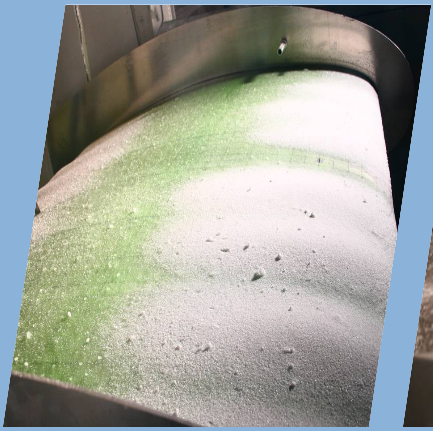
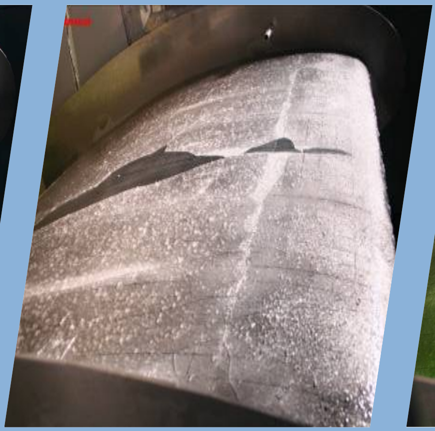
TP 14939E

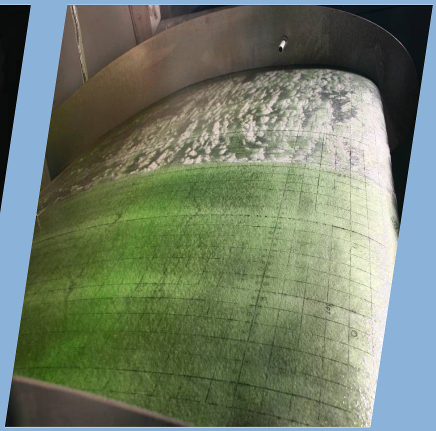
Exploratory Wind Tunnel Aerodynamic Research

Examination of Contaminated Anti-Icing Fluid Flow-Off Characteristics

Winter 2008-09







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Transportation Development Centre

In cooperation with

Civil Aviation
Transport Canada

and

The Federal Aviation Administration
William J. Hughes Technical Center

Prepared by:

APS Aviation Inc.

March 2010
Final Version 1.0

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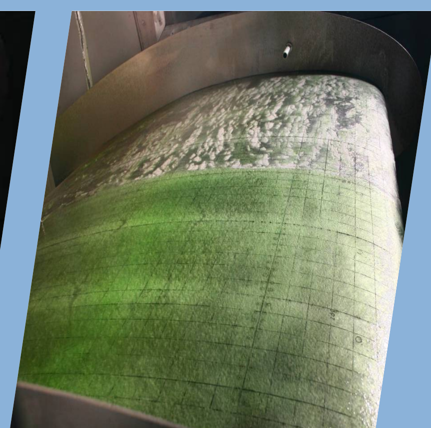

by

Marco Ruggi

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March 2010
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The contents of this report reflect the views of APS Aviation Inc. and not necessarily the official view or opinions of the Transportation Development Centre of Transport Canada.

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

DOCUMENT ORIGIN AND APPROVAL RECORD

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Un sommaire français se trouve avant la table des matières.

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PREFACE

Under contract to the Transportation Development Centre of Transport Canada, 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 evaluate weather data from previous winters that can have an impact on the format of the holdover time guidelines;
- 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 conduct endurance time tests in frost on various test or wing surfaces;
- To conduct endurance time tests on non-aluminum plates;
- To conduct endurance time tests to support the removal of the below -25°C row of the holdover time guidelines;
- To conduct general and exploratory de/anti-icing research;
- To conduct endurance time tests to expand the current holdover guidelines to include conditions of rain and snow;
- To evaluate the effect of poor fluid application on fluid endurance times;
- To evaluate holdover times for anti-icing in a hangar;
- To review the use of the visibility table for use with holdover times;
- To conduct research at the National Research Council Canada wind tunnel to further develop and expand ice pellet allowance times;
- To conduct various aerodynamic research activities at the National Research Council Canada wind tunnel;
- To initiate research for development of ice detection capabilities for departing aircraft at the runway threshold; and
- To update the regression coefficient report with the newly-qualified de/anti-icing fluids.

The research activities of the program conducted on behalf of Transport Canada during the winter of 2008-09 are documented in seven reports. The titles of the reports are as follows:

- TP 14933E Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2008-09 Winter;
- TP 14934E Winter Weather Impact on Holdover Time Table Format (1995-2009);
- 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;
- TP 14936E Aircraft Ground Icing General Research Activities During the 2008-09 Winter;

- TP 14937E Regression Coefficients and Equations Used to Develop the Winter 2009-10 Aircraft Ground Deicing Holdover Time Tables;
- TP 14938E Substantiation of Aircraft Ground Deicing Holdover Times in Frost Conditions; and
- TP 14939E Exploratory Wind Tunnel Aerodynamic Research Examination of Contaminated Anti-Icing Fluid Flow-Off Characteristics Winter 2008-09.

In addition, the following interim report is being prepared:

- *Fluid Endurance Times Using Composite Surfaces.*

This report, TP14939E, 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 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, Matthew Bowen, Chris Burke, Michael Chaput, John D’Avirro, Peter Dawson, Jeff Ford, Benjamin Guthrie, Michael Hawdur, Eric Perocchio, Michelle Pineau, Dany Posteraro, Marco Ruggi, Joey Tiano, David Youssef and Victoria Zoitakis.

Special thanks are extended to Angelo Boccanfuso, Yagusha Bodnar, Frank Eyre, 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.

In memory of the late Barry Myers whose wisdom and knowledge combined with his dedication and perseverance has played a fundamental role in the development of the aircraft ground deicing program. His presence will be missed by all who had the privilege of making his acquaintance.

PROJECT ACKNOWLEDGEMENTS

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.

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

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

- Effects of Surface Roughness: When comparing bare wing versus contaminated wing (with no fluid) the results indicate that as the angle of rotation is increased, the difference in the lift coefficient data is also increased. The testing conducted demonstrated varying aerodynamic effects as a result of the type of contamination adhered to the wing section.
- Light Snow Mixed with Light Rain: The Type IV results demonstrated positive results and supported the flat plate testing results recommending the use of light freezing rain holdover times for conditions of mixed light snow and light rain.
- Moderate Snow Mixed with Light Freezing Rain: Although the results were limited, the results indicate a potential for guidance material in mixed light freezing rain and moderate snow conditions.
- Inadequate Anti-Icing Fluid Application: The results indicate that the inadequate fluid application will generate a visually more severe condition following precipitation, however the severity of these scenario is dependent on the type of precipitation, primarily the potential for adhered contamination.
- Frost Fluid Freeze Point Failure: The wind tunnel results supported previous flat plate testing. Although the contamination did not seem to adhere during the plate tests, the wind tunnel tests demonstrated that the contamination was not removed by the time of rotation, and that the level of contamination worsened by the end of the test.
- Low Speed Ramp Testing: The results indicate that increasing the aerodynamic acceptance test speed profile from 67 knots rotation, to 80+ knots rotation could potentially provide better aerodynamic results for Type IV fluids, and potentially allow Type IV fluids to be certified for low-speed aircraft.
- Heavy Snow: The results indicate that visually, moderate snow holdover times are not applicable for heavy snow conditions; visual results indicate that it should be approximately half the moderate snow. The results were in accordance with the preliminary results obtained during the 2006-07 wind tunnel tests.
- Future Testing: It is recommended that for future wind tunnel testing, the simulated takeoff profile should target the clean wing stall angle as the maximum angle of attack in order to better quantify the observed lift losses. In addition, during contaminated test runs, a baseline fluid only case should be run immediately before, or after the contaminated test run to provide a direct correlation of the results. It is also recommended that aerodynamic research be conducted to investigate the effects of adhered frozen contamination on a super-critical wing model. Additional research should be conducted to continue the work related to mixed light freezing rain and moderate snow, low speed ramp testing, 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, Light Snow Mixed with Light Rain, Moderate Snow Mixed with Light Freezing Rain, Inadequate Anti-Icing, Frost, Heavy Snow	18. Distribution Statement Limited number of copies available from the Transportation Development Centre

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

Plusieurs rapports de 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.

- Effets de la rugosité des surfaces : Lorsqu'une aile nue est comparée à une aile contaminée (sans liquide), les résultats démontrent que la différence dans les données de coefficient de portance augmente en même temps que l'angle de rotation. Les essais réalisés ont démontré des effets aérodynamiques variés selon le type de contaminants ayant adhéré à la section d'aile.
- Conditions mixtes de neige légère et de pluie légère : Les essais réalisés avec le liquide de type IV ont généré des résultats positifs venant corroborer ceux obtenus lors des essais sur plaque plane et qui recommandaient d'utiliser les durées d'efficacité associées à la pluie verglaçante légère pour les conditions mixtes de neige légère et de pluie légère.
- Conditions mixtes de neige modérée et de pluie verglaçante légère : Les résultats, bien que limités, indiquent la possibilité d'élaborer des lignes directrices pour les conditions mixtes de pluie verglaçante légère et de neige modérée.
- Application inadéquate de liquide d'antigivrage : Les résultats indiquent que l'application inadéquate de liquide entraîne des conditions plus graves sur le plan visuel après les précipitations ; la gravité de ce scénario dépend toutefois du type de précipitations, principalement de la possibilité que les contaminants adhèrent aux surfaces.
- Perte d'efficacité au point de congélation du liquide dans des conditions givrantes : Les résultats obtenus dans la soufflerie concordent avec ceux obtenus précédemment sur plaque plane. Même si les contaminants ne semblaient pas adhérer aux surfaces durant les essais sur plaque, les essais en soufflerie ont démontré que la contamination n'avait pas été éliminée au moment de la rotation et que le taux de contamination s'était aggravé à la fin de l'essai.
- Essai d'accélération à basse vitesse : Les résultats indiquent que l'augmentation du profil de vitesse de l'essai d'acceptabilité aérodynamique de 67 nœuds à 80 nœuds et plus pourrait générer de meilleurs résultats aérodynamiques pour les liquides de type IV et permettre à ceux-ci d'être certifiés pour les aéronefs à basse vitesse.
- Neige lourde : Les résultats indiquent que visuellement, les durées d'efficacité dans des conditions de neige modérée ne peuvent être appliquées aux conditions de neige lourde. Les résultats visuels démontrent que les durées d'efficacité devraient être diminuées de moitié par rapport à celles pour la neige modérée. Ces résultats concordent avec les résultats préliminaires obtenus au cours des essais en soufflerie menés en 2006-2007.
- Essais futurs : Pour les prochains essais en soufflerie, le profil de décollage simulé devrait utiliser l'angle de décrochage de l'aile propre comme angle d'attaque maximum afin de mieux quantifier les pertes de portance observées. En outre, durant les essais avec contamination, un essai de référence avec liquide non contaminé devrait être effectué immédiatement avant ou après l'essai avec contamination afin d'établir un lien direct entre les résultats. Des essais aérodynamiques devraient également être réalisés afin d'étudier les effets de la contamination gelée ayant adhéré aux surfaces sur un modèle d'aile supercritique. D'autres recherches devraient être effectuées afin de poursuivre les travaux sur les conditions mixtes de pluie verglaçante légère et de neige modérée, l'accélération à basse vitesse et les conditions de 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 des surfaces, conditions mixtes de neige légère et de pluie légère, conditions mixtes de neige modérée et de pluie verglaçante légère, antigivrage inadéquat, givre, neige lourde	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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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) 3m 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 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* (1).

Objectives

A preliminary test plan was developed for the winter of 2008-09. Testing was conducted with and without contamination. Research was conducted to satisfy the following objectives:

- Examination of the effects of surface roughness on aerodynamic performance;
- Inclusion of mixed light rain or light freezing rain and snow conditions into the holdover time (HOT) guidelines;
- Examination of the aerodynamic effects of inadequate anti-icing applications in freezing precipitation conditions;
- Examination of the aerodynamic effects of fluid freeze point failure in simulated frost conditions;
- Expansion of current low speed ramp aerodynamic acceptance test parameters (67 knot rotation versus 80 knots); and
- Examination of the aerodynamic effects of heavily contaminated anti-icing fluid subjected to artificial snow conditions.

An additional test was conducted to investigate the potential development of ice pellet allowance times for Type I fluid, however, due to procedural limitations, the results have not been included in this report.

Conclusions

Effects of Surface Roughness

When comparing bare wing versus contaminated wing (with no fluid) the results indicate that as the angle of rotation is increased, the difference in the lift coefficient data is also increased. The testing conducted demonstrated varying aerodynamic effects as a result of the type of contamination adhered to the wing section. During one test run, an early wing stall was experienced, indicating that although favourable aerodynamic results were achieved in the shallow angles of attack, the stall angle was significantly reduced due to the contamination.

Light Snow Mixed with Light Rain

The Type IV results demonstrated positive visual contamination ratings, as well as good lift coefficient results. This test supported the flat plate testing results recommending the use of light freezing rain HOTs for conditions of mixed light snow and light rain. Results from preliminary comparative Type I testing was inconclusive due to slush formation during the takeoff run.

Moderate Snow Mixed with Light Freezing Rain

The Type IV testing demonstrated that at the time of rotation, most of the contamination was eliminated, however some contamination remained adhered to the leading edge (aft of the stagnation point). Although the results were inconclusive due to the formation of the adhered contamination during takeoff runs (a result of the outside and inside temperature differentials), the results indicate a potential for guidance material in mixed light freezing rain and moderate snow conditions.

Inadequate Anti-Icing Fluid Application

In all cases tested, the inadequate fluid application generated shorter protection times. In all but one case (ice pellets only), the inadequate fluid application test section demonstrated poor fluid elimination at the time of rotation. The results indicate that the inadequate fluid application will generate a visually more severe condition following precipitation, however, the severity of these scenarios is dependent upon the type of precipitation, primarily the potential for adhered contamination.

Frost Fluid Freeze Point Failure

The results from the wind tunnel tests demonstrated similar crystalline formations as were observed with the white painted insulated aluminum plates. Although the contamination did not seem to adhere during the plate tests, the wind tunnel tests demonstrated that the contamination was not removed by the time of rotation, and that the level of contamination worsened by the end of the test.

Low Speed Ramp Testing

The results indicate that increasing the aerodynamic acceptance test speed profile from 67 knots rotation to 80+ knots 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, however, that these tests were conducted with no contamination, therefore, fluid elimination could potentially be further hampered with the presence of solid or adhered contamination.

Heavy Snow

The results indicate that visually, moderate snow HOTs are not applicable for heavy snow conditions. From a visual perspective, the heavy snow HOT should be approximately half the moderate snow HOT (or relative to the cumulative amount of precipitation applied) in order to have similar visual end conditions. The results from the 2008-09 heavy snow testing were in accordance with the preliminary results obtained during the 2006-07 wind tunnel tests.

Recommendations

Wind Tunnel Testing Methodology

It is recommended that for future wind tunnel testing, the simulated takeoff profile should target the clean wing stall angle as the maximum angle of attack in order to better quantify the observed lift losses. In addition, during contaminated test runs, a baseline fluid-only case should be run immediately before, or after the contaminated test run to provide a direct correlation of the results.

Effects of Surface Roughness

The current generation of “regional jet” aircraft are developed with super critical wing designs and require maintenance procedures to ensure a polished leading edge, as minimal amounts of contamination (in the form of bugs, et cetera.) can result in serious aerodynamic penalties. The same applies for the removal of contamination in the form of frozen precipitation. Due to the popularity of these aircraft, it is recommended that aerodynamic research be conducted to investigate the effects of adhered frozen contamination on a supercritical wing model.

Mixed Light Freezing Rain and Moderate Snow

Preliminary results were inconclusive due to procedural complications, however the results indicate a potential for guidance material in mixed light freezing rain and moderate snow conditions. Further work is required to further develop these preliminary results.

Low Speed Ramp Testing

The 2008-09 testing was conducted with no contamination; fluid elimination could potentially be further hampered with the presence of solid or adhered contamination. Additional testing is recommended to investigate the effect of contamination during low speed ramp test profiles.

Heavy Snow

It is recommended that additional testing be performed, in conjunction with flat plate testing, in order to determine a visually acceptable level of heavy snow contamination, followed by an aerodynamic validation of the flat plate results obtained.

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 le rapport de TC, 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* (1).

Objectifs

Un plan d'essais préliminaires a été élaboré pour l'hiver 2008-2009. Les essais ont été effectués avec et sans contamination. Les objectifs étaient les suivants :

- Examen des effets de la rugosité des surfaces sur la performance aérodynamique ;
- 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 d'une application inadéquate de liquide d'antigivrage dans des conditions de précipitations givrantes ;
- Examen des effets aérodynamiques de la perte d'efficacité des liquides au point de congélation dans des conditions givrantes simulées ;
- Élargissement des paramètres actuels des essais d'acceptabilité aérodynamique à basse vitesse (rotation de 67 nœuds par rapport à 80 nœuds) ; et
- Examen des effets aérodynamiques d'un liquide d'antigivrage fortement contaminé dans des conditions de neige simulées.

Un essai supplémentaire a été mené afin d'étudier l'éventuel développement de marges de tolérance dans des conditions de granules de glace pour les liquides de type I. Toutefois, en raison de restrictions sur le plan des procédures, les résultats n'ont pas été inclus dans le présent rapport.

Conclusions

Effets de la rugosité des surfaces

Lorsqu'une aile nue est comparée à une aile contaminée (sans liquide), les résultats démontrent que la différence dans les données de coefficient de portance augmente en même temps que l'angle de rotation. Les essais réalisés ont démontré des effets aérodynamiques variés selon le type de contaminants ayant adhéré à la section d'aile. Au cours d'un essai, un décrochage précoce de l'aile a été constaté, ce qui indique que, malgré l'obtention de résultats aérodynamiques favorables à des angles d'attaque faibles, l'angle de décrochage a été considérablement réduit en raison de la contamination.

Conditions mixtes de neige légère et de pluie légère

Les essais menés avec du liquide de type IV ont généré des taux de contamination visuelle positifs, ainsi que de bons résultats sur le plan du coefficient de portance. Ces essais viennent corroborer les résultats obtenus lors des essais sur plaque plane qui recommandaient d'utiliser les durées d'efficacité associées à la pluie verglaçante légère pour les conditions mixtes de neige légère et de pluie légère. Les résultats obtenus lors des essais préliminaires comparatifs avec du liquide de type I n'étaient pas concluants en raison de la formation de neige fondante durant la course de décollage.

Conditions mixtes de neige modérée et de pluie verglaçante légère

Les essais menés avec du liquide de type IV ont démontré qu'au moment de la rotation, la contamination avait presque entièrement été éliminée. Une petite quantité avait toutefois adhéré au bord d'attaque (à l'arrière du point d'arrêt). Les résultats n'étaient pas concluants en raison de la formation de contamination adhérant aux surfaces durant les courses de décollage (attribuable à la différence entre la température intérieure et extérieure), mais ils indiquent tout de même la possibilité d'élaborer des lignes directrices dans des conditions mixtes de pluie verglaçante légère et de neige modérée.

Application inadéquate de liquide d'antigivrage

Dans tous les cas testés, l'application inadéquate de liquide a donné lieu à des durées de protection plus courtes. Dans tous les cas sauf un (condition de granules de glace seulement), la section où le liquide avait été mal appliqué a démontré une mauvaise élimination du liquide au moment de la rotation. Les résultats indiquent que l'application inadéquate de liquide entraîne des conditions plus graves sur le plan visuel après les précipitations ; la gravité de ce scénario dépend toutefois du type de précipitations, principalement de la possibilité que les contaminants adhèrent aux surfaces.

Perte d'efficacité au point de congélation du liquide dans des conditions givrantes

Les résultats des essais en soufflerie ont démontré des formations cristallines semblables à celles observées sur les plaques d'aluminium isolées et peintes en blanc. Même si les contaminants ne semblaient pas adhérer aux surfaces durant les essais sur plaque, les essais en soufflerie ont démontré que la contamination n'avait pas été éliminée au moment de la rotation et que le taux de contamination s'était aggravé à la fin de l'essai.

Essai d'accélération à basse vitesse

Les résultats indiquent que l'augmentation du profil de vitesse de l'essai d'acceptabilité aérodynamique de 67 nœuds à 80 nœuds et plus pourrait générer de meilleurs résultats aérodynamiques pour les liquides de type IV et permettre à ceux-ci d'être certifiés pour les aéronefs à basse vitesse. Il convient toutefois de noter que ces essais ont été menés sans contamination ; l'élimination du liquide pourrait donc être entravée davantage par la présence de contaminants solides ou adhérant aux surfaces.

Neige lourde

Les résultats indiquent que visuellement, les durées d'efficacité dans des conditions de neige modérée ne peuvent être appliquées aux conditions de neige lourde. Sur le plan visuel, la durée d'efficacité pour les conditions de neige lourde devrait correspondre à environ la moitié de celle pour les conditions de neige modérée (ou être calculée en fonction du volume cumulé de précipitations appliquées) pour que les conditions visuelles finales soient semblables. Les résultats obtenus lors des essais de 2008-2009 sur les conditions de neige lourde concordaient avec les résultats préliminaires obtenus au cours des essais en soufflerie menés en 2006-2007.

Recommandations

Méthodologie des essais en soufflerie

Pour les prochains essais en soufflerie, le profil de décollage simulé devrait utiliser l'angle de décrochage de l'aile propre comme angle d'attaque maximum afin de mieux quantifier les pertes de portance observées. En outre, durant les essais avec contamination, un essai de référence avec liquide non contaminé devrait être effectué immédiatement avant ou après l'essai avec contamination afin d'établir un lien direct entre les résultats.

Effets de la rugosité des surfaces

Les avions de transport régional à réaction de la génération actuelle sont équipés d'ailes supercritiques et doivent être soumis à des procédures strictes d'entretien afin d'assurer un bord d'attaque poli, car des quantités minimes de contaminants (sous forme d'insectes, etc.) peuvent entraîner d'importantes pertes d'aérodynamisme. Il en va de même pour l'élimination de la contamination sous forme de précipitations gelées. En raison de la popularité de ces aéronefs, il est recommandé de mener des essais aérodynamiques afin d'étudier les effets des contaminants gelés ayant adhéré aux surfaces sur un modèle d'aile supercritique.

Conditions mixtes de pluie verglaçante légère et de neige modérée

Les résultats préliminaires n'étaient pas concluants en raison de complications sur le plan des procédures, mais ils indiquent tout de même la possibilité d'élaborer des lignes directrices dans des conditions mixtes de pluie verglaçante légère et de neige modérée. D'autres travaux sont requis pour développer davantage ces résultats préliminaires.

Essai d'accélération à basse vitesse

Les essais de 2008-2009 ont été menés sans contamination ; l'élimination du liquide pourrait être entravée davantage par la présence de contaminants solides ou adhérant aux surfaces. Il est recommandé d'effectuer d'autres essais afin d'étudier l'effet de la contamination durant les profils d'accélération à basse vitesse.

Neige lourde

Il est recommandé de réaliser d'autres essais, en même temps que les essais sur plaque plane, afin de déterminer le taux visuellement acceptable de contamination sous forme de neige lourde, suivis d'une validation aérodynamique des résultats obtenus sur la plaque plane.

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GLOSSARY

AEA	Association of European Airlines
APS	APS Aviation Inc.
CEF	Climatic Engineering Facility
C_L	Lift Coefficient
EG	Ethylene Glycol
FAA	Federal Aviation Administration
HOT	Holdover Time
HOTDS	Holdover Time Determination Systems
LOUT	Lowest Operational Use Temperature
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
PG	Propylene Glycol
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, 2006-07, 2007-08, and 2008-09 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 and with the Falcon 20 aircraft.

1.2 Objectives

APS conducted a series of preliminary tests during the winter of 2008-09 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 2008-09. Testing was conducted with and without contamination. Research was conducted to satisfy the following objectives:

- Examination of the aerodynamic effects of surface roughness on aerodynamic performance;
- Inclusion of mixed light rain or light freezing rain and snow conditions into the holdover time (HOT) guidelines;
- Examination of the aerodynamic effects of inadequate anti-icing applications in freezing precipitation conditions;
- Examination of the aerodynamic effects of fluid freezing point failure in simulated frost conditions;
- Expansion of current low-speed ramp aerodynamic acceptance test parameters (67 knot rotation versus 80 knots); 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 9 of this report. The work statement for these tests is provided in Appendix A.

An additional test was conducted to investigate the potential development of ice pellet allowance times for Type I fluid. Due to procedural limitations, the protocol employed was not representative of typical operations. As this was a low-priority objective, the results have not been included in this report. Some limited data from this test (Test #105) is shown in the global test log (Table 3.1). It is recommended that additional work be conducted with Type I fluid during the winter of 2009-10 as a low-priority objective.

1.3 Overview of 2008-09 Testing

Full-scale testing during the winter of 2008-09 was conducted using the NRC PIWT. The primary objective of the testing was to substantiate and possibly expand the current ice pellet allowance times. More specifically, testing was conducted in the following conditions:

- Type IV Fluid - High-Speed Ramp (Allowance times currently exist);
- Type IV Fluid - Low-Speed Ramp (No Allowance times exist);
- Type III Fluid - Low-Speed Ramp (No Allowance times exist); and
- Type II Fluid (No Allowance times exist).

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 2008-09. Only tests listed in the "Secondary R&D Objectives" grouping are described in this report. Table 1.2 demonstrates in greater detail the groupings for the secondary R&D objectives.

Table 1.1: Summary of 2008-09 Wind Tunnel Tests by Objective

Objective	Runs
1. Type IV High Speed (Total: 24 Runs)	8, 9, 10, 11, 13, 20, 21, 29, 30, 44, 51, 54, 58, 64, 65, 66, 67, 68, 69, 75, 76, 77, 85, 95
4. Type IV Low Speed (Total: 17 Runs)	12, 22, 25, 31, 33, 43, 45, 52, 53, 59, 86, 87, 88, 91, 92, 99, 106
2. Type II Low Speed (Total: 2 Runs)	23, 60
5. Baseline Fluid Only/Dry (Total: 21 Runs)	1, 2, 3, 4, 5, 6, 7, 15, 17, 18, 19, 24, 27, 27A, 28, 42, 46, 49, 55, 56, 98
3. Type III Low Speed (Total: 11 Runs)	14, 16, 26, 47, 48, 57, 73, 74, 78, 100, 101
6. Secondary R&D Objectives (Total: 34 Runs)	32, 34A, 35, 36, 37, 38, 39, 40, 41, 50, 61, 62, 63, 70, 71, 72, 72R, 79, 80, 81, 82, 83, 84, 89, 90, 93, 94, 96, 97, 102A, 103, 104, 105, 107

Table 1.2: Summary of 2008-09 Secondary R&D Objectives

Objective	Runs
1. Surface Roughness (Total: 13 Runs)	34A, 35, 36, 37, 38, 39, 40, 41, 93, 94, 102A, 103, 104
2. Mixed ZR/R & SN Conditions (Total: 5 Runs)	50, 72, 72R, 96, 97
3. Inadequate Anti-Icing (Total: 5 Runs)	32, 79, 83, 84, 107
4. Frost - Fluid Freezing Point Failure (Total: 2 Runs)	89, 90
5. Low Speed - 67 vs. 80 Knots (Total: 3 Runs)	80, 81, 82
6. Heavy Snow (Total: 5 Runs)	61, 62, 63, 70, 71

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 regarding the effects of surface roughness testing;

d) Section 5 describes the data, results, and observations regarding mixed light rain or light freezing rain and snow conditions testing;

e) Section 6 describes the data, results, and observations regarding the inadequate anti-icing application testing;

f) Section 7 describes the data, results, and observations regarding the simulated frost fluid freezing point failure testing;

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

h) Section 9 describes the data, results, and observations regarding the heavy snow testing;

i) Section 10 presents a summary of the conclusions and observations; and

j) Section 11 lists the recommendations for future testing.

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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. The test methodologies specific to the objectives will be described in their respective sections.

2.1 Wind Tunnel Test Site

The 2008-09 wind tunnel 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 testing, the gas turbine was selected to allow for greater flexibility, as it can perform both low- and high-speed operations, whereas the electric drive is limited solely to low-speed operations.

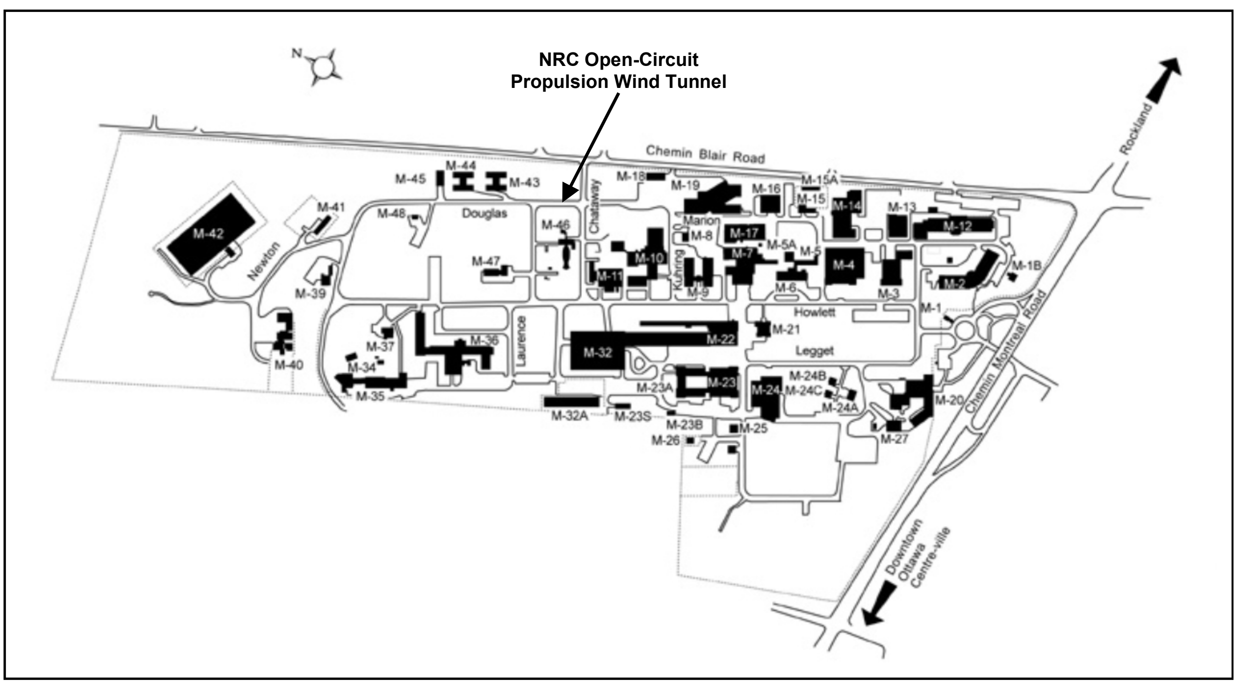

Figure 2.1: Schematic of NRC Montreal Road Campus

2.2 Test Schedule

Testing was conducted over a period of eight weeks starting January 15, 2009 and ending March 3, 2009. Three days were dedicated to setup and calibration prior to the start of the actual testing. Testing was conducted during 18 days over the eight-week period. A two-week "analysis break" was organized in mid-February to allow for a review of the data collected to date, and to allow for a revision of the test plan based on the previous results. Table 2.1 presents the calendar of wind tunnel tests performed in 2008-09. It should be noted that the tests listed comprise all the tests conducted, including the tests 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.

2.3 Wind Tunnel Procedure

To satisfy the program objective, simulated takeoff and climb-out tests were performed with the National Aeronautics and Space Administration (NASA) LS(1)-0417 wing section, and different parameters, including fluid thickness, wing temperature, and fluid freezing point, were recorded at designated times during the tests. This wing section was used during previous NRC tests [see TC report, TP 13426E, *Air-Flap Performance with De-Anti-Icing Fluids and Freezing Precipitation* (2) and TC report, TP 14180E, *Experimental and Numerical Studies of the Effects of Upper Surface Roughness on Aileron Performance* (3)].

The 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. This procedure may have been modified depending on the specific test objective. Variations from this methodology will be described in the respective sections pertaining to the test objective.

Table 2.1: Calendar of Tests

Date	Number of Test Runs	Test Numbers
15-Jan-09	Setup	n/a
16-Jan-09	Setup	n/a
21-Jan-09	Precip. Calib.	n/a
22-Jan-09	4	1, 2, 3, 4
26-Jan-09	6	5, 6, 7, 8, 9, 10
27-Jan-09	9	11, 12, 13, 14, 15, 16, 17, 18, 19
28-Jan-09	9	20, 21, 22, 23, 24, 25, 26, 26A, 26B
29-Jan-09	7	27, 27A, 28, 29, 30, 31, 32
30-Jan-09	10	33, 34, 35, 36, 37, 38, 39, 40, 41, 34A
31-Jan-09	8	42, 43, 44, 45, 46, 47, 48, 49
2-Feb-09	3	50, 51, 52
3-Feb-09	8	53, 54, 55, 54, 57, 58, 59, 60
4-Feb-09	4	61, 62, 63, 64
5-Feb-09	9	65, 66, 67, 68, 69, 70, 71, 72, 72R
23-Feb-09	2	73, 74
24-Feb-09	9	75, 76, 77, 78, 79, 80, 81, 82, 83
25-Feb-09	2	84, 85
28-Feb-09	3	86, 87, 88
1-Mar-09	10	89, 90, 91, 92, 93, 94, 95, 96, 97, 98
2-Mar-09	9	99, 100, 101, 102, 102A, 103, 104, 105, 106
3-Mar-09	1	107

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. Following the end of the first test session (on February 5, 2009), changes were made to the first version of the procedure. These changes were minor and included changes to improve the data collection process, as well as updates to the test plan based on the preliminary analysis. For these reasons, only the final version of the procedure (Version 1.2) has been included in this report in Appendix B.

2.4 Analysis Methodology

Due to the large amount of data collected during each test, a methodology was developed in order to facilitate the analysis process. The analysis typically evaluated ambient temperature, rate of precipitation, exposure time of precipitation, visual contamination ratings at the start of the test and time of rotation, and calculated lift coefficient (C_L) at 8-degree rotation. This methodology was modified as necessary to suit the objectives in this report, as not all evaluation parameters applied in each test. Details regarding this methodology can be found in the 2008-09 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* (1). The lift coefficient data collected as part of the "ice pellet allowance time" research has been included in Appendix C.

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 2.2 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.

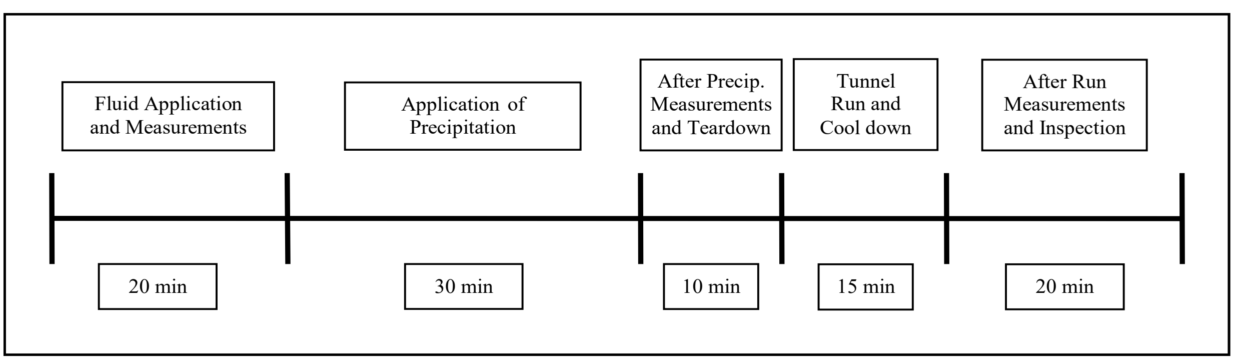

Figure 2.2: Typical Wind Tunnel Test Timeline

2.6 Wind Tunnel

These 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 125 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 NASA LS(1)-0417 Wing Section

The wing section used for testing was a NASA LS(1)-0417 with a Fowler flap, acquired by the NRC. Photo 2.3 shows the wing section used for testing. This wing section was used during previous NRC tests [see TP 13426E (2) and TP 14180E (3)].

2.6.2 NASA LS(1)-0417 Design Characteristics

A cross sectional view of the NASA LS(1)-0417 wing section used for testing has been included in Figure 2.3. Some of the pertinent dimensions of the wing section are:

a) Wingspan not including flap: 1.8 m (6 ft.); and
b) Length: 2.4 m (8 ft.).

The wing section was fitted with a Fowler flap; however, the flap position was fixed at 15º and was not changed during testing. No moveable devices were available on the wing section.

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 2.4 demonstrates the end plates installed on the NASA LS(1)-0417 wing section.

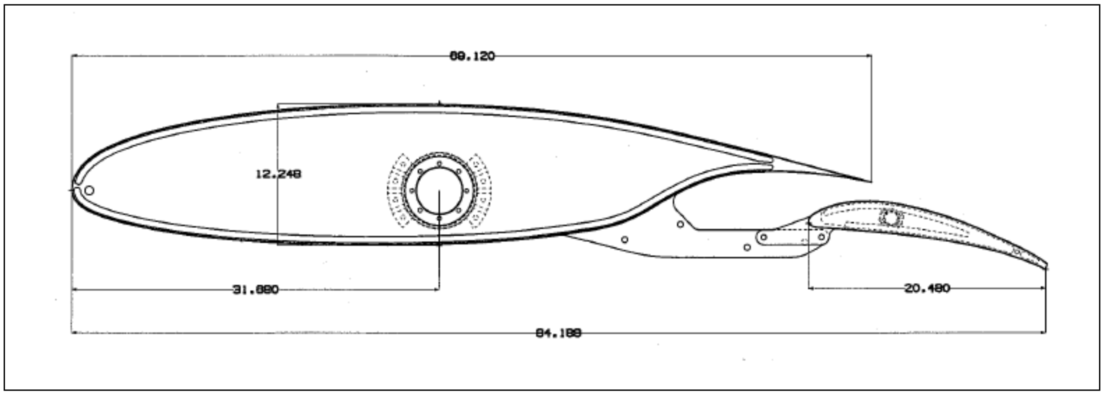

Figure 2.3: NASA LS(1)-0417 Wing Section

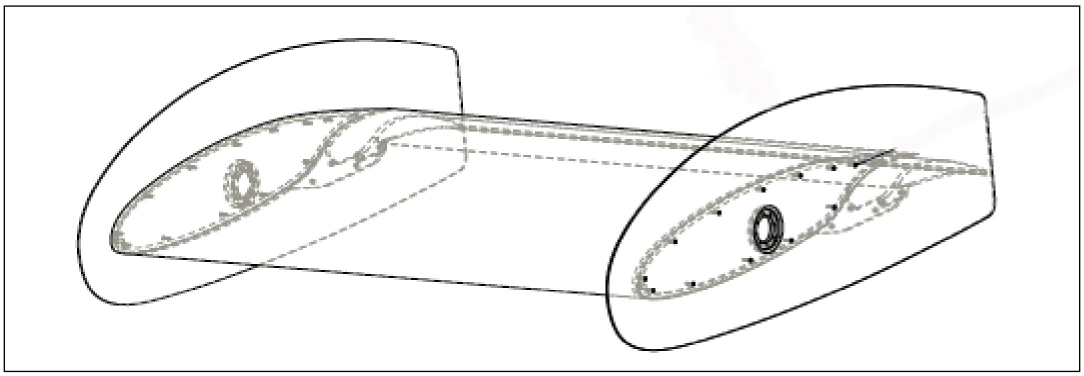

Figure 2.4: End Plates Installed on NASA LS(1)-0417 Wing Section

2.6.3 Wind Tunnel Measurement Capabilities

The NRC NASA LS(1)-0417 wing section was supported on either side by 2-axis weigh scales capable of measuring drag and lift forces generated on the wing section. Based on this information, the lift coefficient (C_L) is a dimensionless number defined by the following formula:

$$C_L = L / (\tfrac{1}{2}\rho\nu^2 A) = L / (qA)$$

Where:

- L is the lift force;
- ρ is air density;
- ν is true airspeed;
- q is dynamic pressure; and
- A is platform area.

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 previous Falcon 20 test data collected. The leading edge of the wing section was also equipped with internal thermistor sensors (installed by APS during the setup week) recording the skin temperature at various locations on the leading edge.

The wind tunnel was 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 1.8 m (6 ft.) wide, leaving 0.3 m (1 ft.) on either side with no grid markings; the width of the wing was 2.4 m (8 ft.). 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.

2.7 Equipment

A considerable amount of test equipment was required to perform these tests. Key items are described in the following subsections; 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 onto the wing from the leading and trailing edge positions of the wing at the same time.

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 the 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 for 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 (5.9 in. x 5.9 in.), over an area of 3.4 m x 3.4 m (11.2 ft. x 11.2 ft.). Pre-measured amounts of ice pellets and snow were dispersed over this area, and the amount collected by each pan was recorded. A distribution footprint of the dispenser was attained, and the 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 one minute). After the dispensing bucket was emptied, the dispenser was shifted over to the next of four positions per dispenser (see Photo 2.7). The dispensers were re-filled approximately every minute for the duration of the test. 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.

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 the 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 2.4 m (8 ft.) 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 2.5 demonstrates the HOT testing rate precipitation breakdown.

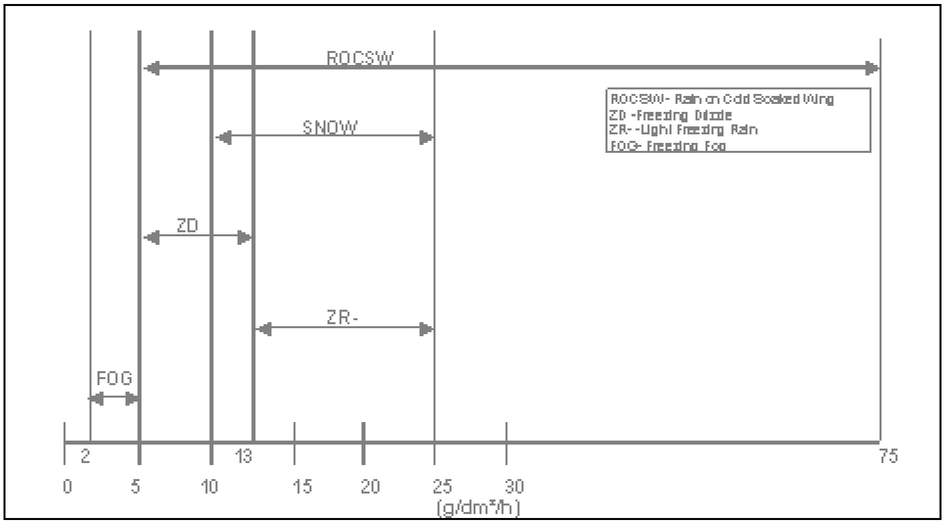

Figure 2.5: Precipitation Rate Breakdown

HOT testing protocol for ice pellets does not currently exist. As a result, ice pellet precipitation rate limits were based upon the freezing rain rate breakdown. The following precipitation rates were used for the full-scale and flat plate testing conducted during the winter of 2008-09:

- 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.

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. The cameras were used 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. 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 close-up view of the trailing edge. In comparison to the 2006-07 camera test setup, the positioning of the cameras was modified slightly due to the end plates installed on the wing and the larger wing rotations, both of which restricted 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 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), 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 B.

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

2.12 Type II/III/IV Fluid Application

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. 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.

2.13 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 during the takeoff runs. At the end of the testing period, the services of Safety-Kleen were employed to safely dispose of the waste glycol fluid.

2.14 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 2008-09 research team (due to scheduling, not all participants were available for the photo).

2.15 Measurement of Test Parameters

It should be noted that during some tests, measurement of some or all test parameters may not have been collected. In such cases, the data not collected has been identified with "N/A." The decision to not measure the test parameters would typically have been made in order to speed up the testing process in cases where the data would have been redundant or not critical to the test objectives.

2.15.1 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 run.

The locations designated for measurement, identified in Figure 2.6, were the following:

- Wing Position 1: 10 cm up from the leading edge stagnation point;
- Wing Position 2: 25 cm up from the leading edge stagnation point;
- Wing Position 3: 40 cm up from the leading edge stagnation point;
- Wing Position 4: 55 cm up from the leading edge stagnation point;
- Wing Position 5: 70 cm up from the leading edge stagnation point;
- Wing Position 6: 30 cm from the trailing edge;
- Wing Position 7: 15 cm from the trailing edge;
- Wing Position 8: 2.5 cm from the trailing edge; and
- Underside: The underside of the wing section, as far as could be reached from the leading edge.

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

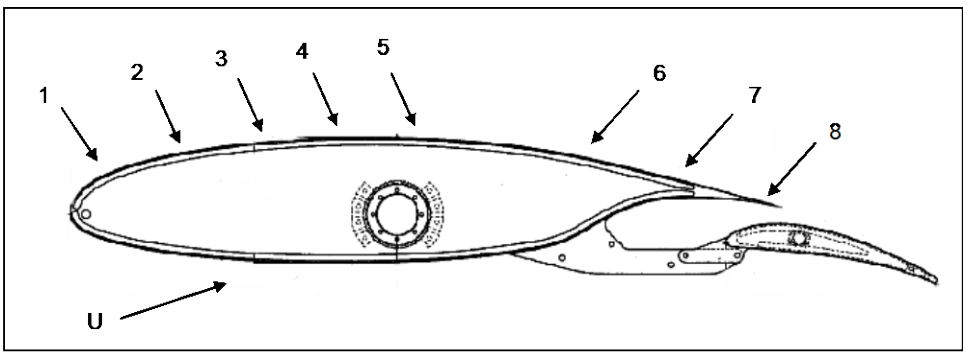

Figure 2.6: Measurement Locations Along Chord of NASA LS(1)-0417 Wing Section

2.15.2 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 run.

The locations designated for fluid thickness measurements, identified in Figure 2.6, were the following:

- Wing Position 1: 10 cm up from the leading edge stagnation point;
- Wing Position 2: 25 cm up from the leading edge stagnation point;
- Wing Position 3: 40 cm up from the leading edge stagnation point;
- Wing Position 4: 55 cm up from the leading edge stagnation point;
- Wing Position 5: 70 cm up from the leading edge stagnation point;
- Wing Position 6: 30 cm from the trailing edge;
- Wing Position 7: 15 cm from the trailing edge;
- Wing Position 8: 2.5 cm from the trailing edge; and
- Underside: The underside of the wing section, as far as could be reached from the leading edge.

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

2.15.3 Wing Skin Temperature

Wing temperatures were measured using a hand-held temperature probe at 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 run.

The locations designated for skin temperature measurements, identified in Figure 2.6, were the following:

- Wing Position 2: 25 cm up from the leading edge stagnation point;
- Wing Position 5: 70 cm up from the leading edge stagnation point; and
- Underside: The underside of wing section, as far as could be reached from the leading edge.

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

The wing section was also equipped with three thermistor sensors (installed by NRC personnel) recording the skin temperature on the leading edge (two sensors) and on the trailing edge (one sensor). These thermistors were used primarily to monitor the skin temperature in real-time through the NRC data display system. The wing skin temperature data used for analysis was manually collected using a hand-held temperature probe by APS personnel.

2.15.4 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 run.

The locations designated for fluid Brix measurements, identified in Figure 2.6, were the following:

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

2.16 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.

2.17 General Methodology

This section describes equipment and general information used for the wind tunnel tests. A considerable amount of test equipment was required to perform these tests. Key items are described in the following subsections; a full list of equipment is provided in the test procedure, which is included in Appendix B.

2.17.1 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 MPIII 2031 ECO;
- Table 2.4 - Clariant MPII Flight and MPIV Launch;
- Table 2.5 - Octagon Octaflo Type I; and
- Table 2.6 - Brix to Refractive Index Conversion Table.

Figure 2.7 contains the fluid freezing points for the Dow EG 106 fluid.

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 MPIII 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 Clariant MPII Flight and 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 2.5: 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 2.6: 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					

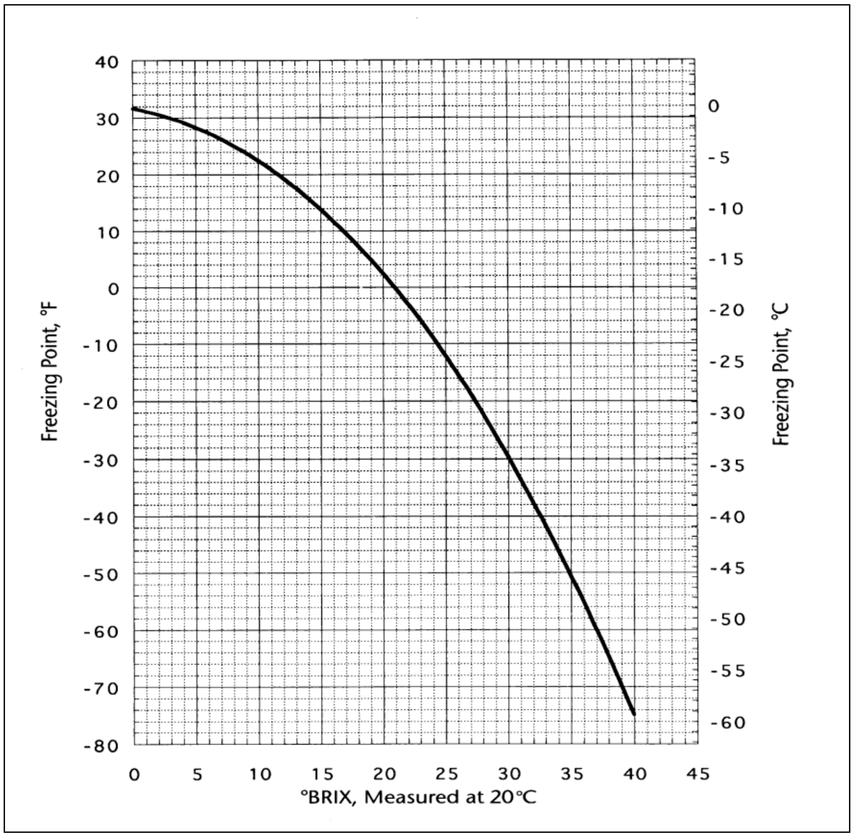

Figure 2.7: Freezing Point vs. Brix of Aqueous Solutions of Dow EG106

2.17.2 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, and an immersion probe was used for measuring and monitoring fluid temperatures.

2.17.3 Thickness Gauges

Wet film thickness gauges, shown in Figure 2.6 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 2.8 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.

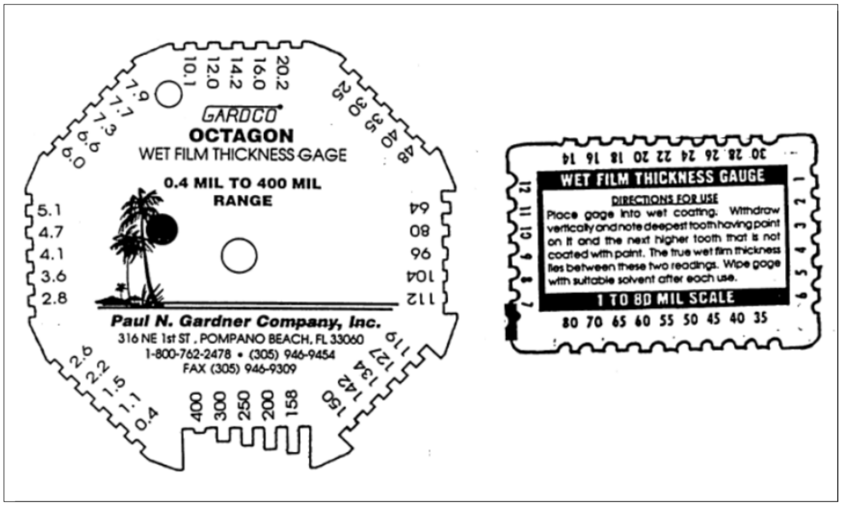

Figure 2.8: Thickness Gauges

2.17.4 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.

2.17.5 Fluids

Six fluids were used during the wind tunnel tests conducted during the winter of 2008-09. The fluid used for testing was at mid-production viscosity. The viscosity of the fluids received was measured using the Brookfield viscometer to ensure the fluid was within the fluid manufacturer production specifications. In addition, falling ball tests were conducted using the Stony Brooke portable field viscometer. The pertinent characteristics of these fluids are given in Table 2.8.

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	72	1.8
70	73	1.8			
75	78	2.0			
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

Table 2.8: Test Fluids

Fluid Name	Batch #	Received	Type	Formulation	Brix (°) of Neat Fluid	LOWV (mPa.s)
Octagon Octaflo	WL-120108	Winter 08-09	I	PG	28.5	N/A
Clariant Safewing MP II Flight	DEG4 143041	Winter 08-09	II	PG	35.25	3,340
Clariant Safewing MP III 2031 ECO	C15012009III	Winter 08-09	III	PG	37.5	30
	C02192009III	Winter 08-09	III	PG	37.5	30
Clariant Safewing MP IV Launch	C15012009IV	Winter 08-09	IV	PG	37	7,550
	C02192009IV	Winter 08-09	IV	PG	37	7,550
Dow UCAR™ Endurance EG106	VK0601GKDR	Winter 08-09	IV	EG	34	24,850
	XA2201GKI6	Winter 08-09	IV	EG	34	24,850
Kilfrost ABC-S PLUS	K01212009IV	Winter 08-09	IV	PG	37	17,900

EG – Ethylene Glycol
PG – Propylene Glycol

Photo 2.1: Outside View of NRC Wind Tunnel Facility

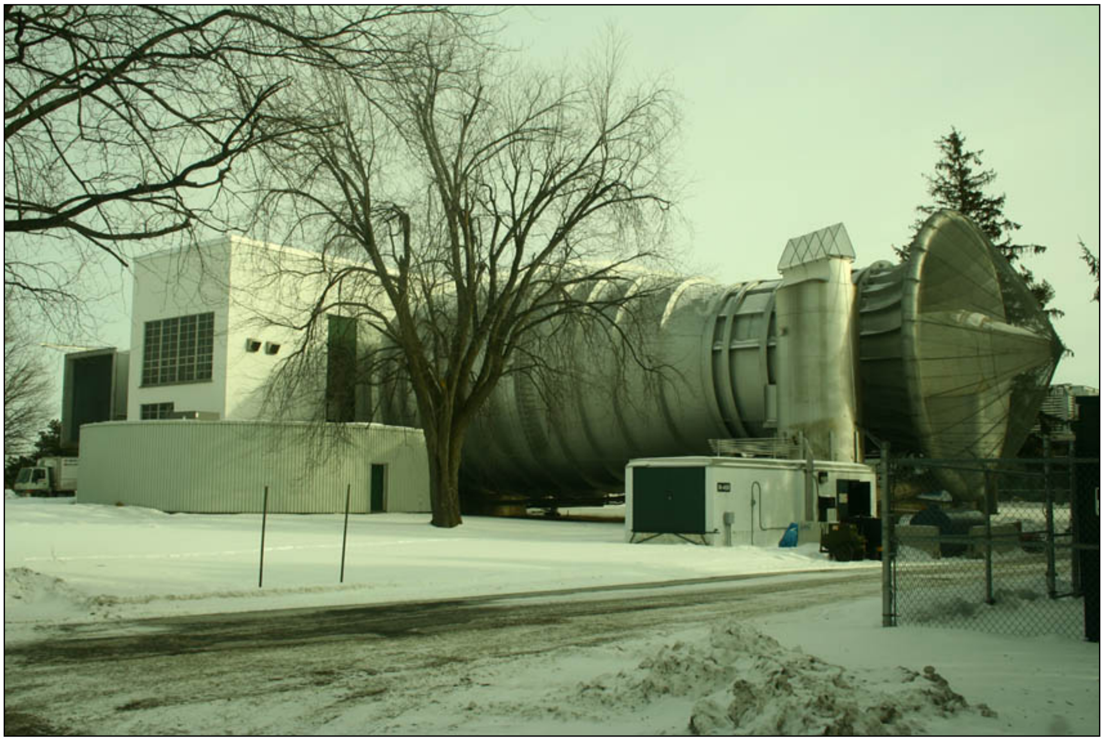

Photo 2.2: Inside View of NRC Wind Tunnel Test Section

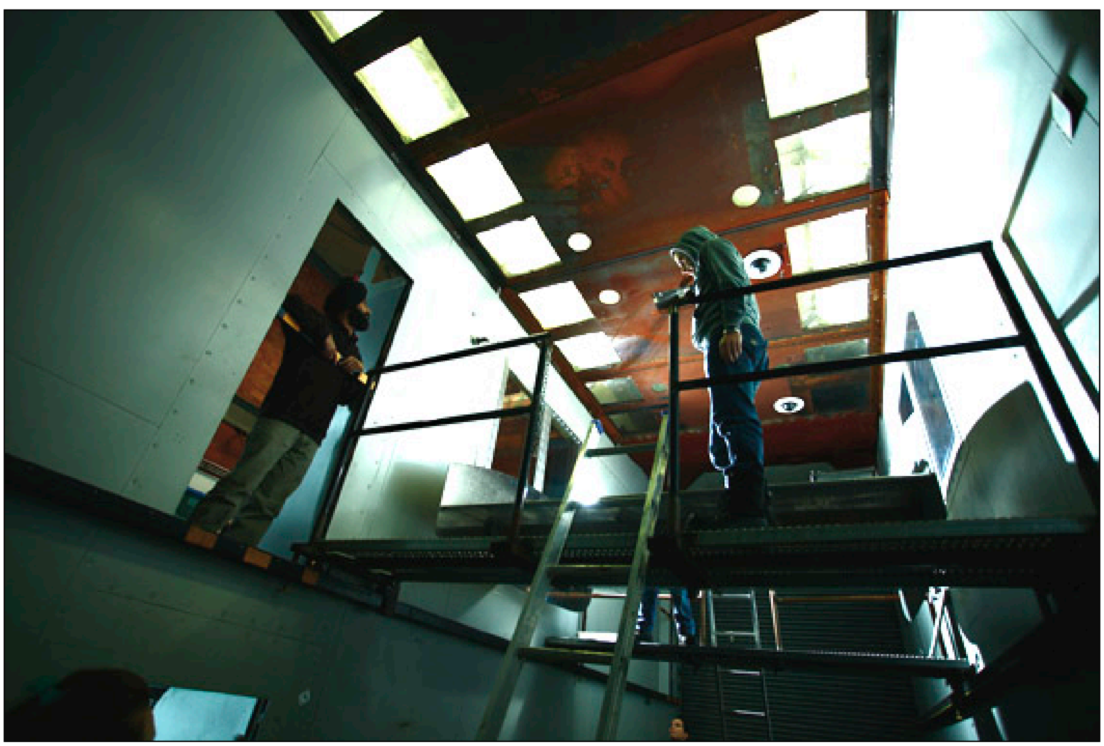

Photo 2.3: NASA LS(1)-0417 Wing Section Used for Testing

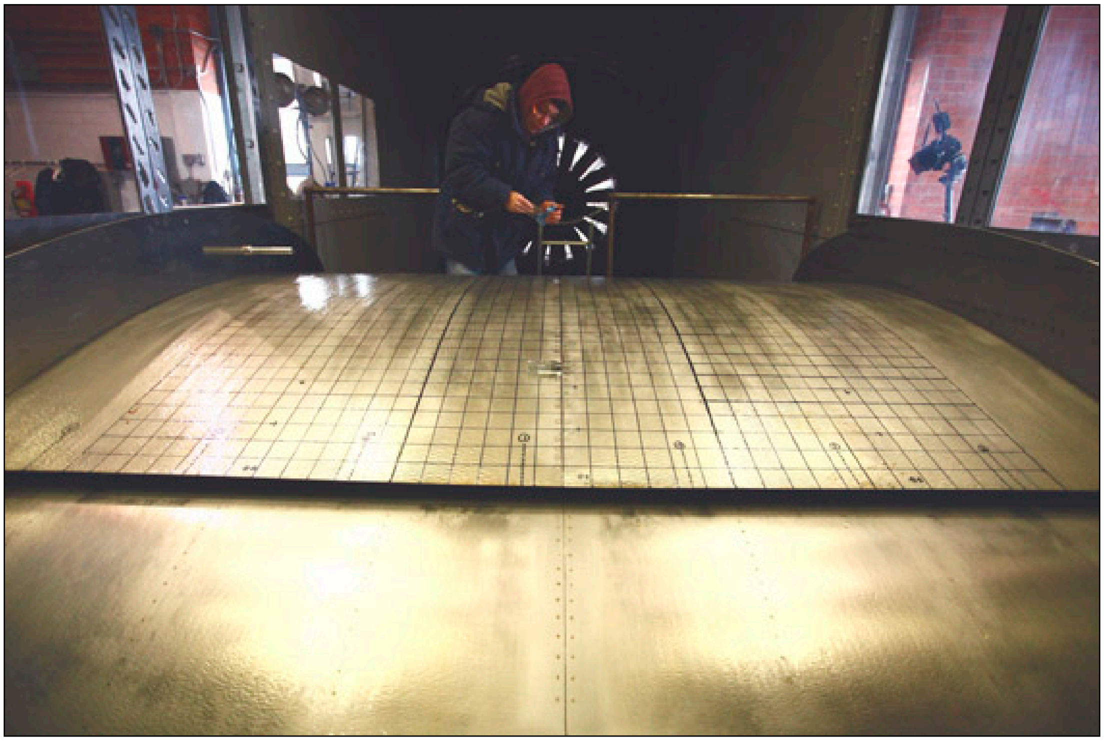

Photo 2.4: Grid Markings on NASA LS(1)-0417 Wing Section

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

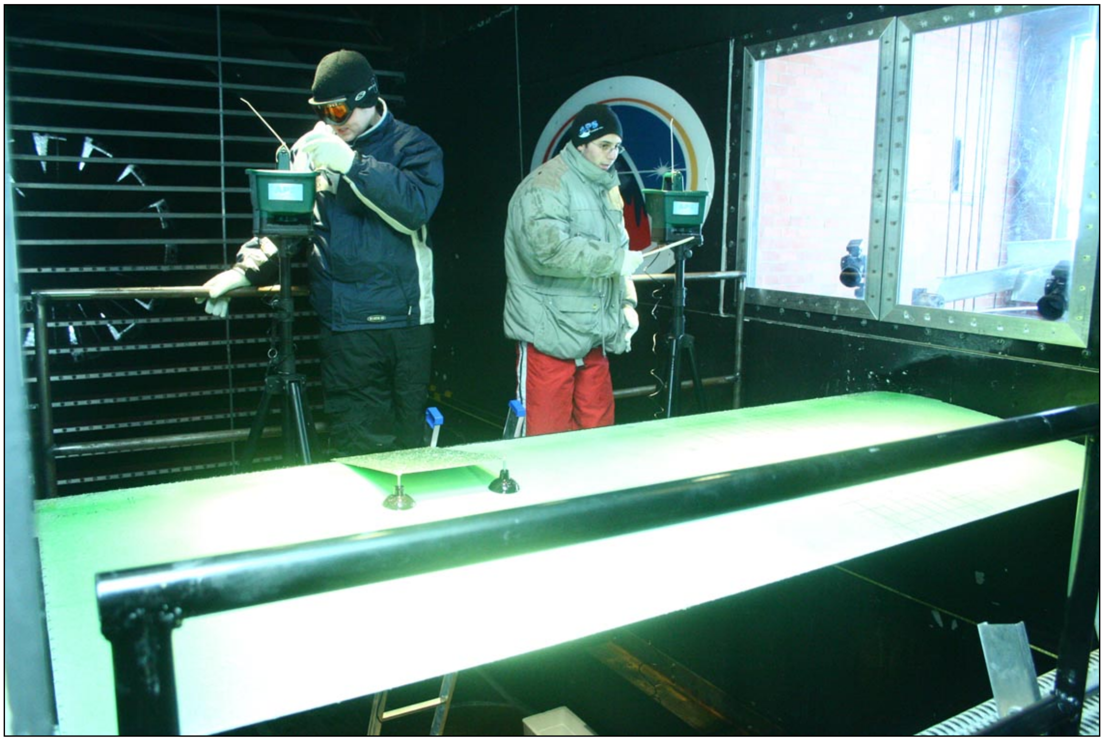

Photo 2.8: Ceiling-Mounted Freezing Rain Sprayer

Photo 2.9: Wind Tunnel Setup for Flashes

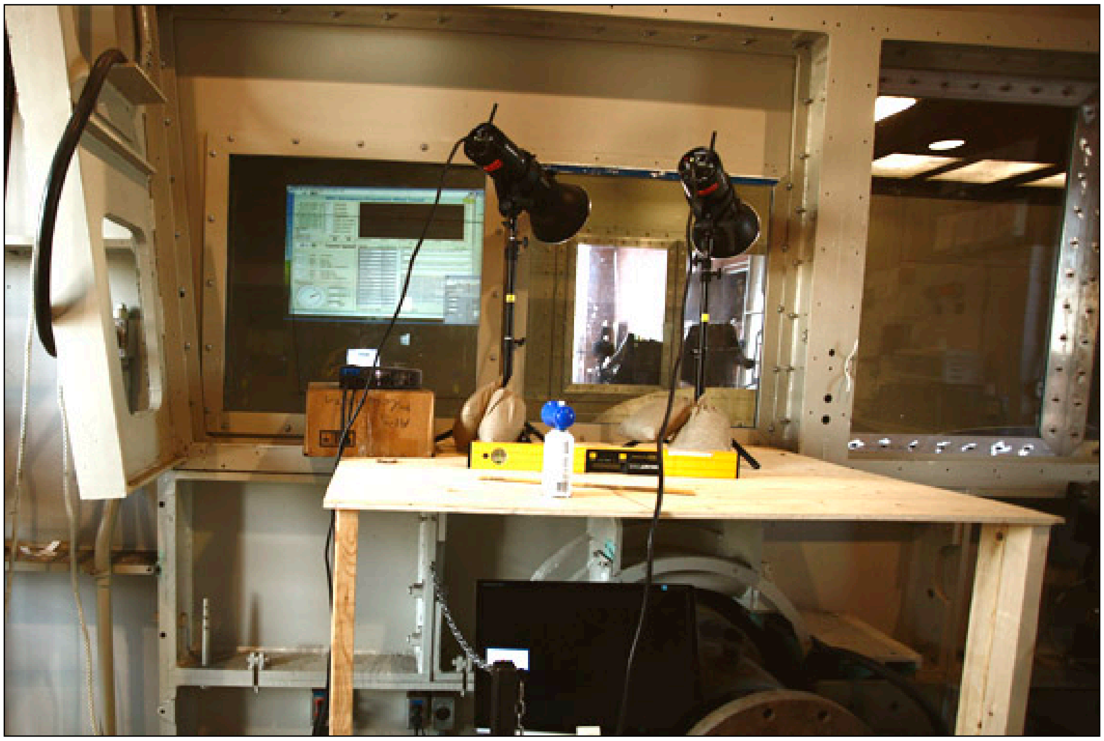

Photo 2.10: Wind Tunnel Setup for Digital Cameras

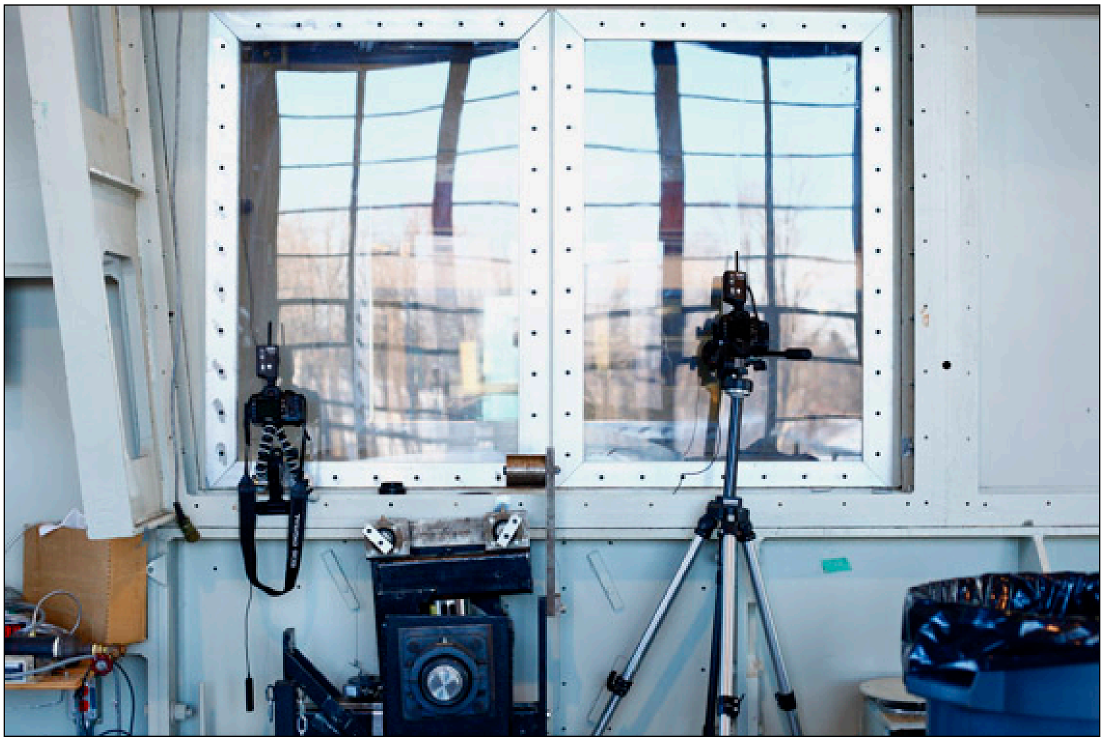

Photo 2.11: Fluid Pour Containers

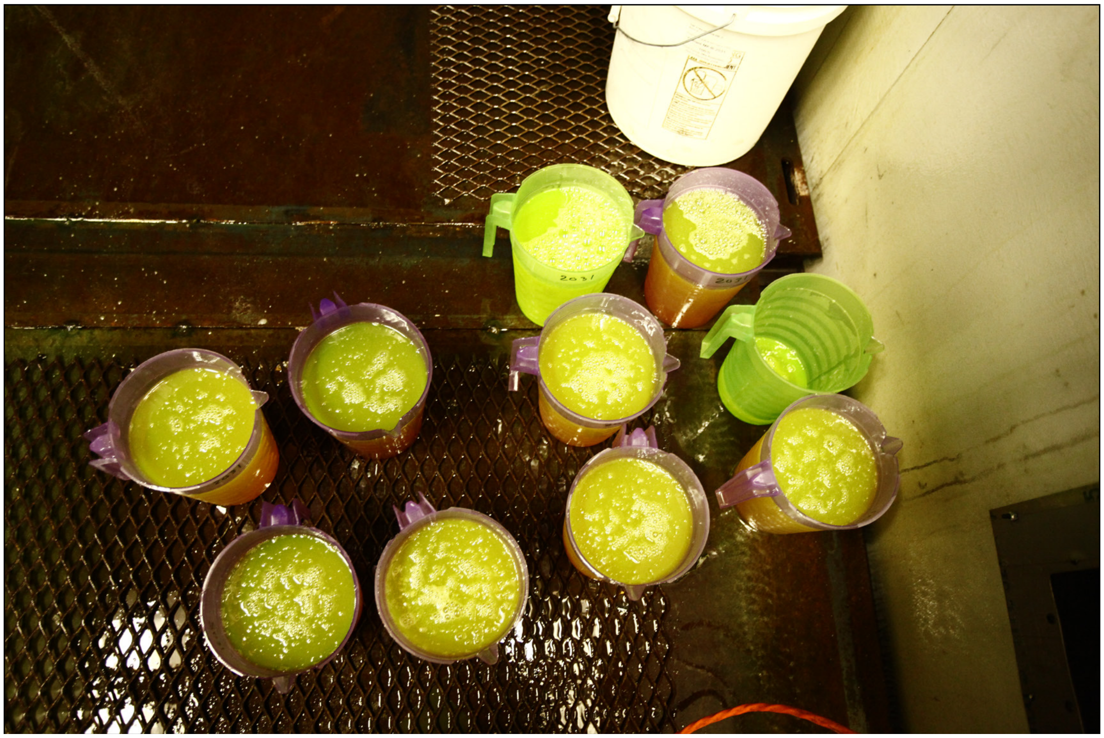

Photo 2.12: 2008-09 Research Team

Photo 2.13: Wet Film Thickness Gauges

Photo 2.14: Hand-Held Temperature Probe

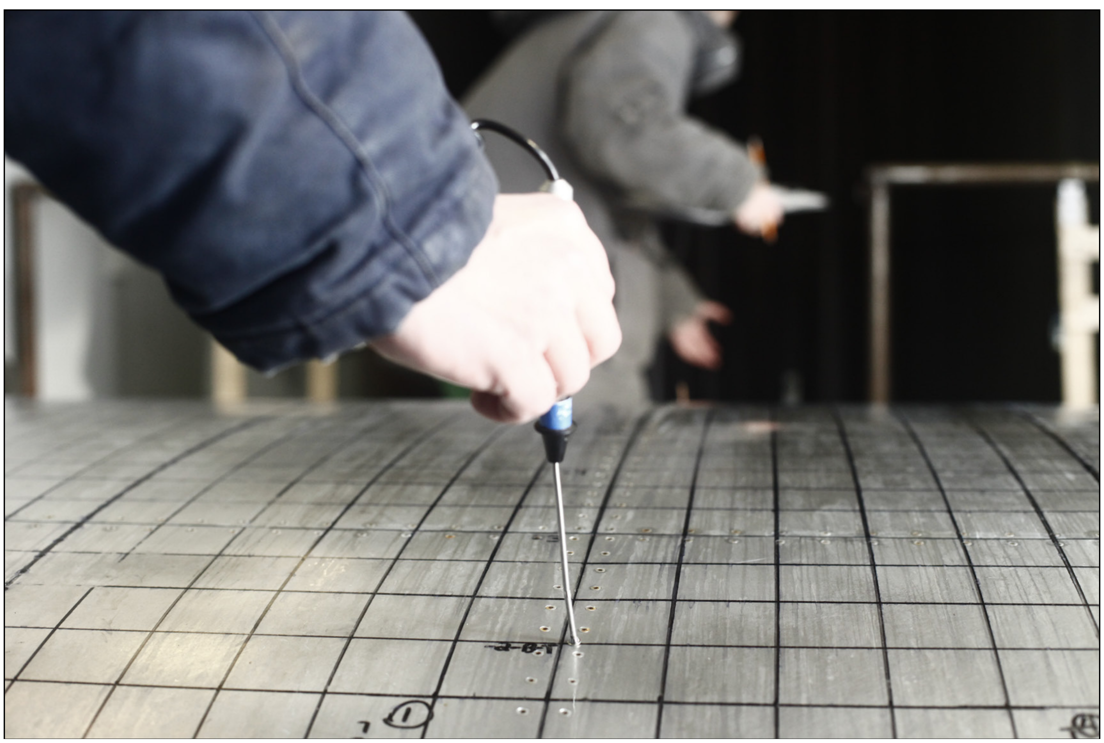

Photo 2.15: Hand-Held Brixometer (Misco 10431VP)

Photo 2.16: Brookfield Digital Viscometer Model DV-1+

3. FULL-SCALE DATA COLLECTED

3.1 Test Log

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. The table 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.

