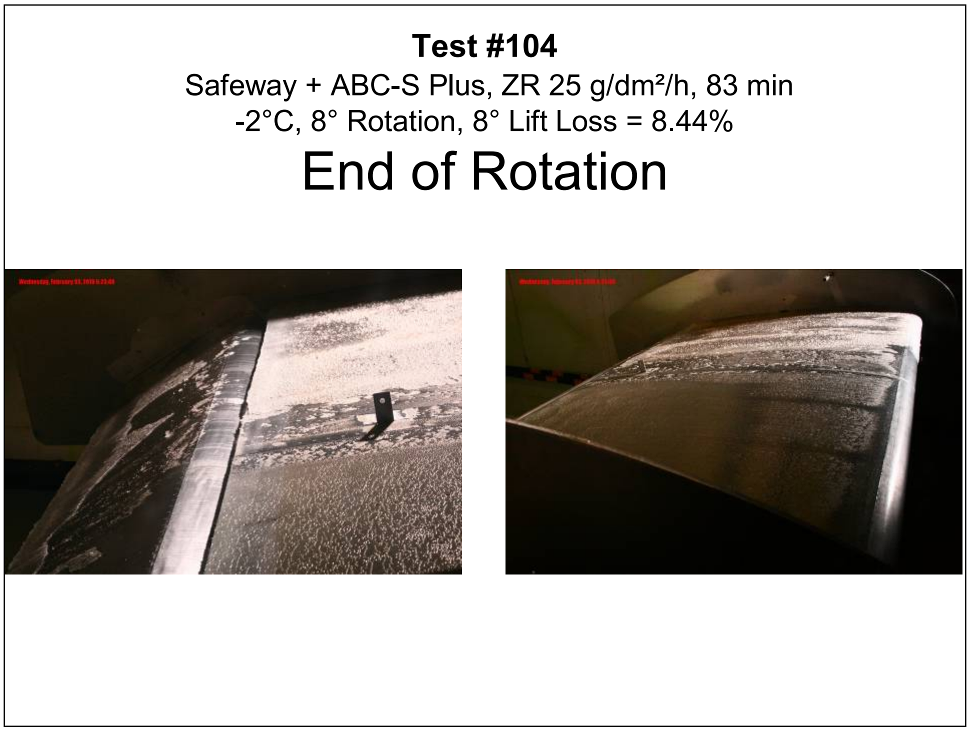
Photo 11.13: Test #104 – Before Rotation



Test #104
Safeway + ABC-S Plus, ZR 25 g/dm²/h, 83 min
-2°C, 8° Rotation

Before Rotation

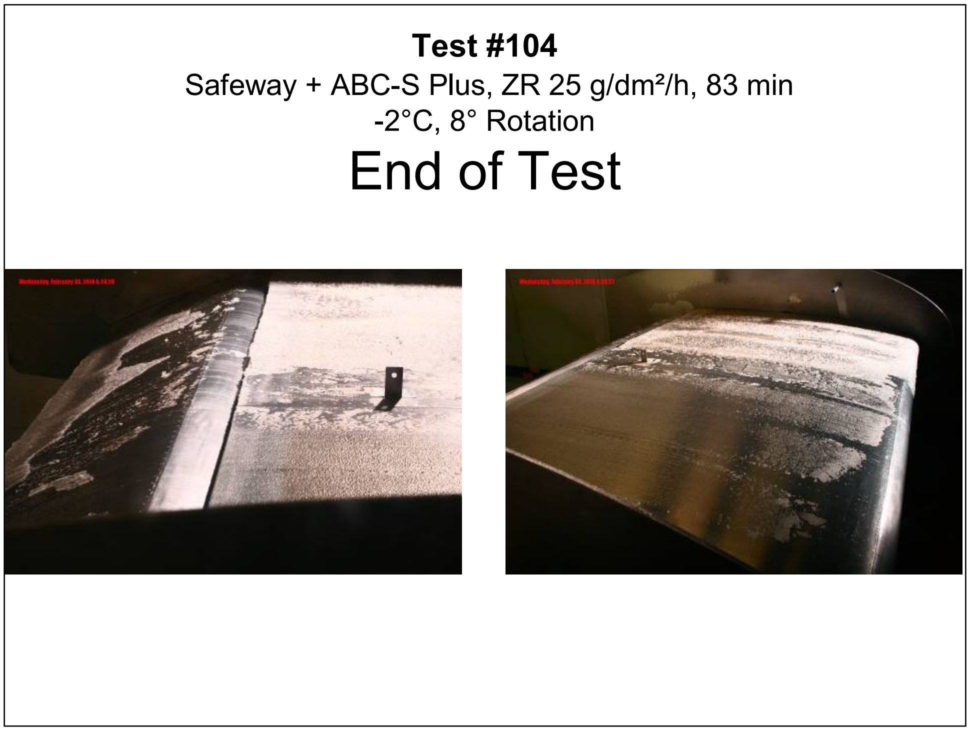
Photo 11.14: Test #104 – End of Rotation



Test #104
Safeway + ABC-S Plus, ZR 25 g/dm²/h, 83 min
-2°C, 8° Rotation, 8° Lift Loss = 8.44%

End of Rotation

Photo 11.15: Test #104 – End of Test



Test #104
Safeway + ABC-S Plus, ZR 25 g/dm²/h, 83 min
-2°C, 8° Rotation

End of Test

12. HEAVY SNOW

Due to the recent industry requirement for guidance material for aircraft operations in mixed conditions with ice pellets, APS conducted a series of plate tests and full-scale tests with the NRC open-circuit wind tunnel and the Falcon 20 aircraft during the winters of 2004-05 to 2008-09. Aerodynamic testing was required due to the melting properties of ice pellets, as the embedded ice pellets required a significantly longer time in comparison to snow to dissolve in anti-icing fluid. Consequently, HOTs were not applicable for ice pellet conditions because contamination was present at the start of the HOT; the criteria for fluid failure (or the end of the HOT) is determined by contamination present on 30 percent of the test plate.

As a direct result of the ice pellet research conducted, the use of fluid endurance times for determining the protection time provided by anti-icing fluids was questioned. The focus was turned towards “aerodynamic failure,” defined as a significant lift loss resulting from contaminated anti-icing fluid. Heavy snow conditions were selected for this study for two reasons. First, snow conditions account for the most significant portion of deicing operations globally. Second, there has been a recent industry interest for HOTs for heavy snow conditions.

Preliminary aerodynamic testing was conducted during the winter of 2006-07, and results are described in an interim report documenting aircraft deicing research in heavy snow conditions. This research was also continued during the winter of 2008-09. The previous work reported residual contamination on the trailing edge of the wing section at the end of the heavy snow tests; the condition worsened as the precipitation rate was increased. Although, visually, this was deemed a severe condition, the lift data collected did not show significant signs of lift losses directly attributable to the heavy snow contamination. It was recommended that the work continue in order to obtain more data to support the conclusions made.

This section provides an overview of each test conducted during the winter of 2009-10 to determine the aerodynamic effects of heavily contaminated anti-icing fluid subjected to simulated heavy snow conditions.

12.1 General Methodology

The methodology used during these tests was in accordance with the methodologies described in Section 2. The intensity and exposure time of the snow precipitation were based on the current HOTs for snow conditions. Comparative tests were conducted simulating moderate and heavy snow conditions.

12.2 Overview of Tests

A summary of the heavy snow tests conducted in the wind tunnel is shown in Table 12.1. The table 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. A more detailed test log of all conditions tested using the wind tunnel is provided in Subsection 3.1. The following is a brief description of the column headings for Table 12.1.

Test #:	Exclusive number identifying each test.
Date:	Date when the test was conducted.
Fluid:	Aircraft deicing fluid specified by product name; all fluids were in the "neat" 100/0 dilution.
Associated Baseline Run:	The associated fluid only baseline run based on fluid selection.
Condition:	Simulated precipitation condition.
Precipitation Rate (g/dm^2/h):	Simulated freezing precipitation rate (or combination of different precipitation rates). "N/A" indicates that no precipitation was applied.
Precip. Time (min.):	Total time of exposure to simulated precipitation.
Tunnel Temp. at Start of Test (ºC):	The tunnel ambient temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.
Avg. Wing Temp. Before Test (ºC):	Average of the wing skin temperature measurements just before the start of the simulated takeoff test, recorded in degrees Celsius.
Visual Contamination Rating Before Takeoff (LE, TE):	Visual contamination rating determined before the start of the simulated takeoff: 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 - Contamination visible, adherence of contamination.
Visual Contamination Rating at Rotation (LE, TE):	Visual contamination rating determined at the time of rotation: 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 - Contamination visible, adherence of contamination.
CL at 8° During Rotation:	Calculated lift coefficient at the 8° wing rotation angle position; data provided by the NRC.
% Lift Loss:	Percentage lift loss calculated based on the comparison of the 8° lift coefficient during the test run versus the dry wing average lift coefficient (calculated to be 1.7213).

Table 12.1: Summary of 2009-10 Heavy Snow Testing

Test No.	Date	Fluid	Associated Baseline Run	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° Rotation	% Lift Loss	Comments
37	22-Jan-10	2031 - Cold	-	S	SN:25	10	-0.9	-1.3	2, 2, 3	1, 1, 1.5	1.64	4.72	Baseline
38	22-Jan-10	2031 - Cold	37	S++	SN:50	5	-2.5	-3	1.7, 1.7, 3	1, 1, 2	1.638	4.84	1/2 Mod Snow HOT
39	22-Jan-10	2031 - Cold	37	S++	SN:50	7.5	-2.9	-4.6	3, 2.7, 3	1, 1.2, 1.5	1.633	5.13	3/4 Mod Snow HOT
40	23-Jan-10	2031 - Cold	37	S++	SN:50	15	-3.1	-7.4	4, 2, 4	1.5, 2.3, 3.8	1.594	7.40	1.5 Mod Snow HOT
83	31-Jan-10	EG 106	-	S	SN:25	40	-4.2	-7	2.4, 2.2, 4	1, 1.2, 1.3	1.693	1.64	Baseline
84	31-Jan-10	EG 106	83	S++	SN:50	30	-6.2	-9.5	3, 2.3, 4	1, 1.7, 1.9	1.683	2.23	3/4 Mod Snow HOT
85	1-Feb-10	EG 106	83	S++	SN:50	20	-6.8	-10.8	2.6, 2.3, 4	1, 1.5, 1.9	1.697	1.41	1/2 Mod Snow HOT
86	1-Feb-10	ABC-S Plus	-	S	SN:25	60	-8.5	-11.5	3.7, 2.9, 4	1.5, 2.2, 3.5	1.512	12.16	Baseline
87	1-Feb-10	ABC-S Plus	86	S++	SN:50	30	-11.6	-14.3	3.7, 2.9, 4	1.7, 2.2, 3.2	1.5	12.86	1/2 Mod Snow HOT
88	1-Feb-10	ABC-S Plus	86	S++	SN:50	10	-12.6	-14	2, 2, 2.8	1.5, 2, 2	1.574	8.56	1/6 Mod Snow HOT
90	1-Feb-10	ABC-S Plus	92	S++	SN:50	10	-2.2	-8.3	2.3, 2.2, 2.2	1.1, 1.5, 1.7	1.619	5.94	1/6 Mod Snow HOT
91	1-Feb-10	ABC-S Plus	92	S++	SN:50	30	-3.8	-11	2.8, 2.7, 3.7	1.5, 2.2, 2.7	1.576	8.44	1/2 Mod Snow HOT
92	1-Feb-10	ABC-S Plus	-	S	SN:25	60	-4.7	-10.3	2.5, 2.3, 3.8	1.5, 2, 2.7	1.577	8.38	Baseline

12.3 Data Collected

12.3.1 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Subsection 2.16.2. Fluid thickness measurements were recorded at the following intervals:

- After fluid application;
- After application of contamination; and
- After the simulated takeoff test.

Tables 12.2 to 12.14 show the fluid thickness measurements collected during the contaminated fluid tests.

Table 12.2: Test #37 Fluid Thickness Data

Test 37: 2031 - Cold, S, Tunnel OAT - 0.9°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.0	1.3	0.1
2	1.5	1.6	0.2
3	1.8	1.8	0.2
4	2.2	2.2	0.2
5	2.7	2.7	0.2
6	3.1	2.9	0.2
7	2.7	2.9	0.2
8	2.2	2.2	0.3
Flap	0.5	0.7	0.2

Table 12.3: Test #38 Fluid Thickness Data

Test 38: 2031 - Cold, S++, Tunnel OAT - 2.5°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.0	N/A	0.0
2	1.7	1.8	0.1
3	2.2	N/A	0.1
4	2.7	N/A	0.2
5	3.1	3.1	0.2
6	3.1	3.5	0.2
7	3.1	3.3	0.2
8	2.2	2.9	0.2
Flap	0.7	slush	0.3

Table 12.4: Test #39 Fluid Thickness Data

Test 39: 2031 - Cold, S++, Tunnel OAT - 2.9°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	0.8	1.6	0.0
2	1.6	1.7	0.2
3	2.2	2.2	0.2
4	3.1	2.5	0.2
5	3.1	3.3	0.2
6	3.1	3.7	0.2
7	3.1	3.1	0.2
8	2.2	2.7	0.2
Flap	0.7	slush	0.2

Table 12.5: Test #40 Fluid Thickness Data

Test 40: 2031 - Cold, S++, Tunnel OAT -3.1°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.1	1.5	0.0
2	1.5	1.8	0.1
3	1.8	2.2	0.1
4	2.2	2.5	0.1
5	2.7	2.9	0.1
6	3.3	3.3	0.1
7	2.5	3.1	0.1
8	2.2	2.5	0.1
Flap	0.5	slush	0.2

Table 12.6: Test #83 Fluid Thickness Data

Test 83: EG106, S, Tunnel OAT -4.2°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Test
1	2.2	1	0.0
2	3.1	1.6	0.0
3	3.5	3.5	0.1
4	4.5	4.5	0.1
5	3.9	4.5	0.1
6	4.5	5.7	0.1
7	4.5	4.5	0.1
8	3.5	3.5	0.1
Flap	1.0	slush	0.0

Table 12.7: Test #84 Fluid Thickness Data

Test 84: EG106, S++, Tunnel OAT -6.2°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.8	0.5	0.0
2	2.5	4.5	0.0
3	3.1	3.5	0.0
4	3.9	5.7	0.1
5	4.5	5.7	0.1
6	4.5	5.7	0.1
7	4.5	7.0	0.0
8	3.9	4.5	0.0
Flap	0.8	slush	0.0

Table 12.8: Test #85 Fluid Thickness Data

Test 85: EG106, S++, Tunnel OAT -6.8°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	2.2	1.3	0.0
2	3.1	2.5	0.0
3	3.7	4.5	0.0
4	3.9	4.5	0.0
5	4.5	3.9	0.1
6	4.5	5.7	0.0
7	4.5	5.7	0.0
8	3.3	4.5	0.0
Flap	0.8	slush	0.0

Table 12.9: Test #86 Fluid Thickness Data

Test 86: ABC-S Plus, S, Tunnel OAT -8.5°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.1	1.2	0.0
2	1.8	2.5	0.0
3	2.2	3.3	0.0
4	2.7	4.5	slush
5	3.1	5.7	slush
6	3.1	4.5	slush
7	2.9	4.5	slush
8	2.5	4.5	slush
Flap	0.7	slush	slush

Table 12.10: Test #87 Fluid Thickness Data

Test 87: ABC-S Plus, S++, Tunnel OAT -11.6°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.3	0.6 (slush)	0.0 (slush)
2	2.2	1.3 (slush)	0.0 (slush)
3	2.7	3.1 (slush)	0.0 (slush)
4	3.1	3.3 (slush)	0.0 (slush)
5	3.7	5.7 (slush)	0.0 (slush)
6	3.3	4.5 (slush)	slush
7	3.1	5.7 (slush)	slush
8	2.7	3.9 (slush)	0.0 (slush)
Flap	0.8	slush	slush

Table 12.11: Test #88 Fluid Thickness Data

Test 88: ABC-S Plus, S++, Tunnel OAT -12.6°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.5	1.7	0.1
2	1.8	2.2	0.1
3	2.2	3.1	0.2
4	2.7	3.1	0.2
5	3.1	3.3	0.2
6	3.1	3.3	0.2
7	2.9	3.7	0.2
8	2.5	2.9	0.3
Flap	0.7	slush	0.3

Table 12.12: Test #90 Fluid Thickness Data

Test 90: ABC-S Plus, S++, Tunnel OAT -2.2°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.6	1.5	0.1
2	2.2	1.7	0.1
3	2.9	3.5	0.1
4	3.3	3.5	0.1
5	3.5	3.9	0.2
6	3.7	4.5	0.2
7	3.7	4.5	0.2
8	3.3	3.3	0.2
Flap	1.0	slush	0.2

Table 12.13: Test #91 Fluid Thickness Data

Test 91: ABC-S Plus, S++, Tunnel OAT -3.8°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.3	2.7	0.0
2	2.2	5.7	0.0
3	2.5	5.7	0.0
4	3.3	5.7	0.1
5	3.3	5.7	0.1
6	3.3	5.7	slush
7	3.3	3.9	slush
8	2.9	4.5	slush
Flap	0.8	1-4.5	0.2

Table 12.14: Test #92 Fluid Thickness Data

Test 92: ABC-S Plus, S, Tunnel OAT -4.7°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.5	1.4	0.0
2	2.2	3.7	0.0
3	2.2	4.5	0.0
4	3.1	4.5	0.0
5	3.5	5.7	0.0 (slush)
6	3.5	5.7	slush
7	3.5	5.7	slush
8	3.1	5.7	slush
Flap	0.8	slush	0.1

12.3.2 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Subsection 2.16.3. Skin temperature measurements were recorded at the following intervals:

- Before fluid application;
- After fluid application;
- After application of contamination; and
- After the simulated takeoff test.

Tables 12.15 to 12.27 show the wing temperature measurements recorded during the contaminated fluid tests.

Table 12.15: Test #37 Wing Skin Temperature Data

Test 37: 2031 - Cold, S, Tunnel OAT - 0.9°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	+1.1	-1.1	-2.8	-3.7
T5	+0.7	-1.7	-1.4	-4.2
TU	-0.6	+0.4	+0.2	-4.3

Table 12.16: Test #38 Wing Skin Temperature Data

Test 38: 2031 - Cold, S++, Tunnel OAT - 2.5°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-0.8	-2.5	-6.9	-2.0
T5	-0.4	-2.8	-2.8	-1.5
TU	-1.8	-1.6	-2.3	-3.4

Table 12.17: Test #39 Wing Skin Temperature Data

Test 39: 2031 - Cold, S++, Tunnel OAT - 2.9°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-1.5	-3.0	-9.1	-3.2
T5	-1.0	-3.2	-2.4	-2.6
TU	-2.9	-2.6	-2.5	-4.7

Table 12.18: Test #40 Wing Skin Temperature Data

Test 40: 2031 - Cold, S++, Tunnel OAT -3.1°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-1.3	-2.6	-11.8	-7.1
T5	-1.1	-3.0	-6.9	-7.5
TU	-3.0	-3.5	-3.5	-7.3

Table 12.19: Test #83 Wing Skin Temperature Data

Test 83: EG106, S, Tunnel OAT -4.2°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Test
T2	-4.3	-5.4	-10.2	-4.6
T5	-4.1	-5.2	-7.6	-3.5
TU	-3.4	-3.8	-3.1	-4.5

Table 12.20: Test #84 Wing Skin Temperature Data

Test 84: EG106, S++, Tunnel OAT -6.2°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-4.3	-5.7	-11.1	-6.6
T5	-3.5	-5.1	-11.3	-5.8
TU	-4.8	-5.7	-6.0	-6.5

Table 12.21: Test #85 Wing Skin Temperature Data

Test 85: EG106, S++, Tunnel OAT -6.8°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-5.7	-6.3	-13.0	-7.8
T5	-5.1	-6.1	-12.0	-7.5
TU	-6.0	-6.3	-7.3	-8.1

Table 12.22: Test #86 Wing Skin Temperature Data

Test 86: ABC-S Plus, S, Tunnel OAT -8.5°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-8.7	-10.0	-11.4	-9.5
T5	-9.0	-10.4	-13.1	-9.7
TU	-9.0	-9.3	-9.9	-10.4

Table 12.23: Test #87 Wing Skin Temperature Data

Test 87: ABC-S Plus, S++, Tunnel OAT -11.6°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-9.7	-10.0	-14.9	-12.7
T5	-9.8	-10.4	-15.9	-13.4
TU	-10.5	-11.1	-12.0	-13.1

Table 12.24: Test #88 Wing Skin Temperature Data

Test 88: ABC-S Plus, S++, Tunnel OAT -12.6°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-11.7	-11.3	-15.7	-12.4
T5	-11.9	-11.4	-14.3	-12.1
TU	-12.6	-12.2	-12	-13.2

Table 12.25: Test #90 Wing Skin Temperature Data

Test 90: ABC-S Plus, S++, Tunnel OAT -2.2°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-5.4	-7.1	-10.1	-7.3
T5	-5.4	-7.8	-9.1	-6.6
TU	-5.2	-5.3	-5.7	-7.9

Table 12.26: Test #91 Wing Skin Temperature Data

Test 91: ABC-S Plus, S++, Tunnel OAT -3.8°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-7.3	-7.0	-12.5	-5.6
T5	-6.6	-6.8	-12.3	-5.2
TU	-7.9	-5.7	-8.2	-6.6

Table 12.27: Test #92 Wing Skin Temperature Data

Test 92: ABC-S Plus, S, Tunnel OAT -4.7°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-5.6	-7.6	-10.4	-7.5
T5	-5.2	-7.8	-11	-7.1
TU	-6.6	-6.7	-9.5	-8.5

12.3.3 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Subsection 2.16.4. Fluid Brix measurements were recorded at the following intervals:

- After fluid application;
- After application of contamination; and
- After the simulated takeoff test.

Tables 12.28 to 12.40 show the fluid Brix measurements collected during the contaminated fluid tests.

Table 12.28: Test #37 Fluid Brix Data

Test 37: 2031 - Cold, S, Tunnel OAT - 0.9°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.75	28.75	31.00
8	36.50	28.25	34.50

Table 12.29: Test #38 Fluid Brix Data

Test 38: 2031 - Cold, S++, Tunnel OAT - 2.5°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.50	16.75	27.50
8	36.50	16.00	33.50

Table 12.30: Test #39 Fluid Brix Data

Test 39: 2031 - Cold, S++, Tunnel OAT - 2.9°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.75	20.75	27.25
8	36.50	22.25	30.25

Table 12.31: Test #40 Fluid Brix Data

Test 40: 2031 - Cold, S++, Tunnel OAT -3.1°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.25	21.25	23.25
8	36.75	24.00	21.00

Table 12.32: Test #83 Fluid Brix Data

Test 83: EG106, S, Tunnel OAT -4.2°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Test
2	32.50	23.00	30.25
8	32.50	19.75	29.25

Table 12.33: Test #84 Fluid Brix Data

Test 84: EG106, S++, Tunnel OAT -6.2°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	31.75	30.25	31.00
8	31.50	15.25	29.75

Table 12.34: Test #85 Fluid Brix Data

Test 85: EG106, S++, Tunnel OAT -6.8°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.75	23.50	34.00
8	32.25	13.75	31.75

Table 12.35: Test #86 Fluid Brix Data

Test 86: ABC-S Plus, S, Tunnel OAT -8.5°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.25	16.00	21.75
8	37.25	17.75	22.75

Table 12.36: Test #87 Fluid Brix Data

Test 87: ABC-S Plus, S++, Tunnel OAT -11.6°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.50	11.50	20.75
8	37.25	20.00	16.75

Table 12.37: Test #88 Fluid Brix Data

Test 88: ABC-S Plus, S++, Tunnel OAT -12.6°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.25	15.25	25.00
8	37.25	21.50	23.00

Table 12.38: Test #90 Fluid Brix Data

Test 90: ABC-S Plus, S++, Tunnel OAT -2.2°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.25	14.25	29.75
8	36.50	19.75	32.00

Table 12.39: Test #91 Fluid Brix Data

Test 91: ABC-S Plus, S++, Tunnel OAT -3.8°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.50	16.00	24.25
8	37.00	19.00	15.75

Table 12.40: Test #92 Fluid Brix Data

Test 92: ABC-S Plus, S, Tunnel OAT -4.7°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.0	19.25	24.25
8	37.00	16.00	20.00

12.4 Photos

High-speed digital photography of each test was taken. For each test, wide-angle photos were taken of the leading edge, and close-up photos were taken of the trailing edge. For each of the tests, photo summaries have been compiled comprising four stages:

- Start of test;
- Before Rotation (just before the wing began to pitch);
- End of Rotation (end of the rotation cycle when the wing position is returned to four degrees); and
- End of test.

Photos 12.1 to 12.72 show the photo summaries of the tests conducted which are organized in order to facilitate comparison. A complete set of photos will be provided to the TDC in electronic format.

12.5 Summary of Test Results

12.5.1 Type III 2031 Fluid

It should be noted that the Type III 2031 fluid sample received for testing was not appropriate for developing ice pellet allowance times due to viscosity issues (see Section 4 for details). Nevertheless, the data collected in heavy snow still has merit due to the comparative methodology used during these tests. It should be noted that the higher viscosity of the Type III fluid sample used could be treated like a Type II or Type IV fluid for discussion purposes.

Four tests were conducted with the Type III 2031 fluid as part of the comparative test set. Test #37, the baseline test for this set, exposed the wing to 10 minutes of moderate snow; this exposure time was based on the current HOTs for Type III fluids. The results demonstrated an acceptable level of visual contamination at the end of the precipitation period, as well as at the time of rotation. In addition, the aerodynamic performance was acceptable with 4.7 percent lift loss compared to the dry wing.

Test #38 was conducted in heavy snow conditions (twice the precipitation rate as the baseline Test #37) for half the exposure time; this resulted in an equivalent amount of contamination being dispensed in Tests #37 and #38. The results demonstrated an acceptable level of visual contamination (slightly better compared to the baseline test) at the end of the precipitation period, as well as at the time of rotation. The aerodynamic performance was also acceptable with 4.8 percent lift loss compared to the dry wing; this was comparable to the baseline test.

Test #39 was conducted in heavy snow conditions for an exposure time of 7.5 minutes, or three-quarters of the baseline moderate snow HOT. The results demonstrated an acceptable level of visual contamination at the end of the precipitation period, as well as at the time of rotation; however, the results were slightly more severe compared to the baseline Test #37. The aerodynamic performance was slightly worse compared to the baseline with 5.1 percent lift loss compared to the dry wing.

The final test, #40, was conducted in heavy snow conditions for an exposure time of 15 minutes, or 1.5 times the baseline moderate snow HOT. The results demonstrated an unacceptable level of visual contamination at the end of the precipitation period, as well as at the time of rotation; severe contamination was present on the leading edge of the wing following the end of the precipitation period, and the leading edge was not clean by the time of rotation. The aerodynamic performance was also worse compared to the baseline with 7.4 percent lift loss compared to the dry wing, which confirmed the visual observations.

The results indicated that using half the moderate snow HOT for heavy snow conditions could be a conservative approach for providing guidance in heavy snow conditions. The HOT could potentially be increased to three-quarters of the moderate snow HOT, as the results did not indicate significant adverse effects compared to the baseline test.

12.5.2 Type IV EG106

Three tests were conducted with Type IV EG106 fluid as part of the comparative test set. Test #83, the baseline test for this set, was exposed to 40 minutes of moderate snow; this exposure time was based on the current HOTs for EG106. The results demonstrated an acceptable level of visual contamination at the end of the precipitation period, as well as at the time of rotation. In addition, the aerodynamic performance was acceptable with 1.6 percent lift loss compared to the dry wing.

Test #84 was conducted in heavy snow conditions for an exposure time of 30 minutes, or three-quarters of the baseline moderate snow HOT. The results demonstrated an acceptable level of visual contamination at the end of the precipitation period, as well as at the time of rotation; however, the results were slightly more severe compared to the baseline Test #83. The aerodynamic performance was slightly worse compared to the baseline with 2.2 percent lift loss compared to the dry wing.

Test #85 was conducted in heavy snow conditions for half the exposure time; this resulted in an equivalent amount of contamination being dispensed in both Tests #83 and #85. The results demonstrated an acceptable level of visual contamination (comparable to the baseline test) at the end of the precipitation period, as well as at the time of rotation. The aerodynamic performance was also acceptable with 1.4 percent lift loss compared to the dry wing; this was slightly better compared to the baseline test.

Similar to the Type III fluid results, the testing indicated that using half the moderate snow HOT for heavy snow conditions could be a conservative approach for providing guidance in heavy snow conditions. The HOT could potentially be increased to three-quarters of the moderate snow HOT, as the results did not indicate significant adverse effects compared to the baseline test.

12.5.3 Type IV PG ABC-S Plus

Two sets of three comparative test runs were conducted with Type IV PG ABC-S Plus fluid. The first set of tests (Tests #86, #87, and #88) was conducted at colder temperatures, and due to the large lift losses observed, the tests were repeated at warmer temperatures (Tests #90, #91, and #92).

Test #86, the baseline test for this first set of tests, was exposed to 60 minutes of moderate snow; this exposure time was based on the current HOTs for ABC-S Plus. The results demonstrated an unacceptable level of visual contamination at the end of the precipitation period, as well as at the time of rotation; severe contamination was present on the leading edge of the wing following the end of the precipitation period, and the leading edge was not clean by the time of rotation. The aerodynamic performance showed significant degradation with 12.2 percent lift loss compared to the dry wing, which confirmed the visual observations.

Test #87 was conducted in heavy snow conditions for half the exposure time; this resulted in an equivalent amount of contamination being dispensed in both Tests #86 and #87. The results were similar to Test #86 in that the test demonstrated an unacceptable level of visual contamination at the end of the precipitation period, as well as at the time of rotation; severe contamination was present on the leading edge of the wing following the end of the precipitation period, and the leading edge was not clean by the time of rotation. The aerodynamic performance also showed significant degradation with 12.9 percent lift loss compared to the dry wing.

Test #88 was conducted in heavy snow conditions for an exposure time of 10 minutes, or one-sixth of the baseline moderate snow HOT. The results demonstrated an acceptable level of visual contamination at the end of the precipitation period; however, the leading edge was not clean at the time of rotation. The aerodynamic performance improved compared to the baseline with 8.6 percent lift loss compared to the dry wing; however, the lift loss was still considered severe and significant.

For the second set of tests, the baseline Test #92 was conducted at the end of the set; Tests #90 and #91 were conducted prior to the baseline. Test #92, the baseline test, was exposed to 60 minutes of moderate snow; this exposure time was based on the current HOTs for ABC-S Plus. The results demonstrated an acceptable level of visual contamination at the end of the precipitation period; however, the leading edge was not clean by the time of rotation. The aerodynamic performance demonstrated a significant lift loss of 8.4 percent compared to the dry wing; the improvement in aerodynamic performance compared to the previous set of tests is likely due to the warmer temperatures.

Test #91 was conducted in heavy snow conditions for half the exposure time; this resulted in an equivalent amount of contamination being dispensed in both Tests #91 and #92. The results demonstrated an acceptable level of visual contamination at the end of the precipitation period, but residual contamination was still present on the leading edge at the time of rotation, as well as at the time of rotation; these results were comparable to the baseline Test #92. The aerodynamic performance demonstrated a significant lift loss of 8.4 percent compared to the dry wing; this was also comparable to the baseline Test #92.

Test #90 was conducted in heavy snow conditions for an exposure time of 10 minutes, or one-sixth of the baseline moderate snow HOT. The results demonstrated an acceptable level of visual contamination at the end of the precipitation period; however, the leading edge still showed some minimal residual contamination at the time of rotation. The aerodynamic performance improved compared to the baseline with 5.4 percent lift loss compared to the dry wing.

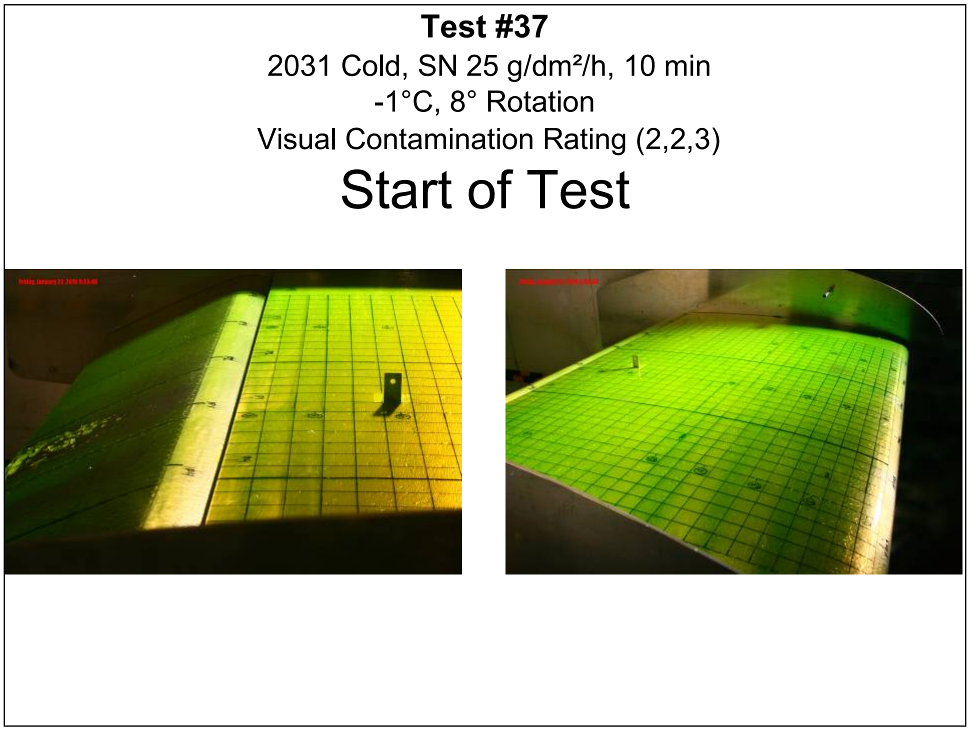
Similar to the results obtained with the Type III PG and Type IV EG fluid, the testing indicated that using half the moderate snow HOT for heavy snow conditions generated comparable visual and aerodynamic results. It should be noted, however, that the lift losses observed with the Type IV PG fluid were much higher compared to the Type III PG and Type IV EG fluids; this was also seen during the ice pellet allowance time testing conducted during the winter of 2009-10. The impact of these lift losses is still being investigated; however, the conclusion remains that using half the moderate snow HOT for heavy snow will generate comparable conditions for the wing by the time of rotation.

12.5.4 General Observations

The results obtained using the three different types of fluid (Type III, Type IV EG, and Type IV PG) indicated that using half the moderate snow HOT for heavy snow conditions could be a viable approach for providing guidance in heavy snow conditions. In all cases, the visual and aerodynamic performance was comparable for the moderate snow test and for the heavy snow test with half the exposure time.

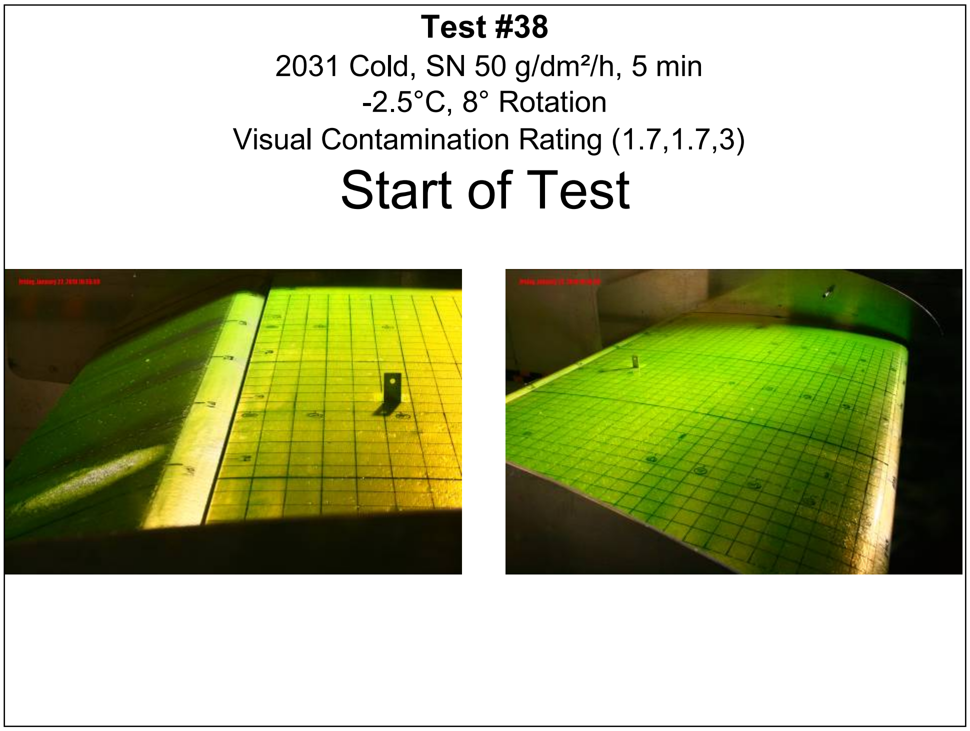
Data collected with the Type III and Type IV EG fluids also indicated that the HOT could potentially be increased to three-quarters of the moderate snow HOT, as the results indicated a slight degradation in performance compared to the baseline test; however, this would need to be further investigated, especially in light of the large lift losses associated with Type IV PG fluids at the colder temperatures.

Photo 12.1: Test #37 – Start of Test



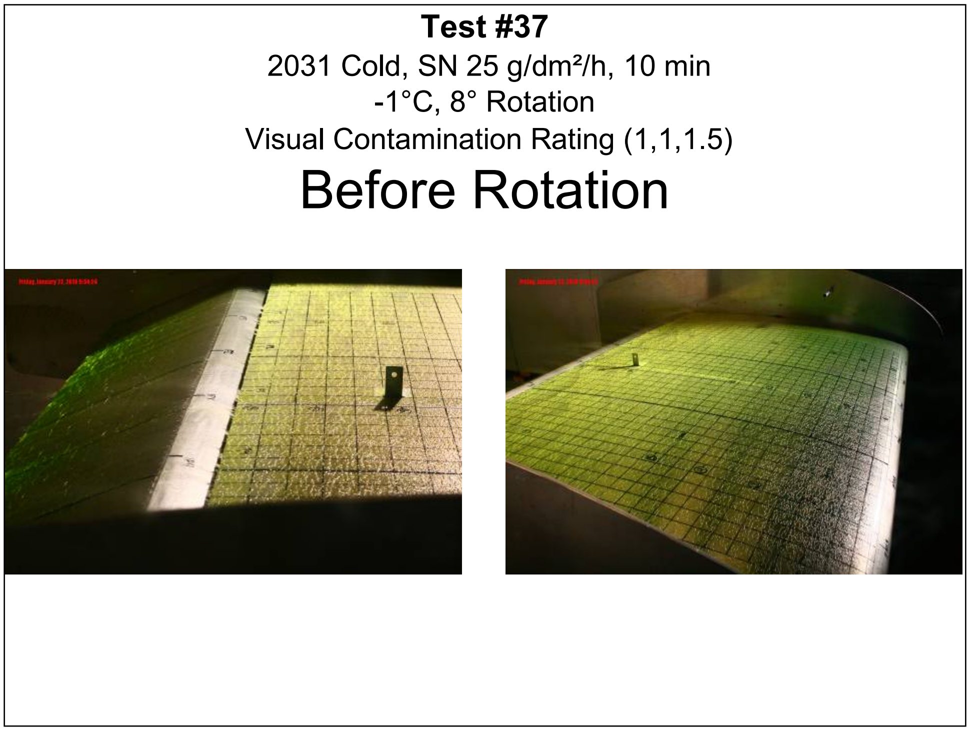
Test #37
2031 Cold, SN 25 g/dm²/h, 10 min
-1°C, 8° Rotation
Visual Contamination Rating (2,2,3)
Start of Test

Photo 12.2: Test #38 – Start of Test



Test #38
2031 Cold, SN 50 g/dm²/h, 5 min
-2.5°C, 8° Rotation
Visual Contamination Rating (1.7,1.7,3)
Start of Test

Photo 12.3: Test #37 – Before Rotation



Test #37

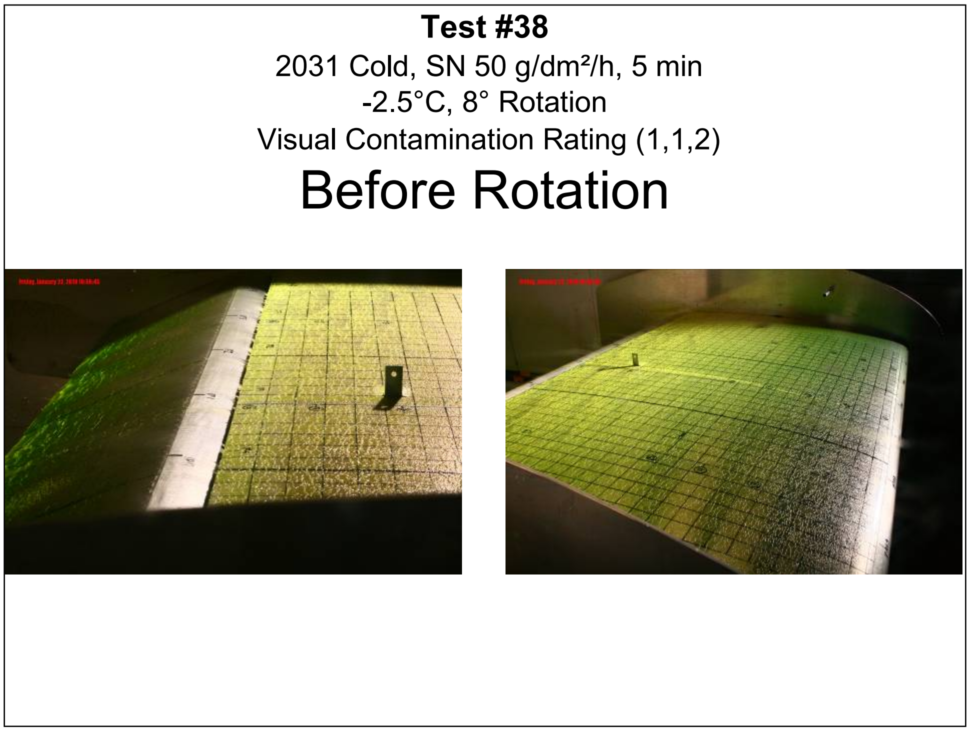
2031 Cold, SN 25 g/dm²/h, 10 min

-1°C, 8° Rotation

Visual Contamination Rating (1,1,1.5)

Before Rotation

Photo 12.4: Test #38 – Before Rotation



Test #38

2031 Cold, SN 50 g/dm²/h, 5 min

-2.5°C, 8° Rotation

Visual Contamination Rating (1,1,2)

Before Rotation

Photo 12.5: Test #37 – End of Rotation

Test #37

2031 Cold, SN 25 g/dm²/h, 10 min

-1°C, 8° Rotation

Visual Contamination Rating (1,1,1.5), 8° Lift Loss = 4.72%

End of Rotation

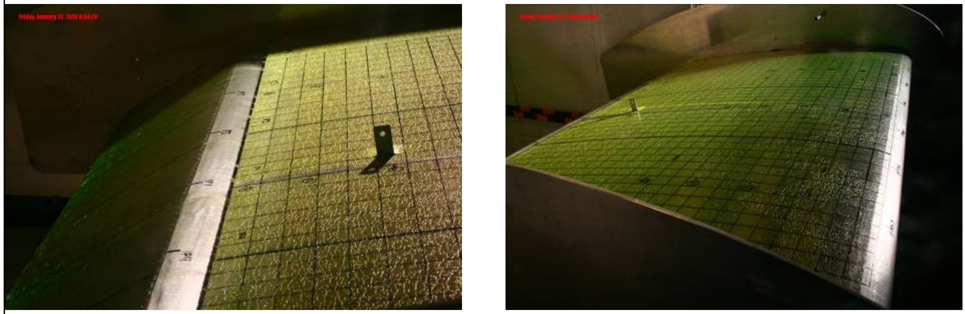


Photo 12.6: Test #38 – End of Rotation

Test #38

2031 Cold, SN 50 g/dm²/h, 5 min

-2.5°C, 8° Rotation

Visual Contamination Rating (1,1,2), 8° Lift Loss = 4.84%

End of Rotation

Photo 12.7: Test #37 – End of Test

Test #37

2031 Cold, SN 25 g/dm²/h, 10 min

-1°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test

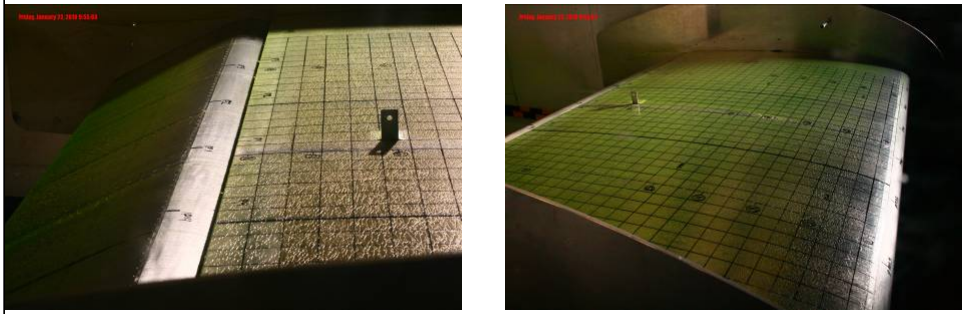


Photo 12.8: Test #38 – End of Test

Test #38

2031 Cold, SN 50 g/dm²/h, 5 min

-2.5°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test

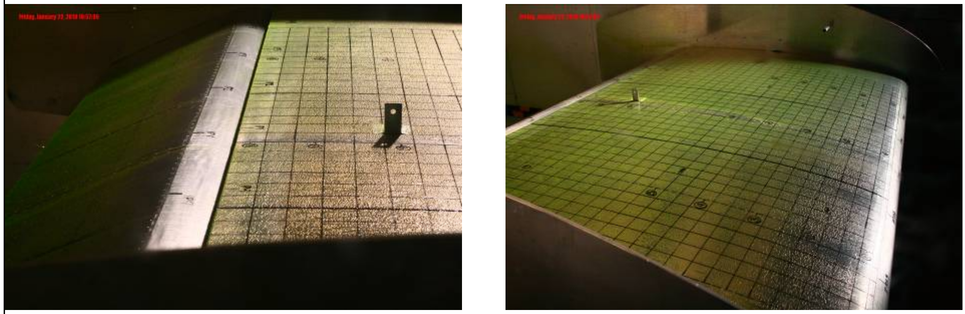


Photo 12.9: Test #37 – Start of Test

Test #37

2031 Cold, SN 25 g/dm²/h, 10 min
-1°C, 8° Rotation
Visual Contamination Rating (2,2,3)

Start of Test

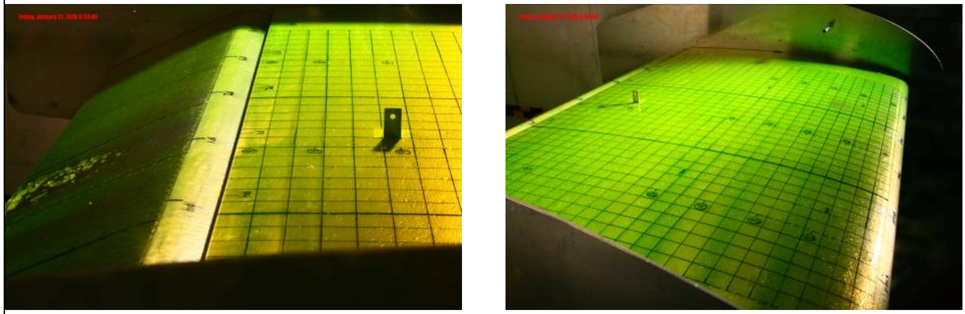


Photo 12.10: Test #39 – Start of Test

Test #39

2031 Cold, SN 50 g/dm²/h, 7.5 min
-3°C, 8° Rotation
Visual Contamination Rating (3,2.7,3)

Start of Test

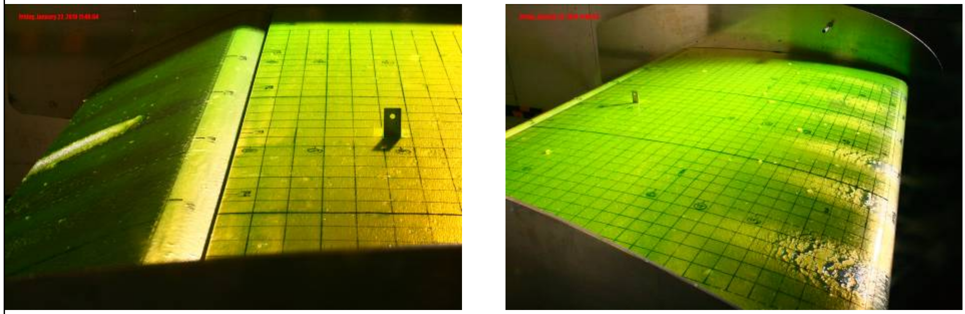
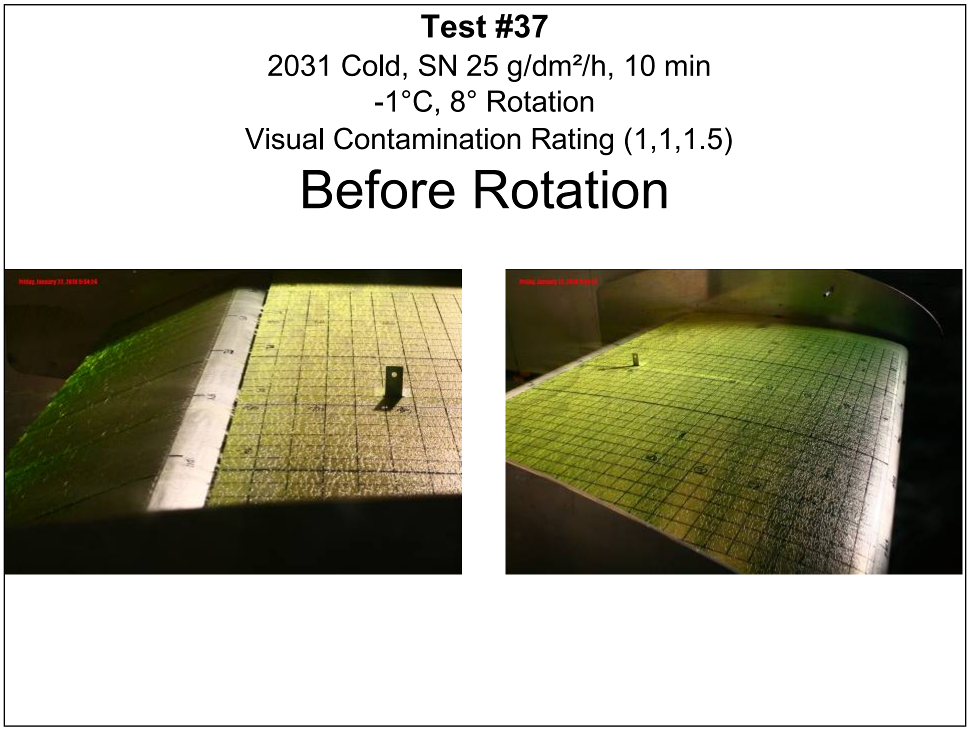


Photo 12.11: Test #37 – Before Rotation



Test #37

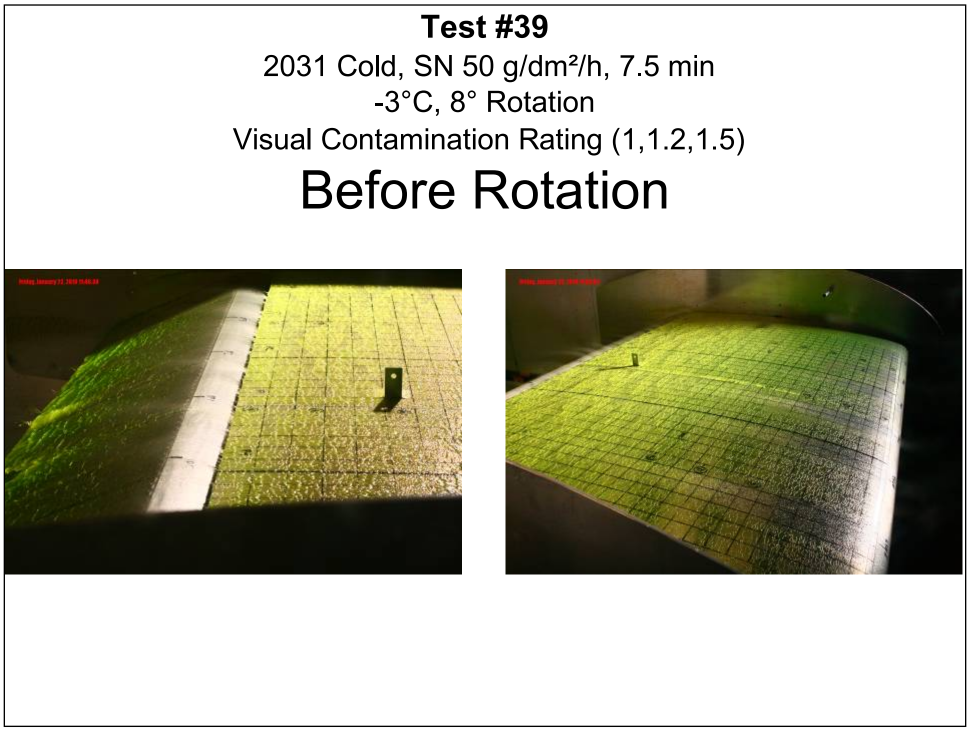
2031 Cold, SN 25 g/dm²/h, 10 min

-1°C, 8° Rotation

Visual Contamination Rating (1,1,1.5)

Before Rotation

Photo 12.12: Test #39 – Before Rotation



Test #39

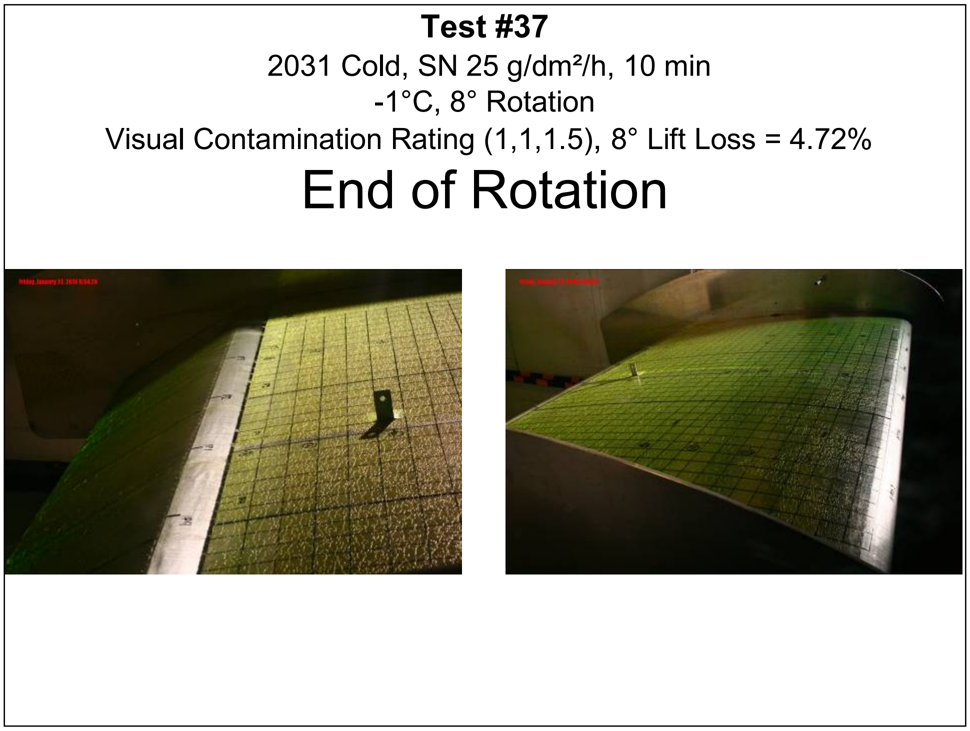
2031 Cold, SN 50 g/dm²/h, 7.5 min

-3°C, 8° Rotation

Visual Contamination Rating (1,1.2,1.5)

Before Rotation

Photo 12.13: Test #37 – End of Rotation



Test #37

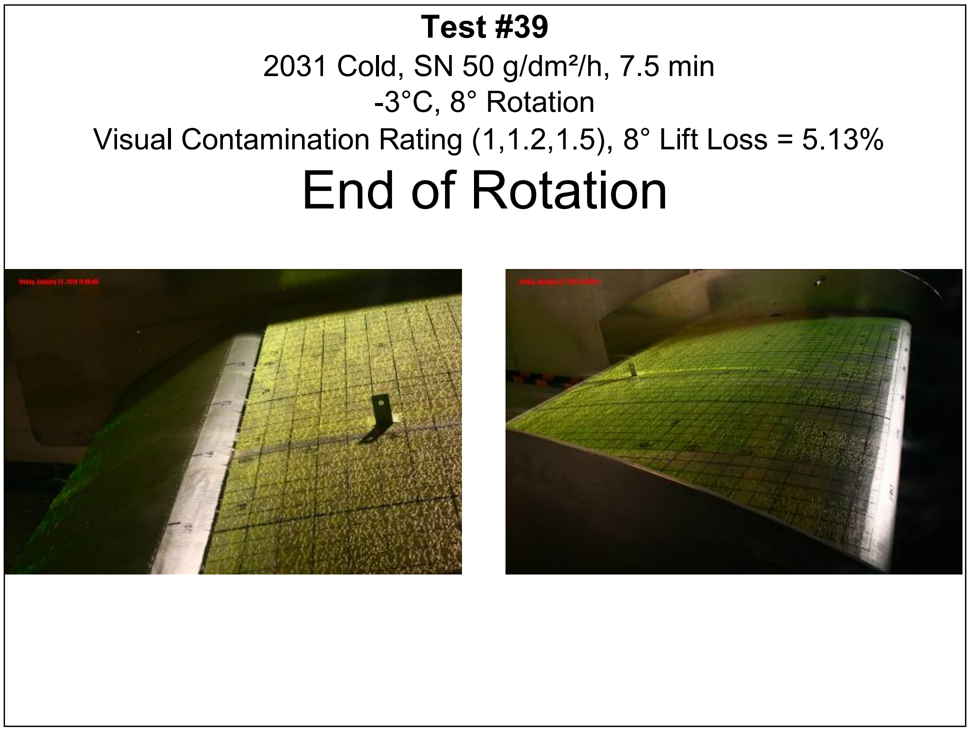
2031 Cold, SN 25 g/dm²/h, 10 min

-1°C, 8° Rotation

Visual Contamination Rating (1,1,1.5), 8° Lift Loss = 4.72%

End of Rotation

Photo 12.14: Test #39 – End of Rotation



Test #39

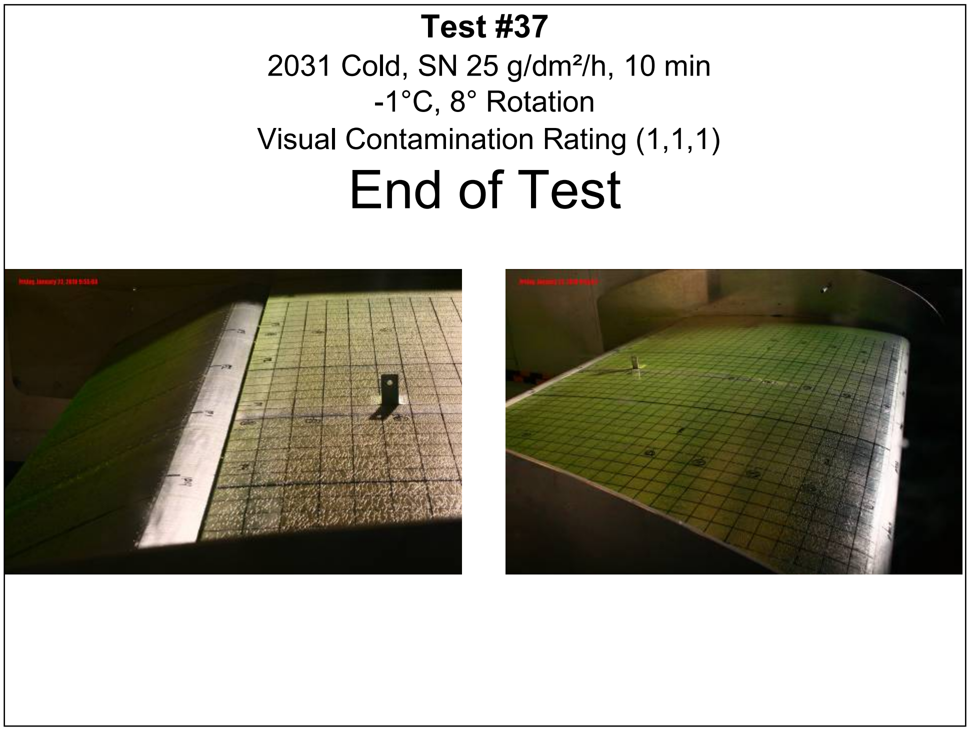
2031 Cold, SN 50 g/dm²/h, 7.5 min

-3°C, 8° Rotation

Visual Contamination Rating (1,1.2,1.5), 8° Lift Loss = 5.13%

End of Rotation

Photo 12.15: Test #37 – End of Test



Test #37

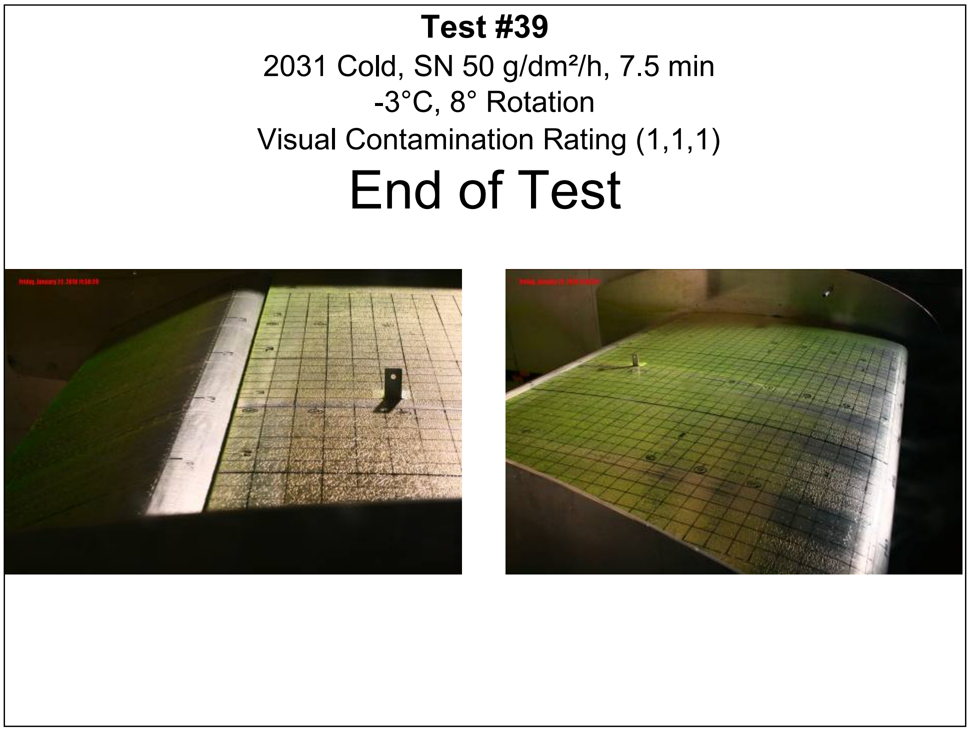
2031 Cold, SN 25 g/dm²/h, 10 min

-1°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test

Photo 12.16: Test #39 – End of Test



Test #39

2031 Cold, SN 50 g/dm²/h, 7.5 min

-3°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test

Photo 12.17: Test #37 – Start of Test

Test #37
2031 Cold, SN 25 g/dm²/h, 10 min
-1°C, 8° Rotation
Visual Contamination Rating (2,2,3)

Start of Test

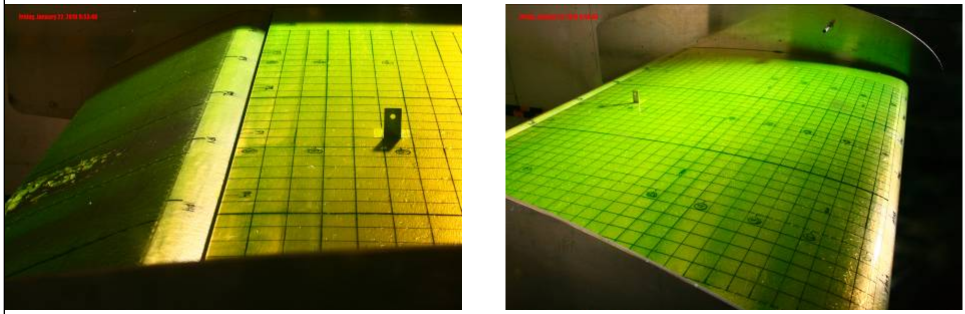


Photo 12.18: Test #40 – Start of Test

Test #40
2031 Cold, SN 50 g/dm²/h, 15 min
-3°C, 8° Rotation
Visual Contamination Rating (4,2,4)

Start of Test

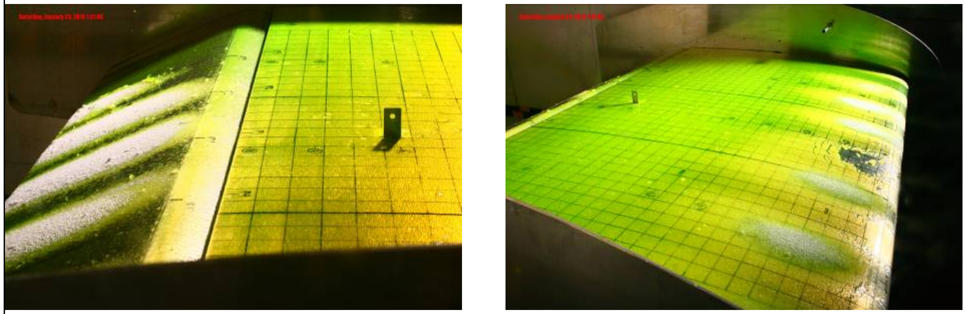


Photo 12.19: Test #37 – Before Rotation

Test #37

2031 Cold, SN 25 g/dm²/h, 10 min

-1°C, 8° Rotation

Visual Contamination Rating (1,1,1.5)

Before Rotation

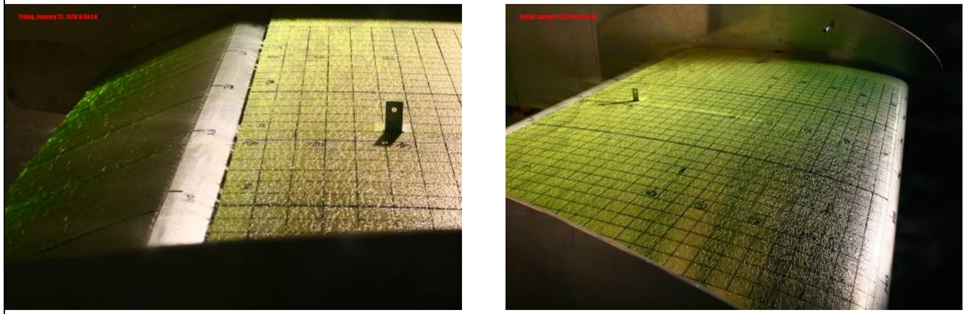


Photo 12.20: Test #40 – Before Rotation

Test #40

2031 Cold, SN 50 g/dm²/h, 15 min

-3°C, 8° Rotation

Visual Contamination Rating (1.5,2.3,3.8)

Before Rotation

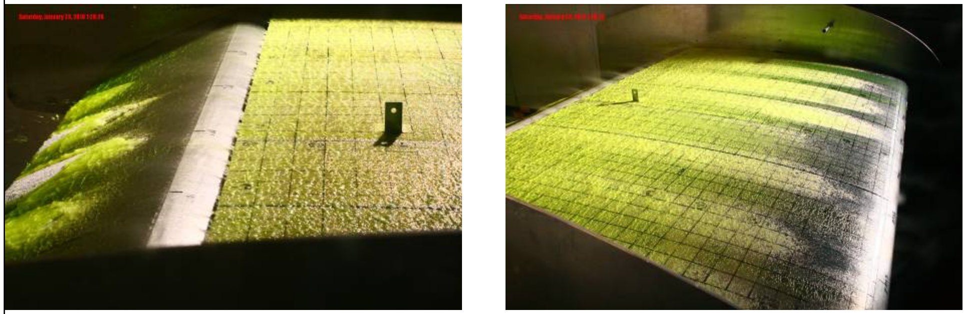


Photo 12.21: Test #37 – End of Rotation

Test #37
2031 Cold, SN 25 g/dm²/h, 10 min
-1°C, 8° Rotation
Visual Contamination Rating (1,1,1.5), 8° Lift Loss = 4.72%

End of Rotation

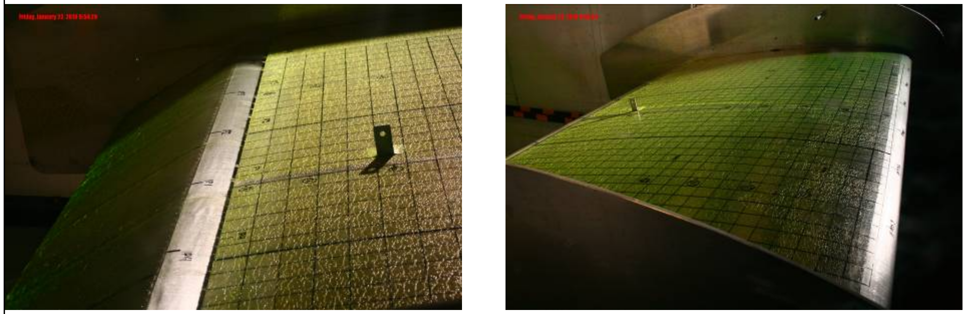
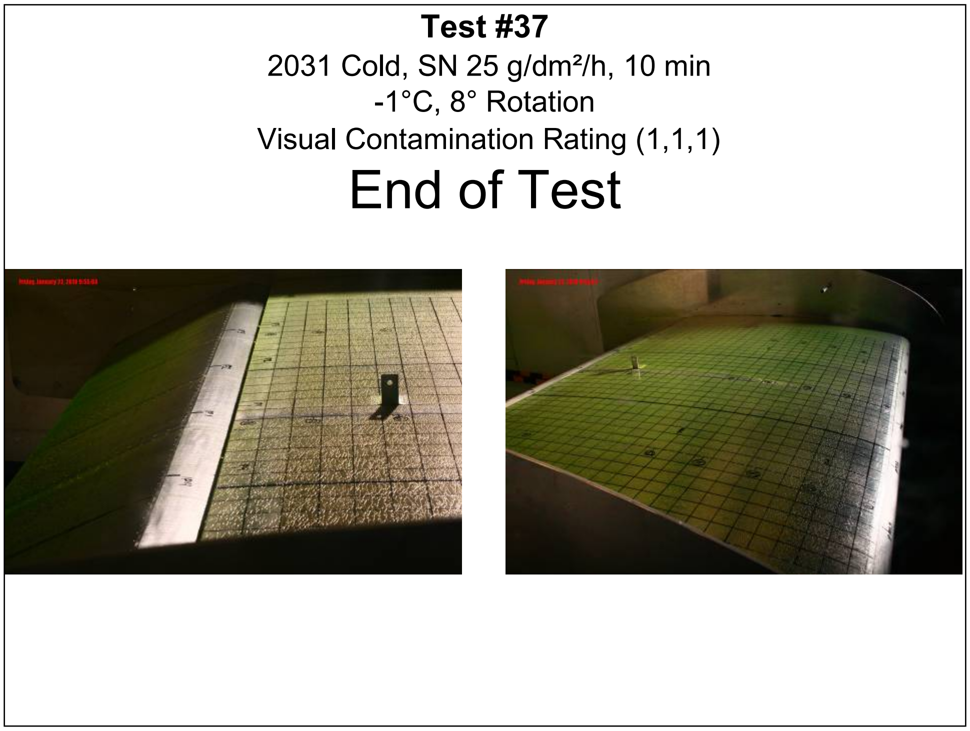


Photo 12.22: Test #40 – End of Rotation

Test #40
2031 Cold, SN 50 g/dm²/h, 15 min
-3°C, 8° Rotation
Visual Contamination Rating (1.5,2.3,3.8), 8° Lift Loss = 7.40%

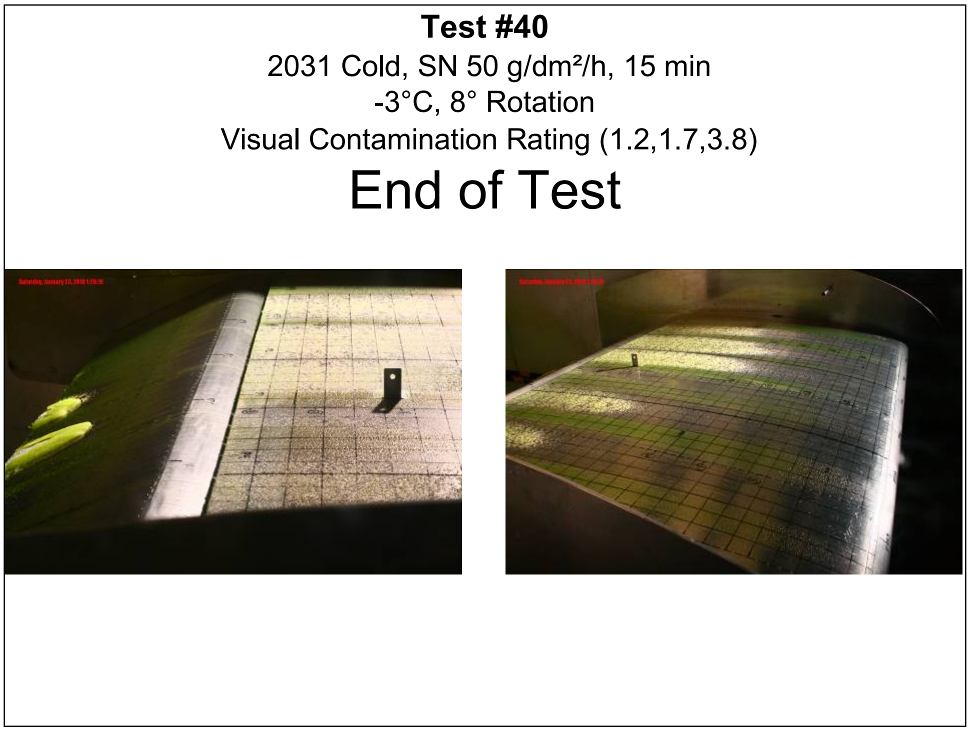
End of Rotation

Photo 12.23: Test #37 – End of Test



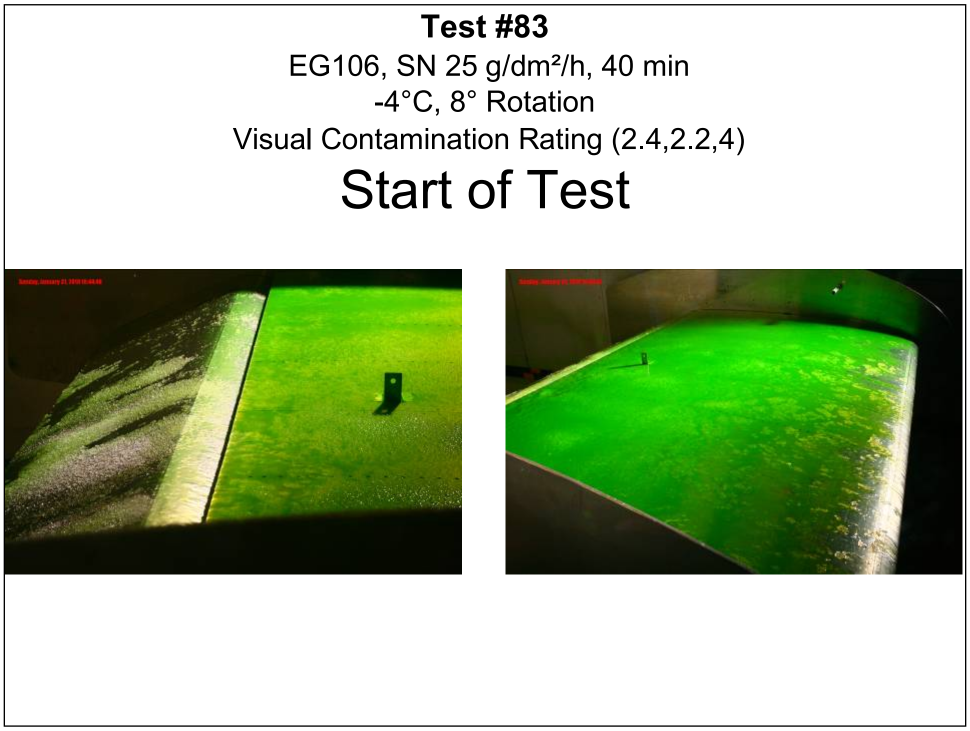
Test #37
2031 Cold, SN 25 g/dm²/h, 10 min
-1°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

Photo 12.24: Test #40 – End of Test



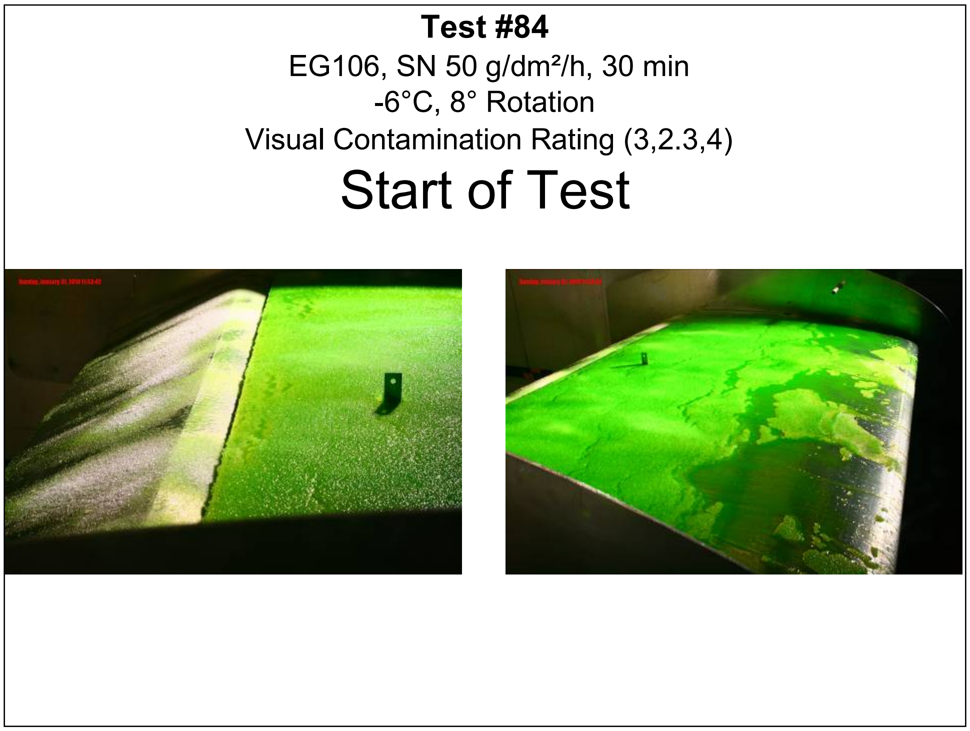
Test #40
2031 Cold, SN 50 g/dm²/h, 15 min
-3°C, 8° Rotation
Visual Contamination Rating (1.2,1.7,3.8)
End of Test

Photo 12.25: Test #83 – Start of Test



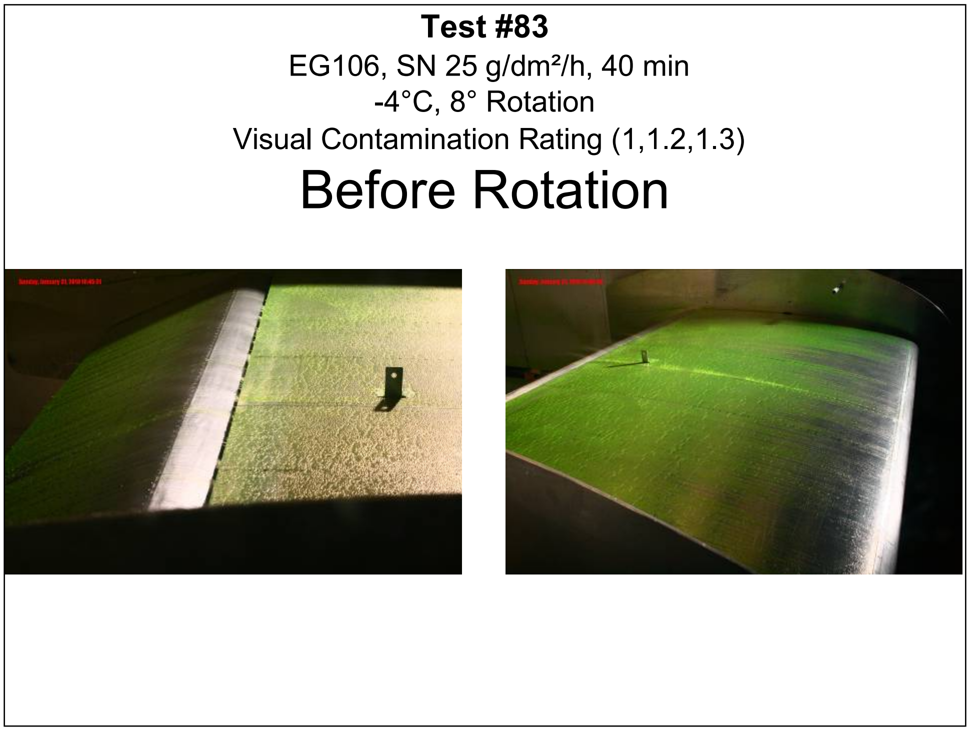
Test #83
EG106, SN 25 g/dm²/h, 40 min
-4°C, 8° Rotation
Visual Contamination Rating (2.4,2.2,4)
Start of Test

Photo 12.26: Test #84 – Start of Test



Test #84
EG106, SN 50 g/dm²/h, 30 min
-6°C, 8° Rotation
Visual Contamination Rating (3,2.3,4)
Start of Test

Photo 12.27: Test #83 – Before Rotation

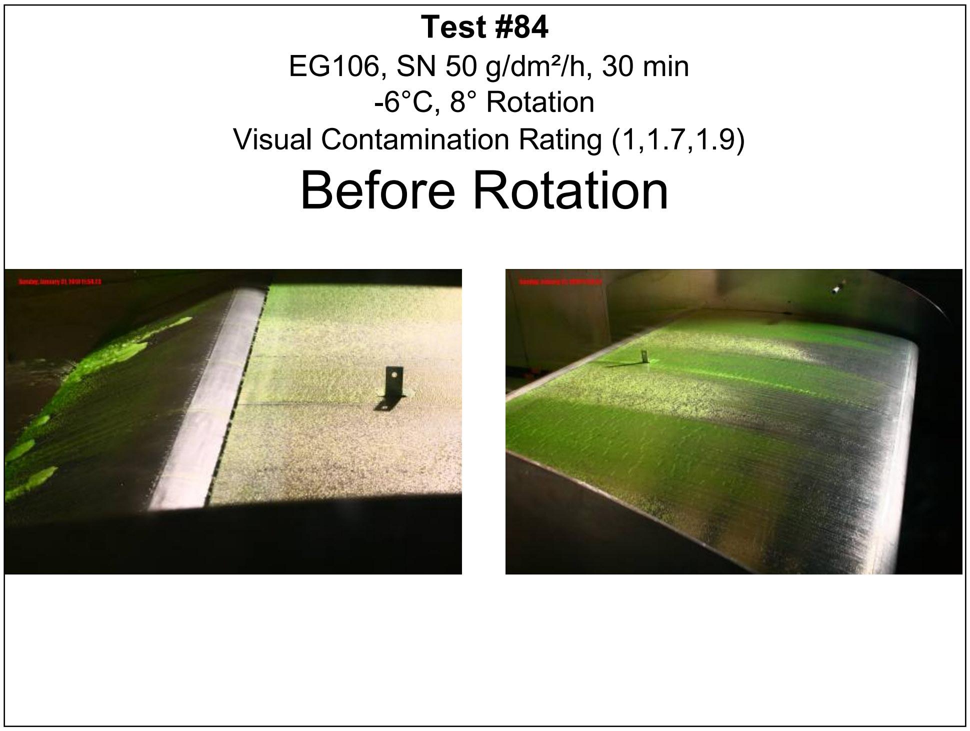


Test #83

EG106, SN 25 g/dm²/h, 40 min
-4°C, 8° Rotation
Visual Contamination Rating (1,1.2,1.3)

Before Rotation

Photo 12.28: Test #84 – Before Rotation

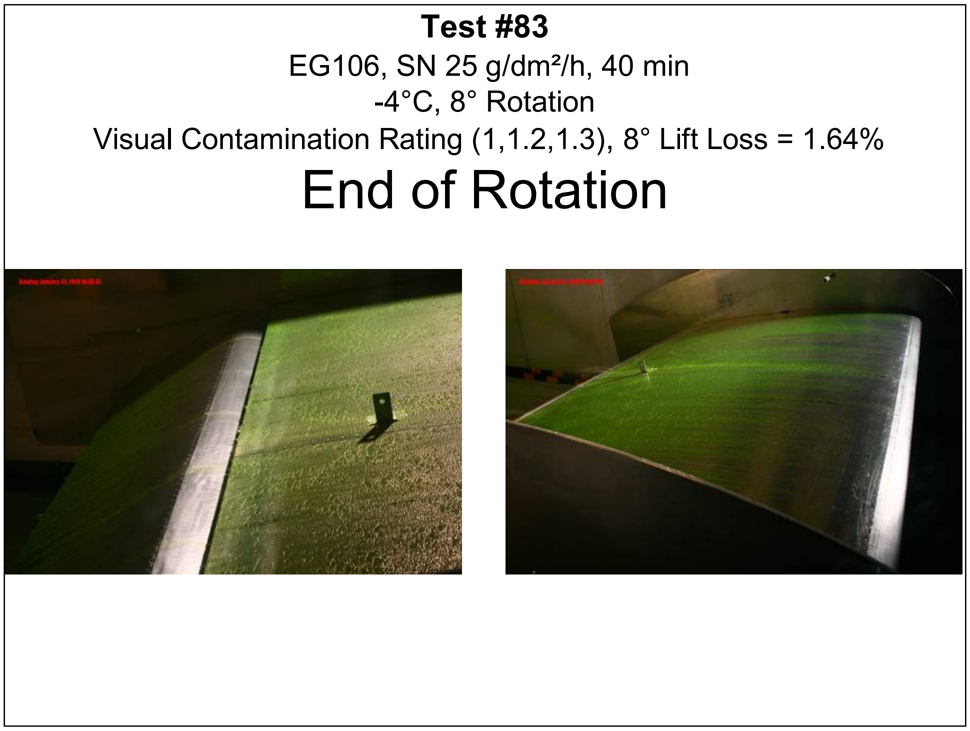


Test #84

EG106, SN 50 g/dm²/h, 30 min
-6°C, 8° Rotation
Visual Contamination Rating (1,1.7,1.9)

Before Rotation

Photo 12.29: Test #83 – End of Rotation



Test #83

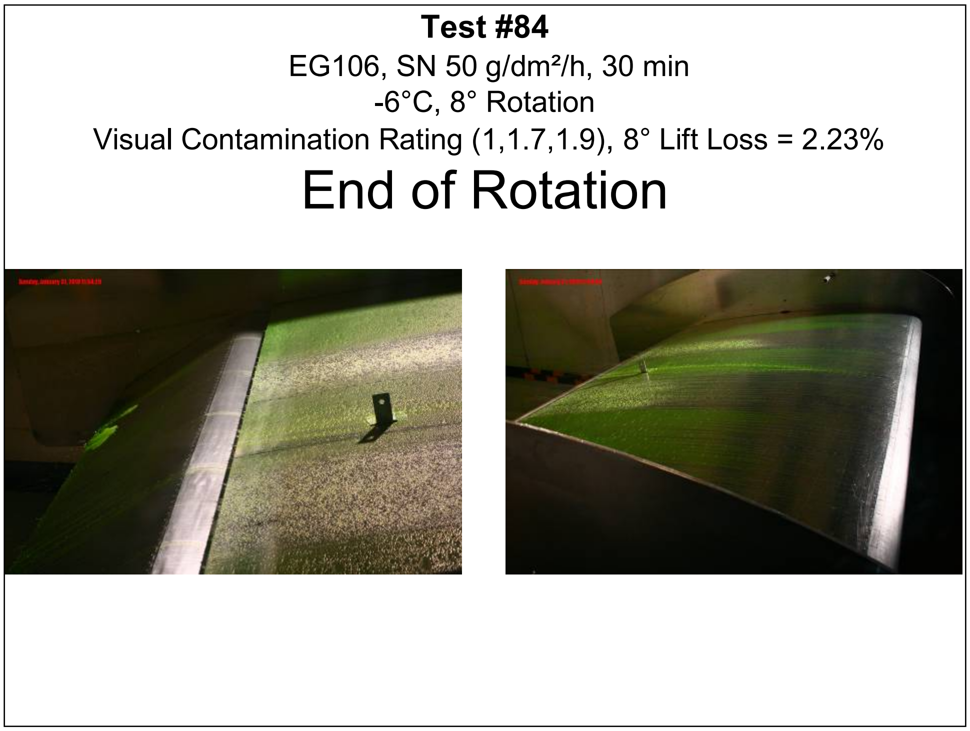
EG106, SN 25 g/dm²/h, 40 min

-4°C, 8° Rotation

Visual Contamination Rating (1,1.2,1.3), 8° Lift Loss = 1.64%

End of Rotation

Photo 12.30: Test #84 – End of Rotation



Test #84

EG106, SN 50 g/dm²/h, 30 min

-6°C, 8° Rotation

Visual Contamination Rating (1,1.7,1.9), 8° Lift Loss = 2.23%

End of Rotation

Photo 12.31: Test #83 – End of Test

Test #83

EG106, SN 25 g/dm²/h, 40 min

-4°C, 8° Rotation

Visual Contamination Rating (1,1,1.3)

End of Test

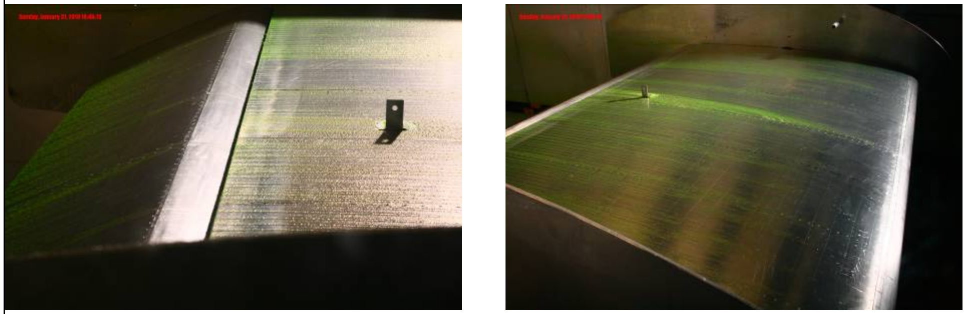


Photo 12.32: Test #84 – End of Test

Test #84

EG106, SN 50 g/dm²/h, 30 min

-6°C, 8° Rotation

Visual Contamination Rating (1,1.2,1)

End of Test

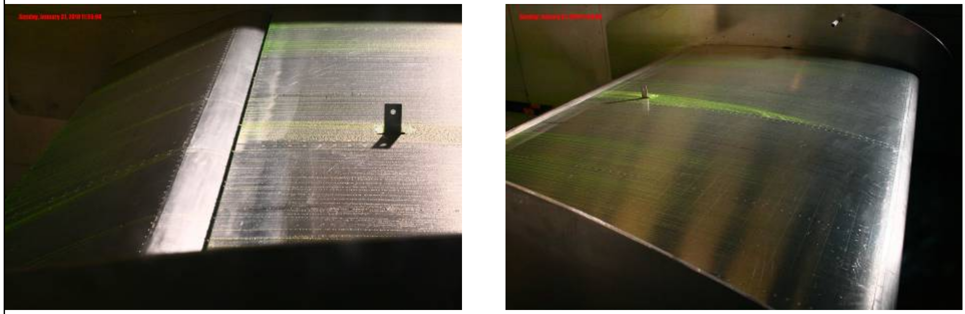


Photo 12.33: Test #83 – Start of Test

Test #83
EG106, SN 25 g/dm²/h, 40 min
-4°C, 8° Rotation
Visual Contamination Rating (2.4,2.2,4)
Start of Test

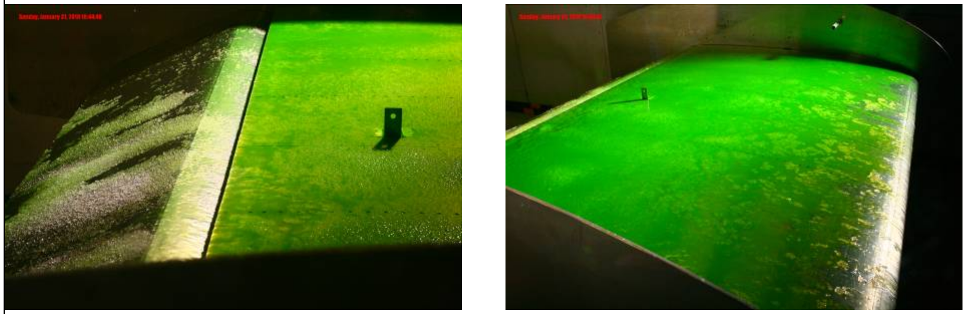


Photo 12.34: Test #85 – Start of Test

Test #85
EG106, SN 50 g/dm²/h, 20 min
-7°C, 8° Rotation
Visual Contamination Rating (2.6,2.3,4)
Start of Test

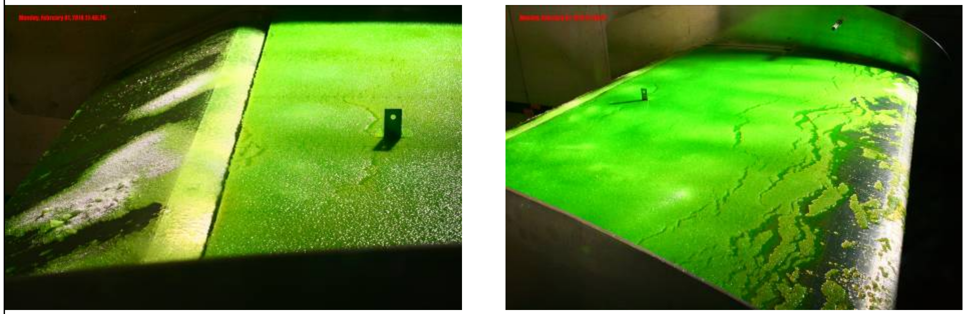


Photo 12.35: Test #83 – Before Rotation

Test #83
EG106, SN 25 g/dm²/h, 40 min
-4°C, 8° Rotation
Visual Contamination Rating (1,1.2,1.3)
Before Rotation

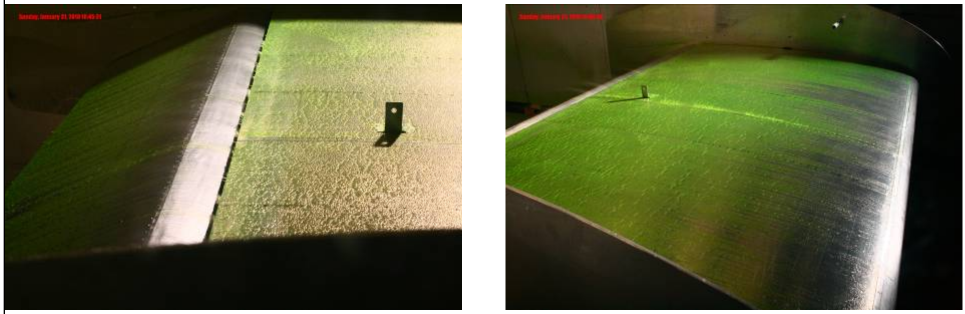


Photo 12.36: Test #85 – Before Rotation

Test #85
EG106, SN 50 g/dm²/h, 20 min
-7°C, 8° Rotation
Visual Contamination Rating (1,1.5,1.9)
Before Rotation

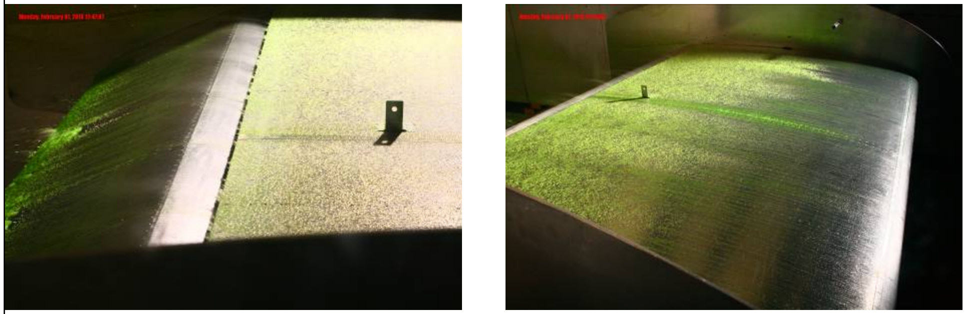


Photo 12.37: Test #83 – End of Rotation

Test #83

EG106, SN 25 g/dm²/h, 40 min

-4°C, 8° Rotation

Visual Contamination Rating (1,1.2,1.3), 8° Lift Loss = 1.64%

End of Rotation

Photo 12.38: Test #85 – End of Rotation

Test #85

EG106, SN 50 g/dm²/h, 20 min

-7°C, 8° Rotation

Visual Contamination Rating (1,1.5,1.9), 8° Lift Loss = 1.41%

End of Rotation

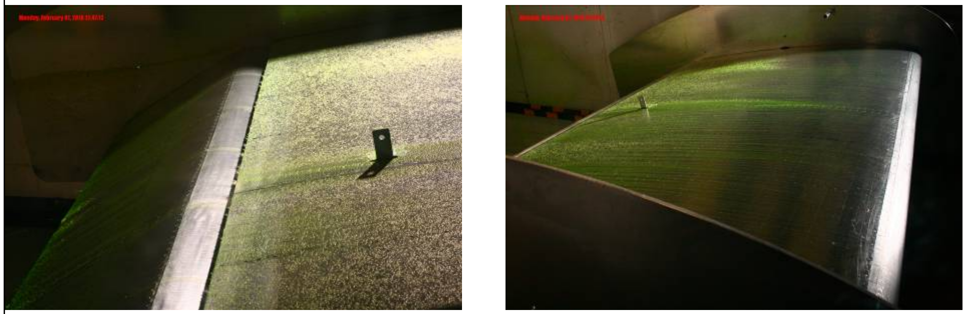


Photo 12.39: Test #83 – End of Test

Test #83
EG106, SN 25 g/dm²/h, 40 min
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1.3)
End of Test