Test #:	Exclusive number identifying each test.
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.
Speed profile:	Maximum speed attained before rotation during simulated takeoff run; generally either high speed (100 knot rotation) or low speed (80 knot rotation).
Rotation Angle:	Maximum angle of rotation obtained during simulated takeoff run; began testing with a max 8º rotation angle and increased to 20º as testing progressed.
Target OAT:	Target outside air temperature for the simulated 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 (ºC):	Outside air temperature recorded just before the start of the simulated takeoff run, measured in degrees Celsius.
Tunnel Temp. Before Test (ºC):	Static tunnel ambient temperature recorded just before the start of the simulated takeoff run, 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 run, recorded in degrees Celsius.

Precipitation Rate (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 0.5; however, in some cases the ratings were rounded up or down to account for outlying ratings and to facilitate analysis. The visual contamination ratings system is further described in Subsection 5.1 of the TP 14935E (1).

Visual Contamination Rating Before Takeoff (LE, TE): Visual contamination rating determined before the start of the simulated takeoff. Two values are indicated [one for the leading edge (LE) and one for the trailing edge (TE)]:

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. Two values are indicated [one for the leading edge (LE) and one for the trailing edge (TE)]:

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):

Visual contamination rating determined at the end of the test. Two values are indicated [one for the leading edge (LE) and one for the trailing edge (TE)]:

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.

C_L at 0º Before Rotation: Calculated lift coefficient at the 0º wing angle position just prior to the start of the rotation; data provided by the NRC.

C_L at 8º During Rotation: Calculated lift coefficient at the 8º wing rotation angle position; data provided by the NRC.

C_L at Peak Angle of Rotation: Calculated lift coefficient at the peak wing rotation angle position; data provided by the NRC. The peak angle varied during the testing period; peak angles were set to 8º, 12º, 14º, 16º, 18º, and 20º according to the test objective.

C_L at 4º Following End of Rotation: Calculated lift coefficient at the 4º wing rotation angle position attained at the end of the rotation cycle; data provided by the NRC.

Table 3.1: Wind Tunnel Test Log

TEST #	32	35	36	37	38	39	40	41
Objective	Bad Application	Baseline / Roughness	Roughness	Roughness	Roughness	Roughness	Baseline / Roughness	Baseline / Roughness
Test Condition	IP Mod	Dry	IP/ZR	Contamination Applied in Test 36	Contamination Applied in Test 36	Contamination Applied in Test 36	Dry	Dry
Fluid	EG 106	None	None	None	None	None	None	None
Speed Profile	High	Low	Low	Low	Low	Low	Low	Low
Rotation Angle	8°	12°	12°	8°	14°	16°	14°	16°
Target OAT (°C)	< -5	-5	-5	-5	-5	-5	-5	-5
TEST PARAMETERS								
Date	29-Jan	30-Jan	30-Jan	30-Jan	30-Jan	30-Jan	30-Jan	30-Jan
Precipitation End Time	22:20	N/A	12:00	N/A	N/A	N/A	N/A	N/A
Tunnel Start Time	22:27	11:19	12:26	12:30	12:35	12:38	14:18	14:23
TEMPERATURES								
OAT Before Test (°C)	-5.7	-6.8	-4.9	-5.2	-5.3	-5.1	-3.5	-3.6
Tunnel Temp Before Test (°C)	-2.7	-6.2	-5.2	-4.7	-4.8	-4.9	-2.1	-4.1
Avg. Wing Temp. Before Test (°C)	-4.5	N/A	-0.3	N/A	N/A	N/A	N/A	N/A
PRECIPITATION								
Precipitation Rate (g/dm²/h)	IP:75	N/A	IP:10, ZR:25.5	N/A	N/A	N/A	N/A	N/A
Exposure Time (min)	25	N/A	12	N/A	N/A	N/A	N/A	N/A
OBSERVATIONS								
Visual Contamination Rating Before Takeoff (LE, TE)	4, 4	1, 1	5, 5	5, 5	5, 5	5, 5	1, 1	1, 1
Visual Contamination Rating at Rotation (LE, TE)	1, 2	1, 1	5, 5	5, 5	5, 5	5, 5	1, 1	1, 1
Visual Contamination Rating After Takeoff (LE, TE)	1, 1	1, 1	5, 5	5, 5	5, 5	5, 5	1, 1	1, 1
C_L at 0° Before Rotation	0.981	0.965	0.927	0.919	-	0.913	0.985	0.973
C_L at 8° During Rotation	1.798	1.77	1.687	1.686	1.691	1.681	1.783	1.759
C_L at Peak Angle of Rotation	1.798	2.282	2.129	1.686	2.335	2.506	2.528	2.778
C_L at 4° Following End of Rotation	1.326	1.308	1.245	1.239	1.244	1.244	1.31	1.306

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

TEST #	34A	50	61	62	63	70	71	72	72R
Objective	Baseline / Roughness	Rain & Snow	Heavy Snow	Heavy Snow	Heavy Snow	Heavy Snow	Heavy Snow	ZR/SN	ZR/S
Test Condition	Dry	R/SN	S	S++	S++	S++	S	ZR/S	Contamination Applied in Test 72
Fluid	None	Launch	EG 106	EG 106	EG 106	Launch	Launch	Launch	Launch
Speed Profile	Low	High	High	High	High	High	High	High	High
Rotation Angle	8°	16°	16°	16°	16°	16°	16°	16°	16°
Target OAT (°C)	-5	< -5	-10	-10	-10	-10	-10	-10	-10
TEST PARAMETERS									
Date	30-Jan	2-Feb	4-Feb	4-Feb	4-Feb	5-Feb	5-Feb	5-Feb	5-Feb
Precipitation End Time	N/A	20:00	19:02	19:59	21:21	19:06	21:09	22:28	N/A
Tunnel Start Time	14:32	20:27	19:09	20:07	21:29	19:13	21:14	22:36	22:47
TEMPERATURES									
OAT Before Test (°C)	-4	-3.9	-11.6	-13	-14.6	-15.5	-15.2	-15.3	-15.3
Tunnel Temp Before Test (°C)	-3.8	-1	-9.9	-11.1	-11.5	-4.5	-3.7	-4.2	-14.9
Avg. Wing Temp. Before Test (°C)	N/A	-1.5	-10.1	-11.5	-13.2	-8.4	-8.4	-5.4	N/A
PRECIPITATION									
Precipitation Rate (g/dm²/h)	N/A	SN:15, R:15	SN:25	SN:50	SN:50	SN:50	SN:25	SN:25, ZR:25	N/A
Exposure Time (min)	N/A	60	40	20	40	60	60	30	N/A
OBSERVATIONS									
Visual Contamination Rating Before Takeoff (LE, TE)	1, 1	1, 1	4, 3	4, 2	4, 4	4, 4	4, 4	5, 4.5	5, 2
Visual Contamination Rating at Rotation (LE, TE)	1, 1	1, 1	2, 2	1, 2	3, 2	4, 4	3, 3	5, 2	5, 1.5
Visual Contamination Rating After Takeoff (LE, TE)	1, 1	1, 1	2, 1	1, 1	1, 1	4, 3	2, 2	5, 4	5, 2
C_L at 0° Before Rotation	0.962	0.958	0.936	0.942	0.921	0.879	0.886	0.821	0.94
C_L at 8° During Rotation	1.764	1.757	1.731	1.756	1.717	1.658	1.667	1.693	1.735
C_L at Peak Angle of Rotation	1.764	2.786	2.773	2.779	2.737	2.596	2.615	2.668	2.715
C_L at 4° Following End of Rotation	1.302	1.301	1.3	1.299	1.295	1.234	1.246	1.259	1.282

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

TEST #	79	80	81	82	83	84	89	90	93
Objective	Bad Application	Low Low Speed	Low Low Speed	Low Low Speed/Baseline	Bad Application	Bad Application	Frost	Frost	Roughness
Test Condition	ZR	Fluid Only	Fluid Only	Fluid Only	ZR	ZR/S/IP	Frost	Frost	ZR/S/IP
Fluid	Launch	ABC-S+	Launch	Launch	EG 106	EG 106	Flight	Flight	None
Speed Profile	High	Low Low (67 knots)	Low Low (67 knots)	Low	High	High	High	High	Low
Rotation Angle	16°	20°	20°	20°	16°	16°	16°	16°	20°
Target OAT (°C)	<-5	<-5	<-5	<-5	<-5	<-5	-24	-24	<-5
TEST PARAMETERS									
Date	24-Feb	24-Feb	24-Feb	24-Feb	24-Feb	25-Feb	1-Mar	1-Mar	1-Mar
Precipitation End Time	5:30	N/A	N/A	N/A	0:41	2:12	N/A	N/A	5:03
Tunnel Start Time	5:38	21:47	22:38	23:18	0:59	2:20	1:07	2:42	5:11
TEMPERATURES									
OAT Before Test (°C)	-13.4	-8.5	-8.3	-8.4	-9.6	-10	-16	-16.1	-18.3
Tunnel Temp Before Test (°C)	-11.4	-3.1	-2.5	-2.6	-2.9	-2.9	-13.6	-16.5	-6
Avg. Wing Temp. Before Test (°C)	N/A	N/A	-3.6	-4.8	P:-1.3 R:-0.1	-4	-5.6	-6.3	-3.6
PRECIPITATION									
Precipitation Rate (g/dm²/h)	ZR:25	N/A	N/A	N/A	ZR:25	IP:15, SN:15, ZR:25	N/A	N/A	IP:15, SN:15, ZR:40-45
Exposure Time (min)	25	N/A	N/A	N/A	55	See HOT	Until Failure	Until Failure	10
OBSERVATIONS									
Visual Contamination Rating Before Takeoff (LE, TE)	Poor:5 Reg:3, Poor:5 Reg:3	1, 1	1, 1	1, 1	Poor:5 Reg:1, Poor:5 Reg:1	4, 4	5, 5	5, 5	5, 5
Visual Contamination Rating at Rotation (LE, TE)	Poor:5 Reg:1, Poor:5 Reg:2	1, 1	1, 1	1, 1	Poor:5 Reg:1, Poor:5 Reg:1	5, 5	5, 5	5, 5	5, 5
Visual Contamination Rating After Takeoff (LE, TE)	Poor:5 Reg:1, Poor:5 Reg:1	1, 1	1, 1	1, 1	Poor:5 Reg:1, Poor:5 Reg:1	5, 5	5, 5	5, 5	5, 5
C_L at 0° Before Rotation	0.976	0.97	0.982	0.971	0.99	0.974	1.006	0.966	0.97
C_L at 8° During Rotation	1.786	1.769	1.76	1.766	1.814	1.761	1.839	1.767	1.715
C_L at Peak Angle of Rotation	2.773	3.188	3.201	3.199	2.814	2.723	2.84	2.747	2.772
C_L at 4° Following End of Rotation	1.327	1.339	1.34	1.335	1.338	1.309	1.339	1.295	1.272

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

TEST #	94	96	97	102A	103	104	105	107
Objective	Roughness	Rain & Snow	Rain & Snow	Roughness	Roughness	Roughness	Type I IP	Bad Application
Test Condition	Contamination Applied In Previous Test	R/SN	ZR	Contamination Applied in Test 102	ZR/IP	ZR/IP Applied in Test 103	IP	ZR
Fluid	None	Type I OctoFlo	Type I OctoFlo	None	None	None	Type I OctoFlo	Launch
Speed Profile	High	High	High	Low	Low	High	High	High
Rotation Angle	16°	16°	16°	20°	20°	16°	16°	16°
Target OAT (°C)	<-5	>-5	>-5	-5	-5	-5	<-5	<-5
TEST PARAMETERS								
Date	1-Mar	1-Mar	1-Mar	2-Mar	2-Mar	2-Mar	2-Mar	3-Mar
Precipitation End Time	N/A	22:49	23:20	N/A	4:26	N/A	5:26	0:58
Tunnel Start Time	5:18	22:55	23:29	4:00	4:44	4:51	5:32	1:12
TEMPERATURES								
OAT Before Test (°C)	-18.6	-10.1	-10	-13.6	-14.8	-14.1	-14.4	-15.5
Tunnel Temp Before Test (°C)	-17.9	-2.6	-2.5	-12.3	-12.6	-12	-13.2	-13.5
Avg. Wing Temp. Before Test (°C)	N/A	N/A	N/A	N/A	N/A	N/A	-8.2	N/A
PRECIPITATION								
Precipitation Rate (g/dm²/h)	Same as previous test	SN:10, R:15	ZR:25	ZR:25	IP:10, ZR:25 (50)	N/A	IP:25	ZR:25
Exposure Time (min)	Same as previous test	5	5	10	10 (+6 for re-contamination)	N/A	5	25
OBSERVATIONS								
Visual Contamination Rating Before Takeoff (LE, TE)	5, 5	2, 2	1, 2	5, 5	5, 5	5, 5	3, 3	P: 5 R: 4, P: 5 R: 4
Visual Contamination Rating at Rotation (LE, TE)	5, 5	5, 5	5, 5	5, 5	5, 5	5, 5	1, 1	P: 5 R: 4, P: 5 R: 4
Visual Contamination Rating After Takeoff (LE, TE)	5, 5	5, 5	4, 5	5, 5	5, 5	5, 5	1, 1	P: 5 R: 1, P: 5 R: 3
C_L at 0° Before Rotation	0.944	0.995	1.006	0.939	0.895	-	0.993	0.994
C_L at 8° During Rotation	1.702	1.826	1.827	1.823	1.741	1.75	1.818	1.791
C_L at Peak Angle of Rotation	2.573	2.821	2.848	3.347	2.526	2.606	2.845	2.773
C_L at 4° Following End of Rotation	1.268	1.34	1.35	1.355	1.304	1.302	1.352	1.325

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4. 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.

The wing section used for the 2008-09 testing was representative of an airfoil typically used on a low-speed aircraft. These types of airfoils are less susceptible to aerodynamic penalties resulting from contamination (as is also the case with large commuter jet type airfoils). Previous testing in the wind tunnel in 2006-07 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 regard to control surfaces, the impact of the surface roughness on the overall aerodynamic performance of the wing needs to be investigated.

It was recommended that some preliminary work be conducted to investigate the effects of various types of adhered frozen contamination on the aerodynamic performance of the airfoil and, more specifically, on the potential for an early wing stall as a result of a contaminated wing section. As a supercritical wing section was not available during the winter of 2008-09, testing was conducted using the available low-speed NASA LS(1)-0417 airfoil. 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.

4.1 General Methodology

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

- Ensure the wing section is clean and dry;
- Ensure outside air temperature 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;
- Run wind tunnel tests and collect lift loss data;

- Compare results to typical fluid only and to contaminated fluid results conducted at similar temperatures;
- Increase level of contamination until appreciable lift losses are observed (greater than 15 percent); and
- Document amount and type of contamination used.

It should be noted that during some tests, contamination was applied by hand to the leading edge of the wing section (at the stagnation point) as it was believed that this would have the greatest impact on aerodynamic performance.

4.2 Overview of Tests

A summary of the wing surface roughness 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.

Rotation Speed(Knots)/ Rot. Angle(°): Max speed at time of rotation, measured in knots, and the maximum angle of attack at the time of rotation, measured in degrees.

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 run, 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 run, recorded in degrees Celsius.

Visual Contamination Rating Before Takeoff (LE, TE): Visual contamination rating determined before the start of the simulated takeoff. Two values are indicated [one for the leading edge (LE) and one for the trailing edge (TE)]:

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. Two values are indicated [one for the leading edge (LE) and one for the trailing edge (TE)]:

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.

C_L at 8º During Rotation: Calculated lift coefficient at the 8º wing rotation angle position; data provided by the NRC.

Eight low-speed tests were conducted as part of a test set to investigate the effects of the angle of attack on the recorded lift losses. Four tests were conducted with a bare wing to obtain the "clean wing" baseline data (Tests #34A, #35, #40, and

#41), and four tests were conducted with adhered freezing rain and ice pellet contamination on the wing (Tests #36, #37, #38, and #39). Five tests were also conducted with no fluid to investigate the aerodynamic effects of various types of adhered contamination (Tests #93, #94, #102A, #103, and #104). The results from these contaminated tests were compared to the baseline clean wing results described earlier (Tests #34A, #35, #40, and #41).

Table 4.1: Summary of 2008-09 Surface Roughness Tests

Test No.	Date	Fluid	Rotation Speed (Knots) / Rot. Angle (°)	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)	Visual Cont. Rating at Rotation (LE, TE)	C_L at 8° During Rotation
34A	30-Jan-09	None	80 / 8	N/A	N/A	N/A	-4	N/A	1, 1	1, 1	1.764
35	30-Jan-09	None	80 / 12	N/A	N/A	N/A	-6	N/A	1, 1	1, 1	1.770
36	30-Jan-09	None	80 / 12	IP/ZR	10/25	12	-5	-0.3	5, 5	5, 5	1.687
37*	30-Jan-09	None	80 / 8	IP/ZR	10/25	12	-5	N/A	5, 5	5, 5	1.686
38*	30-Jan-09	None	80 / 14	IP/ZR	10/25	12	-5	N/A	5, 5	5, 5	1.691
39*	30-Jan-09	None	80 / 16	IP/ZR	10/25	12	-5	N/A	5, 5	5, 5	1.681
40	30-Jan-09	None	80 / 14	N/A	N/A	N/A	-2	N/A	1, 1	1, 1	1.783
41	30-Jan-09	None	80 / 16	N/A	N/A	N/A	-4	N/A	1, 1	1, 1	1.759
93	1-Mar-09	None	80 / 20	IP/SN/ZR	15/15/45	10	-6	-3.6	5, 5	5, 5	1.715
94*	1-Mar-09	None	100 / 16	IP/SN/ZR	15/15/45	10	-18	N/A	5, 5	5, 5	1.702
102A*	2-Mar-09	None	80 / 20	ZR	25	10	-12	N/A	5, 5	5, 5	1.823
103	2-Mar-09	None	80 / 20	IP/ZR	10/25 & 50	10+6	-13	N/A	5, 5	5, 5	1.741
104*	2-Mar-09	None	100 / 16	IP/ZR	10/25 & 50	10+6	-12	N/A	5, 5	5, 5	1.750

***** *Indicates re-run of previous test; contamination was not re-applied.*

4.3 Data Collected

4.3.1 Fluid Thickness Data

It should be noted that during these tests, fluid thickness measurements were not recorded as there was no fluid applied to the wing.

4.3.2 Skin Temperature Data

APS personnel collected skin temperature measurements. The wing positions used for the wind tunnel tests are described in Subsection 2.15.2. Skin temperature measurements were recorded at the following intervals:

- Before fluid application;
- After fluid application;

- After application of contamination; and
- After the simulated takeoff run.

The wing temperature measurements recorded during each test are shown in Tables 4.2 to 4.14.

Table 4.2: Test #34A Wing Skin Temperature Data

Test 34A, Dry, Tunnel OAT -3.8ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	N/A	N/A	N/A	-1.6
T5	N/A	N/A	N/A	-1.3
TU	N/A	N/A	N/A	-1.3

Table 4.3: Test #35 Wing Skin Temperature Data

Test 35, Dry, Tunnel OAT -6.2ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	N/A	N/A	N/A	N/A
T5	N/A	N/A	N/A	N/A
TU	N/A	N/A	N/A	N/A

Table 4.4: Test #36 Wing Skin Temperature Data

Test 36, No Fluid, IP/ZR, Tunnel OAT -5.2ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	-3.1	N/A	-0.1	N/A
T5	-3.2	N/A	-0.2	N/A
TU	-3.2	N/A	-0.6	N/A

Table 4.5: Test #37 Wing Skin Temperature Data

Test 37, No Fluid, IP/ZR, Tunnel OAT -4.7ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	N/A	N/A	N/A	N/A
T5	N/A	N/A	N/A	N/A
TU	N/A	N/A	N/A	N/A

Table 4.6: Test #38 Wing Skin Temperature Data

Test 38, No Fluid, IP/ZR, Tunnel OAT -4.8ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	N/A	N/A	N/A	N/A
T5	N/A	N/A	N/A	N/A
TU	N/A	N/A	N/A	N/A

Table 4.7: Test #39 Wing Skin Temperature Data

Test 39, No Fluid, IP/ZR, Tunnel OAT -4.9ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	N/A	N/A	N/A	-2.0
T5	N/A	N/A	N/A	-2.2
TU	N/A	N/A	N/A	-2.2

Table 4.8: Test #40 Wing Skin Temperature Data

Test 40, Dry, Tunnel OAT -2.1ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	0.5	N/A	N/A	N/A
T5	0.0	N/A	N/A	N/A
TU	-0.1	N/A	N/A	N/A

Table 4.9: Test #41 Wing Skin Temperature Data

Test 41, Dry, Tunnel OAT -4.1ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	N/A	N/A	N/A	N/A
T5	N/A	N/A	N/A	N/A
TU	N/A	N/A	N/A	N/A

Table 4.10: Test #93 Wing Skin Temperature Data

Test 93, No Fluid, IP/SN/ZR, Tunnel OAT -6.0ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	-12.5	N/A	-2.6	N/A
T5	-11.8	N/A	-3.2	N/A
TU	-12.5	N/A	-5.0	N/A

Table 4.11: Test #94 Wing Skin Temperature Data

Test 94, No Fluid, IP/SN/ZR, Tunnel OAT -17.9ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	N/A	N/A	N/A	N/A
T5	N/A	N/A	N/A	N/A
TU	N/A	N/A	N/A	N/A

Table 4.12: Test #102A Wing Skin Temperature Data

Test 102A, No Fluid, ZR, Tunnel OAT -12.3ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	N/A	N/A	N/A	N/A
T5	N/A	N/A	N/A	N/A
TU	N/A	N/A	N/A	N/A

Table 4.13: Test #103 Wing Skin Temperature Data

Test 103, No Fluid, IP/ZR, Tunnel OAT -12.6ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	N/A	N/A	N/A	N/A
T5	N/A	N/A	N/A	N/A
TU	N/A	N/A	N/A	N/A

Table 4.14: Test #104 Wing Skin Temperature Data

Test 104, No Fluid, IP/ZR, Tunnel OAT -12.0ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	N/A	N/A	N/A	N/A
T5	N/A	N/A	N/A	N/A
TU	N/A	N/A	N/A	N/A

4.3.3 Fluid Brix Data

It should be noted that during these tests, fluid Brix measurements were not recorded as there was no fluid applied to the wing.

4.4 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 test, 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 4.1 to 4.52 show the photo summaries of the tests conducted. A complete set of photos will be provided to the TDC.

4.5 General Observations

The following sections describe the observations regarding the testing conducted to investigate the effects of surface roughness on aerodynamic performance.

4.5.1 Effect of Angle of Attack

Eight low-speed tests were conducted as part of a test set to investigate the effects of the angle of attack on the recorded lift losses. Four tests were conducted with a bare wing to obtain the "clean wing" baseline data. In addition, four tests were conducted with adhered freezing rain and ice pellet contamination on the wing (no fluid was used). The contamination was not re-applied in between runs as the contamination was adhered to the wing and the overall condition did not change during the test. Back-to-back runs were conducted using the same contaminated wing, each time with an increase in the maximum angle of attack. Table 4.15 demonstrates the results from the comparison of the C_L data at the max angle of rotation for the clean and contaminated wing tests.

The results indicate that as the angle of rotation is increased, the effects of the contamination are more prominent, and the difference in the lift coefficient data is increased. The percentage lift loss increased from 4 percent to 10 percent as the maximum angle of rotation increased from 8° to 16°. During these tests, a stall condition was not achieved; however, the effects of the adhered contamination were apparent.

Table 4.15: Comparison of C_L Data at Max Angle of Rotation

Test # (Clean - ZR/IP)	Rotation Speed (Knots) / Rot. Angle (°)	Clean Wing C_L @ Max Angle	ZR/IP Contaminated Wing C_L @ Max Angle	Percentage Difference (%)
34A - 37	80 / 8	1.764	1.686	-4%
35 - 36	80 / 12	2.282	2.129	-7%
40 - 38	80 / 14	2.528	2.335	-8%
41 - 39	80 / 16	2.778	2.506	-10%

For future aerodynamic testing, it is recommended that the simulated takeoff profile target the clean wing stall angle as the maximum angle of attack in order to better quantify the observed lift losses. When analysing the data for "Allowance Times" or other ground icing applications, evaluation of the lift results should be conducted at an angle approximately halfway between the typical angle of attack and the stall angle (these angles should be recommended by the airframe manufacturer). In addition, during contaminated test runs, a baseline fluid only case should be run immediately before or after the contaminated test to provide a direct correlation of the results.

4.5.2 Effect of Contamination Type

The testing conducted demonstrated varying aerodynamic effects as a result of the type of contamination adhered to the wing section. During Test #102A conducted with adhered freezing rain only, the aerodynamic performance at the 8° angle of rotation (C_L of 1.823) was better compared to the bare wing results obtained during Tests #34A, #35, #40, and #41 (C_L between 1.759 and 1.783). It is assumed that the smooth surface created by the freezing rain actually helped improve the aerodynamic properties of the wing by smoothing out imperfections (from rivets, wing skin junctions, etc.) of the wing.

During Runs #93 and #94 conducted with adhered ice pellets, snow, and freezing rain, the lift coefficient results were worse compared to the bare wing results obtained during Tests #34A, #35, #40, and #41. On the other hand, lift coefficient results were better compared to the ice pellet and freezing rain results obtained during Tests #36, #37, #38, and #39. Although the amount of cumulative contamination was increased during Runs #93 and #94 (total rate of 75 g/dm²/h compared to 35 g/dm²/h for the first series of contaminated tests), the improvement in the lift coefficient results was likely due to the increase in freezing rain precipitation; the more freezing rain applied, the more the rough contamination (ice pellets and snow) melted and smoothed.

Similar results were seen during Runs #103 and #104, where the increase in freezing rain precipitation increased the aerodynamic performance compared to Tests #36, #37, #38, and #39 with similar forms of contamination.

During Test #103, a wing stall was experienced at approximately 16° angle of attack, indicating that although favourable aerodynamic results were achieved in the shallow angles of attack, the stall angle was significantly reduced due to the contamination. In all other tests, the wing was rotated to a 20° angle of attack without experiencing a stall. During this test, ice pellets were applied by hand directly to the leading edge stagnation point until adhered, which is likely to have led to the results obtained.

To demonstrate the severity of adhered contamination on aerodynamic performance, Figure 4.1 compares the following:

- A fluid covered wing with a level of contamination slightly beyond what is considered acceptable (Test #99, conducted as part of the ice pellet allowance time research);
- A dry wing with adhered freezing rain and ice pellet contamination simulating a severely contaminated and diluted fluid (Test #103); and
- An uncontaminated fluid only wing (Test #92, conducted as part of the ice pellet allowance time research).

The x-axis demonstrates the time in seconds as of the start of the test. Rotation begins at approximately 23 seconds, the wing rotates to a maximum angle of 20° in approximately 7.4 seconds, and then it is rotated back to 4° over a period of approximately 64 seconds. The y-axis indicates the calculated lift coefficient.

The results from this comparison indicate that the performance of the fluid contaminated to the level of failure (Test #99) performs slightly better aerodynamically in comparison to an uncontaminated fluid (Test #92). The contamination is absorbed and dilutes the fluid, consequently reducing the viscosity of the fluid; this is especially true for ethylene fluids. At the time of takeoff, the fluid shears off easier compared to an uncontaminated fluid, which is more viscous. Nevertheless, as is demonstrated by the severely contaminated wing section (Test #103), once a specific level of contamination has been achieved, the wing aerodynamics are significantly compromised, resulting in large lift losses. Test #103 experienced a stall at approximately the 16° rotation angle; however, lift losses are not significantly apparent until the critical angle of 16° is reached.

Test results from Test #103 further support the recommendation to target the clean wing stall angle as the maximum angle of attack in order to better quantify the observed lift losses.