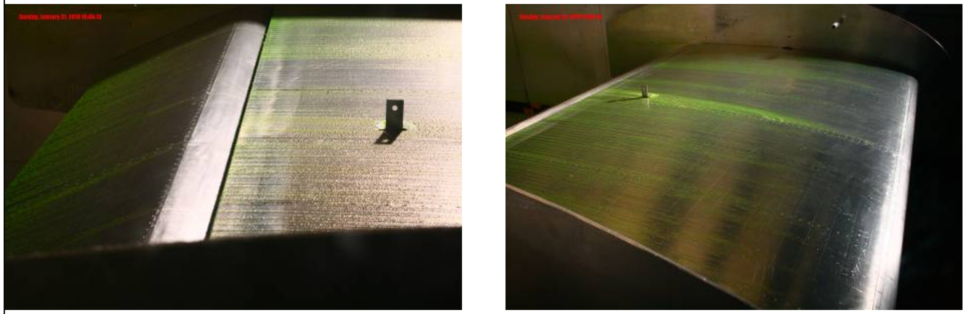


Photo 12.40: Test #85 – End of Test

Test #85
EG106, SN 50 g/dm²/h, 20 min
-7°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

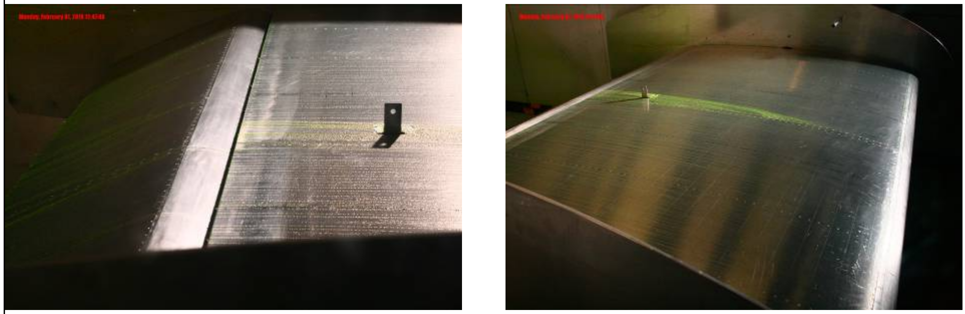


Photo 12.41: Test #86 – Start of Test

Test #86

ABC-S Plus, SN 25 g/dm²/h, 60 min

-8.5°C, 8° Rotation

Visual Contamination Rating (3.7,2.9,4)

Start of Test

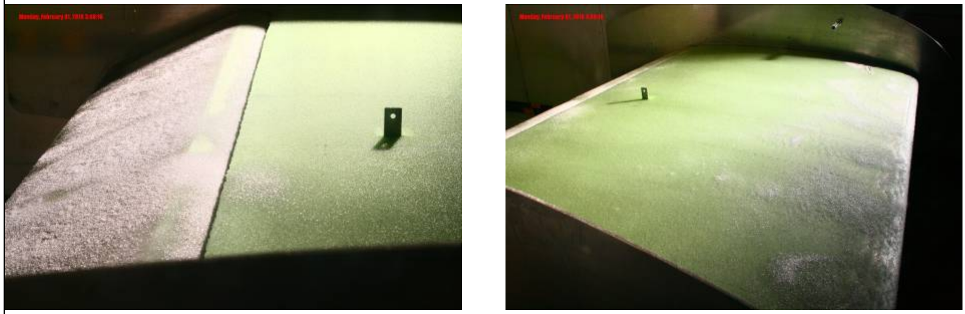


Photo 12.42: Test #87 – Start of Test

Test #87

ABC-S Plus, SN 50 g/dm²/h, 30 min

-12°C, 8° Rotation

Visual Contamination Rating (3.7,2.9,4)

Start of Test

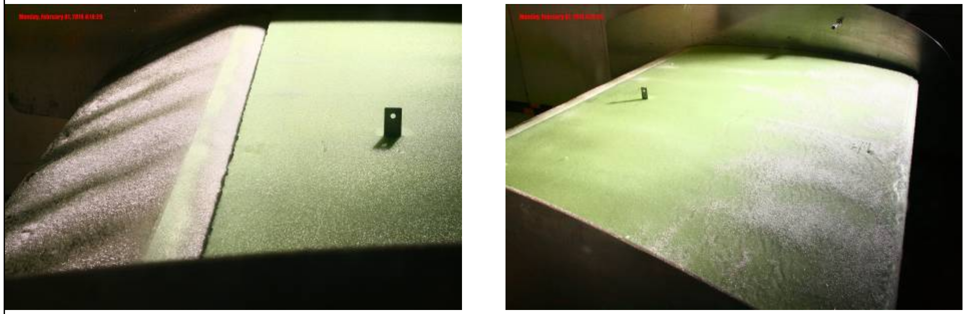
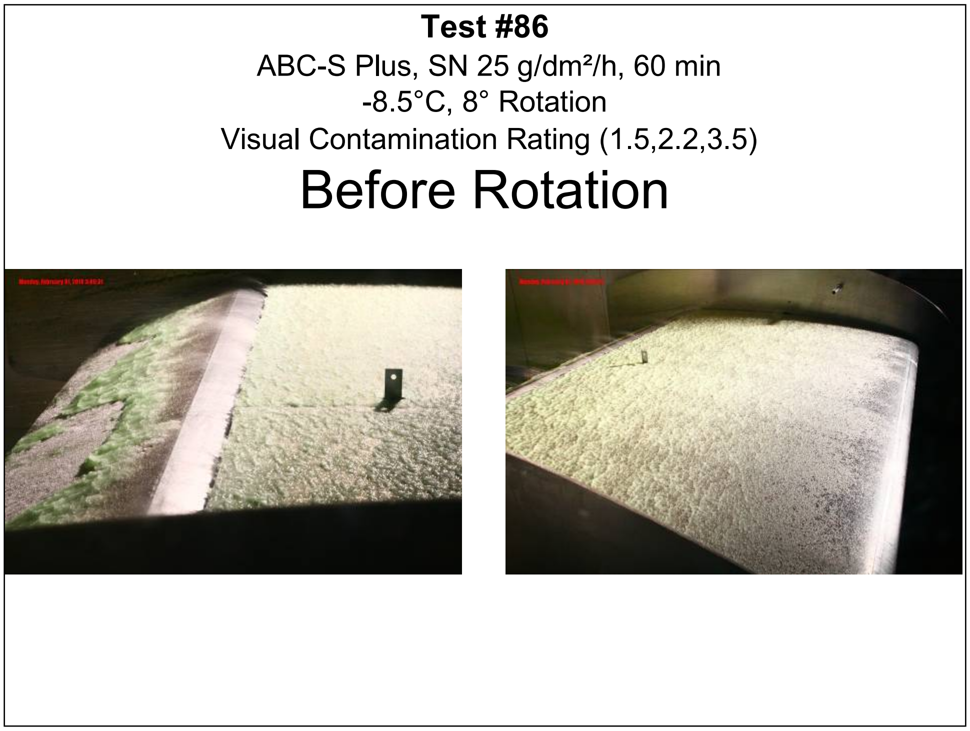
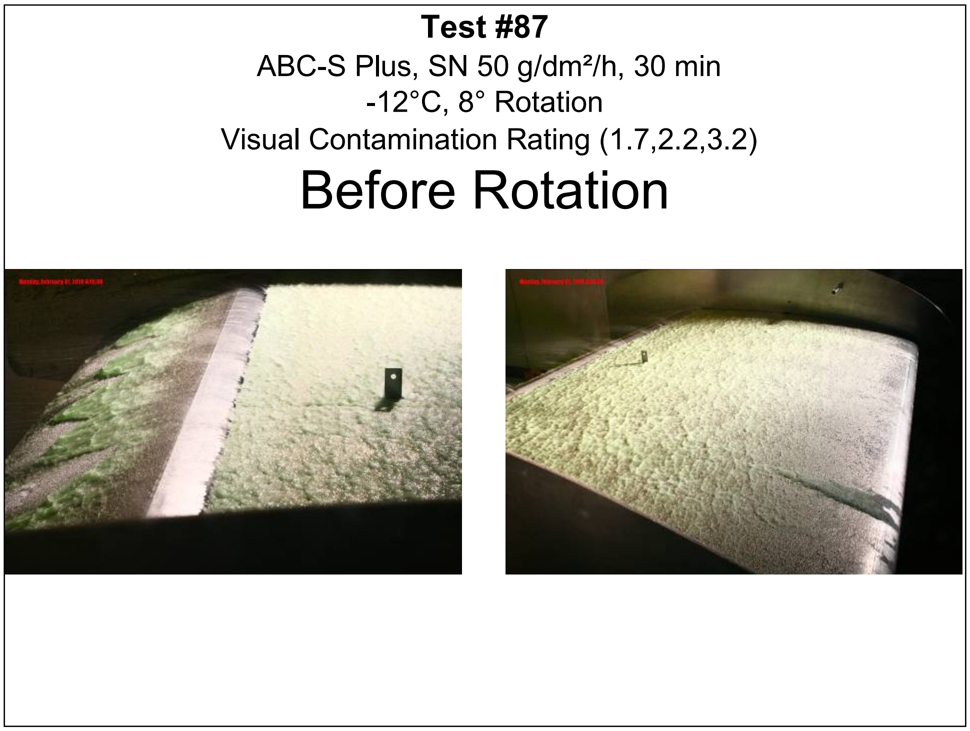


Photo 12.43: Test #86 – Before Rotation



Test #86
ABC-S Plus, SN 25 g/dm²/h, 60 min
-8.5°C, 8° Rotation
Visual Contamination Rating (1.5,2.2,3.5)
Before Rotation

Photo 12.44: Test #87 – Before Rotation



Test #87
ABC-S Plus, SN 50 g/dm²/h, 30 min
-12°C, 8° Rotation
Visual Contamination Rating (1.7,2.2,3.2)
Before Rotation

Photo 12.45: Test #86 – End of Rotation

Test #86
ABC-S Plus, SN 25 g/dm²/h, 60 min
-8.5°C, 8° Rotation
Visual Contamination Rating (1.5,2.2,3.5), 8° Lift Loss = 12.16%
End of Rotation

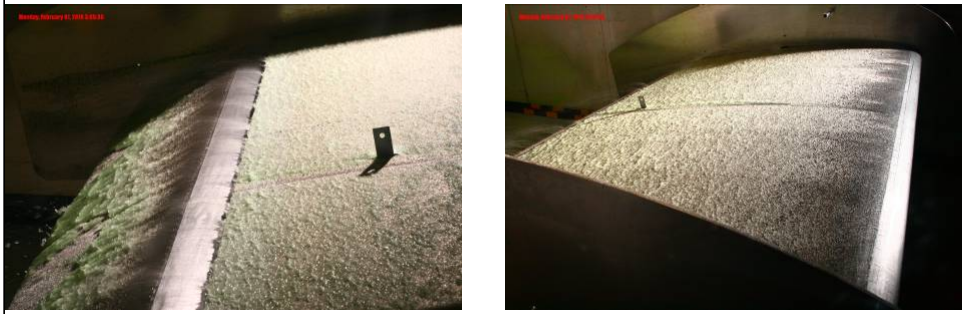


Photo 12.46: Test #87 – End of Rotation

Test #87
ABC-S Plus, SN 50 g/dm²/h, 30 min
-12°C, 8° Rotation
Visual Contamination Rating (1.7,2.2,3.2), 8° Lift Loss = 12.86%
End of Rotation

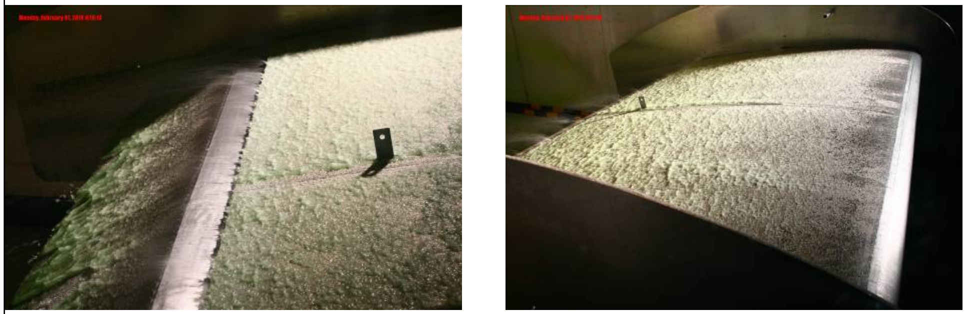


Photo 12.47: Test #86 – End of Test

Test #86
ABC-S Plus, SN 25 g/dm²/h, 60 min
-8.5°C, 8° Rotation
Visual Contamination Rating (1.2,1.8,3)

End of Test

Photo 12.48: Test #87 – End of Test

Test #87
ABC-S Plus, SN 50 g/dm²/h, 30 min
-12°C, 8° Rotation
Visual Contamination Rating (1.2,1.8,2.3)

End of Test

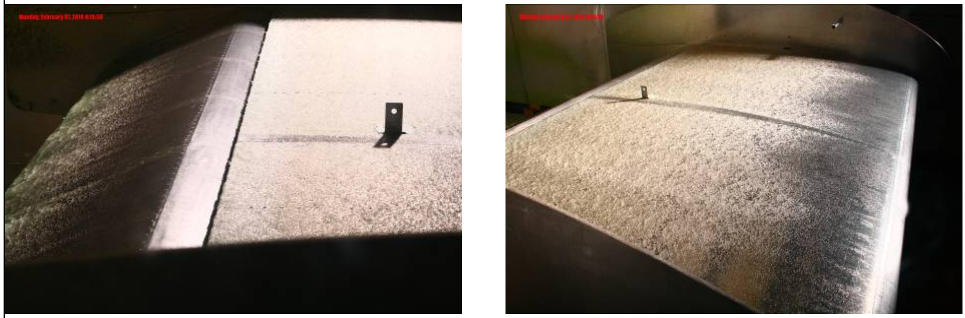
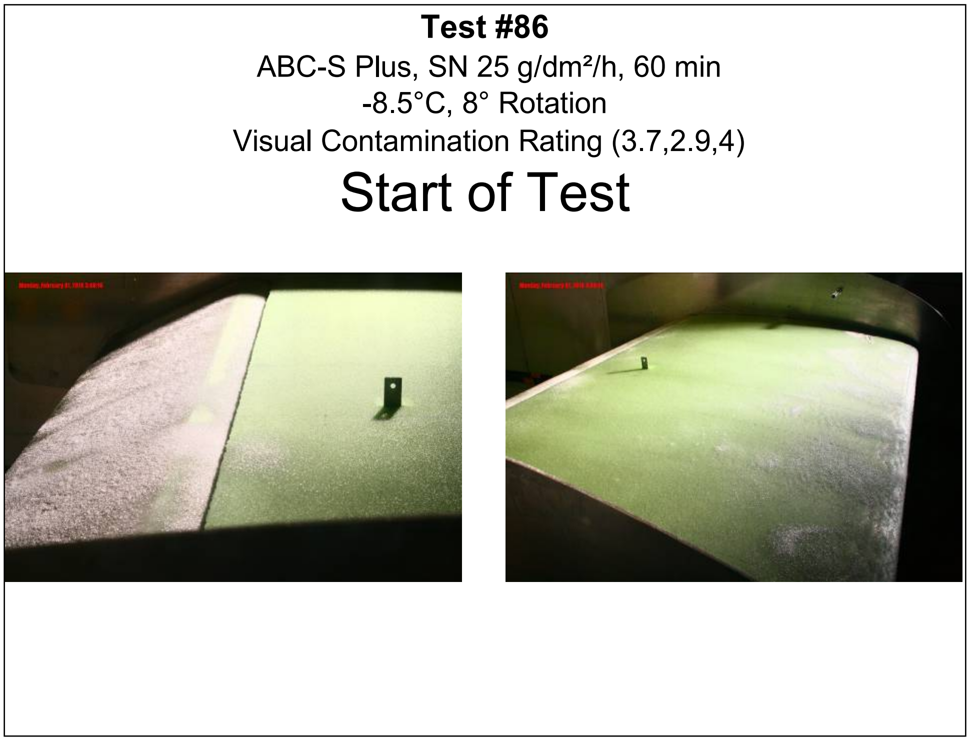


Photo 12.49: Test #86 – Start of Test



Test #86

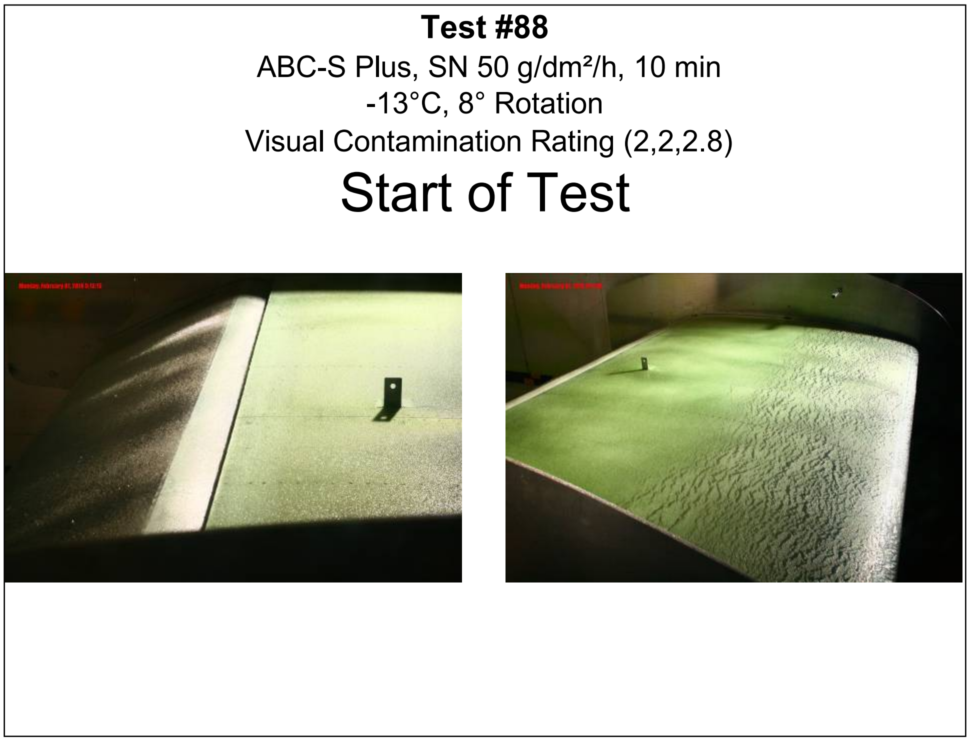
ABC-S Plus, SN 25 g/dm²/h, 60 min

-8.5°C, 8° Rotation

Visual Contamination Rating (3.7,2.9,4)

Start of Test

Photo 12.50: Test #88 – Start of Test



Test #88

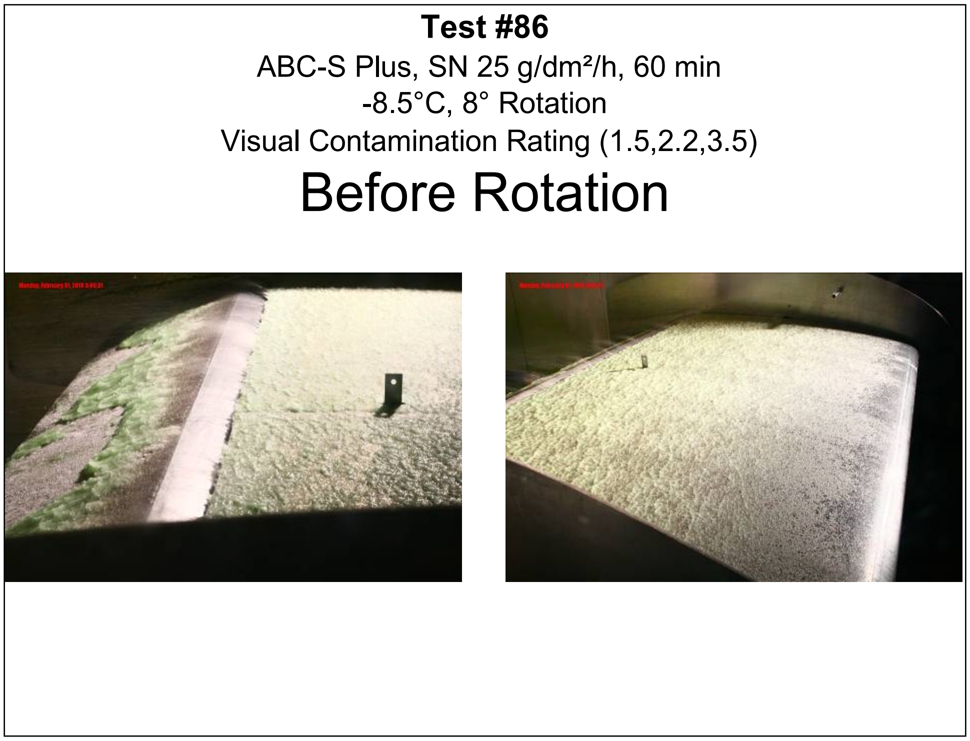
ABC-S Plus, SN 50 g/dm²/h, 10 min

-13°C, 8° Rotation

Visual Contamination Rating (2,2,2.8)

Start of Test

Photo 12.51: Test #86 – Before Rotation



Test #86

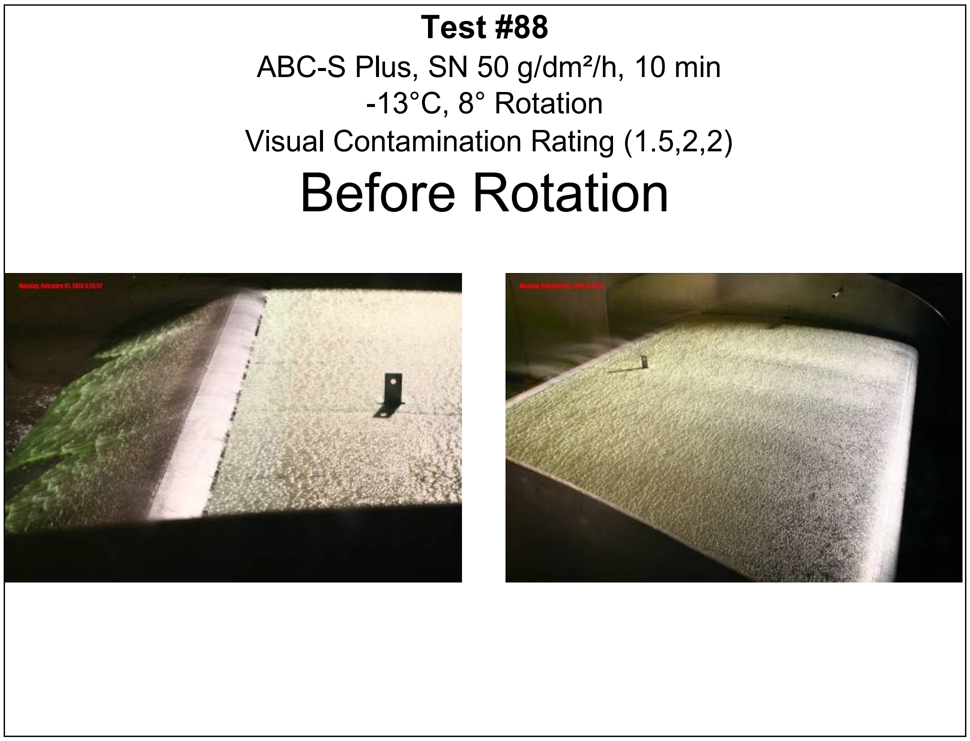
ABC-S Plus, SN 25 g/dm²/h, 60 min

-8.5°C, 8° Rotation

Visual Contamination Rating (1.5,2.2,3.5)

Before Rotation

Photo 12.52: Test #88 – Before Rotation



Test #88

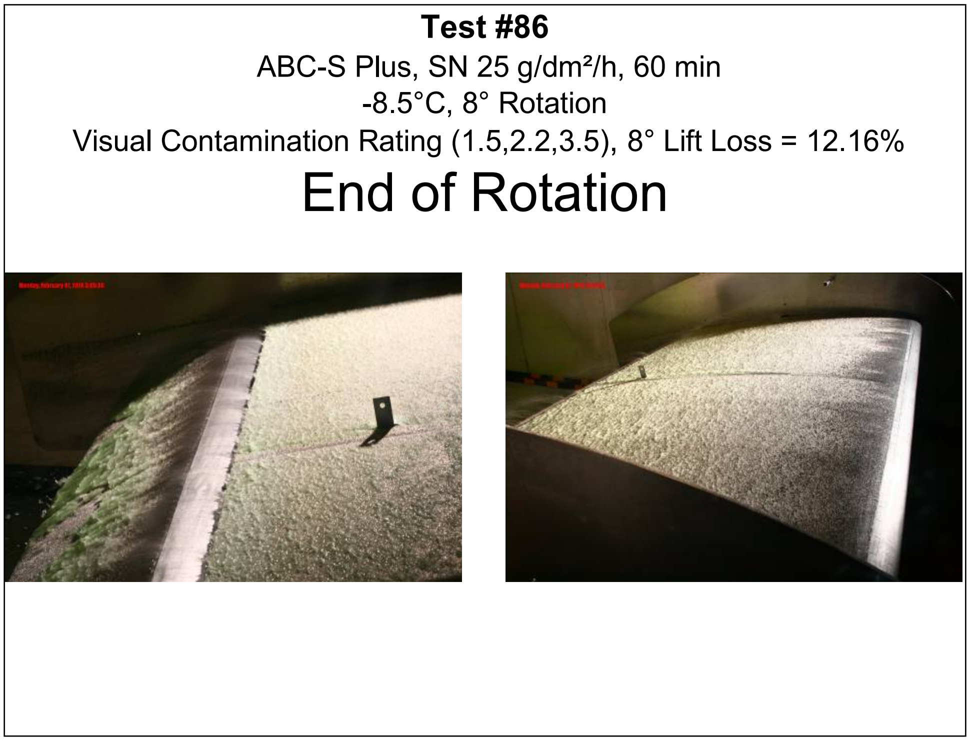
ABC-S Plus, SN 50 g/dm²/h, 10 min

-13°C, 8° Rotation

Visual Contamination Rating (1.5,2,2)

Before Rotation

Photo 12.53: Test #86 – End of Rotation



Test #86

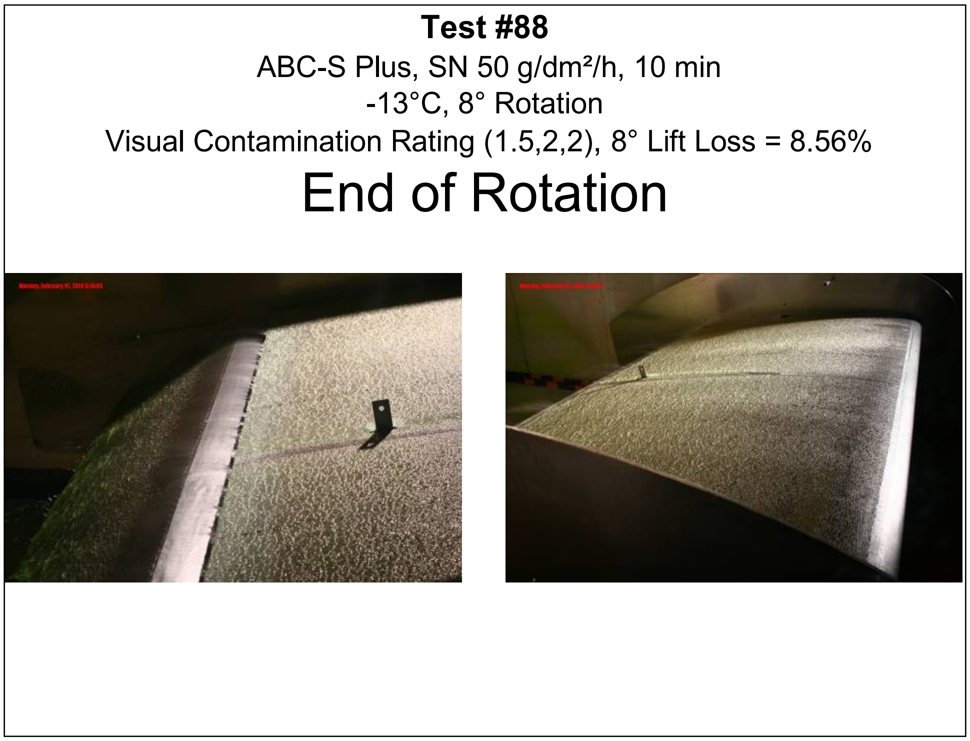
ABC-S Plus, SN 25 g/dm²/h, 60 min

-8.5°C, 8° Rotation

Visual Contamination Rating (1.5,2.2,3.5), 8° Lift Loss = 12.16%

End of Rotation

Photo 12.54: Test #88 – End of Rotation



Test #88

ABC-S Plus, SN 50 g/dm²/h, 10 min

-13°C, 8° Rotation

Visual Contamination Rating (1.5,2,2), 8° Lift Loss = 8.56%

End of Rotation

Photo 12.55: Test #86 – End of Test

Test #86
ABC-S Plus, SN 25 g/dm²/h, 60 min
-8.5°C, 8° Rotation
Visual Contamination Rating (1.2,1.8,3)
End of Test

Photo 12.56: Test #88 – End of Test

Test #88
ABC-S Plus, SN 50 g/dm²/h, 10 min
-13°C, 8° Rotation
Visual Contamination Rating (1.3,1.5,1.5)
End of Test

Photo 12.57: Test #92 – Start of Test

Test #92
ABC-S Plus, SN 25 g/dm²/h, 60 min
-5°C, 8° Rotation
Visual Contamination Rating (2.5,2.3,3.8)
Start of Test

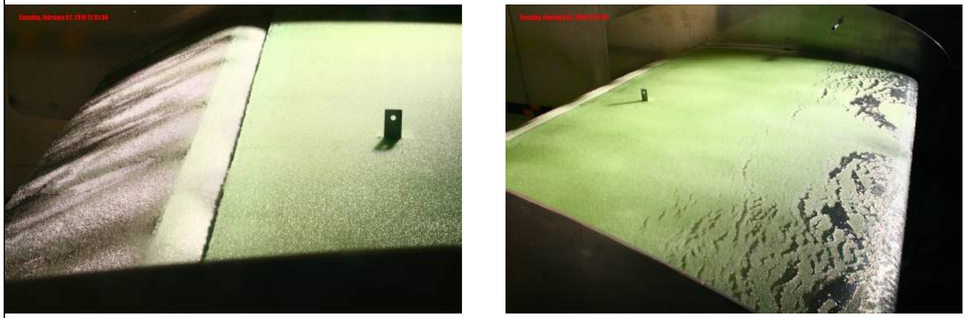


Photo 12.58: Test #90 – Start of Test

Test #90
ABC-S Plus, SN 50 g/dm²/h, 10 min
-2°C, 8° Rotation
Visual Contamination Rating (2.3,2.2,2.2)
Start of Test

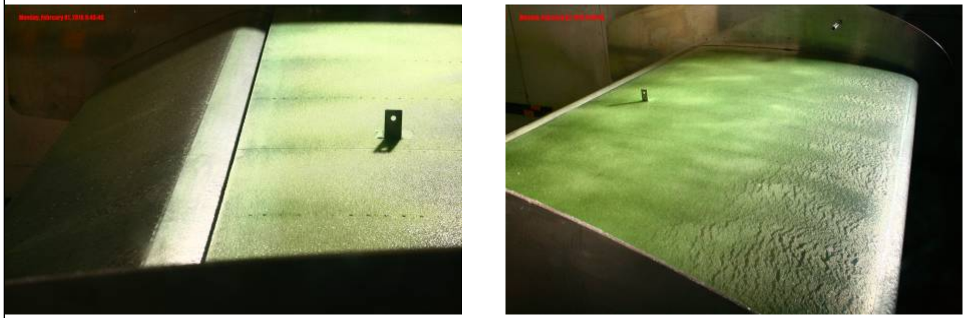
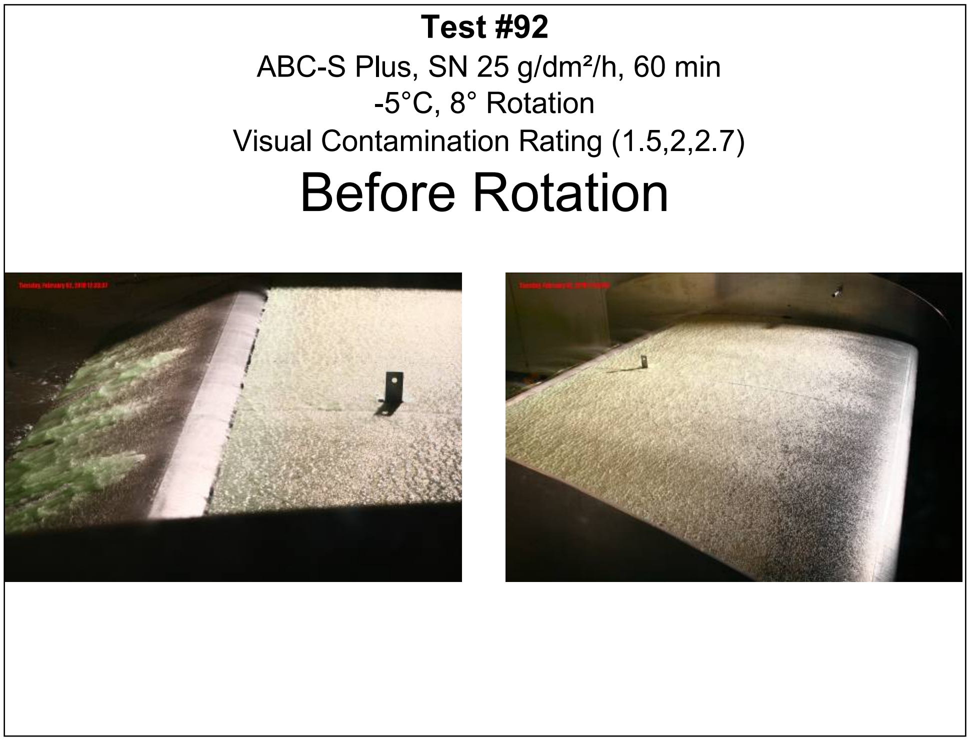
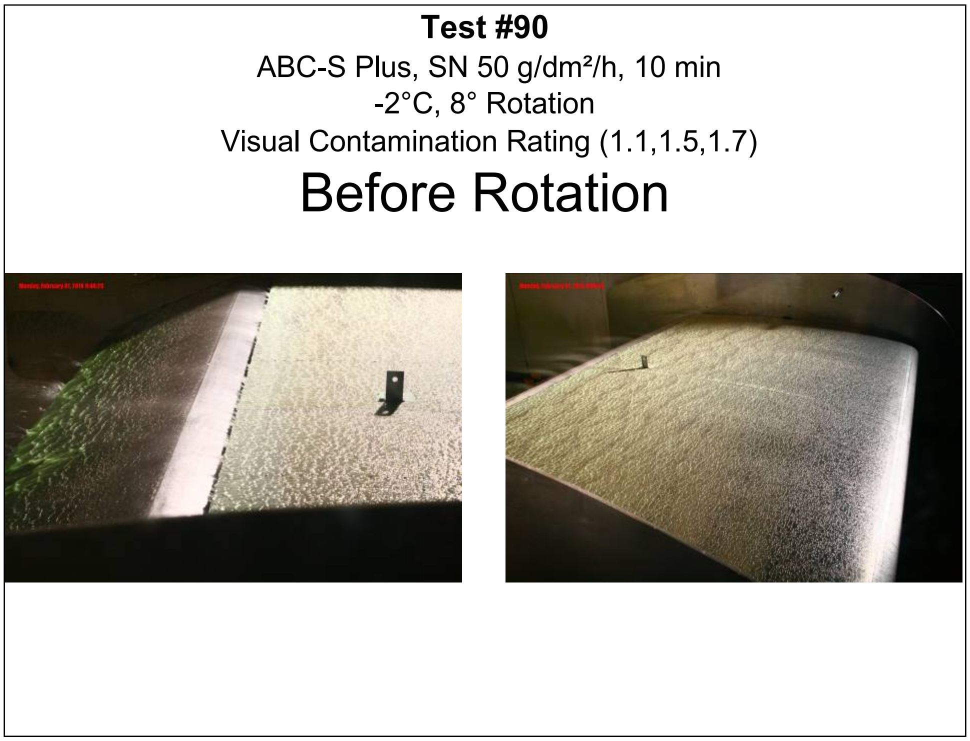


Photo 12.59: Test #92 – Before Rotation



Test #92
ABC-S Plus, SN 25 g/dm²/h, 60 min
-5°C, 8° Rotation
Visual Contamination Rating (1.5,2,2.7)
Before Rotation

Photo 12.60: Test #90 – Before Rotation



Test #90
ABC-S Plus, SN 50 g/dm²/h, 10 min
-2°C, 8° Rotation
Visual Contamination Rating (1.1,1.5,1.7)
Before Rotation

Photo 12.61: Test #92 – End of Rotation

Test #92
ABC-S Plus, SN 25 g/dm²/h, 60 min
-5°C, 8° Rotation
Visual Contamination Rating (1.5,2,2.7), 8° Lift Loss = 8.38%
End of Rotation

Photo 12.62: Test #90 – End of Rotation

Test #90
ABC-S Plus, SN 50 g/dm²/h, 10 min
-2°C, 8° Rotation
Visual Contamination Rating (1.1,1.5,1.7), 8° Lift Loss = 5.94%
End of Rotation

Photo 12.63: Test #92 – End of Test

Test #92

ABC-S Plus, SN 25 g/dm²/h, 60 min

-5°C, 8° Rotation

Visual Contamination Rating (1,1.7,1.8)

End of Test

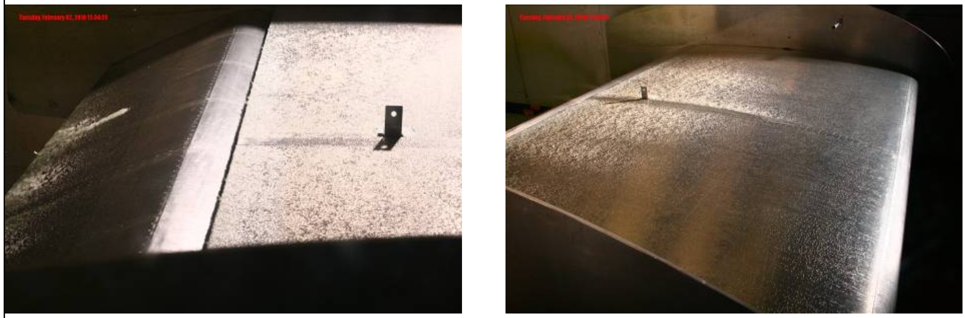


Photo 12.64: Test #90 – End of Test

Test #90

ABC-S Plus, SN 50 g/dm²/h, 10 min

-2°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test

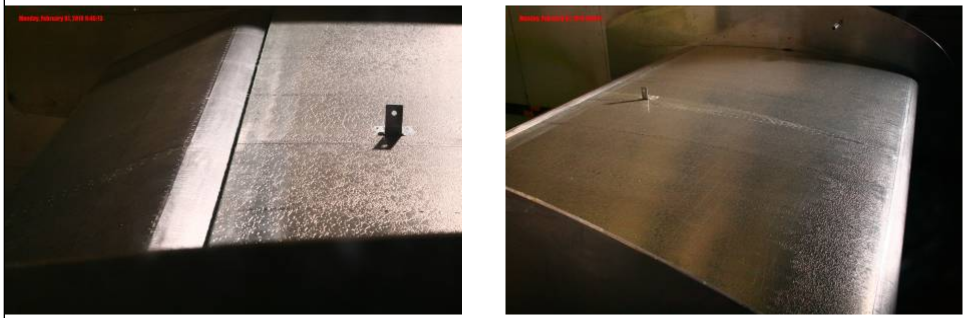


Photo 12.65: Test #92 – Start of Test

Test #92

ABC-S Plus, SN 25 g/dm²/h, 60 min

-5°C, 8° Rotation

Visual Contamination Rating (2.5,2.3,3.8)

Start of Test

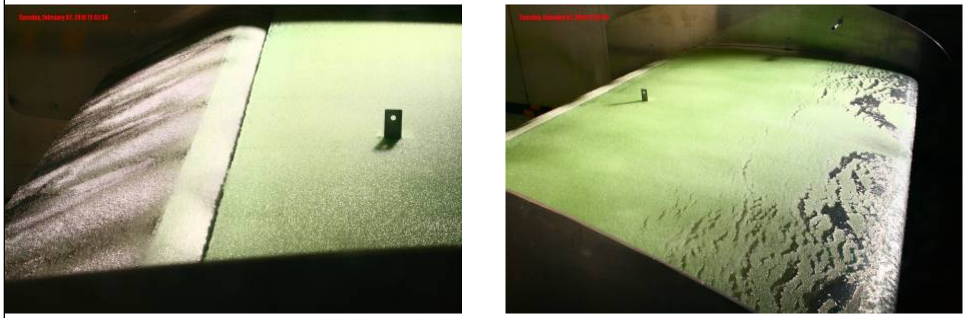


Photo 12.66: Test #91 – Start of Test

Test #91

ABC-S Plus, SN 50 g/dm²/h, 30 min

-4°C, 8° Rotation

Visual Contamination Rating (2.8,2.7,3.7)

Start of Test

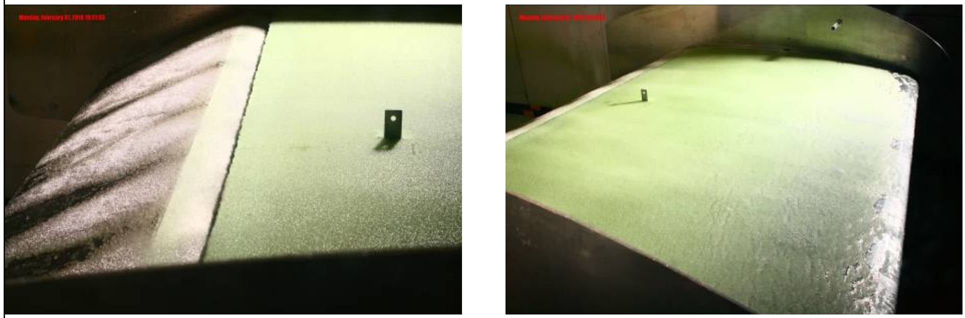
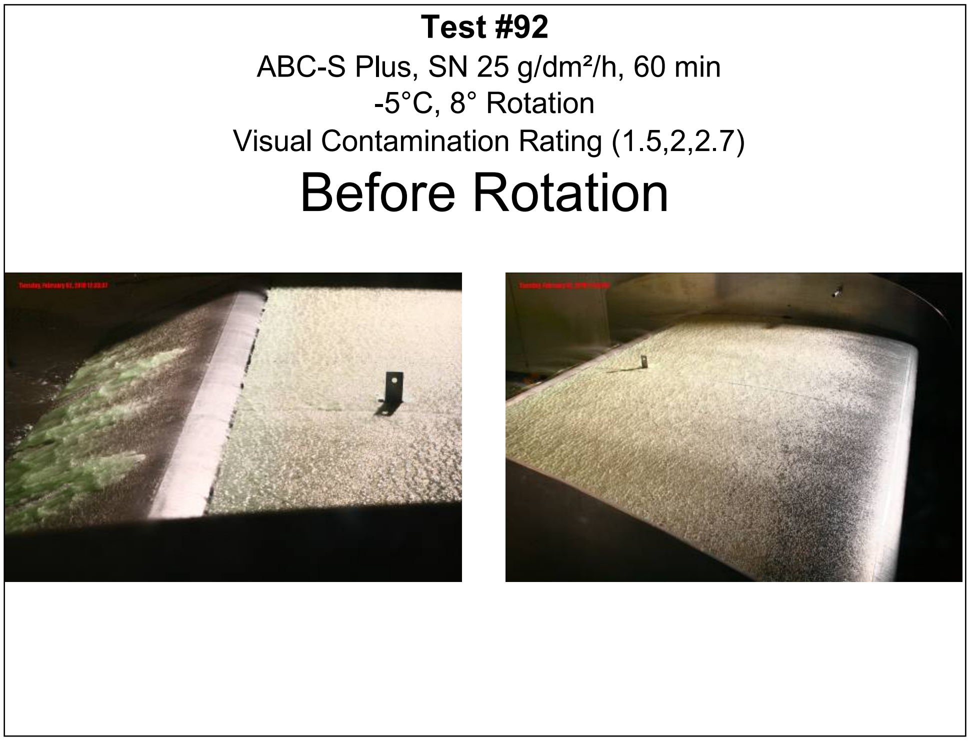
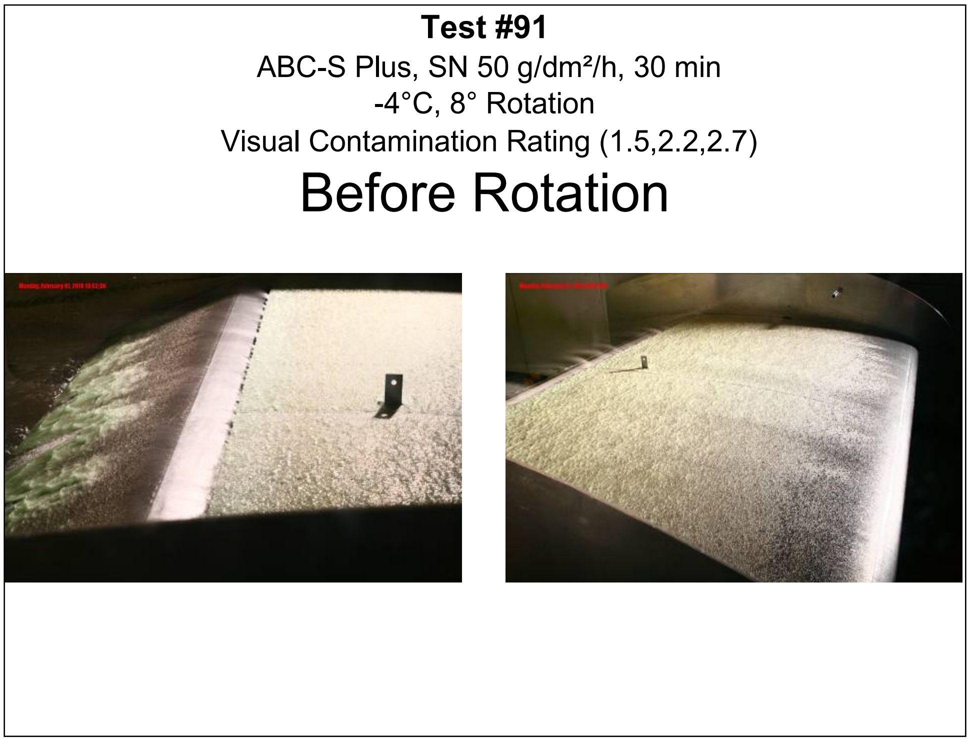


Photo 12.67: Test #92 – Before Rotation



Test #92
ABC-S Plus, SN 25 g/dm²/h, 60 min
-5°C, 8° Rotation
Visual Contamination Rating (1.5,2,2.7)
Before Rotation

Photo 12.68: Test #91 – Before Rotation



Test #91
ABC-S Plus, SN 50 g/dm²/h, 30 min
-4°C, 8° Rotation
Visual Contamination Rating (1.5,2.2,2.7)
Before Rotation

Photo 12.69: Test #92 – End of Rotation

Test #92
ABC-S Plus, SN 25 g/dm²/h, 60 min
-5°C, 8° Rotation
Visual Contamination Rating (1.5,2,2.7), 8° Lift Loss = 8.38%
End of Rotation

Photo 12.70: Test #91 – End of Rotation

Test #91
ABC-S Plus, SN 50 g/dm²/h, 30 min
-4°C, 8° Rotation
Visual Contamination Rating (1.5,2.2,2.7), 8° Lift Loss = 8.44%
End of Rotation

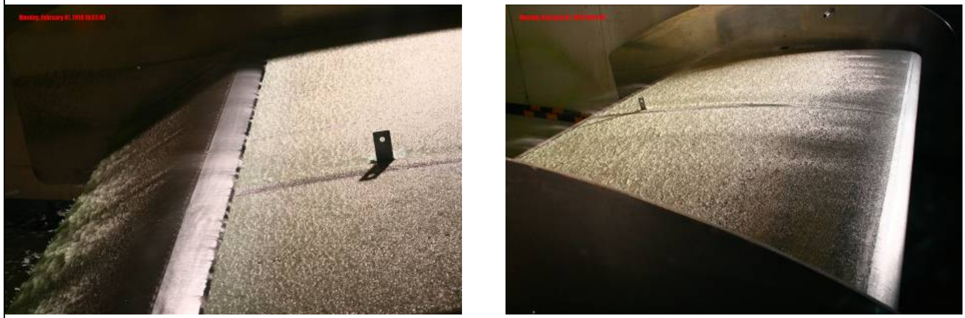
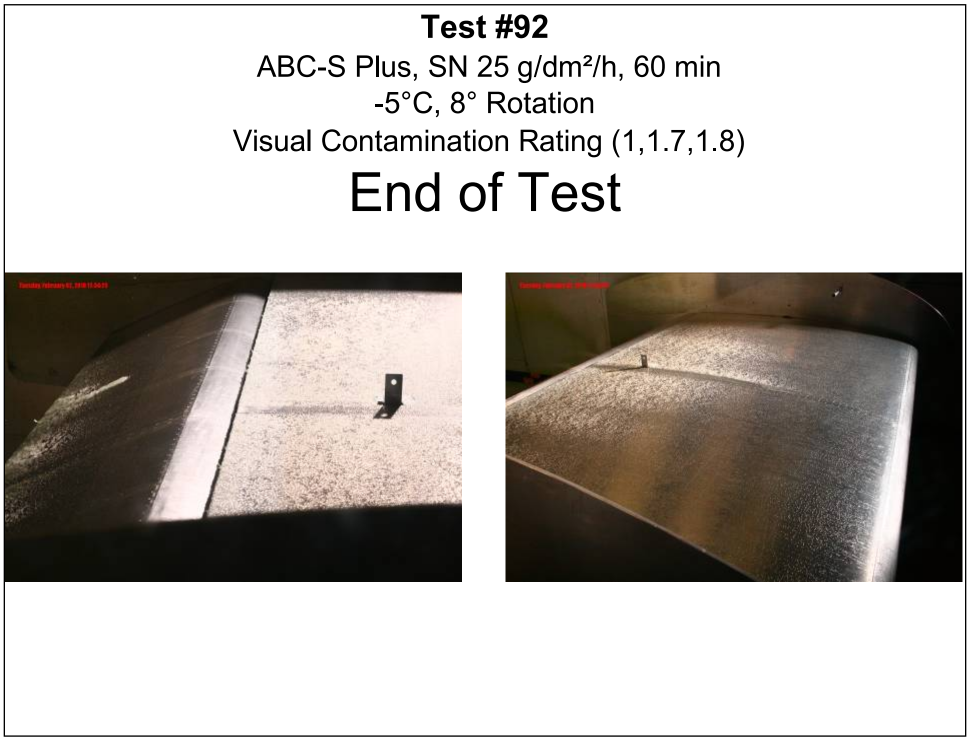


Photo 12.71: Test #92 – End of Test



Test #92

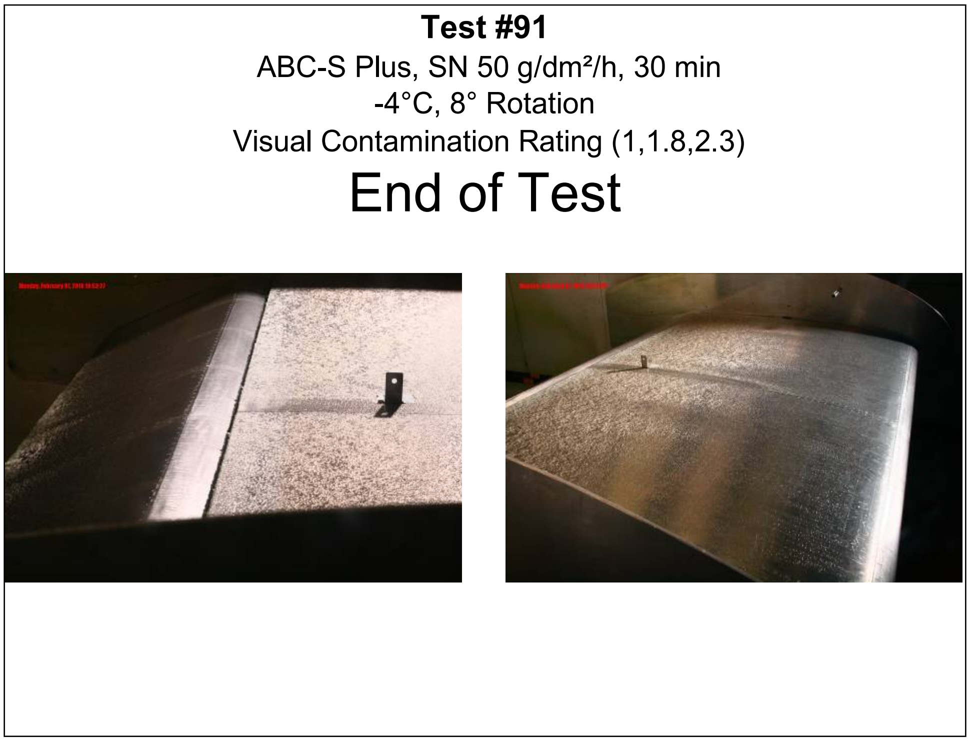
ABC-S Plus, SN 25 g/dm²/h, 60 min

-5°C, 8° Rotation

Visual Contamination Rating (1,1.7,1.8)

End of Test

Photo 12.72: Test #91 – End of Test



Test #91

ABC-S Plus, SN 50 g/dm²/h, 30 min

-4°C, 8° Rotation

Visual Contamination Rating (1,1.8,2.3)

End of Test

13. CONCLUSIONS AND OBSERVATIONS

These observations and conclusions were derived from the testing conducted during the winter of 2009-10.