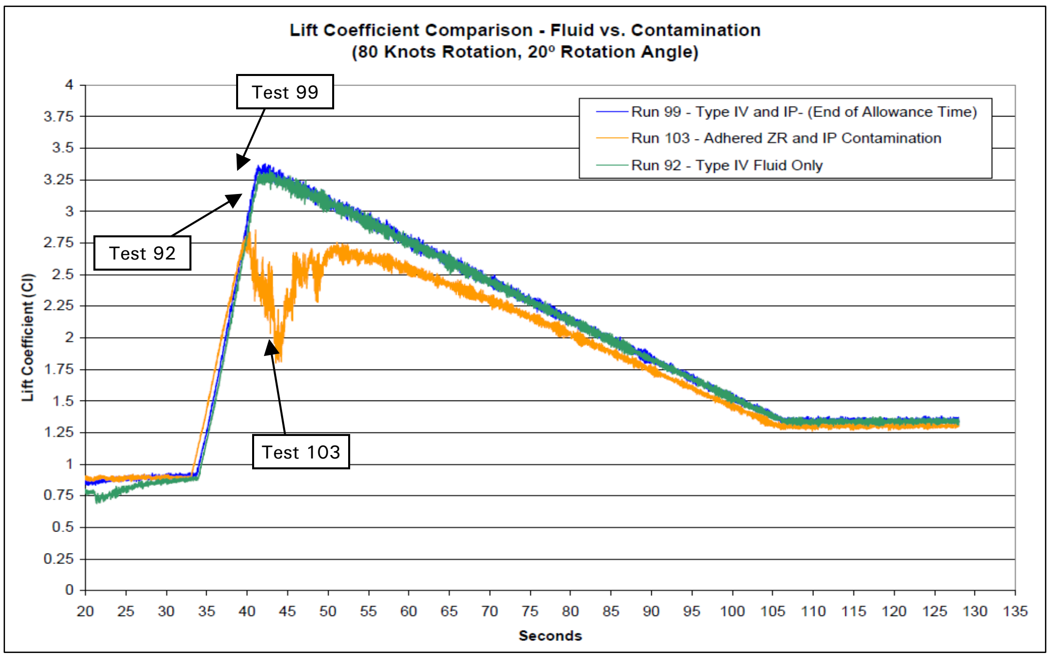

Figure 4.1: Lift Coefficient Comparison – Fluid vs. Contamination

Photo 4.1: Test #34A – Start of Test

No Photo Documentation Available

Photo 4.2: Test #34A – Before Rotation

No Photo Documentation Available

Photo 4.3: Test #34A – End of Rotation

No Photo Documentation Available

Photo 4.4: Test #34A – End of Test

No Photo Documentation Available

Photo 4.5: Test #35 – Start of Test

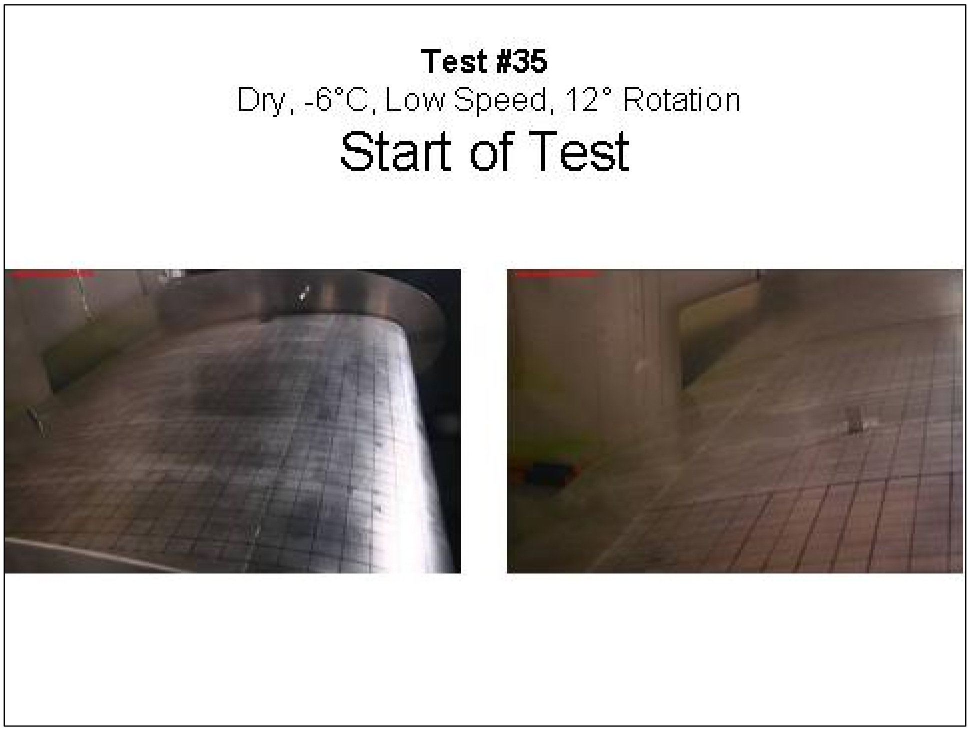

Photo 4.6: Test #35 – Before Rotation

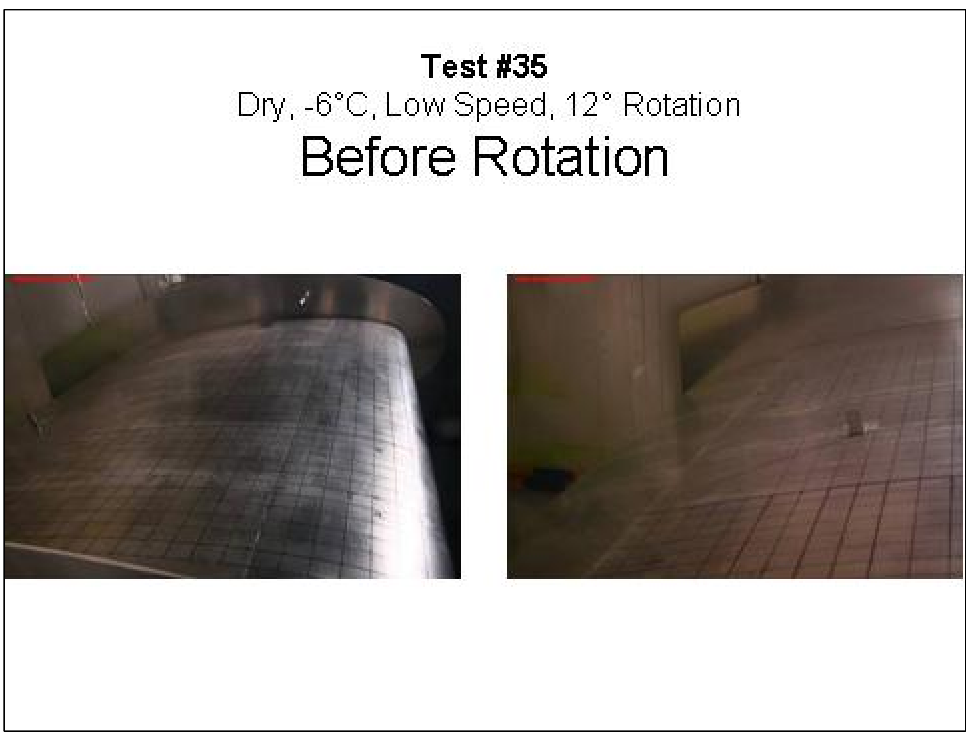

Photo 4.7: Test #35 – End of Rotation

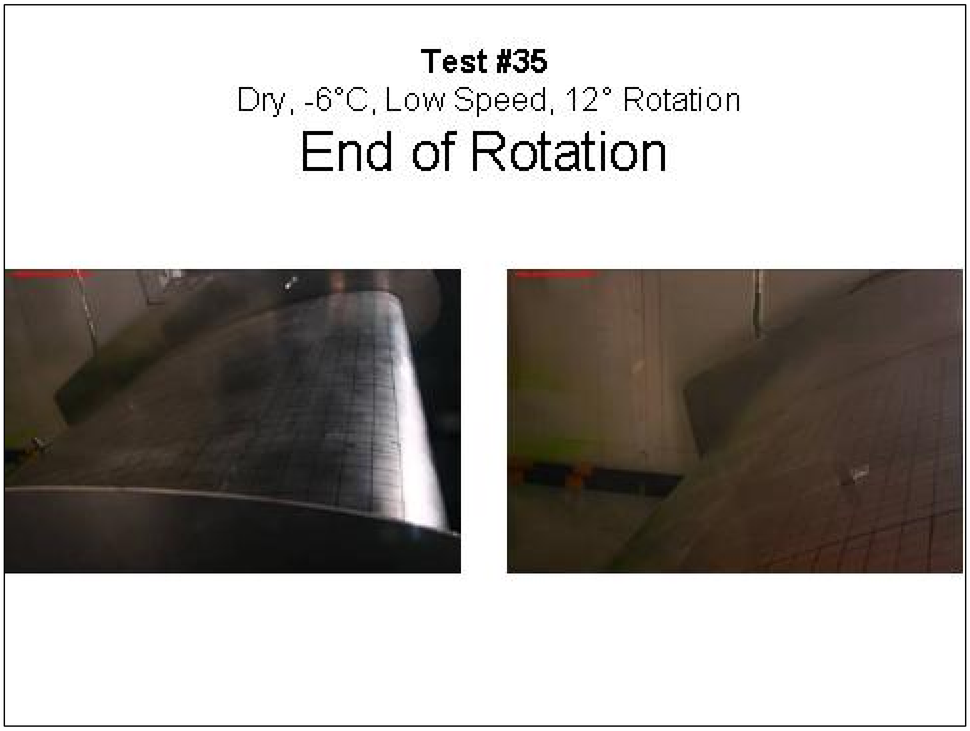

Photo 4.8: Test #35 – End of Test

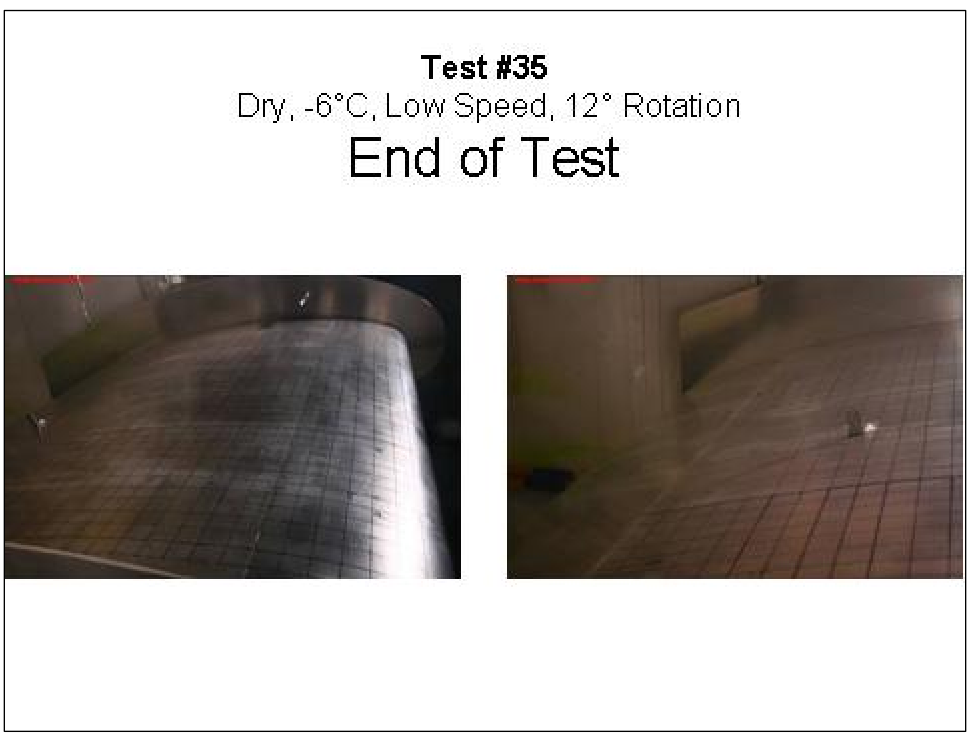

Photo 4.9: Test #36 – Start of Test

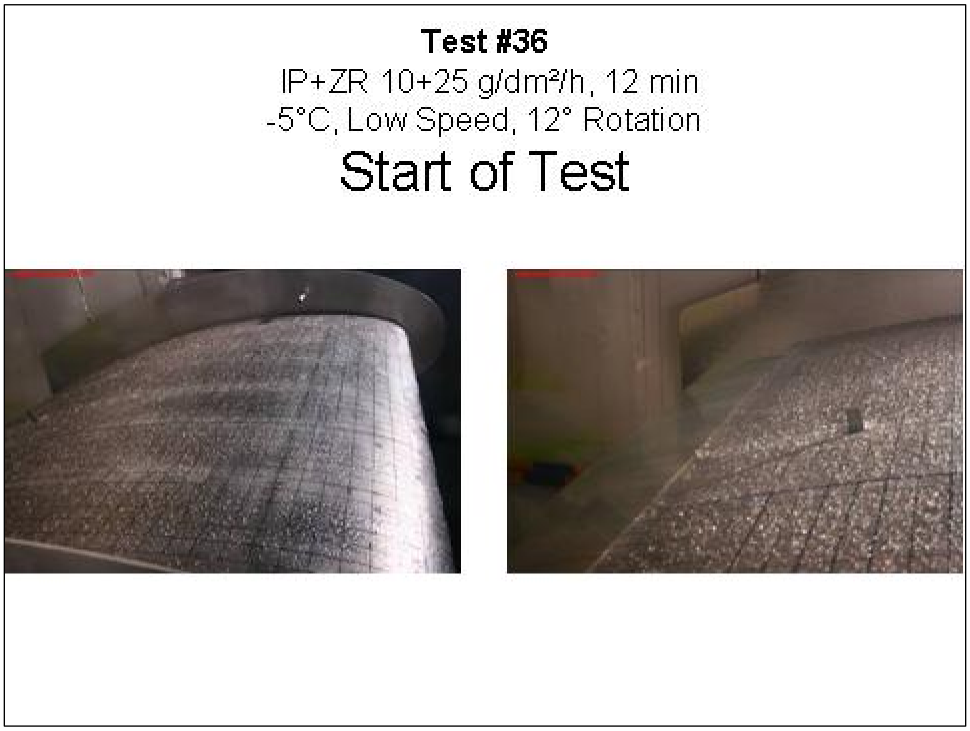

Photo 4.10: Test #36 – Before Rotation

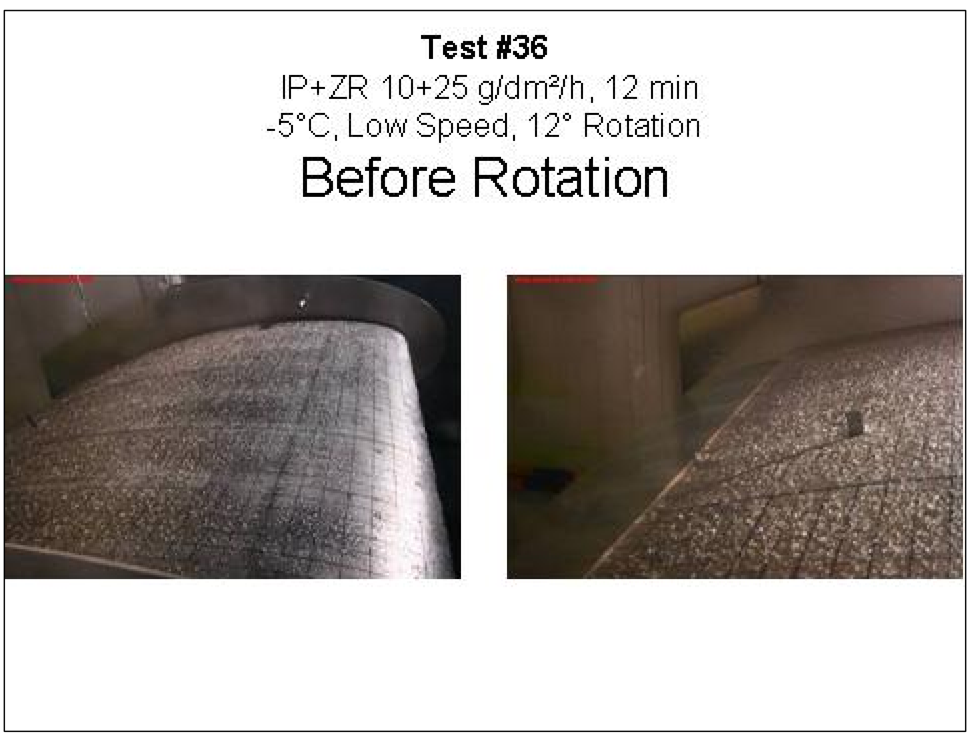

Photo 4.11: Test #36 – End of Rotation

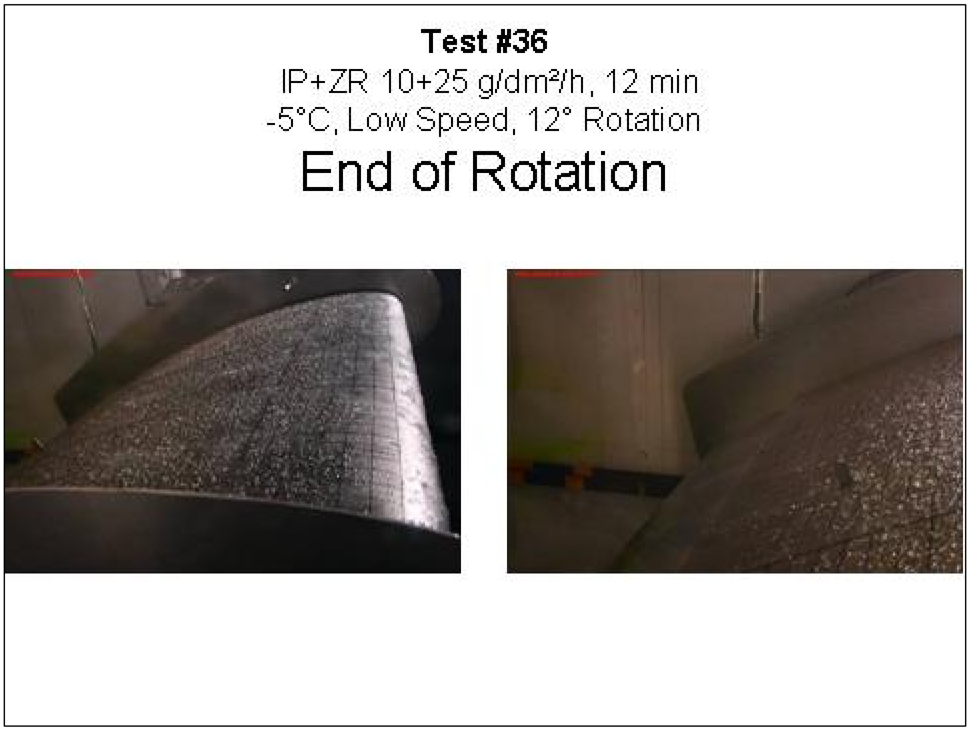

Photo 4.12: Test #36 – End of Test

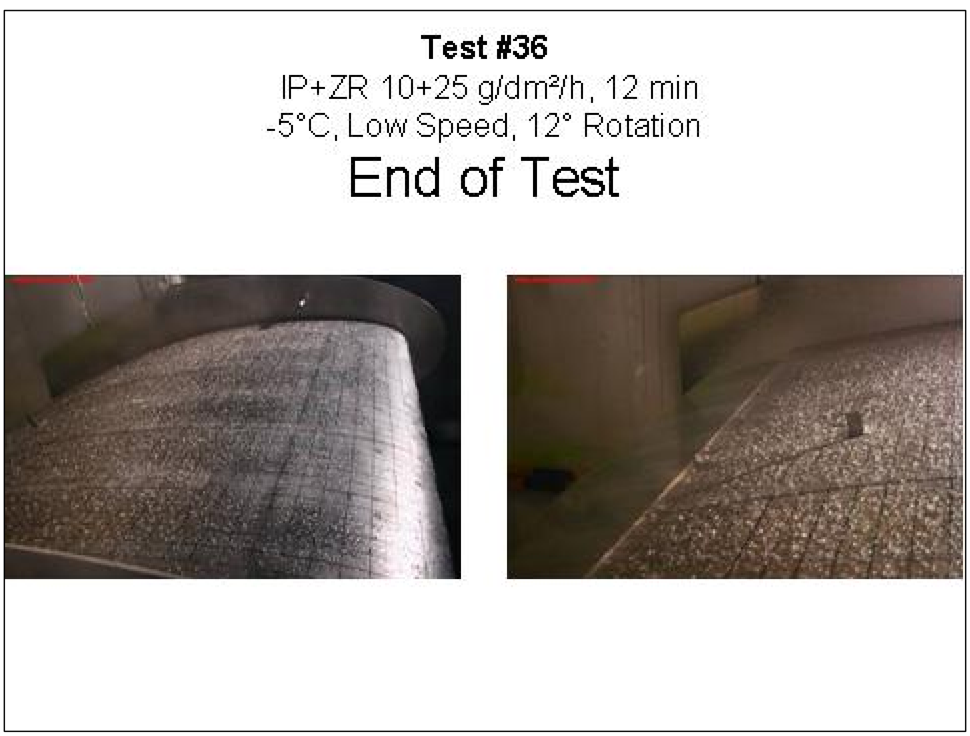

Photo 4.13: Test #37 – Start of Test

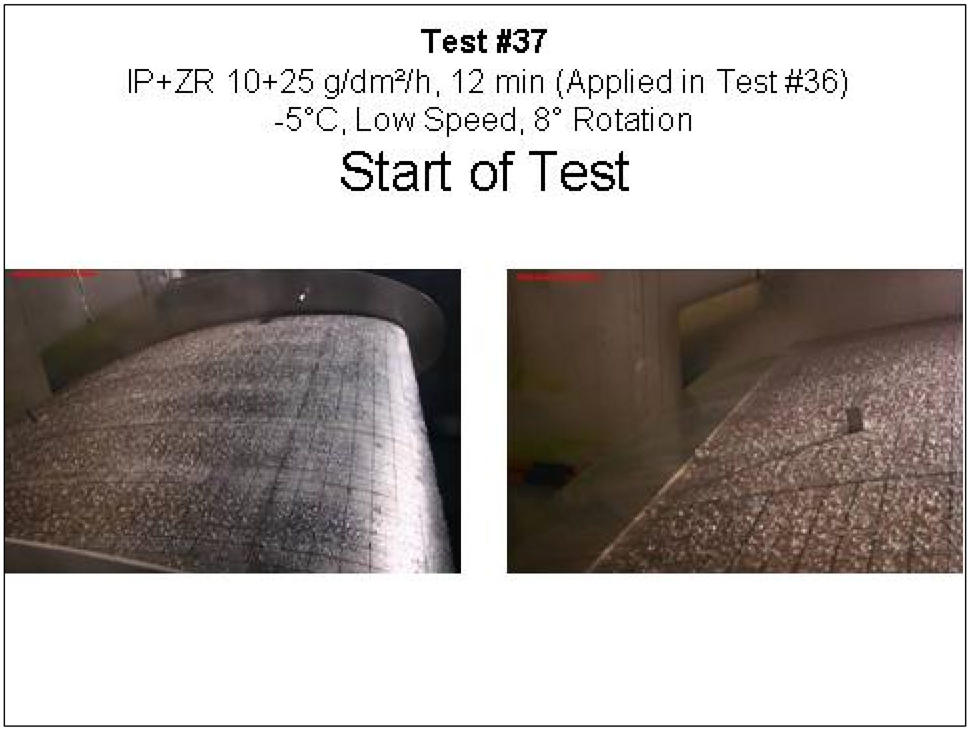

Photo 4.14: Test #37 – Before Rotation

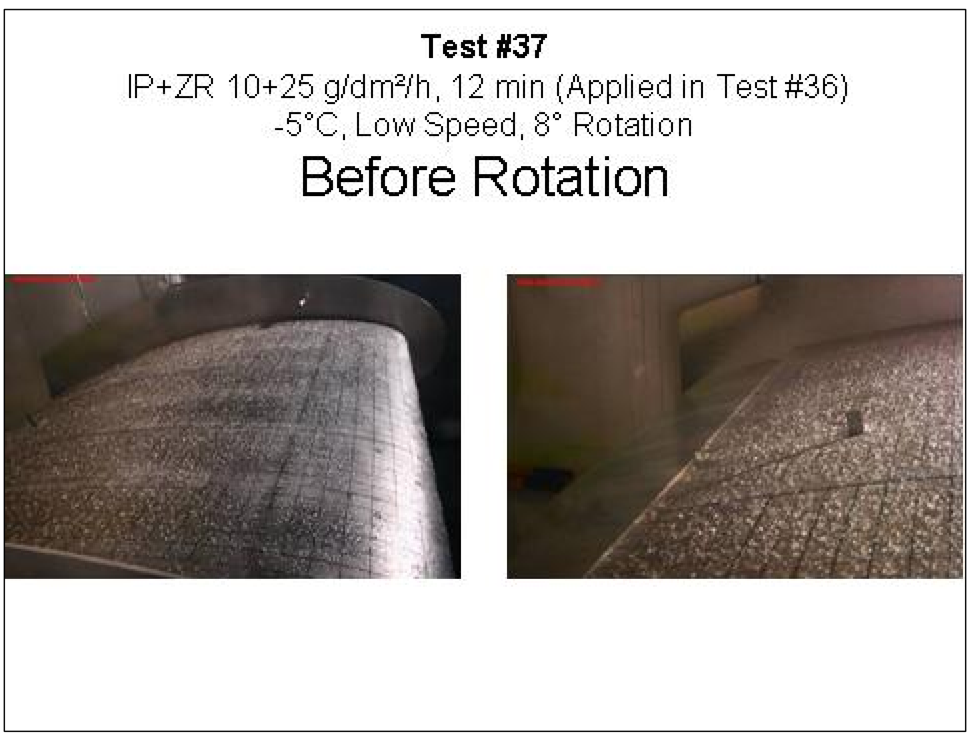

Photo 4.15: Test #37 – End of Rotation

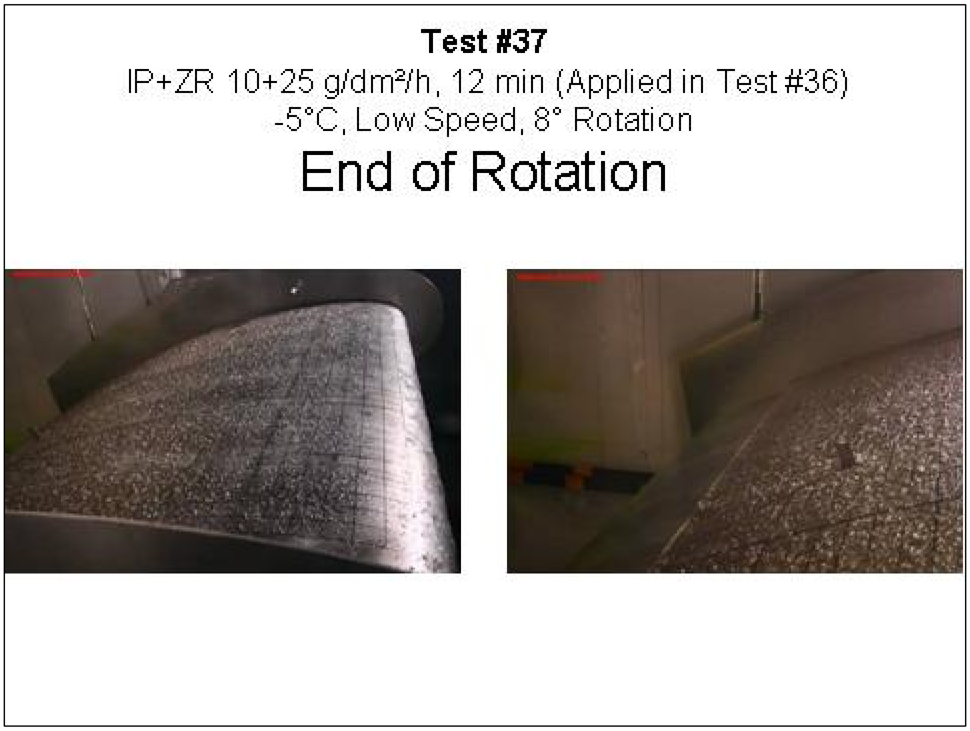

Photo 4.16: Test #37 – End of Test

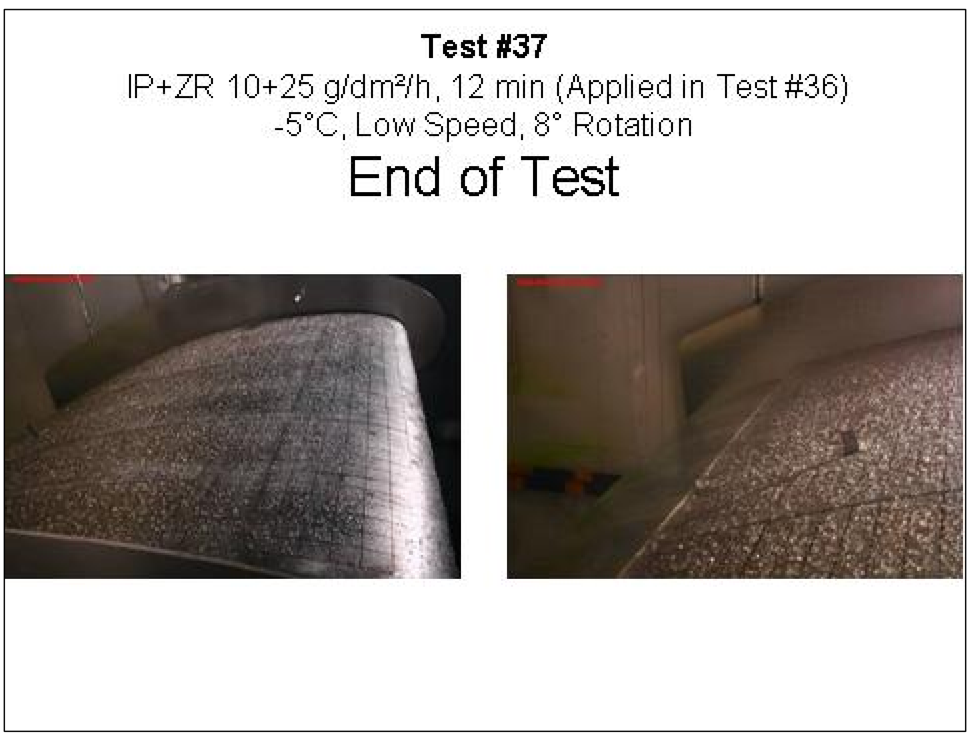

Photo 4.17: Test #38 – Start of Test

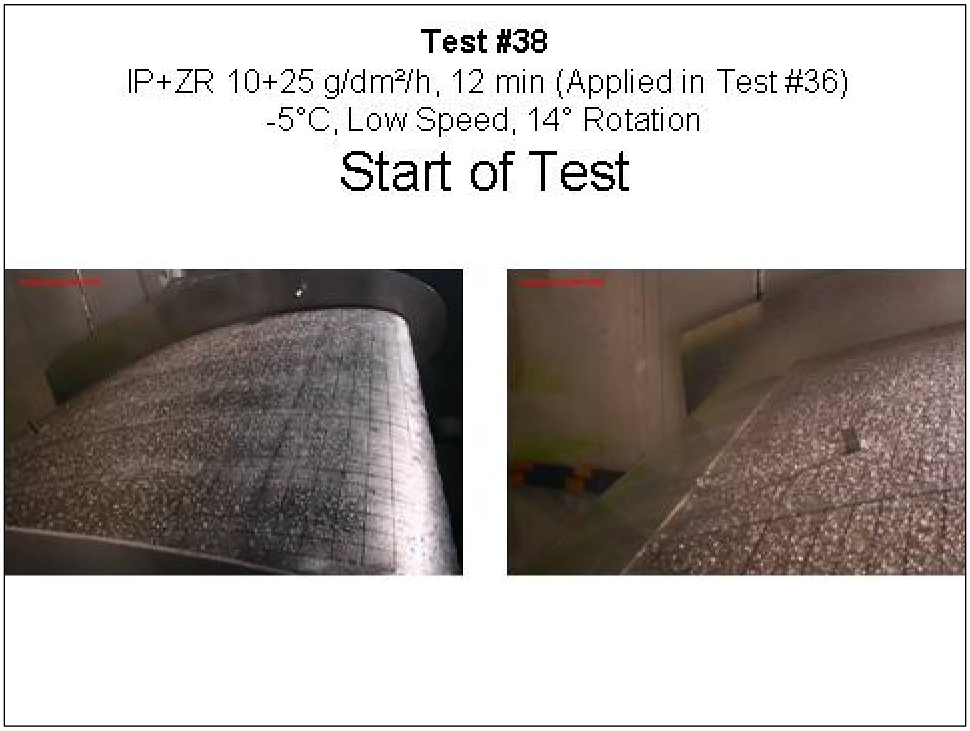

Photo 4.18: Test #38 – Before Rotation

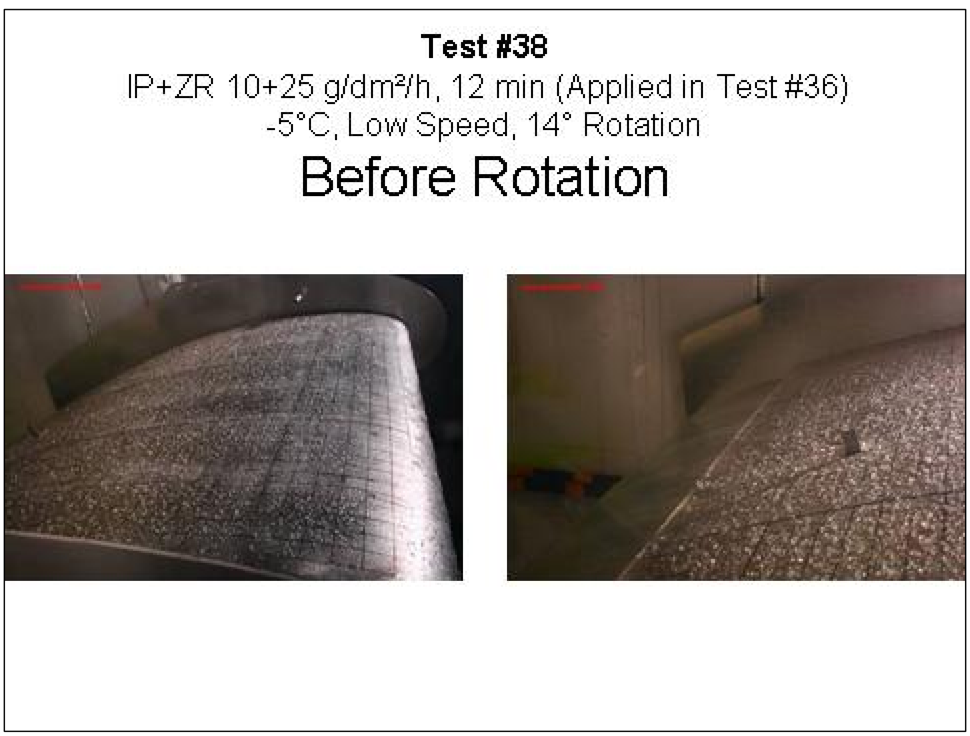

Photo 4.19: Test #38 – End of Rotation

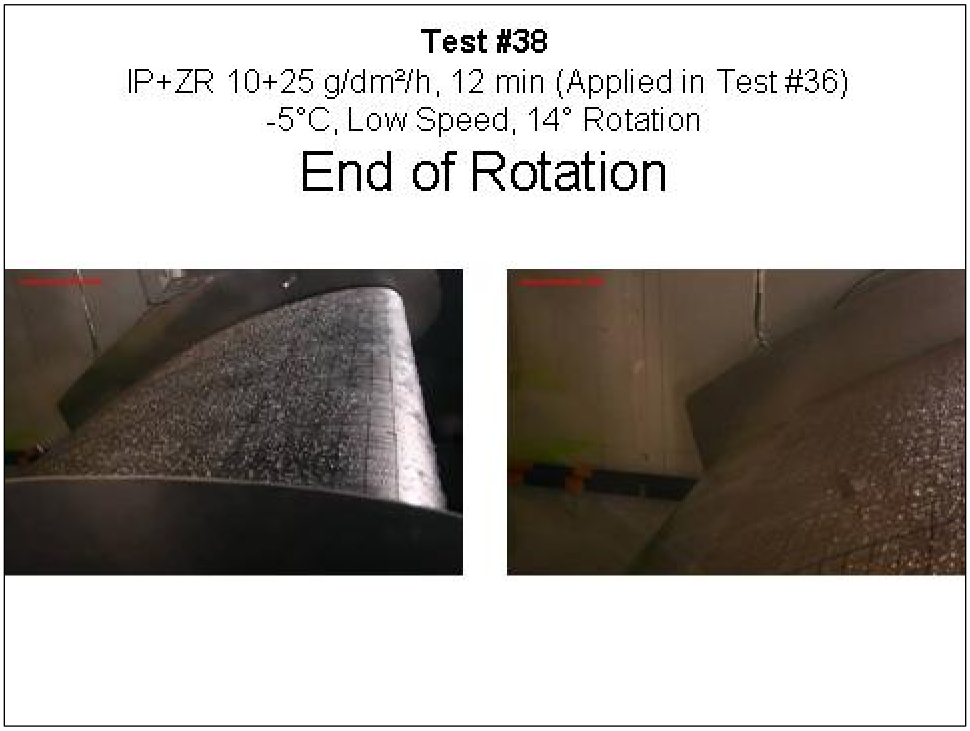

Photo 4.20: Test #38 – End of Test

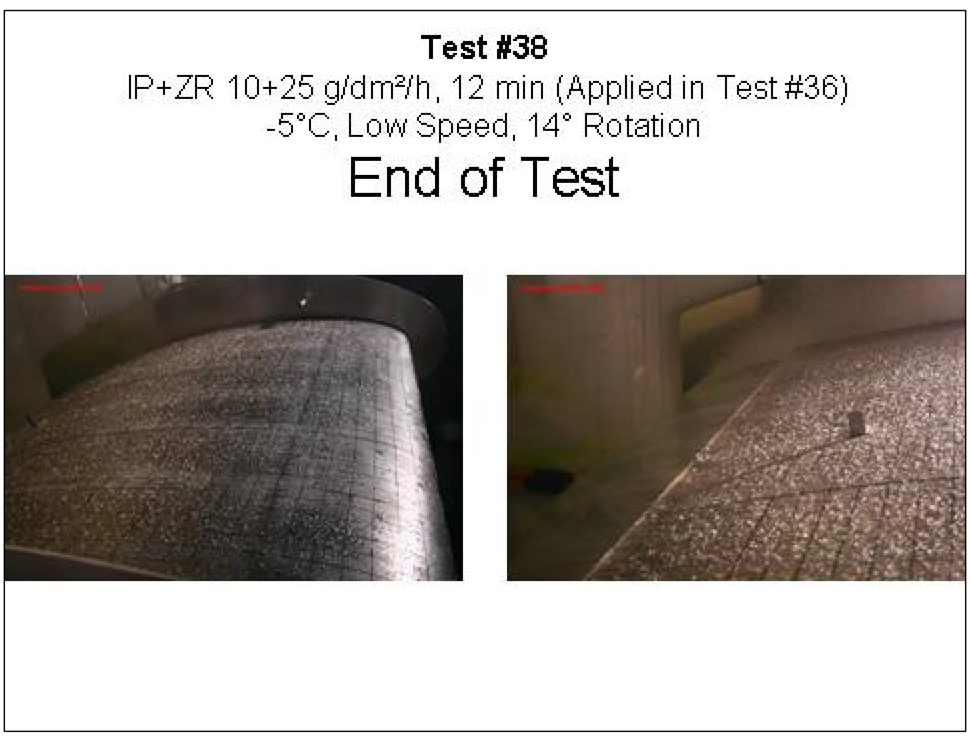

Photo 4.21: Test #39 – Start of Test

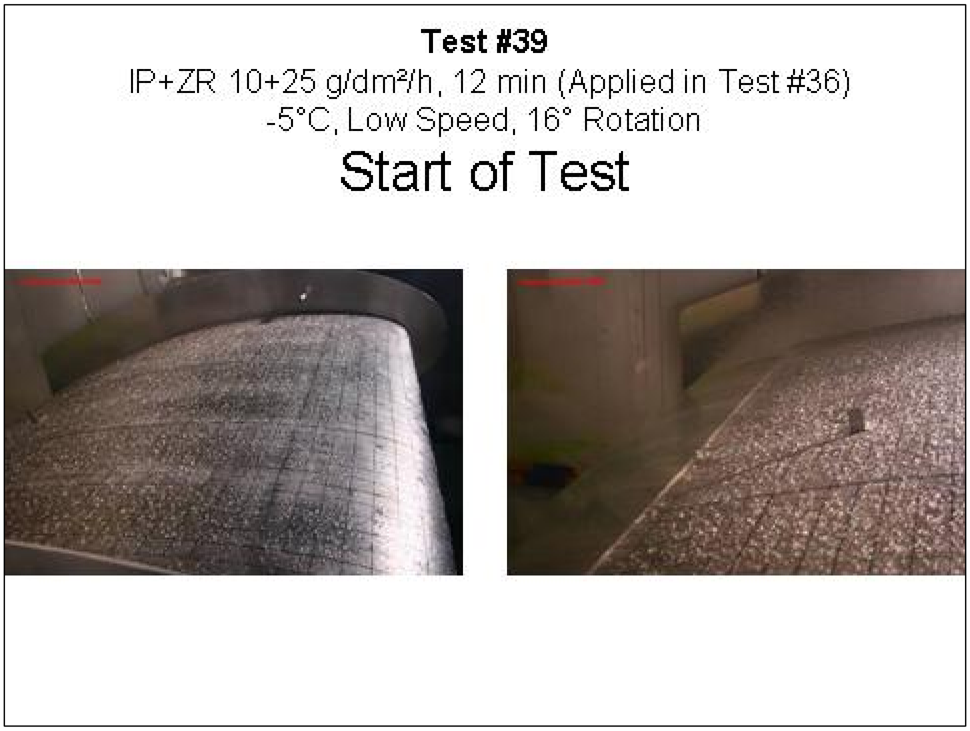

Photo 4.22: Test #39 – Before Rotation

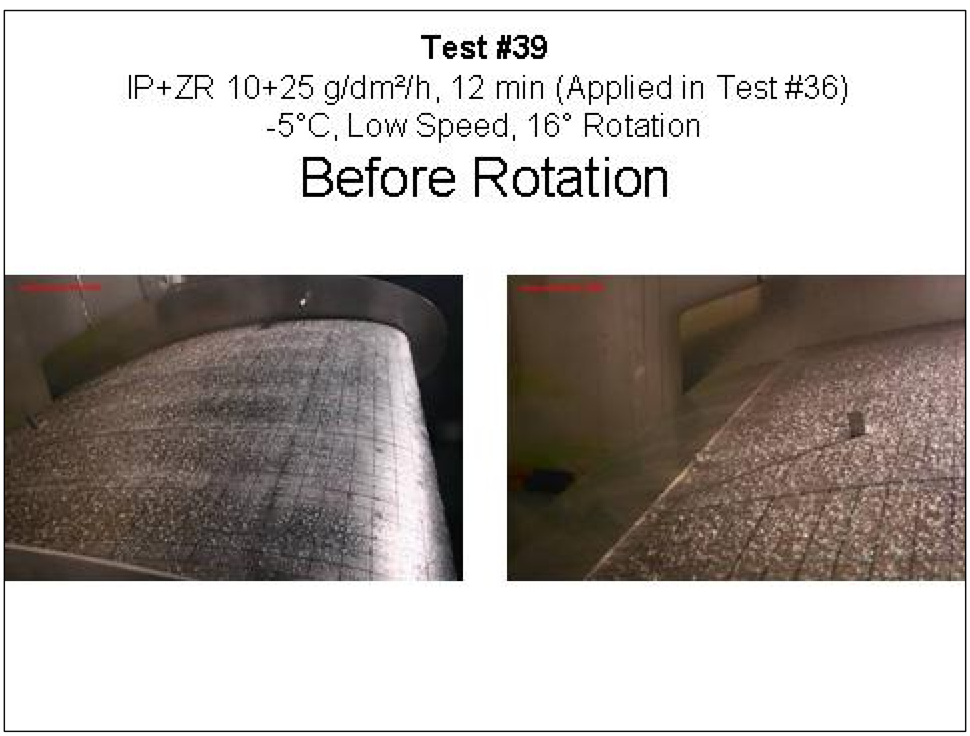

Photo 4.23: Test #39 – End of Rotation

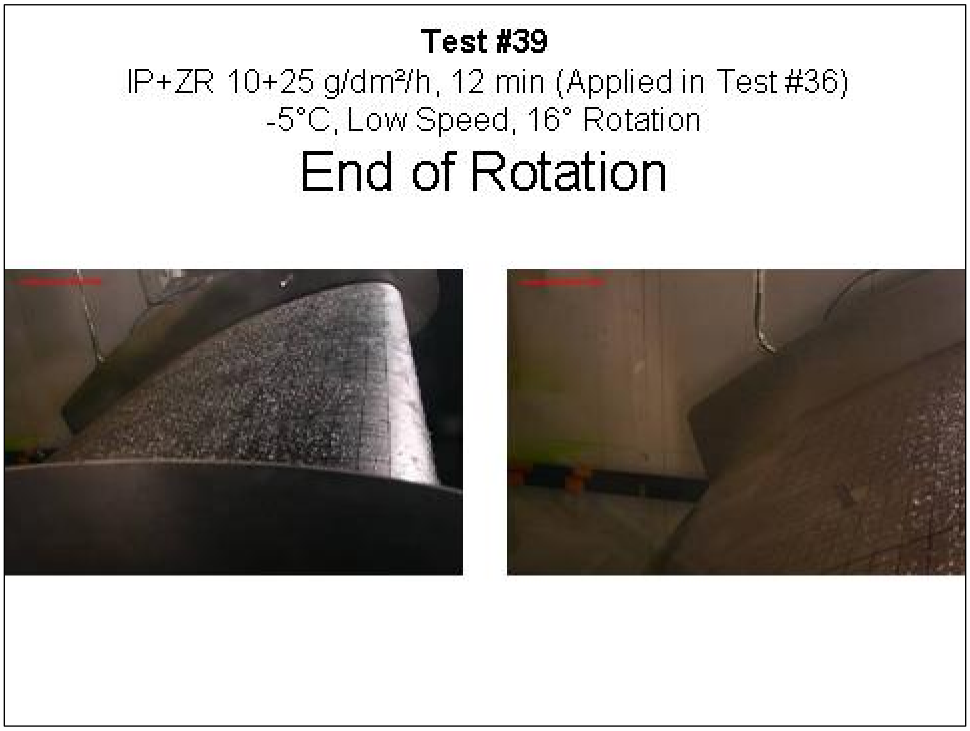

Photo 4.24: Test #39 – End of Test

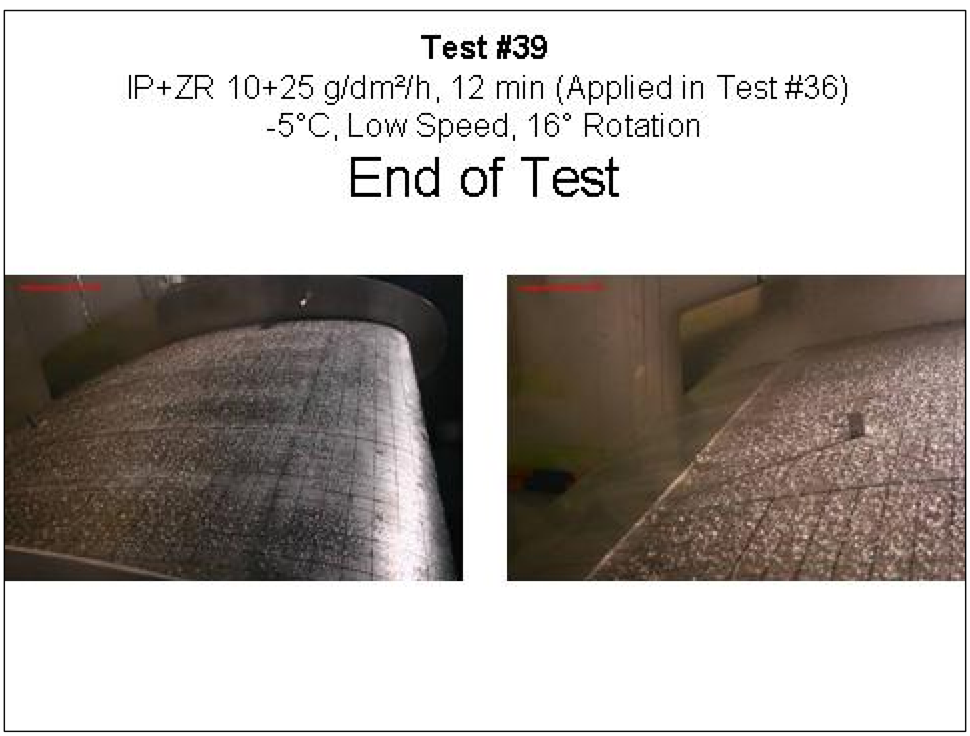

Photo 4.25: Test #40 – Start of Test

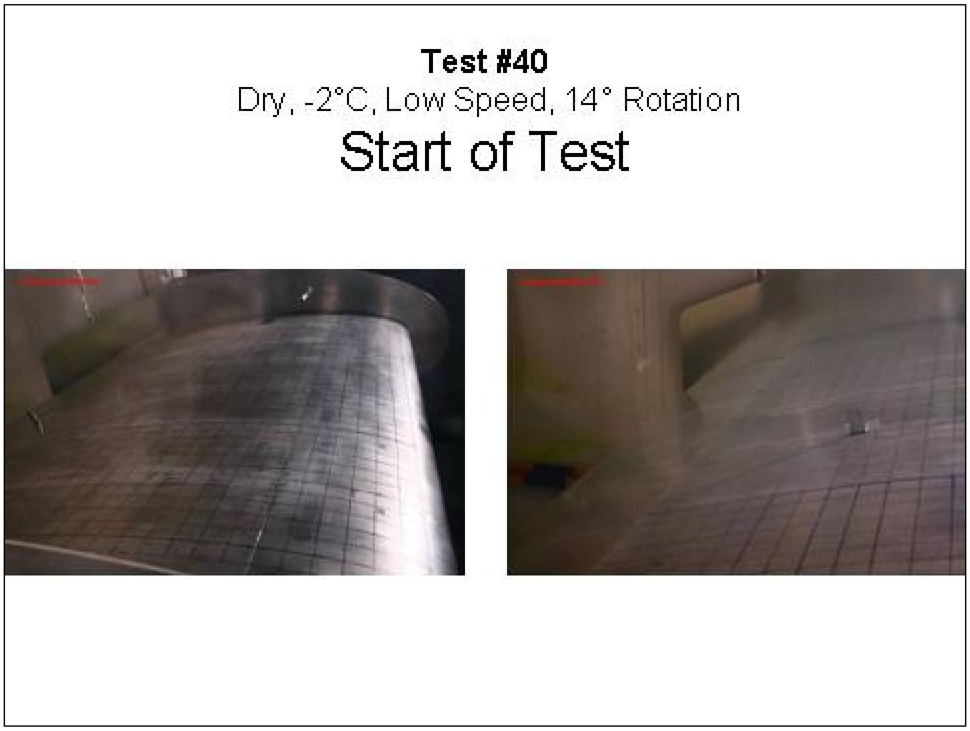

Photo 4.26: Test #40 – Before Rotation

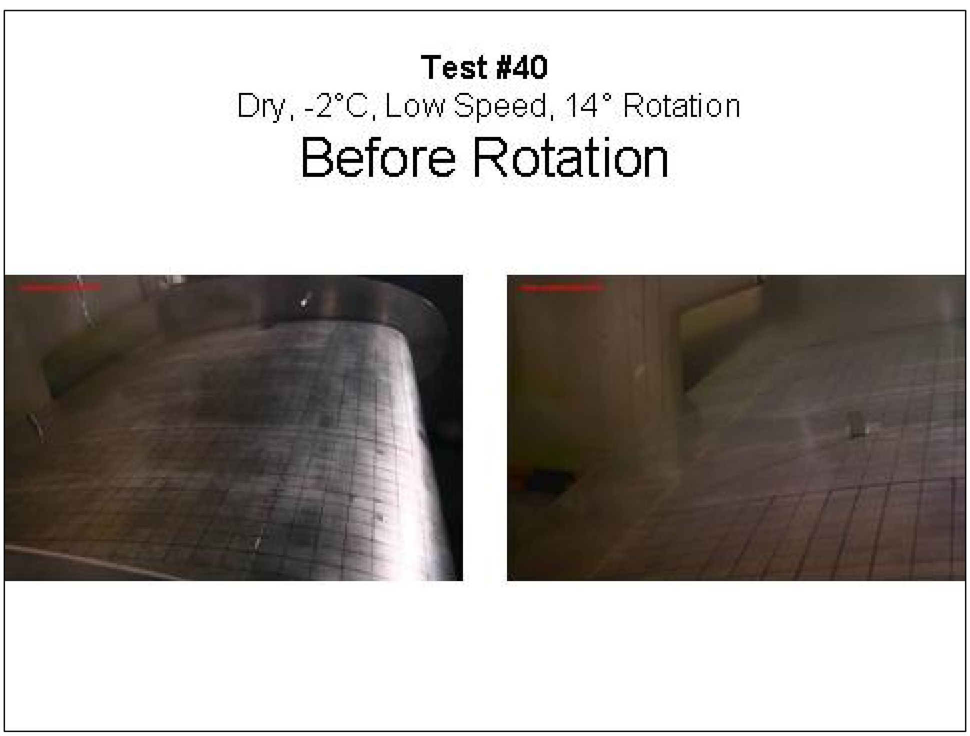

Photo 4.27: Test #40 – End of Rotation

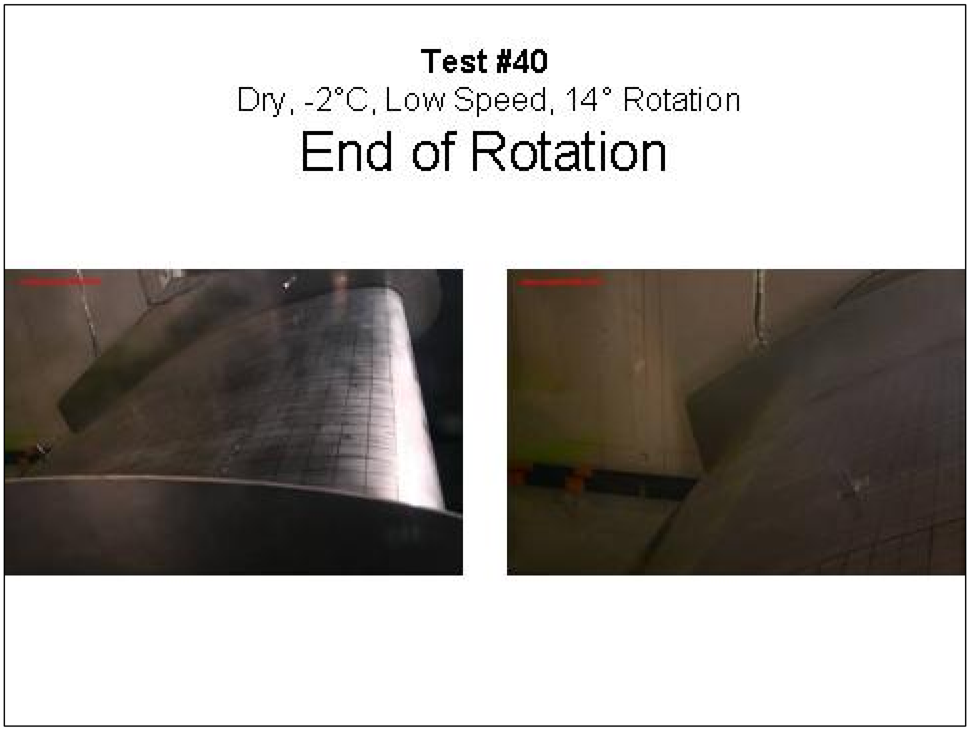

Photo 4.28: Test #40 – End of Test

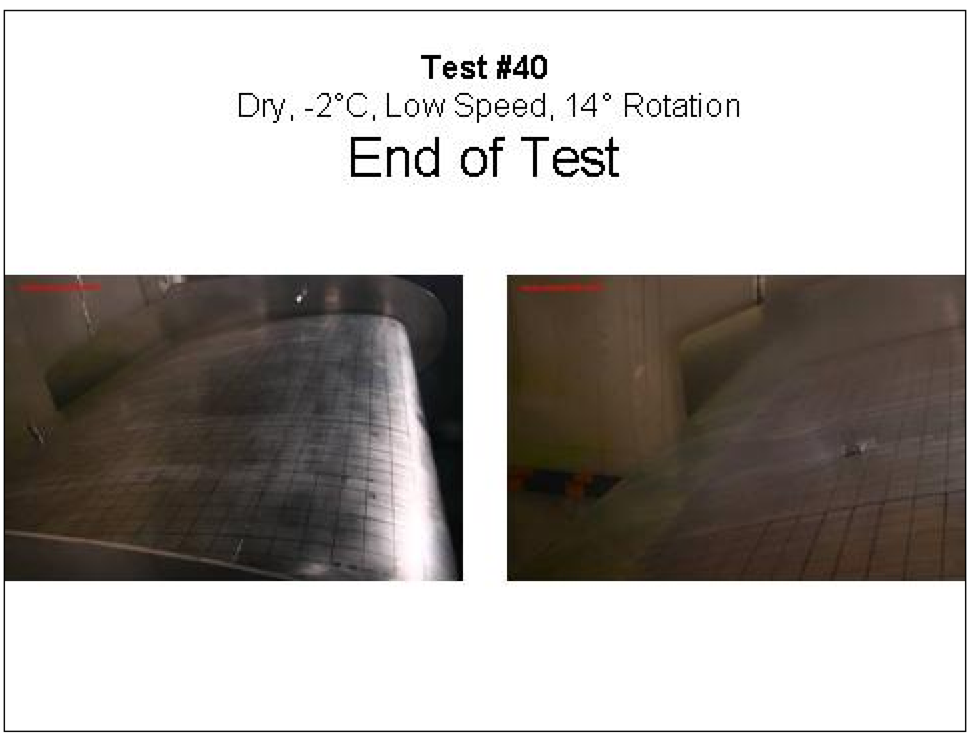

Photo 4.29: Test #41 – Start of Test

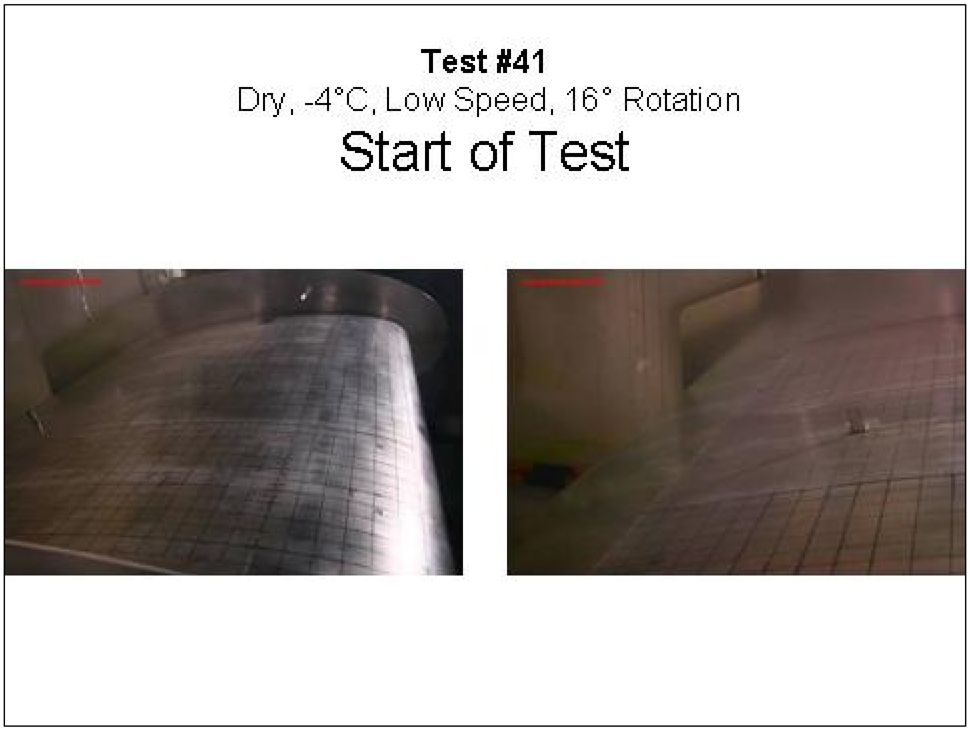

Photo 4.30: Test #41 – Before Rotation

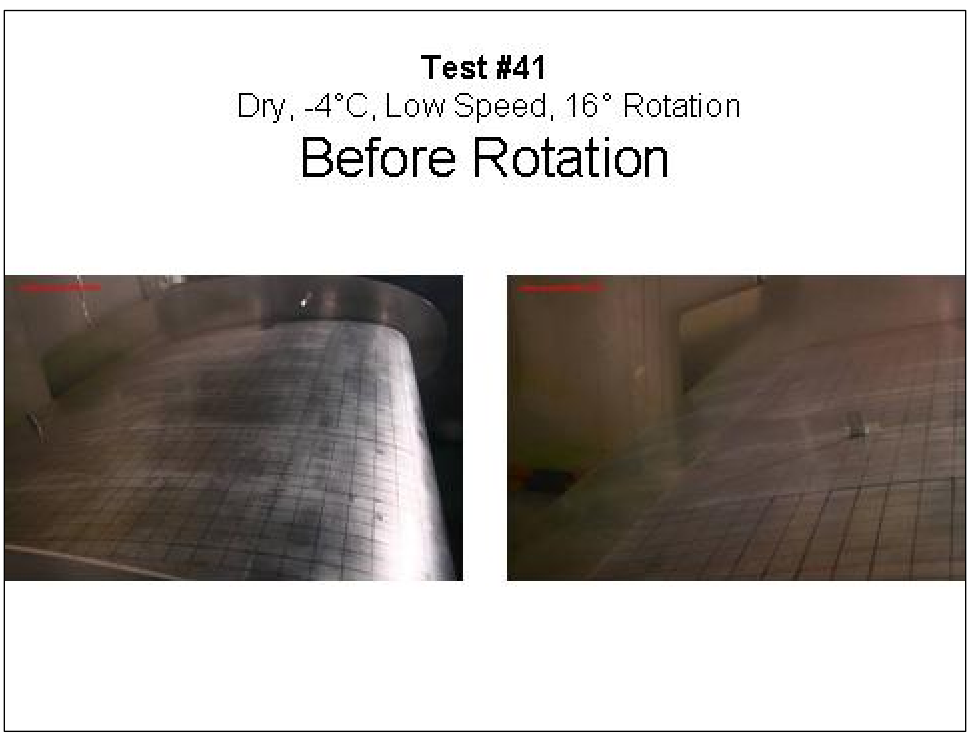

Photo 4.31: Test #41 – End of Rotation

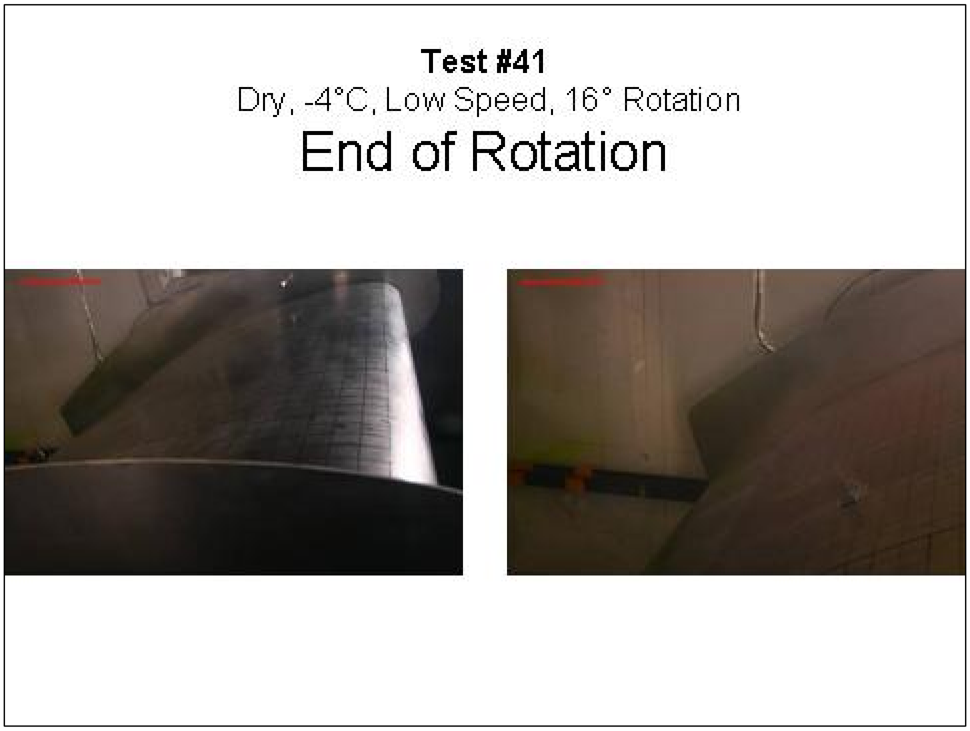

Photo 4.32: Test #41 – End of Test

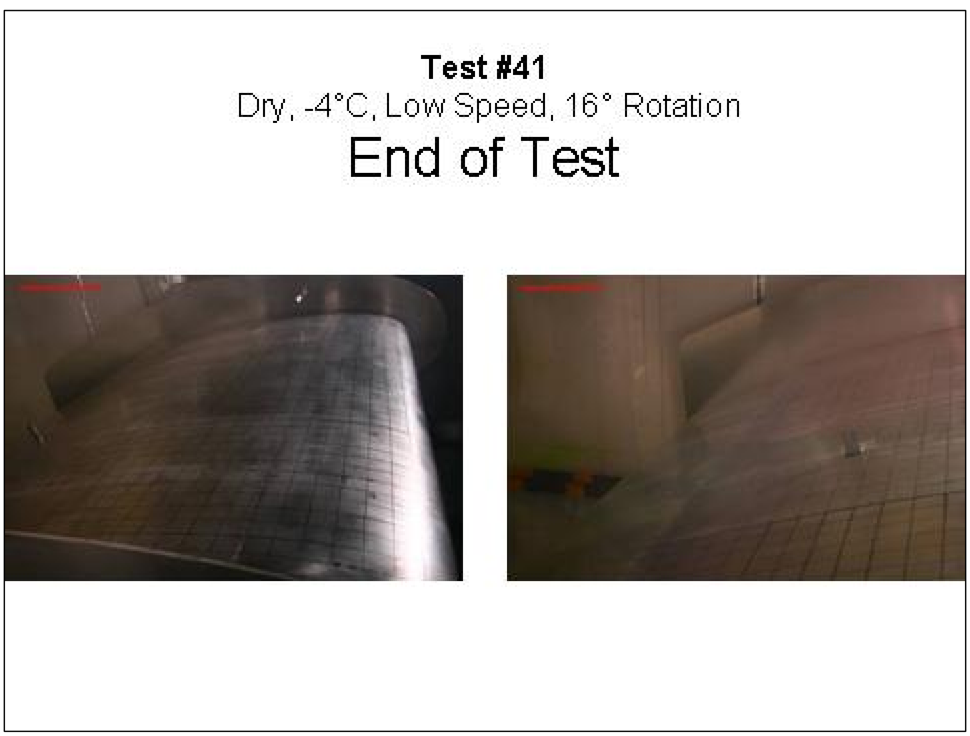

Photo 4.33: Test #93 – Start of Test

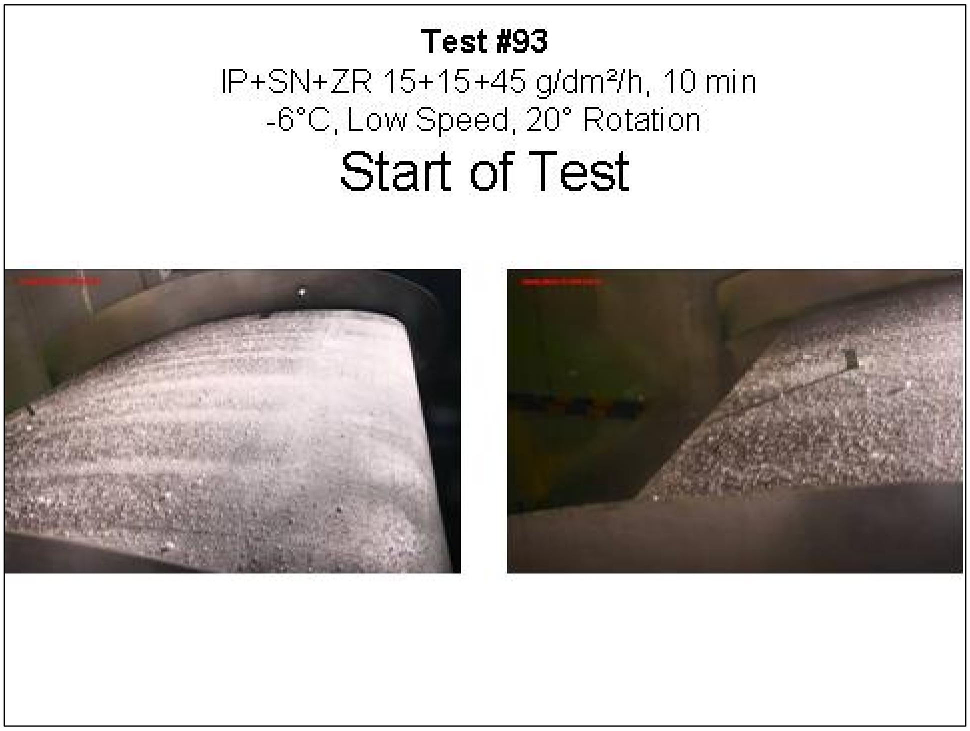

Photo 4.34: Test #93 – Before Rotation

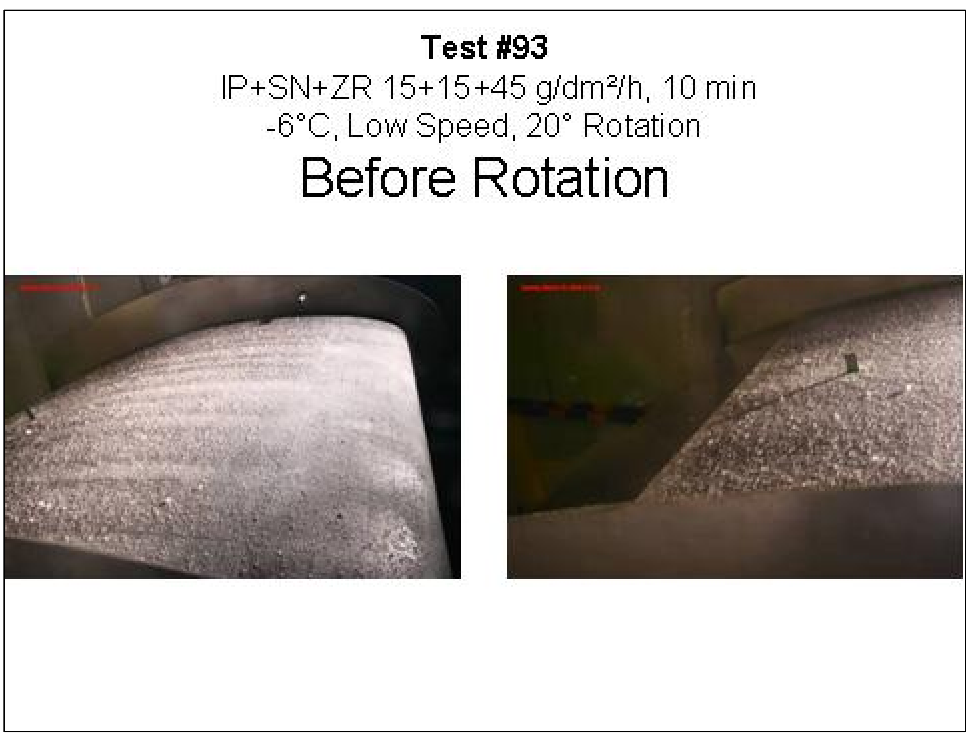

Photo 4.35: Test #93 – End of Rotation

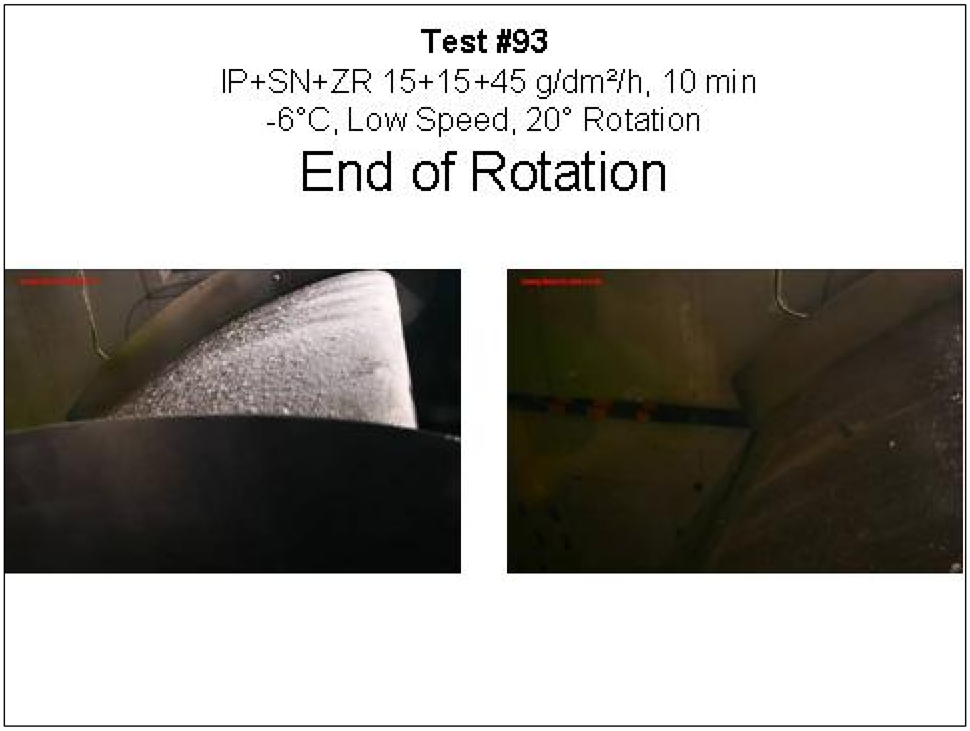

Photo 4.36: Test #93 – End of Test

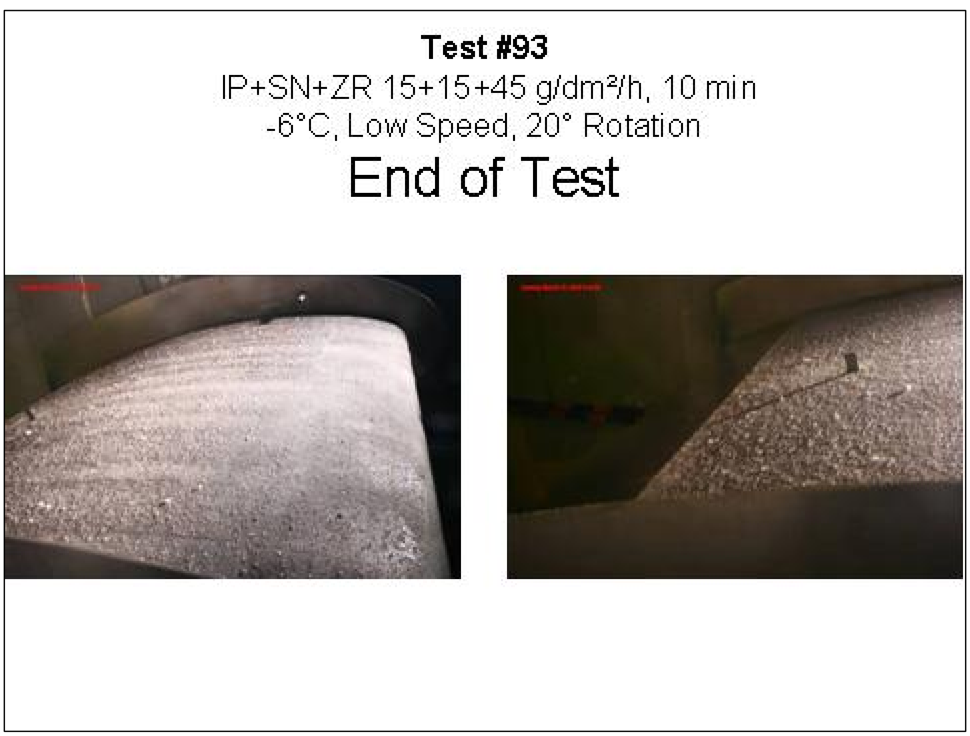

Photo 4.37: Test #94 – Start of Test

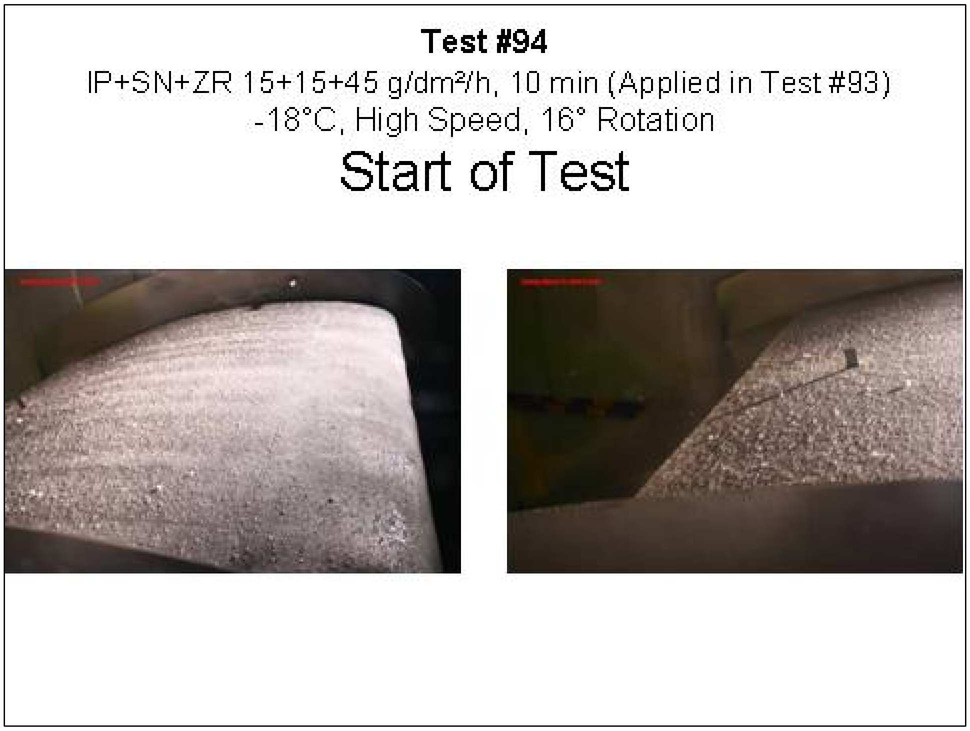

Photo 4.38: Test #94 – Before Rotation

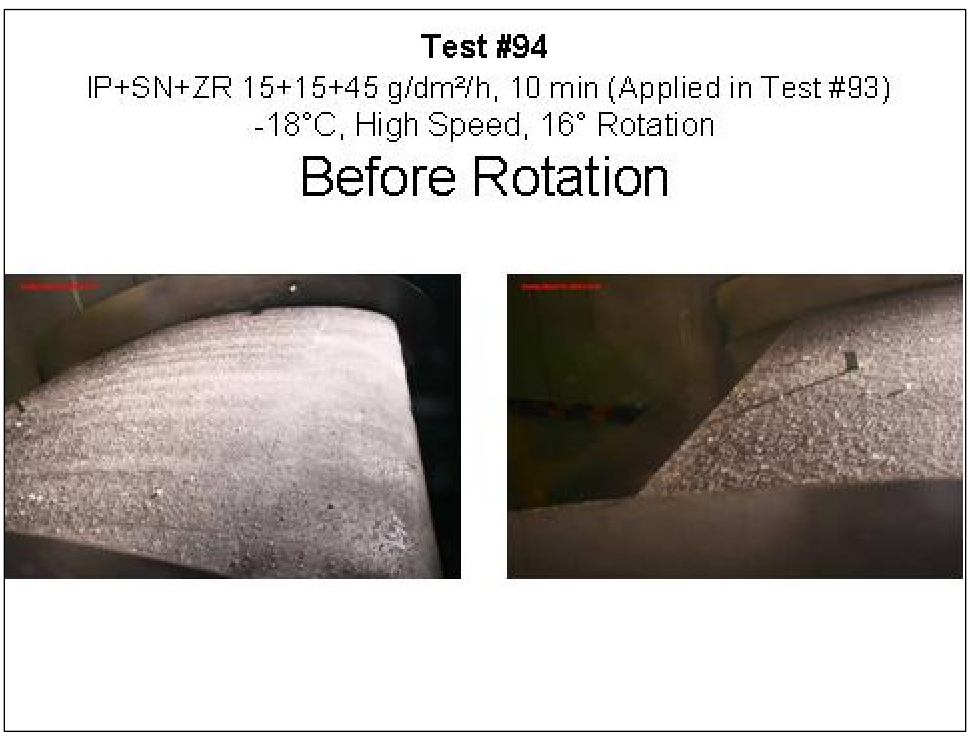

Photo 4.39: Test #94 – End of Rotation

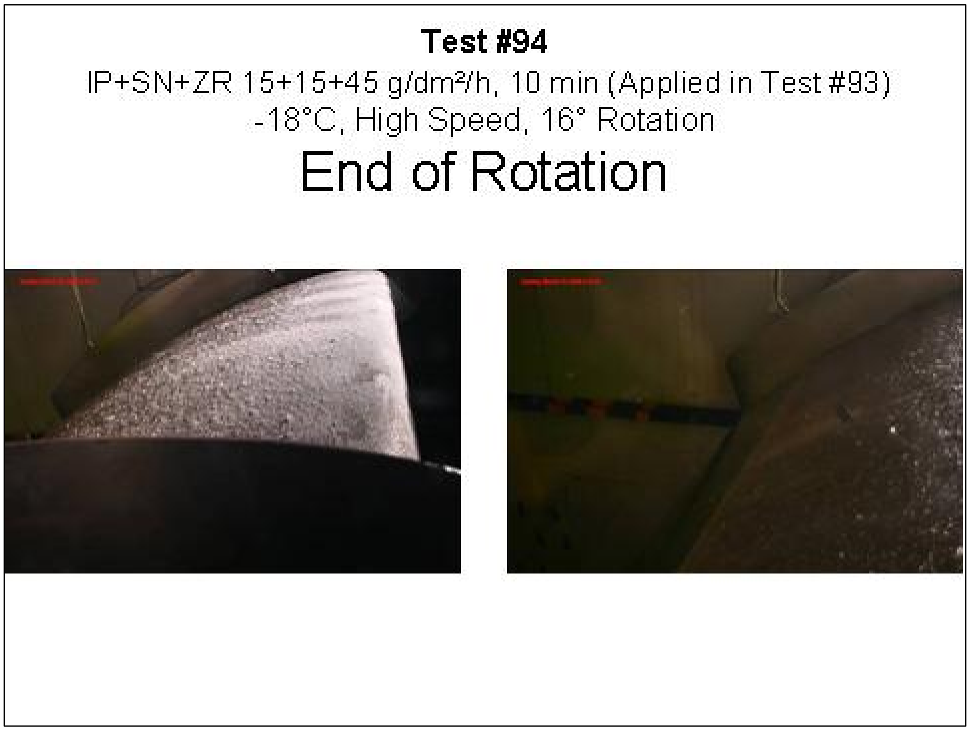

Photo 4.40: Test #94 – End of Test

Photo 4.41: Test #102A – Start of Test

No Photo Documentation Available

Photo 4.42: Test #102A – Before Rotation

No Photo Documentation Available

Photo 4.43: Test #102A – End of Rotation

No Photo Documentation Available

Photo 4.44: Test #102A – End of Test

No Photo Documentation Available

Photo 4.45: Test #103 – Start of Test

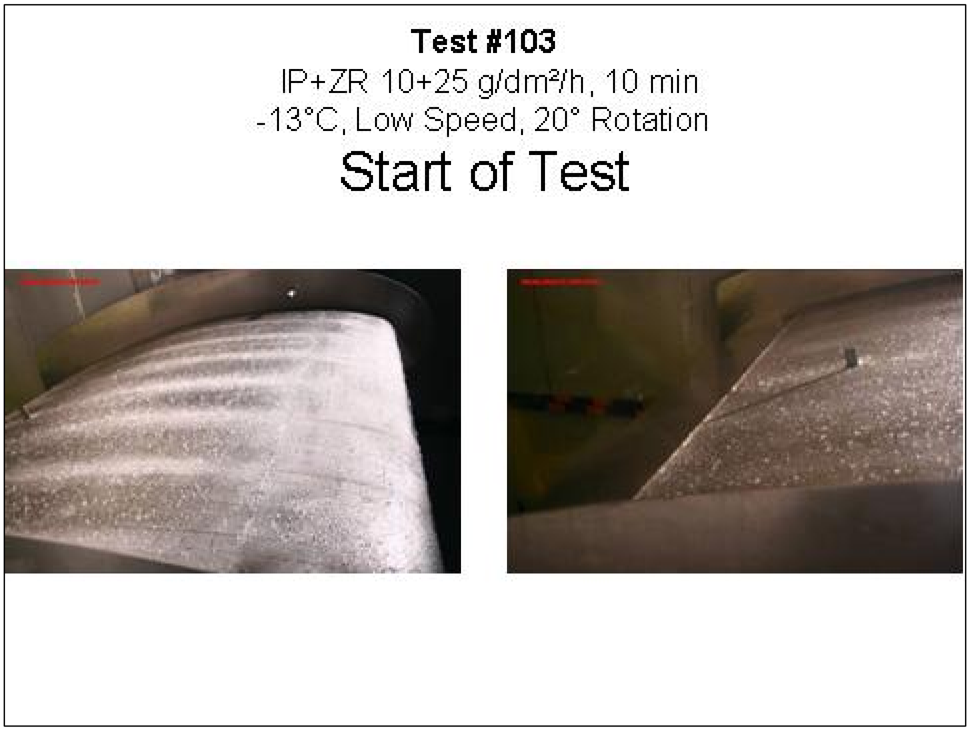

Photo 4.46: Test #103 – Before Rotation

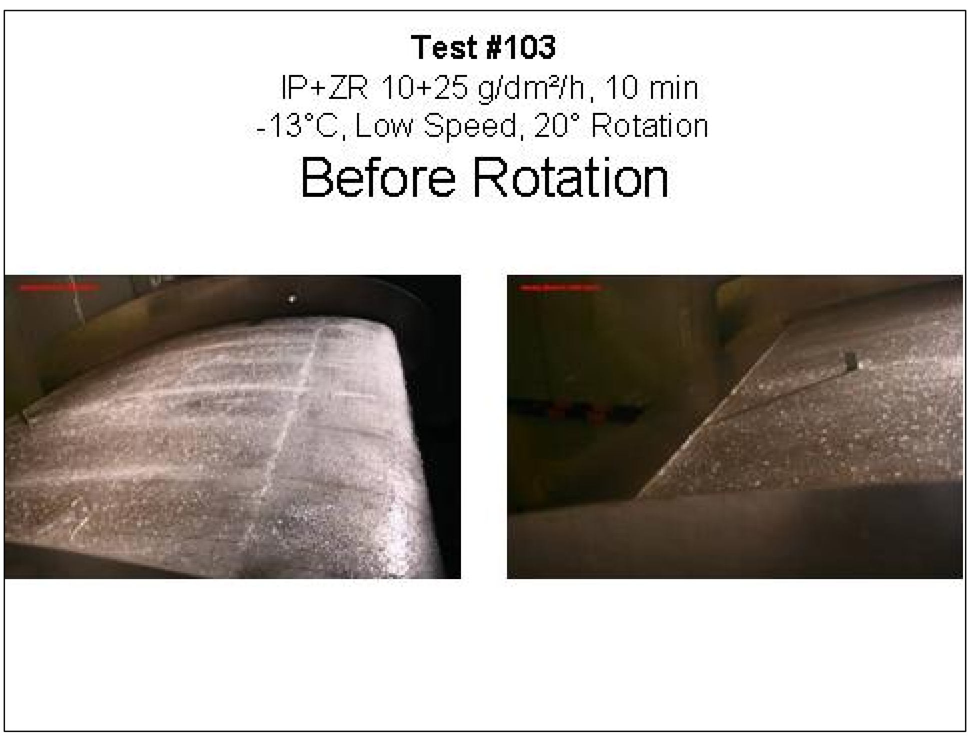

Photo 4.47: Test #103 – End of Rotation

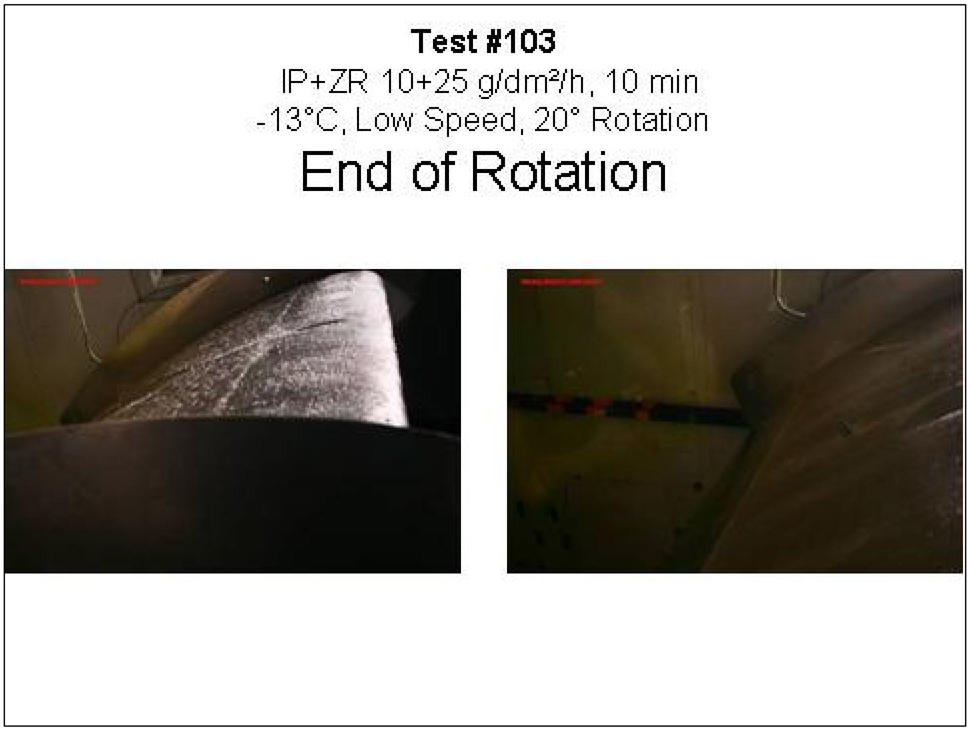

Photo 4.48: Test #103 – End of Test

Photo 4.49: Test #104 – Start of Test

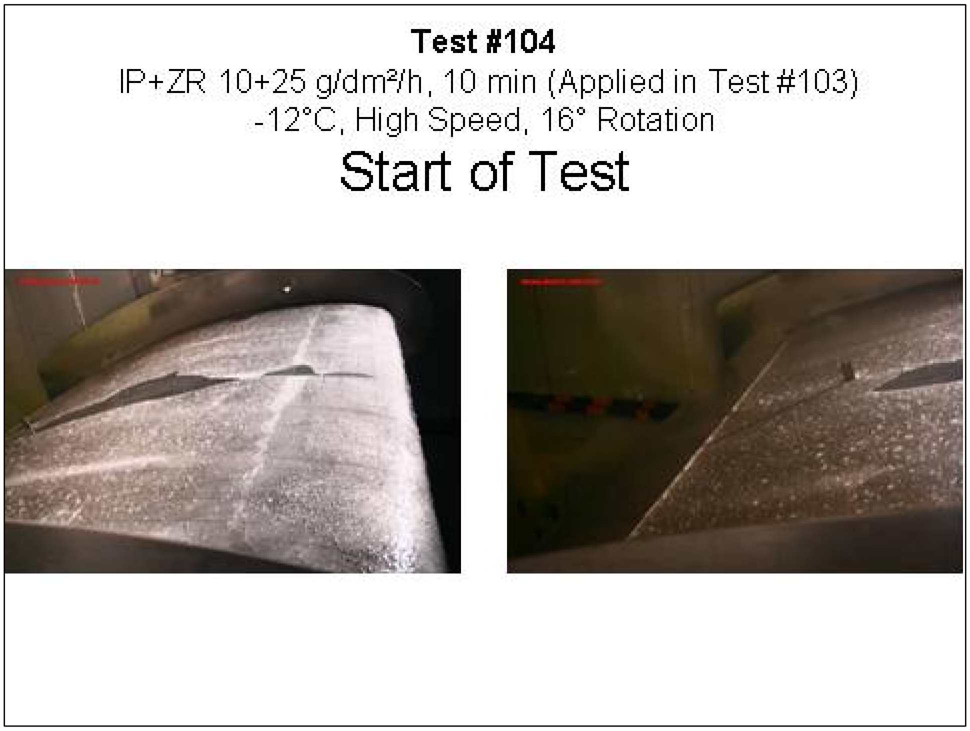

Photo 4.50: Test #104 – Before Rotation

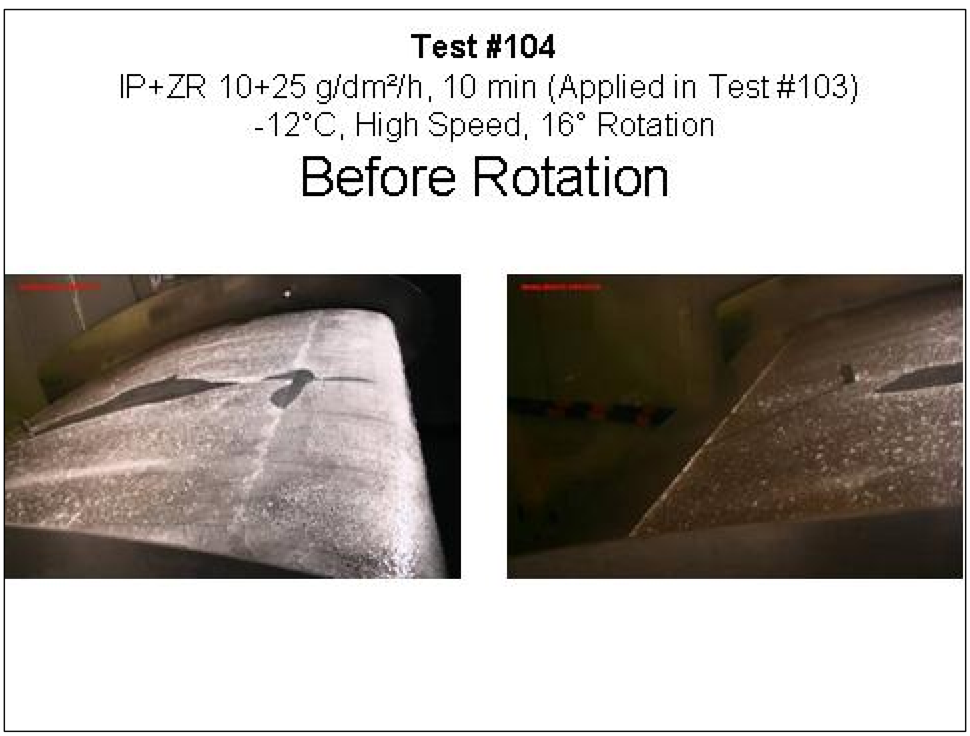

Photo 4.51: Test #104 – End of Rotation

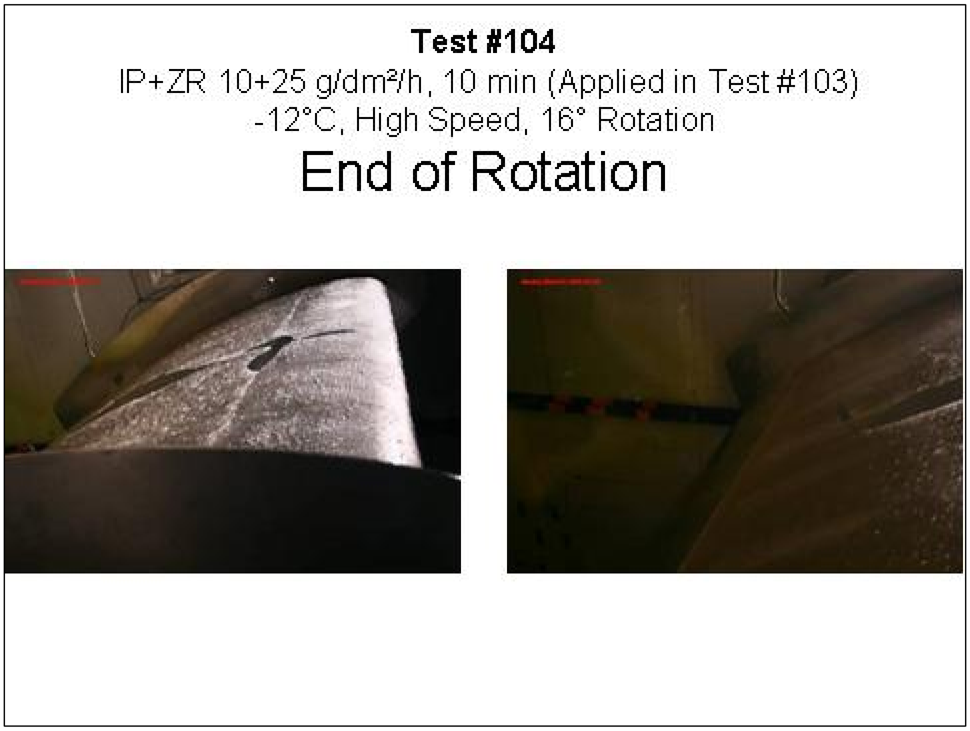

Photo 4.52: Test #104 – End of Test

5. LIGHT SNOW MIXED WITH LIGHT RAIN

As the accuracy of meteorological reporting continues to improve, and with the introduction of Holdover Time Determination Systems (HOTDS), there has evolved an industry need to provide HOT Guidelines for operations in mixed precipitation conditions. Transitional precipitation periods often include a mix of multiple precipitation types, and although these periods are generally short, on many occasions these transitional periods can last several hours, especially at warmer temperatures. As a result, a recent industry need has developed to provide improved guidance material during these transitional periods of mixed precipitation. In addition, providing HOT guidance material for mixed precipitation conditions will further aid the development of HOTDS technology.

TC and the FAA currently do not provide guidelines for operations in mixed light snow and light rain conditions. However, some regulatory agencies and aircraft operators have guidance for dealing with such conditions. The Association of European Airlines (AEA), for example, has recommended the use of light freezing rain HOTs for use during light snow mixed with light rain conditions. Testing was recommended to identify if the current TC and FAA guidelines could be modified to include mixed light snow and light rain conditions.

Flat plate testing was conducted by APS during the winters of 2007-08 and 2008-09 [see TC report, TP 14936E, *Aircraft Ground Icing General Research Activities During the 2008-09 Winter* (4)]. The results indicated that for all fluids tested, the estimated endurance time in light snow and light rain was always longer compared to the light freezing rain only test. At the estimated time of failure for both conditions, adherence was present on the plate. The condition of the fluid during the test showed characteristics similar to light freezing rain conditions (i.e., presence of adherence and erosion of the fluid layer). The level of adherence was generally similar or less severe in the case of light snow and light rain; however, adhered contamination was rougher. Light freezing rain HOTs seemed a good conservative approach for mixed light snow and light rain conditions; this is in accordance with the AEA recommendation. Resultantly, a footnote has been included in all the Type I, II, III, and IV tables of the 2009-2010 HOT Guidelines that indicates the following:

- Use light freezing rain HOTs in conditions of light snow mixed with light rain.

It was recommended that some preliminary aerodynamic research be conducted in mixed light snow and light rain conditions to validate the flat plate results obtained. In addition, it was recommended that testing also be conducted in moderate snow mixed with light freezing rain conditions as a lower priority objective to investigate the potential for providing guidance material in these conditions. This section provides an overview of each test conducted as part of the test program to evaluate the fluid flow-off properties of anti-icing fluid contaminated with light snow mixed with light rain.

5.1 General Methodology

The methodology used during these tests was in accordance with the methodologies described in Section 2. The duration of exposure time was based on the current HOTs for light freezing rain.

5.2 Overview of Tests

A summary of the rain/freezing rain mixed with snow 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.
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 run, 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 run, recorded in degrees Celsius.

Visual Contamination Rating Before Takeoff (LE, TE):

Visual contamination rating determined before the start of the simulated takeoff. Two values are indicated [one for the leading edge (LE) and one for the trailing edge (TE)]:

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. Two values are indicated [one for the leading edge (LE) and one for the trailing edge (TE)]:

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.

C_L at 8° During Rotation:

Calculated lift coefficient at the 8° wing rotation angle position; data provided by the NRC.

One Type IV test was conducted in mixed light snow and light rain conditions (Test #50). A Type I test was also conducted in mixed light snow and light rain (Test #96), and a comparison test (Test #97) was conducted in light freezing rain alone. In addition, one Type IV test was conducted in moderate snow mixed with light freezing rain conditions (Test #72). Due to residual contamination at the end of the test, the test was re-run (as Test #72R) to verify if the leading edge contamination could be eliminated given more time.

Table 5.1: Summary of 2008-09 Light Snow Mixed with Light Rain Tests

Test No.	Date	Fluid	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)	Visual Cont. Rating at Rotation (LE, TE)	C_L at 8° During Rotation
50	2-Feb-09	Launch	R/SN	15/15	60	-1	-1.5	1, 1	1, 1	1.757
72	5-Feb-09	Launch	ZR/SN	25/25	30	-4	-5.4	5, 4.5	5, 2	1.693
72R*	5-Feb-09	Launch	ZR/SN	25/25	30	-15	N/A	5, 2	5, 1.5	1.735
96	1-Mar-09	OctoFlo	R/SN	15/10	5	-3	N/A	2, 2	5, 5	1.826
97	1-Mar-09	OctoFlo	ZR	25	5	-3	N/A	1, 2	5, 5	1.827

**** Indicates re-run of previous test; contamination applied in previous test.***

5.3 Data Collected

5.3.1 Fluid Thickness Data

APS personnel collected fluid thickness measurements. The wing positions used for the wind tunnel tests are described in Subsection 2.15.2. Fluid thickness measurements were recorded at the following intervals:

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

Tables 5.2 to 5.6 show the fluid thickness measurements collected during the tests.

Table 5.2: Test #50 Fluid Thickness Data

Test 50, Launch, R/SN, Tunnel OAT -1°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip, Application	After Takeoff Run
1	0.8	0.2	0.0
2	1.1	0.7	0.0
3	1.4	1.8	0.0
4	2.2	2.2	0.0
5	3.3	3.1	0.0
6	1.2	0.8	0.1
7	1.1	0.5	0.1
8	1.3	0.6	0.1

Table 5.3: Test #72 Fluid Thickness Data

Test 72, Launch, ZR/SN, Tunnel OAT -4°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip, Application	After Takeoff Run
1	0.7	0.3	N/A
2	1.0	0.8	N/A
3	1.1	2.2	N/A
4	1.4	2.5	N/A
5	2.2	3.3	N/A
6	1.1	0.5	N/A
7	1.1	0.5	N/A
8	1.1	0.8	N/A

Table 5.4: Test #72R Fluid Thickness Data

Test 72R, Launch, ZR/SN, Tunnel OAT -14.9°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip, Application	After Takeoff Run
1	N/A	N/A	0.0
2	N/A	N/A	0.0
3	N/A	N/A	0.0
4	N/A	N/A	0.0
5	N/A	N/A	0.0
6	N/A	N/A	0.2
7	N/A	N/A	0.1
8	N/A	N/A	0.3

Table 5.5: Test #96 Fluid Thickness Data

Test 96, OctoFlo, R/SN, Tunnel OAT -2.6ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip, Application	After Takeoff Run
1	N/A	N/A	N/A
2	N/A	N/A	N/A
3	N/A	N/A	N/A
4	N/A	N/A	N/A
5	N/A	N/A	N/A
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	N/A	N/A	N/A

Table 5.6: Test #97 Fluid Thickness Data

Test 97, OctoFlo, ZR, Tunnel OAT -2.5ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip, Application	After Takeoff Run
1	N/A	N/A	N/A
2	N/A	N/A	N/A
3	N/A	N/A	N/A
4	N/A	N/A	N/A
5	N/A	N/A	N/A
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	N/A	N/A	N/A

5.3.2 Skin Temperature Data

APS personnel collected skin temperature measurements. The wing positions used for the wind tunnel tests are described in Subsection 2.15.3. Skin temperature measurements were recorded at the following intervals:

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

The wing temperature measurements recorded during each test are shown in Tables 5.7 to 5.11.

Table 5.7: Test #50 Wing Skin Temperature Data

Test 50, Launch, SN/R, Tunnel OAT -1°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip, Application	After Takeoff Run
T2	1.4	0.2	-1.6	-2.6
T5	1.7	0.2	-0.8	-2.2
TU	1.1	0.2	-2.0	-3.3

Table 5.8: Test #72 Wing Skin Temperature Data

Test 72, Launch, ZR/SN, Tunnel OAT -4°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip, Application	After Takeoff Run
T2	-10.8	-9.6	-5.2	N/A
T5	-9.5	-10.0	-5.4	N/A
TU	-11.5	-10.7	-5.7	N/A

Table 5.9: Test #72R Wing Skin Temperature Data

Test 72R, Launch, ZR/SN, Tunnel OAT -14.9°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip, Application	After Takeoff Run
T2	N/A	N/A	N/A	-11.7
T5	N/A	N/A	N/A	-10.6
TU	N/A	N/A	N/A	-12.3

Table 5.10: Test #96 Wing Skin Temperature Data

Test 96, OctoFlo, R/SN, Tunnel OAT -2.6°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip, Application	After Takeoff Run
T2	-4.6	N/A	N/A	N/A
T5	-4.0	N/A	N/A	N/A
TU	-5.5	N/A	N/A	N/A

Table 5.11: Test #97 Wing Skin Temperature Data

Test 97, OctoFlo, ZR, Tunnel OAT -2.5°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip, Application	After Takeoff Run
T2	N/A	N/A	N/A	N/A
T5	N/A	N/A	N/A	N/A
TU	N/A	N/A	N/A	N/A

5.3.3 Fluid Brix Data

APS personnel collected fluid Brix measurements. The wing positions used for the wind tunnel tests are described in Subsection 2.15.4. Fluid Brix measurements were recorded at the following intervals:

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

Tables 5.12 to 5.16 show the fluid Brix measurements collected during the test.

Table 5.12: Test #50 Fluid Brix Data

Test 50, Launch, SN/R, Tunnel OAT -1°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	36.25	15.00	N/A
8	36.25	10.00	30.75

Table 5.13: Test #72 Fluid Brix Data

Test 72, Launch, ZR/SN, Tunnel OAT -4°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	37.00	17.00	N/A
8	36.50	12.25	N/A

Table 5.14: Test #72R Fluid Brix Data

Test 72R, Launch, ZR/SN, Tunnel OAT -14.9°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	N/A	N/A	30.75
8	N/A	N/A	30.75

Table 5.15: Test #96 Fluid Brix Data

Test 96, OctoFlo, R/SN, Tunnel OAT -2.6°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	N/A	9.25	N/A
8	N/A	N/A	N/A

Table 5.16: Test #97 Fluid Brix Data

Test 97, OctoFlo, ZR, Tunnel OAT -2.5°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	N/A	6.50	N/A
8	N/A	N/A	N/A

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 5.20 show the photo summaries of the tests conducted. A complete set of photos will be provided to the TDC.

5.5 General Observations

The following sections describe the observations regarding the testing conducted in mixed rain/freezing rain and snow precipitation conditions.

5.5.1 Light Snow Mixed with Light Rain

5.5.1.1 Type IV Fluid

One Type IV test was conducted in mixed light snow and light rain conditions (Test #50). A 60-minute exposure time was selected based on the current Type IV fluid HOT for light freezing rain in conditions of -3ºC and above. The results demonstrated positive visual contamination ratings, as well as good lift coefficient results. This test supported the flat plate testing results recommending the use of light freezing rain HOTs for conditions of mixed light snow and light rain.

5.5.1.2 Type I Fluid

A Type I test was conducted in mixed light snow and light rain (Test #96), and a comparison test (Test #97) was conducted in light freezing rain alone. A 5-minute exposure time was selected based on the current Type I fluid HOT for light freezing rain in conditions of -3ºC and above. During both tests, the visual contamination ratings at the end of precipitation were similar and acceptable. During the simulated takeoff run, contamination began to form on the leading and trailing edges by the time of rotation. The freezing slush that formed during the takeoff run was primarily due to the outside air temperature being approximately -10ºC, which was lower compared to the -3ºC ambient temperature in the tunnel at the start of the test. In both cases, the lift coefficient results were positive (better when compared to the Type IV Test #50). This may have been due to the thin layer of Type I fluid, which combined with the rain/freezing rain, actually improved the aerodynamic performance of the wing by eliminating imperfections in the wing skin surface, and smoothed out the snow contamination.

Although the results were inconclusive due to the formation of the slush during the takeoff runs, the visual condition of the wing at the end of the precipitation period was similar for both light rain mixed with light snow and for light freezing rain. In addition, similar lift coefficient data was recorded for both tests, again indicating potential similarities in the two conditions. Further work is required to substantiate these preliminary results.

5.5.2 Moderate Snow Mixed with Light Freezing Rain

One Type IV test was conducted in moderate snow mixed with light freezing rain conditions (Test #72). A 30-minute exposure time was selected based on the current Type IV fluid HOT for moderate snow mixed with light freezing rain in conditions of -3ºC and above (the HOT was approximately halved to account for twice the rate of precipitation). The results indicated severe visual contamination ratings (with the presence of adhered contamination) at the end of the precipitation period. At the time of rotation, most of the contamination was eliminated; however, some contamination remained adhered on the leading edge (aft of the stagnation point). This may have a been a result of the outside air temperature being approximately -15ºC, which was lower compared to the -4ºC in the tunnel at the start of the test; this caused residual diluted fluid to freeze on the wing skin surface during the test. The lift coefficient results also indicated potential lift losses.

The test was re-run (as Test #72R) to verify if the leading edge contamination could be eliminated given more time. The results indicated that the wing condition did not differ much, even after a second takeoff simulation.

Although the results were inconclusive (due to the formation of the adhered contamination during the takeoff runs and the outside and inside temperature differentials), the results indicate a potential for guidance material in moderate snow mixed with light freezing rain conditions. These preliminary tests were conducted as a lower priority objective; therefore, further work is required to develop the results obtained.

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Photo 5.1: Test #50 – Start of Test

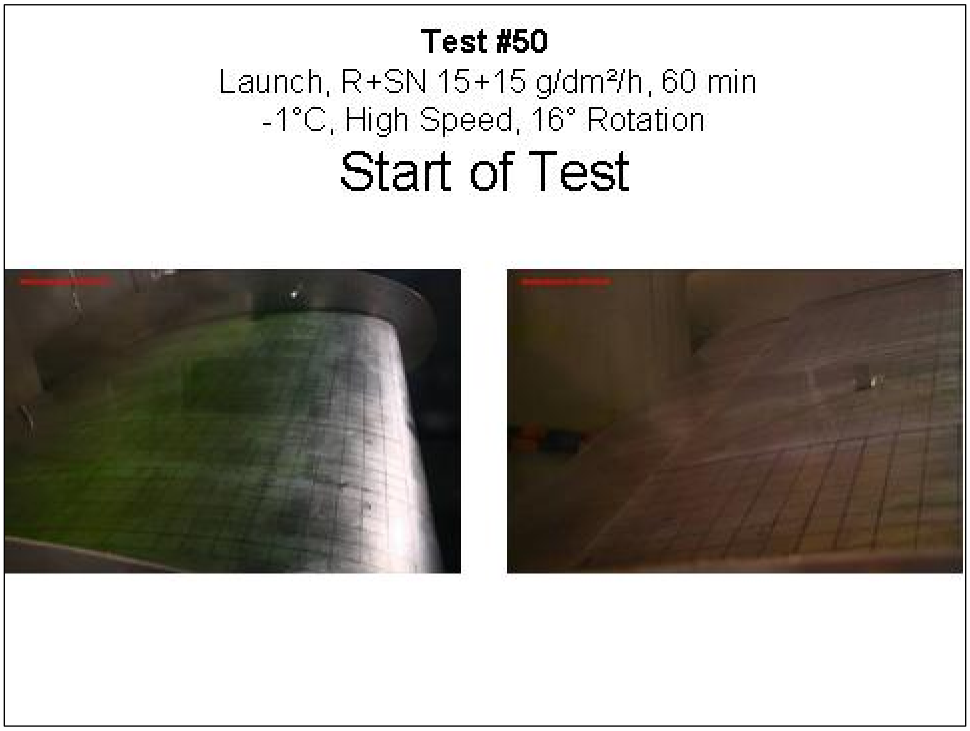


Photo 5.2: Test #50 – Before Rotation

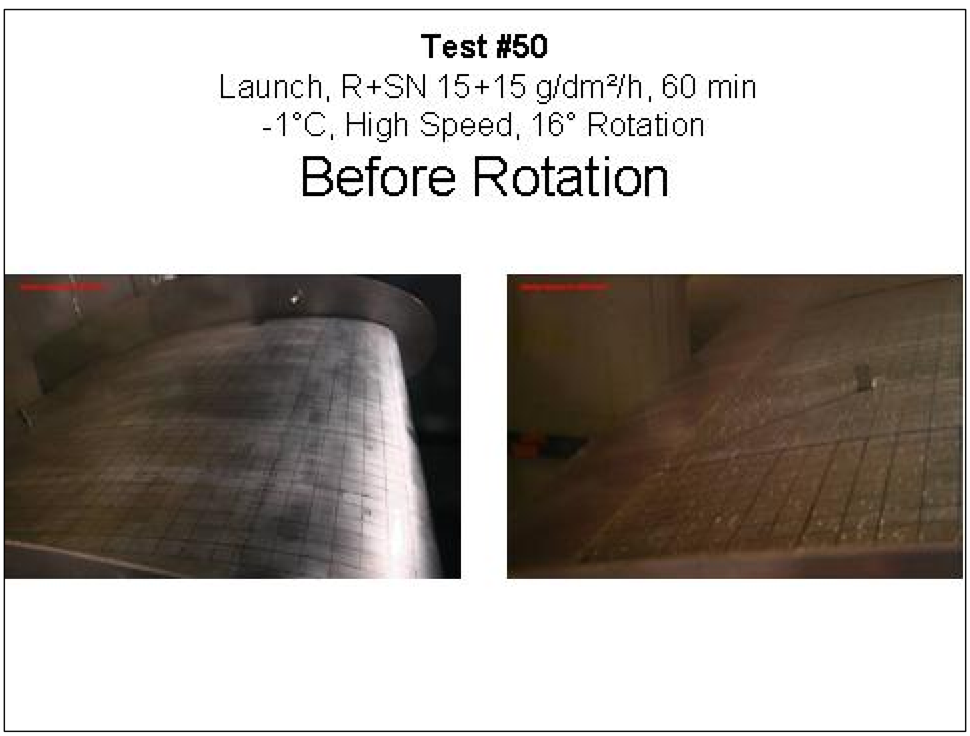


Photo 5.3: Test #50 – End of Rotation

Test #50

Launch, R+SN 15+15 g/dm²/h, 60 min

-1°C, High Speed, 16° Rotation

End of Rotation

Photo 5.4: Test #50 – End of Test

Test #50

Launch, R+SN 15+15 g/dm²/h, 60 min

-1°C, High Speed, 16° Rotation

End of Test

Photo 5.5: Test #72 – Start of Test

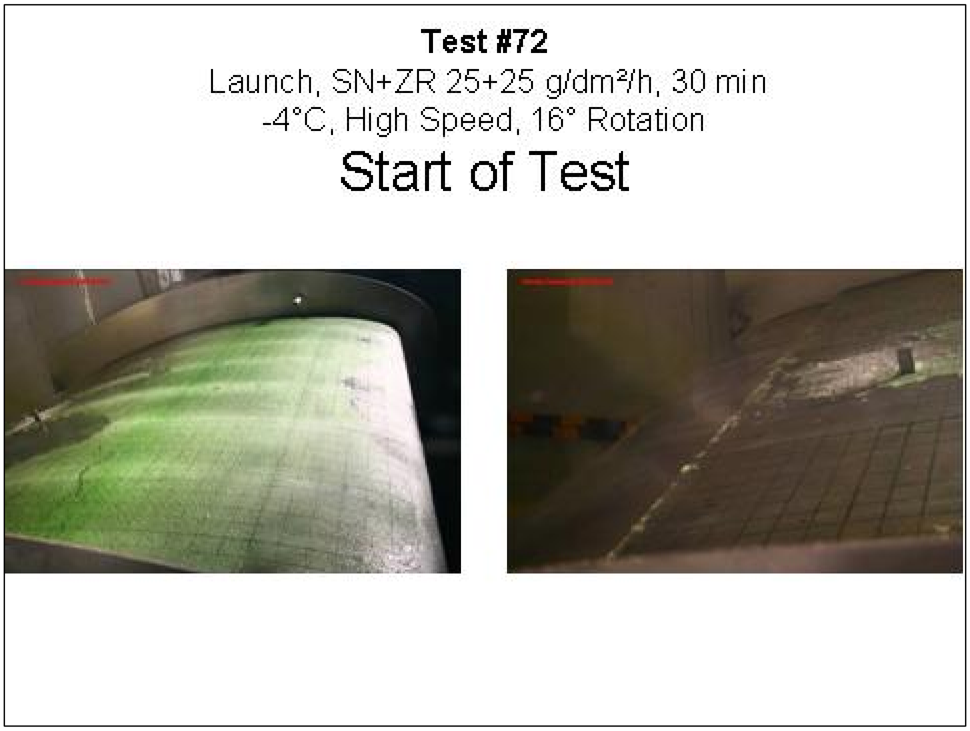


Photo 5.6: Test #72 – Before Rotation

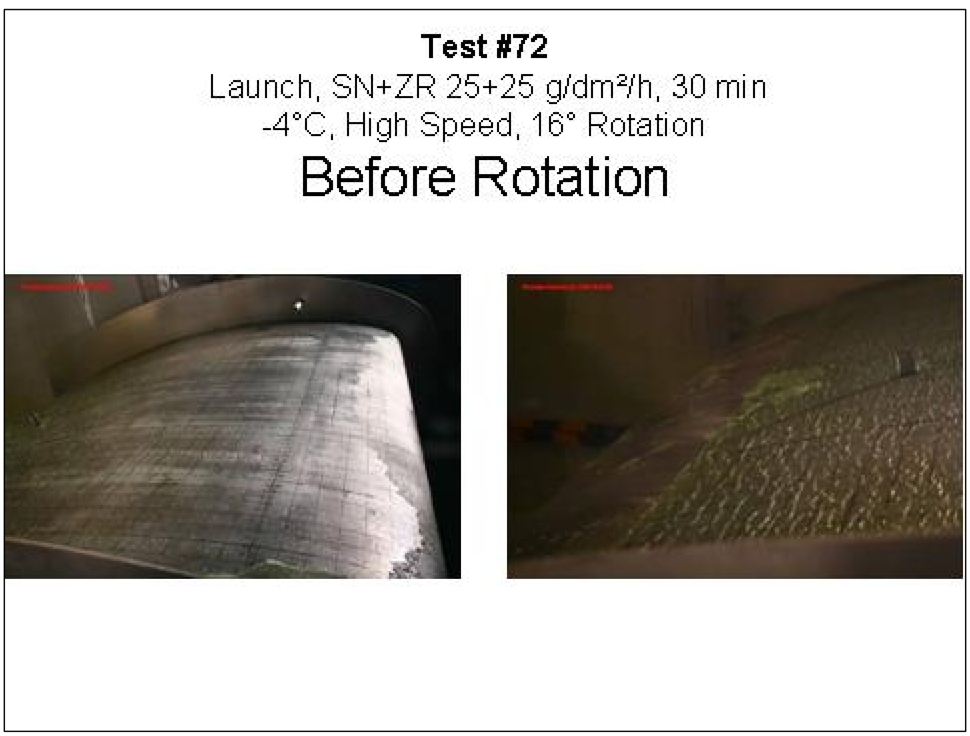


Photo 5.7: Test #72 – End of Rotation

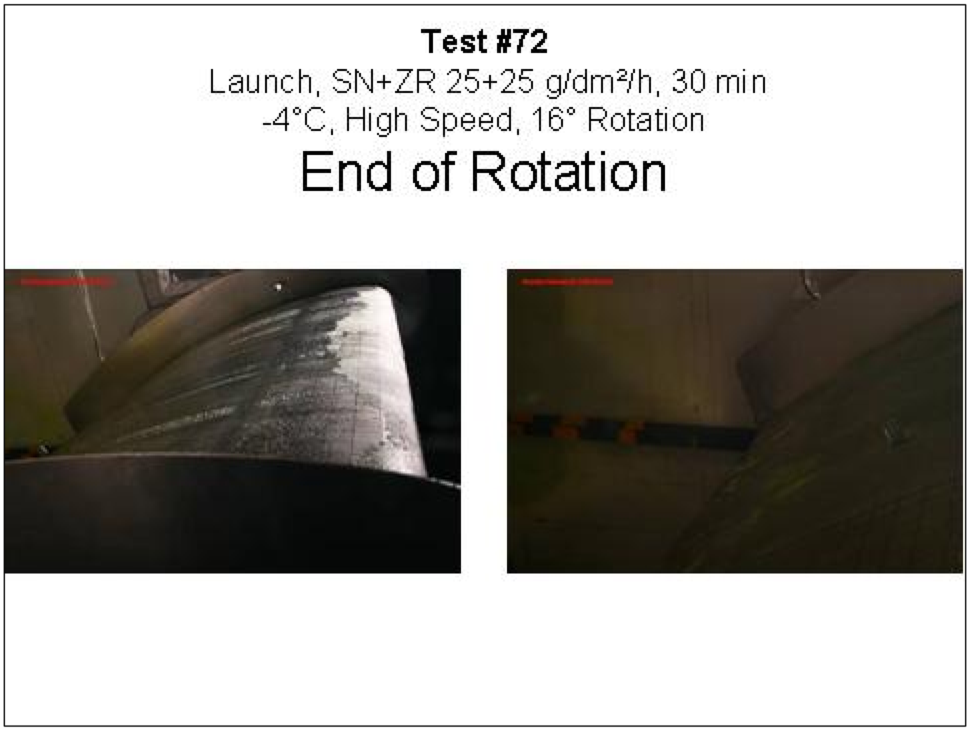


Photo 5.8: Test #72 – End of Test

Photo 5.9: Test #72R – Start of Test

No Photo Documentation Available

Photo 5.10: Test #72R – Before Rotation

No Photo Documentation Available

Photo 5.11: Test #72R – End of Rotation

No Photo Documentation Available

Photo 5.12: Test #72R – End of Test

No Photo Documentation Available

Photo 5.13: Test #96 – Start of Test

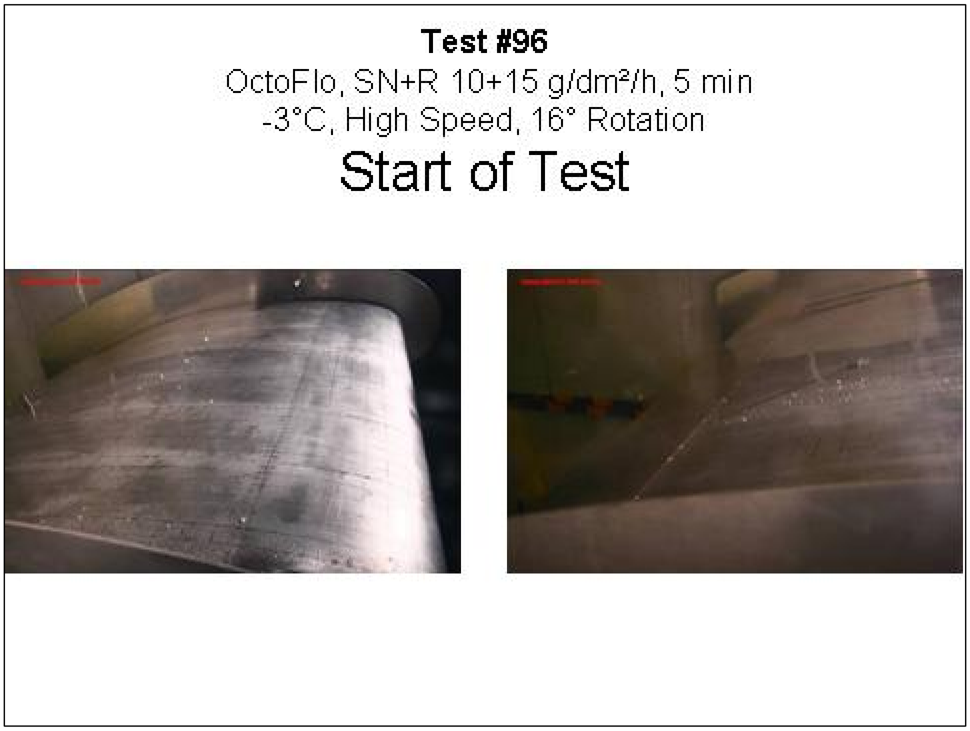


Photo 5.14: Test #96 – Before Rotation

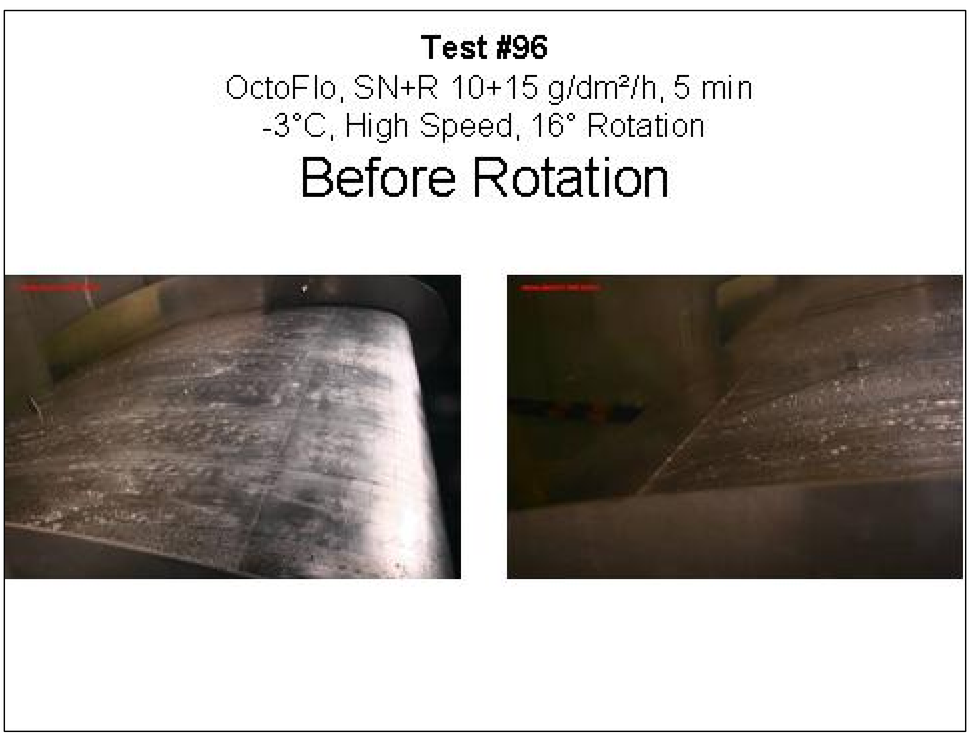


Photo 5.15: Test #96 – End of Rotation

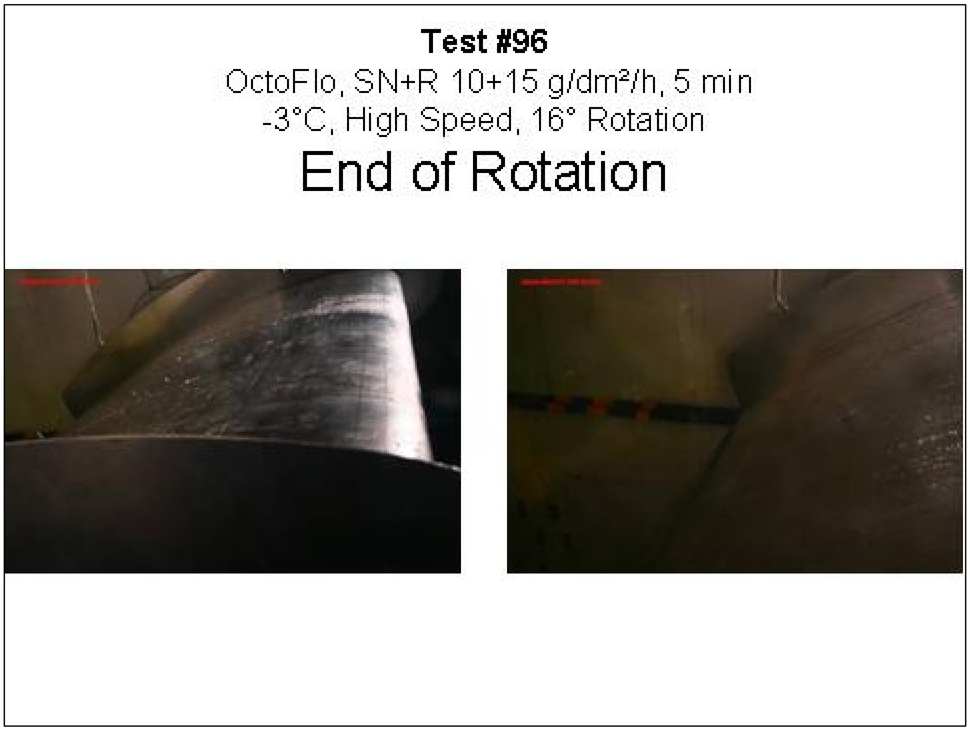


Photo 5.16: Test #96 – End of Test

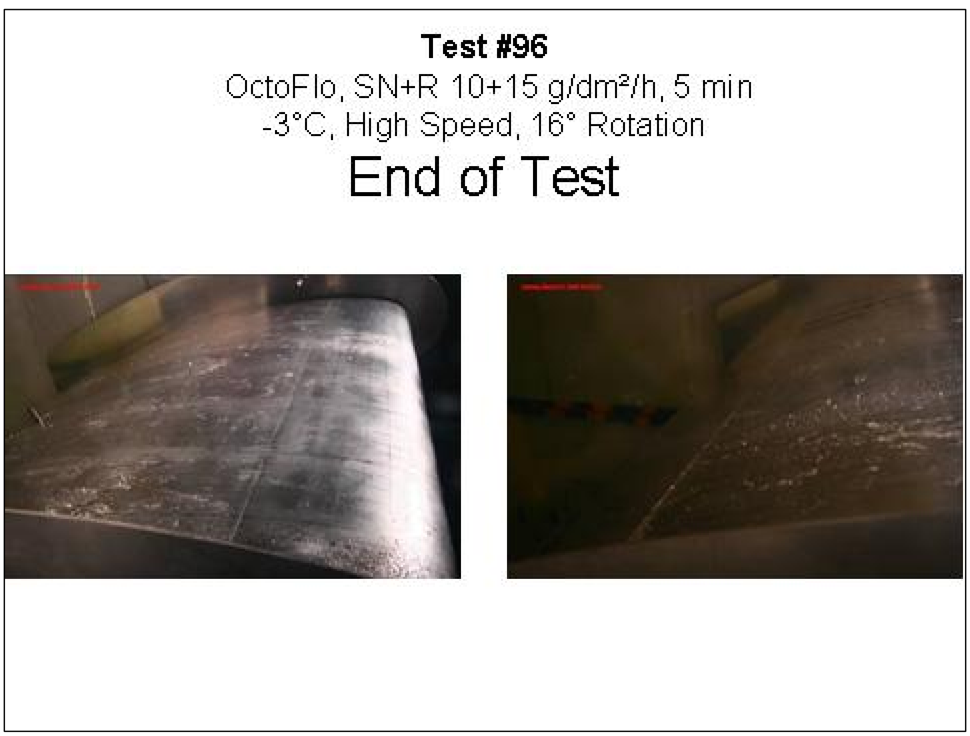


Photo 5.17: Test #97 – Start of Test

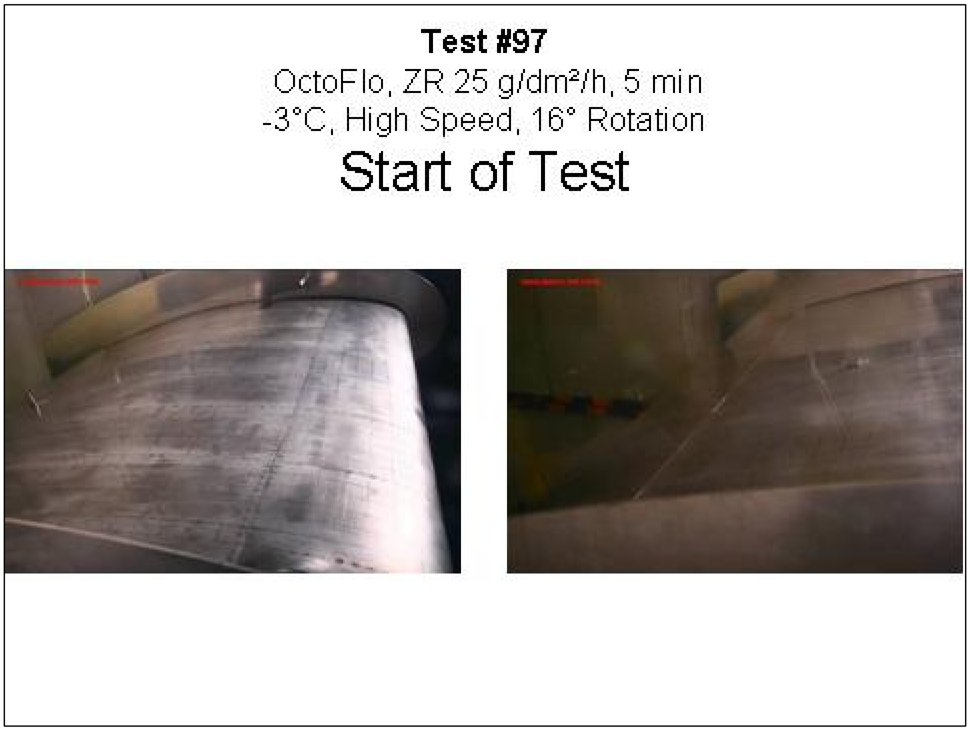


Photo 5.18: Test #97 – Before Rotation

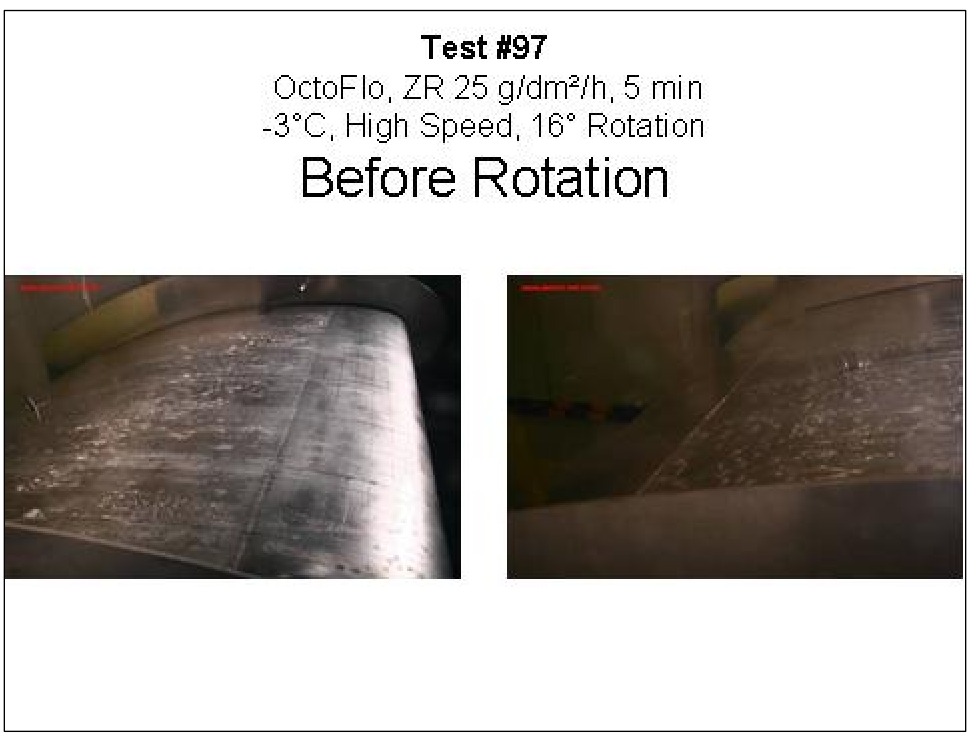


Photo 5.19: Test #97 – End of Rotation

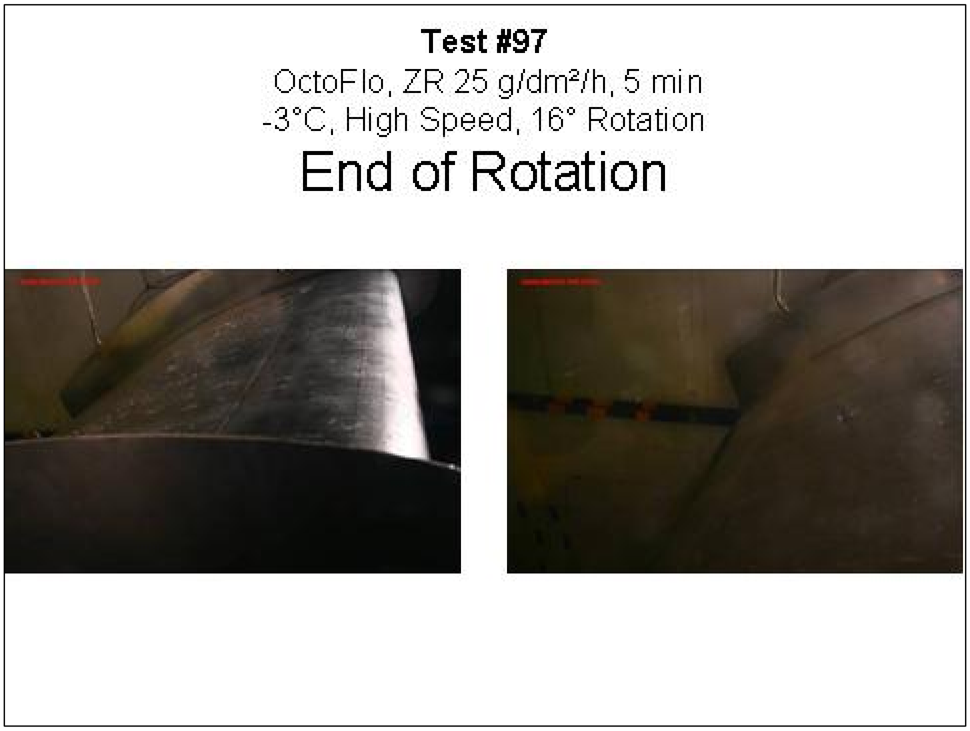
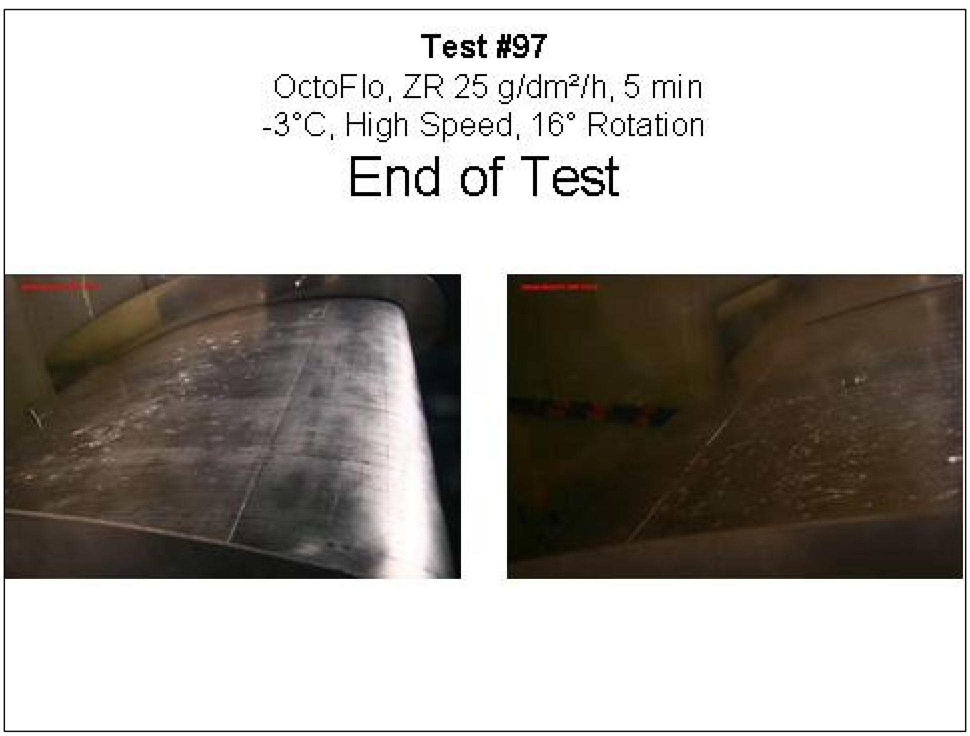


Photo 5.20: Test #97 – End of Test



6. INADEQUATE ANTI-ICING FLUID APPLICATION

There has been recent industry concern as to the consistency of anti-icing fluid applications in actual aircraft ground deicing operations. Although current industry standards and fluid manufacturer user guidelines recommend applying a minimum of 1 L of anti-icing fluid per square meter in operations, human error or inadequate training can lead to insufficient application of fluid. In addition, improperly stored anti-icing fluids can result in a degradation of the fluid viscosity resulting in large reductions in fluid thickness; fluid thickness is a main contributor to the fluid's endurance.

As it is very difficult to simulate the numerous potential human errors that can occur during an anti-icing application, or the various types of fluid degradation, it was recommended that testing be done to simulate varying anti-icing fluid thicknesses and their effects on fluid HOTs. This section provides an overview of each test conducted as part of the test program to investigate the impact of inadequate anti-icing fluid application on contaminated fluid flow-off.

6.1 General Methodology

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

- Apply an inadequate amount of anti-icing fluid to the wing section using a garden sprayer or wetted brush;
- Expose the wing section to simulated freezing rain at a rate of 25 $g/dm^2/h$;
  - Time of exposure should be chosen based on outside air temperature and fluid-specific HOTs;
- Run wind tunnel and collect visual and lift coefficient data;
- Compare results to a proper fluid application test; and
- Repeat test and reduce or increase the amount of anti-icing fluid applied depending on the severity of results obtained.

It should be noted that during some tests, testing was to be done by simulating two tests on the same wing section using two separate strips of fluid; one half of the wing simulated an inadequate fluid application, and the other half simulated a proper fluid application. During these tests, the aerodynamic data collected has little relevance due to the variation in contamination resulting from the different fluid applications.

Typically, the wing was treated with 20 L of anti-icing fluid to achieve appropriate coverage and to obtain an acceptable fluid thickness; this translates to approximately 4.5 L/m²on the wing. To simulate the inadequate anti-icing application, one-tenth of the typical fluid used (or 2 L over the whole wing) was applied; this resulted in approximately 0.45 L/m². During a typical HOT plate test, approximately 6.5 L/m² is applied. The quantity applied to a test plate is higher than the amount of fluid applied during a typical wing test. This is a result of the fluid run-off from the sides of the plate; much more fluid is dripped in excess during a plate test as compared to a wing test.

6.2 Overview of Tests

A summary of the inadequate anti-icing application 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.

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 run, 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 run, recorded in degrees Celsius.

Visual Contamination Rating Before Takeoff (LE, TE):

Visual contamination rating determined before the start of the simulated takeoff. Two values are indicated [one for the leading edge (LE) and one for the trailing edge (TE)]:

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. Two values are indicated [one for the leading edge (LE) and one for the trailing edge (TE)]:

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.

Type of Application:

Simulated anti-icing application:

Bad: Minimal amounts of fluid applied on wing simulating an inadequate anti-icing application (approximately 0.45 L/m²).

Good: Adequate amounts of fluid applied on wing simulating a proper anti-icing application (approximately 4.5 L/m²).

Five tests were conducted to investigate the effects of inadequately applied anti-icing fluid on fluid protection time and aerodynamic performance. Two tests (Tests #32 and #84) were conducted with the whole wing treated with an inadequate anti-icing application. Three tests (Tests #79, #83, and #107) were conducted with half the wing treated with an inadequate anti-icing application and the other half treated with a proper anti-icing application.

Table 6.1: Summary of 2008-09 Inadequate Anti-Icing Fluid Application Tests

Test No.	Date	Fluid	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)	Visual Cont. Rating at Rotation (LE, TE)	Type of Application
32	29-Jan-09	EG106	IP Mod	75	25	-3	-4.5	4, 4	1, 2	Bad
79 *	24-Feb-09	Launch	ZR	25	25	-11	N/A	3, 3 / 5, 5	1, 2 / 5, 5	Good / Bad
83 *	24-Feb-09	EG106	ZR	25	55	-3	-1.3/-0.1	1, 1 / 5, 5	1, 1 / 5, 5	Good / Bad
84	25-Feb-09	EG106	IP/SN/ZR	15/15/25	25	-3	-4.0	4, 4	5, 5	Bad
107 *	3-Mar-09	Launch	ZR	25	25	-14	N/A	4, 4 / 5, 5	4, 4 / 5, 5	Good / Bad

** Indicates a test where half the wing was treated with an inadequate anti-icing application and the other half was treated with a proper anti-icing application.*

6.3 Data Collected

6.3.1 Fluid Thickness Data

APS personnel collected fluid thickness measurements. The wing positions used for the wind tunnel tests are described in Subsection 2.15.2. Fluid thickness measurements were recorded at the following intervals:

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

Tables 6.2 to 6.6 show the fluid thickness measurements collected during the tests.

Table 6.2: Test #32 Fluid Thickness Data

Test 32, EG 106, IP Mod, Tunnel OAT -2.7°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
1	0.2-0.3	slush	0.0
2	0.2-0.3	slush	0.0
3	0.2-0.3	slush	0.0
4	0.4-0.5	slush	0.0
5	0.2-0.4	slush	0.0
6	0.5-0.6	slush	0.0
7	0.5-0.6	slush	0.0
8	0.5-0.6	slush	0.0

Table 6.3: Test #79 Fluid Thickness Data

Test 79, 2031, ZR, Tunnel OAT -11.4°C Good Application			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
1	N/A	1.1	0.0
2	N/A	1.8	0.1
3	N/A	1.8	0.1
4	N/A	2.7	0.2
5	N/A	3.1	0.2
6	N/A	2.2	0.3
7	N/A	2.2	0.3
8	N/A	1.8	0.5

Test 79, 2031, ZR, Tunnel OAT -11.4°C Bad Application			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
1	N/A	N/A	N/A
2	N/A	N/A	N/A
3	N/A	N/A	N/A
4	N/A	N/A	N/A
5	N/A	N/A	N/A
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	N/A	N/A	N/A

Table 6.4: Test #83 Fluid Thickness Data

Test 83, EG 106, ZR, Tunnel OAT -2.9°C Good Application			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
1	1.4	0.7	0.0
2	2.2	1.5	0.0
3	2.7	1.7	0.0
4	2.7	2.2	0.0
5	3.7	2.2	0.0
6	1.8	0.4	0.0
7	1.8	0.5	0.0
8	2.2	0.6	0.0

Test 83, EG 106, ZR, Tunnel OAT -2.9°C Bad Application			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
1	0.4	0.1	slush
2	0.6	0.1	slush
3	0.6	0.1	slush
4	0.6	0.1	slush
5	0.6	0.1	slush
6	0.3	0.1	slush
7	0.3	0.1	slush
8	0.3	0.1	slush

Table 6.5: Test #84 Fluid Thickness Data

Test 84, EG 106, IP/SN/ZR, Tunnel OAT -2.9°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
1	0.6	0.4	0.0
2	0.7	1.0	0.0
3	0.7	1.2	0.0
4	0.6	1.1	0.0
5	0.6	1.0	0.0
6	0.3	slush	0.0
7	0.2	slush	0.0
8	0.2	slush	0.0

Table 6.6: Test #107 Fluid Thickness Data

Test 107, Launch, ZR, Tunnel OAT -13.5°C Good Application			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
1	0.6	0.2	0.0
2	0.8	1.1	0.0
3	1.1	1.1	0.1
4	1.2	2.2	0.1
5	2.2	2.5	0.2
6	1.0	1.1	0.2
7	1.0	1.1	0.3
8	1.0	1.4	slush

Test 107, Launch, ZR, Tunnel OAT -13.5°C Bad Application			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
1	0.2	N/A	0.6
2	0.3	N/A	0.6
3	0.4	N/A	0.4
4	0.4	N/A	1.2
5	0.3	N/A	1.0
6	0.3	N/A	slush
7	0.4	N/A	slush
8	0.4	N/A	slush

6.3.2 Skin Temperature Data

APS personnel collected skin temperature measurements. The wing positions used for the wind tunnel tests are described in Subsection 2.15.3. Skin temperature measurements were recorded at the following intervals:

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

The wing temperature measurements recorded during each test are shown in Tables 6.7 to 6.11.

Table 6.7: Test #32 Wing Skin Temperature Data

Test 32, EG 106, IP Mod, Tunnel OAT -2.7ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	-1.4	-1.5	-4.8	-3.6
T5	-1.5	-1.0	-4.5	-3.8
TU	-2.7	-2.2	-4.2	-4.2

Table 6.8: Test #79 Wing Skin Temperature Data

Test 79, Launch, ZR, Tunnel OAT -11.4ºC Good Application				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	-9.6	N/A	N/A	-9.5
T5	-8.9	N/A	N/A	-8.5
TU	-10.2	N/A	N/A	-9.7

Test 79, Launch, ZR, Tunnel OAT -11.4ºC Bad Application				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	N/A	N/A	N/A	N/A
T5	N/A	N/A	N/A	N/A
TU	N/A	N/A	N/A	N/A

Table 6.9: Test #83 Wing Skin Temperature Data

Test 83, EG 106, ZR, Tunnel OAT -2.9ºC Good Application				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	-4.8	-3.9	-0.9	-5.4
T5	-4.1	-3.5	-0.5	-4.0
TU	-5.0	-4.2	-2.4	-6.1

Test 83, EG 106, ZR, Tunnel OAT -2.9ºC Bad Application				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	N/A	-0.9	0.0	N/A
T5	N/A	-0.9	-0.4	N/A
TU	N/A	-2.2	0.1	N/A

Table 6.10: Test #84 Wing Skin Temperature Data

Test 84, EG 106, IP/SN/ZR, Tunnel OAT -2.9ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	-4.8	-2.6	-3.7	N/A
T5	-3.9	-1.9	-3.6	N/A
TU	-5.5	-3.8	-4.6	N/A

Table 6.11: Test #107 Wing Skin Temperature Data

Test 107, Launch, ZR, Tunnel OAT -13.5°C Good Application				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	-10.3	N/A	N/A	N/A
T5	-9.3	N/A	N/A	N/A
TU	-10.8	N/A	N/A	N/A

Test 107, Launch, ZR, Tunnel OAT -13.5°C Bad Application				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	N/A	N/A	N/A	N/A
T5	N/A	N/A	N/A	N/A
TU	N/A	N/A	N/A	N/A

6.3.3 Fluid Brix Data

APS personnel collected fluid Brix measurements. The wing positions used for the wind tunnel tests are described in Subsection 2.15.4. Fluid Brix measurements were recorded at the following intervals:

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

Tables 6.12 to 6.16 show the fluid Brix measurements collected during the test.

Table 6.12: Test #32 Fluid Brix Data

Test 32, EG 106, IP Mod, Tunnel OAT -2.7°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	33.50	5.00	N/A
8	34.00	4.25	N/A

Table 6.13: Test #79 Fluid Brix Data

Test 79, 2031, ZR, Tunnel OAT -11.4°C Good Application			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	N/A	N/A	33.25
8	N/A	N/A	31.50

Test 79, 2031, ZR, Tunnel OAT -11.4°C Bad Application			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	N/A	12.00	17.00
8	N/A	12.25	23.00

Table 6.14: Test #83 Fluid Brix Data

Test 83, EG 106, ZR, Tunnel OAT -2.9ºC Good Application			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	36.00	26.00	35.25
8	34.00	12.50	26.50

Test 83, EG 106, ZR, Tunnel OAT -2.9ºC Bad Application			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	34.50	N/A	N/A
8	34.75	N/A	N/A

Table 6.15: Test #84 Fluid Brix Data

Test 84, EG 106, IP/SN/ZR, Tunnel OAT -2.9°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	33.75	5.00	4.00
8	35.00	5.00	7.00

Table 6.16: Test #107 Fluid Brix Data

Test 107, Launch, ZR, Tunnel OAT -13.5ºC Good Application			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	N/A	19.50	27.00
8	N/A	N/A	11.00

Test 107, Launch, ZR, Tunnel OAT -13.5ºC Bad Application			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	N/A	13.25	11.50
8	N/A	13.00	27.00

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 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 6.1 to 6.25 show the photo summaries of the tests conducted. A complete set of photos will be provided to the TDC.

6.5 General Observations

The following sections describe the observations regarding the testing conducted to verify the effects of inadequate anti-icing fluid applications on fluid flow-off.

6.5.1 Visual Appearance

The results demonstrated that although a minimal amount of Type IV anti-icing fluid was applied (to simulate an inadequate application), the visual appearance of the fluid did not seem significantly different compared to a typical proper fluid application. The green dye in the anti-icing fluid was visible with even minimal amounts of fluid and could be used to easily interpret appropriate fluid application. When the wing was split into two sections (proper and inadequate application), the differences in the fluid applications were more apparent; however, it was still difficult to visually determine exactly how much (or how little) fluid had been applied.

The fluid thickness measurements indicated that although one-tenth of the typical amount of fluid was used to simulate an inadequate application, on average the fluid thickness produced was only three to five times less in comparison to the proper anti-icing application. This indicates that fluid thickness on the wing is not directly proportional to the amount of fluid sprayed, primarily due to fluid run-off and fluid settling due to gravity; once the wing has been flooded with fluid, additional fluid does not result in increased fluid thickness.

6.5.2 Fluid Protection Time

In all cases tested, the inadequate fluid application generated shorter protection times. Testing targeted the respective HOT or allowance time for the specific condition. In all cases, the inadequate application tests demonstrated severe levels of contamination, whereas the proper application tests demonstrated acceptable levels of contamination. The results indicate that fluid thickness is an important factor with respect to fluid protection.

Similar results have been observed during flat plate testing conducted during the winter of 2008-09. The results are summarized in TP 14936E (4).

6.5.3 Fluid Elimination During Simulated Takeoff Runs

In all but the first case tested, the inadequate fluid application test section demonstrated poor fluid elimination at the time of rotation. The exception to this trend was Test #32, which was conducted in ice pellet precipitation alone. The ice pellets only contamination did not result in fluid adherence; therefore, although the surface was heavily contaminated, the precipitation could still be removed by the airflow. In all the other cases, the addition of freezing rain made the thin fluid layer susceptible to fluid adherence; the resulting contamination was not removed at the time of rotation.

In the cases where fluid was properly applied, the fluid was easily removed by the time of rotation with the exception of Test #107. During Test #107, the temperature was below -10ºC (the HOT limit for light freezing rain) and therefore no HOTs exist; however, the test was conducted using the -3ºC to -10ºC HOT of 25 minutes. The colder temperature may have increased the fluid adherence and resulting fluid elimination problems for both the inadequate and proper application sections of the wing.

The results indicate that the inadequate fluid application will generate a visually more severe condition following precipitation; however, the severity of these scenarios is dependent on the type of precipitation and resulting risks of adhered contamination.