13.1 Type III Ice Pellet Allowance Times

Early on in the testing period, a viscosity issue was discovered with the Type III 1000 L fluid tote sample received for testing. It was concluded that the data collected for the development of Type III allowance times was not valid because the fluid used was not to specification and therefore not representative. Replacement fluid could not be obtained in time; therefore, the data collected was dismissed and testing with the Type III fluid was stopped. This incident had large financial implications due to the high cost of testing in the wind tunnel. As a result, a new quality control protocol was put into place by APS concerning fluid received in large totes in order to prevent this occurrence during future tests.

13.2 Effects of Wing Surface Roughness

The lift loss data collected indicated that the aerodynamic performance improved as the wing section became increasingly clean; however, the stall angle data demonstrated results that were counterintuitive, whereby the wing seemed to stall at a higher angle when contaminated compared to the clean wing. It is not uncommon in aerodynamics for added surface roughness to delay stall on airfoils.

Depending on the degree of roughness, added contamination can delay the stall angle by promoting the turbulent boundary layer on the airfoil. This benefit will typically be accompanied by a drag penalty (due to added skin friction) and a lower lift coefficient. This observation is of particular importance if future testing is to explore stall margin rather than lift loss. Additional testing is recommended to further investigate this phenomenon and to understand its potential impact on aircraft operations.

13.3 Effects of a Contaminated Flap

The results of this testing indicated that a contaminated flap section can have significant impacts on aerodynamic performance; results indicated up to a 28 percent lift loss compared to the dry wing with a heavily contaminated flap. The most severe lift losses were observed when the flap leading edge section and stagnation point were contaminated.

Some additional work was conducted to investigate the aerodynamic improvement resulting from having the flap up versus down during taxi following anti-icing; this work is described in TP 15232E (Vol. 2) (2). The results of the work included in the interim report are in line with the results observed during this testing, indicating that a contaminated flap can have significant adverse effects on aerodynamic performance.

13.4 Effect of Applying Excessive Amounts of Anti-Icing Fluid

The fluid thickness results indicated slightly greater fluid thickness on the trailing edge following an excessive anti-icing fluid application; however, differences in residual fluid at the end of the test were minimal. The lift data for both comparative tests were comparable, indicating no difference between a standard application and an excessive application of anti-icing fluid.

The latter observations were of specific importance to the 2009-10 testing due to the flat surface of the wing section that seemed to generate thicker fluid layers. The results from this comparative testing indicated that the fluid will settle shortly after application, and any differences in fluid thickness should not significantly affect the aerodynamic results.

13.5 Low-Speed Ramp Testing

Visually, more fluid was observed to shear off the wing prior to the time of rotation during the 100 knots rotation speed compared to the 65 and 80 knots rotation speed tests; this was also confirmed by the fluid thickness measurements taken following the end of each test run. The results indicated that the aerodynamic performance will significantly improve as the speed is increased. These results supported those obtained during the 2008-09 testing. This should be taken into consideration when developing a new low-speed fluid certification standard.

13.6 Light Freezing Rain Mixed with Moderate Snow Conditions

The Type I fluid test results indicated that the added snow contamination (compared to light freezing rain alone) significantly affected the aerodynamic performance when the wing section was severely contaminated; lift losses increased from 2.7 percent to 15.8 percent with the presence of snow compared to light freezing rain alone. It is recommended that additional testing be conducted with thickened Type II/III/IV fluids, less prone to adhesion, in order to substantiate these results. In addition, the temperature differential between the inside tunnel and the cold air being blown through the tunnel during the ramp-up may have promoted the formation of ice and adherence, causing more severe lift losses than may typically be expected; Type I fluids will be more susceptible to this effect compared to thickened fluids.

13.7 Effects of Snow on an Unprotected Wing

The results from this testing indicated that a takeoff with dry, loose snow on the wings may be feasible at colder temperatures; however, it is not recommended at warmer temperatures where the risk of melting and refreezing is high. Significant lift losses were observed at the warmer temperatures when the contamination melted and re-froze during the takeoff run; however, lift losses during the testing at colder temperatures were generally acceptable. In addition, it may be difficult to identify adhered contamination on a snow-covered wing (due to hot spots, high moisture, or residual fluid); therefore, de/anti-icing may still be recommended as the best practice in order to ensure safe operations.

13.8 Degraded Anti-Icing Fluid Performance Following Contamination with Runway Deicing Fluid

The results of this testing indicated that the effect of runway deicer fluid was visually more apparent following the Type IV application when higher concentrations of runway deicer fluid were used; contamination with 100 percent runway deicer fluid showed almost instant degradation of Type IV fluid, while contamination with 5 percent runway deicer fluid showed little visual difference initially. All three tests demonstrated significant differences between the protection time of anti-icing fluid contaminated with runway deicer fluid and the baseline fluid. The fluid contaminated with runway deicer fluid demonstrated earlier and more severe signs of fluid adherence, and the adhered contamination was not removed at the time of rotation.

This and other work was presented in May 2010 at the Residues Working Group meeting held in Berlin. Following the meeting, a letter was issued on behalf of the Residues Working Group to IATA, EASA, TC, and the FAA to inform the industry of the potential safety issue; the letter also specified that the issue was related to pre-treatment operations with thickened fluid only. The intent was to have the regulators distribute the letter to operators, airports, and service providers, or incorporate the contents of the letter into the regulators' appropriate guidance material. As a result of this, EASA issued a Safety Information Bulletin (#2010-26, issued September 14, 2010) directed at all aircraft operators warning of the potential safety issues involved with cross-contamination of anti-icing fluid and runway deicer fluid during pre-treatment operations. No changes were made to TC/FAA guidelines for the winter of 2010-11; however, consideration is being given to including some guidance in the HOT Guidelines for the winter of 2011-12.

13.9 Heavy Snow

The results obtained using the three different types of fluid (Type III, Type IV EG, and Type IV PG) indicated that using half the moderate snow HOT for heavy snow conditions could be a viable approach for providing guidance in heavy snow conditions. In all cases, the visual and aerodynamic performance was comparable for the moderate snow test and for the heavy snow test with half the exposure time.

Data collected with the Type III and Type IV EG fluids also indicated that the HOT could potentially be increased to three-quarters of the moderate snow HOT, as the results indicated only a slight degradation in performance compared to the baseline test but similar visual contamination ratings. However, this would need to be further investigated, especially in light of the large lift losses observed with Type IV PG fluids at the colder temperatures using the supercritical wing model.

14. RECOMMENDATIONS

The following recommendations were compiled based on the work conducted during the winter of 2009-10.

14.1 Fluid Quality Assurance

When fluid is shipped in large 1000 L totes, fluid sampling for viscosity testing should be done before testing begins by extracting fluid from several layers in the tote (i.e., the bottom, the top, and the middle). This will ensure that any future instances where fluid may have separated or may have been contaminated will be identified early on and will minimize the financial impact on the testing performed.

14.2 Future Work

14.2.1 Type III Ice Pellet Allowance Times

It is recommended that testing continue during the winter of 2010-11 with a fluid sample that has been verified to be within the acceptable specifications for Type III fluids. A preliminary allowance time table was developed during the winter of 2008-09 but was not published due to the limitations of the data. Additional testing should address these limitations (i.e., lack of data, hot versus cold fluid, low speed versus high speed).

14.2.2 Effects of Surface Roughness

Additional testing should be conducted with the supercritical wing with different types of contamination to further investigate the correlation between lift loss and stall angle. This research would be of particular importance if future testing is to explore stall margin rather than lift loss as a measure of aerodynamic performance.

14.2.3 Low-Speed Ramp Testing

The 2009-10 testing was conducted with no contamination with a supercritical wing; fluid elimination could potentially be further hampered by the presence of solid or adhered contamination. Additional testing is recommended to investigate the effect of contamination during low-speed ramp test profiles.

14.2.4 Light Freezing Rain Mixed with Moderate Snow Conditions

It is recommended that additional testing be conducted with thickened Type II/III/IV fluids, less prone to adhesion, in order to substantiate the preliminary results obtained with Type I fluid. Procedural limitations may have generated more conservative results due to Type I fluids being more susceptible compared to thickened fluids.

14.2.5 Effects of Snow on an Unprotected Wing

Additional testing should be conducted to validate the preliminary results obtained. More specifically, testing should be conducted to identify a threshold temperature at which departures with snow on an unprotected wing can be considered acceptable.

14.2.6 Degraded Anti-Icing Fluid Performance Following Contamination with Runway Deicing Fluid

Additional testing should be conducted to further validate the preliminary results obtained. It is recommended that operational data be collected in order to determine a representative amount of runway deicer fluid that could potentially be blown up on a wing upon landing on a wet runway; additional work could also look at contamination with runway deicer fluid during taxi to the runway. Further testing could be done on flat plates (as a less costly alternative) in order to determine the impact on fluid HOTs.

14.2.7 Heavy Snow

The results obtained supported the previous testing results from the winter of 2008-09 wherein using half the moderate snow HOT for heavy snow conditions could be a viable approach for providing guidance in heavy snow conditions. Additional testing using the comparative methodology (heavy snow versus moderate snow) should be conducted with different fluids and at different temperatures in order to generate a thorough data set to support this recommendation. Testing with propylene glycol fluids is of particular importance as results have indicated that these fluids are more prone to lift losses at colder temperatures. Consideration should be given to conducting some flat plate testing in the artificial snow machine in order to reduce associated testing costs.

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. Ruggi, M., *Wind Tunnel Trials to Examine Anti-Icing Fluid Flow-Off Characteristics and to Support the Development of Ice Pellet Allowance Times, Winters 2009-10 to 2012-13,* APS Aviation Inc., Transportation Development Centre, Montreal, November 2013, TP 15232E, 1044.

3. Ruggi, M., *Research for Further Development of Ice Pellet Allowance Times: Aircraft Trials to Examine Anti-Icing Fluid Flow-Off Characteristics Winter 2007-08*, APS Aviation Inc., Transportation Development Centre, Montreal, March 2009, TP 14871E, 312.

4. Ruggi, M., *Research for Further Development of Ice Pellet Allowance Times: Wind Tunnel Trials to Examine Anti-Icing Fluid Flow-Off Characteristics Winter 2008-09*, APS Aviation Inc., Transportation Development Centre, Montreal, November 2009, TP 14935E, 252.

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APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE WORK STATEMENT EXCERPT – AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2009-10

TRANSPORTATION DEVLOPMENT
CENTRE WORK STATEMENT EXCERPT –
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2009-10

5.3 AIRCRAFT PERFORMANCE RESEARCH

5.3.2 Additional Wind Tunnel Research

It is anticipated that wind tunnel testing during the winter of 2009-10 will be conducted in accordance with the objectives described in 1.3.1. This item (1.3.2) has been included in the event that additional testing is required and is budgeted to account for one additional week of testing.

a) Develop a procedure and test plan with the NRC staff who operates the PWT;

b) Perform wind tunnel tests to determine aerodynamic failure;

c) Conduct testing to investigate surface roughness of a wing surface as it pertains to lift loss;

d) Investigate aerodynamic effects of mixed light freezing rain and snow conditions, simulated snow pellet conditions, low speed ramp fluid flow off, bare wing and snow contamination take-off (both cold and warm temperatures), and reduced Type I endurance times on composite surfaces;

e) Conduct testing to investigate fluid flow off properties of heavily contaminated fluid during simulated heavy snow conditions; and

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

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APPENDIX B

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

CM2169.002

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

Winter 2009-10

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Marco Ruggi

Reviewed by: John D'Avirro

APS Aviation Inc.

December 23, 2009
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.

It was recommended that additional testing be conducted in the PIWT during the winter of 2009-10 using a super critical wing test model. The objective of the testing is to validate the current allowance times for aircraft with supercritical airfoils, and to potentially expand the results to include different conditions, fluids, and acceleration profiles.

2. OBJECTIVES

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

- Validate the current allowance times for newer generation aircraft (with super critical wings).
- Expand the current allowance times for the following conditions:
  - IP-/SN- conditions below -10°C;
  - IP-/SN conditions below -5°C;

- Type III Fluid in all conditions, heated and un-heated; and
- Low rotation speed aircraft.

As lower priority objectives, testing will be conducted to investigate the aerodynamic effects of:

- Super-critical vs. Low Speed Airfoil;
- Aerodynamic testing in heavy snow conditions;
- Low Low Speed vs. Low Speed
- Effect of ice phobic coatings on contaminated airfoil aerodynamic performance ;
- Reduced Type I endurance times on composite surfaces;
- Surface roughness as a result of adhered contamination;
- Anti-icing fluid exposed to simulated snow pellet conditions;
- Light Freezing Rain and Snow;
- Snow on an un-protected wing;
- Degraded Anti-icing Fluid Performance Following Contamination with Runway Deicing Fluid; and
- Frost CSW Spot Deicing.

Testing will objectively determine the level of contamination of anti-icing fluid at which the aerodynamic shear forces during takeoff ground roll, rotation and lift off fail to remove the resultant slush.

To satisfy these objectives, a super-critical wing section (Figure 2.1) will be subjected to a series of tests in the NRC wind tunnel. 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.

Four weeks of testing have been scheduled for the conduct of these tests. The start date for testing is currently scheduled for January 5th and testing will continue until February 1st.

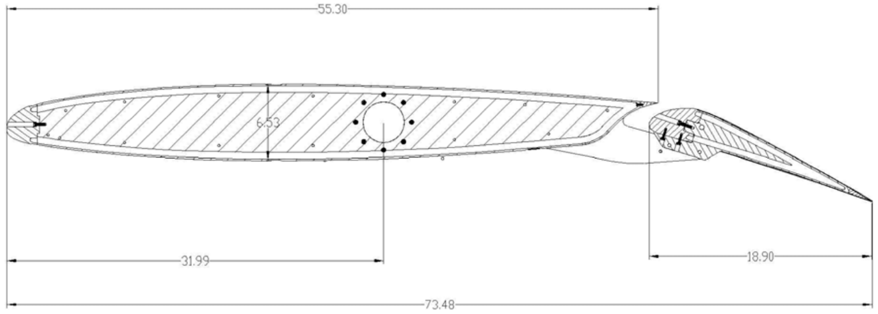


Figure 2.1: Super-Critical Wing Section

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

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

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

Each test shall be comprised of one fluid at one temperature and one contamination scenario. A test series will be comprised of one fluid at one temperature, using one form of contamination, with varying levels of exposure to the contamination. Baseline fluid-only tests are to be conducted following each contaminated test (or series of sequential tests conducted during similar conditions).

Table 3.1: Preliminary Test Calendar

Week	Monday	Tuesday	Wednesday	Thursday	Friday
1	**Setup** Unload and Organize Equipment *Possibly done before Holiday Shutdown*	**ZR, S, S++, SP, IP Calibration** **Dry Run Test**	**<-5°C** **Type IV HS Validation** Super Critical Validation All Cond. Priority 1	**<-10°C** **Type IV HS Validation** Super Critical Validation All Cond. Priority 1	**-25°C** **Type IV HS Validation** Super Critical Validation All Cond. Priority 1
2	**< -10°C** **Type IV HS Expansion** SN/IP and IP/Mod R Priority 1	**-5°C** **Type III** All IP Conditions ***HEATED, COLD, HS AND LS*** Priority 1(HS) and 2(LS)	**-10°C** **Type III** All IP Conditions ***HEATED, COLD, HS AND LS*** Priority 1(HS) and 2(LS)	**-25°C** **Type III** All IP Conditions ***HEATED, COLD, HS AND LS*** Priority 1(HS) and 2(LS)	**<-5°C** **Heavy Snow** S++ Priority 1
3	**<-5°C** **Heavy Snow** S++ Priority 1	**<-5°C** **Heavy Snow** S++ Priority 1	**<-5°C** **Super Critical vs. Low Speed Airfoil** Dry and with fluid Priority 2	**<-5°C** **Snow on Unprotected Wing** SN Priority 2	**<-5°C** **Frost CSW Spot Deicing** Frost Priority 2
4	**<-5°C** **Bad Application and Runway Deicer** ZR Priority 3	**<-5°C** **Composite** ZR Priority 3	**< -10°C** **Type IV Low Speed** IP, IP-, IP-/S, IP-/SN- (Not Included) Priority 3	**<-5°C** **LZR and SN Mod** ZR-/SN **67 vs. 80 Knots** Fluid Only Priority 3	**<-5°C** **Surface Roughness** ZR/IP/SN **Snow Pellets** SP vs. SN Priority 3
5	**<-5°C** **Ice Phobic Coatings** IP/ZR/SN **Type II Low Speed** IP, IP-, IP-/S, IP-/SN- Priority 4	**Teardown** Dismantle Equipment and Bring back to YUL			

Table 3.2: Proposed Test Plan

Test Plan #	Objective	Priority	Test Condition	Fluid	IP Rate (g/dm^2/h)	SN Rate (g/dm^2/h)	ZR Rate (g/dm^2/h)	R Rate (g/dm^2/h)	Exposure Time	Target OAT (ºC)	Ramp (kts)
P1	IP Validation	1	IP-	EG 106	25	-	-	-	50	-5	100
P2	IP Validation	1	IP-	ABC-S Plus	25	-	-	-	50	-5	100
P3	IP Validation	2	IP-	Launch	25	-	-	-	50	-5	100
P4	IP Validation	1	IP Mod	EG 106	75	-	-	-	25	-5	100
P5	IP Validation	1	IP Mod	ABC-S Plus	75	-	-	-	25	-5	100
P6	IP Validation	2	IP Mod	Launch	75	-	-	-	25	-5	100
P7	IP Validation	1	IP- / ZR-	EG 106	25	-	25	-	25	-5	100
P8	IP Validation	1	IP- / ZR-	ABC-S Plus	25	-	25	-	25	-5	100
P9	IP Validation	2	IP- / ZR-	Launch	25	-	25	-	25	-5	100
P10	IP Validation	1	IP- / SN-	EG 106	25	10	-	-	25	-5	100
P11	IP Validation	1	IP- / SN-	ABC-S Plus	25	10	-	-	25	-5	100
P12	IP Validation	2	IP- / SN-	Launch	25	10	-	-	25	-5	100
P13	IP Validation	1	IP- / SN	EG 106	25	25	-	-	10	-5	100
P14	IP Validation	1	IP- / SN	ABC-S Plus	25	25	-	-	10	-5	100
P15	IP Validation	2	IP- / SN	Launch	25	25	-	-	10	-5	100
P16	IP Validation	1	IP-	EG 106	25	-	-	-	30	-10	100
P17	IP Validation	1	IP-	ABC-S Plus	25	-	-	-	30	-10	100
P18	IP Validation	2	IP-	Launch	25	-	-	-	30	-10	100
P19	IP Validation	1	IP Mod	EG 106	75	-	-	-	10	-10	100
P20	IP Validation	1	IP Mod	ABC-S Plus	75	-	-	-	10	-10	100
P21	IP Validation	2	IP Mod	Launch	75	-	-	-	10	-10	100
P22	IP Validation	1	IP- / ZR-	EG 106	25	-	25	-	10	-10	100
P23	IP Validation	1	IP- / ZR-	ABC-S Plus	25	-	25	-	10	-10	100
P24	IP Validation	2	IP- / ZR-	Launch	25	-	25	-	10	-10	100
P25	IP Validation	1	IP- / SN-	EG 106	25	10	-	-	15	-10	100
P26	IP Validation	1	IP- / SN-	ABC-S Plus	25	10	-	-	15	-10	100
P27	IP Validation	2	IP- / SN-	Launch	25	10	-	-	15	-10	100
P28	IP Validation	1	IP-	EG 106	25	-	-	-	30	-25	100
P29	IP Validation	1	IP-	ABC-S Plus	25	-	-	-	30	-25	100
P30	IP Validation	2	IP-	Launch	25	-	-	-	30	-25	100
P31	IP Validation	1	IP Mod	EG 106	75	-	-	-	10	-25	100
P32	IP Validation	1	IP Mod	ABC-S Plus	75	-	-	-	10	-25	100
P33	IP Validation	2	IP Mod	Launch	75	-	-	-	10	-25	100
P34	IP Expansion	1	IP- / SN-	EG 106	25	10	-	-	40	-5	100
P35	IP Expansion	1	IP- / SN-	ABC-S Plus	25	10	-	-	40	-5	100
P36	IP Expansion	2	IP- / SN-	Launch	25	10	-	-	40	-5	100
P37	IP Expansion	1	IP- / SN	EG 106	25	25	-	-	15-20	-5	100
P38	IP Expansion	1	IP- / SN	ABC-S Plus	25	25	-	-	15-20	-5	100
P39	IP Expansion	2	IP- / SN	Launch	25	25	-	-	15-20	-5	100
P40	IP Expansion	1	IP / R Mod	EG 106	25	-	-	75	40	-5	100
P41	IP Expansion	1	IP / R Mod	ABC-S Plus	25	-	-	75	40	-5	100
P42	IP Expansion	2	IP / R Mod	Launch	25	-	-	75	40	-5	100
P43	IP Expansion	1	IP- / SN-	EG 106	25	10	-	-	18	-10	100

Table 3.2 (cont'd): Proposed Test Plan

Test Plan #	Objective	Priority	Test Condition	Fluid	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	ZR Rate (g/dm²/h)	R Rate (g/dm²/h)	Exposure Time	Target OAT (°C)	Ramp (kts)
P44	IP Expansion	1	IP- / SN-	ABC-S Plus	25	10	-	-	18	-10	100
P45	IP Expansion	2	IP- / SN-	Launch	25	10	-	-	18	-10	100
P46	IP Expansion	1	IP- / SN	EG 106	25	25	-	-	5-10	-10	100
P47	IP Expansion	1	IP- / SN	ABC-S Plus	25	25	-	-	5-10	-10	100
P48	IP Expansion	2	IP- / SN	Launch	25	25	-	-	5-10	-10	100
P49	IP Expansion	1	IP- / SN-	EG 106	25	10	-	-	10	-25	100
P50	IP Expansion	1	IP- / SN-	ABC-S Plus	25	10	-	-	10	-25	100
P51	IP Expansion	2	IP- / SN-	Launch	25	10	-	-	10	-25	100
P52	IP Expansion	1	IP- / SN	EG 106	25	25	-	-	5	-25	100
P53	IP Expansion	1	IP- / SN	ABC-S Plus	25	25	-	-	5	-25	100
P54	IP Expansion	2	IP- / SN	Launch	25	25	-	-	5	-25	100
P55	Type III HS	1	IP-	2031 - Hot	25	-	-	-	10	-5	100
P56	Type III HS	1	IP Mod	2031 - Hot	75	-	-	-	5	-5	100
P57	Type III HS	1	IP- / ZR-	2031 - Hot	25	-	25	-	7	-5	100
P58	Type III HS	1	IP- / SN-	2031 - Hot	25	10	-	-	10	-5	100
P59	Type III HS	1	IP- / SN	2031 - Hot	25	25	-	-	10	-5	100
P60	Type III HS	1	IP-	2031 - Hot	25	-	-	-	10	-10	100
P61	Type III HS	1	IP Mod	2031 - Hot	75	-	-	-	5	-10	100
P62	Type III HS	1	IP- / ZR-	2031 - Hot	25	-	25	-	5	-10	100
P63	Type III HS	1	IP- / SN-	2031 - Hot	25	10	-	-	10	-10	100
P64	Type III HS	1	IP- / SN	2031 - Hot	25	25	-	-	5	-10	100
P65	Type III HS	1	IP-	2031 - Hot	25	-	-	-	10	-25	100
P66	Type III HS	1	IP Mod	2031 - Hot	75	-	-	-	5	-25	100
P67	Type III HS	1	IP-	2031 - Cold	25	-	-	-	10	-5	100
P68	Type III HS	1	IP Mod	2031 - Cold	75	-	-	-	5	-5	100
P69	Type III HS	1	IP- / ZR-	2031 - Cold	25	-	25	-	7	-5	100
P70	Type III HS	1	IP- / SN-	2031 - Cold	25	10	-	-	10	-5	100
P71	Type III HS	1	IP- / SN	2031 - Cold	25	25	-	-	10	-5	100
P72	Type III HS	1	IP-	2031 - Cold	25	-	-	-	10	-10	100
P73	Type III HS	1	IP Mod	2031 - Cold	75	-	-	-	5	-10	100
P74	Type III HS	1	IP- / ZR-	2031 - Cold	25	-	25	-	5	-10	100
P75	Type III HS	1	IP- / SN-	2031 - Cold	25	10	-	-	10	-10	100
P76	Type III HS	1	IP- / SN	2031 - Cold	25	25	-	-	5	-10	100
P77	Type III HS	1	IP-	2031 - Cold	25	-	-	-	10	-25	100
P78	Type III HS	1	IP Mod	2031 - Cold	75	-	-	-	5	-25	100
P79	Type III LS	2	IP-	2031 - Hot	25	-	-	-	10	-5	80
P80	Type III LS	2	IP Mod	2031 - Hot	75	-	-	-	5	-5	80
P81	Type III LS	2	IP- / ZR-	2031 - Hot	25	-	25	-	7	-5	80
P82	Type III LS	2	IP- / SN-	2031 - Hot	25	10	-	-	10	-5	80
P83	Type III LS	2	IP- / SN	2031 - Hot	25	25	-	-	10	-5	80
P84	Type III LS	2	IP-	2031 - Hot	25	-	-	-	10	-10	80
P85	Type III LS	2	IP Mod	2031 - Hot	75	-	-	-	5	-10	80
P86	Type III LS	2	IP- / ZR-	2031 - Hot	25	-	25	-	5	-10	80
P87	Type III LS	2	IP- / SN-	2031 - Hot	25	10	-	-	10	-10	80
P88	Type III LS	2	IP- / SN	2031 - Hot	25	25	-	-	5	-10	80

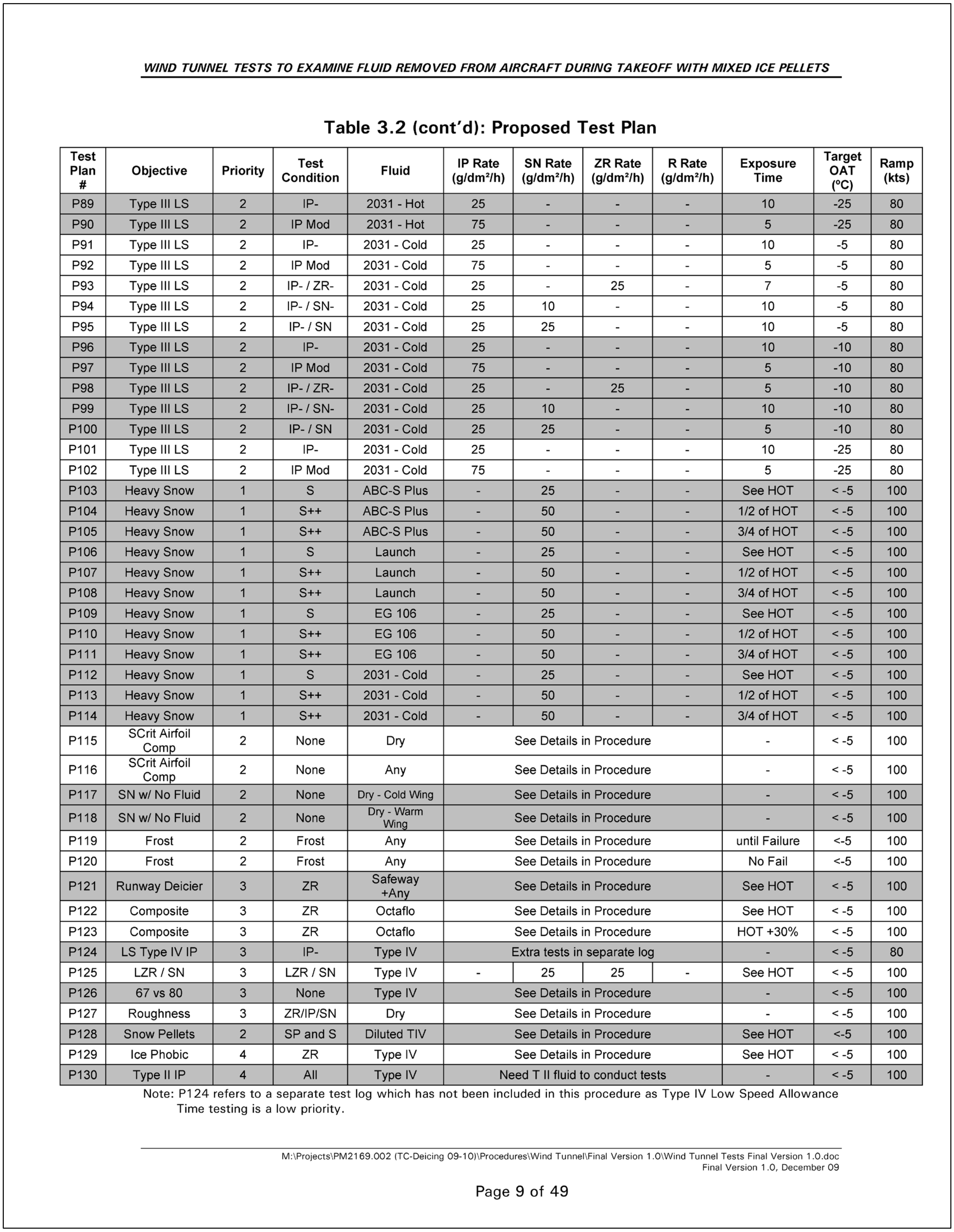


Table 3.2 (cont'd): Proposed Test Plan

Test Plan #	Objective	Priority	Test Condition	Fluid	IP Rate (g/dm^2/h)	SN Rate (g/dm^2/h)	ZR Rate (g/dm^2/h)	R Rate (g/dm^2/h)	Exposure Time	Target OAT (ºC)	Ramp (kts)
P89	Type III LS	2	IP-	2031 - Hot	25	-	-	-	10	-25	80
P90	Type III LS	2	IP Mod	2031 - Hot	75	-	-	-	5	-25	80
P91	Type III LS	2	IP-	2031 - Cold	25	-	-	-	10	-5	80
P92	Type III LS	2	IP Mod	2031 - Cold	75	-	-	-	5	-5	80
P93	Type III LS	2	IP- / ZR-	2031 - Cold	25	-	25	-	7	-5	80
P94	Type III LS	2	IP- / SN-	2031 - Cold	25	10	-	-	10	-5	80
P95	Type III LS	2	IP- / SN	2031 - Cold	25	25	-	-	10	-5	80
P96	Type III LS	2	IP-	2031 - Cold	25	-	-	-	10	-10	80
P97	Type III LS	2	IP Mod	2031 - Cold	75	-	-	-	5	-10	80
P98	Type III LS	2	IP- / ZR-	2031 - Cold	25	-	25	-	5	-10	80
P99	Type III LS	2	IP- / SN-	2031 - Cold	25	10	-	-	10	-10	80
P100	Type III LS	2	IP- / SN	2031 - Cold	25	25	-	-	5	-10	80
P101	Type III LS	2	IP-	2031 - Cold	25	-	-	-	10	-25	80
P102	Type III LS	2	IP Mod	2031 - Cold	75	-	-	-	5	-25	80
P103	Heavy Snow	1	S	ABC-S Plus	-	25	-	-	See HOT	< -5	100
P104	Heavy Snow	1	S++	ABC-S Plus	-	50	-	-	1/2 of HOT	< -5	100
P105	Heavy Snow	1	S++	ABC-S Plus	-	50	-	-	3/4 of HOT	< -5	100
P106	Heavy Snow	1	S	Launch	-	25	-	-	See HOT	< -5	100
P107	Heavy Snow	1	S++	Launch	-	50	-	-	1/2 of HOT	< -5	100
P108	Heavy Snow	1	S++	Launch	-	50	-	-	3/4 of HOT	< -5	100
P109	Heavy Snow	1	S	EG 106	-	25	-	-	See HOT	< -5	100
P110	Heavy Snow	1	S++	EG 106	-	50	-	-	1/2 of HOT	< -5	100
P111	Heavy Snow	1	S++	EG 106	-	50	-	-	3/4 of HOT	< -5	100
P112	Heavy Snow	1	S	2031 - Cold	-	25	-	-	See HOT	< -5	100
P113	Heavy Snow	1	S++	2031 - Cold	-	50	-	-	1/2 of HOT	< -5	100
P114	Heavy Snow	1	S++	2031 - Cold	-	50	-	-	3/4 of HOT	< -5	100
P115	SCrit Airfoil Comp	2	None	Dry	See Details in Procedure				-	< -5	100
P116	SCrit Airfoil Comp	2	None	Any	See Details in Procedure				-	< -5	100
P117	SN w/ No Fluid	2	None	Dry - Cold Wing	See Details in Procedure				-	< -5	100
P118	SN w/ No Fluid	2	None	Dry - Warm Wing	See Details in Procedure				-	< -5	100
P119	Frost	2	Frost	Any	See Details in Procedure				until Failure	<-5	100
P120	Frost	2	Frost	Any	See Details in Procedure				No Fail	<-5	100
P121	Runway Deicier	3	ZR	Safeway +Any	See Details in Procedure				See HOT	< -5	100
P122	Composite	3	ZR	Octaflo	See Details in Procedure				See HOT	< -5	100
P123	Composite	3	ZR	Octaflo	See Details in Procedure				HOT +30%	< -5	100
P124	LS Type IV IP	3	IP-	Type IV	Extra tests in separate log				-	< -5	80
P125	LZR / SN	3	LZR / SN	Type IV	-	25	25	-	See HOT	< -5	100
P126	67 vs 80	3	None	Type IV	See Details in Procedure				-	< -5	100
P127	Roughness	3	ZR/IP/SN	Dry	See Details in Procedure				-	< -5	100
P128	Snow Pellets	2	SP and S	Diluted TIV	See Details in Procedure				See HOT	<-5	100
P129	Ice Phobic	4	ZR	Type IV	See Details in Procedure				See HOT	< -5	100
P130	Type II IP	4	All	Type IV	Need T II fluid to conduct tests				-	< -5	100

Note: P124 refers to a separate test log which has not been included in this procedure as Type IV Low Speed Allowance Time testing is a low priority.

A rating system has been developed and will be filled out by the onsite experts (Attachment XIV). 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. The first test in each series will closely emulate expected holdover time or allowance time. The second test will effectively double or halve the first time depending on whether failure to clear has occurred. The third test will double or halve the previous time or halve the interval to the previous test depending on the failure history. This decision matrix is shown in Figure 3.1 with a beginning exposure time of 60 minutes.

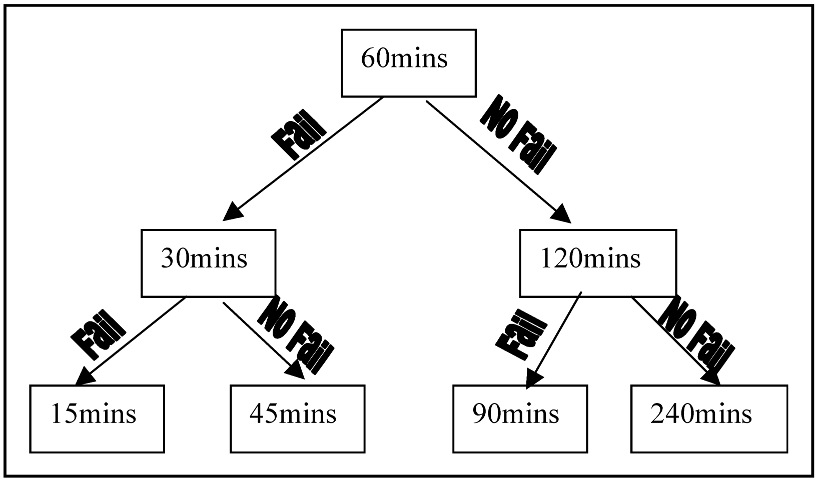


Figure 3.1: Decision Matrix for Each Test Series

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;
- Mark wing data collection locations and draw grid on the wing (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 VIII.

5. DATA FORMS

The following data forms are required for the January – February 2010 wind tunnel tests:

- Attachment IX – General Form;
- Attachment X – Wing Temperature, Fluid Thickness and Fluid Brix Form;
- Attachment XI & XII – Ice Pellet and Snow Dispensing Forms;
- Attachment XIII– Sprayer Calibration Form;
- Attachment XIV – Visual Evaluation Rating Form
- Attachment XV– Condition of Wing and Plate Form; and
- Attachment XVI – Fluid Receipt Form (Generic form used by APS; will be used for this project as appropriate);
- Attachment XVII – Log of Fluid Sample Bottles.

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

6. PROCEDURE

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

6.1 Initial Test Conditions Survey

- Record ambient conditions of the test (Attachment 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;
- 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.

Note: Dispensing forms should be printed for each run and included along with data forms. Any comments regarding dispensing activities should be documented directly on the dispensing form. Information regarding ice pellet and snow precipitation should also be filled out in the General Form (Attachment IX).

6.3.3 Application of Freezing Rain/Drizzle

- Ensure correct rate of precipitation is being generated by NRC freezing precipitation sprayer (see Attachment XIII);
- Record rate of precipitation dispersed (Attachment IX);
- Record application times (Attachment IX); and
- Photograph and videotape the appearance of the fluid on the wing.

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 XV);
- 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 XVI) 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 XVII). 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

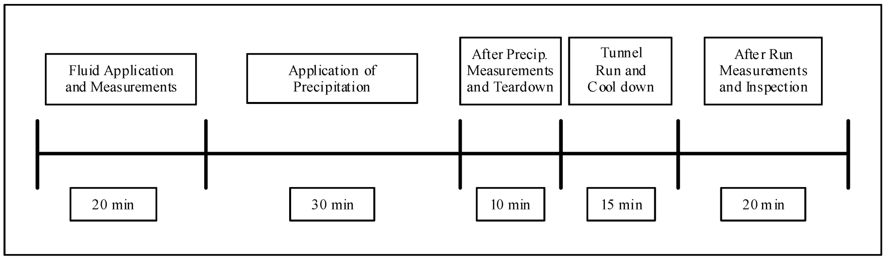


Figure 6.1: Typical Wind Tunnel Run Timeline

6.11 Procedure for Application of Heated Type III Fluid for Wind Tunnel Tests

Testing with Type III fluid will require testing with both fluid at ambient temperature, and heated fluid. A procedure has been developed to describe the heating and application methods for the Type III heated tests and is included in Attachment XVIII.

6.12 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:

1. Super-critical vs. Low Speed Airfoil (Attachment XIX);
2. Aerodynamic testing in heavy snow conditions (Attachment XX);
3. Low Low Speed vs. Low Speed (Attachment XXI);
4. Effect of ice phobic coatings on contaminated airfoil aerodynamic performance (Attachment XXII);
5. Reduced Type I endurance times on composite surfaces (Attachment XXIII);
6. Surface roughness as a result of adhered contamination (Attachment XXIV);
7. Anti-icing fluid exposed to simulated snow pellet conditions (Attachment XXV);
8. Light Freezing Rain and Snow (Attachment XXVI);
9. Snow on an un-protected wing (Attachment XXVII);
10. Degraded Anti-icing Fluid Performance Following Contamination with Runway Deicing Fluid (Attachment XXVIII); and
11. Frost CSW Spot Deicing (Attachment XXIX).

As these full-scale R&D activities have in general not been previously attempted, 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 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 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		Blenders x6+	
Squeegees		Ice pellets sieves	
Isopropyl		Folding tables	
Gloves, paper towel		Measuring cups	
Extension cords		Wooden Spoons	
Clipboards, pencils, wing markers for sample locations and solvent		Rubber Mats	
Large Clock x1		Extension Cords	
Printer, printer paper, and ink cartridge			
Walkie Talkies x8		***Freezing Rain Equipment***	
Envelopes and labels		NRC Freezing rain sprayer	
Previous 05-06, 06-07, 07-08, and 08-09 F20/WT reports		APS PC equipped with rate station software	
Grid Section + Location docs		White plastic rate pans (100) wooden boards, and rubber suction cup feet	
Large Sharpies for Gird Section		Sartorius Wiegh Scale x1 + NCAR Scale x 1	
Projector for laptop		Black Shelving Unit	
YOW employee contracts		Portable hard drive and memory card reader	
Blow Horns x4			
Small 90º Ruler			
Camera Equipment			
Digital still cameras x4 (with lenses, chargers, batteries, etc)			
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			
Test Plate			
Speed tape			
Thickness Gauges			
Temperature Probe x 2 and spare batteries			
Brixometers X3			
Adherence Probes (Oral B) x4 with tips and charger			
Fluid pouring jugs x30 (6 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			
Snow Pellet and Snow Large Dispensing Spoon x6			
Long Ruler for marking wing x2			
Small 90º aluminum ruler for wing			
20L containers (DY order from YUL)			
hard water chemicals			
Ice Phobic Product (Nusil or PowerNano)			
Poster board (8"x3") for flap section			

8. FLUIDS

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

Table 8.1: Fluid Requirements for Wind Tunnel Tests

Fluid	Type	Dilution	Viscosity	Quantity (L)
Octagon Octaflo (PG)	I	Concentrate	N/A	100
Clariant MP III 2031	III	100/0	Mid	800
DOW UCAR EG 106	IV	100/0	Mid	900
Kilfrost ABC-S +	IV	100/0	Mid	900
Clariant MP IV Launch	IV	100/0	Mid	800

9. PERSONNEL

Five APS staff members are required for the tests at the NRC wind tunnel. Four 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.

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.

Table 9.1: Personnel List

Wind Tunnel 08-09 - Tentative	
Person	**Responsibility**
John	Overall Co-ordinator
Marco	Co-ordinator / General
Victoria	IP Manager / Camera Documentation / Fluid Manager
Michelle	Forms & Data Collection Manager / YOW Pers. Manager
Dave	Data Collection /IP Support / Fluid Application
YOW Personnel	
Ben	Photography
Mike	Fluids / IP / Dispensing
Eric	Fluids / IP / Dispensing
YOW 1	Fluids / IP / Dispensing
YOW 2	Fluids / IP / Dispensing

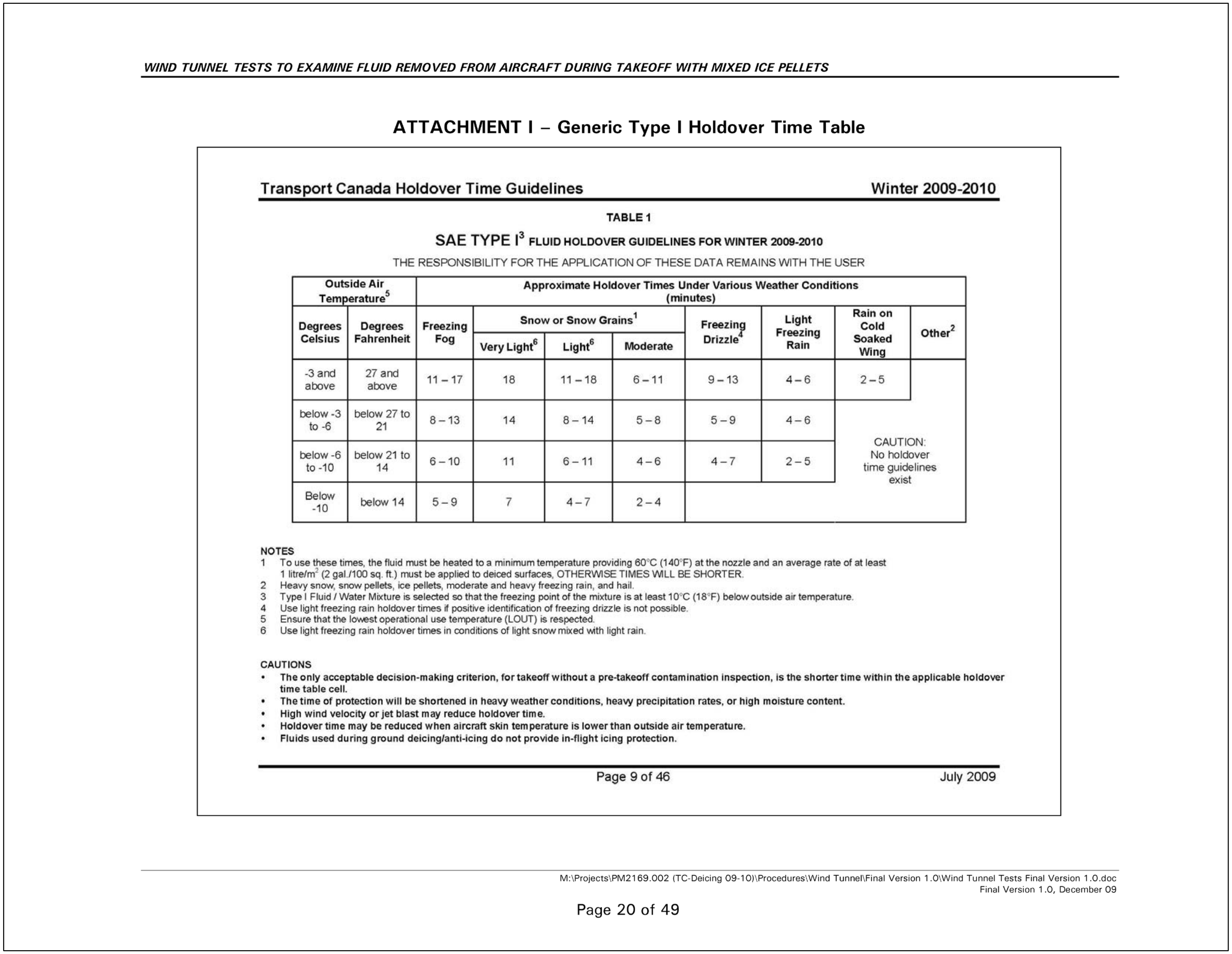
* Consider Ryan, Mike or Eric for YOW positions

NRC Institute of Aerospace Research

- Eric Perron: (613) 229-2058
- Marc MacMaster: (613) 998-6932

10. SAFETY

- 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.



WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH MIXED ICE PELLETS

ATTACHMENT I – Generic Type I Holdover Time Table

Transport Canada Holdover Time Guidelines **Winter 2009-2010**

TABLE 1

SAE TYPE I[3] FLUID HOLDOVER GUIDELINES FOR WINTER 2009-2010

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

Outside Air Temperature[5]		Approximate Holdover Times Under Various Weather Conditions (minutes)							
			Snow or Snow Grains[1]						
Degrees Celsius	**Degrees Fahrenheit**	**Freezing Fog**	**Very Light[6]**	**Light[6]**	**Moderate**	**Freezing Drizzle[4]**	**Light Freezing Rain**	**Rain on Cold Soaked Wing**	**Other[2]**
-3 and above	27 and above	11 – 17	18	11 – 18	6 – 11	9 – 13	4 – 6	2 – 5	CAUTION: No holdover time guidelines exist
below -3 to -6	below 27 to 21	8 – 13	14	8 – 14	5 – 8	5 – 9	4 – 6		
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 To use these times, the fluid must be heated to a minimum temperature providing 60°C (140°F) at the nozzle and an average rate of at least 1 litre/m^2 (2 gal./100 sq. ft.) must be applied to deiced surfaces, OTHERWISE TIMES WILL BE SHORTER.
2 Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
3 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.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 Ensure that the lowest operational use temperature (LOUT) is respected.
6 Use light freezing rain holdover times in conditions of light snow mixed with light 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 deicing/anti-icing do not provide in-flight icing protection.**

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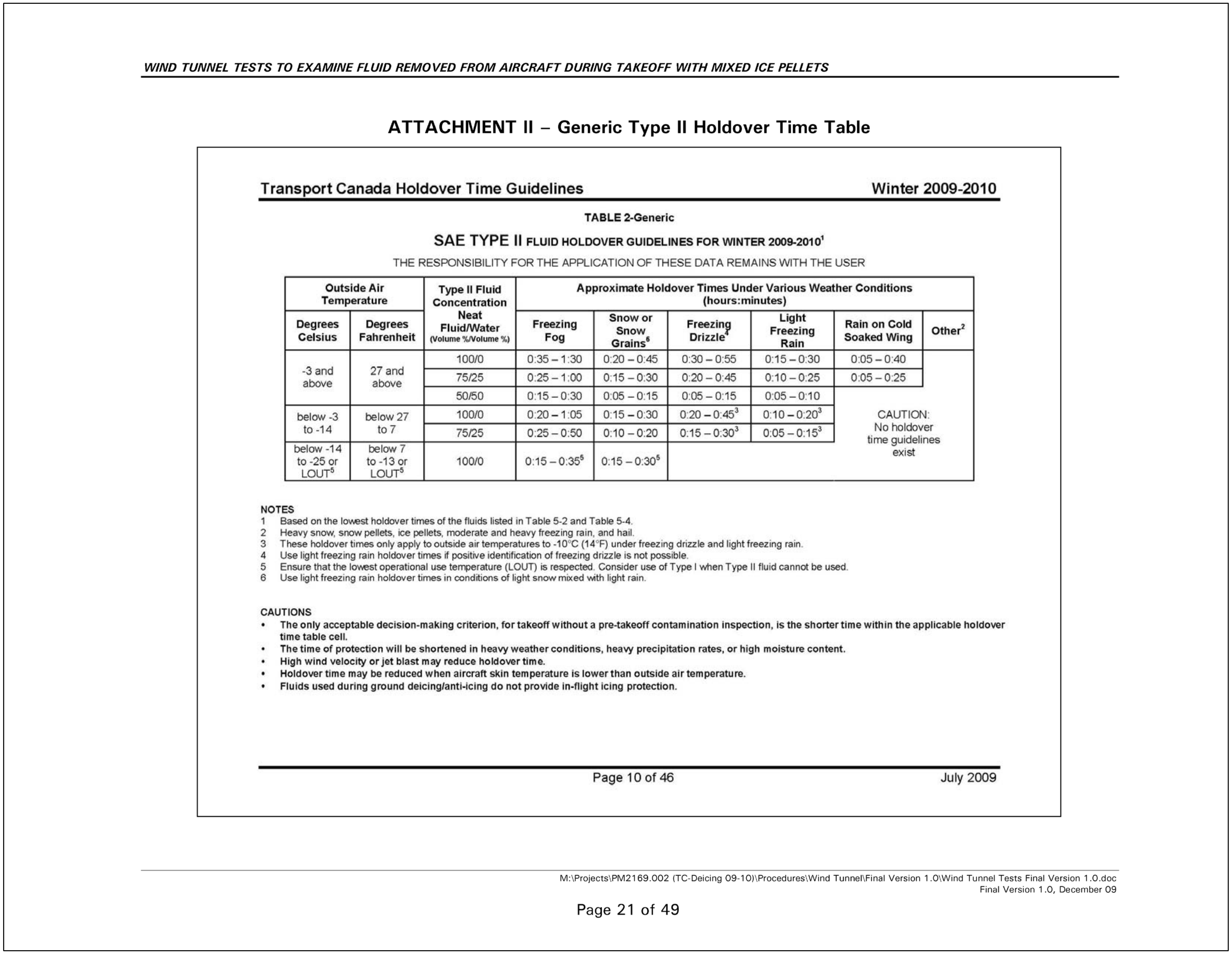

WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH MIXED ICE PELLETS

ATTACHMENT II – Generic Type II Holdover Time Table

Transport Canada Holdover Time Guidelines **Winter 2009-2010**

TABLE 2-Generic

SAE TYPE II FLUID HOLDOVER GUIDELINES FOR WINTER 2009-2010[1]

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

Outside Air Temperature		Type II Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)					
Degrees Celsius	**Degrees Fahrenheit**		**Freezing Fog**	**Snow or Snow Grains[6]**	**Freezing Drizzle[4]**	**Light Freezing Rain**	**Rain on Cold Soaked Wing**	**Other[2]**
-3 and above	27 and above	100/0	0:35 – 1:30	0:20 – 0:45	0:30 – 0:55	0:15 – 0:30	0:05 – 0:40	CAUTION: No holdover time guidelines exist
		75/25	0:25 – 1:00	0:15 – 0:30	0:20 – 0:45	0:10 – 0:25	0:05 – 0:25	
		50/50	0:15 – 0:30	0:05 – 0:15	0:05 – 0:15	0:05 – 0:10		
below -3 to -14	below 27 to 7	100/0	0:20 – 1:05	0:15 – 0:30	0:20 – 0:45[3]	0:10 – 0:20[3]		
		75/25	0:25 – 0:50	0:10 – 0:20	0:15 – 0:30[3]	0:05 – 0:15[3]		
below -14 to -25 or LOUT[5]	below 7 to -13 or LOUT[5]	100/0	0:15 – 0:35[5]	0:15 – 0:30[5]				

NOTES

1 Based on the lowest holdover times of the fluids listed in Table 5-2 and Table 5-4.
2 Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
3 These holdover times only apply to outside air temperatures to -10°C (14°F) under freezing drizzle and light freezing rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I when Type II fluid cannot be used.
6 Use light freezing rain holdover times in conditions of light snow mixed with light 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 deicing/anti-icing do not provide in-flight icing protection.**

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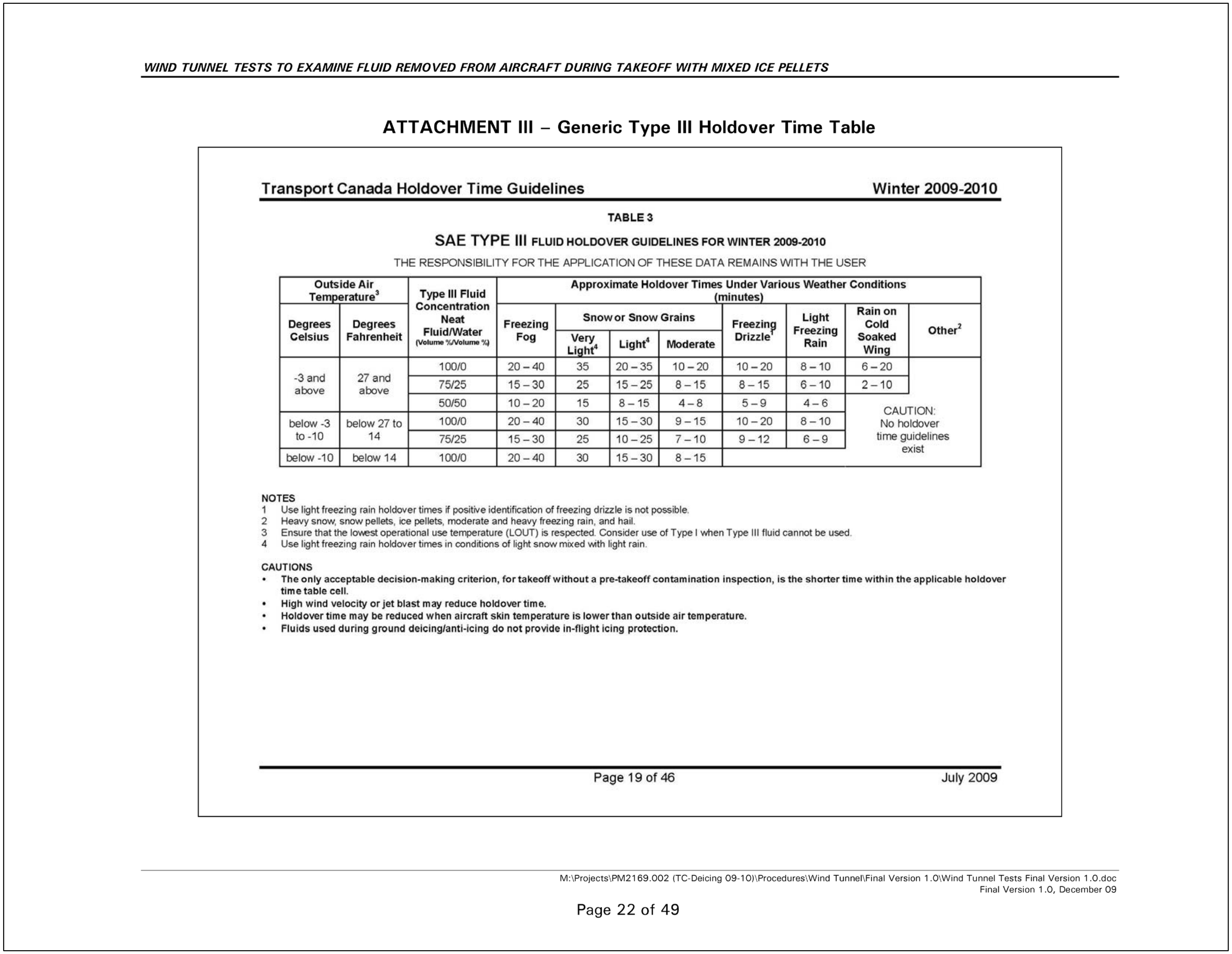


ATTACHMENT III – Generic Type III Holdover Time Table

TABLE 3

SAE TYPE III FLUID HOLDOVER GUIDELINES FOR WINTER 2009-2010

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

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

NOTES

1 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.

2 Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.

3 Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I when Type III fluid cannot be used.

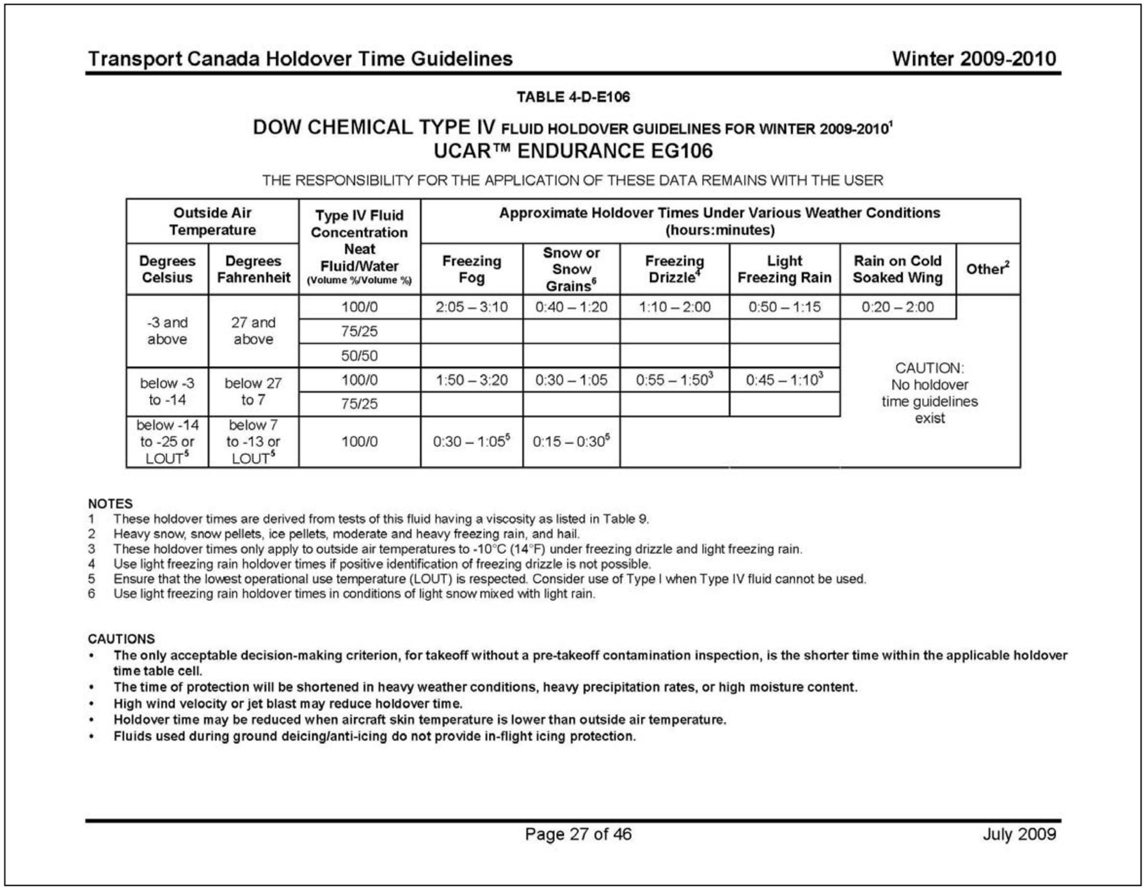
4 Use light freezing rain holdover times in conditions of light snow mixed with light rain.

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.**
- **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 deicing/anti-icing do not provide in-flight icing protection.**

WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH MIXED ICE PELLETS

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



Transport Canada Holdover Time Guidelines — Winter 2009-2010

TABLE 4-D-E106

DOW CHEMICAL TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2009-2010[1]
UCAR™ ENDURANCE EG106

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

Outside Air Temperature		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 or Snow Grains[6]**	**Freezing Drizzle[4]**	**Light Freezing Rain**	**Rain on Cold Soaked Wing**	**Other[2]**
-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	
		75/25					CAUTION: No holdover time guidelines exist	
		50/50						
below -3 to -14	below 27 to 7	100/0	1:50 – 3:20	0:30 – 1:05	0:55 – 1:50[3]	0:45 – 1:10[3]		
		75/25						
below -14 to -25 or LOUT[5]	below 7 to -13 or LOUT[5]	100/0	0:30 – 1:05[5]	0:15 – 0:30[5]				

NOTES

1 These holdover times are derived from tests of this fluid having a viscosity as listed in Table 9.
2 Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
3 These holdover times only apply to outside air temperatures to -10°C (14°F) under freezing drizzle and light freezing rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I when Type IV fluid cannot be used.
6 Use light freezing rain holdover times in conditions of light snow mixed with light 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 deicing/anti-icing do not provide in-flight icing protection.**

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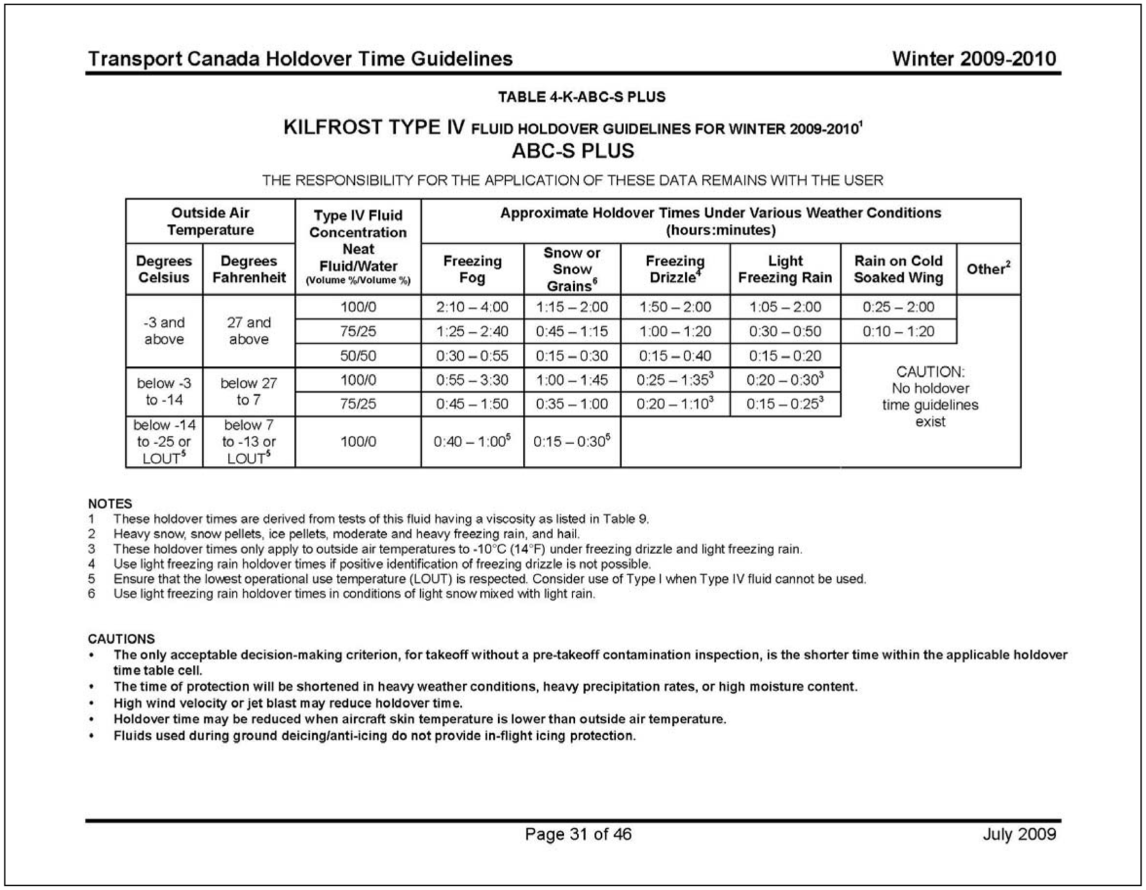
ATTACHMENT V – Kilrost ABC-S Plus Type IV Holdover Time Table



Transport Canada Holdover Time Guidelines Winter 2009-2010

TABLE 4-K-ABC-S PLUS

KILFROST TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2009-2010[1]
ABC-S PLUS

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

Outside Air Temperature		**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 or Snow Grains[6]**	**Freezing Drizzle[4]**	**Light Freezing Rain**	**Rain on Cold Soaked Wing**	**Other[2]**
-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[3]	0:20 – 0:30[3]		
		75/25	0:45 – 1:50	0:35 – 1:00	0:20 – 1:10[3]	0:15 – 0:25[3]		
below -14 to -25 or LOUT[5]	below 7 to -13 or LOUT[5]	100/0	0:40 – 1:00[5]	0:15 – 0:30[5]				

NOTES

1 These holdover times are derived from tests of this fluid having a viscosity as listed in Table 9.
2 Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
3 These holdover times only apply to outside air temperatures to -10°C (14°F) under freezing drizzle and light freezing rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I when Type IV fluid cannot be used.
6 Use light freezing rain holdover times in conditions of light snow mixed with light 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 deicing/anti-icing do not provide in-flight icing protection.**

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

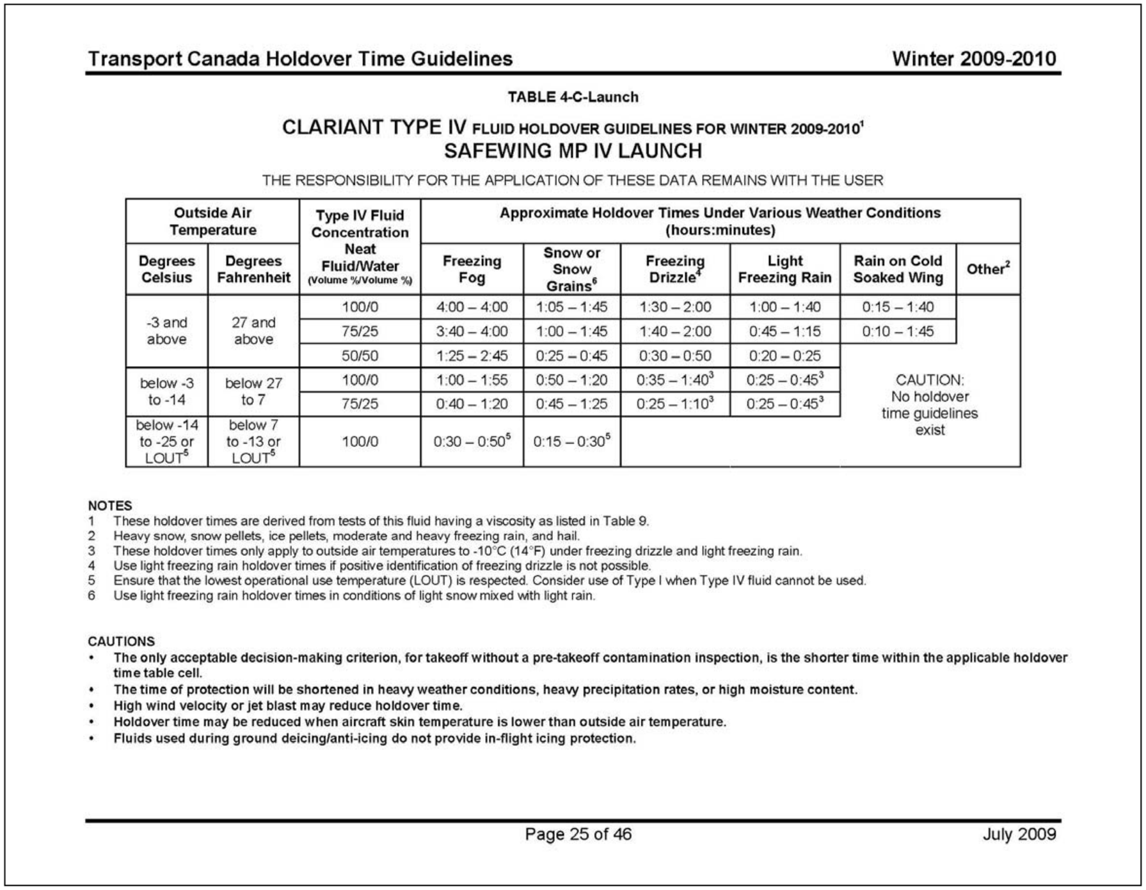


TABLE 4-C-Launch

CLARIANT TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2009-2010[1]
SAFEWING MP IV LAUNCH

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

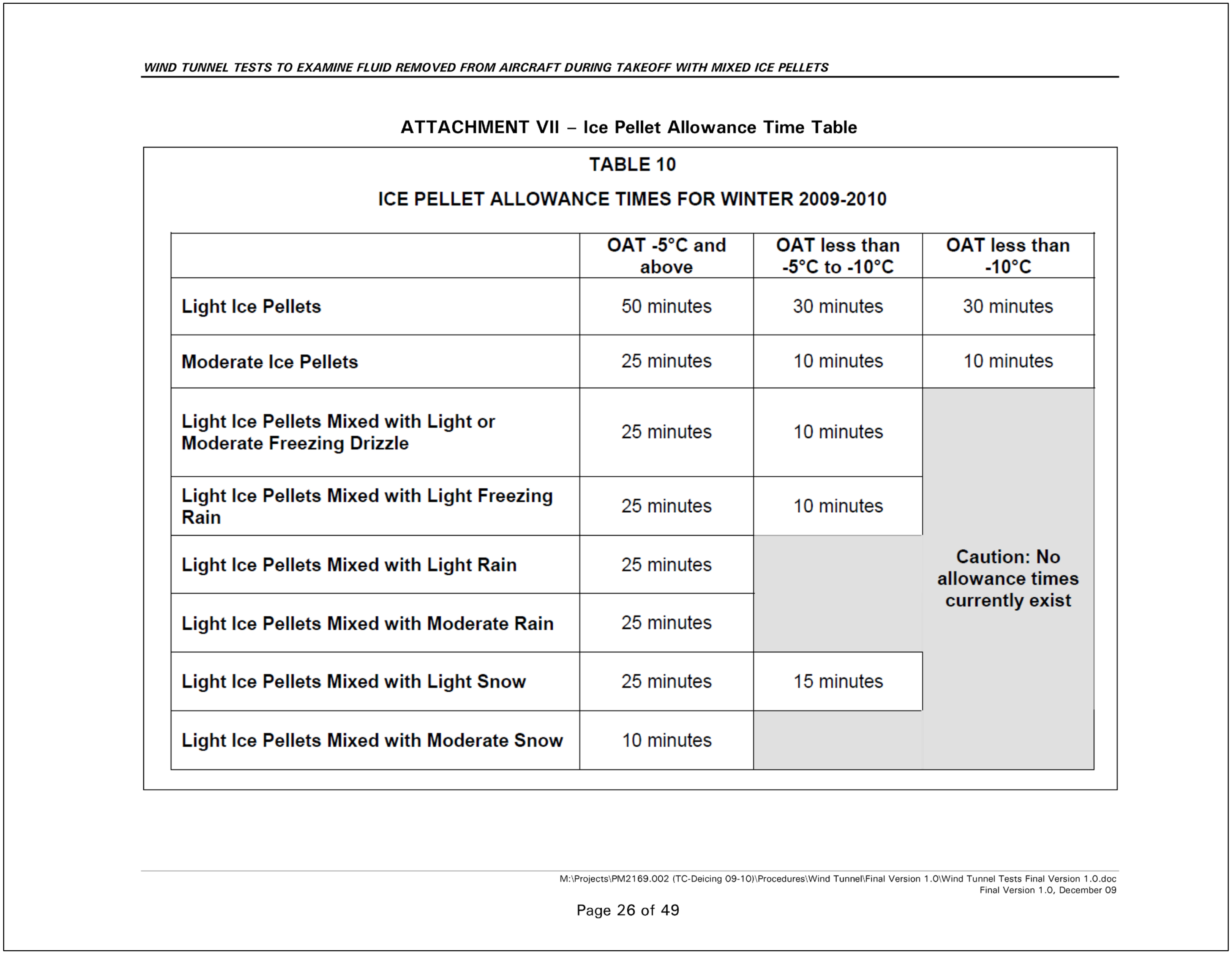
Outside Air Temperature		Type IV Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)					
Degrees Celsius	**Degrees Fahrenheit**		**Freezing Fog**	**Snow or Snow Grains[6]**	**Freezing Drizzle[4]**	**Light Freezing Rain**	**Rain on Cold Soaked Wing**	**Other[2]**
-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	CAUTION: No holdover time guidelines exist
		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		
below -3 to -14	below 27 to 7	100/0	1:00 – 1:55	0:50 – 1:20	0:35 – 1:40[3]	0:25 – 0:45[3]		
		75/25	0:40 – 1:20	0:45 – 1:25	0:25 – 1:10[3]	0:25 – 0:45[3]		
below -14 to -25 or LOUT[5]	below 7 to -13 or LOUT[5]	100/0	0:30 – 0:50[5]	0:15 – 0:30[5]				

NOTES

1 These holdover times are derived from tests of this fluid having a viscosity as listed in Table 9.
2 Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
3 These holdover times only apply to outside air temperatures to -10°C (14°F) under freezing drizzle and light freezing rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I when Type IV fluid cannot be used.
6 Use light freezing rain holdover times in conditions of light snow mixed with light 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 deicing/anti-icing do not provide in-flight icing protection.**

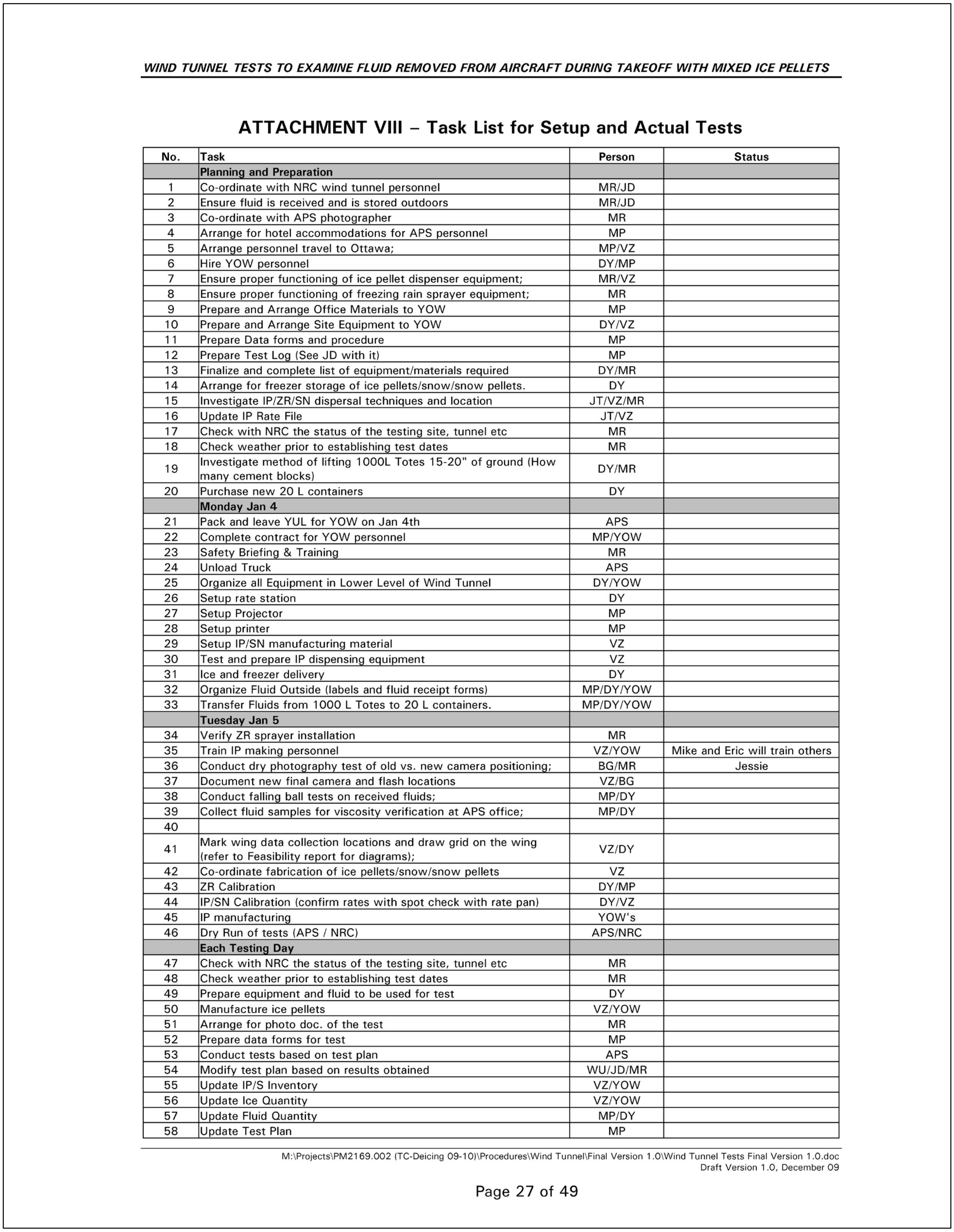


ATTACHMENT VII – Ice Pellet Allowance Time Table

TABLE 10

ICE PELLET ALLOWANCE TIMES FOR WINTER 2009-2010

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



WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH MIXED ICE PELLETS

ATTACHMENT VIII – 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 and is stored outdoors	MR/JD	
3	Co-ordinate with APS photographer	MR	
4	Arrange for hotel accommodations for APS personnel	MP	
5	Arrange personnel travel to Ottawa;	MP/VZ	
6	Hire YOW personnel	DY/MP	
7	Ensure proper functioning of ice pellet dispenser equipment;	MR/VZ	
8	Ensure proper functioning of freezing rain sprayer equipment;	MR	
9	Prepare and Arrange Office Materials to YOW	MP	
10	Prepare and Arrange Site Equipment to YOW	DY/VZ	
11	Prepare Data forms and procedure	MP	
12	Prepare Test Log (See JD with it)	MP	
13	Finalize and complete list of equipment/materials required	DY/MR	
14	Arrange for freezer storage of ice pellets/snow/snow pellets.	DY	
15	Investigate IP/ZR/SN dispersal techniques and location	JT/VZ/MR	
16	Update IP Rate File	JT/VZ	
17	Check with NRC the status of the testing site, tunnel etc	MR	
18	Check weather prior to establishing test dates	MR	
19	Investigate method of lifting 1000L Totes 15-20" of ground (How many cement blocks)	DY/MR	
20	Purchase new 20 L containers	DY	
	Monday Jan 4		
21	Pack and leave YUL for YOW on Jan 4th	APS	
22	Complete contract for YOW personnel	MP/YOW	
23	Safety Briefing & Training	MR	
24	Unload Truck	APS	
25	Organize all Equipment in Lower Level of Wind Tunnel	DY/YOW	
26	Setup rate station	DY	
27	Setup Projector	MP	
28	Setup printer	MP	
29	Setup IP/SN manufacturing material	VZ	
30	Test and prepare IP dispensing equipment	VZ	
31	Ice and freezer delivery	DY	
32	Organize Fluid Outside (labels and fluid receipt forms)	MP/DY/YOW	
33	Transfer Fluids from 1000 L Totes to 20 L containers.	MP/DY/YOW	
	Tuesday Jan 5		
34	Verify ZR sprayer installation	MR	
35	Train IP making personnel	VZ/YOW	Mike and Eric will train others
36	Conduct dry photography test of old vs. new camera positioning;	BG/MR	Jessie
37	Document new final camera and flash locations	VZ/BG	
38	Conduct falling ball tests on received fluids;	MP/DY	
39	Collect fluid samples for viscosity verification at APS office;	MP/DY	
40			
41	Mark wing data collection locations and draw grid on the wing (refer to Feasibility report for diagrams);	VZ/DY	
42	Co-ordinate fabrication of ice pellets/snow/snow pellets	VZ	
43	ZR Calibration	DY/MP	
44	IP/SN Calibration (confirm rates with spot check with rate pan)	DY/VZ	
45	IP manufacturing	YOW's	
46	Dry Run of tests (APS / NRC)	APS/NRC	
	Each Testing Day		
47	Check with NRC the status of the testing site, tunnel etc	MR	
48	Check weather prior to establishing test dates	MR	
49	Prepare equipment and fluid to be used for test	DY	
50	Manufacture ice pellets	VZ/YOW	
51	Arrange for photo doc. of the test	MR	
52	Prepare data forms for test	MP	
53	Conduct tests based on test plan	APS	
54	Modify test plan based on results obtained	WU/JD/MR	
55	Update IP/S Inventory	VZ/YOW	
56	Update Ice Quantity	VZ/YOW	
57	Update Fluid Quantity	MP/DY	
58	Update Test Plan	MP	

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ATTACHMENT IX – General Form (to be filled by MP)

DATE: ______________ FLUID APPLIED: ______________ RUN #: __________

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

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

WIND TUNNEL START TIME: __________ WIND TUNNEL STOP TIME: __________

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): ______________
Total Time: ______________

FREEZING RAIN/DRIZZLE APPLICATION (if applicable)

Actual start time: ______________ Actual End Time: ______________
Rate of Precipitation Applied (g/dm^{2}h): ______________ Droplet Size (mm): ______________
Total 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): ______________
Total Time: ______________

COMMENTS ______________________________

MEASUREMENTS BY: ______________ **HANDWRITTEN BY:** ______________

ATTACHMENT X – Wing Temperature, Fluid Thickness and Fluid Brix Form (to be filled by MP)

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

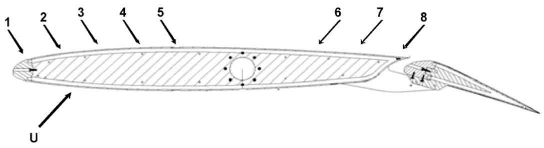
Date: ______________________

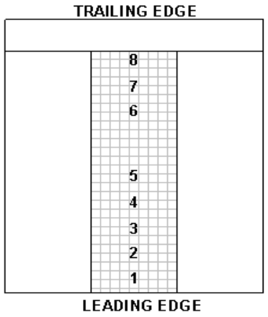
Run: ______________

WING TEMPERATURE				
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			
Time:			

FLUID THICKNESS			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2			
3			
4			
5			
6			
7			
8			
Time			





Wing Position 1: On the leading edge;

Wing Position 2, 3, 4, 5: At equal distances (approximately 15 cm) between rivets 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

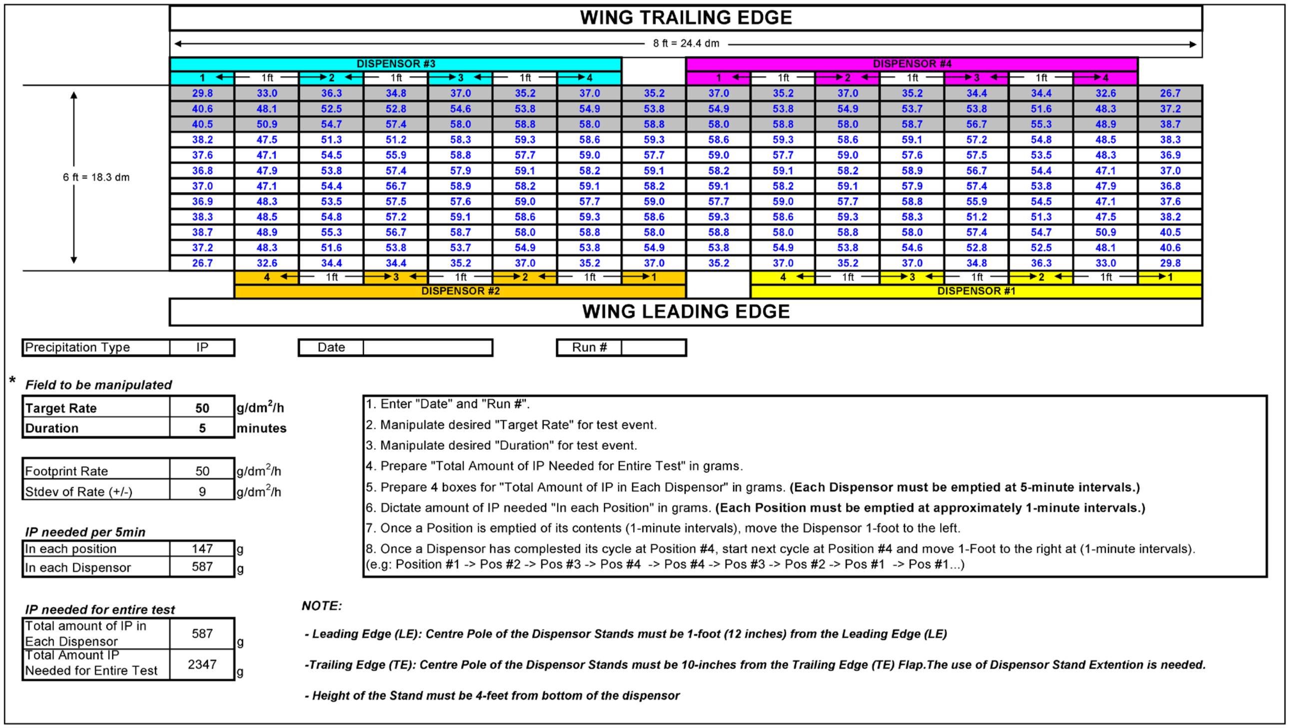
Underside: The underside of wing section, as far as could be reached from the leading edge.