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Photo 6.1: Test #32 – After Fluid Application

Test #32

EG 106, IP Mod 75 g/dm²/h, 25 min

-3°C, High Speed, 8° Rotation

After Fluid Application

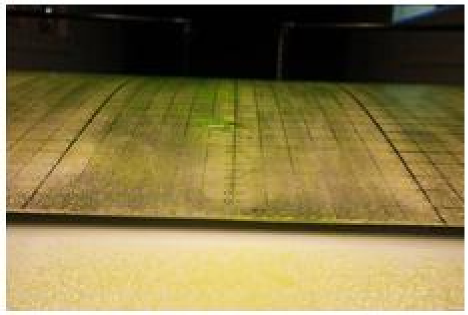

Photo 6.2: Test #32 – Start of Test

Test #32

EG 106, IP Mod 75 g/dm²/h, 25 min

-3°C, High Speed, 8° Rotation

Start of Test

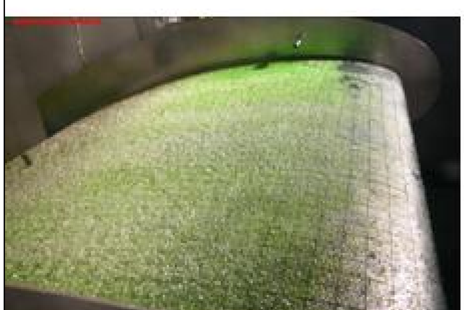

Photo 6.3: Test #32 – Before Rotation

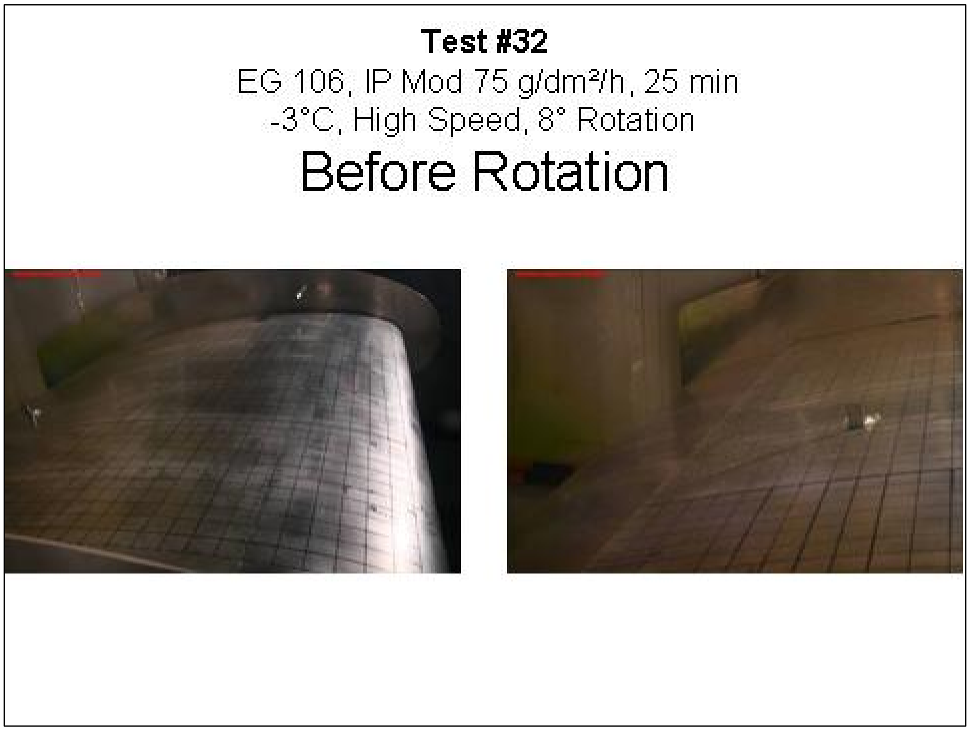

Photo 6.4: Test #32 – End of Rotation

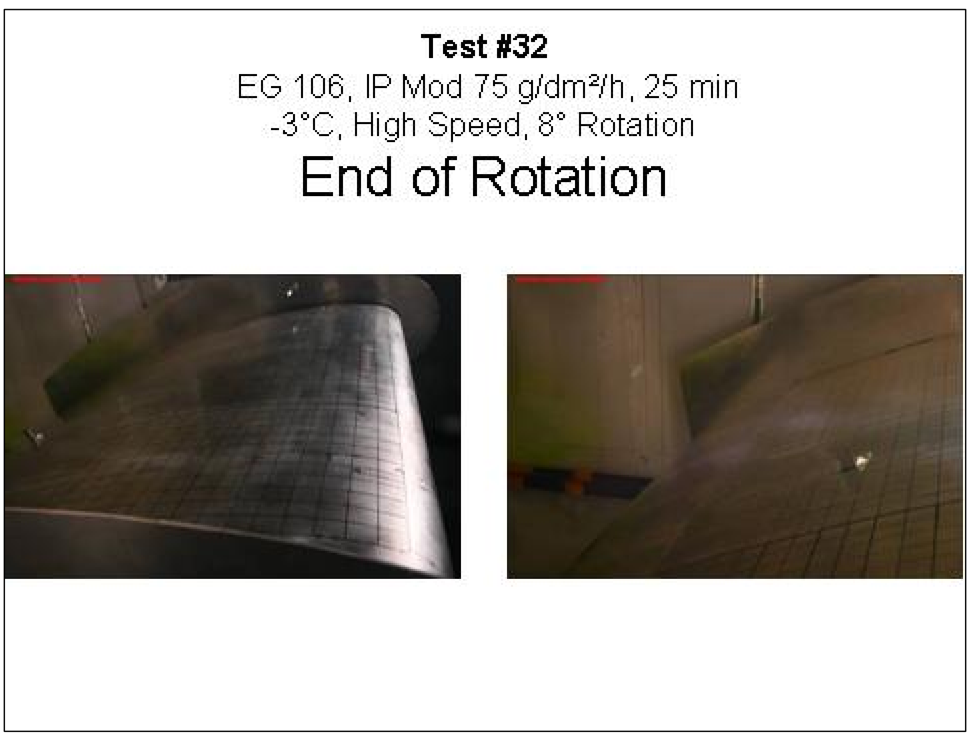

Photo 6.5: Test #32 – End of Test

Test #32
EG 106, IP Mod 75 g/dm²/h, 25 min
-3°C, High Speed, 8° Rotation
End of Test

Photo 6.6: Test #79 – After Fluid Application

Test #79
Launch, ZR 25 g/dm²/h, 25 min
-11°C, High Speed, 16° Rotation
After Fluid Application

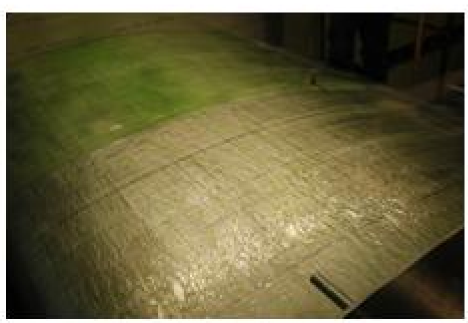

Photo 6.7: Test #79 – Start of Test

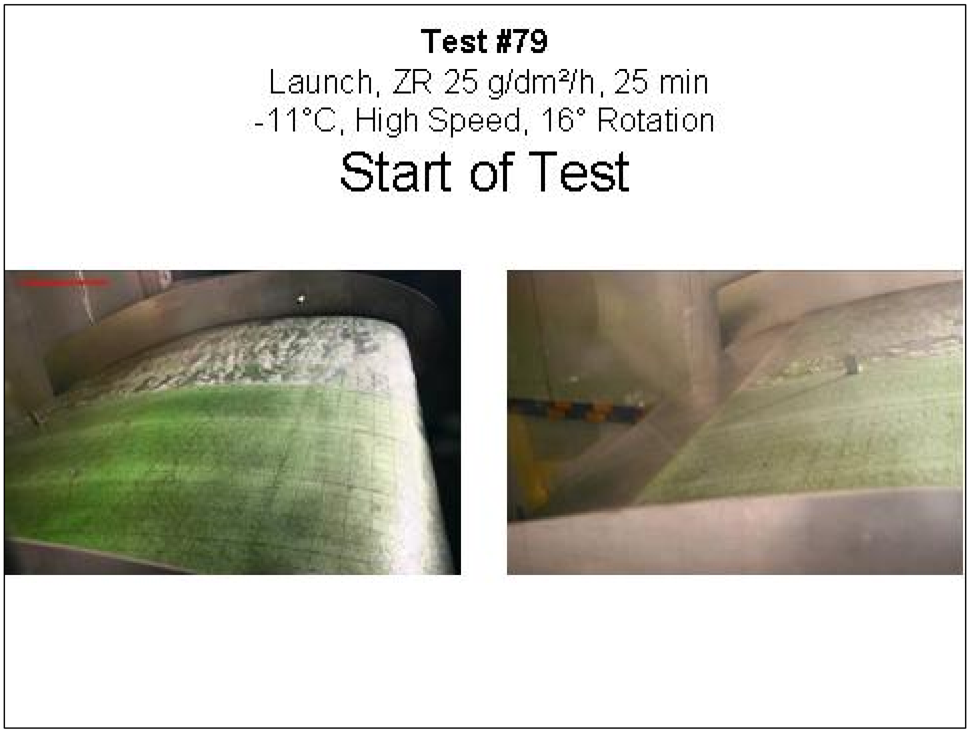

Photo 6.8: Test #79 – Before Rotation

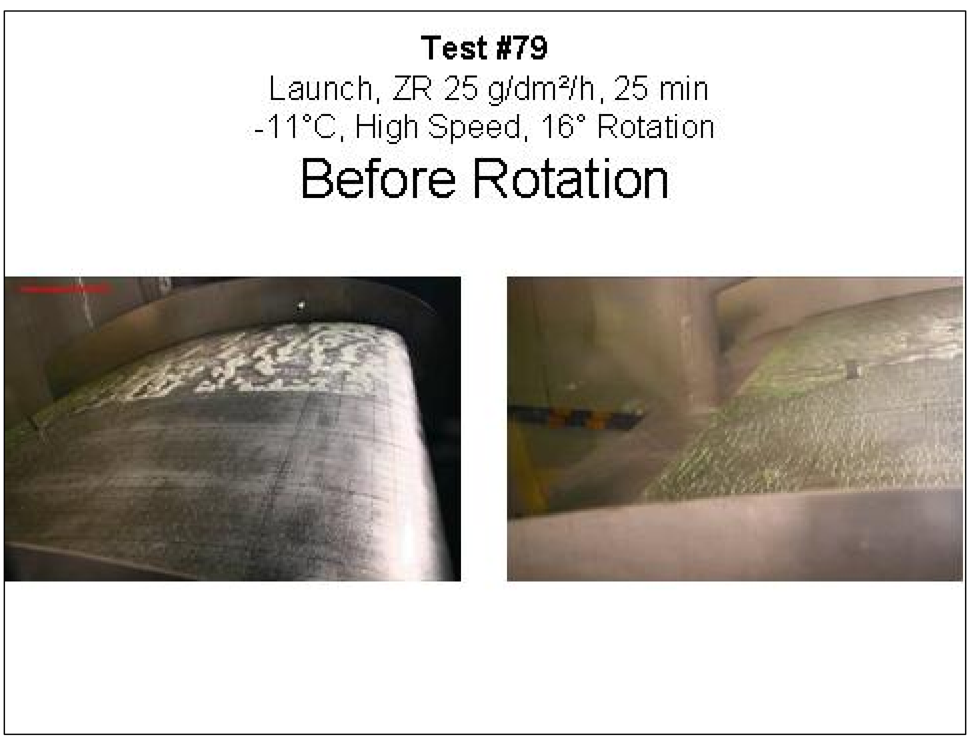

Photo 6.9: Test #79 – End of Rotation

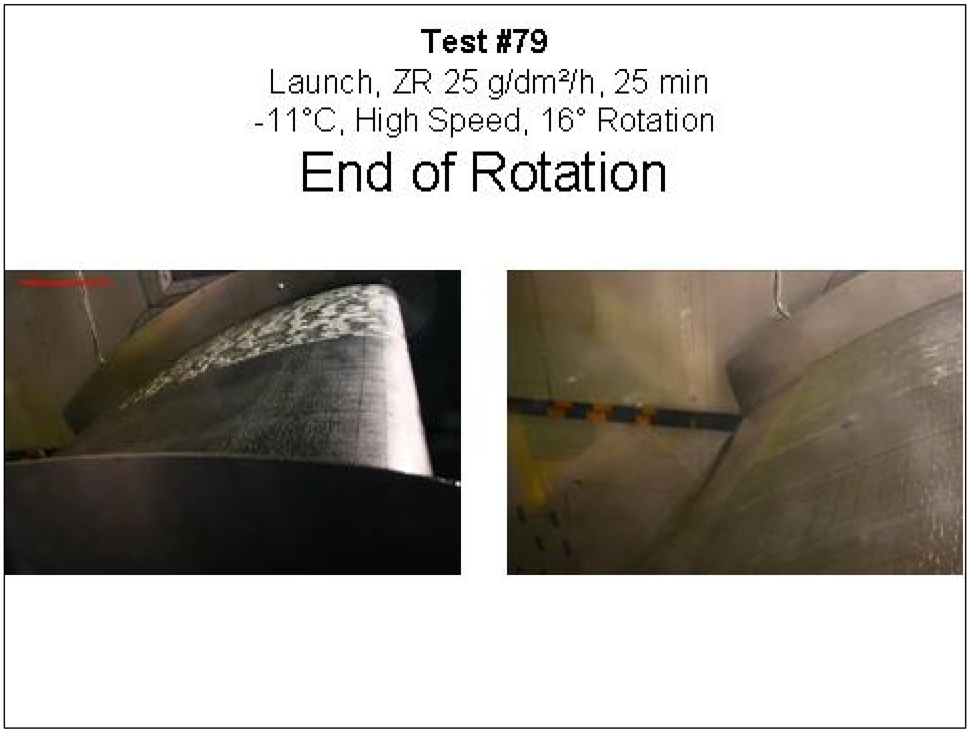

Photo 6.10: Test #79 – End of Test

Photo 6.11: Test #83 – After Fluid Application

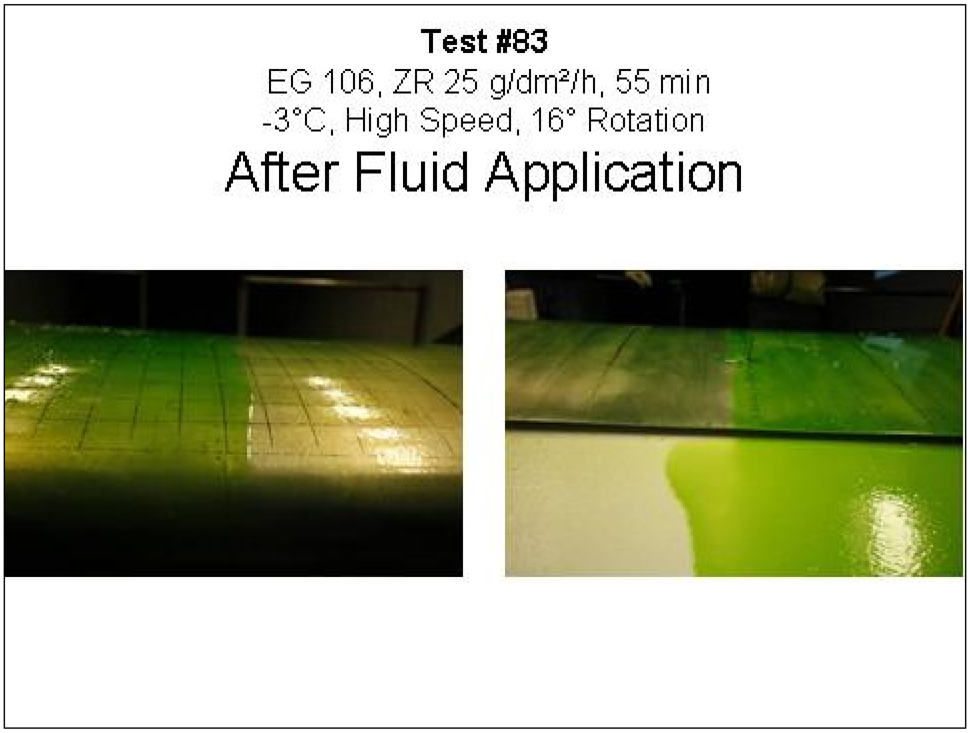

Photo 6.12: Test #83 – Start of Test

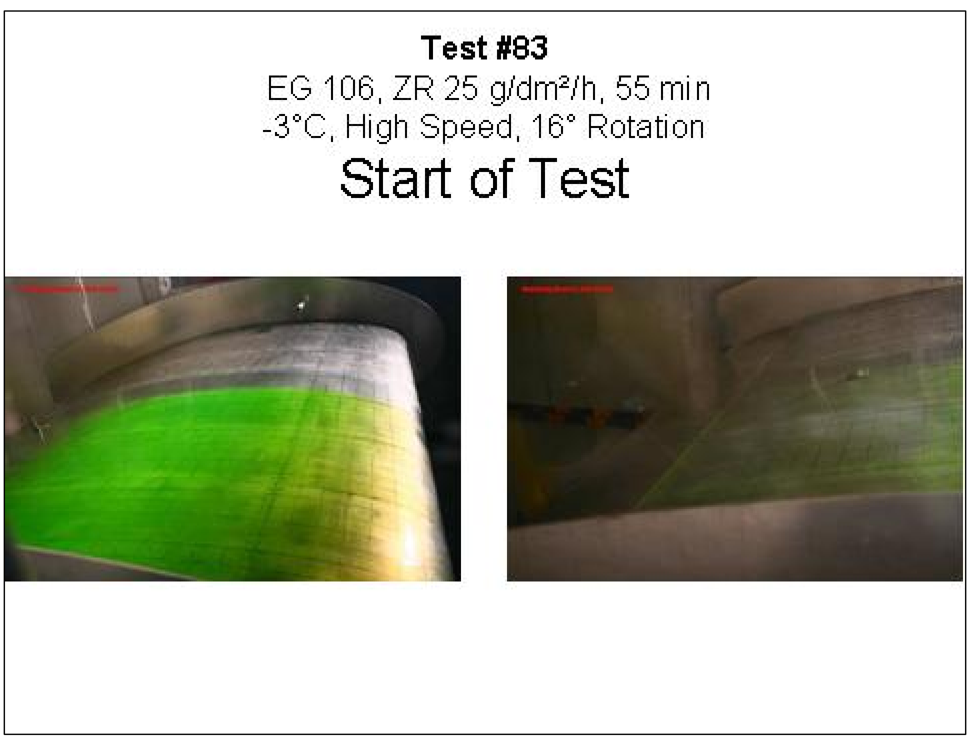

Photo 6.13: Test #83 – Before Rotation

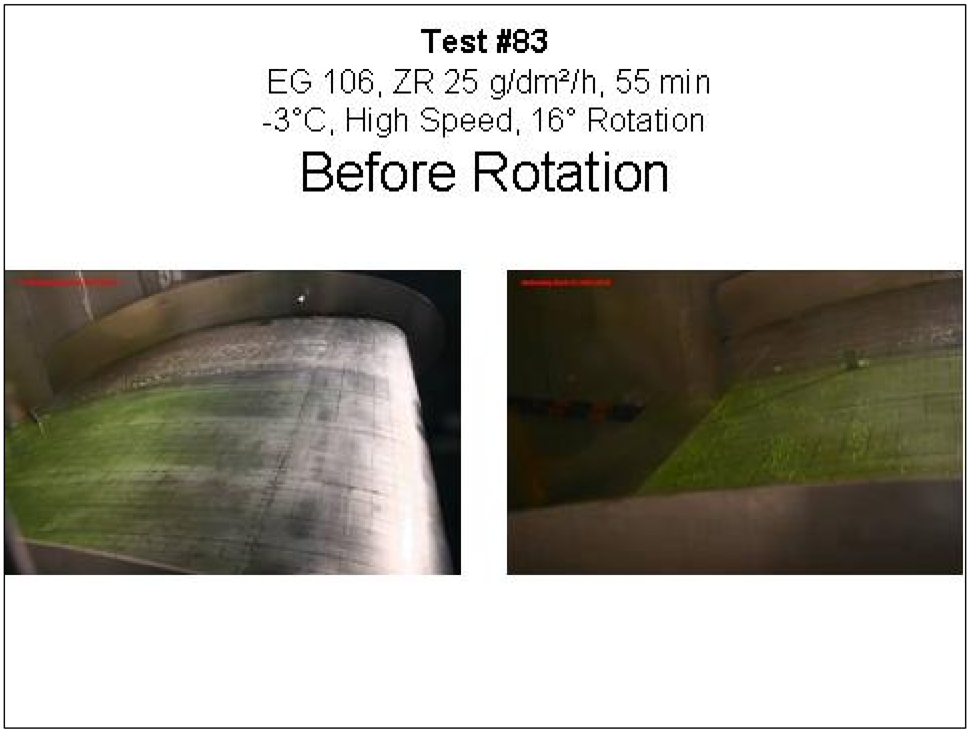

Photo 6.14: Test #83 – End of Rotation

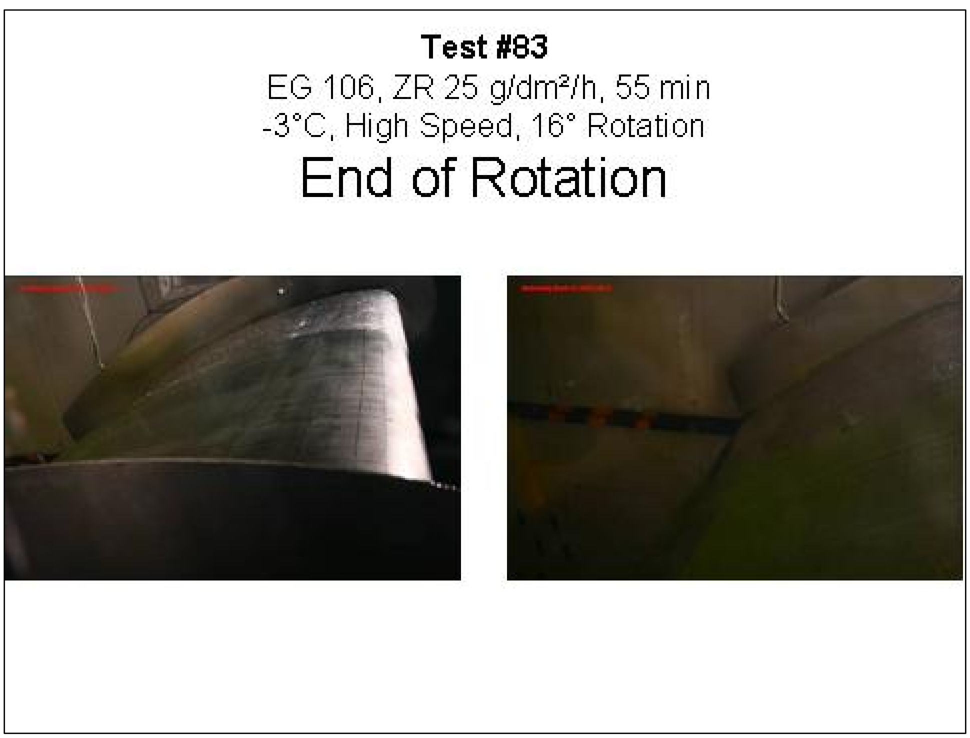

Photo 6.15: Test #83 – End of Test

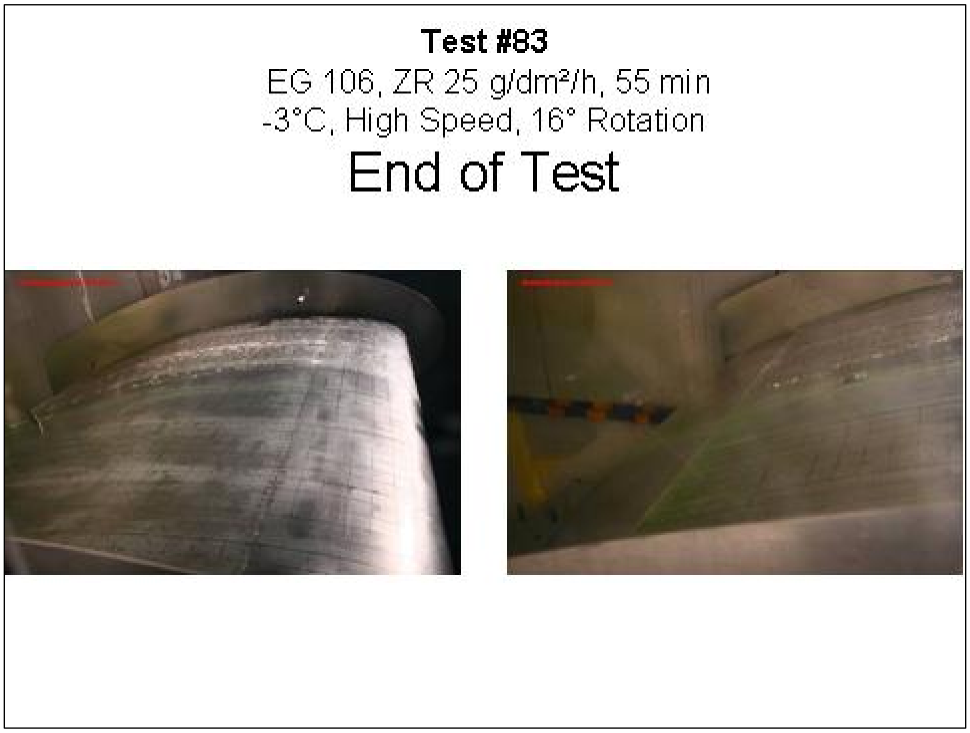

Photo 6.16: Test #84 – After Fluid Application

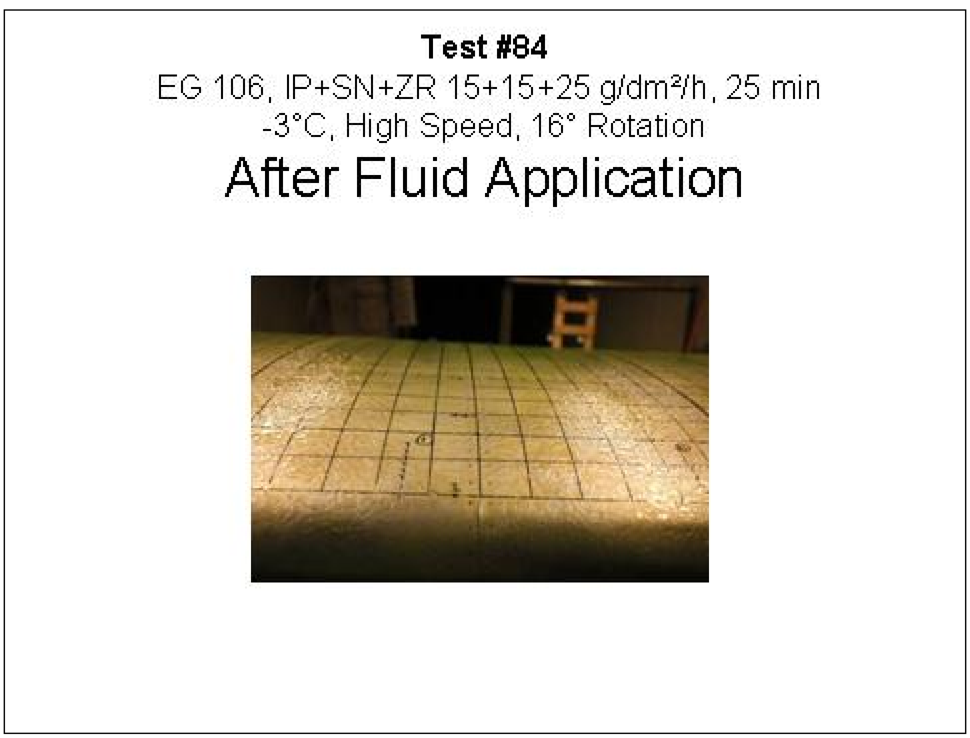

Photo 6.17: Test #84 – Start of Test

Test #84
Launch, IP+SN+ZR 15+15+25 g/dm²/h, 25 min
-3°C, High Speed, 16° Rotation
Start of Test

Photo 6.18: Test #84 – Before Rotation

Test #84
Launch, IP+SN+ZR 15+15+25 g/dm²/h, 25 min
-3°C, High Speed, 16° Rotation
Before Rotation

Photo 6.19: Test #84 – End of Rotation

Photo 6.20: Test #84 – End of Test

Photo 6.21: Test #107 – After Fluid Application

Test #107
Launch, ZR 25 g/dm²/h, 25 min
-14°C, High Speed, 16° Rotation
After Fluid Application

Photo 6.22: Test #107 – Start of Test

Test #107
Launch, ZR 25 g/dm²/h, 25 min
-14°C, High Speed, 16° Rotation
Start of Test

Photo 6.23: Test #107 – Before Rotation

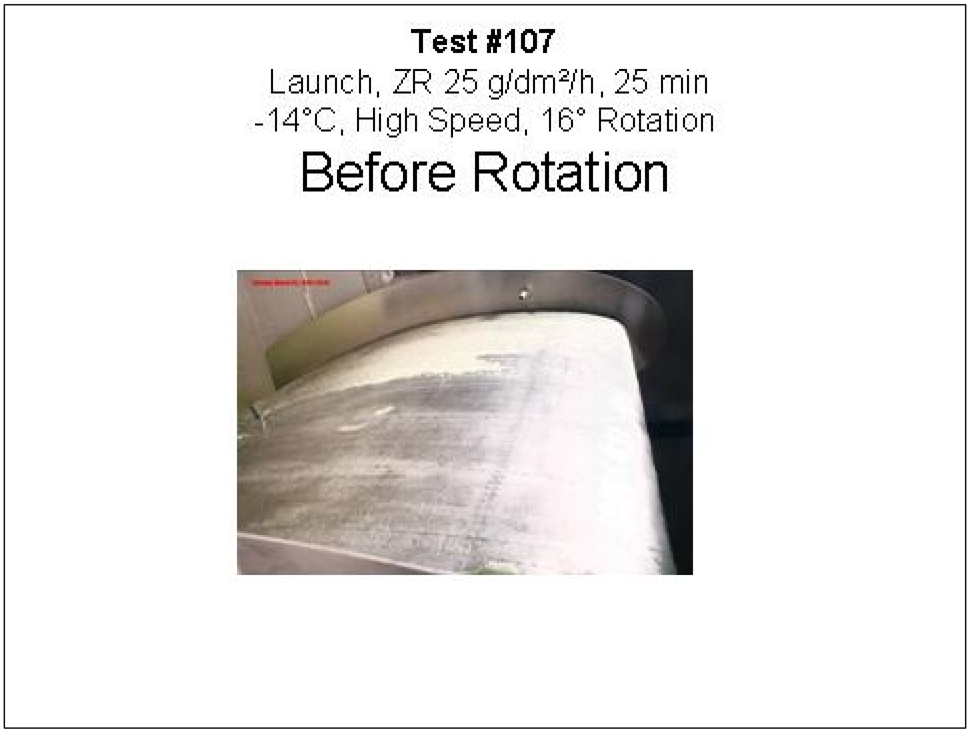

Photo 6.24: Test #107 – End of Rotation

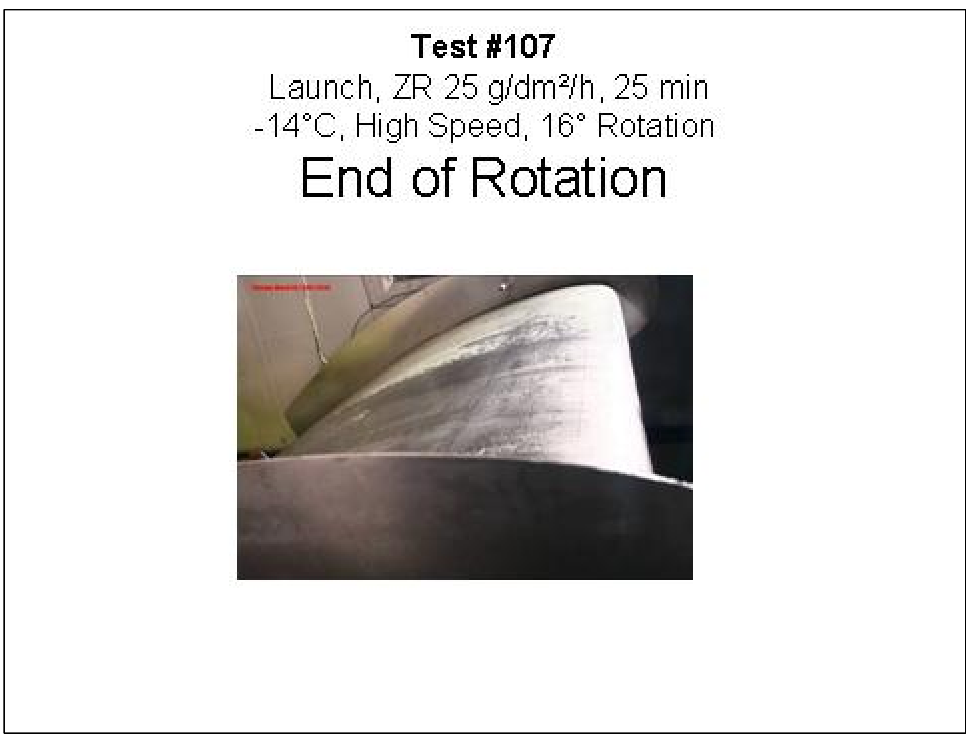

Photo 6.25: Test #107 – End of Test

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7. FROST FLUID FREEZING POINT FAILURE

Previous flat plate testing conducted in natural frost conditions demonstrated that anti-icing fluids could experience premature failure when approaching the fluid Lowest Operational Use Temperature (LOUT) [see TC report, TP 14938E, *Substantiation of Aircraft Ground Deicing Holdover Times in Frost Conditions* (5)]. Due to radiation cooling, the temperature of the test surface would approach the fluid freezing point, causing ice to form sporadically in the fluid. The ice contamination did not seem to adhere to the surface; however, the aerodynamic impact of the failed fluid needed to be investigated. This section provides an overview of each test conducted as part of the test program to investigate the fluid flow-off properties of anti-icing fluid failure as a result of the skin temperature reaching the fluid freezing point.

7.1 General Methodology

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

- If possible, conduct testing when outside air temperature is close to -24ºC;
- Apply anti-icing fluid diluted to 75/25 to the wing section;
- If outside air temperature is not cold enough, dilute fluid to a negative buffer respective to outside air temperature;
- Monitor condition of fluid; and
- When an acceptable level of freezing point crystalline failure is observed, run wind tunnel and collect lift loss and visual data.

It should be noted that the colder -24ºC temperature was never achieved; therefore, testing was conducted with 50/50 and 25/75 fluids due to the warmer ambient temperature.

7.2 Overview of Tests

A summary of the simulated frost fluid freezing point 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, Dilution: Aircraft deicing fluid specified by product name, and dilution specified in percentage.

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 (ºC): The tunnel ambient temperature prior to the start of the simulated takeoff run, 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 run, recorded in degrees Celsius.

Visual Contamination Rating Before Takeoff (LE, TE): Visual contamination rating determined before the start of the simulated takeoff. Two values are indicated [one for the leading edge (LE) and one for the trailing edge (TE)]:

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. Two values are indicated [one for the leading edge (LE) and one for the trailing edge (TE)]:

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.

C_L at 8º During Rotation: Calculated lift coefficient at the 8º wing rotation angle position; data provided by the NRC.

Two tests were conducted to simulate fluid freezing point failure during frost conditions. Test #89 was conducted with a 25/75 fluid; however, the fluid provided only a very thin layer of anti-icing fluid on the wing section. A second test, Test #90, was conducted with a 50/50 fluid and was more representative of a thickened fluid anti-icing treatment.

Table 7.1: Summary of 2008-09 Frost Fluid Freezing Point Failure Tests

Test No.	Date	Fluid, Dilution	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)	Visual Cont. Rating at Rotation (LE, TE)	C_L at 8° During Rotation
89	1-Mar-09	Flight, 50/50	Frost	N/A	N/A	-14	-5.6	5, 5	5, 5	1.839
90	1-Mar-09	Flight, 25/75	Frost	N/A	N/A	-17	-6.3	5, 5	5, 5	1.767

7.3 Data Collected

7.3.1 Fluid Thickness Data

APS personnel collected fluid thickness measurements. The wing positions used for the wind tunnel tests are described in Subsection 2.15.2. Fluid thickness measurements were recorded at the following intervals:

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

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

Table 7.2: Test #89 Fluid Thickness Data

Test 89, Flight, Frost, Tunnel OAT -13.6°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
1	0.2	N/A	slush
2	0.2	N/A	slush
3	0.2	N/A	slush
4	0.3	N/A	slush
5	0.5	N/A	slush
6	0.2	N/A	slush
7	0.2	N/A	slush
8	0.1	N/A	slush

Table 7.3: Test #90 Fluid Thickness Data

Test 90, Flight, Frost, Tunnel OAT -16.5°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
1	1.4	N/A	slush
2	1.8	N/A	slush
3	2.5	N/A	slush
4	3.3	N/A	slush
5	5.7	N/A	slush
6	1.3	N/A	slush
7	1.6	N/A	slush
8	1.7	N/A	slush

7.3.2 Skin Temperature Data

APS personnel collected skin temperature measurements. The wing positions used for the wind tunnel tests are described in Subsection 2.15.2. Skin temperature measurements were recorded at the following intervals:

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

The wing temperature measurements recorded during each test are shown in Tables 7.4 to 7.5.

Table 7.4: Test #89 Wing Skin Temperature Data

Test 89, Flight, Frost, Tunnel OAT -13.6°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	-10.6	-5.2	N/A	-10.6
T5	-10.2	-5.8	N/A	-9.8
TU	-11.5	-5.8	N/A	-11.1

Table 7.5: Test #90 Wing Skin Temperature Data

Test 90, Flight, Frost, Tunnel OAT -16.5°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	-10.0	-5.7	N/A	-12.4
T5	-9.5	-5.7	N/A	-12.1
TU	-10.6	-7.6	N/A	-12.9

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 2.15.3.

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

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

Table 7.6: Test #89 Fluid Brix Data

Test 89, Flight, Frost, Tunnel OAT -13.6°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	11.25	N/A	11.25
8	11.50	N/A	12.50

Table 7.7: Test #90 Fluid Brix Data

Test 90, Flight, Frost, Tunnel OAT -16.5°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	19.50	N/A	23.00
8	20.00	N/A	20.75

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 7.10 show the photo summaries of the tests conducted. A complete set of photos will be provided to the TDC.

7.5 General Observations

The following sections describe the observations regarding the testing conducted to evaluate the aerodynamic effects of fluid freezing point failure during frost conditions. The operational impact of these results is described in more detail in TP 14938E (5).

7.5.1 Summary of Results

During Test #89, a 25/75 fluid provided a very thin layer of anti-icing fluid on the wing section. As a result of the -7ºC buffer, the fluid began to freeze almost immediately in large sections; ice formations resembled large sheets of ice. The results were not representative of the previous experience during the outdoor endurance time tests conducted on flat plates. Those tests produced ice crystals within the fluid, as opposed to sheets of ice. During the high-speed test, the wing skin temperature was further cooled, and the ice sheets grew in size; the contamination was not removed by the time of rotation. It was recommended that the test be repeated with a higher glycol content fluid to generate a more representative sample.

During Test #90, a 50/50 fluid was applied to the wing section; the fluid provided a 1ºC buffer with respect to the wing section temperature. The fluid thickness was greater compared to Test #89 and was more representative of a thickened fluid anti-icing treatment. Crystallization in the fluid did not occur immediately; therefore, the wind tunnel was run on idle speed (30-40 knots) to help cool down the wing and accelerate the crystallization process. Once an acceptable level of fluid failure was achieved (approximately 33 percent of the wing surface), a high-speed test was conducted (see Photo 7.5).

The ice formations observed during Test #90 were similar in shape and appearance to the ice formations observed during outdoor endurance time tests conducted on flat plates. The formations began as small nucleation points and grew outwards to form opaque circular shapes. The growth of these ice formations was rapid once the wing skin temperatures dropped below the fluid freezing point.

During the high-speed test, the contamination present did not flow-off at time of rotation (see Photo 7.6), contrary to expectations. This was due to the crystallization forming on the interface between the wing skin and the fluid, therefore having greater adhesive forces compared to other forms of frozen contamination (i.e., snow), which primarily sit on the top layer of the fluid. As the tunnel continued to run, the wing skin temperature cooled further, and the ice formations grew greater in size and were not removed; contamination was greater by the end of the test (see Photo 7.8).

It should be noted that these results are conservative due to the limitations of the test protocol. In a typical frost operation, the wing skin temperatures would be warmed during taxi and takeoff as the outside air temperature would be several degrees above the wing skin temperature, compared to the wind tunnel tests where the outside air temperature was several degrees below the skin temperature. Nevertheless, it is unknown whether the taxi and takeoff following a typical overnight frost anti-icing application would provide enough time to melt any ice formations embedded in the fluid.

7.5.2 Observations

The results from the wind tunnel tests demonstrated similar crystalline formations as were observed with the white-painted, insulated aluminum plates. Although the contamination did not seem to adhere during the plate tests, the wind tunnel tests demonstrated that the contamination was not removed by the time of rotation and that the level of contamination worsened by the end of the test. However, during a typical frost operation, the wing skin temperature would be warmed during taxi and takeoff (rather than cooled as in the wind tunnel), and the results may potentially be less severe.

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Photo 7.1: Test #89 – After Fluid Application

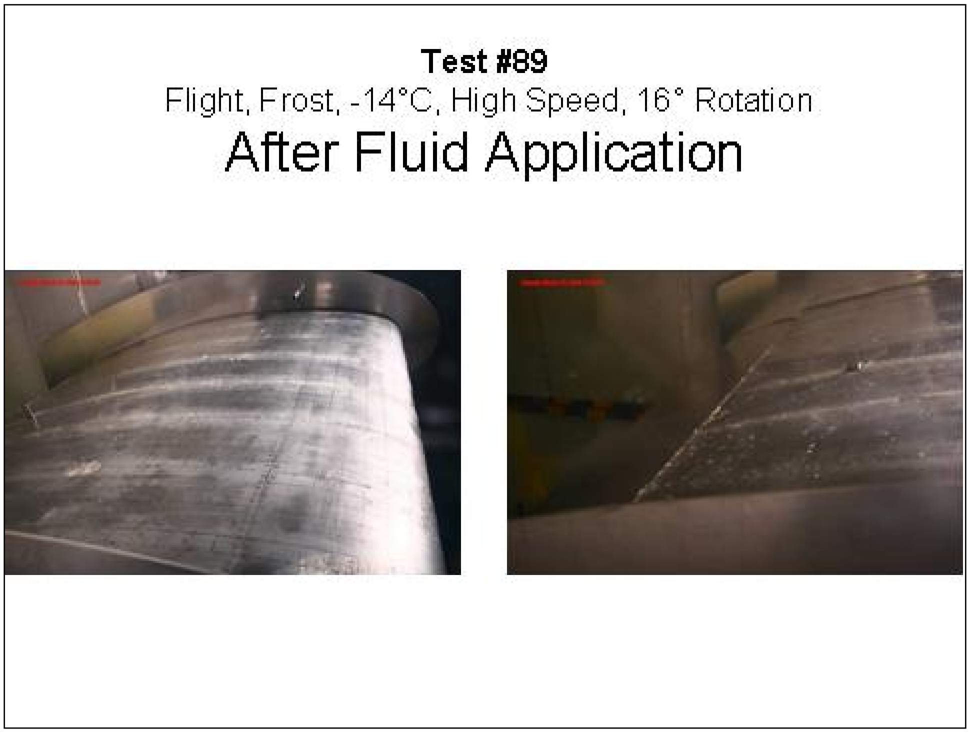

Photo 7.2: Test #89 – Start of Test

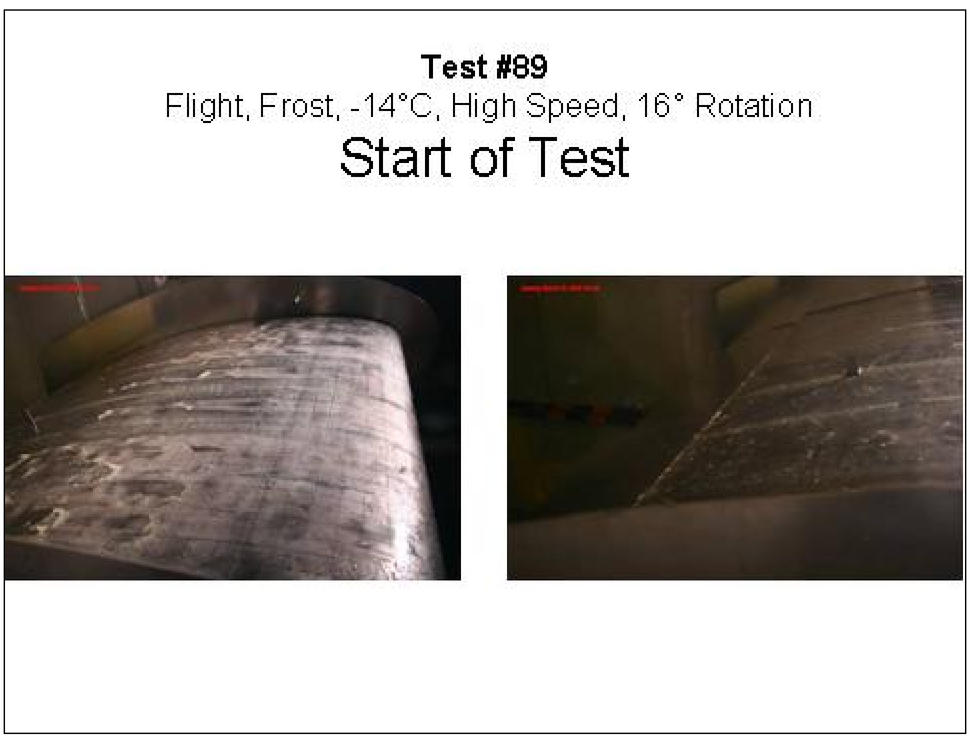

Photo 7.3: Test #89 – Before Rotation

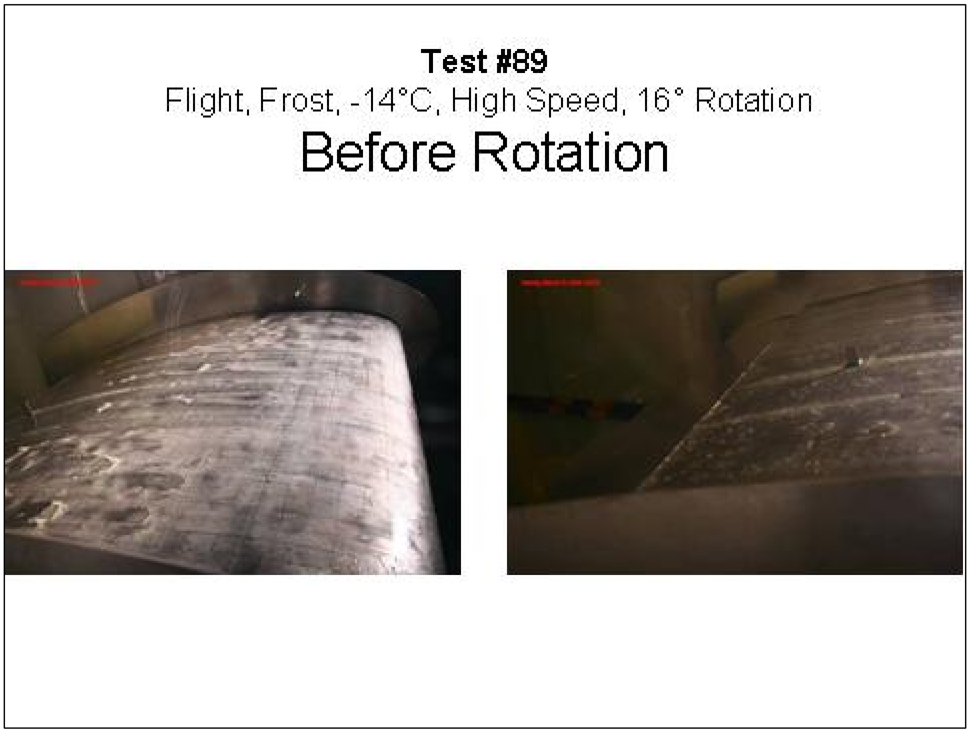

Photo 7.4: Test #89 – End of Rotation

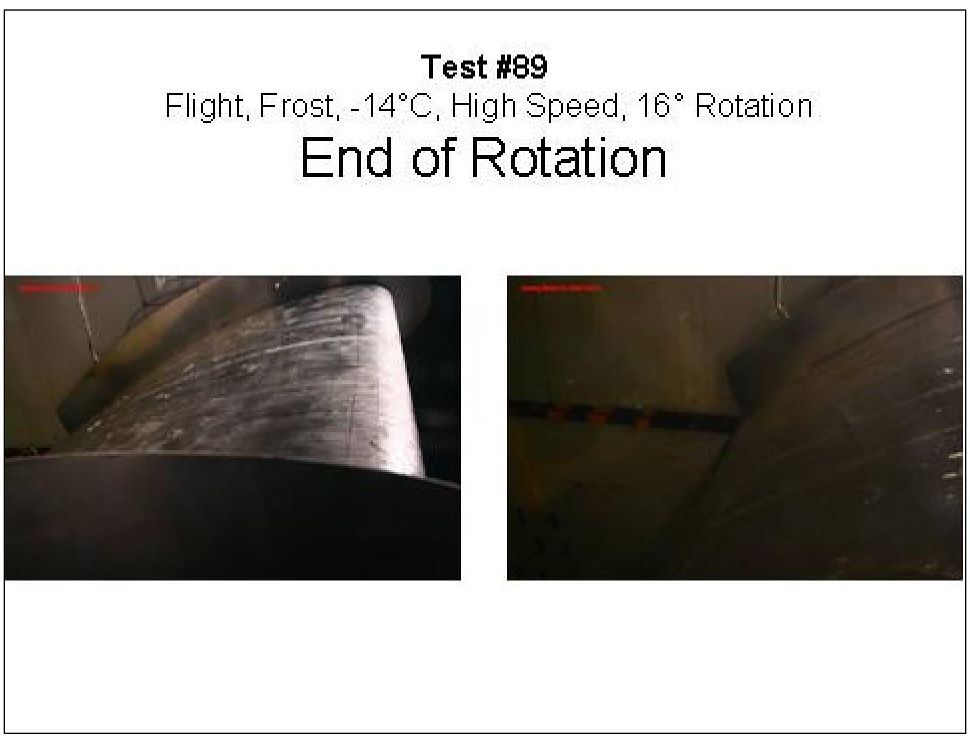

Photo 7.5: Test #89 – End of Test

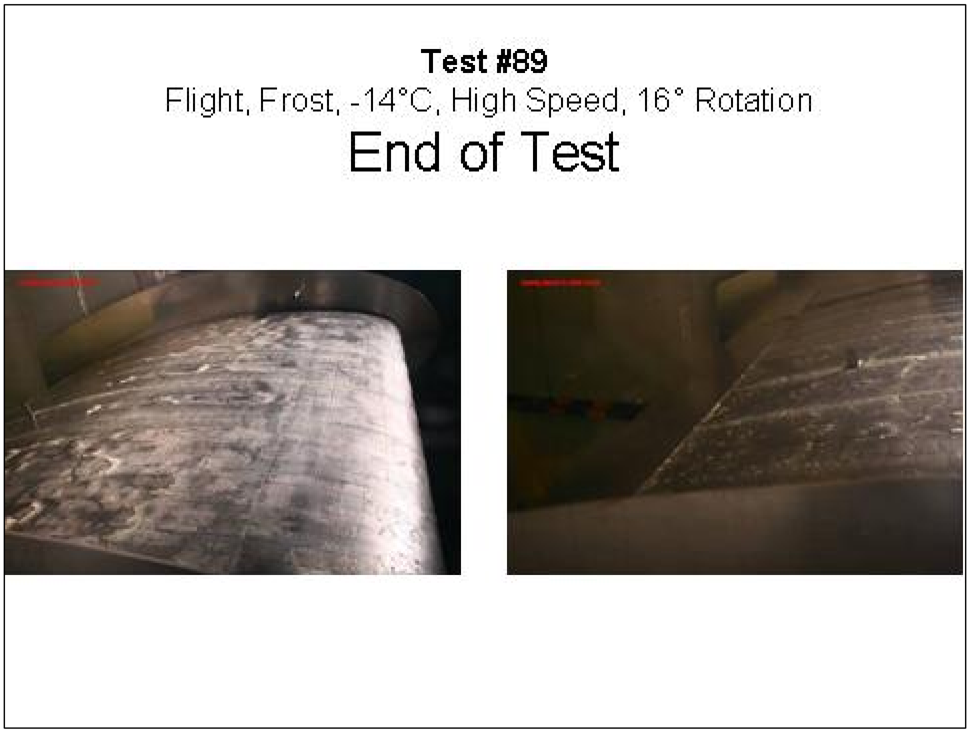

Photo 7.6: Test #90 – After Fluid Application

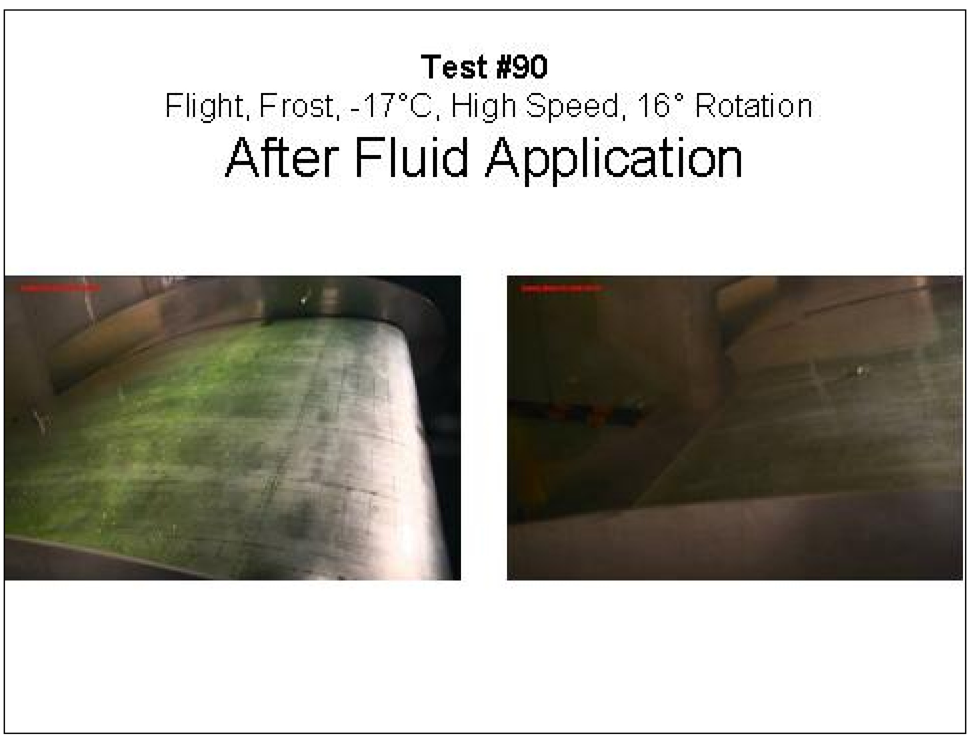

Photo 7.7: Test #90 – Start of Test

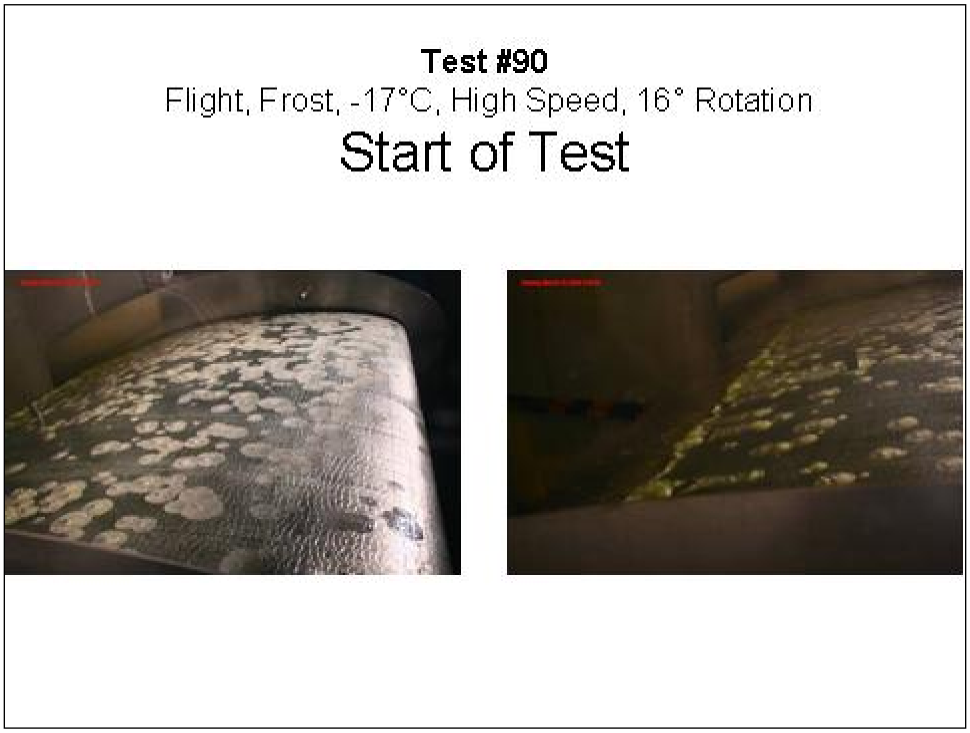

Photo 7.8: Test #90 – Before Rotation

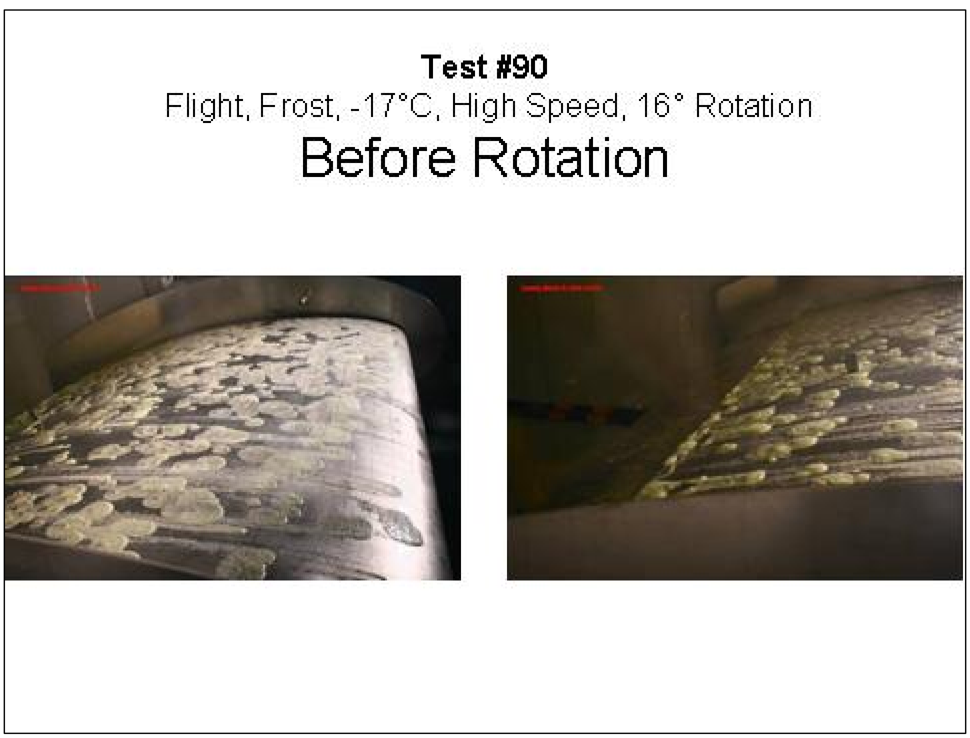

Photo 7.9: Test #90 – End of Rotation

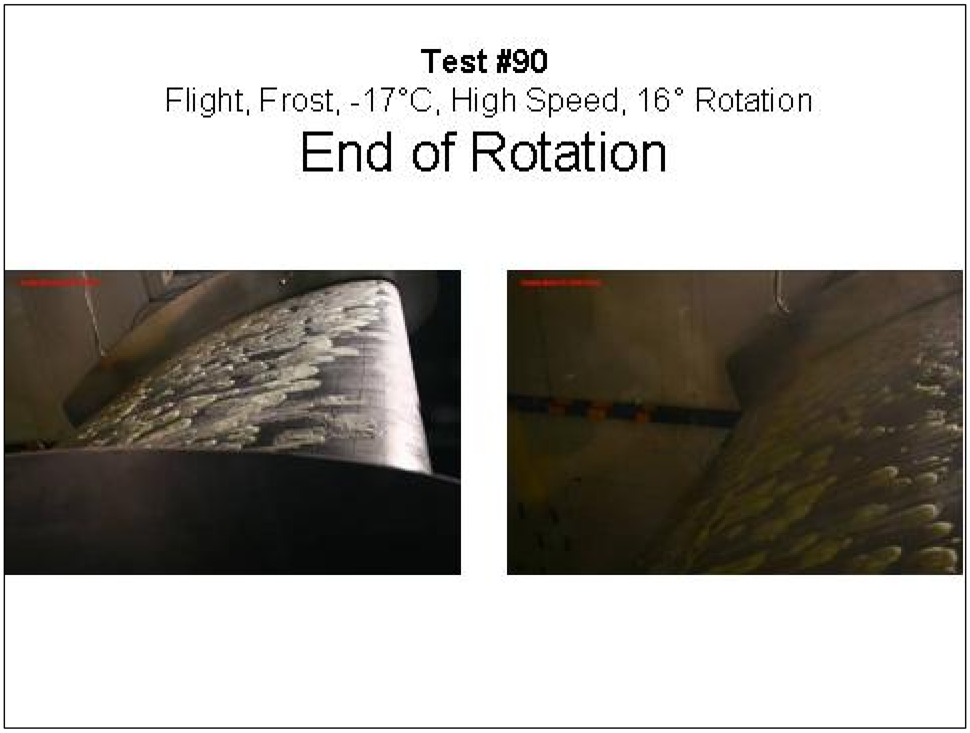

Photo 7.10: Test #90 – End of Test

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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 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 operational aircraft.

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. This section provides an overview of each test conducted as part of the test program to investigate the aerodynamic performance of Type IV anti-icing fluid using the current low-speed aerodynamic acceptance takeoff profile.

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.
Rotation Speed (Knots)/Rot. Angle (º):	Maximum speed at time of rotation, measured in knots, and the maximum angle of attack at the time of rotation, measured in degrees.
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 (ºC):	The tunnel ambient temperature prior to the start of the simulated takeoff run, 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 run, recorded in degrees Celsius.
Visual Contamination Rating Before Takeoff (LE, TE):	Visual contamination rating determined before the start of the simulated takeoff. Two values are indicated [one for the leading edge (LE) and one for the trailing edge (TE)]: 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. Two values are indicated [one for the leading edge (LE) and one for the trailing edge (TE)]:

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.

C_L at 8° During Rotation: Calculated lift coefficient at the 8° wing rotation angle position; data provided by the NRC.

Three tests were conducted to investigate the fluid flow-off characteristics during 67 and 80 knot rotation speed tests. During the first test, Test #80, the acceleration to 67 knots was slower compared to the typical acceleration used during the typical wind tunnel tests. Test #81 was a re-run of Test #80 with a different propylene glycol (PG) fluid. Test #82 was conducted using the 80 knots takeoff profile and was performed primarily as a baseline comparison test for Test #81.

Table 8.1: Summary of 2008-09 Low-Speed Ramp Testing

Test No.	Date	Fluid	Rotation Speed (Knots) / Rot. Angle (°)	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel OAT at Start of Test (°C)	AVG. Wing Temp. Before Test (°C)	Visual Cont. Rating Before Takeoff (LE, TE)	Visual Cont. Rating at Rotation (LE, TE)	C_L at 8° During Rotation
80	24-Feb-09	ABC-S Plus	67/20	N/A	N/A	N/A	-3	N/A	1, 1	1, 1	1.769
81	24-Feb-09	Launch	67/20	N/A	N/A	N/A	-3	-3.6	1, 1	1, 1	1.760
82	24-Feb-09	Launch	80/20	N/A	N/A	N/A	-3	-4.8	1, 1	1, 1	1.766

8.3 Data Collected

8.3.1 Fluid Thickness Data

APS personnel collected fluid thickness measurements. The wing positions used for the wind tunnel tests are described in Subsection 2.15.2. Fluid thickness measurements were recorded at the following intervals:

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

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

Table 8.2: Test #80 Fluid Thickness Data

Test 80, ABC-S Plus, Fluid Only, Tunnel OAT -3.1°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
1	1.0	N/A	0.0
2	1.4	N/A	0.1
3	2.2	N/A	0.2
4	2.9	N/A	0.2
5	4.5	N/A	0.2
6	1.5	N/A	0.5
7	1.6	N/A	0.5
8	1.7	N/A	0.6

Table 8.3: Test #81 Fluid Thickness Data

Test 81, Launch, Fluid Only, Tunnel OAT -2.5°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
1	1.4	N/A	0.0
2	1.4	N/A	0.0
3	2.2	N/A	0.1
4	2.7	N/A	0.1
5	3.7	N/A	0.2
6	1.3	N/A	0.5
7	1.3	N/A	0.5
8	1.5	N/A	0.6

Table 8.4: Test #82 Fluid Thickness Data

Test 82, Launch, Fluid Only, Tunnel OAT -2.6°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
1	1.1	N/A	0.0
2	1.4	N/A	0.0
3	2.2	N/A	0.0
4	N/A	N/A	0.0
5	3.7	N/A	0.0
6	1.6	N/A	0.3
7	1.6	N/A	0.4
8	1.7	N/A	0.6

8.3.2 Skin Temperature Data

APS personnel collected skin temperature measurements. The wing positions used for the wind tunnel tests are described in Subsection 2.15.3. Skin temperature measurements were recorded at the following intervals:

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

The wing temperature measurements recorded during each test are shown in Tables 8.5 to 8.7

Table 8.5: Test #80 Wing Skin Temperature Data

Test 80, ABC-S Plus, Fluid Only, Tunnel OAT -3.1°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	-3.0	-4.0	N/A	-4.4
T5	-1.9	-3.3	N/A	-3.4
TU	-4.0	-4.6	N/A	-5.2

Table 8.6: Test #81 Wing Skin Temperature Data

Test 81, Launch, Fluid Only, Tunnel OAT -2.5°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	-4.4	-3.3	N/A	-5.2
T5	-3.4	-3.4	N/A	-4.3
TU	-5.2	-4.0	N/A	-5.7

Table 8.7: Test #82 Wing Skin Temperature Data

Test 82, Launch, Fluid Only, Tunnel OAT -2.6°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	-5.2	-4.8	N/A	-4.8
T5	-4.3	-4.9	N/A	-4.1
TU	-5.7	-4.8	N/A	-5.0

8.3.3 Fluid Brix Data

APS personnel collected fluid Brix measurements. The wing positions used for the wind tunnel tests are described in Subsection 2.15.4. Fluid Brix measurements were recorded at the following intervals:

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

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

Table 8.8: Test #80 Fluid Brix Data

Test 80, ABC-S Plus, Fluid Only, Tunnel OAT -3.1°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	37	N/A	39.00
8	37.25	N/A	37.75

Table 8.9: Test #81 Fluid Brix Data

Test 81, Launch, Fluid Only, Tunnel OAT -2.5°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	36.75	N/A	40.75
8	37.00	N/A	38.00

Table 8.10: Test #82 Fluid Brix Data

Test 82, Launch, Fluid Only, Tunnel OAT -2.6°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	37.50	N/A	42.00
8	36.75	N/A	38.50

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 8.12 show the photo summaries of the tests conducted. A complete set of photos will be provided to the TDC.

8.5 General Observations

During Test #80, conducted with a PG fluid, the acceleration to 67 knots was slower compared to the typical acceleration during wind tunnel tests; this was the first test, and the NRC controller was cautious not to overshoot the target speed. The visual results indicated significant amounts of fluid left over aft of the first third of the wing at the time of rotation. In addition, at the time of rotation, fluid was still visible on the leading edge. Fluid thickness measurements were not conducted during this test run, and a re-run was attempted to identify if the acceleration profile had any impact on the results obtained.

Test #81 was a re-run of Test #80, however with a different PG fluid. The results obtained were similar to those of Test #80, whereby there were significant amounts of fluid left over aft of the first third of the wing at the time of rotation. Also, at the time of rotation, fluid was still visible on the leading edge.

Test #82 was conducted with the same PG fluid as Test #81, but using the 80 knots takeoff profile. At the time of rotation, there were significant amounts of fluid left over aft of the first third of the wing, as well as fluid visible on the leading edge. Although a significant amount of fluid was still present on the wing, it was visually apparent that there was considerably less fluid on the wing at the time of rotation during the 80 knot test compared to the 67 knot test. The ripples on the trailing edge (a result of the fluid shearing off) were also less prominent during the 80 knot test.

Table 8.9 shows a comparison of the fluid thickness measurements taken after the takeoff test (at the end of the test) for both Test #81 (67 knot rotation) and Test #82 (80 knot rotation). The grey cells indicate measurement locations where the fluid thickness was greater during the 67 knot test in comparison to the 80 knot test. The results indicate that the leading edge (Wing Positions 1 to 5) was clean by the end of the 80 knot test, whereas the 67 knot test still had fluid present. On the trailing edge (Wing Positions 6 to 8), residual fluid was present for both tests; however, the 67 knot test demonstrated slightly greater amounts of residual fluid.

Table 8.9: Comparison of Thickness Data for 67 vs. 80 Knot Test

FLUID THICKNESS (mm)		
After Takeoff Test		
Wing Position	Test #81 (67 Knots)	Test #82 (80 Knots)
1	0	0
2	0	0
3	**0.1**	0
4	**0.1**	0
5	**0.2**	0
6	**0.5**	0.3
7	**0.5**	0.4
8	0.6	0.6

The results indicate 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 these tests were conducted with no contamination; therefore, fluid elimination could potentially be hampered with the presence of solid or adhered contamination.

Photo 8.1: Test #80 – Start of Test

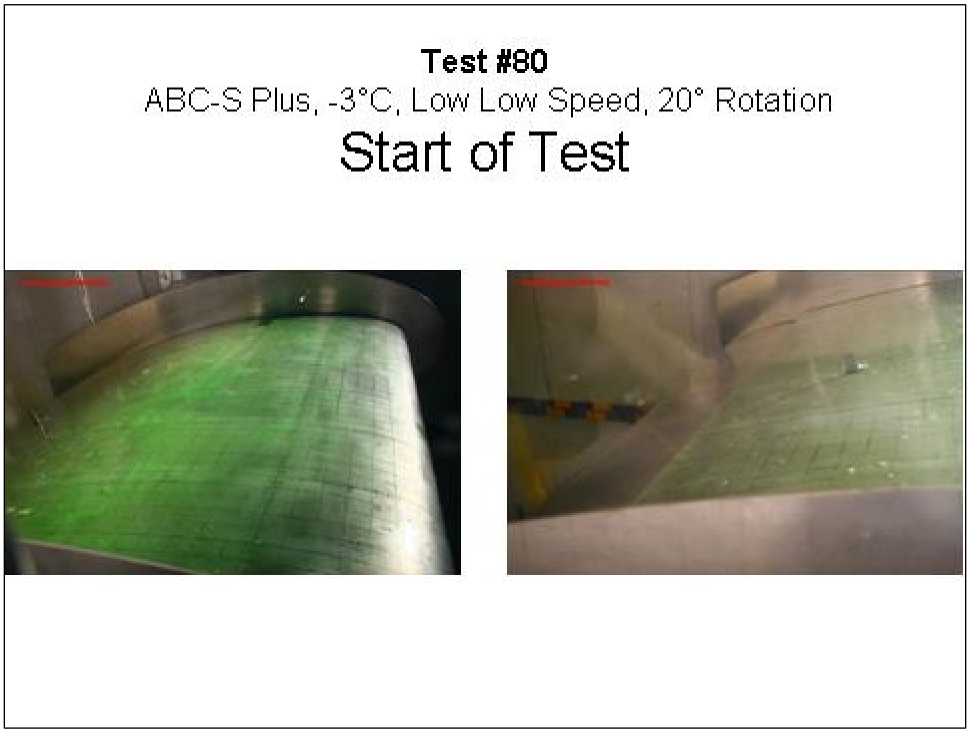

Photo 8.2: Test #80 – Before Rotation

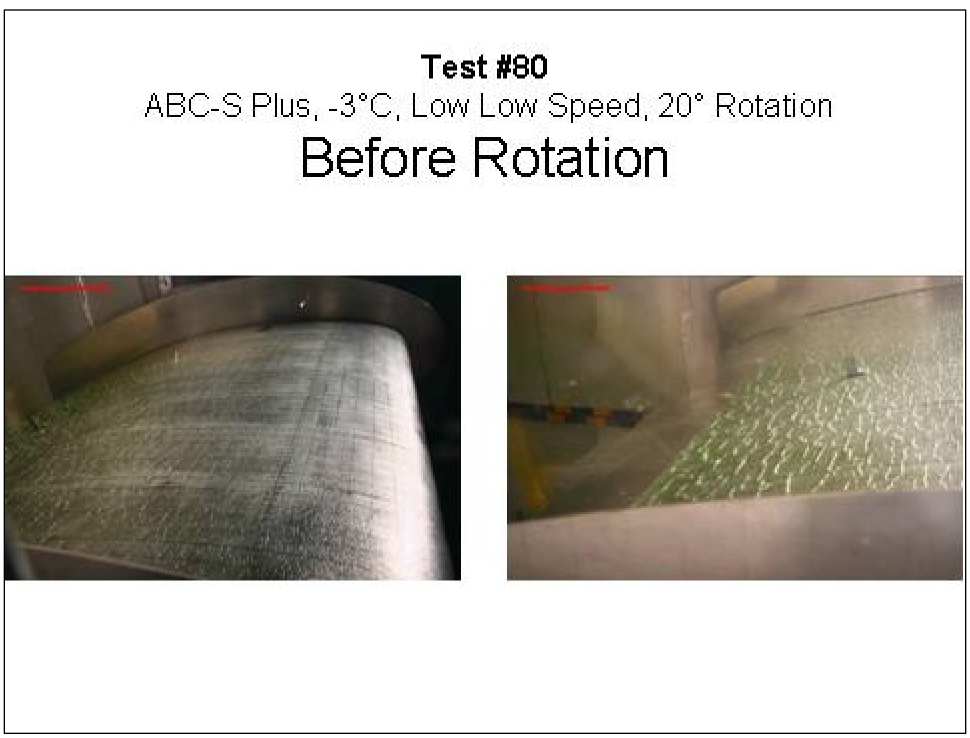

Photo 8.3: Test #80 – End of Rotation

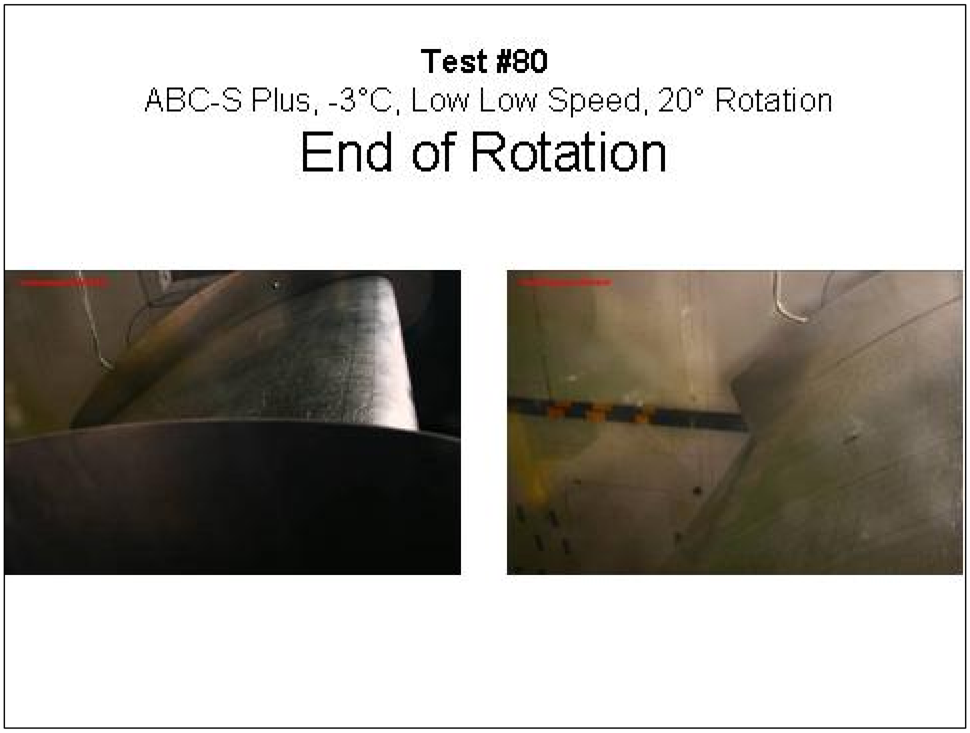

Photo 8.4: Test #80 – End of Test

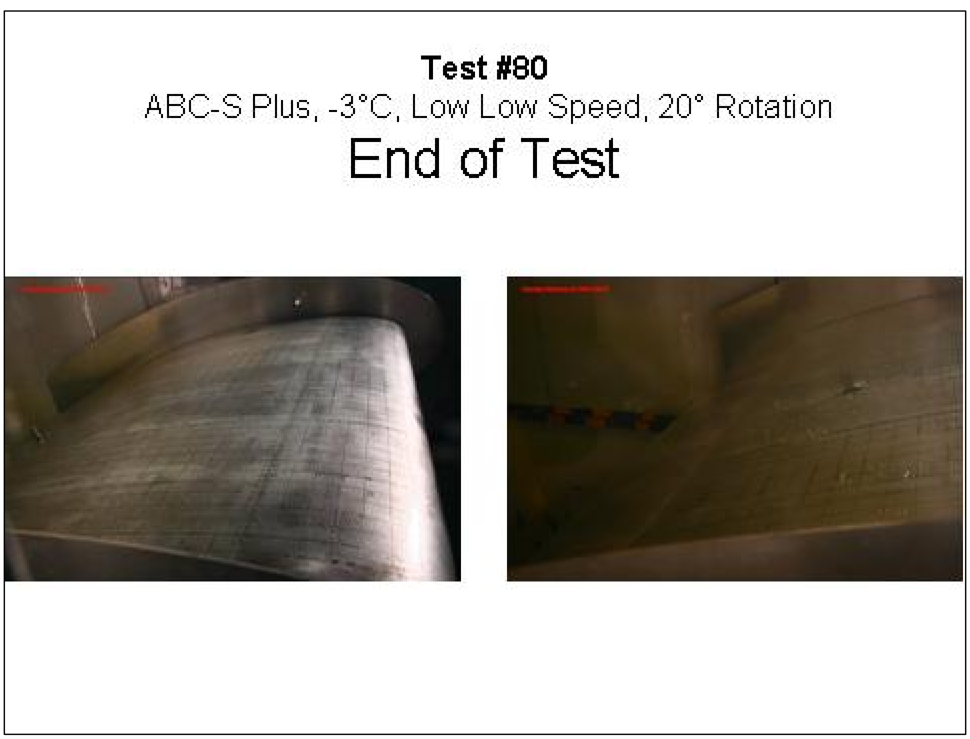

Photo 8.5: Test #81 – Start of Test

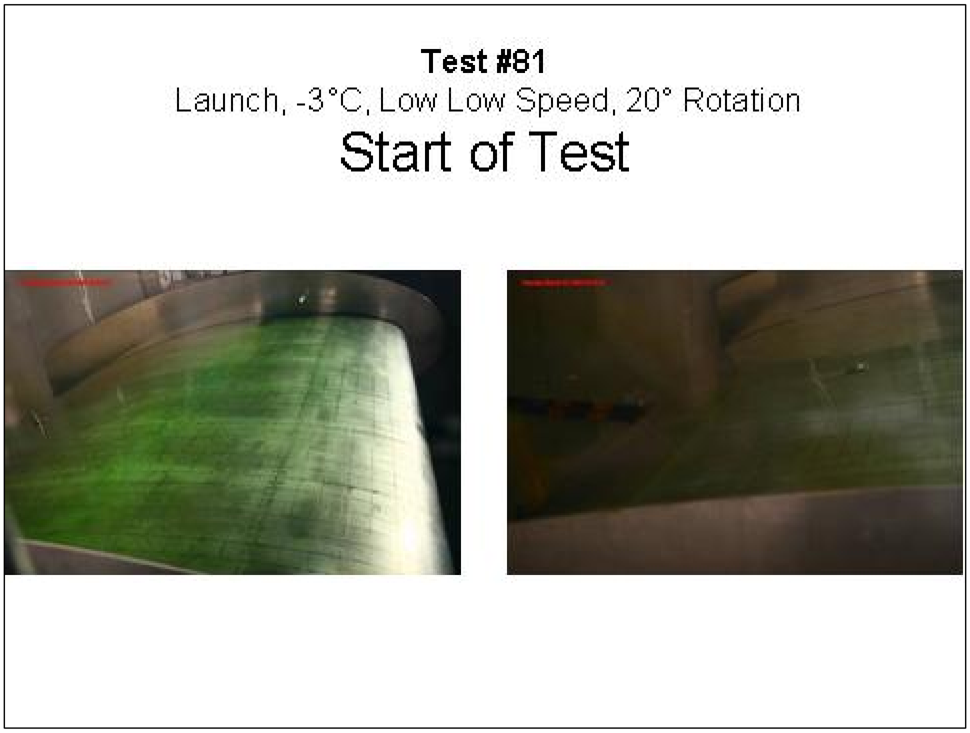

Photo 8.6: Test #81 – Before Rotation

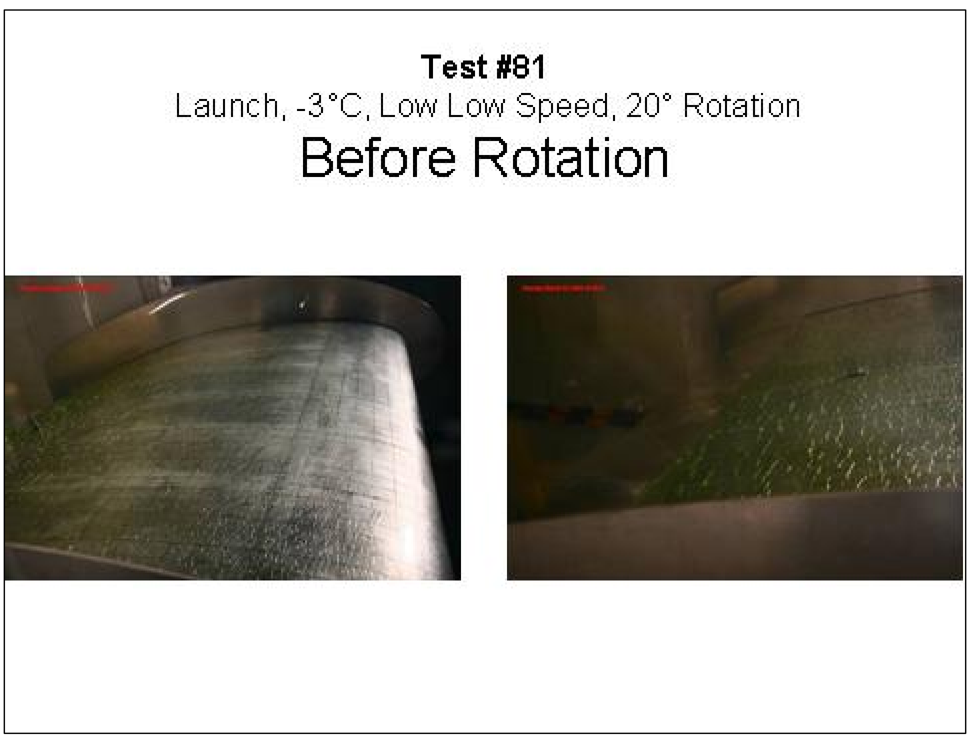

Photo 8.7: Test #81 – End of Rotation

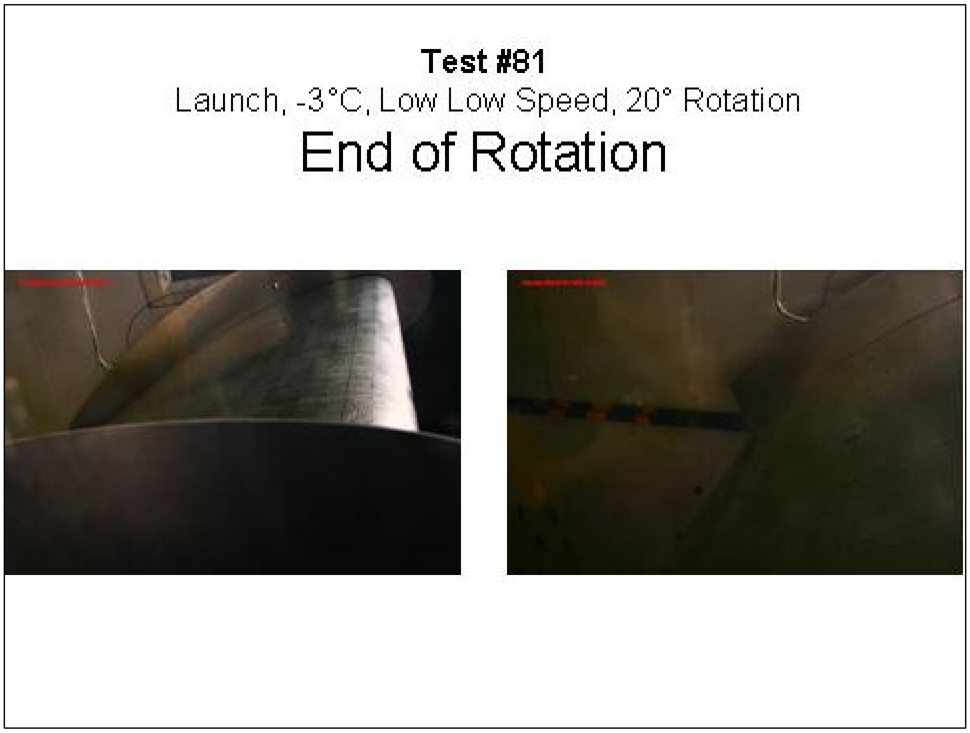

Photo 8.8: Test #81 – End of Test

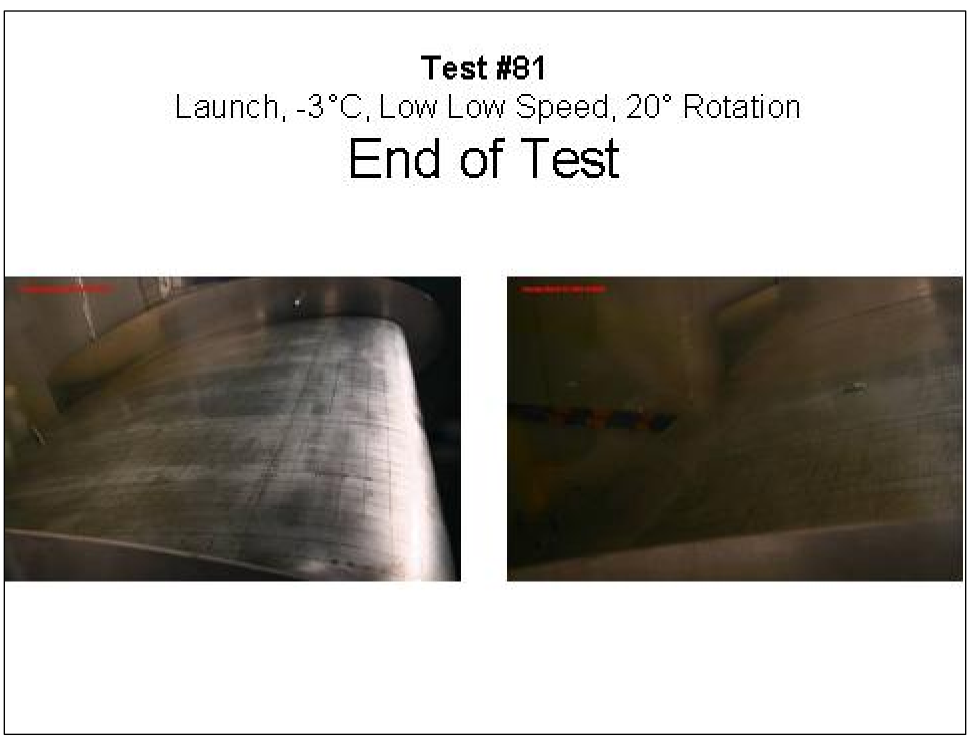

Photo 8.9: Test #82 – Start of Test

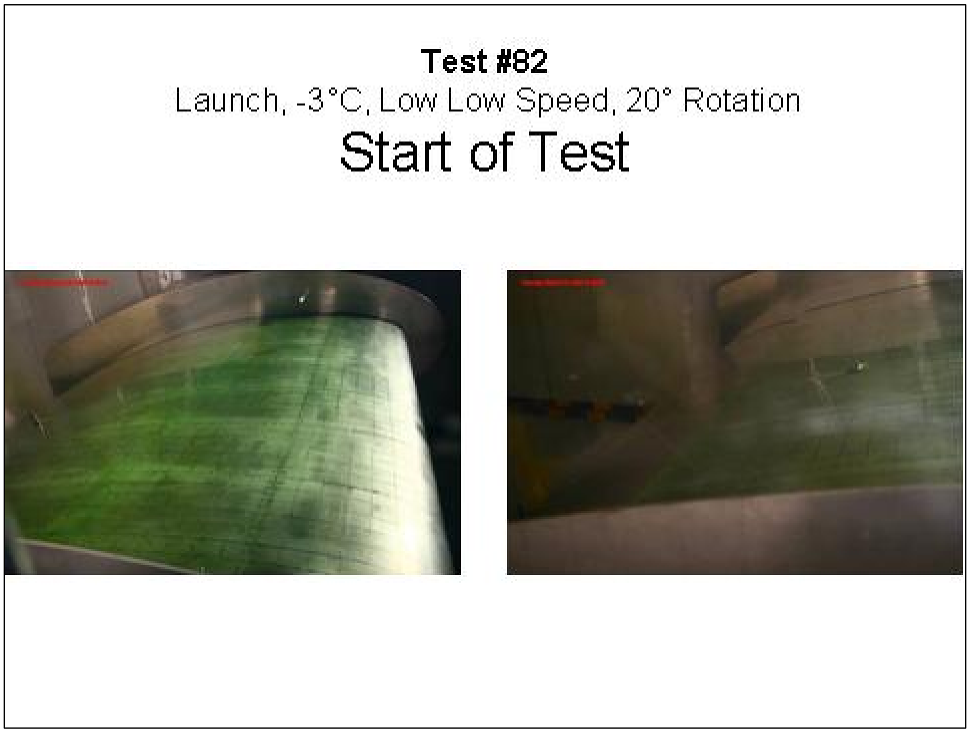

Photo 8.10: Test #82 – Before Rotation

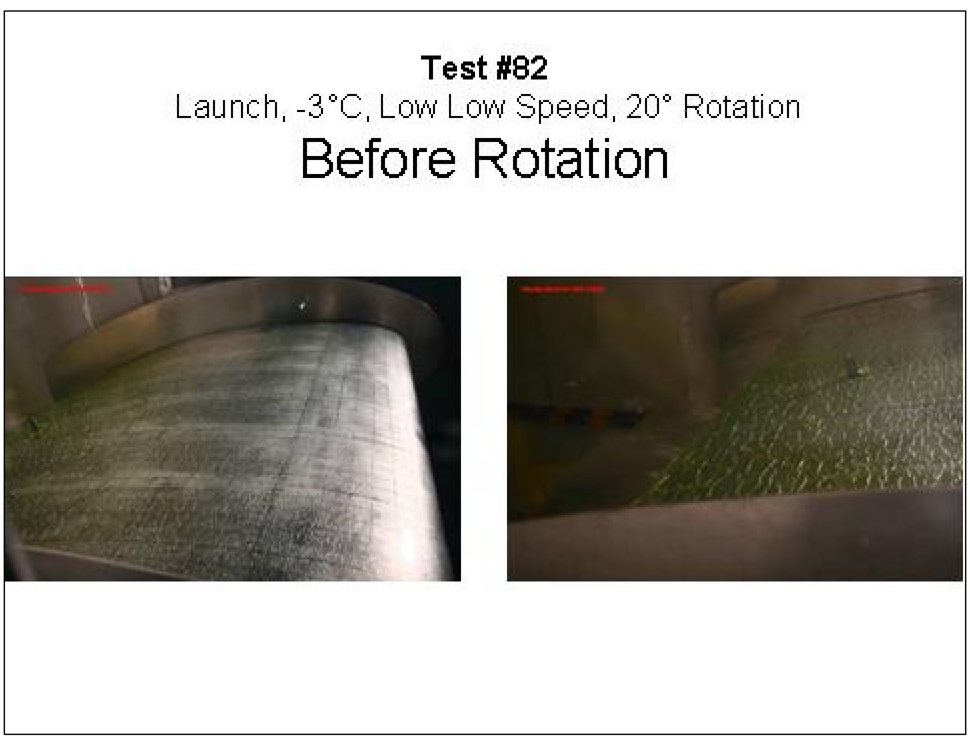

Photo 8.11: Test #82 – End of Rotation

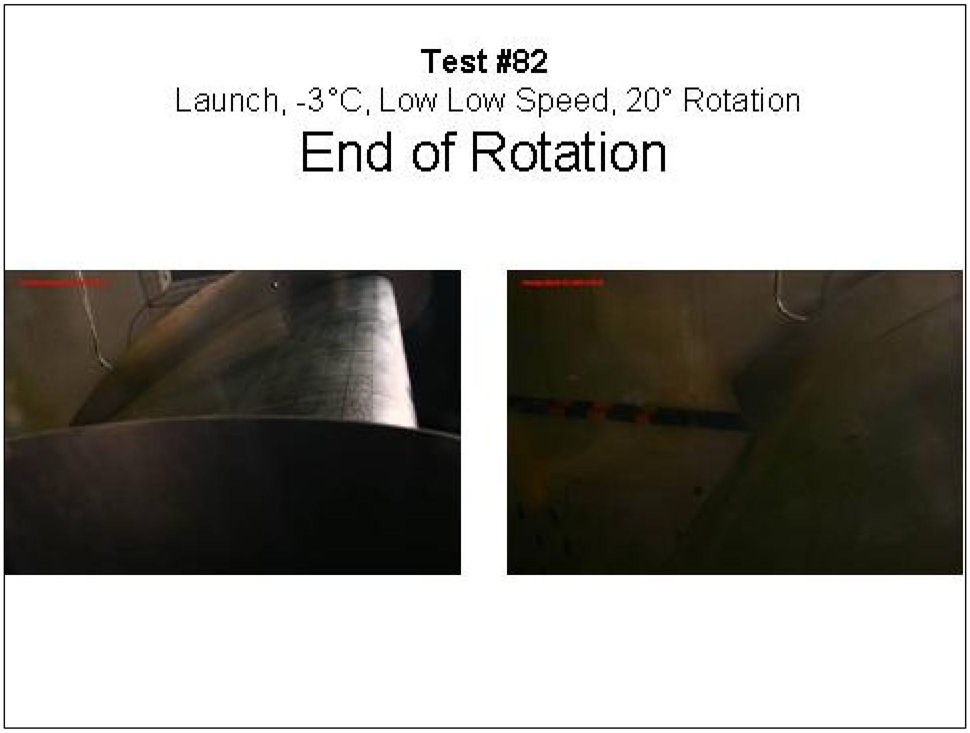

Photo 8.12: Test #82 – End of Test

9. 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 with 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 HOTs 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 interim report documenting aircraft deicing research in heavy snow conditions.

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

9.1 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.

9.2 Overview of Tests

A summary of the heavy 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.

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 run, 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 run, recorded in degrees Celsius.

Visual Contamination Rating Before Takeoff (LE, TE): Visual contamination rating determined before the start of the simulated takeoff. Two values are indicated [one for the leading edge (LE) and one for the trailing edge (TE)]:

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. Two values are indicated [one for the leading edge (LE) and one for the trailing edge (TE)]:

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.

C_L at 8º During Rotation: Calculated lift coefficient at the 8º wing rotation angle position; data provided by the NRC.

Five tests were conducted to investigate the flow-off properties of fluid contaminated with moderate and heavy snow. Test #61 was performed as the baseline moderate snow test for comparison with Test #62, and Test #63. Test #62 was conducted in heavy snow conditions with half the exposure time of Test #61, and Test #63 was conducted in heavy snow conditions with exposure time (40 min.) equal to that of Test #61. Two tests were also conducted with PG fluid: Test #71 was performed as the baseline moderate snow test for comparison with Test #70, which was conducted in heavy snow conditions with exposure time (60 min.) equal to that of Test #71.

Table 9.1: Summary of 2008-09 Heavy Snow Tests

Test No.	Date	Fluid	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)	Visual Cont. Rating at Rotation (LE, TE)	C_L at 8° During Rotation
61	4-Feb-09	EG106	SN	25	40	-10	-10.1	4, 3	2, 2	1.731
62	4-Feb-09	EG106	SN++	50	20	-11	-11.5	4, 2	1, 2	1.756
63	4-Feb-09	EG106	SN++	50	40	-12	-13.2	4, 4	3, 2	1.717
70	5-Feb-09	Launch	SN++	50	60	-5	-8.4	4, 4	4, 4	1.658
71	5-Feb-09	Launch	SN	25	60	-4	-8.4	4, 4	3, 3	1.667

9.3 Data Collected

9.3.1 Fluid Thickness Data

APS personnel collected fluid thickness measurements. The wing positions used for the wind tunnel tests are described in Subsection 2.15.2. Fluid thickness measurements were recorded at the following intervals:

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

Tables 9.2 to 9.6 show the fluid thickness measurements collected during the tests.

Table 9.2: Test #61 Fluid Thickness Data

Test 61, EG 106, SN, Tunnel OAT -9.9°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
1	1.8	slush	0.0
2	2.5	2.9	0.0
3	3.5	3.5	0.0
4	3.9	3.5	0.0
5	3.9	3.7	0.0
6	3.1	1.8	0.1
7	2.5	1.8	0.1
8	2.5	1.8	0.1

Table 9.3: Test #62 Fluid Thickness Data

Test 62, EG 106, SN++, Tunnel OAT -11.1°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
1	1.8	0.8	0.0
2	2.5	0.8	0.0
3	3.3	2.5	0.0
4	3.9	3.7	0.0
5	3.9	4.5	0.0
6	2.7	2.2	0.1
7	2.5	2.2	0.2
8	2.5	1.8	0.2

Table 9.4: Test #63 Fluid Thickness Data

Test 63, EG 106, SN++, Tunnel OAT -11.5°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
1	1.8	slush	0.0
2	2.5	slush	0.0
3	3.3	slush	0.0
4	4.5	4.5	0.0
5	4.5	4.5	0.0
6	2.7	1.2	0.0
7	2.5	1.2	0.0
8	2.2	1.0	0.0

Table 9.5: Test #70 Fluid Thickness Data

Test 70, Launch, SN++, Tunnel OAT -4.5°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
1	0.6	5.7	0.0
2	0.7	7	0.0
3	1.1	5.7	0.0
4	1.4	4.5	0.0
5	1.8	3.9	0.0
6	0.7	5.7 (slush)	slush
7	0.8	5.7 (slush)	slush
8	0.8	5.7 (slush)	slush

Table 9.6: Test #71 Fluid Thickness Data

Test 71, Launch, SN, Tunnel OAT -3.7°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
1	0.7	0.8	0.0
2	1.0	1.8	0.1
3	1.4	2.2	0.1
4	1.8	3.1	0.1
5	2.2	2.9	0.2
6	1.2	2.2	slush
7	1.1	2.2	slush
8	1.3	2.2	slush

9.3.2 Skin Temperature Data

APS personnel collected skin temperature measurements. The wing positions used for the wind tunnel tests are described in Subsection 2.15.3. Skin temperature measurements were recorded at the following intervals:

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

The wing temperature measurements recorded during each test are shown in Tables 9.7 to 9.11.

Table 9.7: Test #61 Wing Skin Temperature Data

Test 61, EG 106, SN, Tunnel OAT -9.9°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	-5.8	-7.2	-11.2	-8.5
T5	-6.0	-7.5	-8.2	-8.3
TU	-6.3	-7.2	-11.0	-8.4

Table 9.8: Test #62 Wing Skin Temperature Data

Test 62, EG 106, SN++, Tunnel OAT -11.1°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	-8.5	-9.5	-12.3	-9.8
T5	-8.3	-9.0	-10.2	-9.1
TU	-8.4	-9.0	-12.1	-10.0

Table 9.9: Test #63 Wing Skin Temperature Data

Test 63, EG 106, SN++, Tunnel OAT -11.5°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	-9.8	-10.4	-14.0	-11.8
T5	-9.1	-10.0	-12.2	-11.5
TU	-10.0	-10.2	-13.3	-12.3

Table 9.10: Test #70 Wing Skin Temperature Data

Test 70, Launch, SN++, Tunnel OAT -4.5°C				
WING TEMPERATURE (°C)				
Wing Positio n	Before Fluid Applicatio n	After Fluid Applicatio n	After Precip. Applicatio n	After Takeof f Run
T2	-9.6	-10.5	-8.3	-11.2
T5	-9.0	-10.0	-8.8	-11.0
TU	-10.6	-10.9	-8.2	-11.8

Table 9.11: Test #71 Wing Skin Temperature Data

Test 71, Launch, SN, Tunnel OAT -3.7°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Run
T2	-8.4	-9.4	-8.5	-10.8
T5	-8.6	-9.2	-8.3	-9.5
TU	-10.1	-9.6	-8.3	-11.5

9.3.3 Fluid Brix Data

APS personnel collected fluid Brix measurements. The wing positions used for the wind tunnel tests are described in Subsection 2.15.4. Fluid Brix measurements were recorded at the following intervals:

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

Tables 9.12 to 9.16 show the fluid Brix measurements collected during the test.

Table 9.12: Test #61 Fluid Brix Data

Test 61, EG 106, SN, Tunnel OAT -9.9°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	34.50	28.00	37.00
8	33.75	27.00	32.25

Table 9.13: Test #62 Fluid Brix Data

Test 62, EG 106, SN++, Tunnel OAT -11.1°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	34.25	27.00	36.50
8	33.75	27.00	32.50

Table 9.14: Test #63 Fluid Brix Data

Test 63, EG 106, SN++, Tunnel OAT -11.5°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	34.00	20.00	39.00
8	33.75	18.00	23.00

Table 9.15: Test #70 Fluid Brix Data

Test 70, Launch, SN++, Tunnel OAT -4.5°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	37.00	13.50	17.00
8	37.00	12.50	21.00

Table 9.16: Test #71 Fluid Brix Data

Test 71, Launch, SN, Tunnel OAT -3.7°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Run
2	37.00	17.00	13.50
8	36.50	16.00	22.75

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 9.20 show the photo summaries of the tests conducted. A complete set of photos will be provided to the TDC.

9.5 General Observations

The following sections describe the observations regarding the testing conducted in heavy snow conditions.

9.5.1 Visual Fluid Failure Observations

The precipitation periods for moderate snow tests were determined based on the fluid HOTs for the specific conditions tested. In both cases tested (Tests #61 and #71), an additional 10 minutes of precipitation time was added to the HOT for the moderate snow case. In both the ethylene glycol (EG) and PG cases, the fluid condition at the end of the precipitation period demonstrated signs of bridging contamination (loose, unabsorbed particles of snow sitting on the top of the fluid) and therefore was visually a severe condition. The PG fluid performed worse than the EG fluid, having greater areas of bridging snow on the surface.

During the first EG fluid heavy snow test (Test #62), the precipitation rate was doubled compared to the respective moderate snow test (Test #61), but the exposure time was cut in half giving the same total amount of precipitation (16.7 g/dm²). Visually, the results for heavy snow were generally similar but slightly less severe than those during the moderate snow test (Test #61). During the second heavy snow test (Test #63), the precipitation rate was doubled compared to the moderate snow test (Test #61), but the exposure time was left at 40 minutes (equivalent to the moderate snow test), giving double the total amount of precipitation (33.3 g/dm²).

Visually, the results were generally similar but slightly more severe compared to the moderate snow test (Test #61).

During the PG heavy snow test (Test #70), the precipitation rate was doubled compared to the moderate snow test (Test #71), but the exposure time was equal to the moderate snow test at 60 minutes, giving total amounts of precipitation of 50 and 25 g/dm² respectively. Visually, the results were generally similar but slightly more severe compared to the results obtained during the moderate snow test (Test #61).

The preliminary results from the data collected indicate that, visually, moderate snow HOTs are not applicable for heavy snow conditions. From a visual perspective, the heavy snow HOT should be approximately half the moderate snow HOT (or relative to the cumulative amount of precipitation applied) in order to have similar visual end conditions.

9.5.2 Comparison of C_L data

Table 9.17 demonstrates the lift coefficient data collected during the comparative test runs. The results indicate that during the EG tests (Tests #61, #62, and #63), there was little difference in the aerodynamic performance (approximately ±1 percent) when comparing a moderate snow test to a heavy snow test with either half or equal precipitation exposure time. In all the cases with EG fluid, the lift coefficient data was acceptable.

During the PG tests (Runs #71 and #70), there was little difference in the aerodynamic performance (1 percent) when comparing a moderate snow test to a heavy snow test with equal precipitation exposure time. However, during both PG tests, the lift coefficient data recorded was below the C_L pass/fail criteria of 1.7 at 8º rotation (as determined during the ice pellet allowance time research TP 14935E (1).

Table 9.17: Comparison of C_L Data for Moderate vs. Heavy Snow Tests

Test # (Mod - Heavy)	Fluid Type	Rotation Speed (Knots) / Rot. Angle (º)	Moderate Snow C_L @ 8º	Heavy Snow C_L @ 8º	Percentage Difference (%)
61-62	Type IV EG	100/16	1.731	1.756	1%
61-63	Type IV EG	100/16	1.731	1.717	-1%
71-70	Type IV PG	100/16	1.667	1.658	-1%

9.5.3 *Residual Contamination*

Table 9.18 demonstrates a comparison of the residual fluid thickness data collected after the takeoff runs for the comparative test runs. The results support the aerodynamic data collected, demonstrating larger amounts of residual fluid (or slush) during the PG fluid tests compared to the EG fluid tests. When comparing moderate versus heavy snow for EG or PG fluids, the results were similar for both snow conditions.

Table 9.18: Comparison of Residual Fluid Thickness Data for Moderate vs. Heavy Snow Tests

FLUID THICKNESS (mm)					
After Takeoff Run					
Wing Position	Test #61 Mod. Snow EG, 40 min.	Test #62 Heavy Snow EG, 20 min.	Test #63 Heavy Snow EG, 40 min.	Test #71 Mod. Snow PG, 60 min.	Test #70 Heavy Snow PG, 60 min.
1	0	0	0	0	0
2	0	0	0	0.1	0
3	0	0	0	0.1	0
4	0	0	0	0.1	0
5	0	0	0	0.2	0
6	0.1	0.1	0	slush	slush
7	0.1	0.2	0	slush	slush
8	0.1	0.2	0	slush	slush

9.5.4 Previous and Future Heavy Snow Research

The results from the 2008-09 heavy snow testing were in accordance with the preliminary results obtained during the 2006-07 wind tunnel tests (see the interim report documenting aircraft deicing research in heavy snow conditions. The previous 2006-07 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. Visual contamination results obtained with the Falcon 20 confirmed the 2006-07 results obtained in the wind tunnel.

It is recommended that additional testing be performed, in conjunction with flat plate testing, in order to determine a visually acceptable level of heavy snow contamination, followed by an aerodynamic validation of the flat plate results obtained. Testing should be conducted with several PG fluids, as this appears to be the more stringent fluid aerodynamically. The comparative methodology (heavy snow versus moderate snow) should be continued; however, a baseline “fluid only” test should also be conducted with each comparative set of tests in order to provide a better understanding of the results obtained.