Comments: ______________________________

OBSERVER: ______________________

ASSISTED BY: ______________________

ATTACHMENT XI – Ice Pellet Dispensing Form



WING TRAILING EDGE

8 ft = 24.4 dm

6 ft = 18.3 dm

DISPENSOR #3								DISPENSOR #4							
1 ←	1ft	→ 2 ←	1ft	→ 3 ←	1ft	→ 4		1 ←	1ft	→ 2 ←	1ft	→ 3 ←	1ft	→ 4	
29.8	33.0	36.3	34.8	37.0	35.2	37.0	35.2	37.0	35.2	37.0	35.2	34.4	34.4	32.6	26.7
40.6	48.1	52.5	52.8	54.6	53.8	54.9	53.8	54.9	53.8	54.9	53.7	53.8	51.6	48.3	37.2
40.5	50.9	54.7	57.4	58.0	58.8	58.0	58.8	58.0	58.8	58.0	58.7	56.7	55.3	48.9	38.7
38.2	47.5	51.3	51.2	58.3	59.3	58.6	59.3	58.6	59.3	58.6	59.1	57.2	54.8	48.5	38.3
37.6	47.1	54.5	55.9	58.8	57.7	59.0	57.7	59.0	57.7	59.0	57.6	57.5	53.5	48.3	36.9
36.8	47.9	53.8	57.4	57.9	59.1	58.2	59.1	58.2	59.1	58.2	58.9	56.7	54.4	47.1	37.0
37.0	47.1	54.4	56.7	58.9	58.2	59.1	58.2	59.1	58.2	59.1	57.9	57.4	53.8	47.9	36.8
36.9	48.3	53.5	57.5	57.6	59.0	57.7	59.0	57.7	59.0	57.7	58.8	55.9	54.5	47.1	37.6
38.3	48.5	54.8	57.2	59.1	58.6	59.3	58.6	59.3	58.6	59.3	58.3	51.2	51.3	47.5	38.2
38.7	48.9	55.3	56.7	58.7	58.0	58.8	58.0	58.8	58.0	58.8	58.0	57.4	54.7	50.9	40.5
37.2	48.3	51.6	53.8	53.7	54.9	53.8	54.9	53.8	54.9	53.8	54.6	52.8	52.5	48.1	40.6
26.7	32.6	34.4	34.4	35.2	37.0	35.2	37.0	35.2	37.0	35.2	37.0	34.8	36.3	33.0	29.8
	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	**50**	**g/dm²/h**
Duration	**5**	**minutes**

Footprint Rate	50	g/dm²/h
Stdev of Rate (+/-)	9	g/dm²/h

IP needed per 5min

In each position	147	g
In each Dispensor	587	g

IP needed for entire test

Total amount of IP in Each Dispensor	587	g
Total Amount IP Needed for Entire Test	2347	g

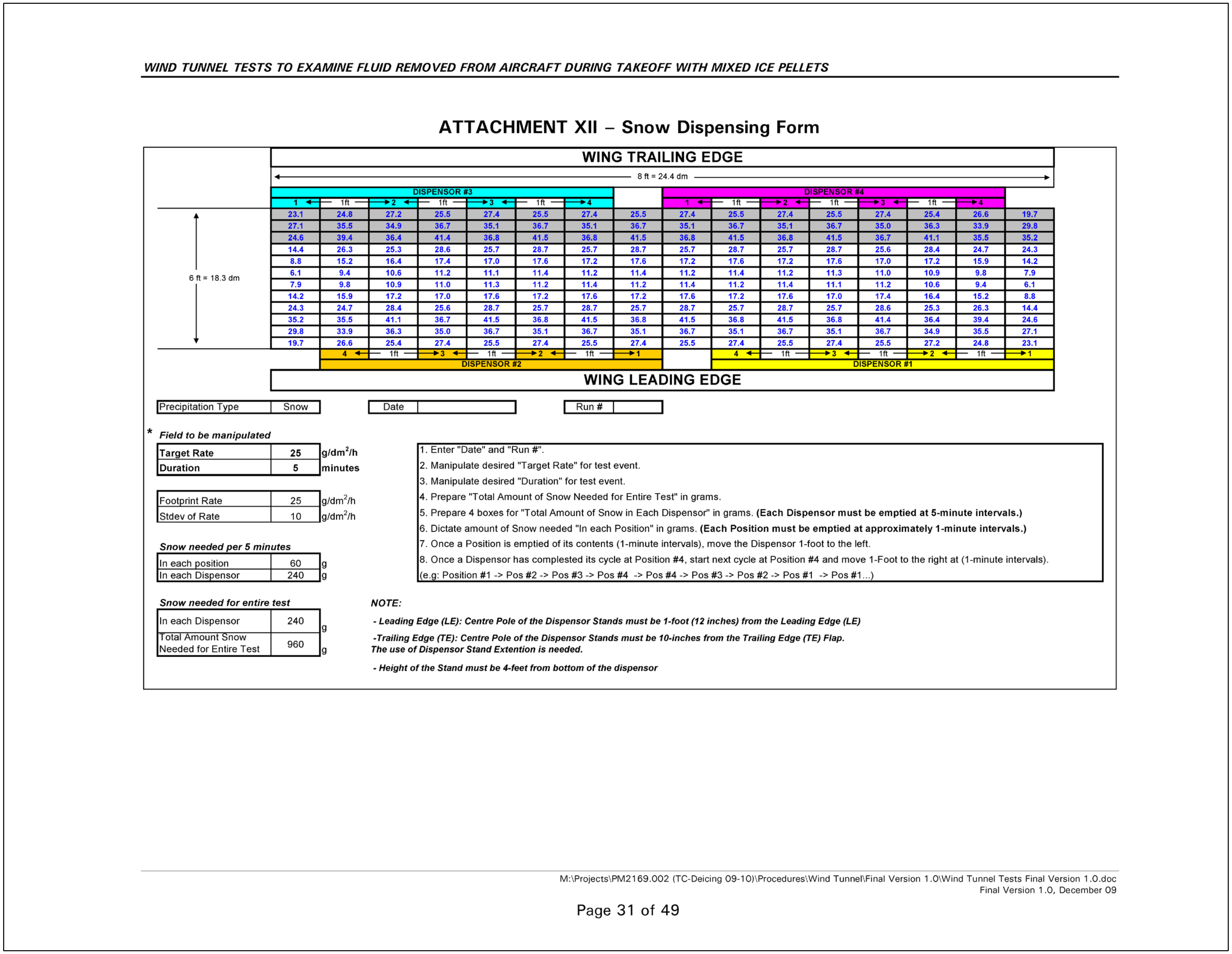
1. Enter "Date" and "Run #".
2. Manipulate desired "Target Rate" for test event.
3. Manipulate desired "Duration" for test event.
4. Prepare "Total Amount of IP Needed for Entire Test" in grams.
5. Prepare 4 boxes for "Total Amount of IP in Each Dispensor" in grams. **(Each Dispensor must be emptied 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 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 XII – 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/dm^2/h**
Duration	**5**	**minutes**

Footprint Rate	25	g/dm^2/h
Stdev of Rate	10	g/dm^2/h

Snow needed per 5 minutes

In each position	60	g
In each Dispensor	240	g

Snow needed for entire test

In each Dispensor	240	g
Total Amount Snow Needed for Entire Test	960	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 – Sprayer Calibration Form

WIND TUNNEL FREEZING RAIN SPRAYER CALIBRATION

Trail No	Aprox Start Time	Sprayer Settings							Precipitation Rate (g/dm^2/h)	Comments
		Translation		Nozzles	Speed	Water Flow Rate (mL/min/nozzle)	Air Pressure	Software Setting		
		x	y							
2-Feb-09		Full 24 Scans	Full 335 Steps	2x20		500 mL/min	45		50	x-axis=24 Scans, 66.24º. y-axis=60.3º
4-Feb-09		Full 24 Scans	Full 335 Steps	2x20		250 mL/min	45		25	MVD=1-1.2mm. x-axis=24 Scans, 66.24º. y-axis=60.3º
25-Feb-09		Full 24 Scans	Full 335 Steps	2x17		750 mL/min	45		75	x-axis=24 Scans, 66.24º. y-axis=60.3º
1-Mar-09		Full 24 Scans	Full 335 Steps	2x20		150 mL/min	45		15	x-axis=24 Scans, 66.24º. y-axis=60.3º

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	

At Rotation

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

After Take-off Run

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

Additional Observations: ____

____

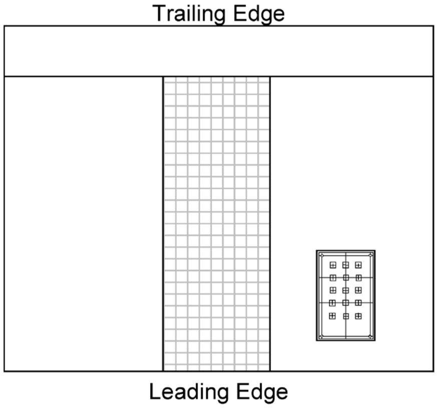
____

OBSERVER: __________________________

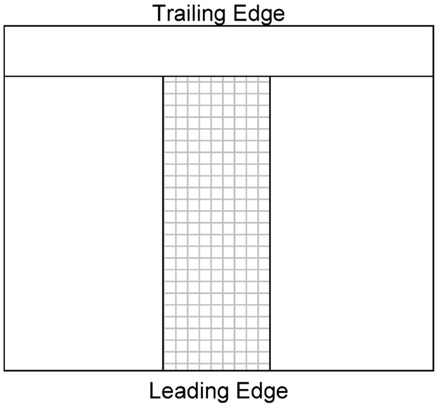
ATTACHMENT XV – Condition of Wing and Plate Form (to be filled by MP/DY)

Date: ____________________ Run Number: _______

Wing and Plate Condition Before the Takeoff Run (Time ______________________)



Wing Condition After the Takeoff Run (Time: ___________________________)



Observations: ____

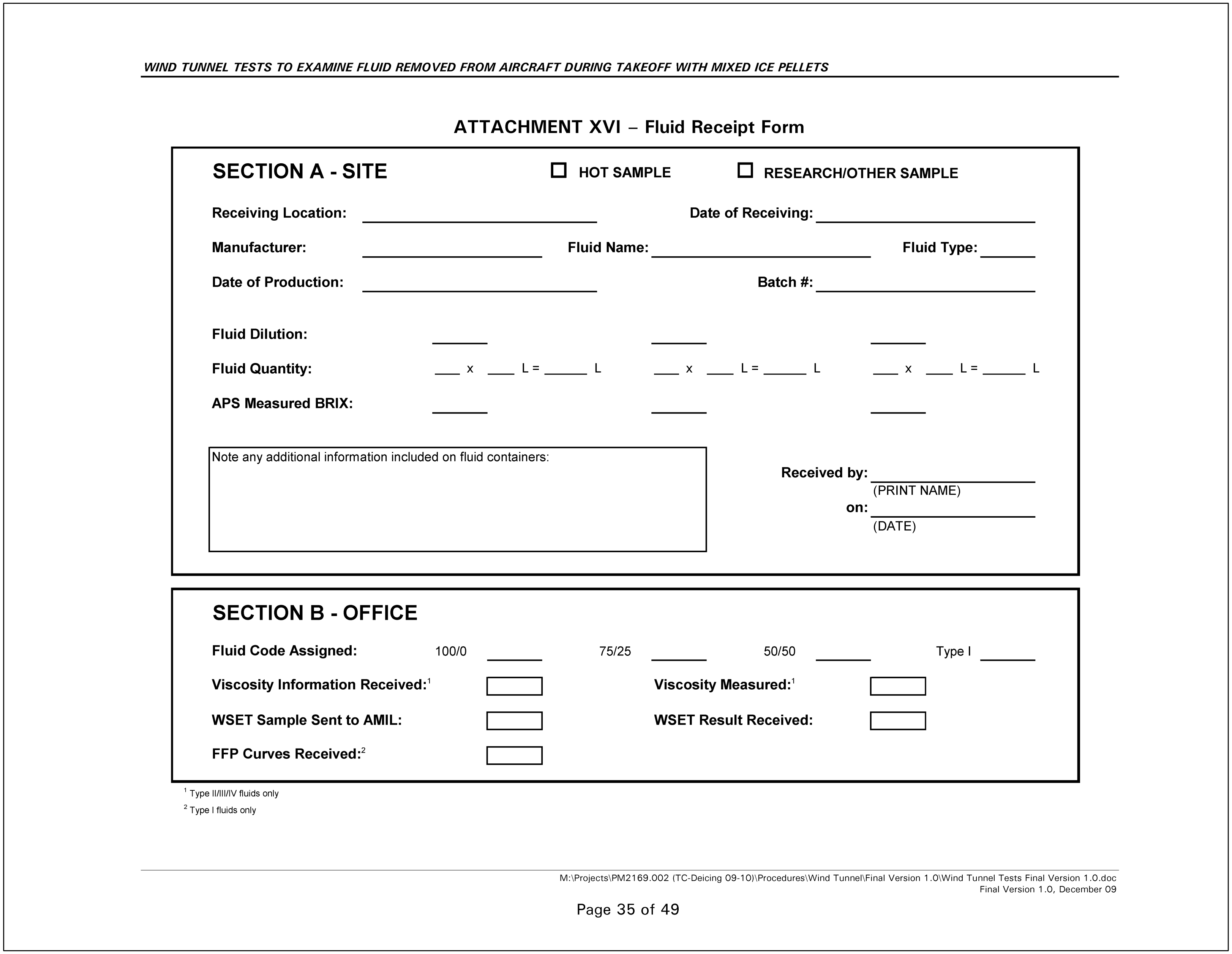
____

____

____

____

OBSERVER:___________________________ **ASSISTED BY:** _______________________



ATTACHMENT XVI – 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

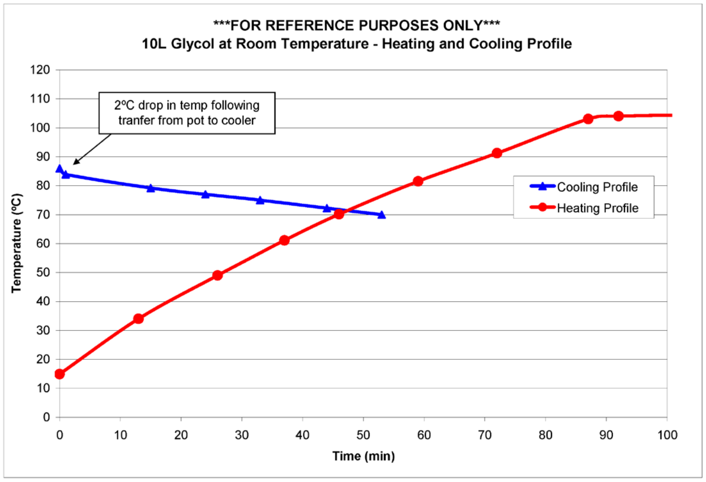
ATTACHMENT XVII – Log of Fluid Sample Bottles

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

ATTACHMENT XVIII– Procedure: Application of Heated Type III Fluid for Wind Tunnel Tests

Heating

- Type III should be stored indoors at room temperature to minimize heating required;
- Heat Type III fluid 10L at a time using a hotplate and an aluminum cooking pot with a lid. The hotplate should be set to the "Max" setting. Two pots should be heated simultaneously to prepare the 20L required for each test;
- Fluid temperature should be monitored every 10 minutes, and the fluid should be stirred frequently;
- Once a temperature of 70ºC is achieved (approx 45 minutes), the two 10L pots of fluid should be transferred to individual warm insulated coolers.
- *Note: Although 60ºC is the target application temperature, the fluid will be transferred into the coolers at 70ºC to allow for some cooling during transportation to the test section and transfer into the pouring jug*s.


FOR REFERENCE PURPOSES ONLY
10L Glycol at Room Temperature - Heating and Cooling Profile

2ºC drop in temp following tranfer from pot to cooler

Application

NOTE: It is critical that all precipitation dispensing equipment be ready to go prior to fluid application. Application of precipitation should occur immediately after the fluid application is complete to minimize heat loss from the wing.

- Heated Type III fluid should be transferred from the insulated coolers into hand held 2-3L pour containers;
- 20 L (see "Application Quantity" section for details) of fluid should be applied evenly to the whole wing section using the typical methodology for applying

fluid in the wind tunnel. Two people will be required to pour 10L from the leading edge and 10L from the trailing edge.
- Precipitation shall be timed to start immediately after the completion of the fluid application. Thickness and Brix measures can be omitted for the "after pour" application.

Application Quantity

Note: Quantities in brackets (xx L) will be total volume required based on wind tunnel wing section area.

- HOT guidelines recommend 1L/m² (3.7L) as final step
- Original APS assumption was to use about five times the amount, so about 5.4L/m(20L)
- FAA original recommendation was < (20L), but > (3.7L), and suggested (6-8 L)
- A review was conducted of operator data for “one-step de/anti-icing procedures using Type I”
  - Details in the report “Research Data to Support the Development of the Airport De-Icer Management System Model (ADMS)

Fluid quantities for one-step de/anti-icing procedures using Type I
Based on review of report data for Moderate Snow and Freezing Rain conditions

- Large Canadian Operator for Commuter Aircraft (Dash 8 or CRJ)
  - 5 L/m² (19L) and 10L/m² (37L)
- Large US Operator for Commuter Aircraft (Dash 8 or CRJ)
  - 2L/m² (7L) and 3L/m² (11L)
- Large Canadian Operator for Large W/B Aircraft (A340)
  - 3 L/m² (11L) and 6L/m² (22L)
- Servisair Recommended Spray Quantities for Commuter Aircraft (Dash 8 or CRJ)
  - Waiting on data, will update once received.

Conclusion:

Review of data provides a range of 2L/m² (7L) to 10L/m² (37L).

Following a discussion of this data, it is recommended that initial testing be conducted with both 2.7L/m² (10L) and 5.4L/m² (20L) to evaluate the severity of the heat involved. Following a review of the test data, a decision may be made to proceed with either the larger or smaller amount.

ATTACHMENT XIX – Procedure: Super-Critical vs. Low Speed Airfoil

Background

Previous testing in the wind tunnel was conducted with low speed airfoils. To simulate the newer generation aircraft, a super-critical wing section was designed and constructed for the 2009-10 winter testing. In order to objectively evaluate the tests conducted, the new super-critical wing performance must be compared to the low speed airfoils previously used for testing.

Objective

To investigate the aerodynamic performance of the new super-critical airfoil as compared to the previous low speed airfoils used.

Methodology

- Testing should be conducted in dry wing and fluid only conditions.
- Testing should try to recreate the weather conditions for select baseline dry and fluid only tests conducted in 2008-09 in order to have low speed airfoil comparison data points.
- Characteristics such as lift and stall angle should be compared in both dry and fluid only cases.

Test Plan

Five tests are anticipated: a dry test, and four tests with the representative Type III and Type IV fluids selected for testing.

ATTACHMENT XX – 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 has 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 winter of 2006-07 and 2008-09.

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) for the same exposure time used during the moderate snow test;
- 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

Ten to twelve comparative tests are anticipated.

ATTACHMENT XXI – Procedure: Low Speed Ramp Testing

Background

The current low speed aerodynamic acceptance test for anti-icing fluids simulates a rotation speed of 67 knots on a flat plate; this takeoff profile was developed based on older generation low speed aircraft. In recent years, the newer generation low speed aircraft have rotation speeds closer to 80 to 85 knots. As all of the low speed testing conducted in the wind tunnel has been performed simulating an 80 knot rotation speed (representing the newer generation aircraft), it was recommended to verify the fluid flow-off properties of anti-icing fluid using the historical 67 knot rotation speed takeoff profile used for the aerodynamic acceptance tests.

Objective

To investigate the fluid flow-off performance during low speed ramp take-off.

Methodology

- Testing should be conducted in fluid only conditions;
- Testing will consist of two comparative tests done sequentially with the same fluid in similar weather conditions:
  - 67 knots rotation;
  - 80 knots rotation;
- Compare lift data, visual observations, and manually collected data;

Test Plan

Four to six tests are anticipated with two to three different fluids.

ATTACHMENT XXII – Procedure: Effect of Ice Phobic Coatings on Contaminated Airfoil Aerodynamic Performance

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. It was recommended that testing be conducted 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.

Objective

To investigate the aerodynamic flow-off characteristics and lift losses associated with a wing section treated with ice-phobic coatings following contamination, with and without anti-icing fluid.

Methodology

- The wing should be clean and dry before the start of test;
- The wing section should be covered with speed tape. If it is not feasible to cover the entire wing, the first 12-24" of the leading edge should be covered with speed tape;
- The wing should be sectioned in half: un-treated and treated with ice-phobic coating;
- One side should be treated with the ice phobic coating as per the manufacturer specification. The other side should be left untreated;
- The first test should be conducted with no fluid protection during light freezing rain conditions;
- Run wind tunnel and collect data;
- The following test should be conducted with anti-icing fluid protection. The wing should be exposed to simulated light freezing rain at a rate of 25 g/dm^2/h and the time of exposure should be chosen based on OAT and fluid specific HOT's;
- Run wind tunnel and collect data;
- The performance of the treated and un-treated sections of the wing should be compared.

Test Plan

Two to four tests are anticipated.

ATTACHMENT XXIII – Procedure: Reduced Type I HOT's on Composite Surfaces

Background

Previous comparative flat plate testing was conducted using aluminum and composite surfaces. Results indicated that anti-icing fluid endurance times were comparable, however Type I fluids experienced HOT reductions when applied to composite surfaces. The Type I HOT's were approximately 30% shorter on composite surfaces in natural snow conditions. Full-scale data is required to verify the aerodynamic impact of reduced Type I HOT's on composite surfaces.

Objective

To investigate the aerodynamic flow-off characteristics and lift losses associated with reduced Type I HOT's on composite surfaces.

Methodology

- To simulate aluminum wing, apply heated Type I fluid to wing section (heated to 60°C);
- Expose wing section to simulated snow at a rate of 25 g/dm²/h until fluid is failed;
- Run wind tunnel and collect lift loss data;
- To simulate composite wing, apply heated Type I fluid to wing section (heated to 60°C);
- Expose wing section to simulated snow at a rate of 25 g/dm²/h. Time of exposure should be 30% longer than previous test
    - Exposure time = 1.3 * ET of simulated aluminum wing test;
- Run wind tunnel and collect lift loss data;
- Compare results of both tests;

Note: Testing can also be done by simulating both alumunim and composite Type I tests on the same wing section using two separate strips of fluid. If this procedure if preferred, the composite test section should be exposed to precipitation first to ensure that the precipitation is stopped simultaneously for both sections.

Test Plan

Two comparative sets of tests are anticipated.

ATTACHMENT XXIV – Procedure: Aerodynamic Impact of Wing Surface Roughness

Background

Previous testing in the wind tunnel demonstrated that although contamination was present on the wing section, significant lift losses were not apparent. Lift losses were incurred upon application of anti-icing fluid (when compared to a bare wing) however, the presence of contamination, whether adhered or not, did not generate significant list losses when compared to the uncontaminated fluid. Although the presence of adhered contamination may be hazardous with regards to control surfaces, the impact of the surface roughness on the overall aerodynamic performance of the wing needs to be investigated.

Objective

To investigate wing surface roughness and how it pertains to lift loss.

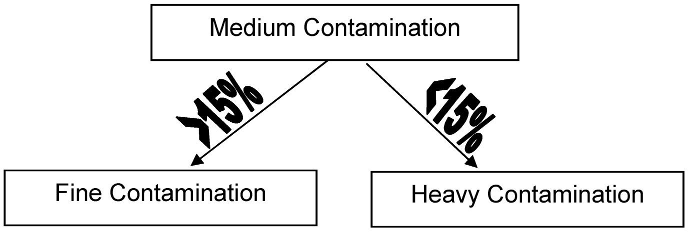
Methodology

Contamination can be in the form of abrasive sandpaper (similar to what is used by the NRC Flight Laboratory) or frozen precipitation on a bare wing. During the winter of 2008-09, adhered freezing rain, ice pellets, and snow were used to create a rough surface on the wing section.

- Apply abrasive material or contamination to full length of the leading edge of wing section;
- Run wind tunnel test, collect lift loss data, compare to fluid only results;
- Increase grit of sandpaper level of frozen contamination until appreciable lift losses are observed (greater than 15%); and
- Document type and level of contamination and resulting effects on lift loss.

Test Plan

Three to four tests are anticipated. Testing will proceed according to the following decision matrix.



ATTACHMENT XXV – Procedure: Effect of Snow Pellets on Fluid Flow Off

Background

Previous comparative flat plate testing was conducted in simulated snow pellets and simulated snow. Results indicated that anti-icing fluid endurance times were comparable in both conditions. Additional plate testing will be conducted to support the recommendation to incorporate snow pellets into the snow HOT column. Aerodynamic data is required to verify that both snow and snow pellets have similar fluid flow off characteristics.

Objective

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

Methodology

- Testing should be conducted on two 2 foot wide chords of the wing section (one section will be for snow pellets and the other for snow);
- Manufacture snow pellets (**Note: this process is labor intensive and should be planned well ahead of the anticipated test**);
- Depending on the OAT, choose a diluted fluid with the shortest HOT;
- Apply two strips of fluid to the wing section;
- Simultaneously dispense simulated snow pellets on one test section and snow on the other test section (ensure equal rate of precipitation and distribution);
- Expose both sections to equal amounts of contamination for equal amounts of time (the expected fluid HOT);
- Run wind tunnel; and
- Compare visual fluid flow-off behavior of both contaminated sections;

Test Plan

Due to the labor intensive process of manufacturing snow pellet, a maximum of two tests are anticipated.

ATTACHMENT XXVI – Procedure: Light Freezing Rain and Moderate Snow

Background

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

Objective

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

Methodology

The general methodology to be used during these tests is in accordance with the methodologies used for typical snow and light freezing rain tests conducted in the wind tunnel. The light freezing rain and moderate snow endurance times will be compared to the light freezing rain only HOT's.

- For a chosen fluid, conduct a test simulating light freezing rain and moderate snow conditions for an exposure time derived from the HOT table based on light freezing rain conditions.
- Record lift data, visual observations, and manually collected data;
- Conduct a comparative test simulating light freezing rain conditions for the same exposure time used during the light freezing rain and moderate snow test;
- Record lift data, visual observations, and manually collected data;
- Compare the light freezing rain and moderate snow conditions results to the light freezing rain results. If the light freezing rain and moderate snow results are worse, repeat the test with a reduced exposure time, if the results are better, repeat the test with a 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

Four to six comparative tests are anticipated.

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

Test Plan

Three to four comparative tests are anticipated.

ATTACHMENT XXVIII – Procedure: Degraded Anti-icing Fluid Performance Following Contamination with Runway Deicing Fluid

Background

Recent operational reports have indicated a significant degradation effect as a result of cross-contamination of thickened anti-icing fluids with runway deicing fluids. This is especially of concern for landings on a wet runway with reverse thrusters followed by preventative anti-icing applications. Full-scale data is required to verify the aerodynamic impact of degraded anti-icing fluid flow off following contamination.

Objective

To investigate the aerodynamic flow-off characteristics and lift losses associated with degraded anti-icing fluid flow off following contamination.

Methodology

- The wing should be clean and dry before the start of test;
- The wing should be sectioned in half: good side and degraded fluid side;
- The degraded fluid side should be treated with a spray of diluted runway deicer fluid;
- Anti-icing fluid should be applied to the whole wing (both good and degraded fluid side);
- Expose wing section to simulated light freezing rain at a rate of 25 g/dm²/h. Time of exposure should be chosen based on OAT and fluid specific HOT's;
- Run wind tunnel and collect data;
- Repeat test and reduce or increase amount of runway deicer fluid applied;

Test Plan

Four to six tests are anticipated with various Type III and Type IV fluids.

ATTACHMENT XXIX – Procedure: Type I Deicing and Spot 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

Two to three tests are anticipated; frost contamination tests and one fluid only test.

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APPENDIX C

LIFT COEFFICIENT PROVIDED BY THE NRC

LIST OF FIGURES

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EFFECTS OF WING SURFACE ROUGHNESS

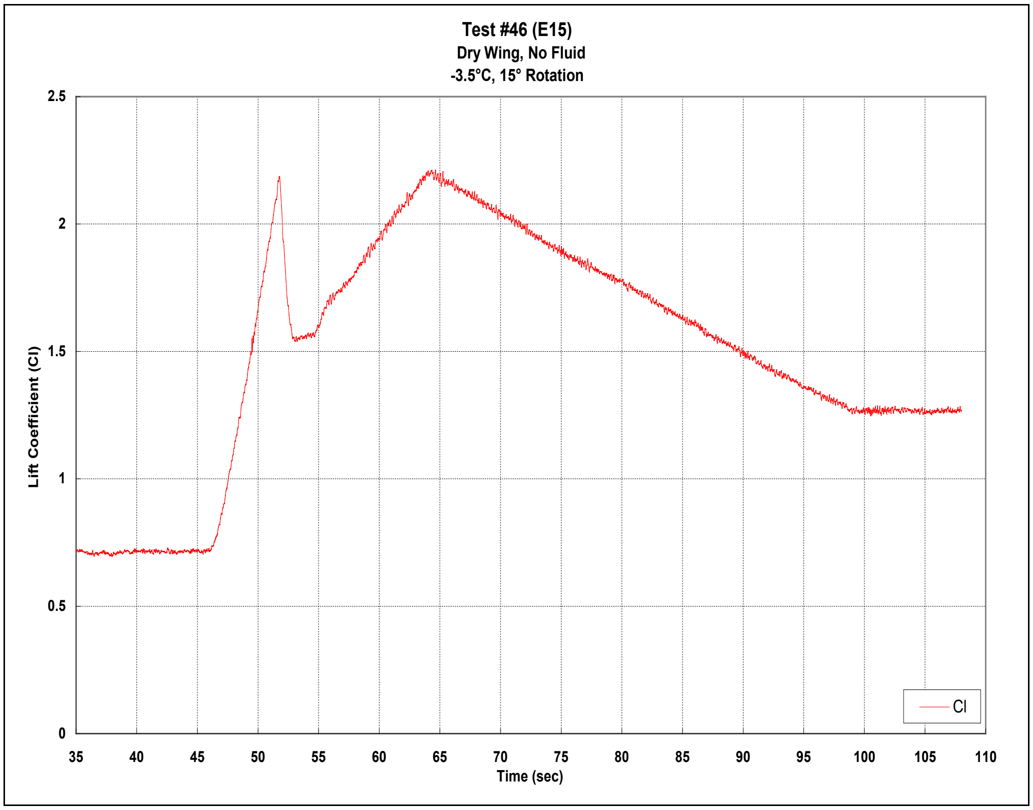

Figure C1: Run #46

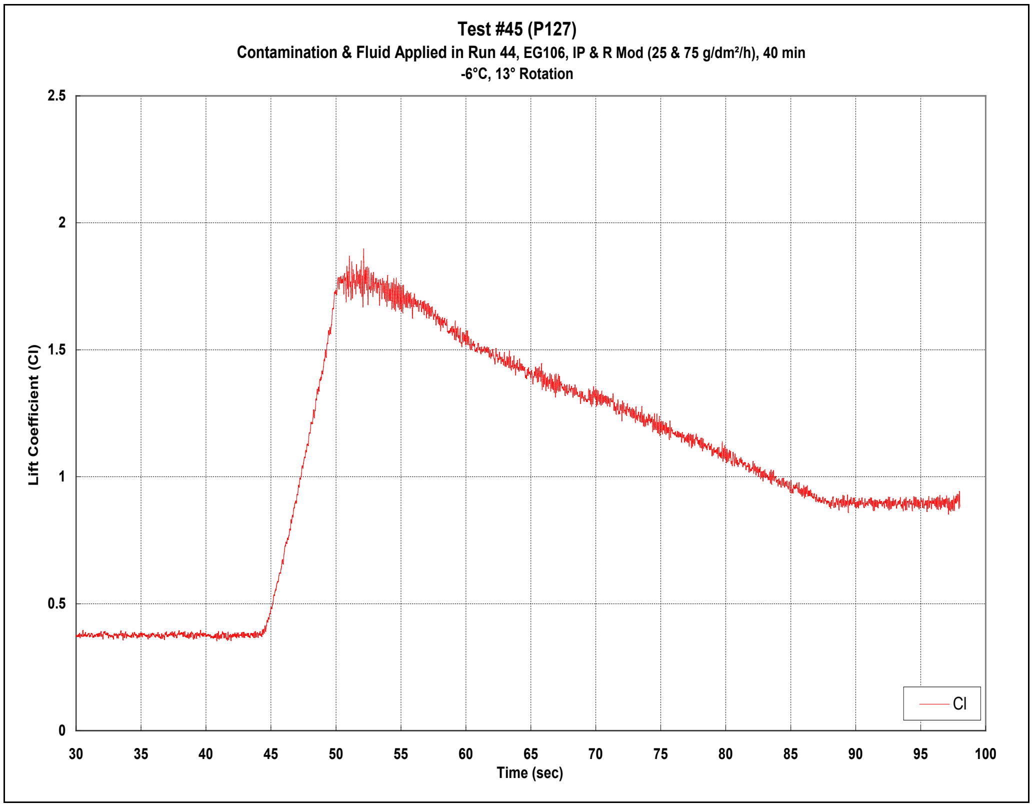

Figure C2: Run #45

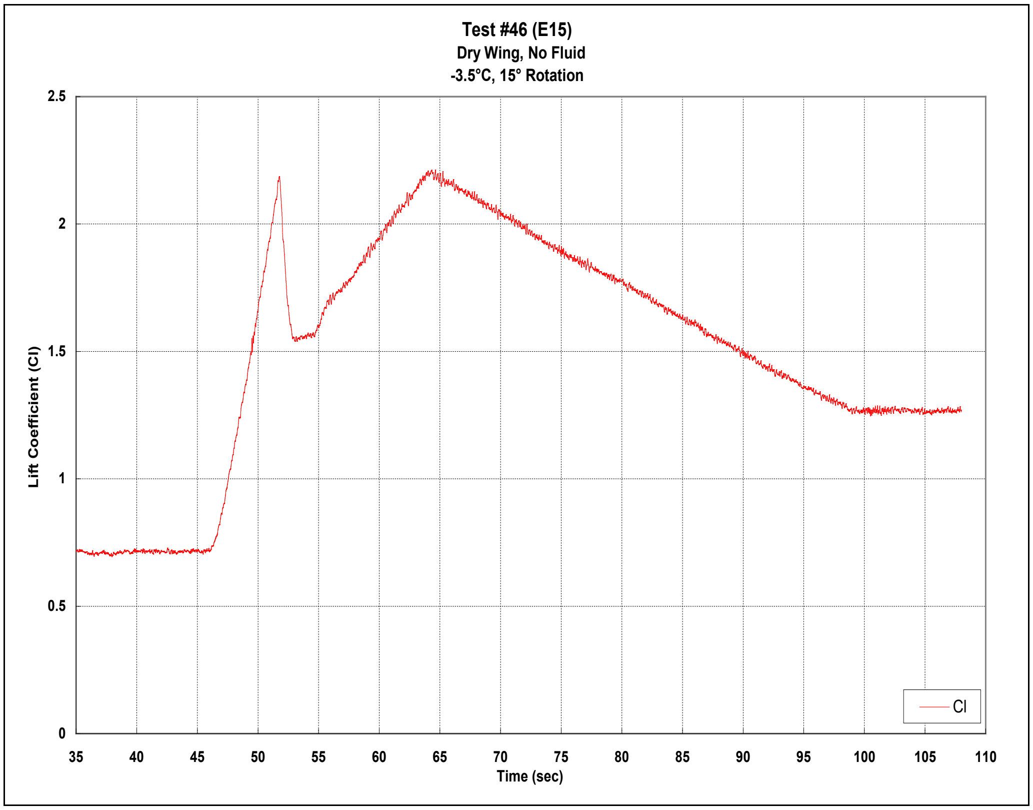

Figure C3: Run #46

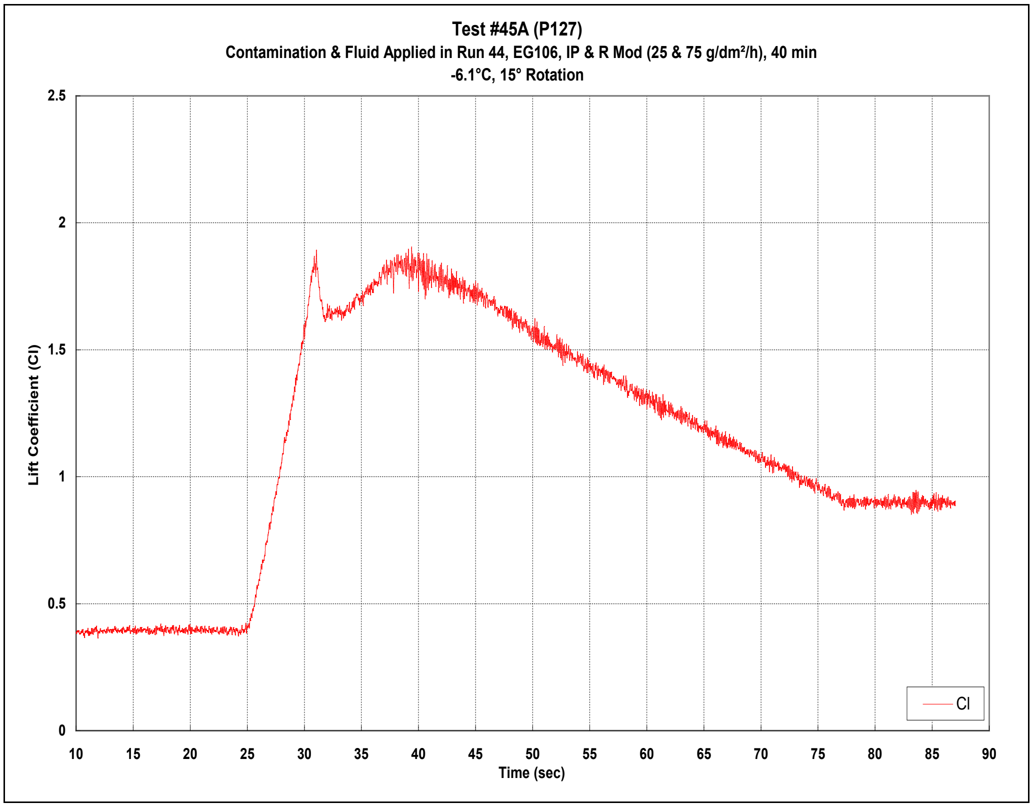

Figure C4: Run #45A

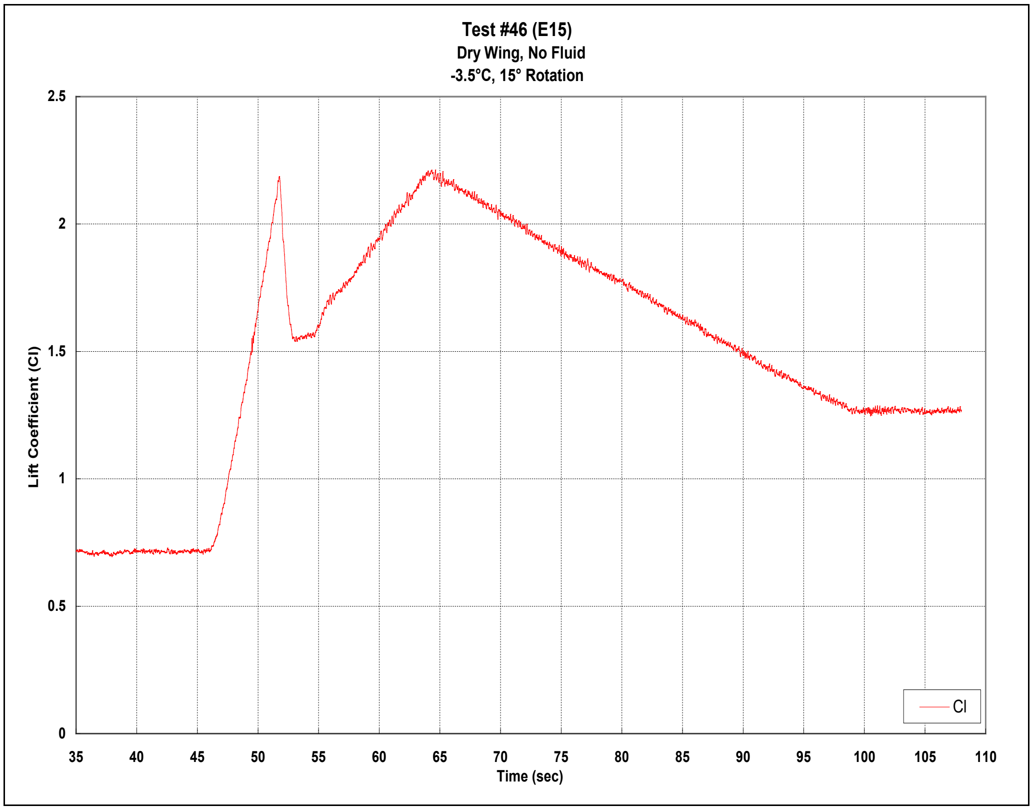

Figure C5: Run #46

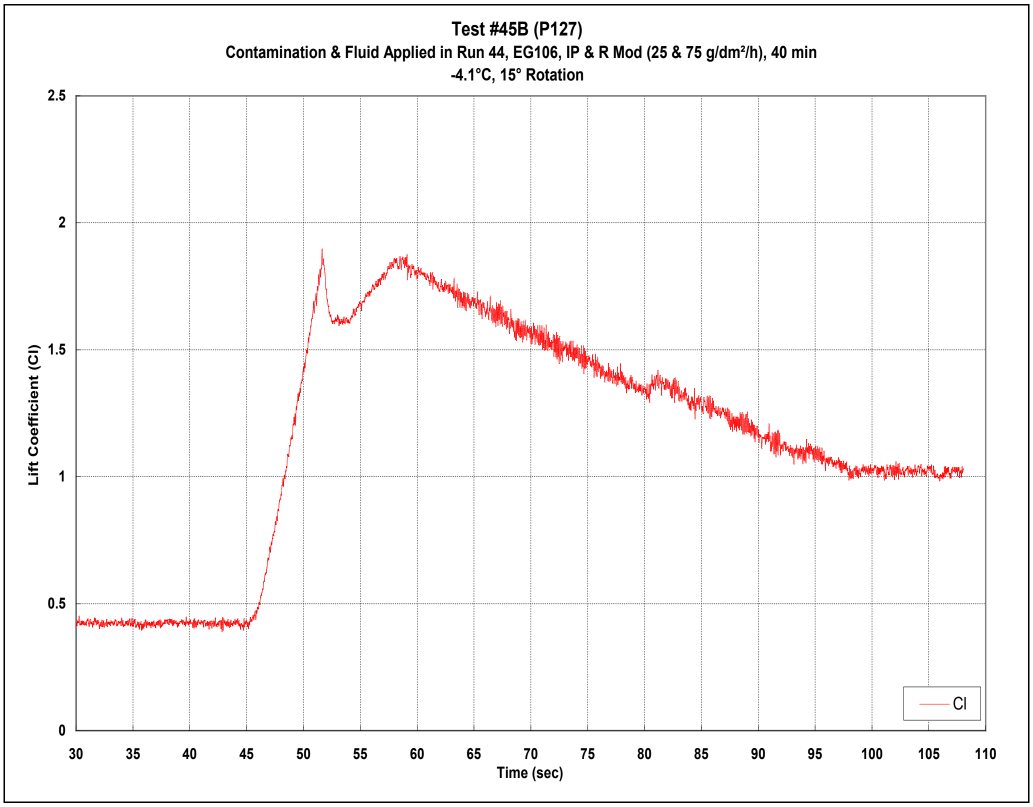

Figure C6: Run #45B

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EFFECTS OF A CONTAMINATED FLAP