Photo 9.1: Test #61 – Start of Test

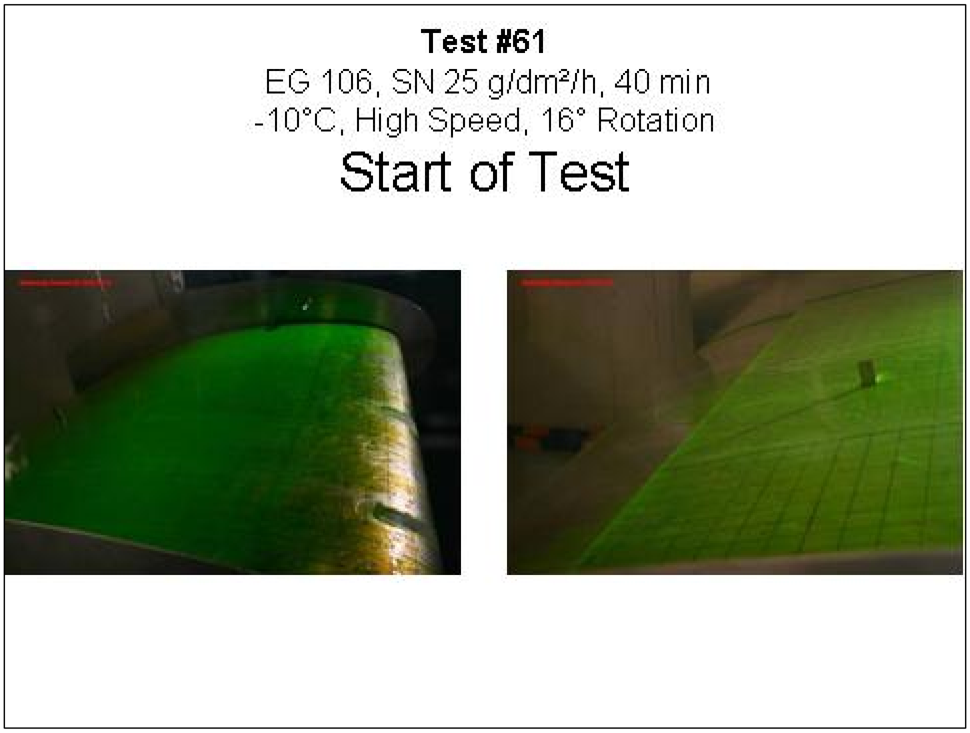

Photo 9.2: Test #61 – Before Rotation

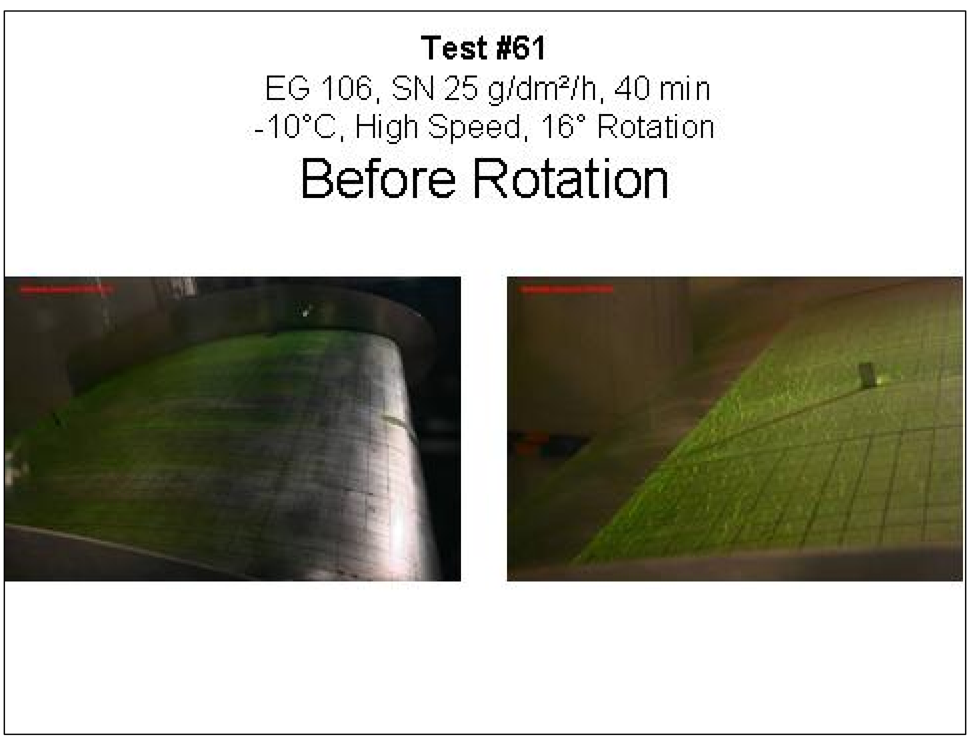

Photo 9.3: Test #61 – End of Rotation

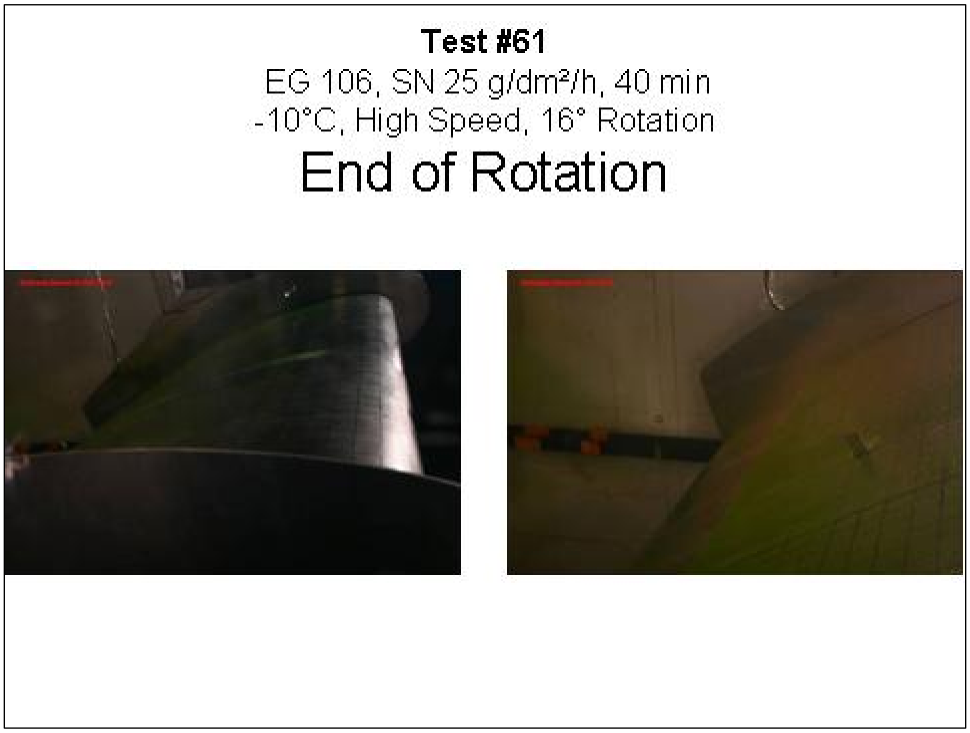

Photo 9.4: Test #61 – End of Test

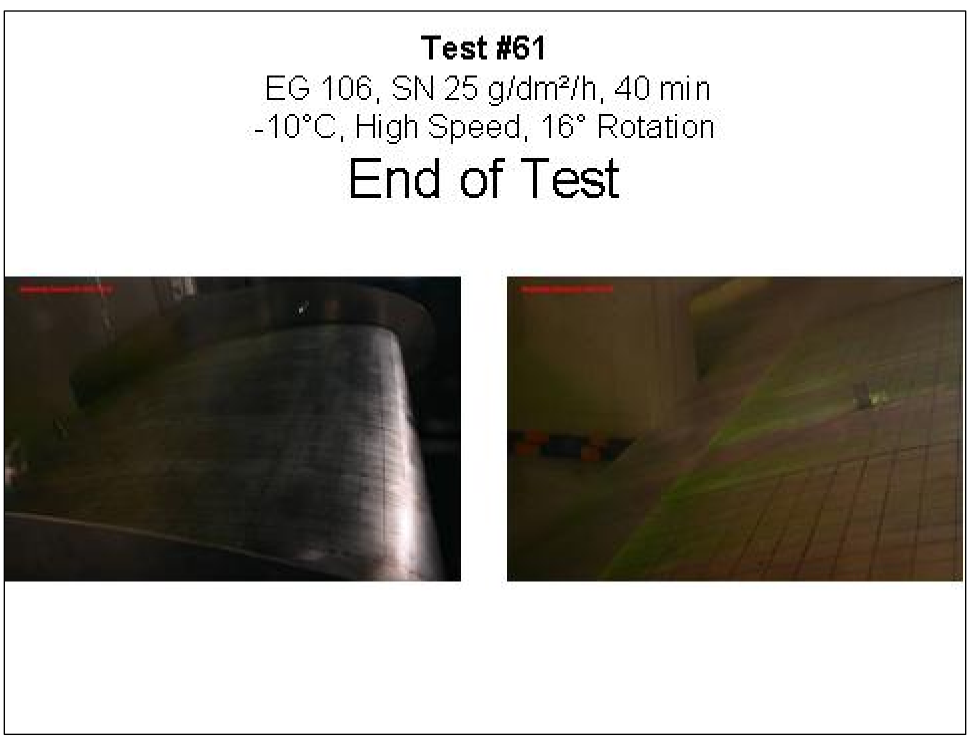

Photo 9.5: Test #62 – Start of Test

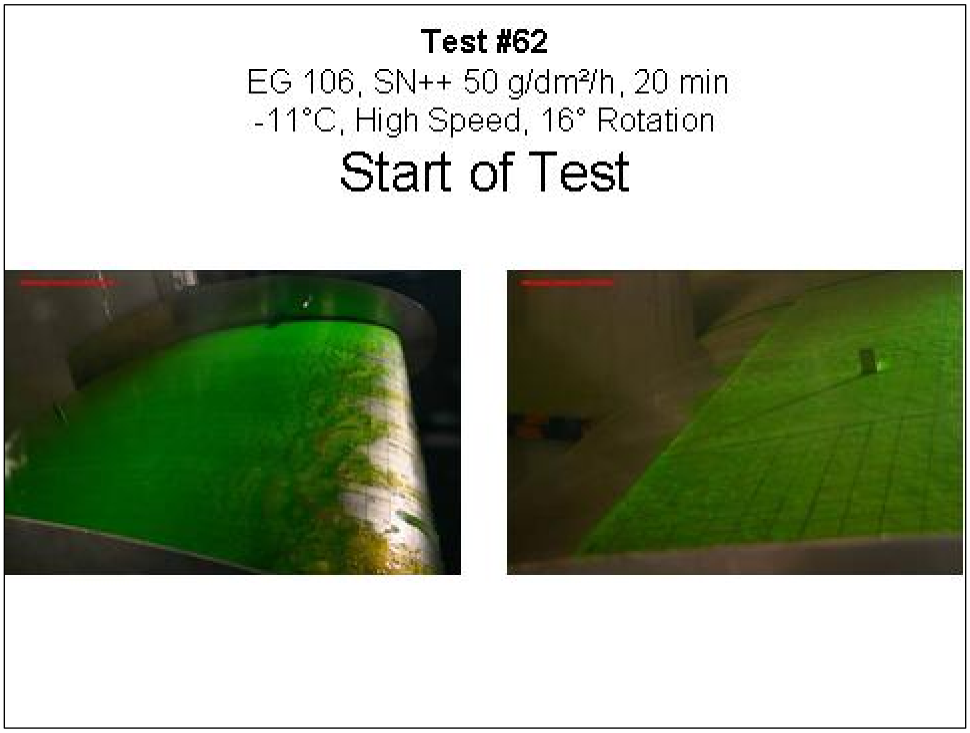

Photo 9.6: Test #62 – Before Rotation

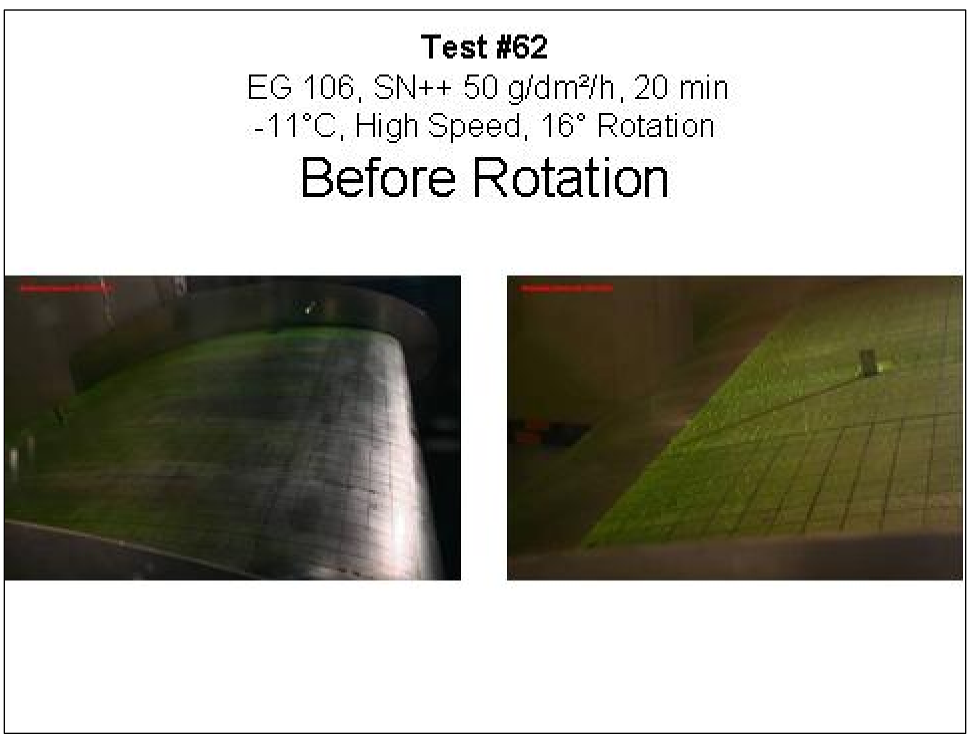

Photo 9.7: Test #62 – End of Rotation

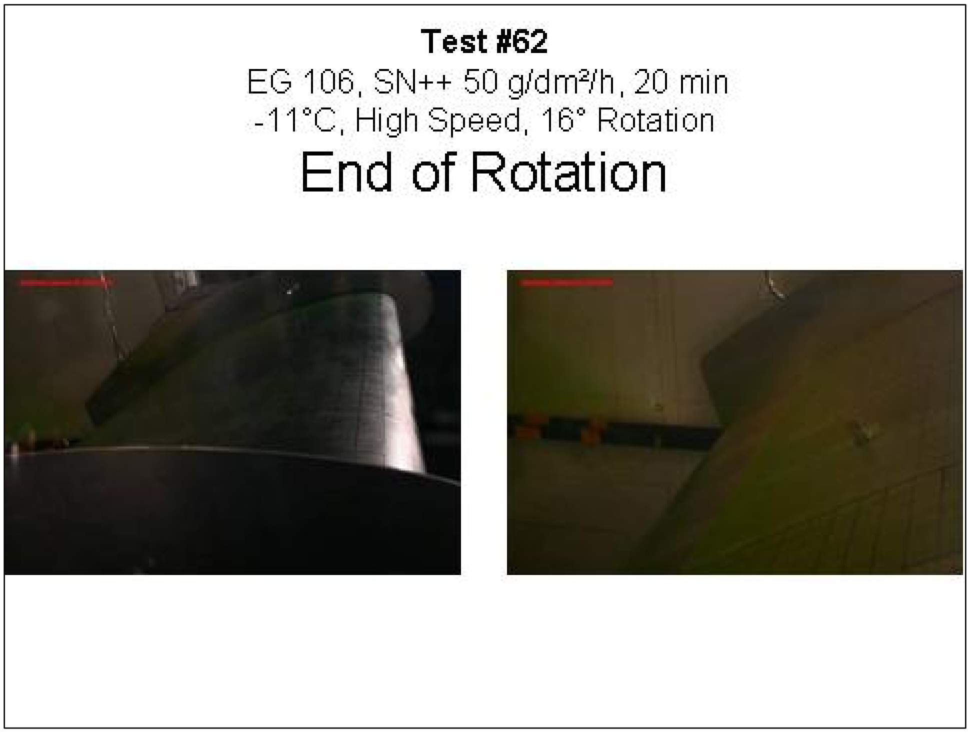

Photo 9.8: Test #62 – End of Test

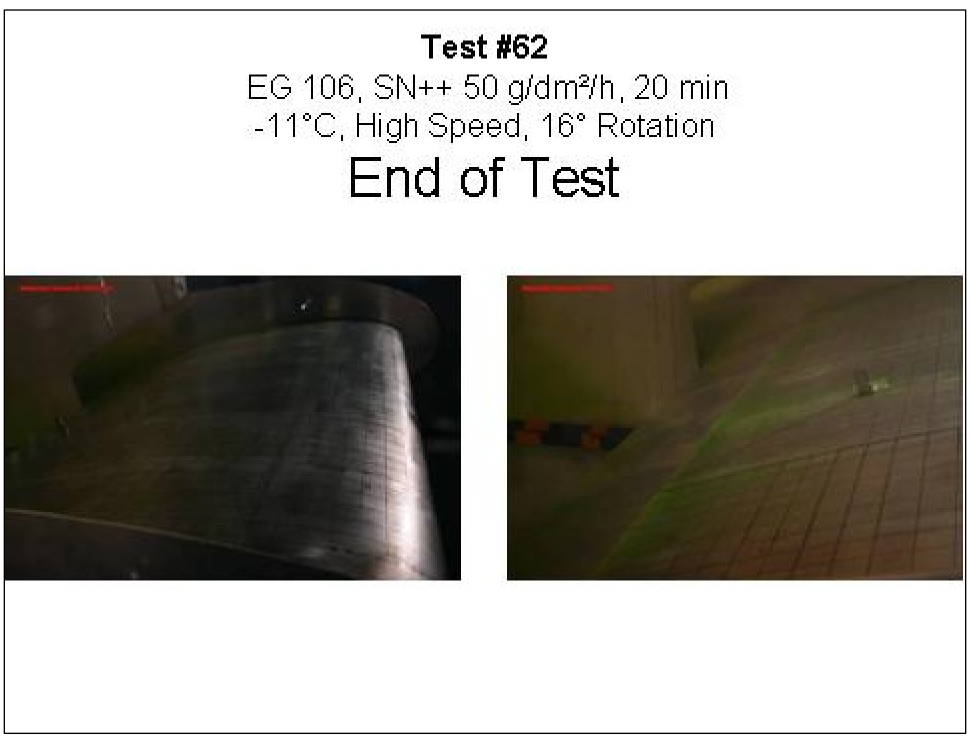

Photo 9.9: Test #63 – Start of Test

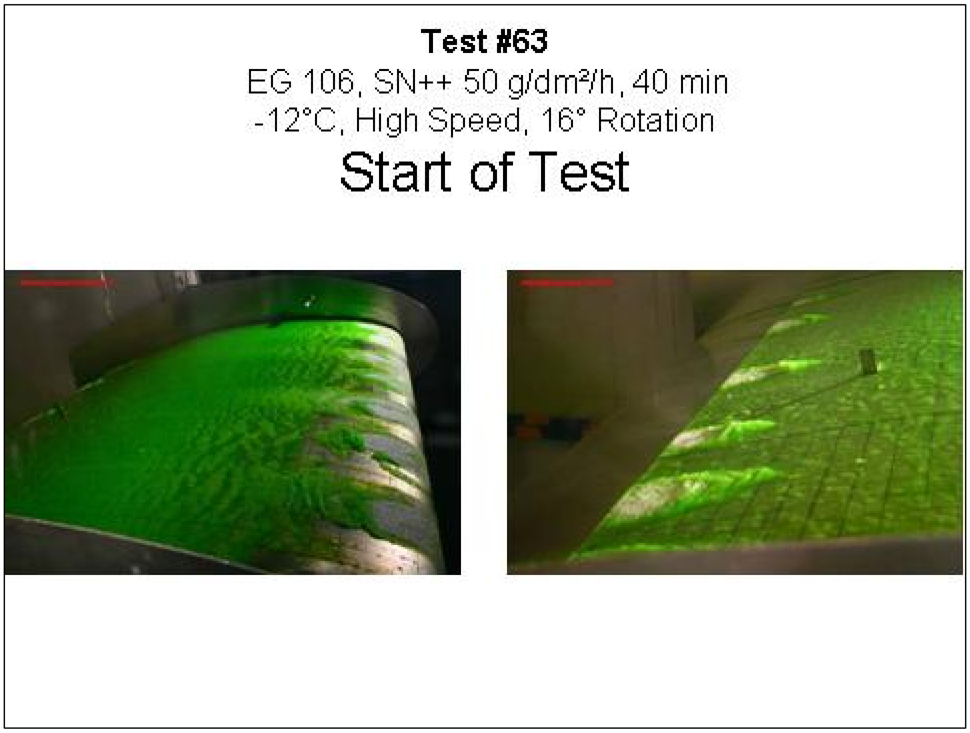

Photo 9.10: Test #63 – Before Rotation

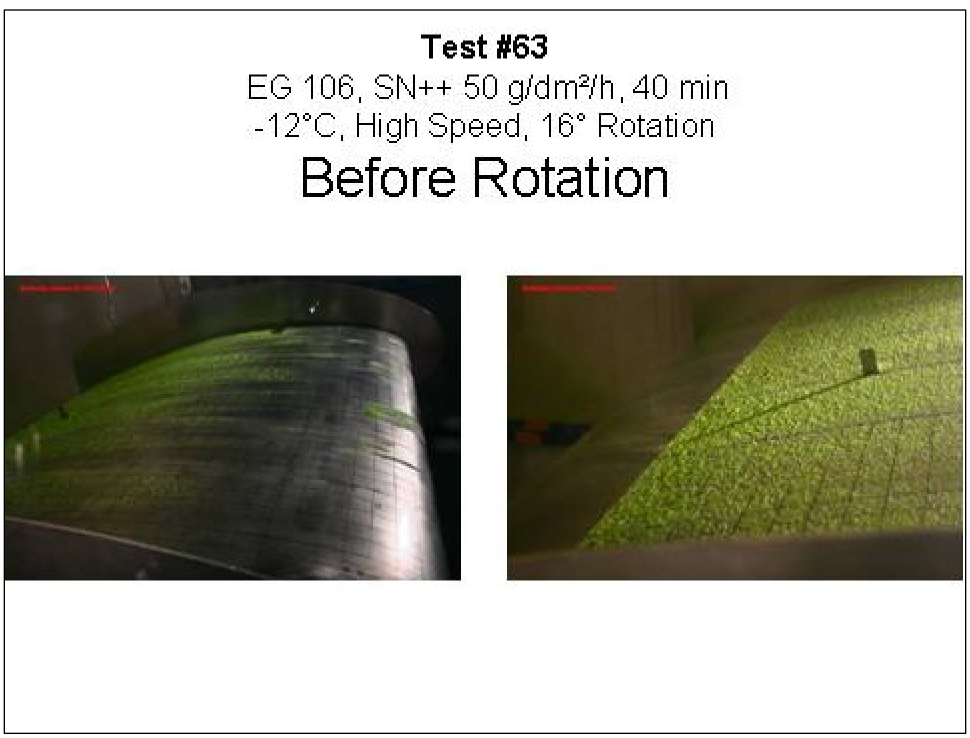

Photo 9.11: Test #63 – End of Rotation

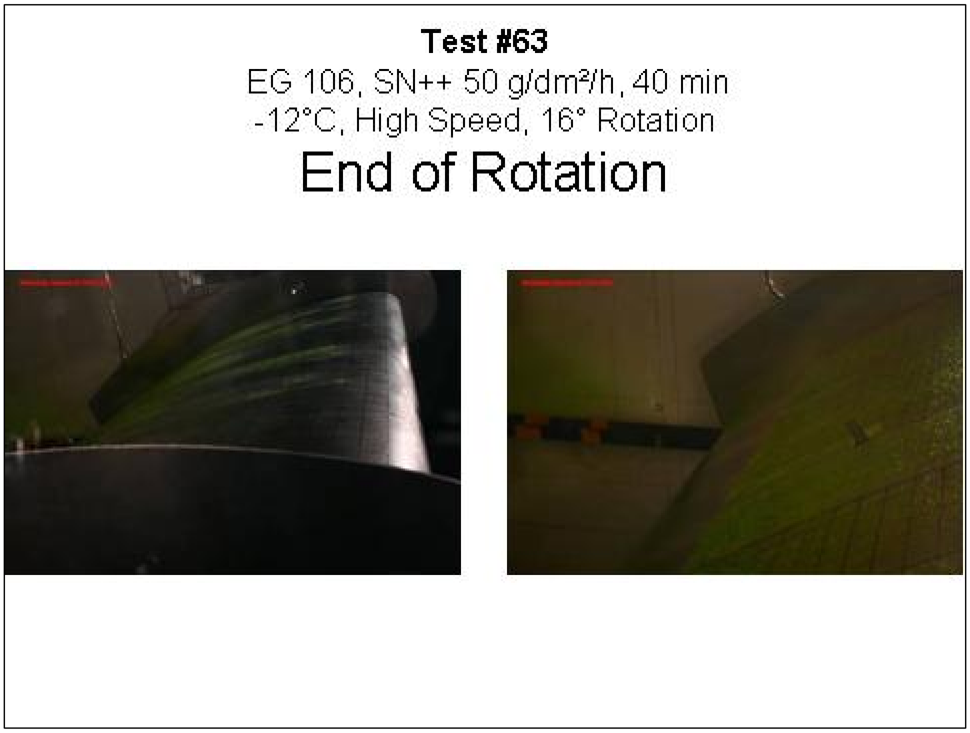

Photo 9.12: Test #63 – End of Test

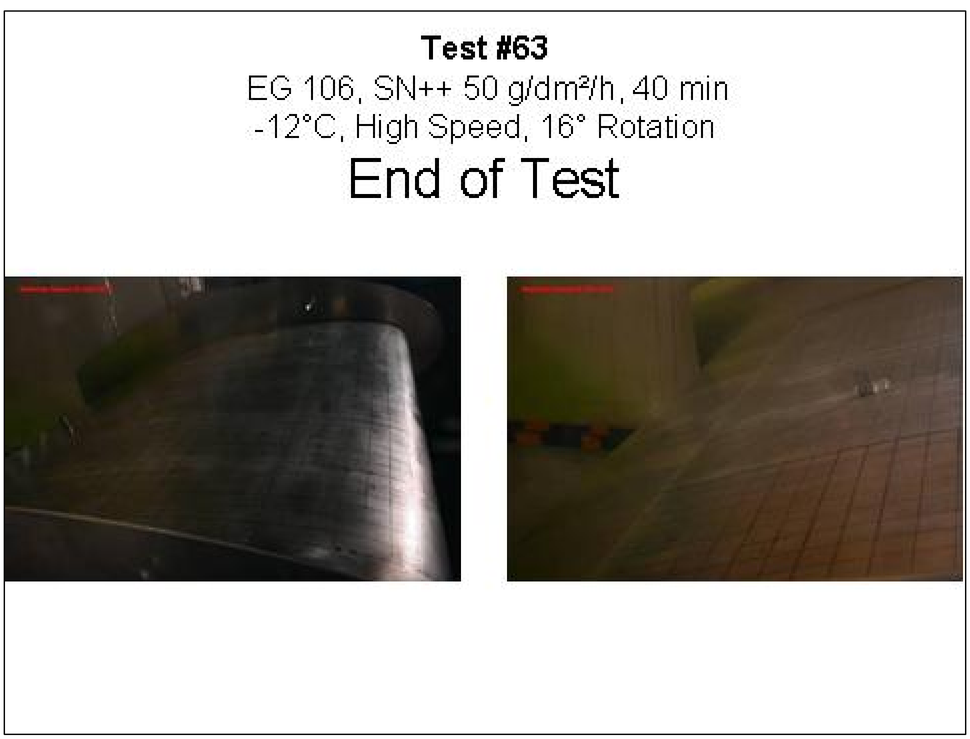

Photo 9.13: Test #70 – Start of Test

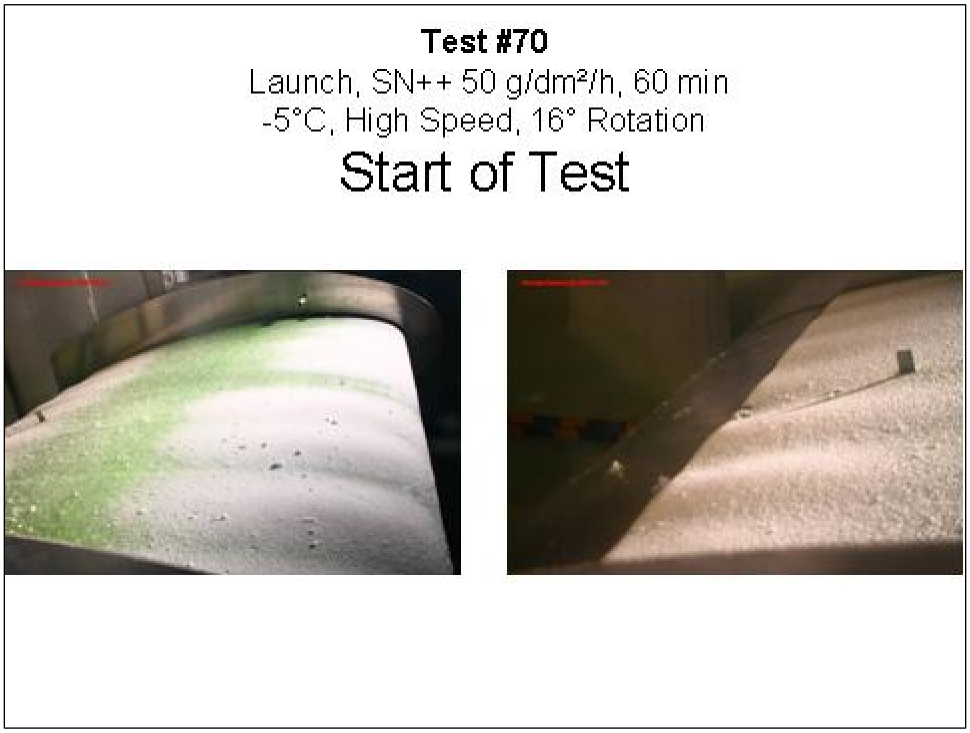

Photo 9.14: Test #70 – Before Rotation

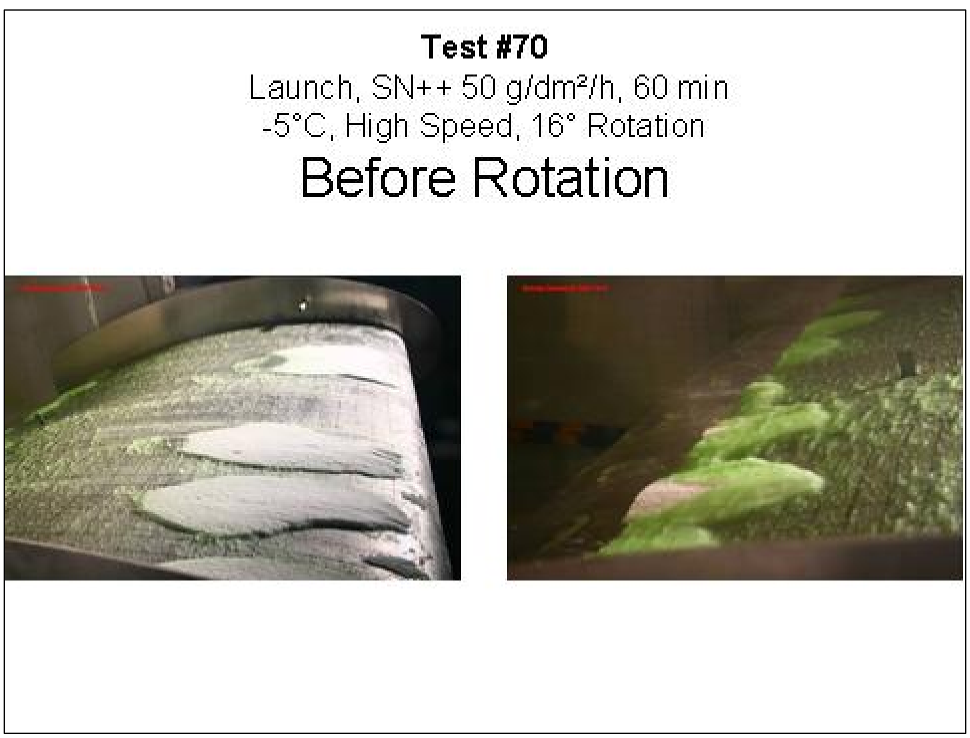

Photo 9.15: Test #70 – End of Rotation

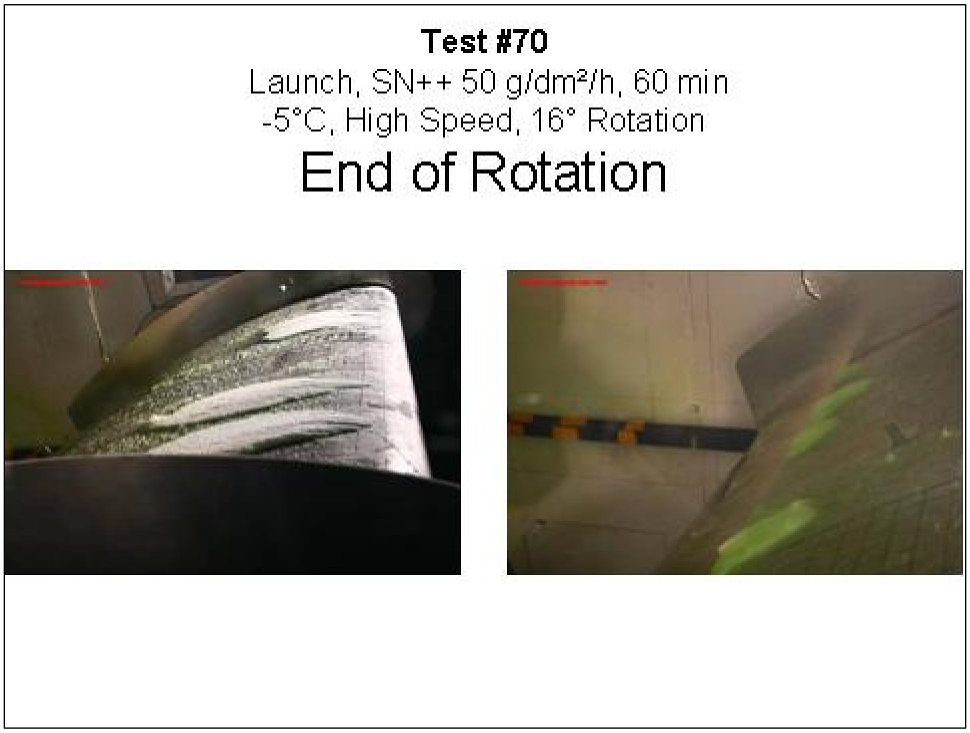

Photo 9.16: Test #70 – End of Test

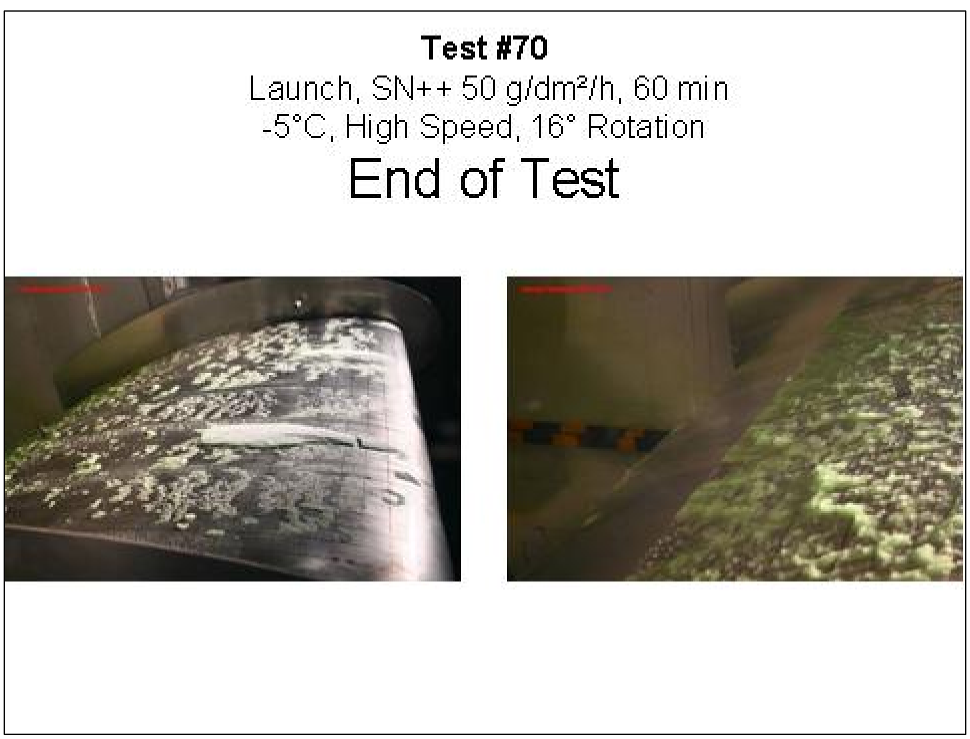

Photo 9.17: Test #71 – Start of Test

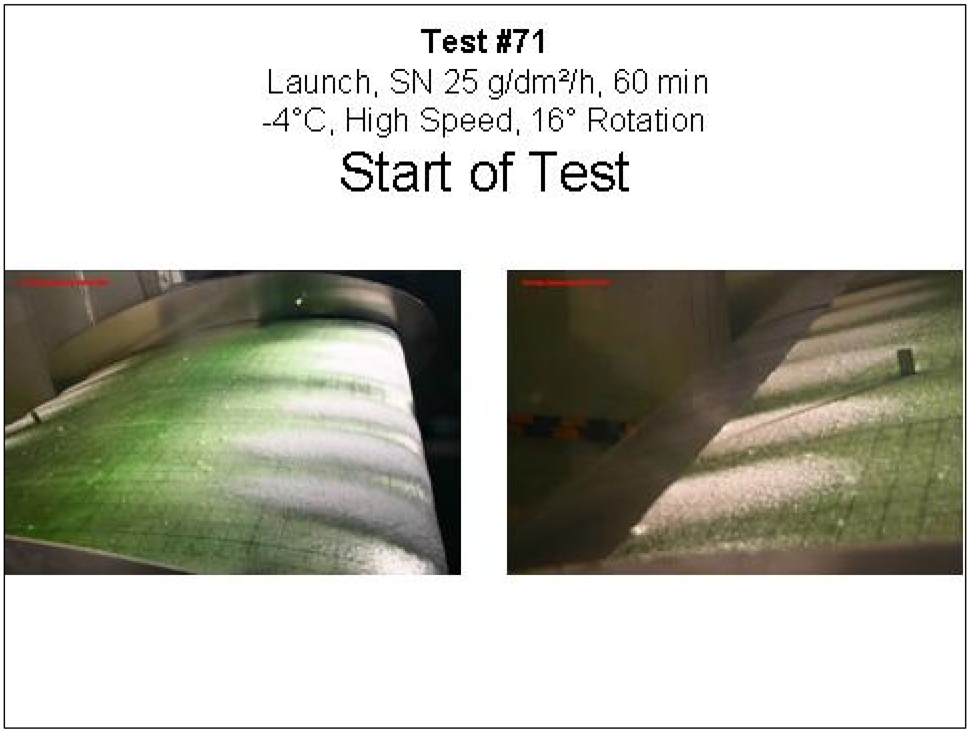

Photo 9.18: Test #71 – Before Rotation

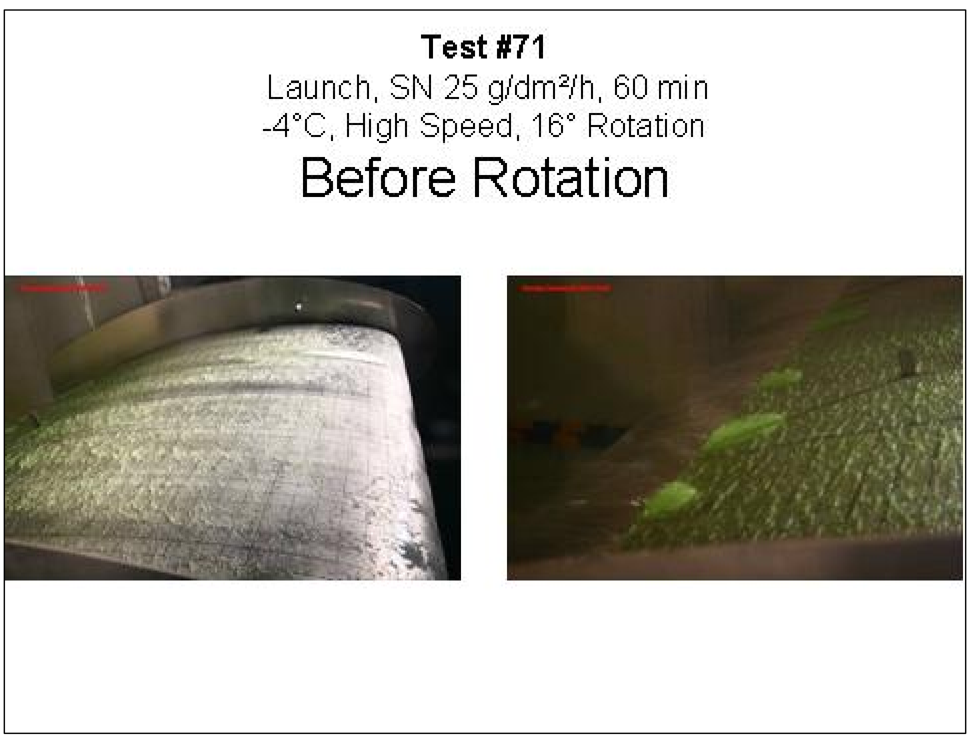

Photo 9.19: Test #71 – End of Rotation

Photo 9.20: Test #71 – End of Test

10. CONCLUSIONS AND OBSERVATIONS

These observations and conclusions were derived from the testing conducted during the winter of 2008-09.

10.1 Effects of Surface Roughness

When comparing bare wing versus contaminated wing (with no fluid), the results indicated that as the angle of rotation is increased, the difference in the lift coefficient data is also increased. The percentage lift loss increased from four percent to 10 percent as the maximum angle of rotation increased from 8º to 16º.

The testing conducted demonstrated varying aerodynamic effects as a result of the type of contamination adhered to the wing section. Results indicated that the smooth surface created by the freezing rain actually helped improve the aerodynamic properties of the wing by smoothing out imperfections from rivets, wing skin junctions, and other imperfections of the wing. During mixed precipitation tests, the freezing rain appeared to help reduce adverse aerodynamic effects from other rougher precipitation types such as snow and ice pellets.

During one test run, an early wing stall was experienced, indicating that although favourable aerodynamic results were achieved in the shallow angles of attack, the stall angle was significantly reduced due to the contamination. During this test, ice pellets were applied by hand directly to the leading edge stagnation point and adhered, which is likely to have led to the results obtained.

10.2 Light Snow Mixed with Light Rain

10.2.1 Light Snow Mixed with Light Rain

The Type IV results demonstrated positive visual contamination ratings, as well as good lift coefficient results. This test supported the flat plate testing results recommending the use of light freezing rain HOTs for conditions of mixed light snow and light rain.

Results from comparative Type I testing were inconclusive due to slush formation during the takeoff run (a result of the outside and inside temperature differentials); however, the visual condition of the wing at the end of the precipitation period was similar for both light rain mixed with light snow and for light freezing rain. In addition, similar lift coefficient data was recorded for both tests, again indicating potential similarities in the two conditions.

10.2.2 Moderate Snow Mixed with Light Freezing Rain

The Type IV testing demonstrated that at the time of rotation, most of the contamination was eliminated; however, some contamination remained adhered on the leading edge (aft of the stagnation point). Although the results were inconclusive due to the formation of the adhered contamination during takeoff runs (a result of the outside and inside temperature differentials), the results indicate a potential for guidance material in mixed light freezing rain and moderate snow conditions.

10.3 Inadequate Anti-Icing Fluid Application

The results demonstrated that although a minimal amount of Type IV anti-icing fluid was applied (to simulate an inadequate application), the visual appearance of the fluid did not seem significantly different compared to the typical proper fluid application. In all cases tested, the inadequate fluid application generated shorter protection times. In all but one case tested (ice pellets only), the inadequate fluid application test section demonstrated poor fluid elimination at the time of rotation. Generally, the addition of freezing rain made the thin fluid layer susceptible to fluid adherence, and the resulting contamination was not removed at the time of rotation. The results indicate that the inadequate fluid application will generate a visually more severe condition following precipitation; however, the severity of these scenarios is dependent on the type of precipitation and relates primarily to the potential for adhered contamination.

10.4 Frost Fluid Freezing Point Failure

The results from the wind tunnel tests demonstrated crystalline formations similar to those observed with the white-painted, insulated aluminum plates. Although the contamination did not seem to adhere during the plate tests, the wind tunnel tests demonstrated that the contamination was not removed by the time of rotation and that the level of contamination worsened by the end of the test. However, during a typical frost operation, the wing skin temperature would be warmed during taxi and takeoff (rather than cooled as in the wind tunnel), and the results may potentially be less severe.

10.5 Low-Speed Ramp Testing

The results indicate that increasing the aerodynamic acceptance test speed profile from the 67 knots rotation to the 80 knots 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, however, be noted that these tests were conducted with no contamination; therefore, fluid elimination could potentially be further hampered by the presence of solid or adhered contamination.

10.6 Heavy Snow

The results indicate that, visually, moderate snow HOTs are not applicable for heavy snow conditions. From a visual perspective, the heavy snow HOT should be approximately half the moderate snow HOT (or relative to the cumulative amount of precipitation applied) in order to have similar visual end conditions. The lift coefficient results indicate that there was little difference in the aerodynamic performance when comparing a moderate snow test to a heavy snow test with either half or equivalent endurance time. The aerodynamic performance of the PG fluid was worse compared to the EG fluid in both moderate and heavy snow conditions. The results from the 2008-09 heavy snow testing were in accordance with the preliminary results obtained during the 2006-07 wind tunnel tests.

10.7 Type I Ice Pellet Allowance Times

Due to procedural limitations, the protocol employed was not representative of typical operations. It is recommended that additional work be conducted during the winter of 2009-10 as a low priority objective.

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11. RECOMMENDATIONS

The following recommendations were compiled based on the work conducted during the winter of 2008-09.

11.1 Wind Tunnel Testing Methodology

It is recommended that for future wind tunnel testing, the simulated takeoff profile should target the clean wing stall angle as the maximum angle of attack in order to better quantify the observed lift losses. When analysing the data for "Allowance Time" or other ground icing applications, evaluation of the lift results should be conducted at an angle approximately halfway between the typical angle of attack at rotation and the stall angle (these angles should be recommended by the airframe manufacturer). In addition, during contaminated test runs, a baseline fluid only case should be run immediately before or after the contaminated test run to provide a direct correlation of the results.

11.2 Future Work

11.2.1 Effects of Surface Roughness

The current generation of "regional jet" aircrafts is developed with supercritical wing design and requires maintenance procedures to ensure a polished leading edge, as minimal amounts of contamination (in the form of bugs, etc.) can result in serious aerodynamic penalties. The same applies for the removal of contamination in the form of frozen precipitation. Due to the popularity of these aircraft, it is recommended that aerodynamic research be conducted to investigate the effects of adhered frozen contamination on a supercritical wing model.

11.2.2 Mixed Light Freezing Rain and Moderate Snow

Preliminary results were inconclusive due to procedural complications; however, the results indicate a potential for guidance material in mixed light freezing rain and moderate snow conditions. Further work is required to develop these preliminary results obtained.

11.2.3 Low-Speed Ramp Testing

The 2008-09 testing was conducted with no contamination; fluid elimination could potentially be further hampered with the presence of solid or adhered contamination. Additional testing is recommended to investigate the effects of contamination during low-speed ramp test profiles.

11.2.4 Heavy Snow

It is recommended that additional testing be performed, in conjunction with flat plate testing, in order to determine a visually acceptable level of heavy snow contamination, followed by an aerodynamic validation of the flat plate results obtained. Testing should be conducted with several PG fluids, as this appears to be the more stringent fluid aerodynamically. The comparative methodology (heavy snow versus moderate snow) should be continued; however, a baseline “fluid only” test should also be conducted with each group of tests in order to provide a better understanding of the results obtained.

REFERENCES

1. 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.

2. Myron, O., Penna, P., *Air-Flap Performance with De-Anti-Icing Fluids and Freezing Precipitation,* National Research Council Canada, Transportation Development Centre, Ottawa, May 1999, TP 13426E, 14.

3. Penna P.J., Su, J.C., Syms, G.F.*, Experimental and Numerical Studies of the Effects of Upper Surface Roughness on Aileron Performance,* National Research Council Canada, Transportation Development Centre, Ottawa, November 2003, TP 14180E, 38.

4. APS Aviation Inc., *Aircraft Ground Icing General Research Activities During the 2008-09 Winter*, APS Aviation Inc., Transportation Development Centre, Montreal, December 2009, TP 14936E, XX (to be published).

5. Ruggi, M., *Substantiation of Aircraft Ground Deicing Holdover Times in Frost Conditions,* APS Aviation Inc., Transportation Development Centre, Montreal, October 2009, TP 14938E, 120.

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APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT –
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2008-09

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT –
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2008-09

4.3 AIRCRAFT PERFORMANCE RESEARCH

4.3.2 Wind Tunnel Research to Evaluate Aerodynamic Failures

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

b) Perform wind tunnel tests to compare flat plate fluid failure to aerodynamic failure;

c) Work in conjunction with TDC to conduct roughness analysis of a wing surface as it pertains to lift loss;

d) Investigate aerodynamic effects of simulated frost conditions on de/anti-icing fluids, simulated snow pellet conditions on de/anti-icing fluids, 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

CM2169.001

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

Winter 2008-09

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Marco Ruggi

Reviewed by: John D'Avirro

APS Aviation Inc.

February 23, 2009
Final Version 1.2

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, 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-takeoff contamination check. This protocol was feasible for common air carrier aircraft that provide 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, UPS aircraft in Louisville were grounded for several hours due to extended ice pellet conditions. Due to cargo aircraft configuration, pre-takeoff contamination checks by the on-board crew were not possible. Fed-Ex had been faced with similar problems in Memphis.

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. In 2005, aerodynamic and endurance time testing were conducted in simulated ice pellet conditions. Based on the preliminary data, an allowance of 20 minutes in light ice pellet conditions was proposed.

During the winter of 2006-07, the FAA provided a 25-minute allowance as a preliminary guideline; Transport Canada (TC) remained status quo. This allowance was based on the previous research conducted during the winter of 2005-06, primarily as a result of Falcon 20 aerodynamic research; these results were presented at the Society of Automotive Engineers (SAE) meeting in Lisbon in May 2006. To address the option of a pre-takeoff contamination check, the 20-minute proposed allowance was extended to 25 minutes; pre-takeoff contamination checks would no longer apply. This allowance was followed by a list of conditions; one restriction was that operations would be limited to conditions of ice pellets alone (no mixed conditions).

Due to the high frequency of ice pellets occurring in combination 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, TC and the FAA provided allowance time guidance material for operations in mixed conditions with ice pellets. These allowance times were based on the research that was conducted during the winter of 2006-07. The recommended allowance times were based on aerodynamic research conducted using the National Research Council (NRC) Open Circuit Wind Tunnel 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.

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. In addition, guidance material for low rotation speed aircraft was also required. Additional endurance time testing and aerodynamic research were conducted in simulated mixed ice pellet conditions during the winter of 2007-08; these results were presented at the SAE meeting in Warsaw in May 2008. Testing was conducted using the NRC Falcon 20 and T-33 aircraft; the wind tunnel was not available for testing during the winter of 2007-08. It was recommended that further work be conducted in the wind tunnel prior to modifying the current ice pellet allowance times due the lack of aerodynamic lift data; no changes were made to the allowance time guidelines for the winter of 2008-09.

Tests were conducted at the NRC Wind Tunnel over a three week period in January and February of 2009 using a previous version of this procedure (Version 1.0). This updated procedure Version 1.2 will be used for the second round of tests that will be done starting February 23, 2009. Changes to the procedure to improve the data collection process and these changes were minor. Additional tests were added to the test plan after the analysis of the data collected in the first session.

2. OBJECTIVES

The objective of this testing is to conduct aerodynamic testing to:

- Expand the current allowance times to include guidance for:
  - IP/SN conditions below -5°C;
  - Low rotation speed aircraft; and
  - Type II and Type III fluids.
- Validate the current allowance times.

As lower priority objectives, testing will be conducted to:

- Investigate wing surface roughness and how it pertains to lift loss; and
- Investigate the aerodynamic effects of:
    - Failed anti-icing fluid in frost conditions;
    - Anti-icing fluid exposed to simulated snow pellet conditions;
    - Reduced Type I endurance times on composite surfaces; and
    - Inadequate anti-icing application.

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 NASA LS(1)-0417 wing section (Figure 2.1) will be subjected to a series of tests in the NRC wind tunnel. This wing section was used during previous NRC tests (see TC reports *"Airfoil-Flap Performance with De/AntiIcing Fluids and Freezing Precipitation"* TP13426E and *"Experimental and Numerical Studies of the Effects of Upper Surface Roughness on Aileron Performance"* TP14180E).

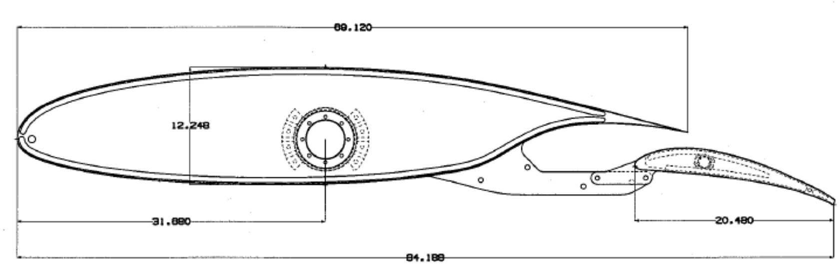


Figure 2.1: NASA LS(1)-0417 Wing Section

The tentative dates for the first session of testing are January 15th to February 6, 2009. An additional testing session is currently scheduled for February 23rd to March 10th, 2009; a decision to proceed with the additional testing, and the total number of expected days of testing, will be made following the end of the first test session.

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. 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.

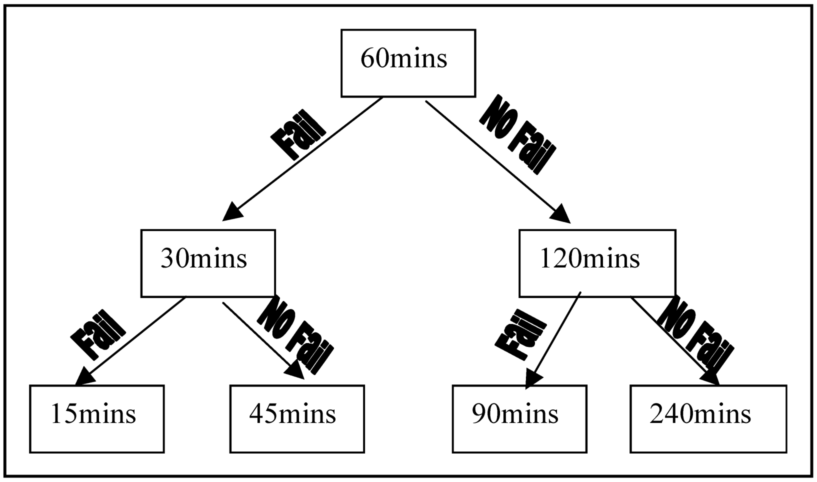


Figure 3.1: Decision Matrix for Each Test Series

Table 3.1: Preliminary Test Calendar

Week	Monday	Tuesday	Wednesday	Thursday	Friday
Setup and Cali				**Setup**	**ZR, S, S++, SP, and IP Dispensing Calibration** Confirm rates
1	**-5ºC** **Baseline Testing** Dry and fluid Only Priority 1	**-25ºC** **Baseline Testing** Dry and fluid Only Priority 1	**-5ºC** **IP Expansion** SN and IP Priority 1	**-10ºC** **IP Expansion** SN and IP Priority 1	**-25ºC** **IP Expansion** SN and IP Priority 1
2	**-5ºC** **Low Speed 80 Knots** SN and IP / ZR and IP Priority 1	**-10ºC** **Low Speed 80 Knots** SN and IP / ZR and IP Priority 1	**-25ºC** **Low Speed 80 Knots** SN and IP Priority 1	**-5ºC** **IP Validation** IP, IP-, ZR/IP, S/IP Priority 2	**-10ºC** **IP Validation** IP, IP-, ZR/IP, S/IP Priority 2
3	**-25ºC** **IP Validation** IP, IP-, S/IP Priority 2	**< -5ºC** **Heavy Snow** **Snow** Priority 2	**< -5ºC** **Heavy Snow** **Snow** Priority 2	**< -5ºC** **Surface Roughness** Sand Paper Tests Priority 3	**-14ºC** **Frost** Priority 3
4	**-25ºC** **Frost** Priority 3	**< -5ºC** **Composite Type I** Priority 3	**< -5ºC** **Composite Type I** Priority 3	**< -5ºC** **Degraded / Bad Application Fluid** Priority 3	**< -5ºC** **Surface Roughness vs. Aero Failure (Sand Paper)** Priority 3
5	**< -5ºC** **Snow Pellets** Priority 3	**< -5ºC** **Snow Pellets** Priority 3	**< -5ºC** **Rain and Snow** Priority 3	**< -5ºC** **IP and Mod Rain** Priority 3	**TEAR DOWN**

Table 3.2: Proposed Test Plan

Test #'s	Test Plan #	Objective	Priority	Test Condition	Speed Profile	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 (s/kts)
1	P1	Baseline	done	Dry	High	None	-	-	-	-	-	-5	25/100
27, 27A	P2	Baseline	done	Fluid Only	High	EG 106	-	-	-	-	-	-5	25/100
3, 17	P3	Baseline	done	Fluid Only	High	ABC-S Plus	-	-	-	-	-	-5	25/100
19	P4	Baseline	done	Fluid Only	High	Launch	-	-	-	-	-	-5	25/100
55, 56	P5	Baseline	done	Fluid Only	High	Flight	-	-	-	-	-	-5	25/100
2	P6	Baseline	done	Dry	Low	None	-	-	-	-	-	-5	17/80
28	P7	Baseline	done	Fluid Only	Low	EG 106	-	-	-	-	-	-5	17/80
4, 18	P8	Baseline	done	Fluid Only	Low	ABC-S Plus	-	-	-	-	-	-5	17/80
	P9	Baseline	1	Fluid Only	Low	Launch	-	-	-	-	-	-5	17/80
24	P10	Baseline	done	Fluid Only	Low	Flight	-	-	-	-	-	-5	17/80
15	P11	Baseline	done	Fluid Only	Low	2031	-	-	-	-	-	-5	17/80
5	P12	Baseline	done	Dry	High	None	-	-	-	-	-	-25	25/100
	P13	Baseline	1	Fluid Only	High	EG 106	-	-	-	-	-	-25	25/100
7	P14	Baseline	done/ redo?	Fluid Only	High	ABC-S Plus	-	-	-	-	-	-25	25/100
	P15	Baseline	1	Fluid Only	High	Launch	-	-	-	-	-	-25	25/100
	P16	Baseline	1	Fluid Only	High	Flight	-	-	-	-	-	-25	25/100
6	P17	Baseline	done	Dry	Low	None	-	-	-	-	-	-25	17/80
	P18	Baseline	1	Fluid Only	Low	EG 106	-	-	-	-	-	-25	17/80
	P19	Baseline	1	Fluid Only	Low	ABC-S Plus	-	-	-	-	-	-25	17/80

Table 3.2: Proposed Test Plan (cont'd)

Test #'s	Test Plan #	Objective	Priority	Test Condition	Speed Profile	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 (ºC)	Ramp (s/kts)
	P20	Baseline	1	Fluid Only	Low	Launch	-	-	-	-	-	-25	17/80
	P21	Baseline	1	Fluid Only	Low	Flight	-	-	-	-	-	-25	17/80
	P22	Baseline	1	Fluid Only	Low	2031	-	-	-	-	-	-25	17/80
11, 54	P23	IP Expansion	done	IP/SN	High	ABC-S Plus	25	25	-	-	25	-5	25/100
52	P24	IP Expansion	done	IP/SN	High	EG 106	25	25	-	-	25	-5	25/100
13, 58	P25	IP Expansion	done	IP/SN	High	Launch	25	25	-	-	25	-5	25/100
8, 9	P26	IP Expansion	done	IP/SN	High	ABC-S Plus	25	25	-	-	10	-10	25/100
44	P27	IP Expansion	done	IP/SN	High	EG 106	25	25	-	-	10	-10	25/100
10	P28	IP Expansion	done	IP/SN	High	Launch	25	25	-	-	10	-10	25/100
	P29	IP Expansion	3	IP/SN	High	ABC-S Plus	25	25	-	-	10	-25	25/100
	P30	IP Expansion	3	IP/SN	High	EG 106	25	25	-	-	10	-25	25/100
	P31	IP Expansion	3	IP/SN	High	Launch	25	25	-	-	10	-25	25/100
31, 52	P32	Low Speed	done	IP/SN	Low	EG 106	25	25	-	-	25	-5	17/80
12, 53	P33	Low Speed	done	IP/SN	Low	ABC-S Plus	25	25	-	-	25	-5	17/80
22	P34	Low Speed	done	IP/ZR	Low	Launch	25	-	25	-	25	-5	17/80
23	P35	Low Speed	done	IP/ZR	Low	Flight	25	-	25	-	25	-5	17/80
14, 16, 57	P36	Type III	done	IP/SN	Low	2031	25	25	-	-	10	-5	17/80
26, 26A, 26B	P36R	Type III	done/ redo?	IP/ZR	Low	2031	25	-	25	-	25	-5	17/80
43	P37	Low Speed	done	IP/SN	Low	EG 106	25	25	-	-	10	-10	17/80

Table 3.2: Proposed Test Plan (cont'd)

Test #'s	Test Plan #	Objective	Priority	Test Condition	Speed Profile	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 (s/kts)
45	P38	Low Speed	done	IP/SN	Low	ABC-S Plus	25	25	-	-	10	-10	17/80
59	P39	Low Speed	done	IP/ZR	Low	Launch	25	-	25	-	10	-10	17/80
60	P40	Low Speed	done	IP/ZR	Low	Flight	25	-	25	-	10	-10	17/80
47	P41A	Type III	done	IP/SN	Low	2031	25	25	-	-	10	-10	17/80
48	P41	Type III	done	IP/SN	Low	2031	25	25	-	-	5	-10	17/80
	P42	Low Speed	3	IP/SN	Low	EG 106	25	25	-	-	10	-25	17/80
	P43	Low Speed	3	IP/SN	Low	ABC-S Plus	25	25	-	-	10	-25	17/80
	P44	Low Speed	3	IP/SN	Low	Launch	25	25	-	-	10	-25	17/80
21	P45	IP Validation	done	IP-	High	ABC-S Plus	25	-	-	-	50	-5	25/100
20	P46	IP Validation	done	IP Mod	High	ABC-S Plus	75	-	-	-	25	-5	25/100
30	P47	IP Validation	done	IP-	High	EG 106	25	-	-	-	50	-5	25/100
29	P48	IP Validation	done	IP Mod	High	EG 106	75	-	-	-	25	-5	25/100
25	P49R	IP Val/ Low Speed	done	ZR/IP	Low	ABC-S Plus	25	-	25	-	25	-5	17/80
33	P50	IP Val/ Low Speed	done	ZR/IP	Low	EG106	25	-	25	-	25	-5	17/80
65	P51	IP Validation	done	ZR/IP	High	ABC-S Plus	25	-	25	-	10	-10	25/100
64	P52	IP Validation	done	ZR/IP	High	EG106	25	-	25	-	10	-10	25/100
66	P53	IP Validation	done	IP-	High	Launch	25	-	-	-	30	-25	25/100
67	P54	IP Validation	done	IP Mod	High	ABC-S Plus	75	-	-	-	10	-25	25/100
68	P55	IP Validation	done	IP-	High	EG 106	25	-	-	-	30	-25	25/100

Table 3.2: Proposed Test Plan (cont'd)

Test #'s	Test Plan #	Objective	Priority	Test Condition	Speed Profile	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 (s/kts)
69	P56	IP Validation	done	IP Mod	High	EG 106	75	-	-	-	10	-25	25/100
62	P57	Heavy Snow	done	S++	High	EG 106	-	50	-	-	20	-10	25/100
63	P57R	Heavy Snow	done	S++	High	EG 106	-	50	-	-	40	-10	25/100
61	P58	Heavy Snow	done	S	High	EG 106	-	25	-	-	40	-10	25/100
	P59	Heavy Snow	1	S++	High	ABC-S Plus	-	50	-	-	half of HOT	<-5	25/100
	P60	Heavy Snow	1	S	High	ABC-S Plus	-	25	-	-	See HOT	<-5	25/100
70	P61	Heavy Snow	done	S++	High	Launch	-	50	-	-	60	-10	25/100
71	P62	Heavy Snow	done	S	High	Launch	-	25	-	-	60	-10	25/100
	P63	Heavy Snow	2	S++	High	Flight	-	50	-	-	half of HOT	<-5	25/100
	P64	Heavy Snow	2	S	High	Flight	-	25	-	-	See HOT	<-5	25/100
	P65	Frost	2	Frost	High	Flight	See Details in Procedure			-	until Failure	-25	25/100
	P66	Composite	2	ZR	High	Octaflo	-	-	25	-	See HOT	<-5	25/100
32	P67	Bad Application	done/ redo?	IP	High	One Step Type IV	25	-		-	25	< -5	25/100
	P68	Snow Pellets	2	SP and S	High	Diluted TIV	See Details in Procedure			-	See HOT	<-5	25/100
50	P69	Rain & Snow	done	R/SN	High	Type IV	-	25	-	25	60	>-5	25/100
51	P70	IP & Mod Rain	done	IP/R	High	Type IV	25	-	-	75	25	>-5	25/100
34, 34A	PRO1	Roughness	done	Dry	Low	None	-	-	-	-	-	-5	17/80
35	PRO2	Roughness	done	Dry	Low	None	-	-	-	-	-	-5	17/80
36	PRO3	Roughness	done	IP/ZR	Low	None	10.5	-	25.5	-	12	-5	17/80

Table 3.2: Proposed Test Plan (cont'd)

Test #'s	Test Plan #	Objective	Priority	Test Condition	Speed Profile	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 (s/kts)
37	PRO4	Roughness	done	IP/ZR	Low	None	10.5	-	25.5	-	12	-5	17/80
38	PRO5	Roughness	done	IP/ZR	Low	None	10.5	-	25.5	-	12	-5	17/80
39	PRO6	Roughness	done	IP/ZR	Low	None	10.5	-	25.5	-	12	-5	17/80
40	PRO7	Roughness	done	Dry	Low	None	-	-	-	-	-	-5	17/80
41	PRO8	Roughness	done	Dry	Low	None	-	-	-	-	-	-5	17/80
42	PE1	Baseline	done	Dry	Low	EG 106	-	-	-	-	-	-10	17/80
46	PE2	Baseline	done	Dry	High	ABC-S Plus	-	-	-	-	-	-10	25/100
49	PE3	Baseline	done	Dry	Low	2031	-	-	-	-	-	-10	17/80
72, 72R	PE4	ZR/SN	done	ZR/S	High	Launch	-	25	25	-	30	-10	25/100
	P53R	IP Validation	3	IP-	High	Type IV PG	25	-	-	-	30	-25	25/100
	P54R	IP Validation	2	IP Mod	High	ABC-S Plus	75	-	-	-	10	-25	25/100
	P70R	IP & Mod Rain	1	IP/R	High	Type IV PG	25	-	-	75	25	>-5	25/100
	P70R2	IP & Mod Rain	1	IP/R	High	EG 106	25	-	-	75	25	>-5	25/100
	P23R	IP Expansion	2	IP/SN-	High	ABC-S Plus	25	10	-	-	40	-5	25/100
	P24R	IP Expansion	2	IP/SN-	High	EG 106	25	10	-	-	40	-5	25/100
	P25R	IP Expansion	2	IP/SN-	High	Launch	25	10	-	-	40	-5	25/100
	P26R	IP Expansion	1	IP/SN-	High	ABC-S Plus	25	10	-	-	10	-10	25/100
	P27R	IP Expansion	1	IP/SN-	High	EG 106	25	10	-	-	10	-10	25/100
	P28R	IP Expansion	1	IP/SN-	High	Launch	25	10	-	-	10	-10	25/100

Table 3.2: Proposed Test Plan (cont'd)

Test #'s	Test Plan #	Objective	Priority	Test Condition	Speed Profile	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 (ºC)	Ramp (s/kts)
	P29R	IP Expansion	1	IP/SN-	High	ABC-S Plus	25	10	-	-	10	-25	25/100
	P30R	IP Expansion	1	IP/SN-	High	EG 106	25	10	-	-	10	-25	25/100
	P31R	IP Expansion	1	IP/SN-	High	Launch	25	10	-	-	10	-25	25/100
	PE5	Type III	1	ZR/IP	Low	2031	25	-	25	-	10	-5	17/80
	PE6	Type III	1	ZR/IP	Low	2031	25	-	25	-	5	-10	17/80
	PE7	Type III	2	IP Mod	Low	2031	75	-	-	-	5	-5	17/80
	PE8	Type III	2	IP Mod	Low	2031	75	-	-	-	5	-10	17/80
	PE9	Type III	2	IP Mod	Low	2031	75	-	-	-	5	-25	17/80
	PE10	Type III	2	IP-	Low	2031	25	-	-	-	20	-5	17/80
	PE11	Type III	2	IP-	Low	2031	25	-	-	-	10	-10	17/80
	PE12	Type III	2	IP-	Low	2031	25	-	-	-	10	-25	17/80
	PE13	Type III	1	IP/SN	Low	2031	25	25	-	-	5	-25	17/80
	PE14	Type III	2	IP/SN-	Low	2031	25	10	-	-	20	-5	17/80
	PE15	Type III	2	IP/SN-	Low	2031	25	10	-	-	10	-10	17/80
	PE16	Type III	2	IP/SN-	Low	2031	25	10	-	-	10	-25	17/80
	PE17	Type III	3	ZR/IP	High	2031	25	-	25	-	10	-5	25/100
	PE18	Type III	3	ZR/IP	High	2031	25	-	25	-	5	-10	25/100
	PE19	Type III	3	IP Mod	High	2031	75	-	-	-	5	-5	25/100
	PE20	Type III	3	IP Mod	High	2031	75	-	-	-	5	-10	25/100

Table 3.2: Proposed Test Plan (cont'd)

Test #'s	Test Plan #	Objective	Priority	Test Condition	Speed Profile	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 (s/kts)
	PE21	Type III	3	IP Mod	High	2031	75	-	-	-	5	-25	25/100
	PE22	Type III	3	IP-	High	2031	25	-	-	-	20	-5	25/100
	PE23	Type III	3	IP-	High	2031	25	-	-	-	10	-10	25/100
	PE24	Type III	3	IP-	High	2031	25	-	-	-	10	-25	25/100
	PE25	Type III	3	IP/SN	High	2031	25	25	-	-	5	-25	25/100
	P36R	Type III	3	IP/SN	High	2031	25	25	-	-	10	-5	25/100
	P41R	Type III	3	IP/SN	High	2031	25	25	-	-	5	-10	25/100
	PE26	Type III	3	IP/SN-	High	2031	25	10	-	-	20	-5	25/100
	PE27	Type III	3	IP/SN-	High	2031	25	10	-	-	10	-10	25/100
	PE28	Type III	3	IP/SN-	High	2031	25	10	-	-	10	-25	25/100
	P38R	Low Speed	2	IP/SN	Low	ABC-S Plus	25	25	-	-	10	-10	17/80
	P40R	Low Speed	2	IP/ZR	Low	Flight	25	-	25	-	10	-10	17/80
	PE29	Low Speed	1	IP-	High	ABC-S Plus	25	-	-	-	50	-5	17/80
	PE30	Low Speed	1	IP Mod	High	ABC-S Plus	75	-	-	-	25	-5	17/80
	PE31	Low Speed	1	IP-	High	EG 106	25	-	-	-	50	-5	17/80
	PE32	Low Speed	1	IP Mod	High	EG 106	75	-	-	-	25	-5	17/80
	PE33	Low Speed	1	IP-	High	Launch	25	-	-	-	30	-25	17/80
	PE34	Low Speed	1	IP Mod	High	ABC-S Plus	75	-	-	-	10	-25	17/80
	PE35	Low Speed	1	IP-	High	EG 106	25	-	-	-	30	-25	17/80

Table 3.2: Proposed Test Plan (cont'd)

Test #'s	Test Plan #	Objective	Priority	Test Condition	Speed Profile	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 (ºC)	Ramp (s/kts)
	PE36	Low Speed	1	IP Mod	High	EG 106	75	-	-	-	10	-25	17/80
	P33R	Low Speed	2	IP/SN	Low	ABC-S Plus	25	25	-	-	15-20	-5	17/80
	P61R	Heavy Snow	2	S++	High	Launch	-	50	-	-	30	-10	25/100
	P69R	Rain & Snow	2	R/SN	High	Type I	-	15	-	15	4	>-5	25/100
	PE37	Low Low Speed	1	Fluid Only	Low Low	Type IV PG	-	-	-	-	-	<-5	14/65
	PE38	Low Low Speed	1	Fluid Only	Low	Type IV PG or previous test	-	-	-	-	-	<-5	17/80
	P67R / PE4R	Bad Application	1	ZR/S/IP	High	One Step Type IV	15	15	25	-	25	<-5	25/100
	PE39	Bad Application	2	ZR/S/IP	High	Two Step I&IV	15	15	25	-	25	<-5	25/100
	PE39	Bad Application	1	ZR	High	Thin Type IV			25	-	See HOT	<-5	25/100
	PE40	Bad Application	2	ZR	High	One Step Type IV (good app)			25	-	See HOT	<-5	25/100
	PRO9	Roughness (20º)	2	ZR/IP	Low	None	10	-	25	-	15	<-5	17/80
	PRO10	Roughness (20º)	2	Dry	Low	None	10	-	25	-	15	<-5	17/80

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 - March 2009 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; 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 and properly dispose of the fluid upon return to Montreal.

6.9 Camera Setup

A new window has been installed in the tunnel on the control room side. It is anticipated that that both the cameras will be positioned in the new window on the control room side, along with the flashes. A comparison dry run test with the old setup (cameras opposite to control room side) will be conducted to verify that photo results from both setups are comparable and that the new setup is satisfactory.

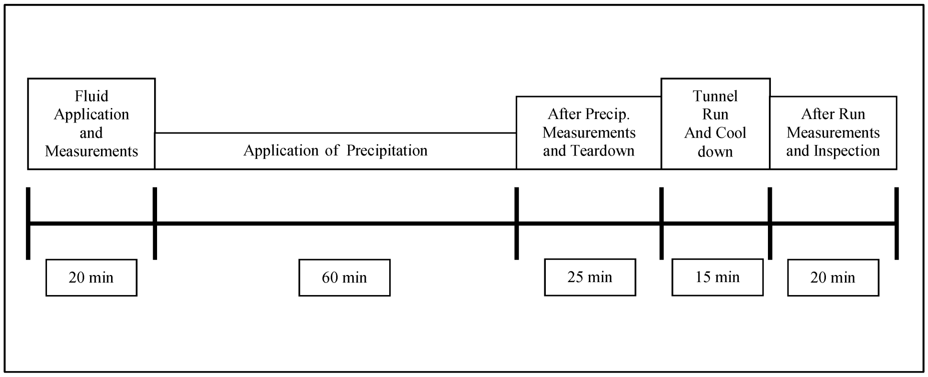
6.10 Demonstration of a Typical Wind Tunnel Test Sequence

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. - Photograph test area.
8:20:00	- Pour fluid over test area.
8:30:00	- Measure Brix, thickness, wing temperature. - Photograph test area.
8:35:00	- Apply contamination over test area. (i.e. 30 min)
9:05:00	- Measure Brix, thickness, wing temperature. - Photograph test area.
9:10:00	- Clear area and start wind tunnel
9:25:00	- Wind tunnel stopped
9:35:00	- Measure Brix, thickness, wing temperature. - Photograph test area. - Record test observations
9:45:00	END OF TEST

Figure 6.1: Typical Wind Tunnel Run Timeline



6.11 Procedures for R&D Activities

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

1. Investigate wing surface roughness and how it pertains to lift loss (Attachment XVIII);
2. Investigate aerodynamic effects of failed anti-icing fluid in frost conditions (Attachment XIX);
3. Investigate aerodynamic effects of anti-icing fluid exposed to simulated snow pellet conditions (Attachment XX);
4. Investigate aerodynamic effects of reduced Type I endurance times on composite surfaces conditions (Attachment XXI); and
5. Investigate aerodynamic effects of inadequate anti-icing application conditions (Attachment XXII).

As these full-scale R&D activities have 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
General Support Equipment	
Large tape measure	
Fluids (ORDER and SHIP to Ottawa)	
Horse and tap for fluid barrel x 2	
Funnels	
Sample bottles for viscosity measurement	
Squeegees	
Isopropyl	
Gloves, paper towel	
Extension cords	
Clipboards, pencils, wing markers for sample locations and solvent	
Large Clock x1	
Printer, printer paper, and ink cartridge	
Walkie Talkies x7	
Envelopes and labels	
Previous 05-06, 06-07, and 07-08 F20/WT reports	
Grid Section + Location docs	
Preojector for laptop	
YOW employee contracts	
Blow Horns x4	
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 x6	
Ice pellets dispersers x6	
Stands for ice pellets dispensing devices x6	
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	
Small 90° aluminum ruler for wing	
Gas Containers for EG 106 fluid x5	
hard water chemicals	
Ice Pellets Fabrication Equipment	
Refrigerated Truck	
Ice pellets Styrofoam containers x20++	
Ice bags	
Ice bags storage freezer	
Blenders x6+	
Ice pellets sieves	
Folding tables	
Measuring cups	
Wooden Spoons	
Rubber Mats	
Freezing Rain Equipment	
NRC Freezing rain sprayer	
APS PC equiped with rate station software	
White plastic rate pans (100) wooden boards, and rubber suction cup feet	
Sartorius Wiegh Scale x1 + NCAR Scale x 1	
Black Shelving Unit	
Portable hard drive and memory card reader	

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 II Flight	II	100/0	Mid	180
Clariant MP III 2031	III	100/0	Mid	200
DOW UCAR EG 106	IV	100/0	Mid	600
Kilfrost ABC-S +	IV	100/0	Mid	600
Clariant MP IV Launch	IV	100/0	Mid	400

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. Two additional APS personnel will be onsite during the first week of testing for training purposes. Table 9.1 demonstrates the personnel required and their associated tasks.

Fluid and ice pellets applications will be performed by APS 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 and Manager / YOW Pers. Manager
Dave	Data Collection /IP Support / Fluid Application
Temporary for First Week	
Joey	IP Manager / Data Collection
Stephanie	Forms & Data / Fluid / YOW Personnel Manager
YOW People	
Ben	Photography
YOW 1	Fluids / IP / Dispensing
YOW 2	Fluids / IP / Dispensing
YOW 3	Fluids / IP / Dispensing
YOW 4	Fluids / IP / Dispensing

* Consider Ryan, Mike or Eric for YOW positions

NRC Institute of Aerospace Research

- Keith Hansen: (613) 993-2589
- Xing Zhong Huang: (613) 993-0165

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;
- If fluid comes into contact with skin, rinse hands under running water; and
- If fluid comes into contact with eyes, flush with the portable eye wash station.

ATTACHMENT I – Generic Type I Holdover Time Table

Transport Canada Holdover Time Guidelines **Winter 2008-2009**

TABLE 1

SAE TYPE I[3] FLUID HOLDOVER GUIDELINES FOR WINTER 2008-2009

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**	**Active Frost**	**Freezing Fog**	**Very Light**	**Light**	**Moderate**	**Freezing Drizzle[4]**	**Light Freezing Rain**	**Rain on Cold Soaked Wing**	**Other[2]**
-3 and above	27 and above	45	11 – 17	18	11 – 18	6 – 11	9 – 13	4 – 6	2 – 5	
below -3 to -6	below 27 to 21	45	8 – 13	14	8 – 14	5 – 8	5 – 9	4 – 6	CAUTION: No holdover time guidelines exist	
below -6 to -10	below 21 to 14	45	6 – 10	11	6 – 11	4 – 6	4 – 7	2 – 5		
below -10	below 14	45	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.

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 II – Clariant Safewing MP II Flight Type II Holdover Time Table

Transport Canada Holdover Time Guidelines **Winter 2008-2009**

TABLE 2-C-Flight

CLARIANT TYPE II FLUID HOLDOVER GUIDELINES FOR WINTER 2008-2009[1]
SAFEWING MP II FLIGHT

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**		**Active Frost**	**Freezing Fog**	**Snow or Snow Grains**	**Freezing Drizzle[4]**	**Light Freezing Rain**	**Rain on Cold Soaked Wing**	**Other[2]**
-3 and above	27 and above	100/0	8:00	3:30 – 4:00	1:00 – 1:35	1:20 – 2:00	0:45 – 1:25	0:10 – 1:30	CAUTION: No holdover time guidelines exist
		75/25	5:00	2:30 – 4:00	0:40 – 1:20	1:15 – 2:00	0:30 – 0:55	0:05 – 1:20	
		50/50	3:00[5]	0:55 – 1:45	0:10 – 0:25	0:20 – 0:30	0:10 – 0:15		
below -3 to -14	below 27 to 7	100/0	8:00[5]	0:55 – 1:45	0:40 – 1:05	0:35 – 1:30[3]	0:25 – 0:45[3]		
		75/25	5:00[5]	0:40 – 1:10	0:20 – 0:40	0:25 – 1:10[3]	0:30 – 0:40[3]		
below -14 to -25	below 7 to -13	100/0	8:00[5]	0:30 – 0:50	0:15 – 0:30				
below -25	below -13	100/0	Type II fluid may be used below -25°C (-13°F) provided the freezing point of the fluid is at least 7°C (13°F) below the outside air temperature and the aerodynamic acceptance criteria are met. Consider use of Type I when Type II fluid cannot be used.						

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 Radiational cooling during active frost conditions may reduce holdover times when operating close to the lower end of the outside air temperature range.

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 2008-2009

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

Outside Air Temperature[3]		Approximate Holdover Times Under Various Weather Conditions (minutes)									
					Snow or Snow Grains						
Degrees Celsius	Degrees Fahrenheit	Type III Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Active Frost	Freezing Fog	Very Light	Light	Moderate	Freezing Drizzle[1]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[2]
-3 and above	27 and above	100/0	120	20 – 40	35	20 – 35	10 – 20	10 – 20	8 – 10	6 – 20	
		75/25	60	15 – 30	25	15 – 25	8 – 15	8 – 15	6 – 10	2 – 10	
		50/50	30	10 – 20	15	8 – 15	4 – 8	5 – 9	4 – 6	CAUTION: No holdover time guidelines exist	
below -3 to -10	below 27 to 14	100/0	120	20 – 40	30	15 – 30	9 – 15	10 – 20	8 – 10		
		75/25	60	15 – 30	25	10 – 25	7 – 10	9 – 12	6 – 9		
below -10	below 14	100/0	120	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.

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.**

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

TABLE 4-D-E106

DOW CHEMICAL TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2008-2009[1]
UCAR™ ENDURANCE EG106

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

Outside Air Temperature		Type IV Fluid Concentration	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)						
Degrees Celsius	**Degrees Fahrenheit**	**Neat Fluid/Water** (Volume %/Volume %)	**Active Frost**	**Freezing Fog**	**Snow or Snow Grains**	**Freezing Drizzle[4]**	**Light Freezing Rain**	**Rain on Cold Soaked Wing**	**Other[2]**
-3 and above	27 and above	100/0	12:00	2:05 – 3:10	0:40 – 1:20	1:10 – 2:00	0:50 – 1:15	0:20 – 2:00	CAUTION: No holdover time guidelines exist
		75/25							
		50/50							
below -3 to -14	below 27 to 7	100/0	12:00[5]	1:50 – 3:20	0:30 – 1:05	0:55 – 1:50[3]	0:45 – 1:10[3]		
		75/25							
below -14 to -25	below 7 to -13	100/0	12:00[5]	0:30 – 1:05	0:15 – 0:30				
below -25	below -13	100/0	Type IV fluid may be used below -25°C (-13°F) provided the freezing point of the fluid is at least 7°C (13°F) below the outside air temperature and the aerodynamic acceptance criteria are met. Consider use of Type I when Type IV fluid cannot be used.						

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 Radiational cooling during active frost conditions may reduce holdover times when operating close to the lower end of the outside air temperature range.

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

TABLE 4-K-ABC-S PLUS

KILFROST TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2008-2009[1]
ABC-S PLUS

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

Outside Air Temperature		Type IV Fluid Concentration	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)						
Degrees Celsius	Degrees Fahrenheit	Neat Fluid/Water (Volume %/Volume %)	Active Frost	Freezing Fog	Snow or Snow Grains	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[2]
-3 and above	27 and above	100/0	12:00	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	5:00	1:25 – 2:40	0:45 – 1:15	1:00 – 1:20	0:30 – 0:50	0:10 – 1:20	
		50/50	3:00[5]	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	12:00[5]	0:55 – 3:30	1:00 – 1:45	0:25 – 1:35[3]	0:20 – 0:30[3]		
		75/25	5:00[5]	0:45 – 1:50	0:35 – 1:00	0:20 – 1:10[3]	0:15 – 0:25[3]		
below -14 to -25	below 7 to -13	100/0	12:00[5]	0:40 – 1:00	0:15 – 0:30				
below -25	below -13	100/0	Type IV fluid may be used below -25°C (-13°F) provided the freezing point of the fluid is at least 7°C (13°F) below the outside air temperature and the aerodynamic acceptance criteria are met. Consider use of Type I when Type IV fluid cannot be used.						

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 Radiational cooling during active frost conditions may reduce holdover times when operating close to the lower end of the outside air temperature range.

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

TABLE 4-C-Launch

CLARIANT TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2008-2009[1]
SAFEWING MP IV LAUNCH

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

Outside Air Temperature		Type IV Fluid Concentration	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)						
Degrees Celsius	Degrees Fahrenheit	Neat Fluid/Water (Volume %/Volume %)	Active Frost	Freezing Fog	Snow or Snow Grains	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[2]
-3 and above	27 and above	100/0	12:00	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	5:00	3:40 – 4:00	1:00 – 1:45	1:40 – 2:00	0:45 – 1:15	0:10 – 1:45	
		50/50	3:00[5]	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	12:00[5]	1:00 – 1:55	0:50 – 1:20	0:35 – 1:40[3]	0:25 – 0:45[3]		
		75/25	5:00[5]	0:40 – 1:20	0:45 – 1:25	0:25 – 1:10[3]	0:25 – 0:45[3]		
below -14 to -25	below 7 to -13	100/0	12:00[5]	0:30 – 0:50	0:15 – 0:30				
below -25	below -13	100/0	Type IV fluid may be used below -25°C (-13°F) provided the freezing point of the fluid is at least 7°C (13°F) below the outside air temperature and the aerodynamic acceptance criteria are met. Consider use of Type I when Type IV fluid cannot be used.						

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 Radiational cooling during active frost conditions may reduce holdover times when operating close to the lower end of the outside air temperature range.