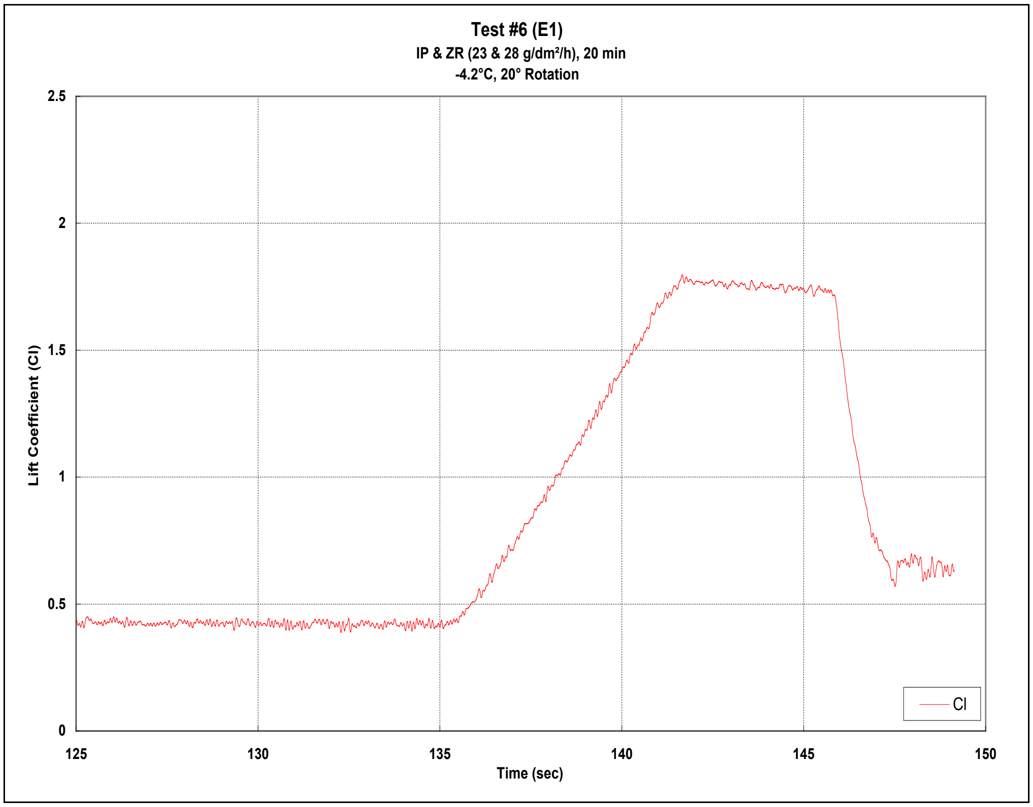

Figure C7: Run #6

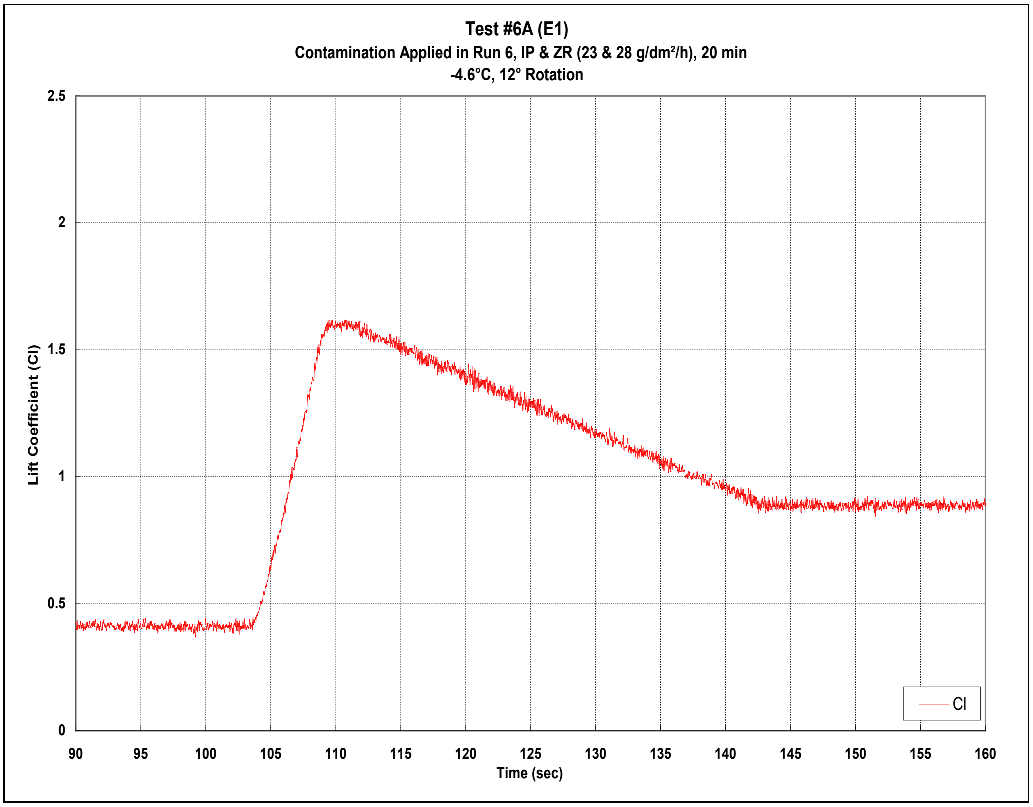

Figure C8: Run 6A

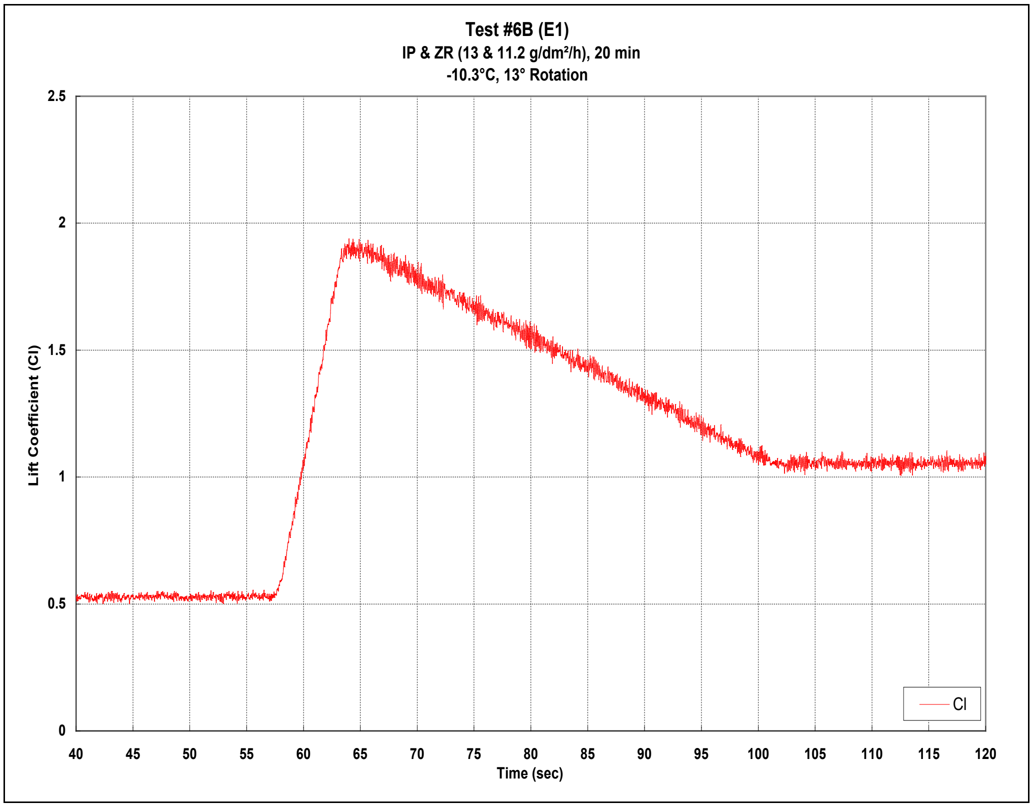

Figure C9: Run #6B

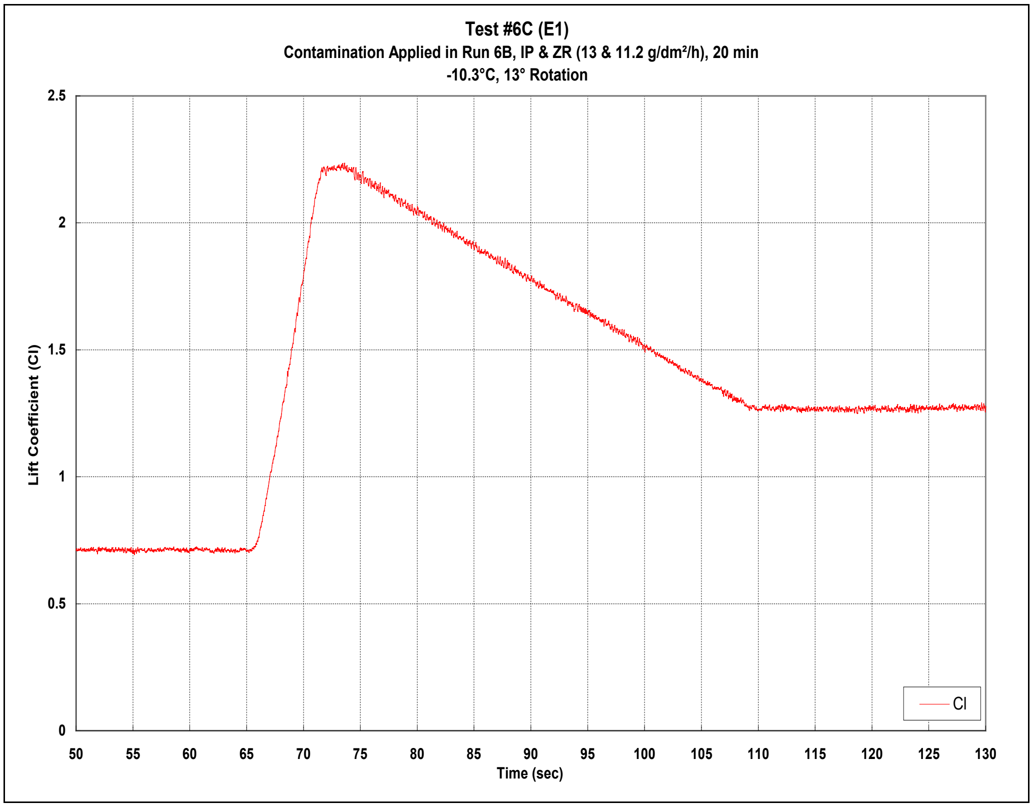

Figure C10: Run #6C

EFFECTS OF APPLYING OF EXCESSIVE AMOUNTS OF ANTI-ICING FLUID

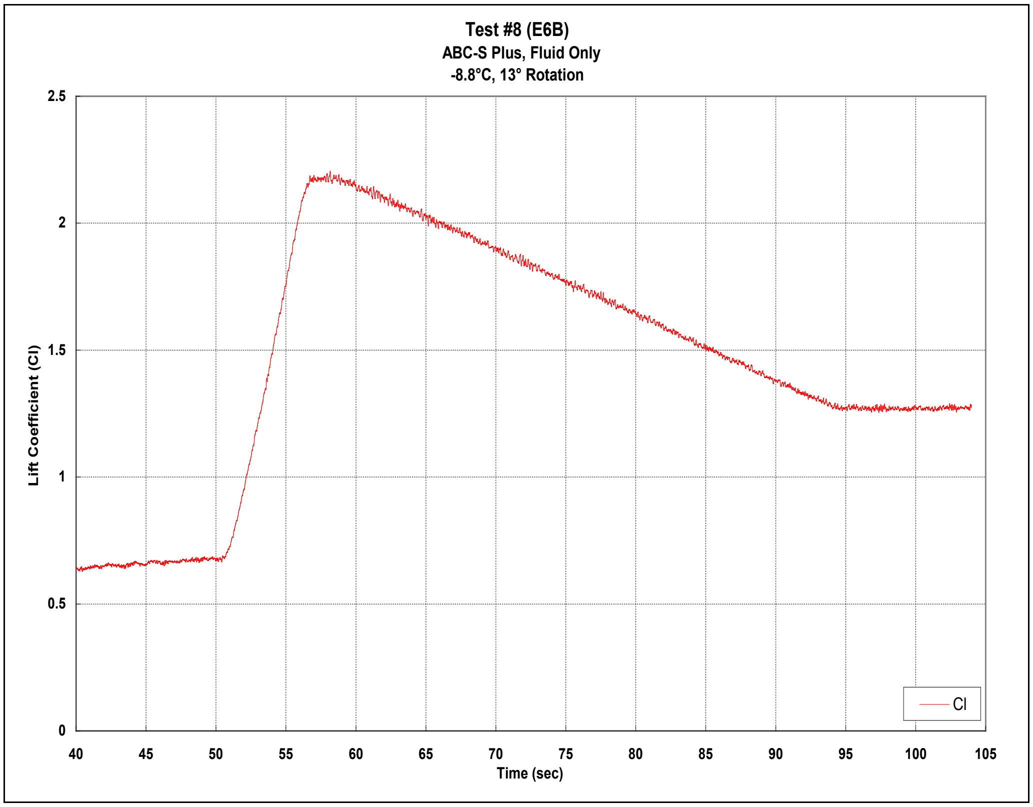

Figure C11: Run #8

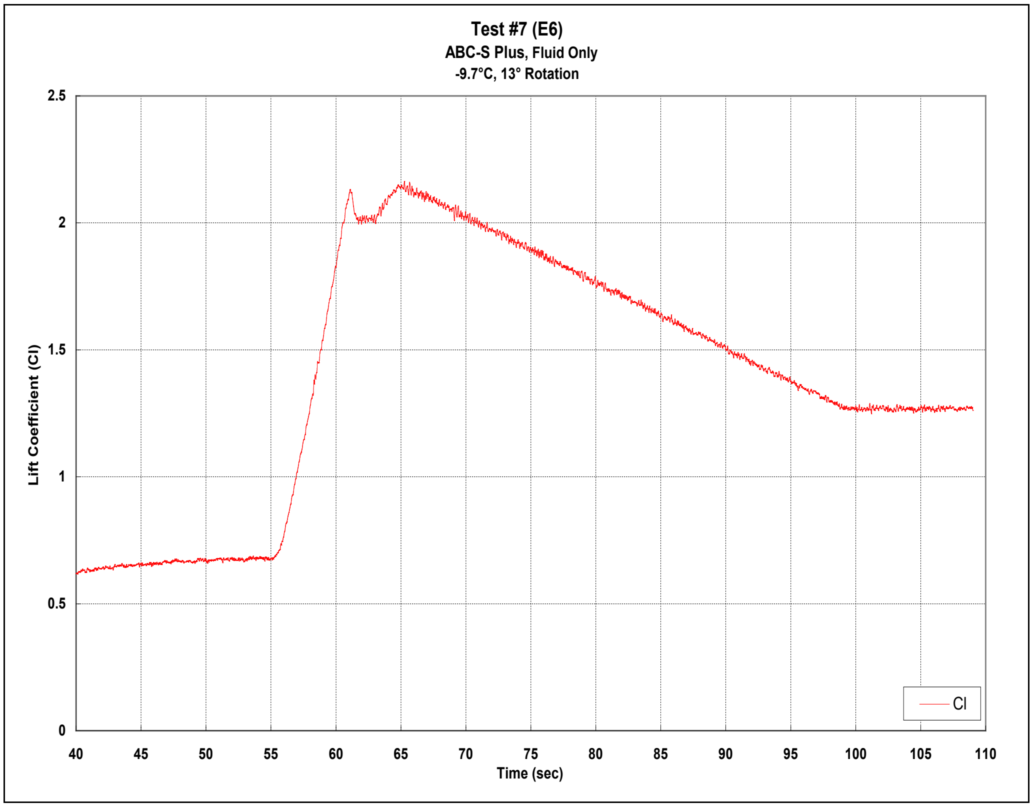

Figure C12: Run #7

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LOW SPEED RAMP TESTING

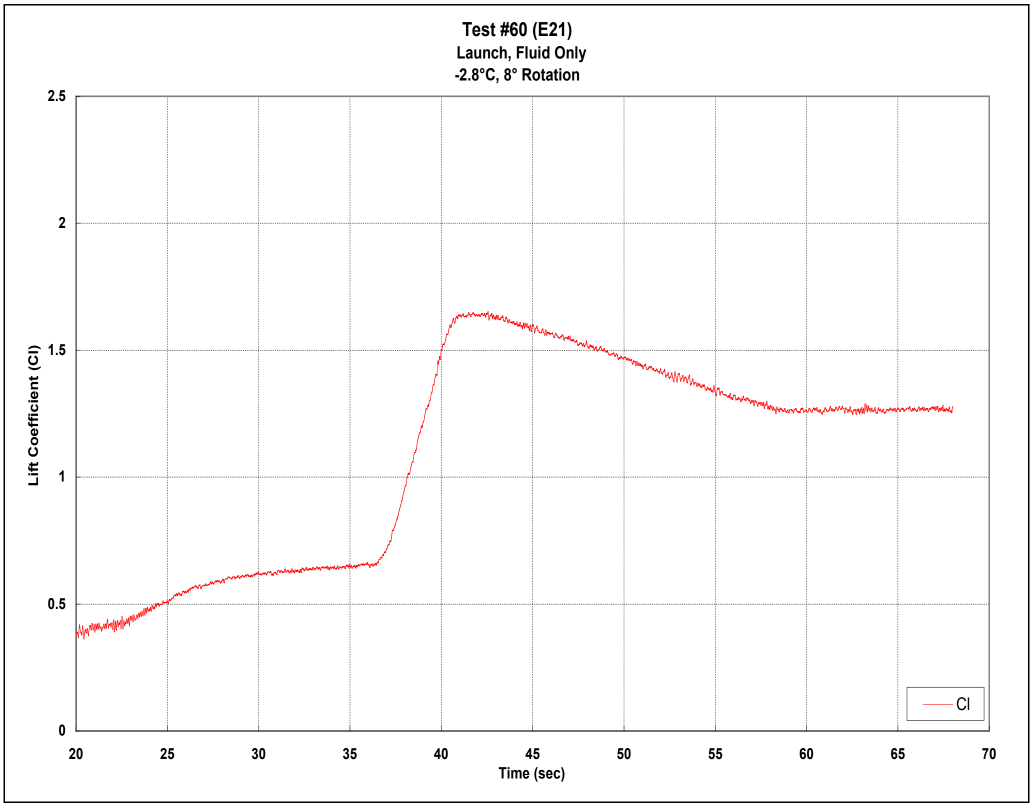

Figure C13: Run #60

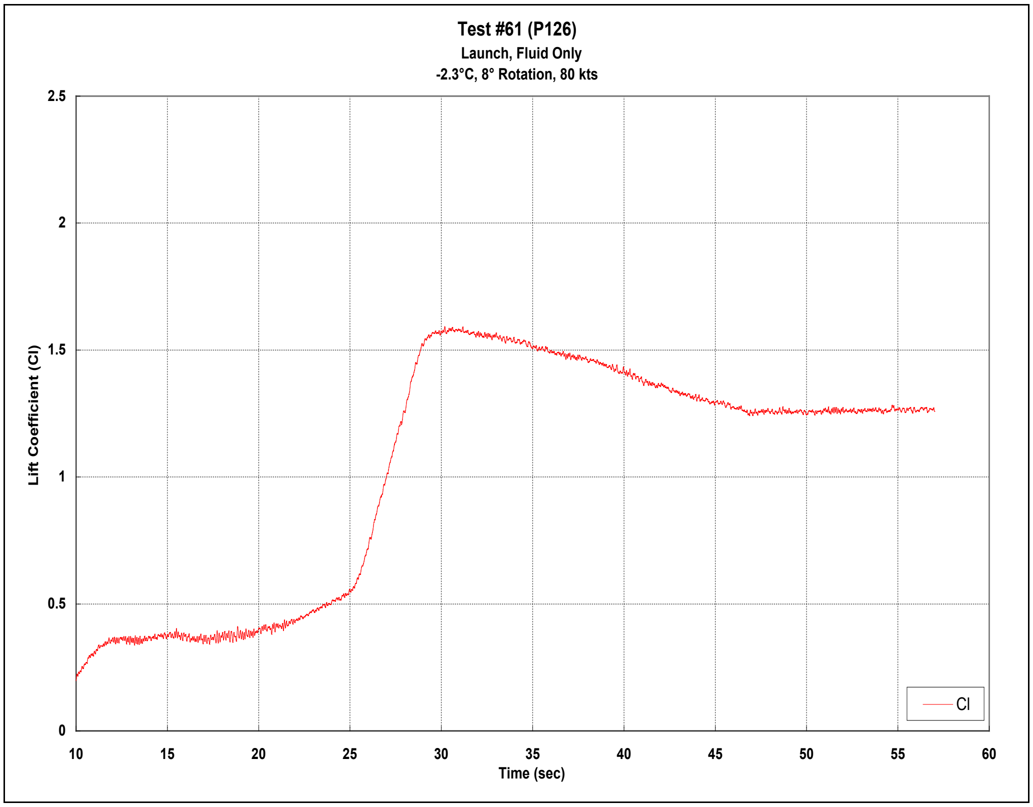

Figure C14: Run #61

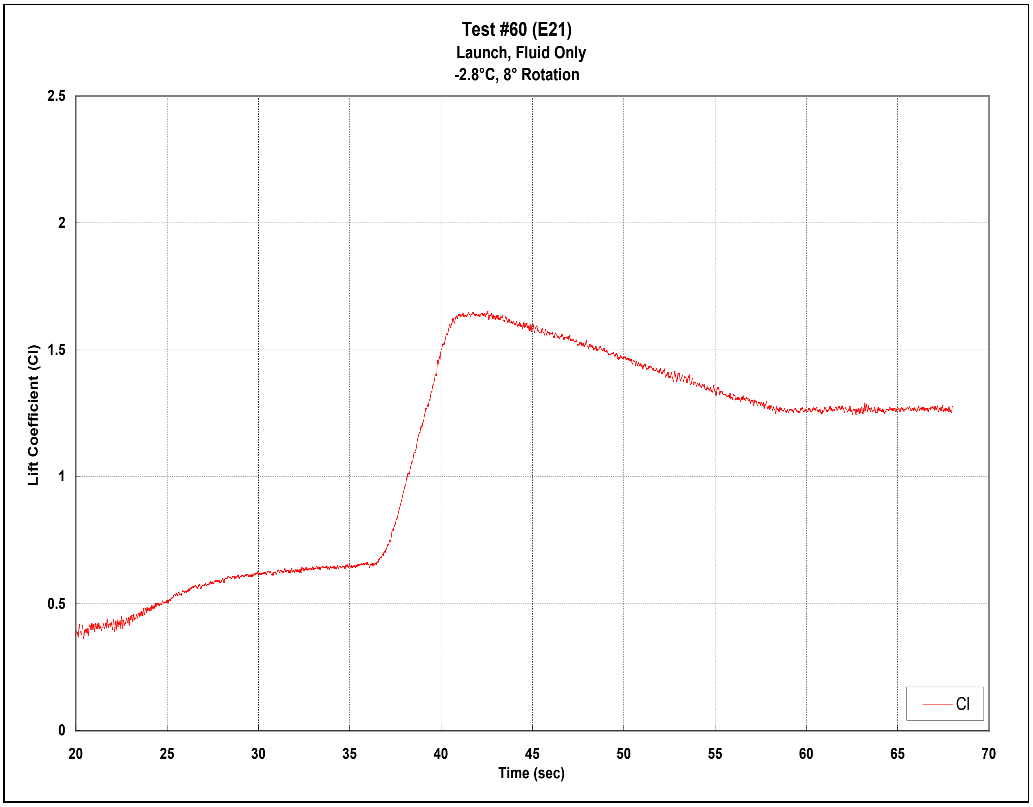

Figure C15: Run #60

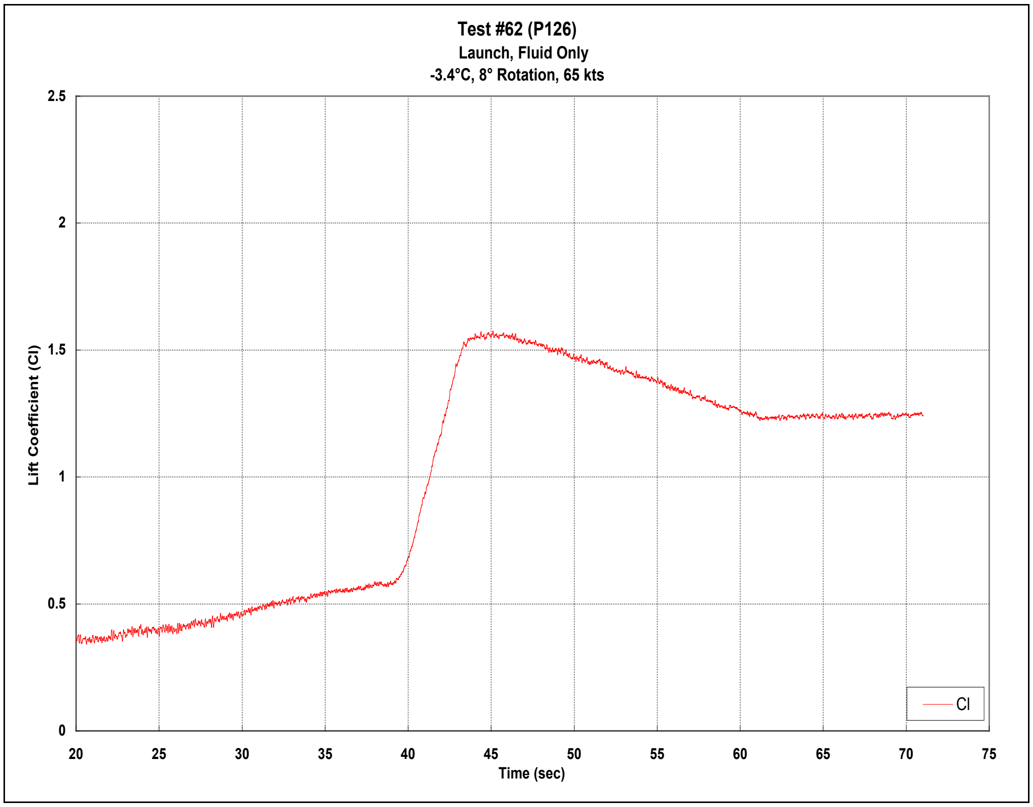

Figure C16: Run #62

LIGHT FREEZING RAIN MIXED WITH MODERATE SNOW CONDITIONS

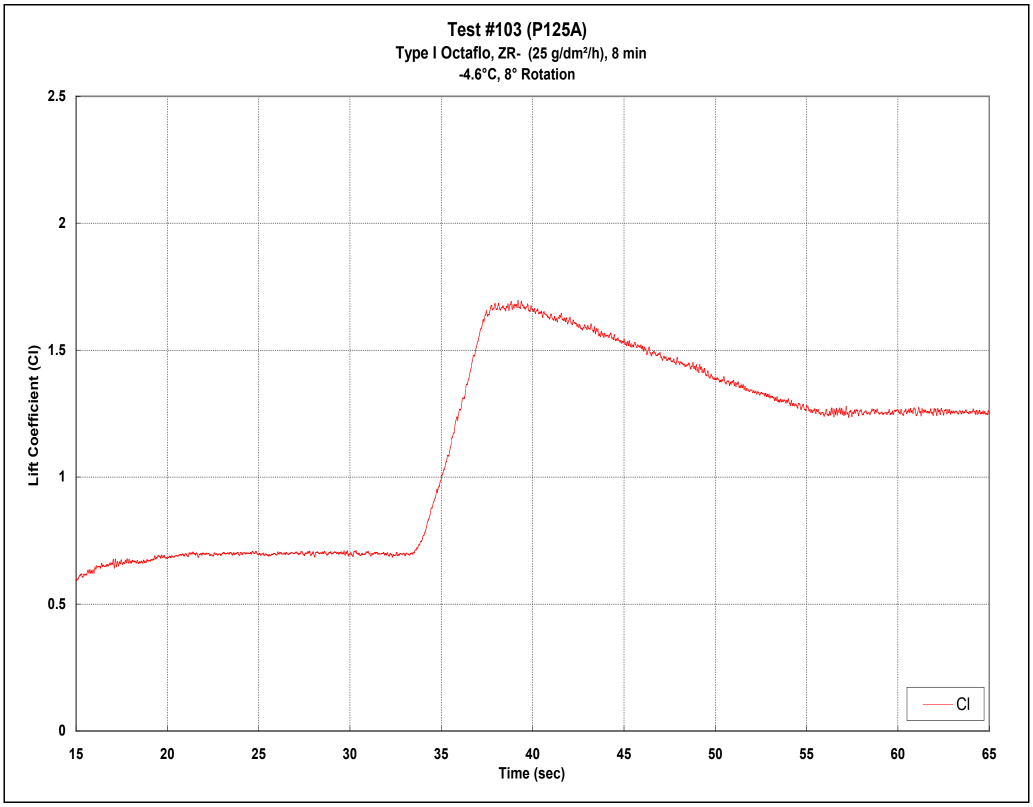

Figure C17: Run #103

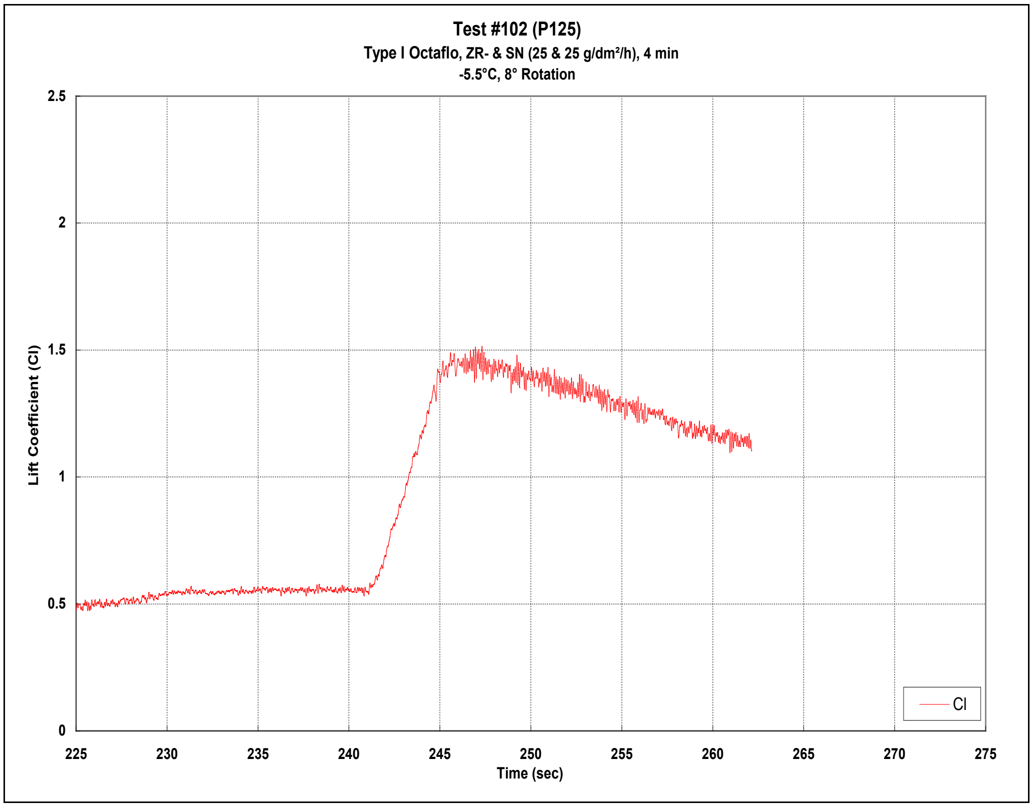

Figure C18: Run #102

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EFFECTS OF SNOW ON AN UN-PROTECTED WING

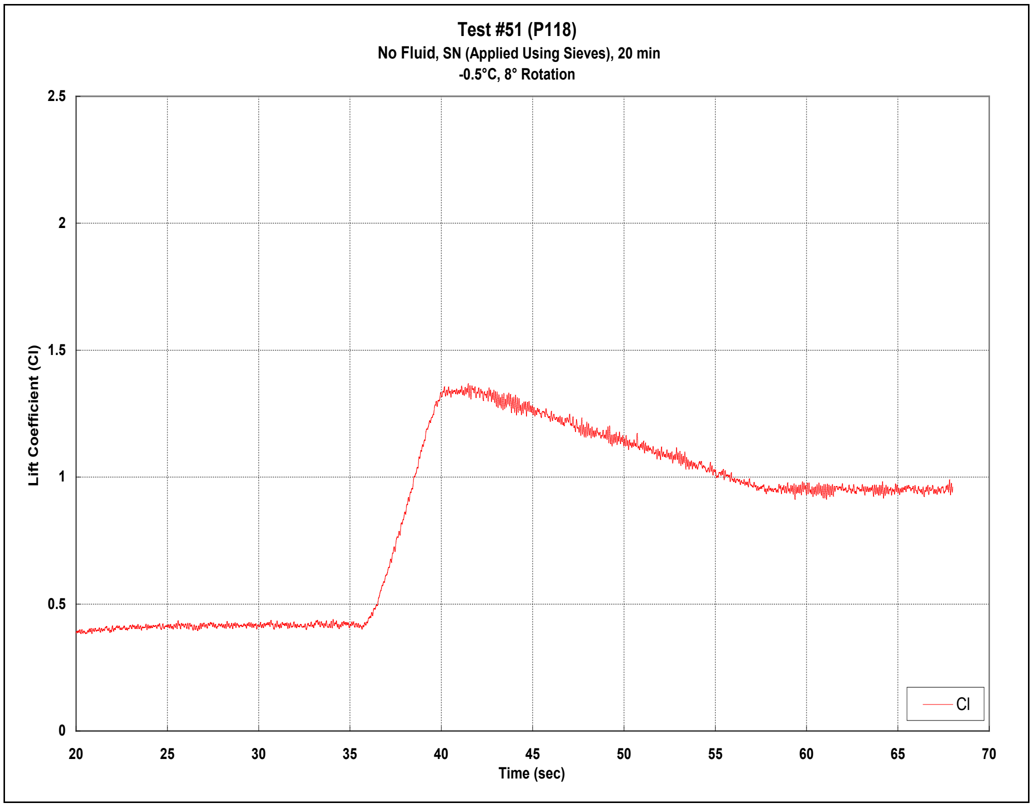


Figure C19: Run #51

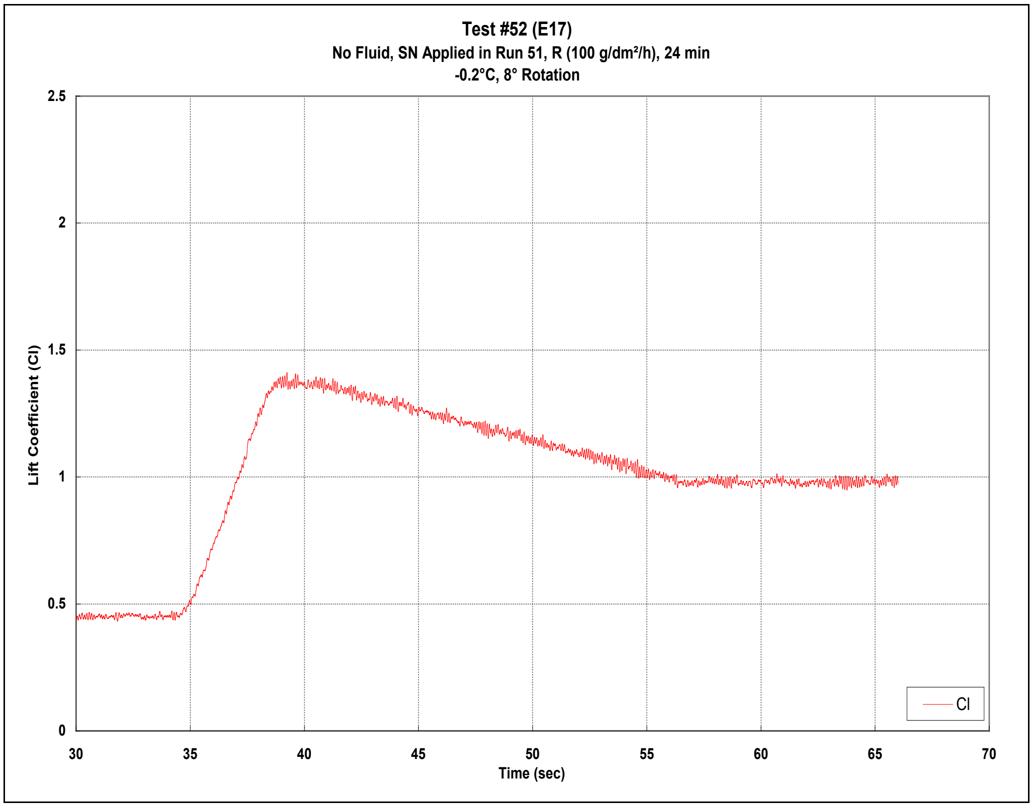


Figure C20: Run #52

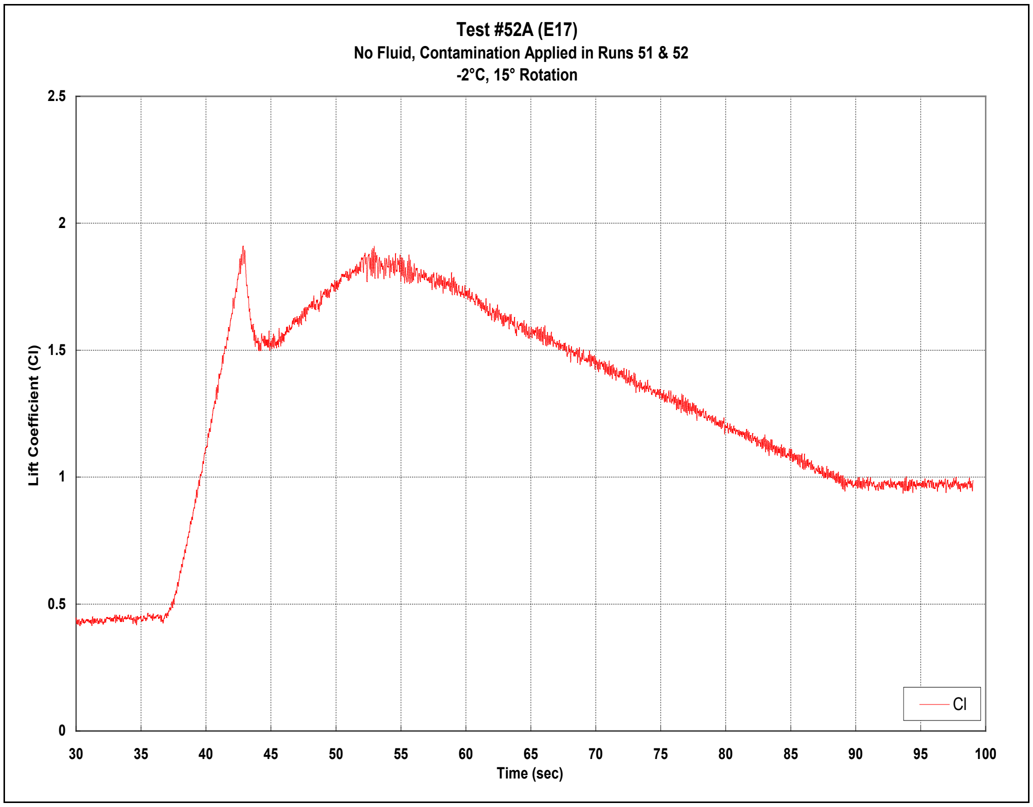


Figure C21: Run #52A

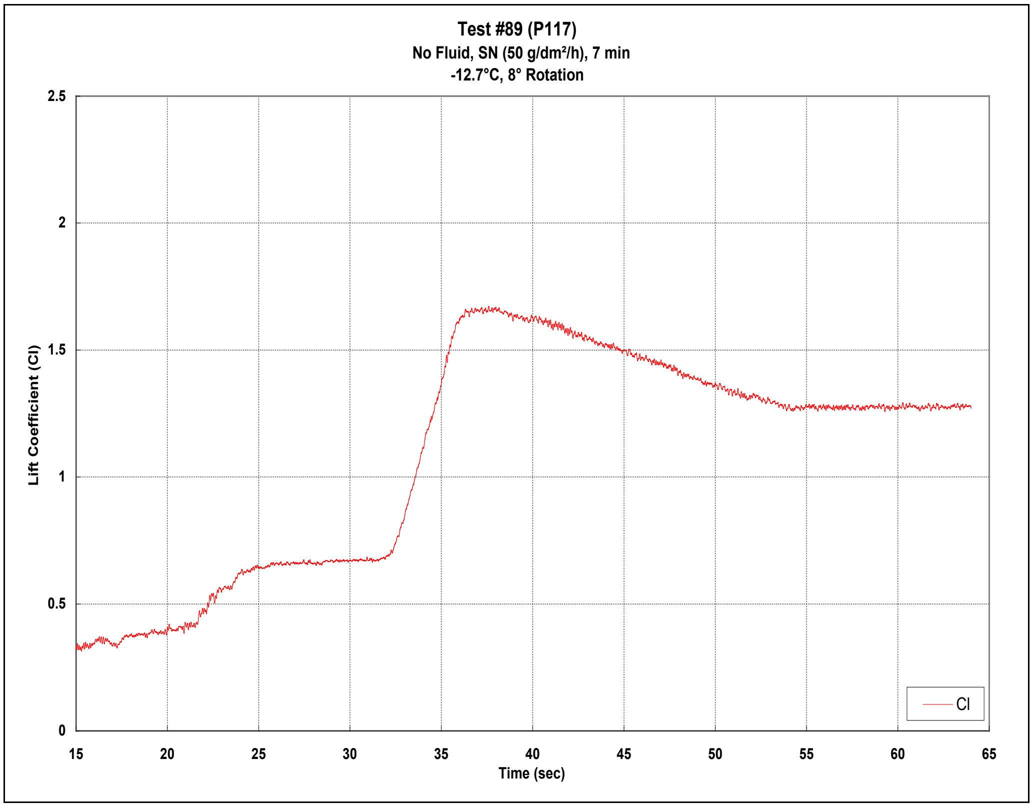


Figure C22: Run #89

DEGRADED ANTI-ICING FLUID PERFORMANCE FOLLOWING CONTAMINATION WITH RUNWAY DEICING FLUID

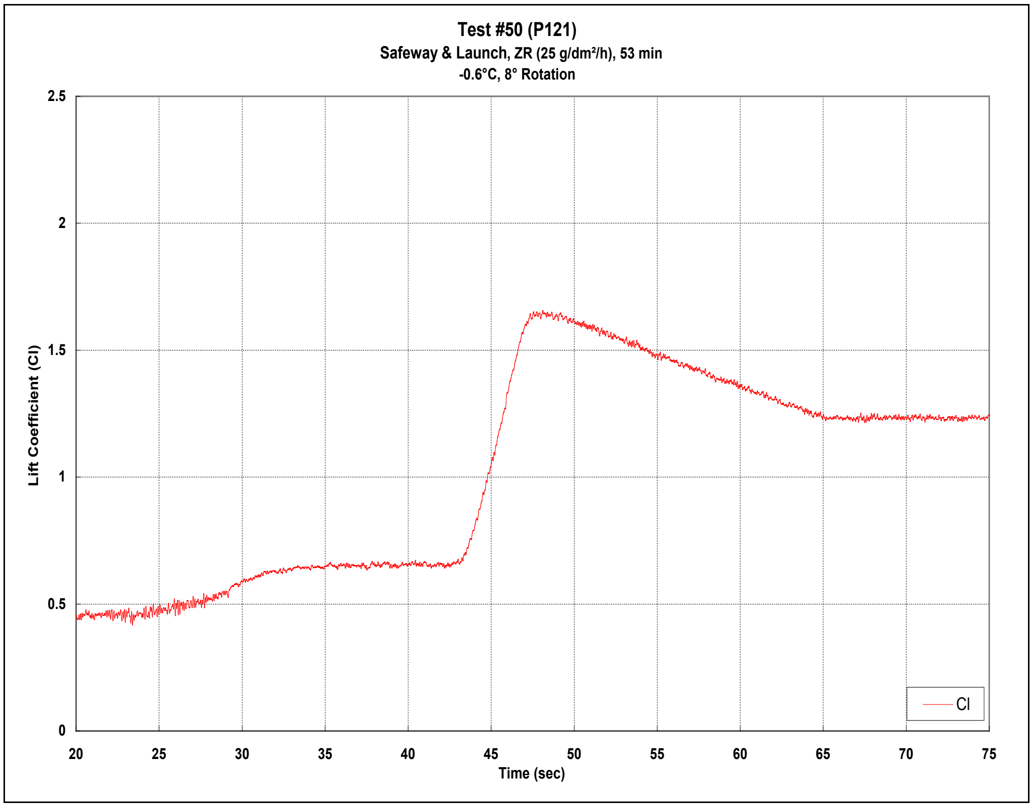


Figure C23: Run #50

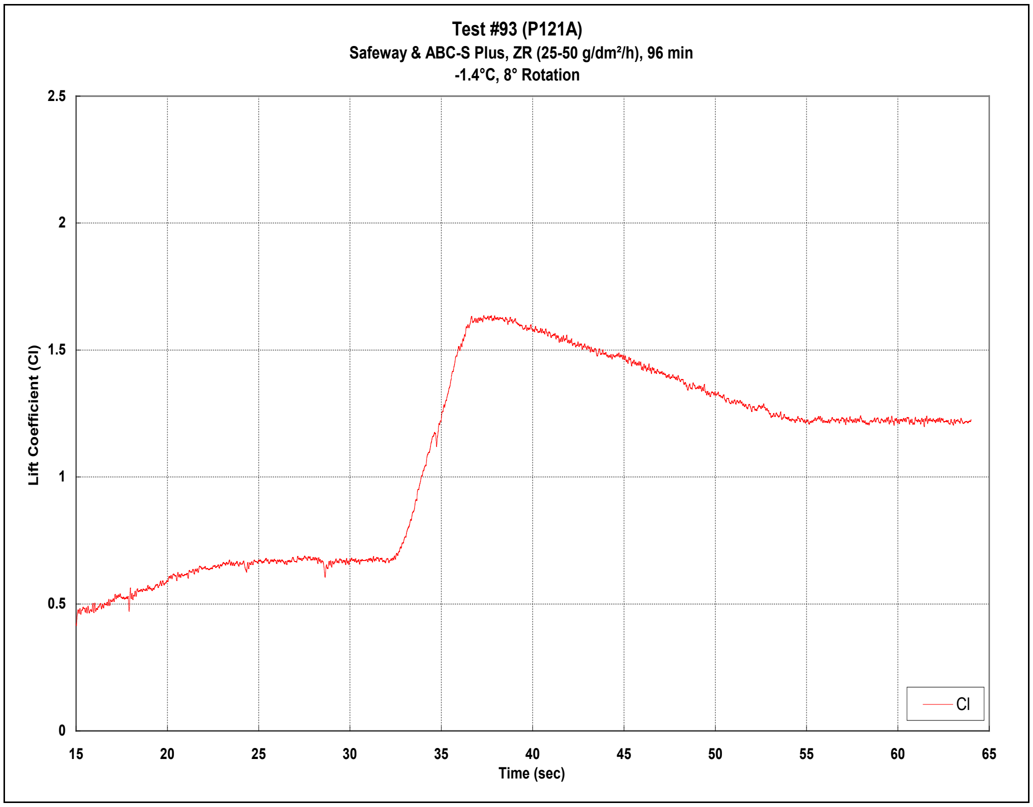


Figure C24: Run #93

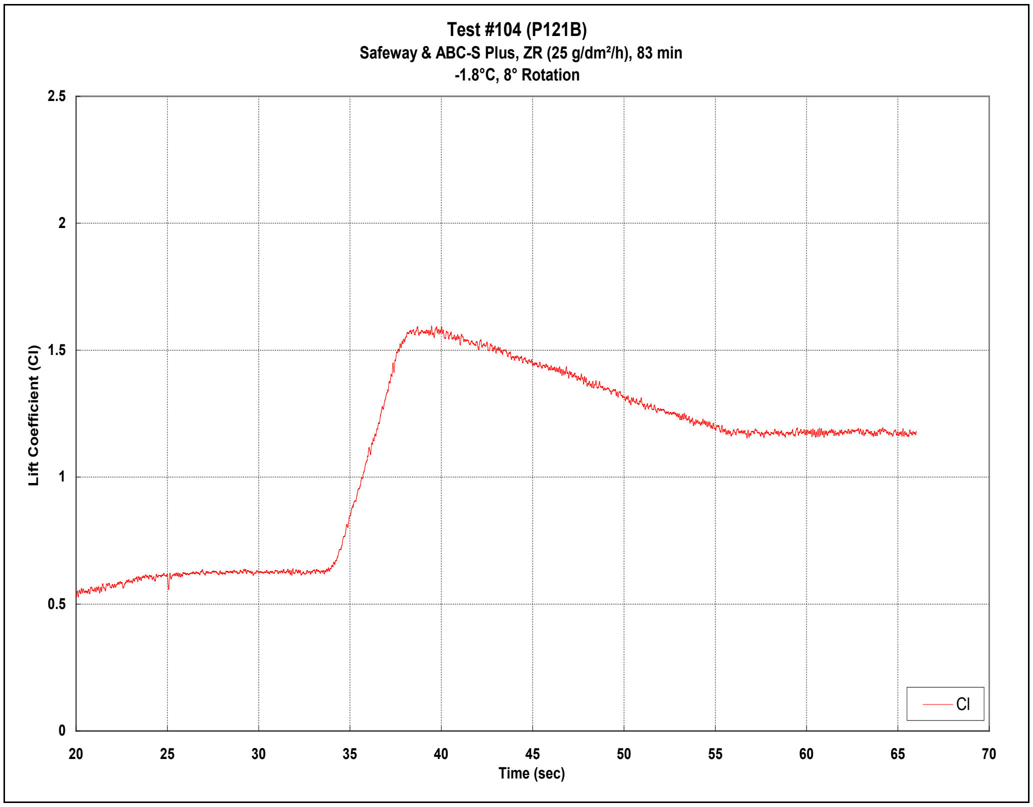


Figure C25: Run #104

HEAVY SNOW

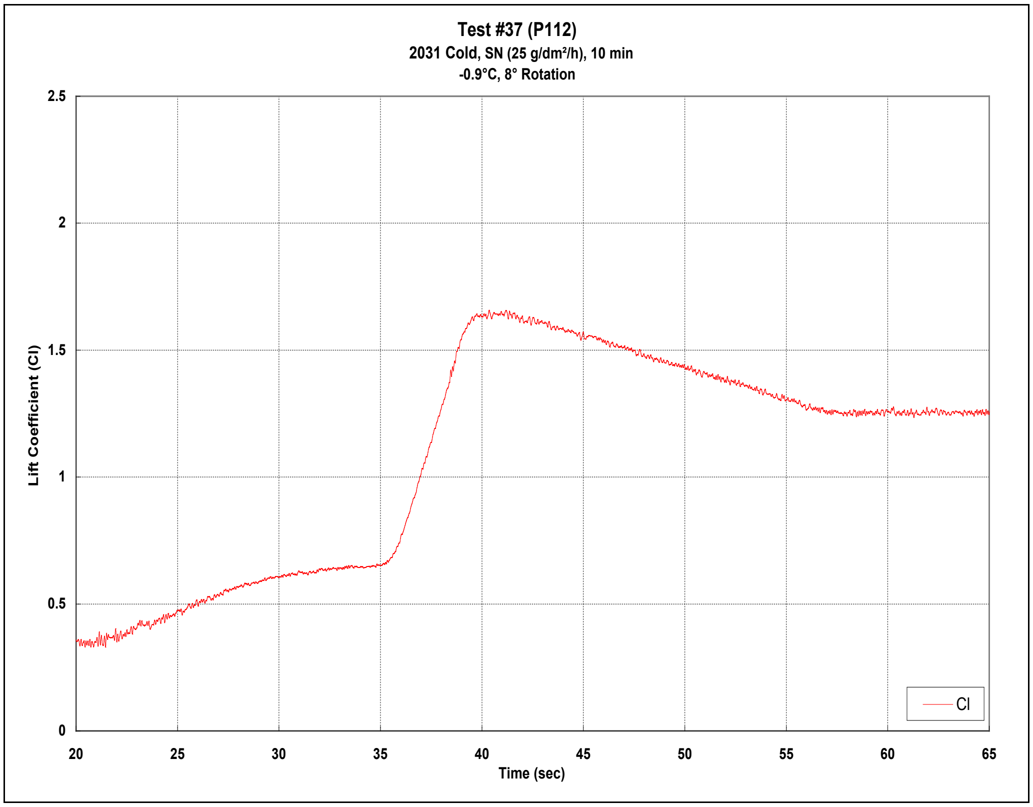


Figure C26: Run #37

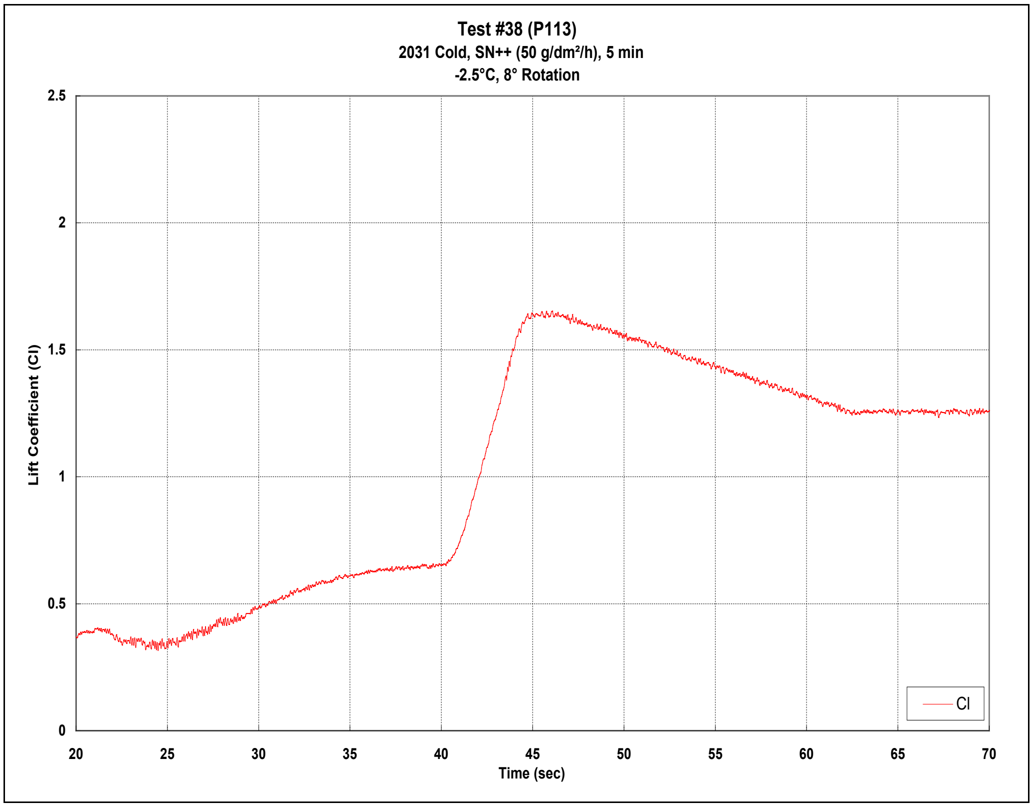


Figure C27: Run #38

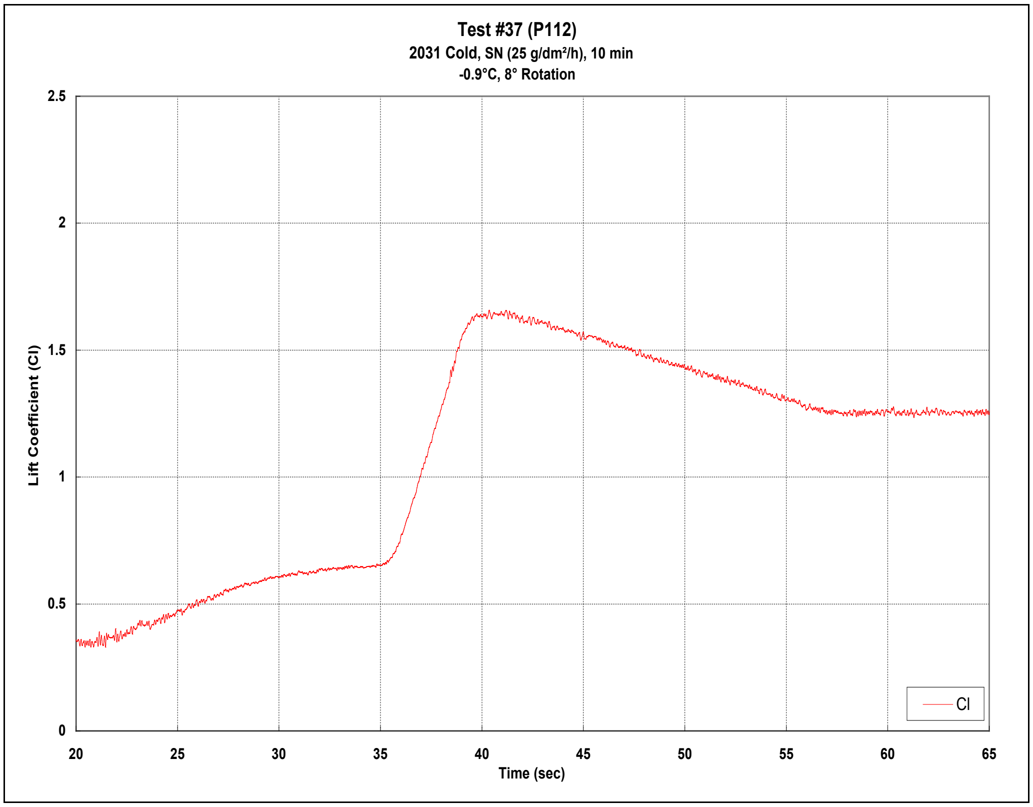


Figure C28: Run #37

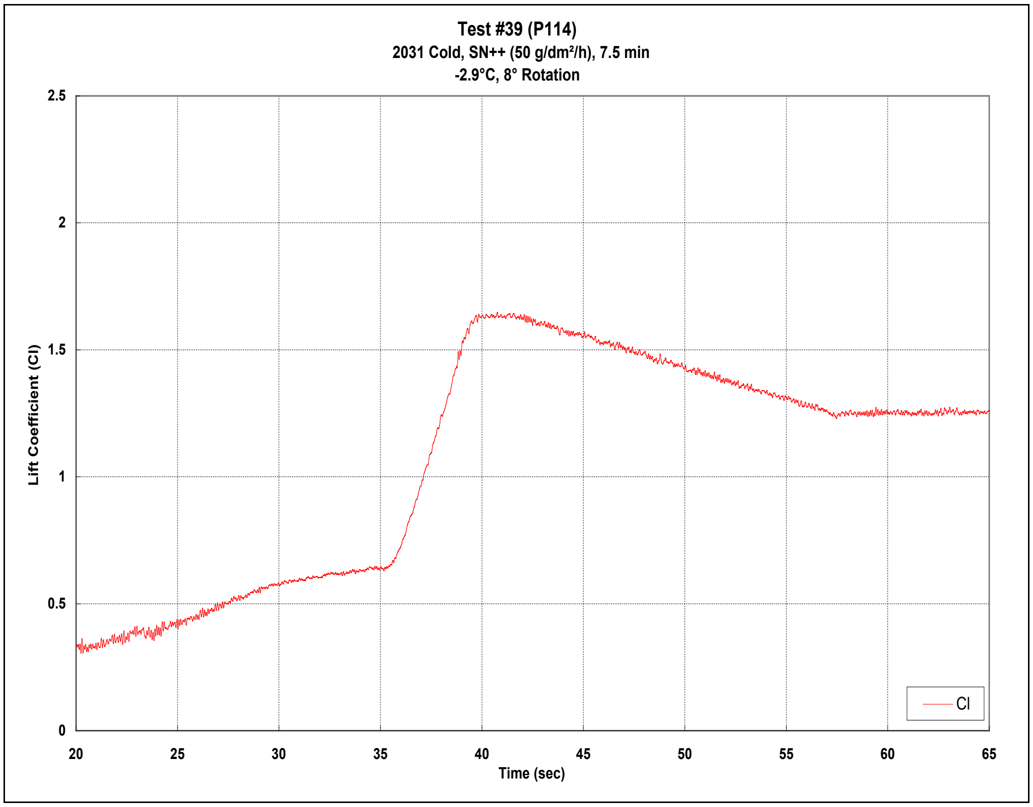


Figure C29: Run #39

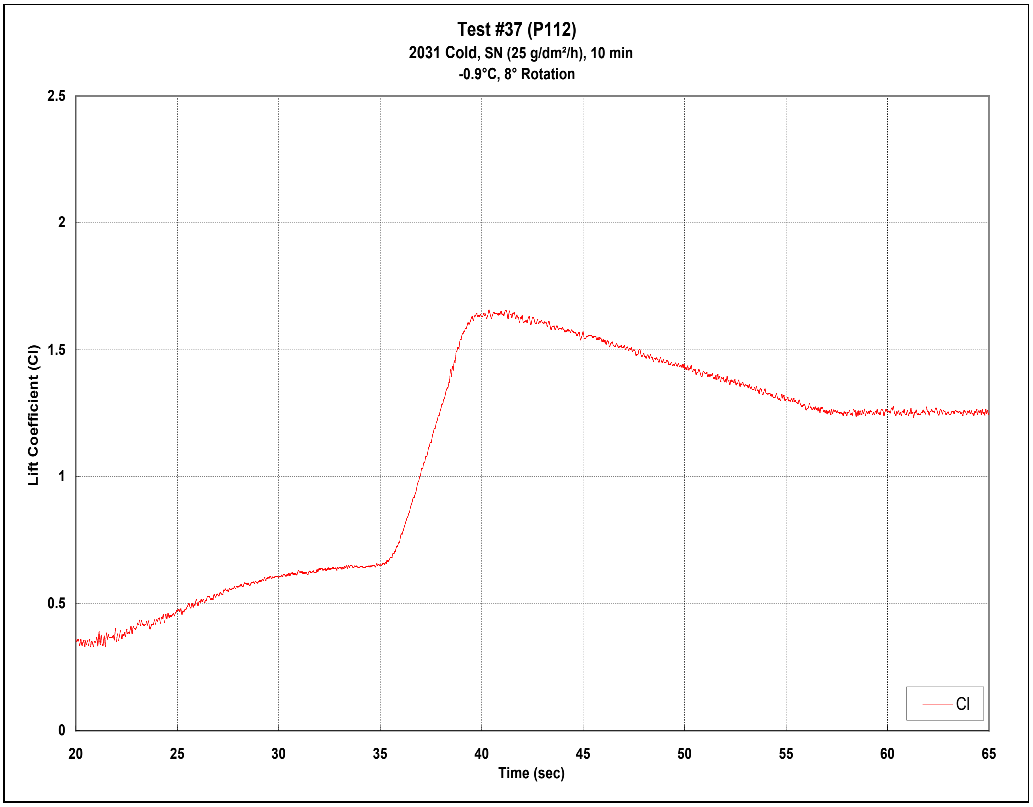


Figure C30: Run #37

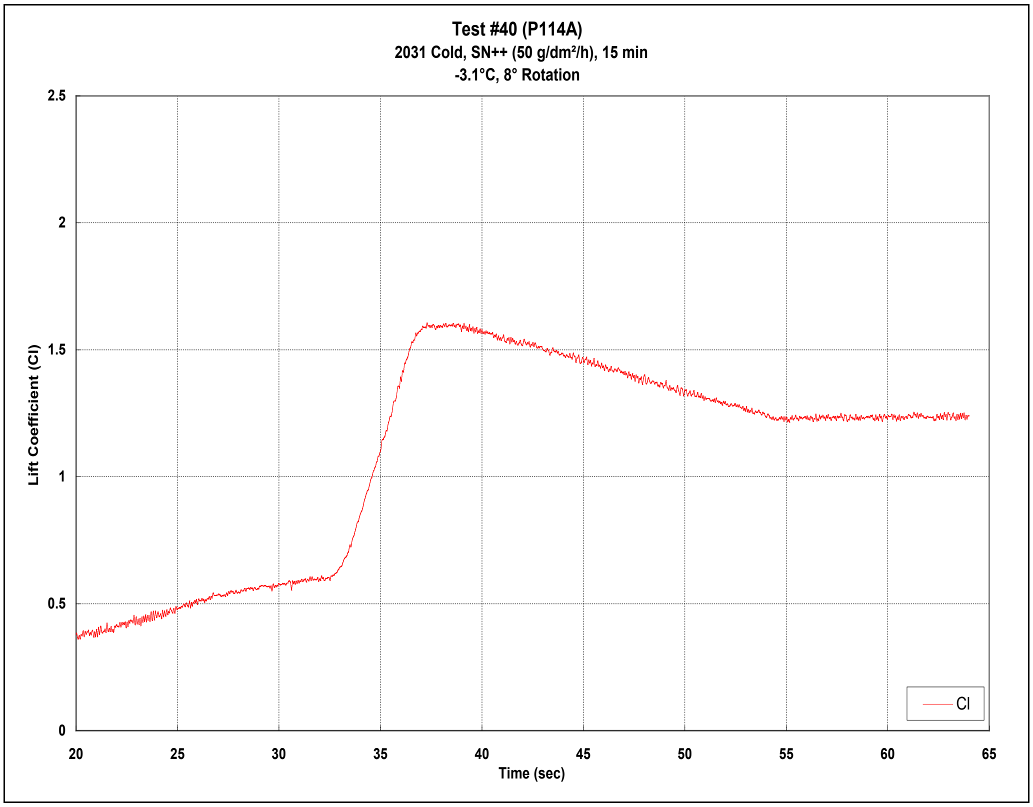


Figure C31: Run #40

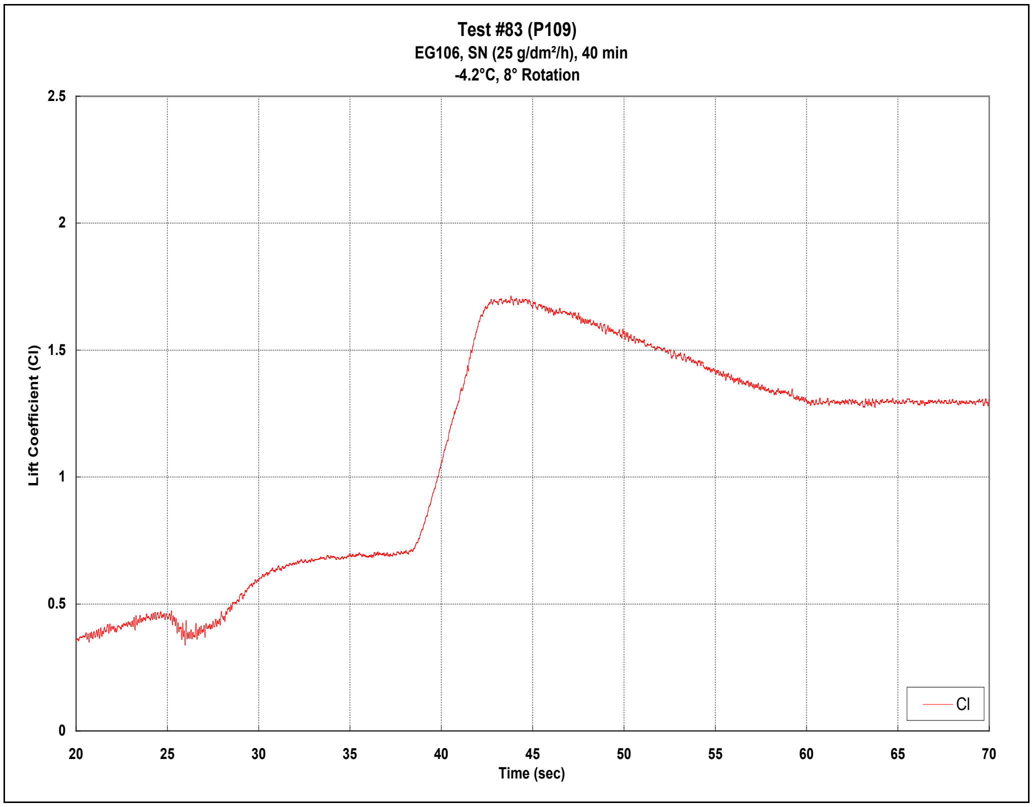


Figure C32: Run #83

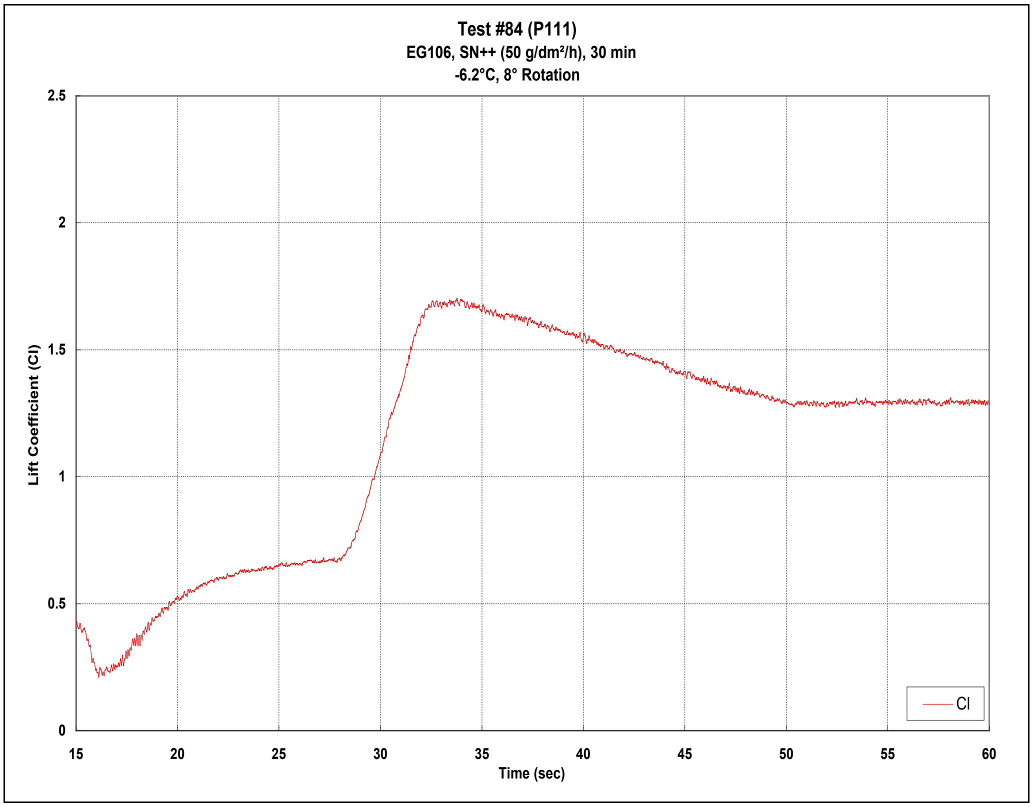


Figure C33: Run #84

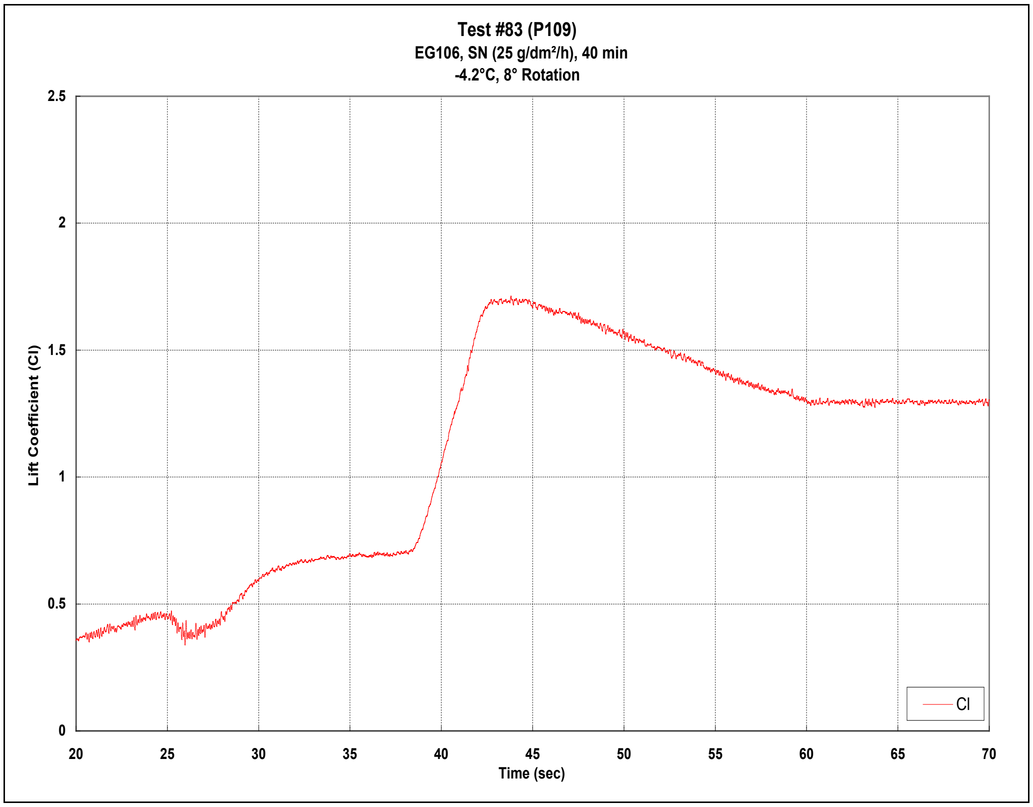


Figure C34: Run #83

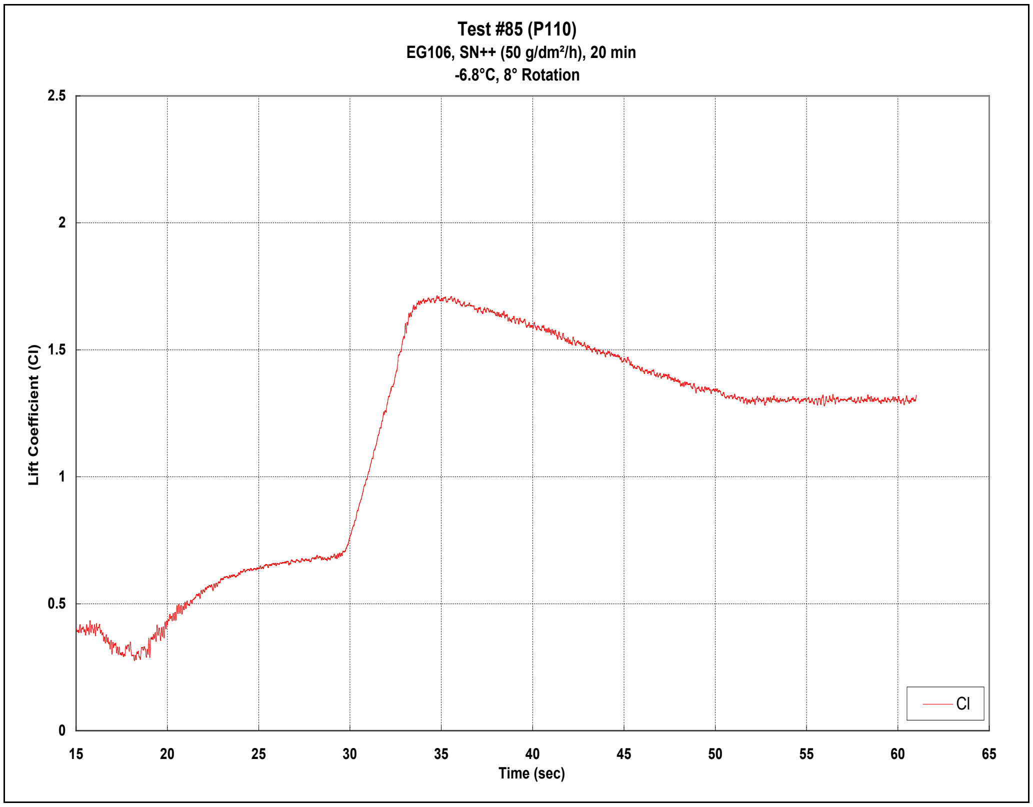


Figure C35: Run #85

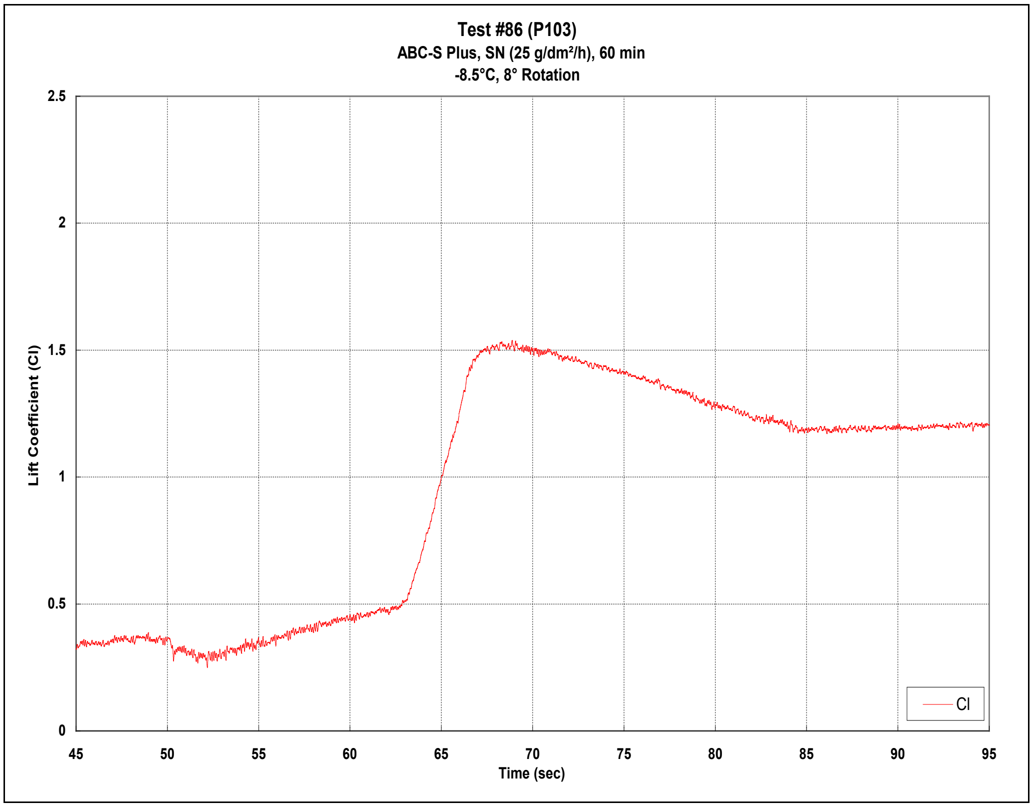


Figure C36: Run #86

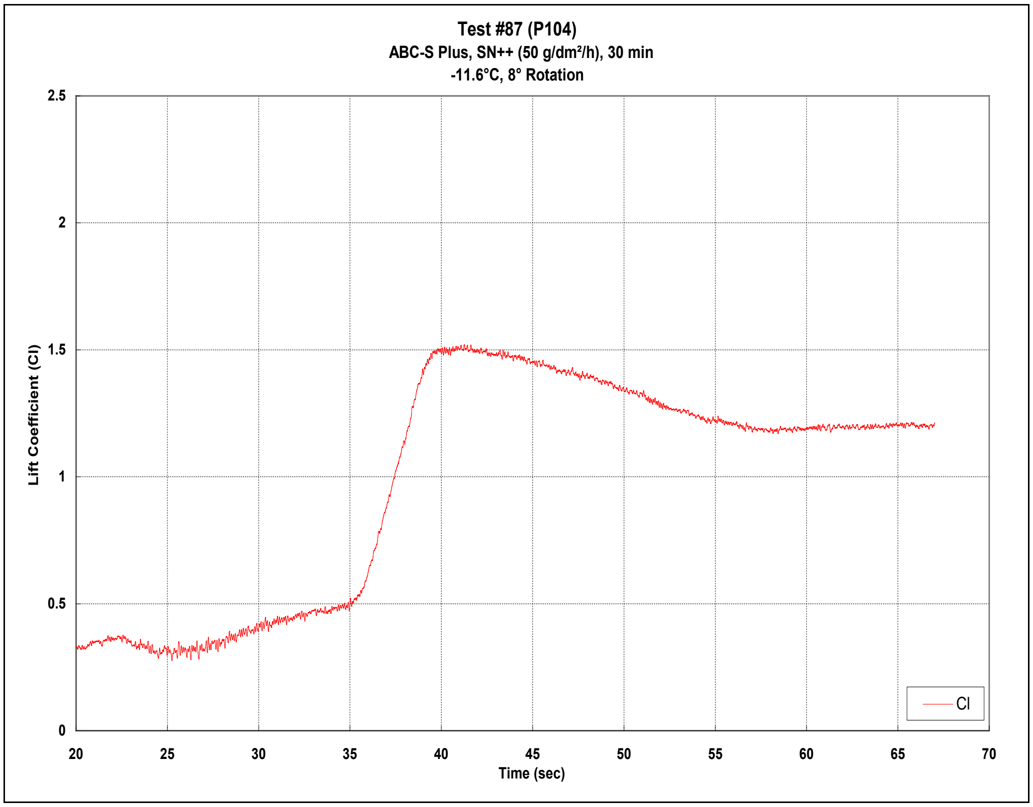


Figure C37: Run #87

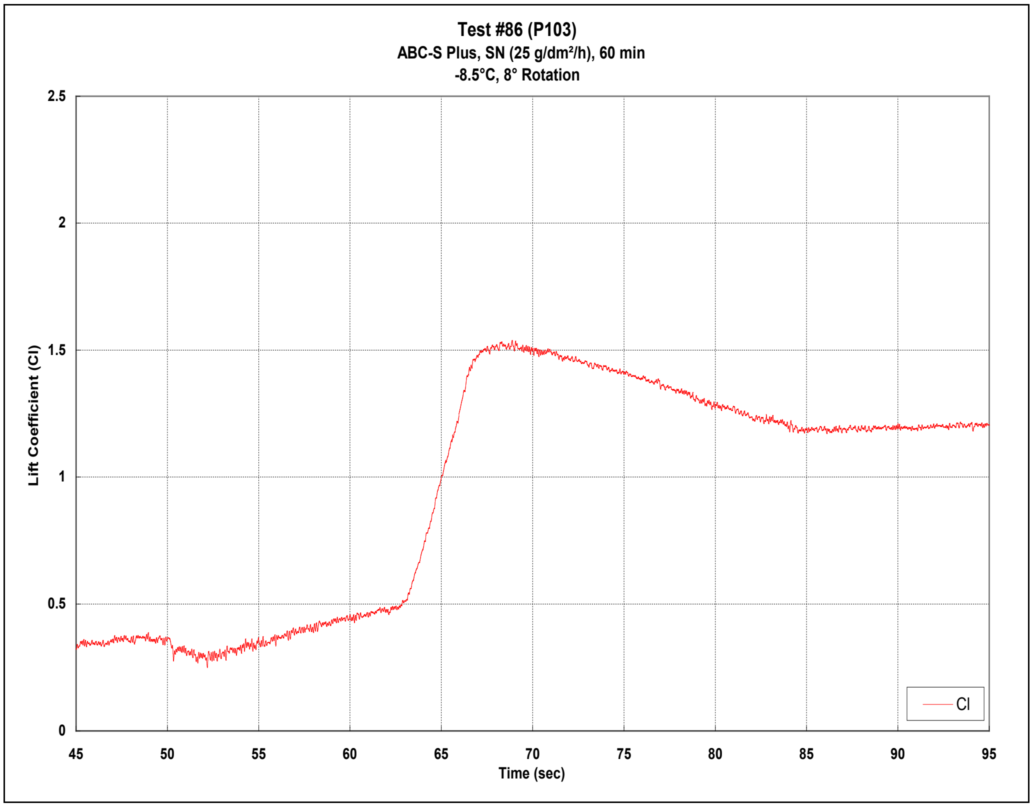
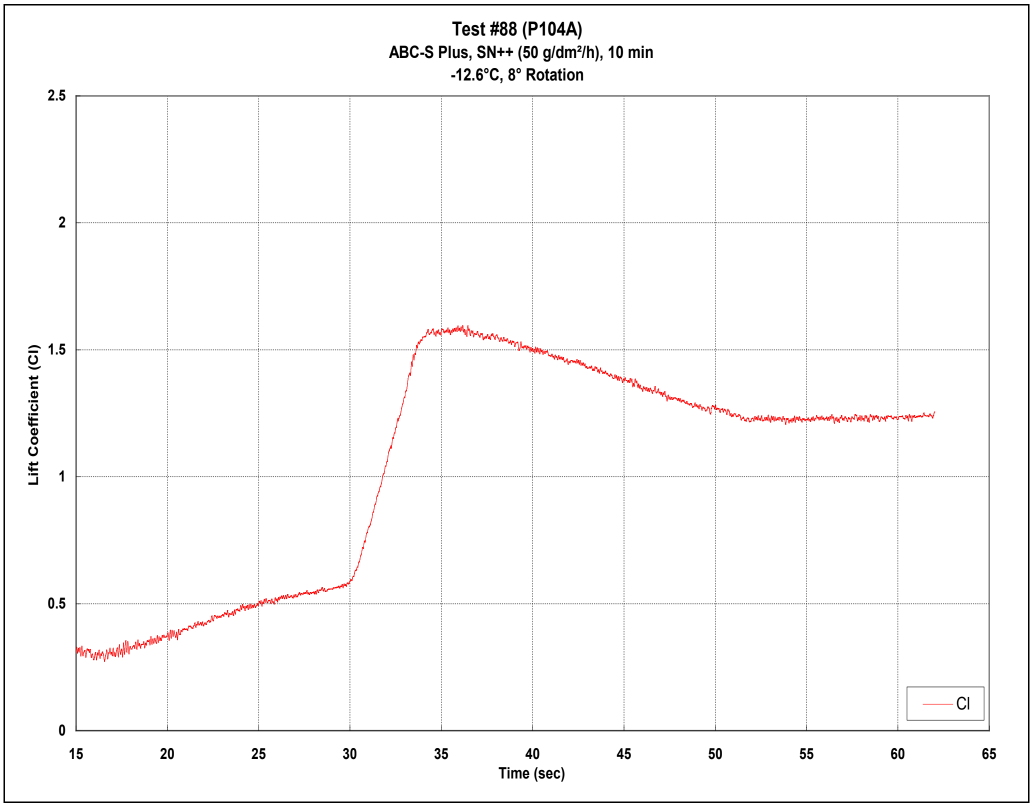


Figure C38: Run #86



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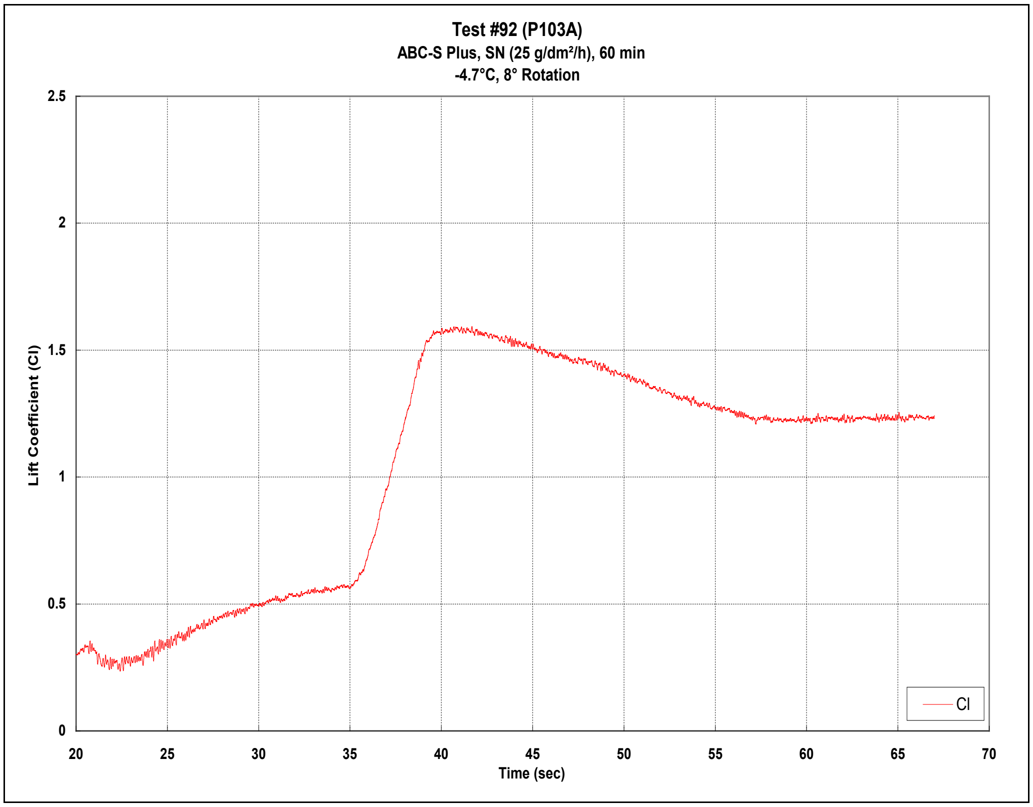
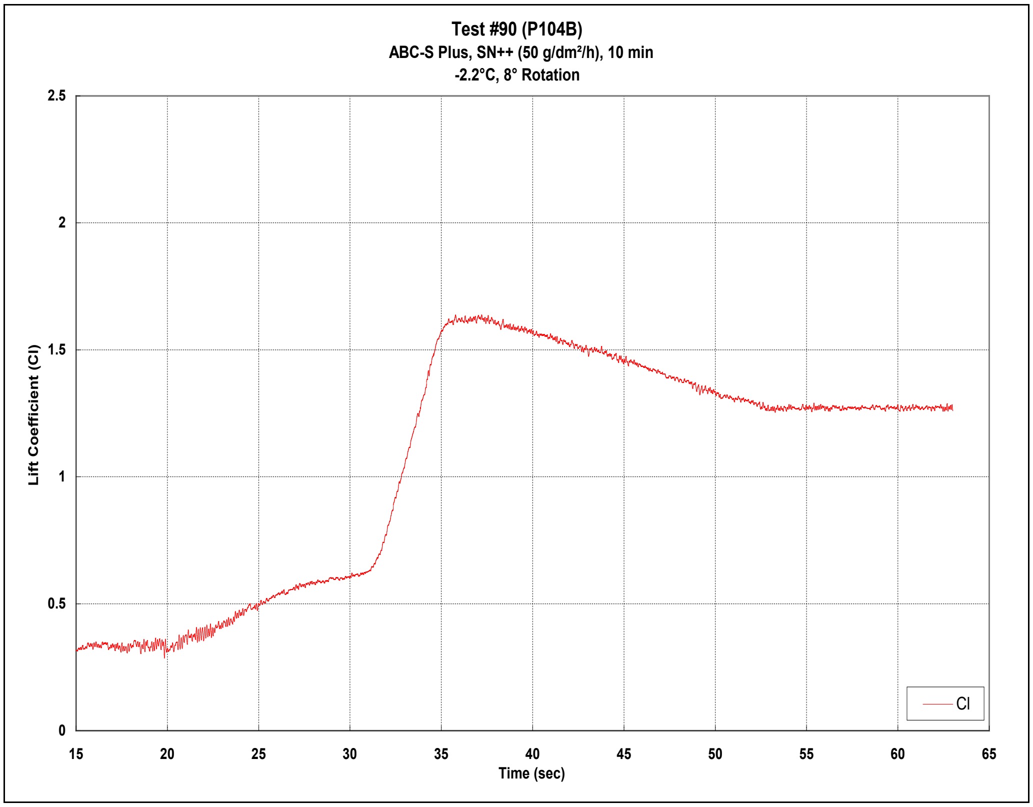


Figure C40: Run #92



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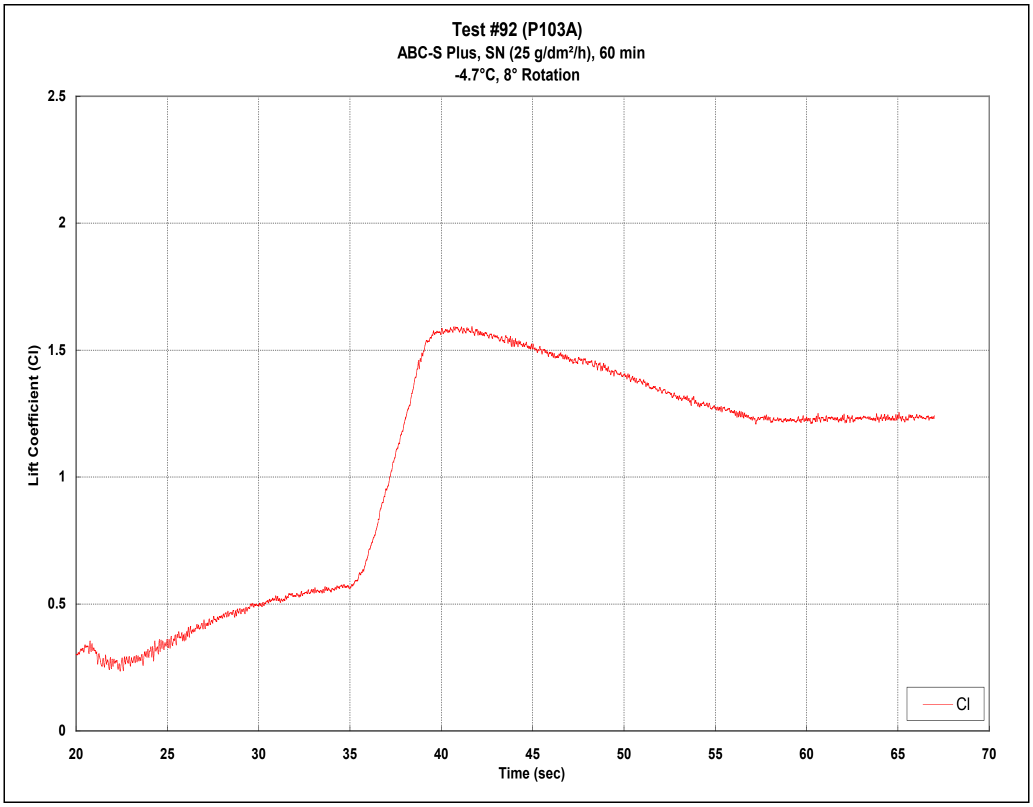

Figure C42: Run #92

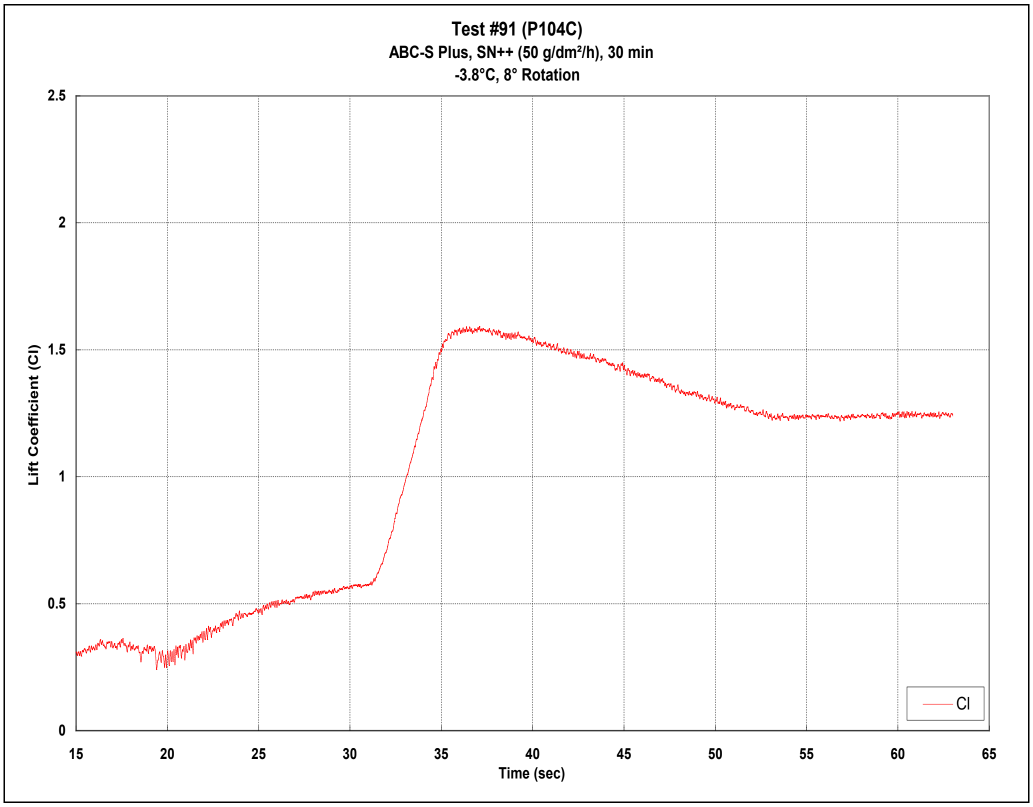

Figure C43: Run #91

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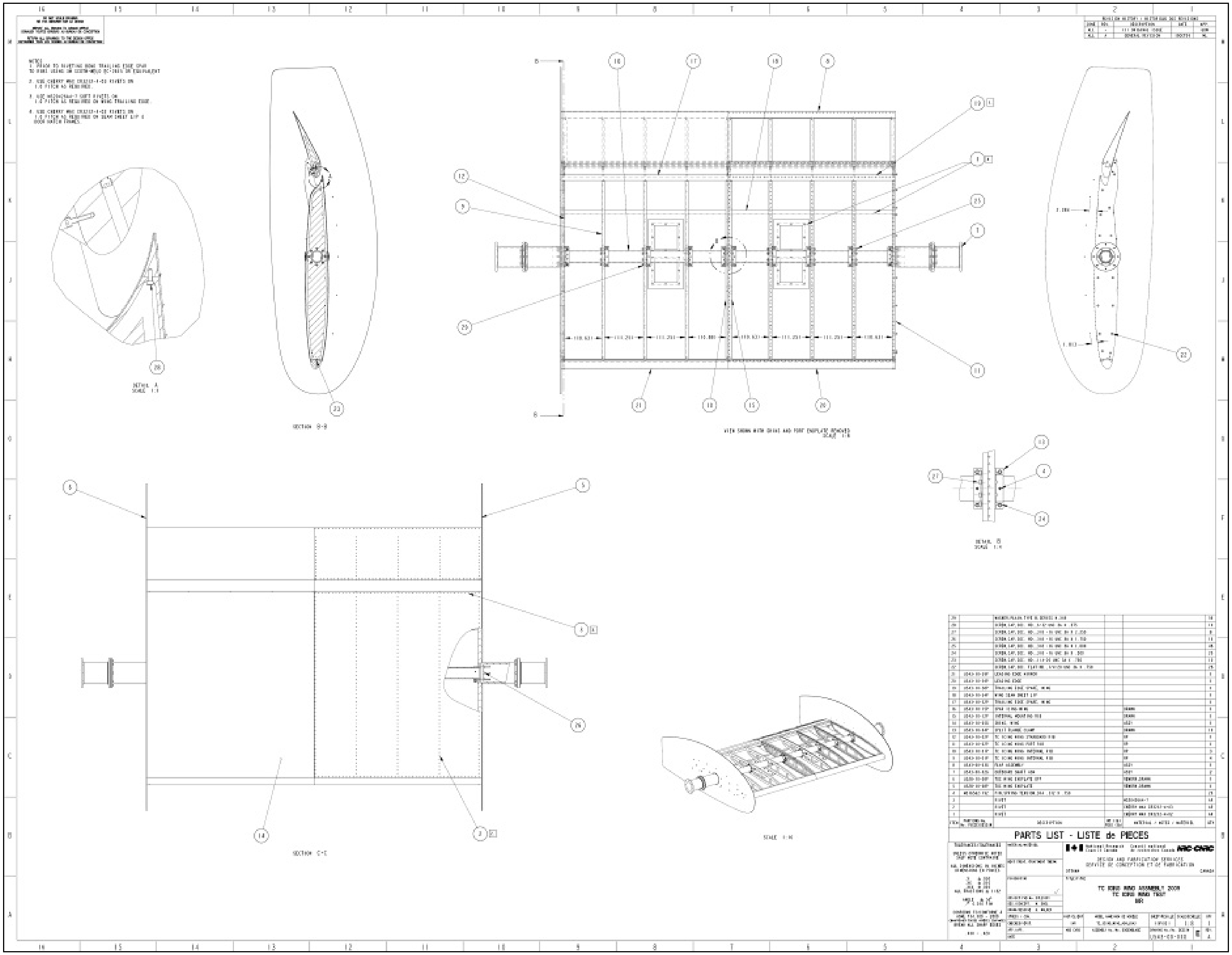
APPENDIX D

WING COORDINATES

Main Airfoil (Flap 0º) Coordinates		Main Airfoil (Flap 0º) Coordinates Cont'd		Main Airfoil (Flap 0º) Coordinates Cont'd		Flap Deployed (20º) Coordinates		Main Aft Coordinates	
1.000	-0.0011	0.069	-0.0240	0.375	0.0540	1.017	-0.0849	0.773	0.0314
0.999	-0.0011	0.065	-0.0235	0.400	0.0536	1.009	-0.0823	0.772	0.0311
0.997	-0.0012	0.060	-0.0228	0.425	0.0531	1.001	-0.0794	0.770	0.0309
0.995	-0.0012	0.055	-0.0221	0.450	0.0524	0.992	-0.0762	0.769	0.0305
0.990	-0.0013	0.049	-0.0213	0.475	0.0515	0.982	-0.0727	0.767	0.0302
0.985	-0.0014	0.043	-0.0205	0.500	0.0506	0.971	-0.0688	0.765	0.0297
0.980	-0.0015	0.037	-0.0195	0.525	0.0495	0.960	-0.0647	0.764	0.0294
0.970	-0.0017	0.032	-0.0185	0.550	0.0482	0.947	-0.0604	0.762	0.0289
0.960	-0.0020	0.026	-0.0174	0.575	0.0469	0.934	-0.0559	0.760	0.0283
0.950	-0.0022	0.021	-0.0161	0.600	0.0454	0.921	-0.0514	0.758	0.0278
0.940	-0.0024	0.016	-0.0148	0.620	0.0441	0.907	-0.0469	0.757	0.0273
0.930	-0.0027	0.012	-0.0132	0.640	0.0427	0.893	-0.0424	0.755	0.0267
0.920	-0.0030	0.009	-0.0116	0.660	0.0413	0.879	-0.0380	0.753	0.0256
0.910	-0.0034	0.006	-0.0098	0.680	0.0398	0.865	-0.0338	0.750	0.0247
0.900	-0.0038	0.004	-0.0080	0.700	0.0382	0.852	-0.0298	0.749	0.0240
0.880	-0.0048	0.002	-0.0061	0.720	0.0364	0.840	-0.0260	0.747	0.0231
0.860	-0.0058	0.001	-0.0043	0.740	0.0346	0.828	-0.0225	0.745	0.0222
0.840	-0.0071	0.000	-0.0027	0.760	0.0327	0.817	-0.0193	0.744	0.0213
0.820	-0.0084	0.000	-0.0012	0.780	0.0307	0.807	-0.0164	0.741	0.0199
0.800	-0.0099	0.000	0.0000	0.800	0.0286	0.798	-0.0137	0.739	0.0188
0.780	-0.0114	0.000	0.0013	0.820	0.0264	0.790	-0.0114	0.738	0.0177
0.760	-0.0129	0.000	0.0029	0.840	0.0241	0.783	-0.0093	0.736	0.0167
0.740	-0.0145	0.001	0.0049	0.860	0.0217	0.777	-0.0075	0.735	0.0158
0.720	-0.0162	0.001	0.0071	0.880	0.0192	0.771	-0.0058	0.733	0.0142
0.700	-0.0179	0.002	0.0096	0.900	0.0166	0.766	-0.0043	0.731	0.0129
0.680	-0.0196	0.004	0.0124	0.910	0.0152	0.762	-0.0023	0.729	0.0117
0.660	-0.0213	0.006	0.0152	0.920	0.0139	0.760	0.0002	0.727	0.0100
0.640	-0.0231	0.010	0.0181	0.930	0.0125	0.758	0.0030	0.725	0.0081
0.620	-0.0248	0.013	0.0210	0.940	0.0110	0.758	0.0058	0.724	0.0066
0.600	-0.0265	0.018	0.0237	0.950	0.0096	0.758	0.0081	0.723	0.0055
0.575	-0.0285	0.023	0.0261	0.960	0.0081	0.759	0.0104	0.721	0.0041
0.550	-0.0303	0.029	0.0282	0.970	0.0065	0.761	0.0126	0.720	0.0032
0.525	-0.0319	0.035	0.0300	0.980	0.0048	0.764	0.0149	0.719	0.0020
0.500	-0.0333	0.041	0.0316	0.985	0.0039	0.767	0.0171	0.718	0.0007
0.475	-0.0345	0.047	0.0331	0.990	0.0030	0.771	0.0192	0.717	-0.0009
0.450	-0.0356	0.053	0.0345	0.995	0.0021	0.776	0.0209	0.716	-0.0023
0.425	-0.0364	0.059	0.0356	0.997	0.0017	0.782	0.0225	0.714	-0.0036
0.400	-0.0370	0.065	0.0366	0.999	0.0013	0.789	0.0238	0.713	-0.0049
0.375	-0.0375	0.070	0.0374	1.000	0.0011	0.796	0.0247	0.712	-0.0058
0.350	-0.0378	0.074	0.0381			0.805	0.0247	0.711	-0.0067
0.325	-0.0379	0.082	0.0393			0.815	0.0234	0.709	-0.0080
0.300	-0.0379	0.090	0.0405			0.825	0.0203	0.708	-0.0090
0.280	-0.0377	0.098	0.0417			0.836	0.0159	0.706	-0.0107
0.260	-0.0373	0.108	0.0429			0.847	0.0103	0.704	-0.0116
0.240	-0.0368	0.117	0.0440			0.859	0.0041	0.703	-0.0126
0.220	-0.0362	0.127	0.0451			0.872	-0.0024	0.701	-0.0136
0.200	-0.0354	0.138	0.0462			0.885	-0.0092	0.699	-0.0145
0.187	-0.0347	0.150	0.0473			0.899	-0.0163	0.698	-0.0150
0.174	-0.0340	0.162	0.0483			0.912	-0.0235	0.696	-0.0159
0.161	-0.0332	0.174	0.0494			0.925	-0.0307	0.695	-0.0164
0.149	-0.0323	0.187	0.0504			0.938	-0.0377	0.693	-0.0169
0.138	-0.0315	0.200	0.0512			0.951	-0.0446	0.692	-0.0174
0.127	-0.0305	0.220	0.0522			0.963	-0.0513	0.690	-0.0179
0.117	-0.0296	0.240	0.0529			0.974	-0.0575	0.688	-0.0183
0.107	-0.0286	0.260	0.0535			0.985	-0.0634	0.687	-0.0186
0.098	-0.0276	0.280	0.0539			0.994	-0.0689	0.684	-0.0191
0.089	-0.0265	0.300	0.0541			1.003	-0.0740	0.681	-0.0195
0.081	-0.0255	0.325	0.0543			1.011	-0.0787		
0.073	-0.0246	0.350	0.0543			1.018	-0.0829		


PARTS LIST - LISTE de PIECES
NRC-CNRC
DESIGN AND FABRICATION SERVICES
SERVICE DE CONCEPTION ET DE FABRICATION
CANADA

APPENDIX E

ADDITIONAL NOTES AND OBSERVATIONS AT THE NRC WIND TUNNEL

Form 5

CAMERA LOCATIONS FORM

(Fill in only once unless camera locations are changed)

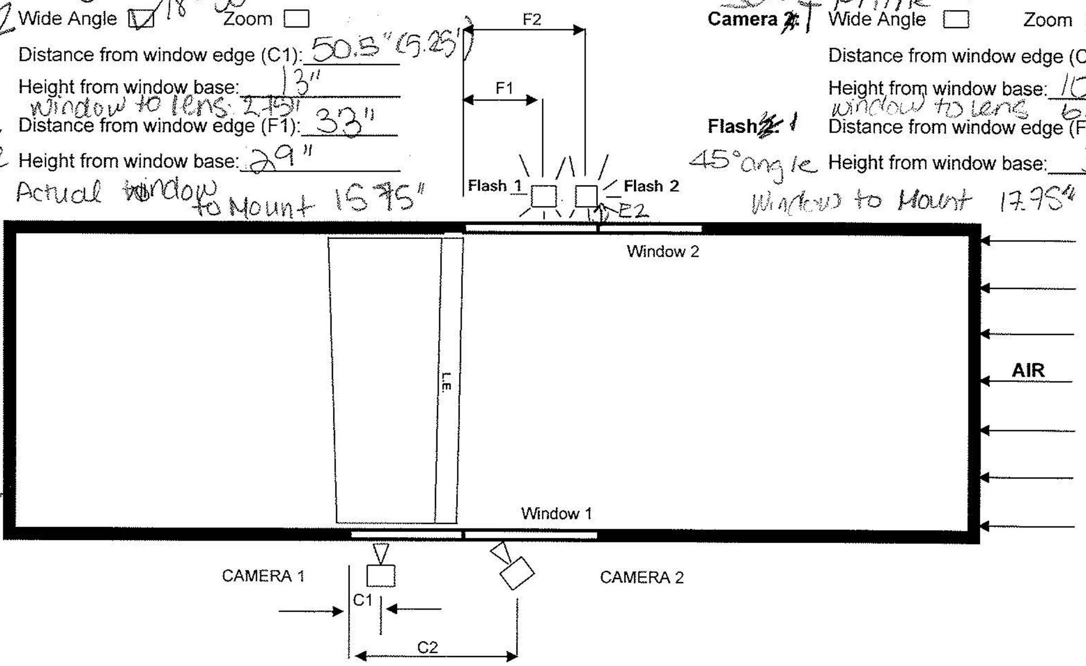
Date: February 2, 2010
Time: 23:30
Run Numbers: ______

Camera ~~1~~: 2 Wide Angle ☑ 18-50 Zoom ☐
Distance from window edge (C1): 50.5" (5.25')
Height from window base: 13"
window to lens: 2.75"

Flash ~~1~~: 2
45° angle
Distance from window edge (F1): 33"
Height from window base: 29"
Actual window to Mount 15 75"

Sony Prime
Camera ~~2~~: 1 Wide Angle ☐ Zoom ☐
Distance from window edge (C2): 3"
Height from window base: 10"
window to lens 6.75"

Flash ~~2~~: 1
45° angle
Distance from window edge (F2): 29"*
Height from window base: 39"
Window to Mount 17.75"



*99.5" from edge of window FLASH 2

OBSERVER: Ben

ASSISTED BY: VICTORIA

Observations: ______

M:/Groups/PM2020(TC-Deicing 05-06)/Procedures/Data Forms/WT VZ docs

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