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

ICE PELLET ALLOWANCE TIMES FOR WINTER 2008-2009

	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 Light or Moderate Snow	25 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 Preperation		
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	VZ	
7	Ensure proper functioning of ice pellet dispenser equipment;	JT/VZ/MR	
8	Ensure proper functioning of freezing rain sprayer equipment;	MR	
9	Prepare and arrange for transport of equipment to Ottawa;	DY/VZ	
10	Prepare Data forms and procedure	MP	
11	Finalize and complete list of equipment/materials required	MR/DY	
12	Arrange for freezer storage of ice pellets/snow/snow pellets.	DY	
13	Investigate IP/ZR/SN dispersal techniques and location	JT/VZ/MR	
	Wednesday Jan 14th		
14	Check with NRC the status of the testing site, tunnel etc	MR	
15	Check weather prior to establishing test dates	MR	
16	Arrange for hotel and transportation for personnel	MP/VZ	
17	Pack and leave YUL for YOW on Jan 14th	APS	
	Thursday Jan 15th		
18	Unload Truck	APS	
19	Setup rate station	DY	
20	Setup Projector	MP	
21	Setup printer	MP	
22	Setup IP/SN manufacturing material	JT/VZ	
23	Test and prepare IP dispensing equipment	JT/VZ	
24	Verify ZR sprayer installation	MR	
25	Ice and freezer delivery	DY	
26	Train IP making personnel	JT/VZ	
27	Conduct dry photography test of old vs. new camera positioning;	BG/MR	
28	Document new final camera and flash locations	VZ/BG	
29	Conduct falling ball tests on received fluids;	MP/DY/VZ	
30	Collect fluid samples for viscosity verification at APS office;	MP/DY/VZ	
31	Complete contract for YOW personnel	MP	
32	Mark wing data collection locations and draw grid on the wing (refer to Feasibility report for diagrams);	VZ/MR	
33	Co-ordinate fabrication of ice pellets/snow/snow pellets	JT/VZ	
34	Organize Fluid outside	MP/DY/YOW	
35	Transfer EG 106 and other drum fluids to pour gas containers	MP/DY/YOW	
	Friday Jan 16th		
36	ZR Calibration	DY/MP	
37	IP/SN Calibration	JT/VZ	
38	IP manufacturing	YOW's	
39	Dry Run of tests (APS / NRC)	APS/NRC	
	Perform Tests at NRC Test site		
40	Check with NRC the status of the testing site, tunnel etc	MR	
41	Check weather prior to establishing test dates	MR	
42	Arrange for hotel and transportation for personnel	MP/VZ	
43	Prepare equipment and fluid to be used for test	DY	
44	Manufacture ice pellets	VZ/YOW	
45	Arrange for photo doc. of the test	MR	
46	Prepare data forms for test	MP	
47	Conduct tests based on test plan	APS	
48	Modify test plan based on results obtained	WU/JD/MR	

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

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/dm²/h):		Ice Pellets Size (mm):	
Total Time:			

FREEZING RAIN/DRIZZLE APPLICATION (if applicable)			
Actual start time:		Actual End Time:	
Rate of Precipitation Applied (g/dm²/h):		Droplet Size (mm):	
Total Time:		Needle:	
		Flow:	
		Pressure	

SNOW APPLICATION (if applicable)			
Actual start time:		Actual End Time:	
Rate of Snow Applied (g/dm²/h):		Snow Size (mm):	
Total Time:			

COMMENTS ____________

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

M:\Projects\PM2169 (TC-Deicing 08-09)\Procedures\Wind Tunnel\Final Version 1.2\Wind Tunnel Tests Final Version 1.2.doc
Final Version 1.2, February 09

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

Date: ______________________ Run: ______________

WING TEMPERATURE

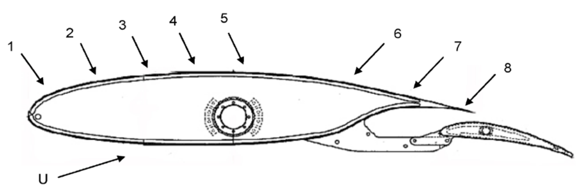
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
T2				
T5				
TU				
Time				

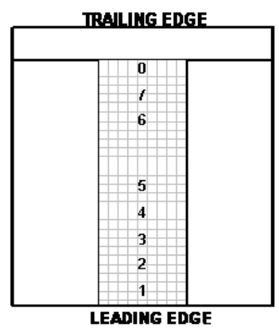
FLUID BRIX

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

8 ft = 24.4 dm

6 ft = 18.3 dm

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

Precipitation Type	IP

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 (+/-)	5	$g/dm^2/h$
Effective Rate	23	$g/dm^2/h$

IP needed per 5min

In each position	73	g
In each Dispensor	293	g

IP needed for entire test

Total amount of IP in Each Dispensor	293	g
Total Amount IP Needed for Entire Test	1173	g

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

ATTACHMENT XII – Snow Dispensing Form

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						

Precipitation Type	Snow

Date	

Run #	

* ***Field to be manipulated***

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

Footprint Rate	25	g/dm²/h
Stdev of Rate	10	g/dm²/h
Effective Rate	22	g/dm²/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 complested its cycle at Position #4, start next cycle at Position #4 and move 1-Foot to the right at (1-minute intervals).
(e.g: Position #1 -> Pos #2 -> Pos #3 -> Pos #4 -> Pos #4 -> Pos #3 -> Pos #2 -> Pos #1 -> Pos #1...)

ATTACHMENT XIII – Sprayer Calibration Form (To Stay in Control Room)

WIND TUNNEL FREEZING RAIN SPRAYER CALIBRATION FORM **(Date: ______________________________)**

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							
Dry Run Settings	-	Full	Partial	2x23, 2x24	Low	12.2 x 15	30	Dry Run Setting	22	MVD = 1.2mm

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: ____

____

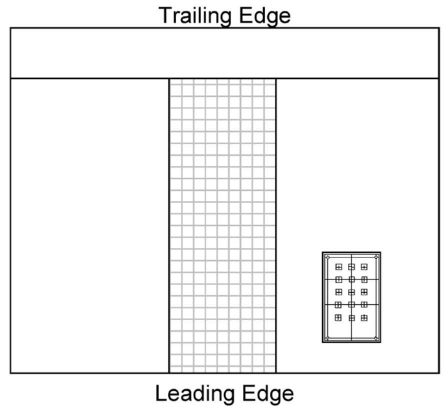
____

OBSERVER: ______________________

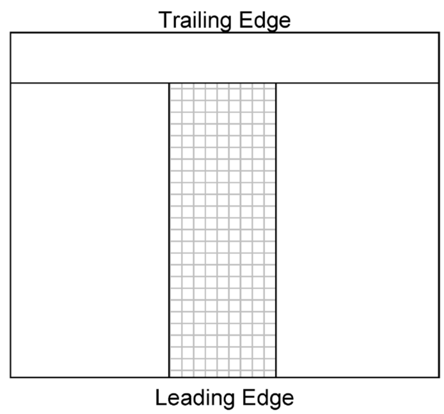
ATTACHMENT XV – Condition of Wing and Plate Form (to be filled by MP/DY)

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 – Aerodynamic Impact of Wing Surface Roughness Procedure

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

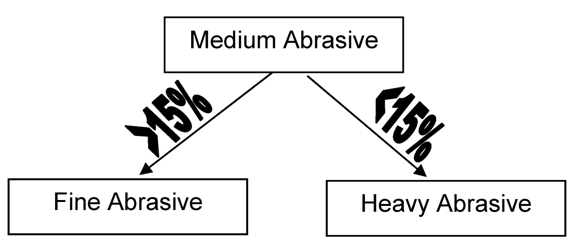
To investigate wing surface roughness and how it pertains to lift loss.

Methodology

- Consult with NRC Flight Laboratory regarding abrasive paper previously used in aerodynamic testing (previous testing was done with a sand paper with an adhesive backing);
- Purchase or acquire abrasive material;
- Apply abrasive material to full length of the leading edge of wing section;
- Apply fluid;
- Run wind tunnel test, collect lift loss data, compare to fluid only results;
- Increase grit of sand paper (or abrasive material) until appreciable lift losses are observed (greater than 15%); and
- Document type of abrasive material and effects on lift loss.

Test Plan

Three to four tests are anticipated. Testing will proceed according to the following decision matrix.



ATTACHMENT XIX – Frost Anti-Icing Fluid Freeze Point Failure During Frost Conditions Procedure

Background

Previous flat plate testing conducted in natural frost conditions demonstrated that anti-icing fluids could experience premature failure when approaching the fluid LOUT. Due to radiational cooling, the temperature of the test surface would approach the fluid freeze point causing ice to form sporadically in the fluid. The ice contamination did not seem to adhere to the surface, however, the aerodynamic impact of the failed fluid needs to be investigated.

Objective

To investigate the aerodynamic impact of anti-icing fluid failed during active frost conditions as a result of the surface temperature approaching the fluid freeze point.

Methodology

- If possible, conduct testing when OAT is close to -24°C;
- Apply Clariant Flight 75/25 anti-icing fluid to wing section;
- If OAT is not cold enough, dilute fluid to a negative buffer (-3 to -6°) respective to OAT;
- Monitor condition of fluid;
- When an acceptable level of freeze point crystalline failure is experienced, run wind tunnel and collect lift loss data;
- Repeat test with same conditions and fluid, however, run tunnel immediately after fluid application to minimize freeze point failure; and
- Compare results.

Test Plan

Two to three tests are anticipated: contamination tests and one fluid only test.

ATTACHMENT XX – Effect of Snow Pellets on Fluid Flow Off Procedure

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. This experiment is qualitative; lift data will not be compared.

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 manually dispense simulated snow pellets on one test section and snow on the other test section (ensure equal rate of precipitation and distribution by monitoring Brix);
- 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 2 tests are anticipated.

ATTACHMENT XXI – Reduced Type I HOT's on Composite Surfaces Procedure

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 freezing rain 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 freezing rain at a rate of 25 g/dm²/h. Time of exposure should be 30% longer than previous test
    - Exposure time = ET of simulated aluminum wing test / 0.7;
- Run wind tunnel and collect lift loss data;
- Compare results of both tests; and
- Consider running tests with snow.

Note: Testing can also be done by simulating both aluminium 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 XXII – Inadequate Anti-Icing Fluid Application Procedure

Background

There has been recent industry concern as to the consistency of anti-icing fluid application in actual aircraft ground deicing operations. Although current industry standards recommend applying a minimum of one liter of anti-icing fluid per meter squared, in operations, human error can lead to insufficient application of fluid. Full-scale data is required to verify the aerodynamic impact of inadequate anti-icing fluid application of fluid flow off. .

Objective

To investigate the aerodynamic flow-off characteristics and lift losses associated with inadequate anti-icing fluid application.

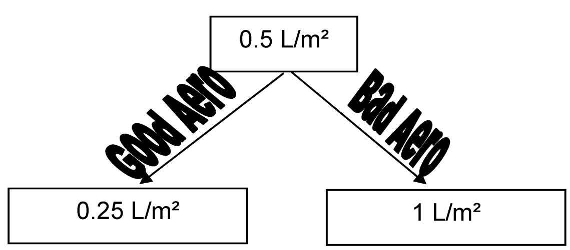
Methodology

- Perform a two step application of fluid;
- Apply heated Type I fluid to wing section (heated to 60°C);
- Wait 5 minutes to allow fluid to settle;
- Apply an inadequate amount of anti-icing fluid to wing section;
- Expose wing section to simulated 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 lift loss data; and
- Repeat test and reduce or increase amount of anti-icing fluid applied.

Note: Testing can also be done by simulating two tests on the same wing section using two separate strips of fluid.

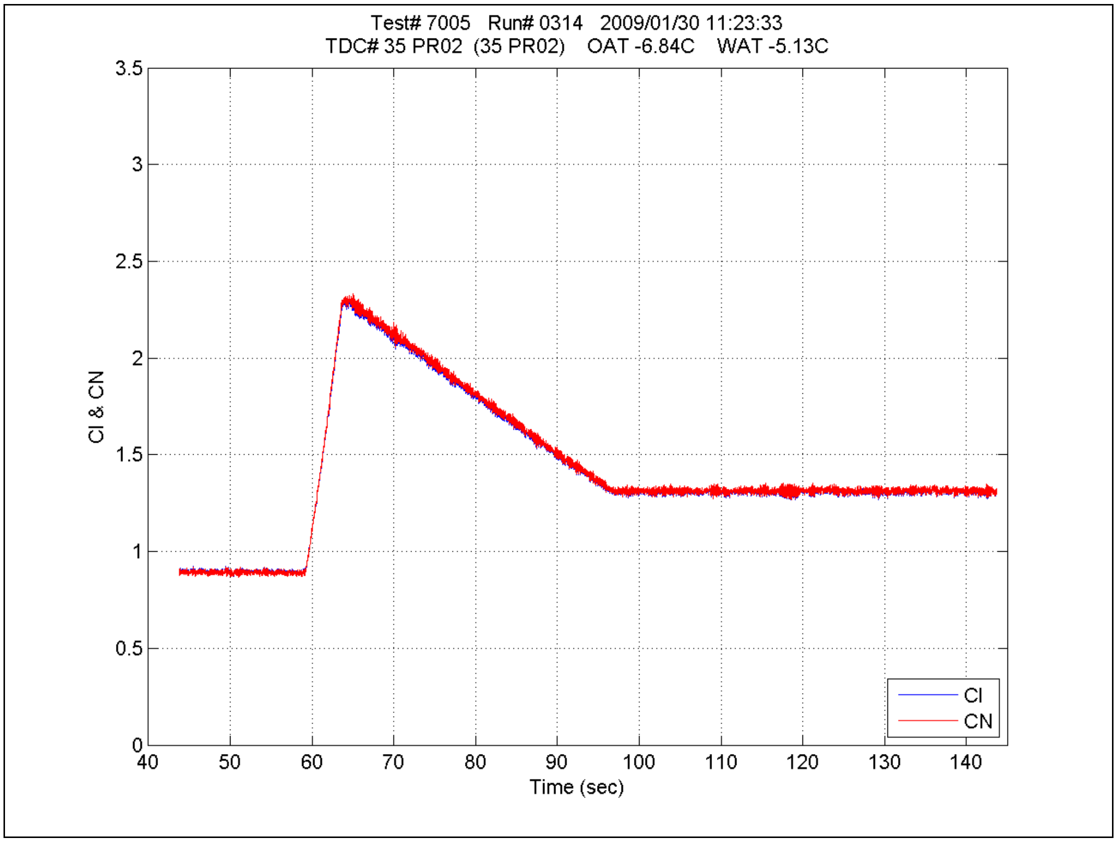
Test Plan

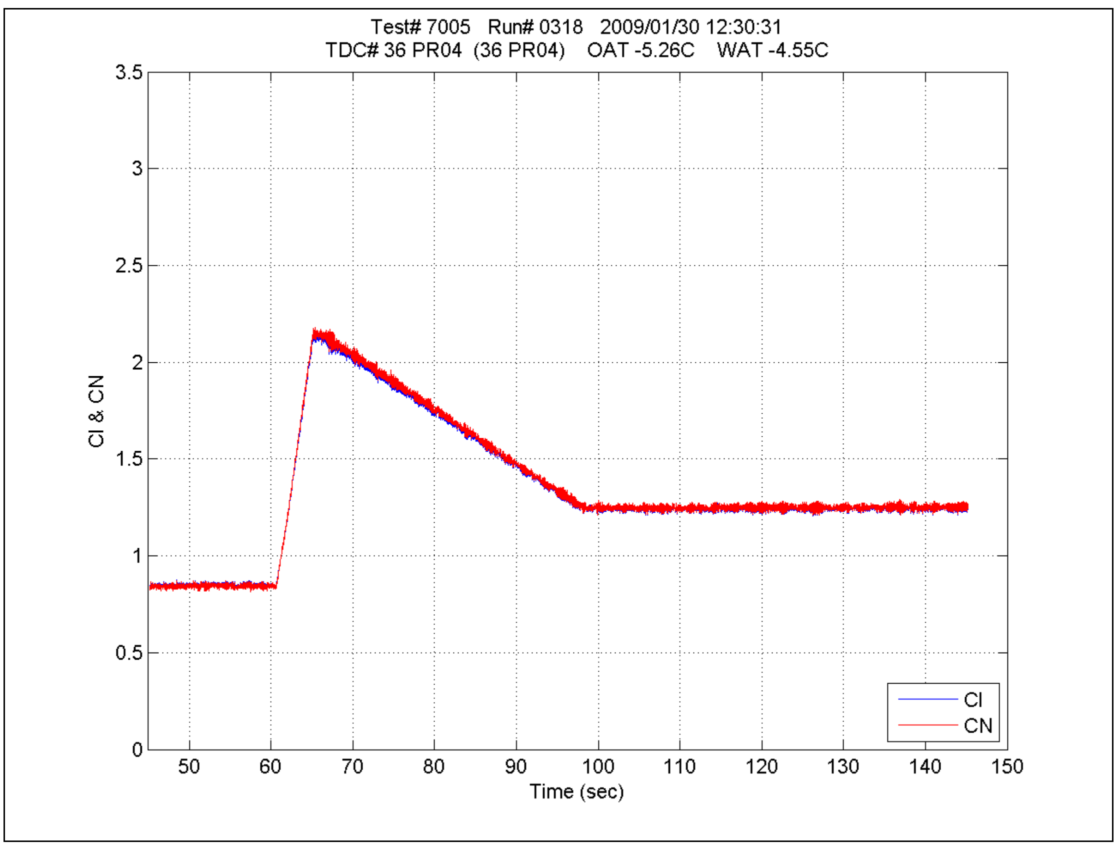
Four to six tests are anticipated. Testing will proceed according to the following decision matrix.

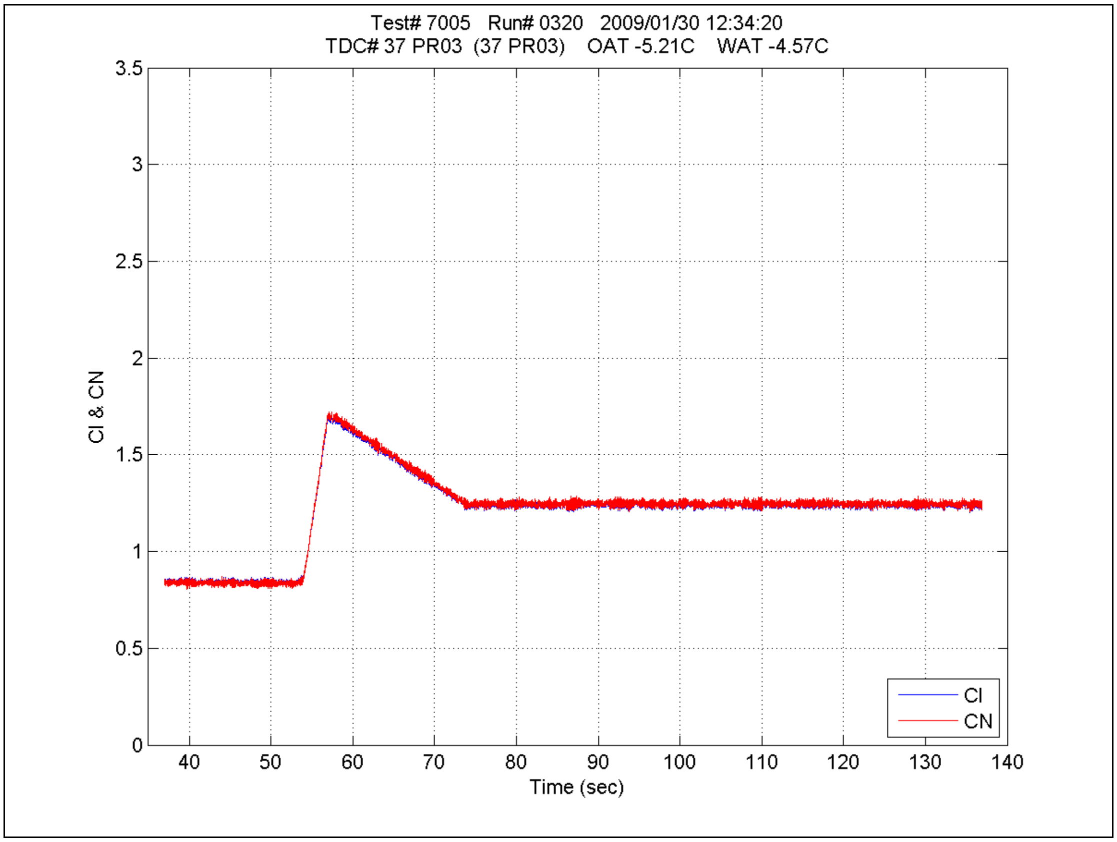


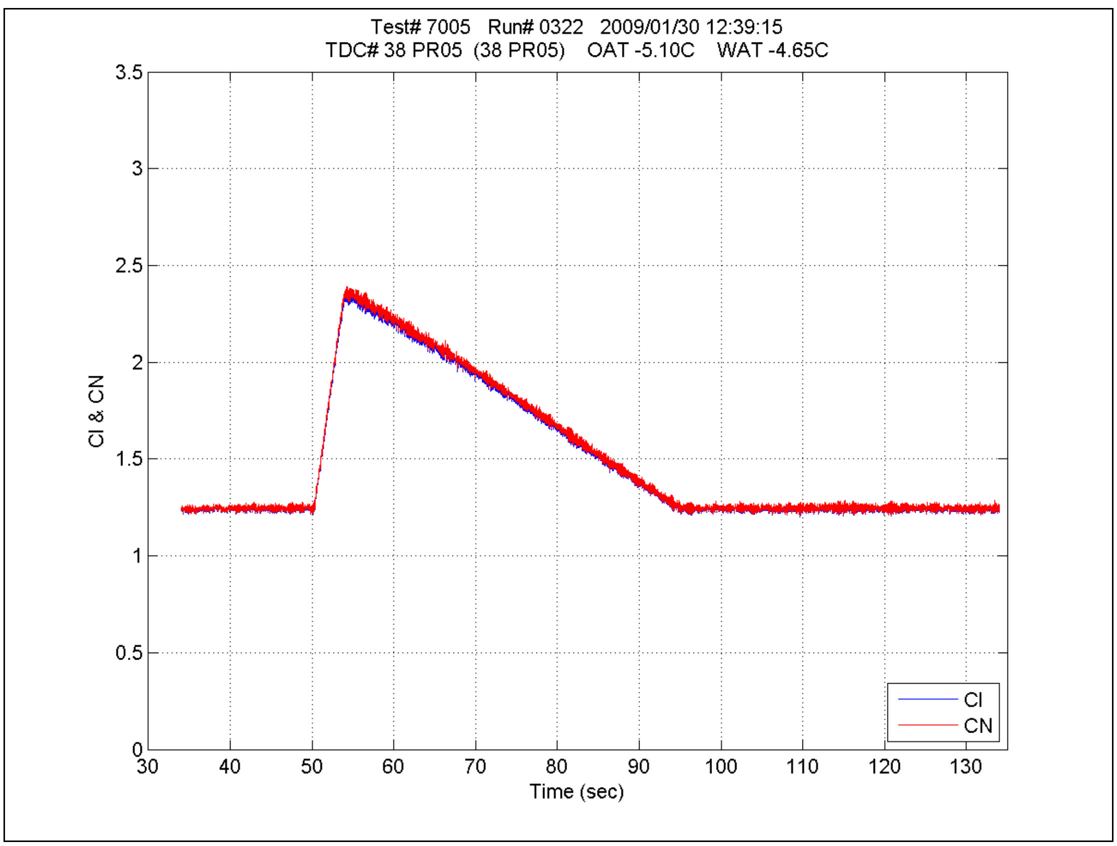
APPENDIX C

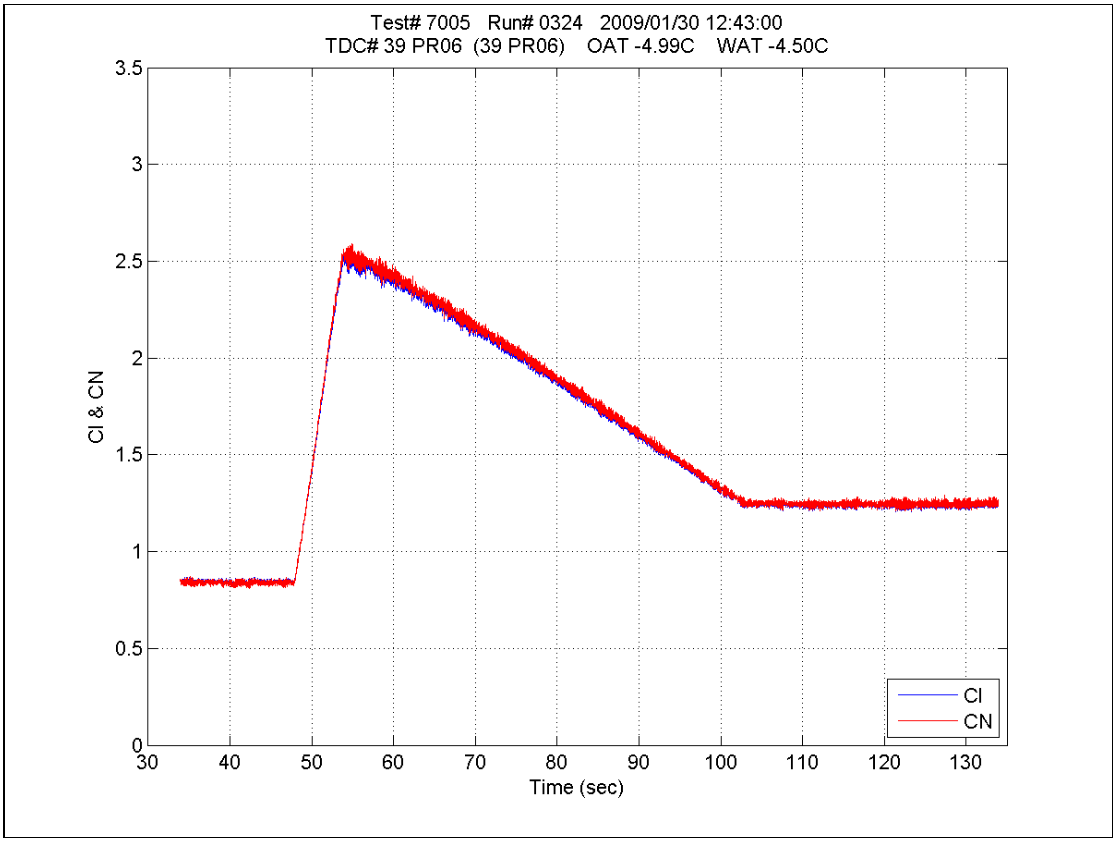
LIFT COEFFICIENT AND NORMAL COEFFICIENT DATA PROVIDED BY NRC

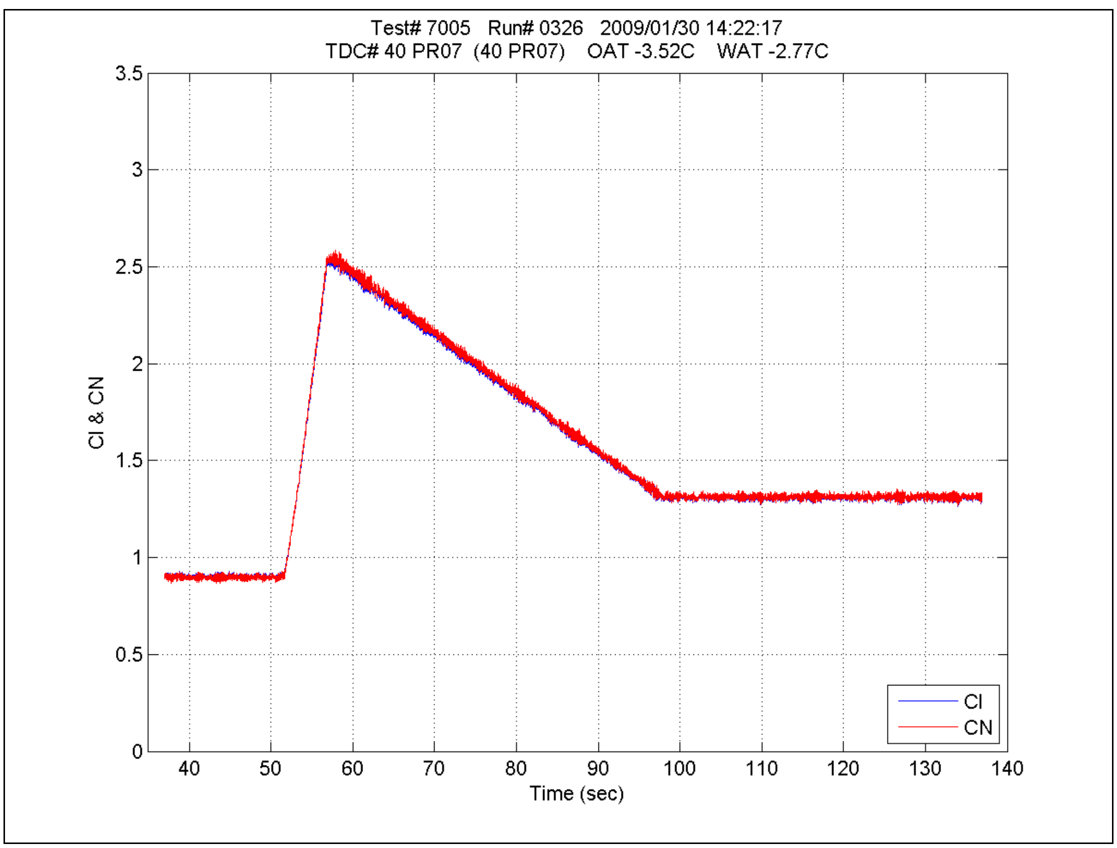

Test# 7005 Run# 0314 2009/01/30 11:23:33
TDC# 35 PR02 (35 PR02) OAT -6.84C WAT -5.13C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
40
50
60
70
80
90
100
110
120
130
140

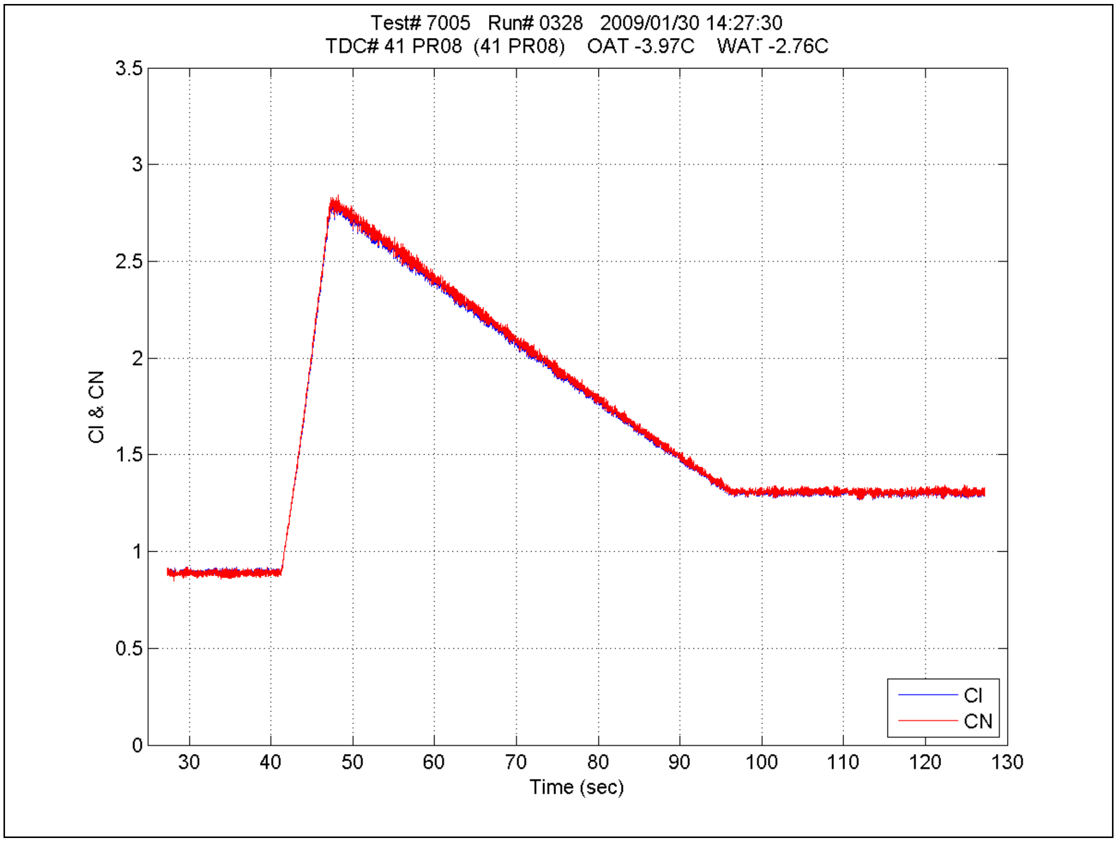

Test# 7005 Run# 0318 2009/01/30 12:30:31
TDC# 36 PR04 (36 PR04) OAT -5.26C WAT -4.55C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
50
60
70
80
90
100
110
120
130
140
150

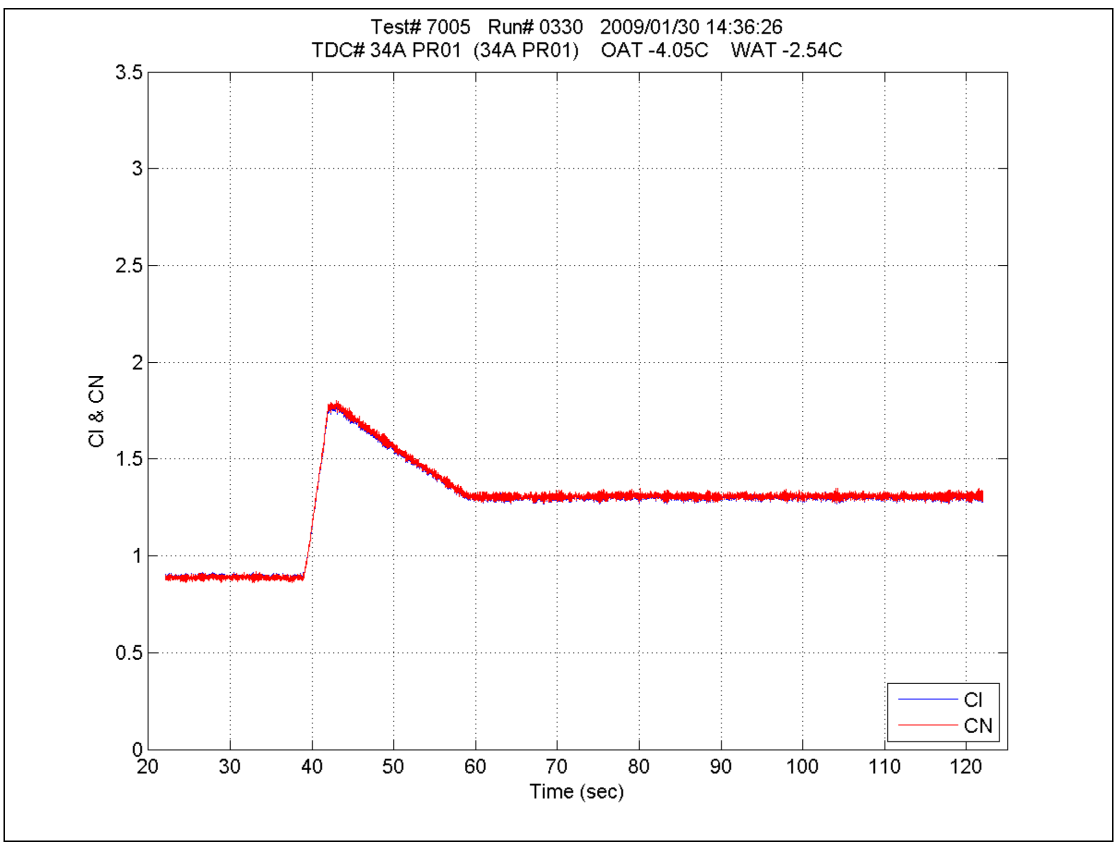

Test# 7005 Run# 0320 2009/01/30 12:34:20
TDC# 37 PR03 (37 PR03) OAT -5.21C WAT -4.57C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
40
50
60
70
80
90
100
110
120
130
140

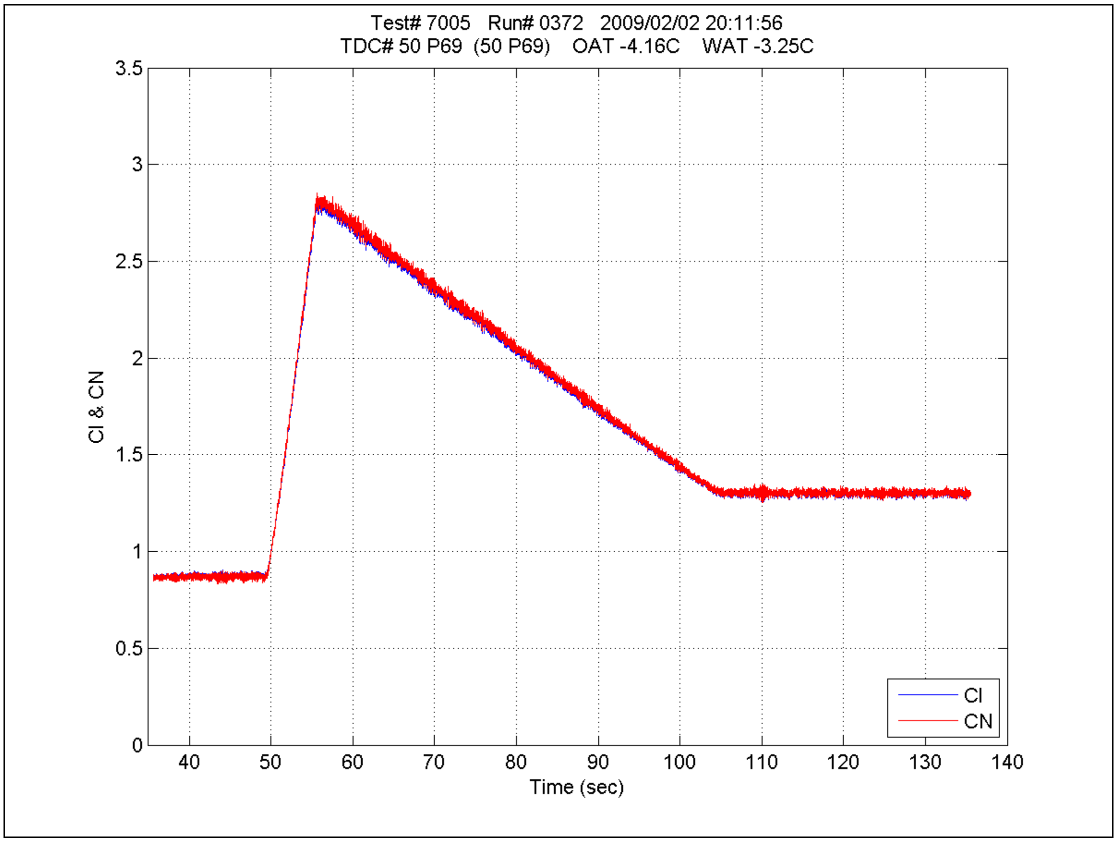

Test# 7005 Run# 0322 2009/01/30 12:39:15
TDC# 38 PR05 (38 PR05) OAT -5.10C WAT -4.65C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
30
40
50
60
70
80
90
100
110
120
130

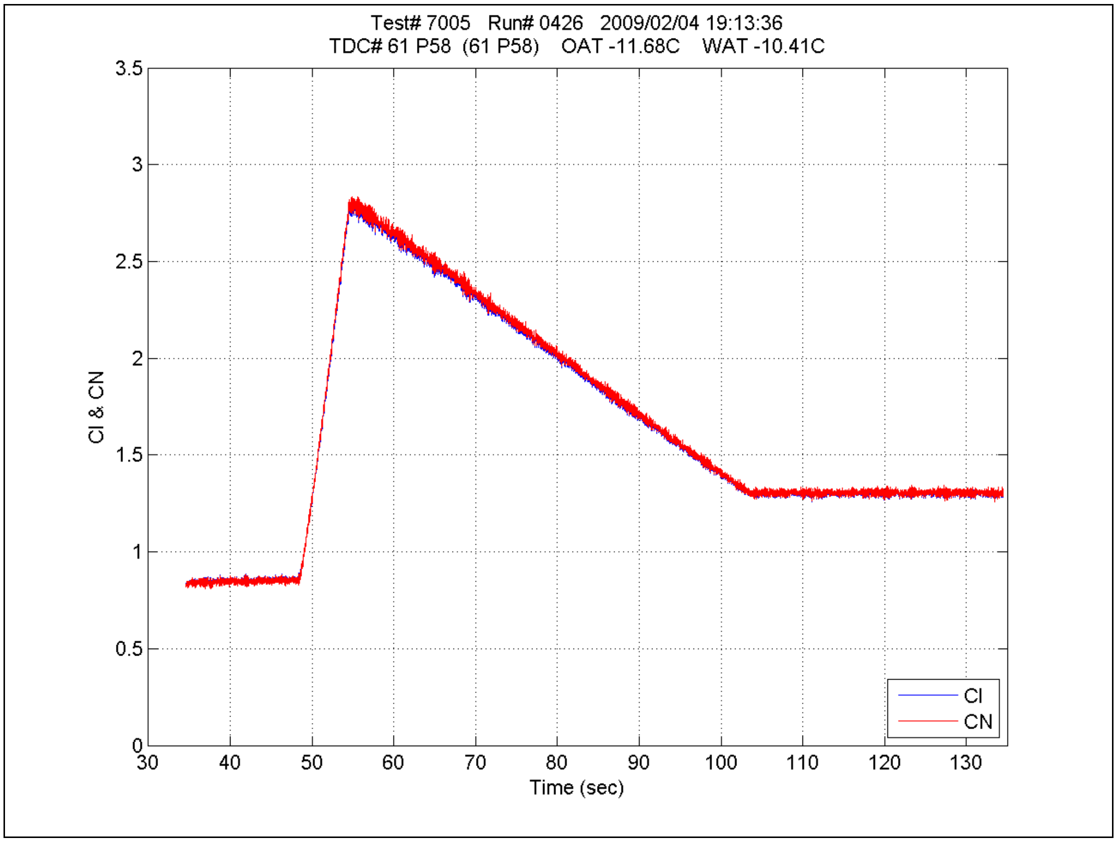

Test# 7005 Run# 0324 2009/01/30 12:43:00
TDC# 39 PR06 (39 PR06) OAT -4.99C WAT -4.50C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
30
40
50
60
70
80
90
100
110
120
130

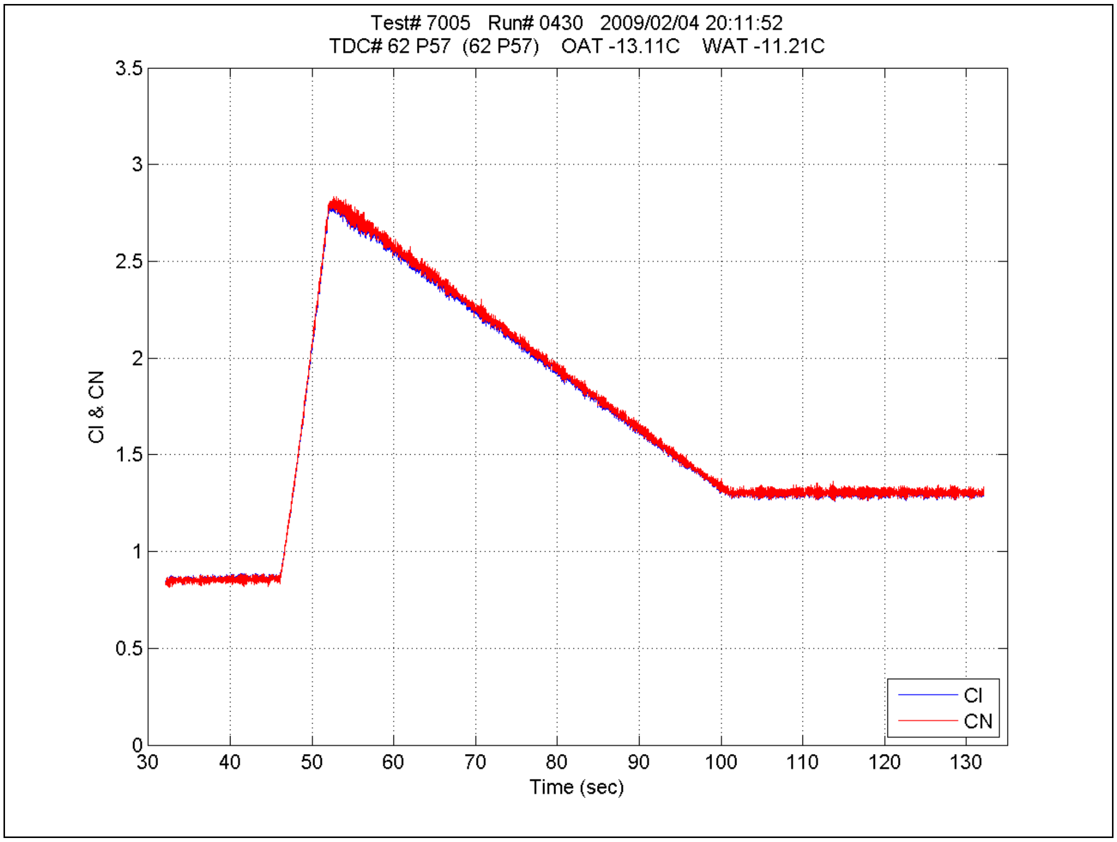

Test# 7005 Run# 0326 2009/01/30 14:22:17
TDC# 40 PR07 (40 PR07) OAT -3.52C WAT -2.77C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
40
50
60
70
80
90
100
110
120
130
140

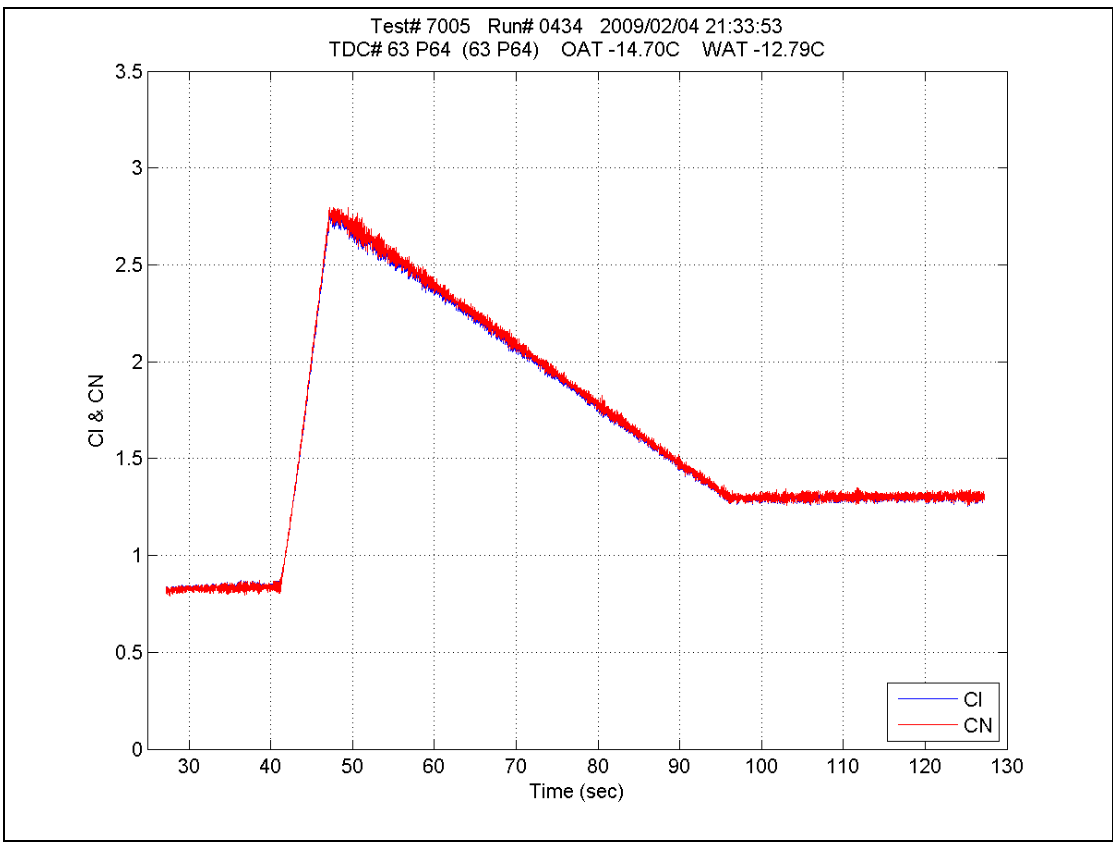

Test# 7005 Run# 0328 2009/01/30 14:27:30
TDC# 41 PR08 (41 PR08) OAT -3.97C WAT -2.76C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
30
40
50
60
70
80
90
100
110
120
130

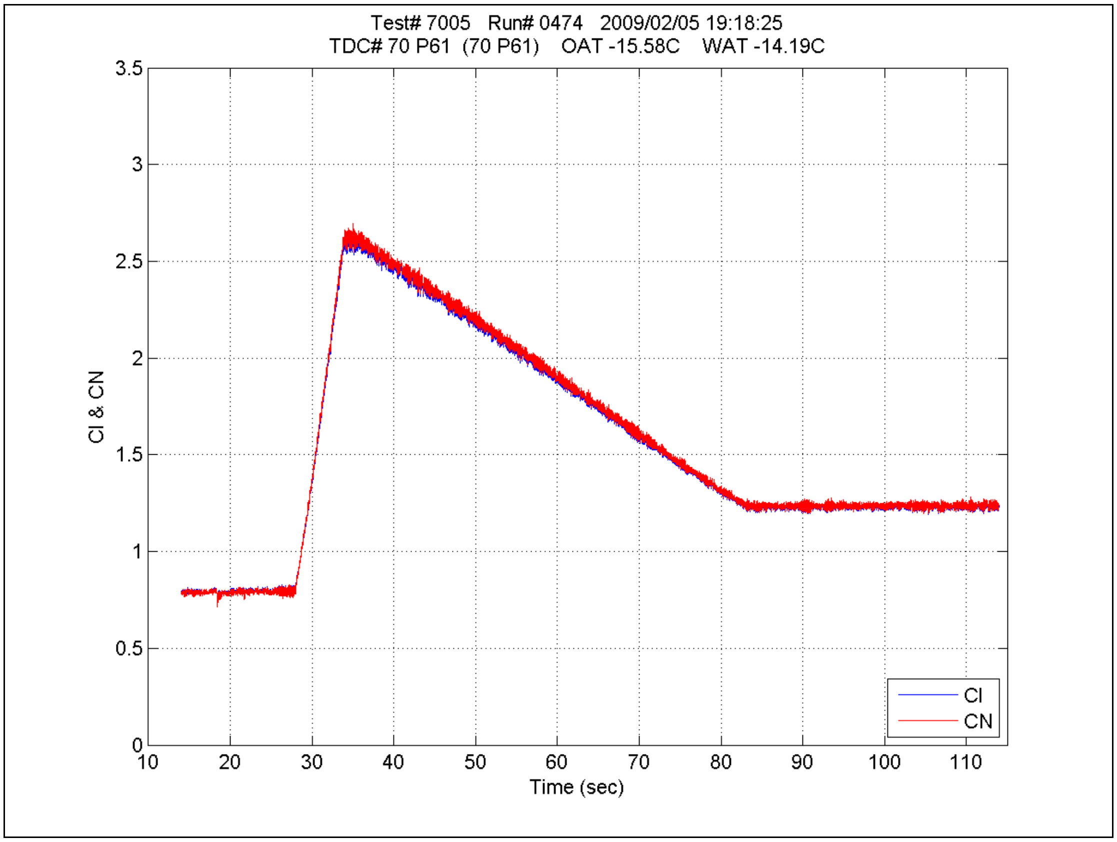

Test# 7005 Run# 0330 2009/01/30 14:36:26
TDC# 34A PR01 (34A PR01) OAT -4.05C WAT -2.54C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
20
30
40
50
60
70
80
90
100
110
120

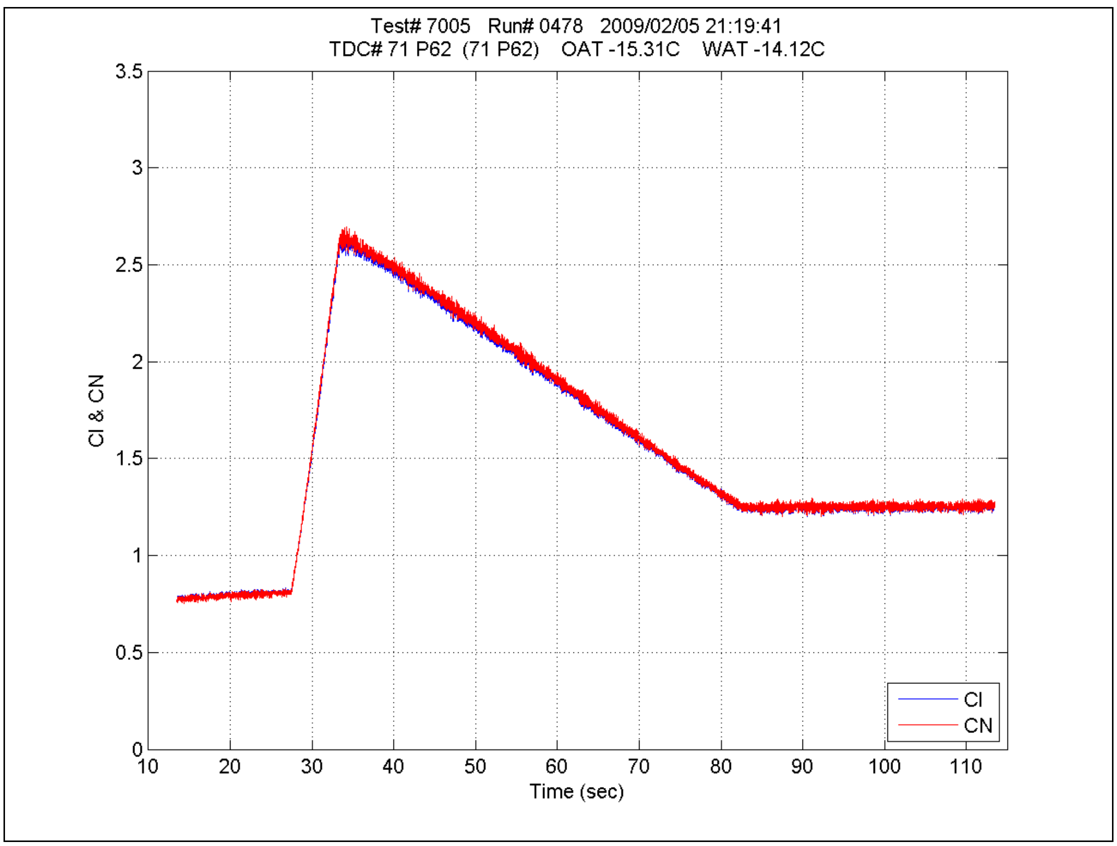

Test# 7005 Run# 0372 2009/02/02 20:11:56
TDC# 50 P69 (50 P69) OAT -4.16C WAT -3.25C
CI & CN
Time (sec)
CI
CN

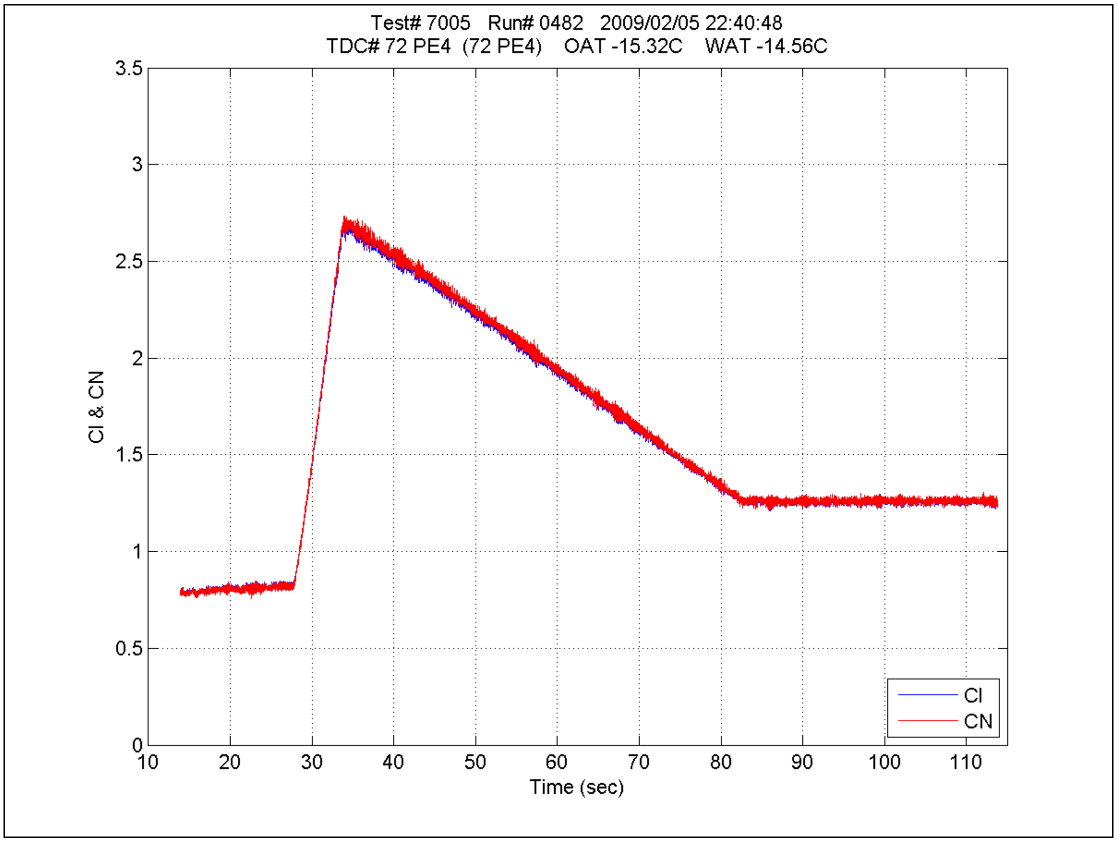

Test# 7005 Run# 0426 2009/02/04 19:13:36
TDC# 61 P58 (61 P58) OAT -11.68C WAT -10.41C
CI & CN
Time (sec)
CI
CN

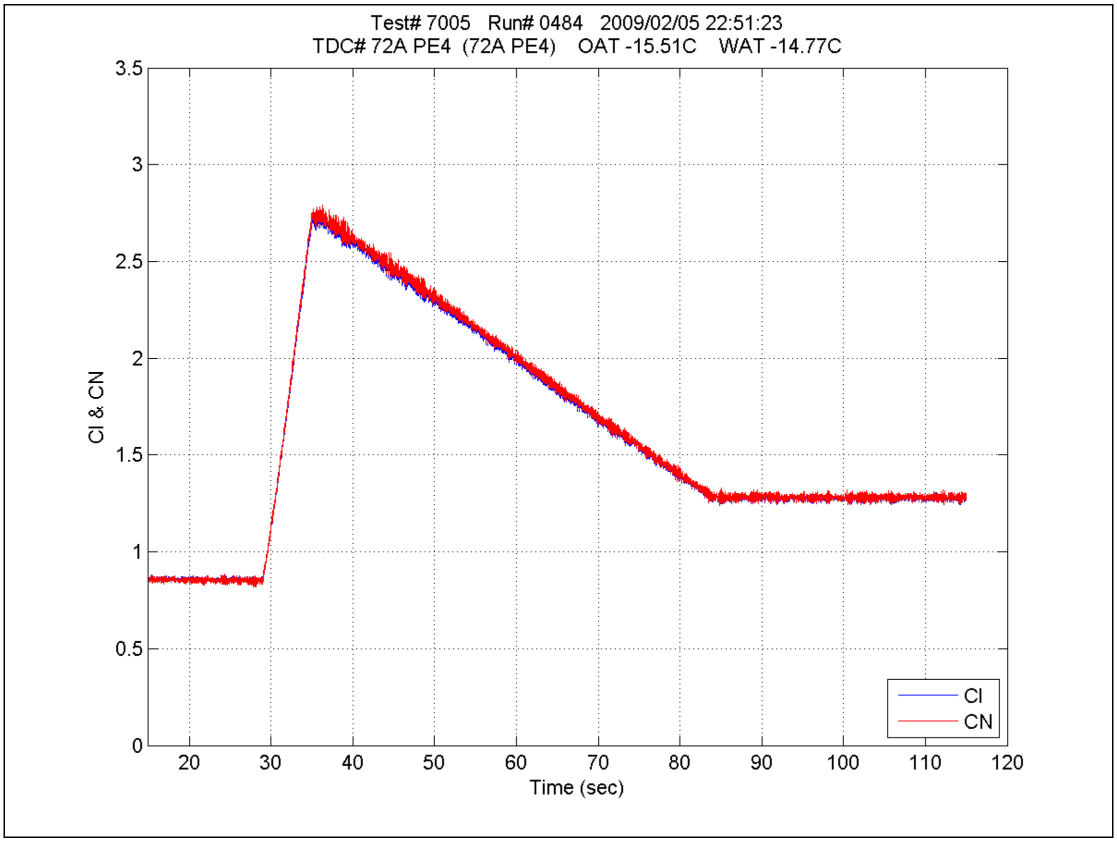

Test# 7005 Run# 0430 2009/02/04 20:11:52
TDC# 62 P57 (62 P57) OAT -13.11C WAT -11.21C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
30
40
50
60
70
80
90
100
110
120
130

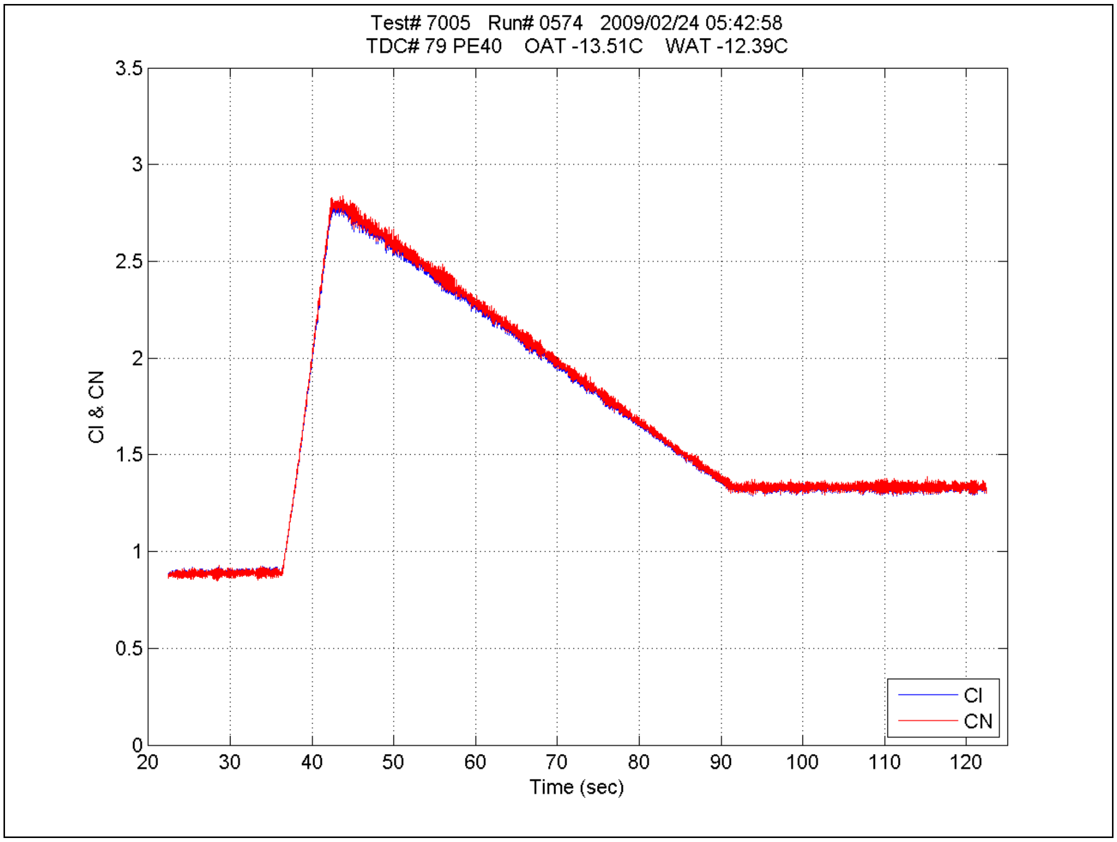

Test# 7005 Run# 0434 2009/02/04 21:33:53
TDC# 63 P64 (63 P64) OAT -14.70C WAT -12.79C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
30
40
50
60
70
80
90
100
110
120
130

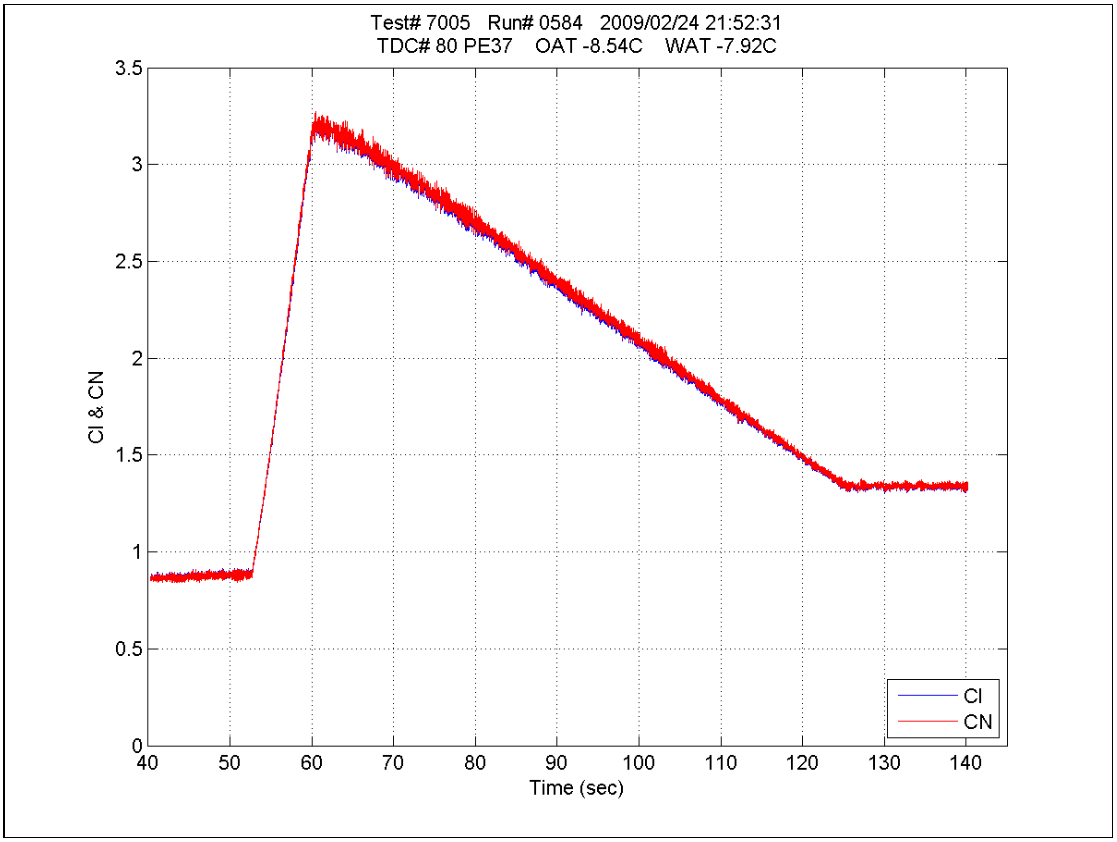

Test# 7005 Run# 0474 2009/02/05 19:18:25
TDC# 70 P61 (70 P61) OAT -15.58C WAT -14.19C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
10
20
30
40
50
60
70
80
90
100
110

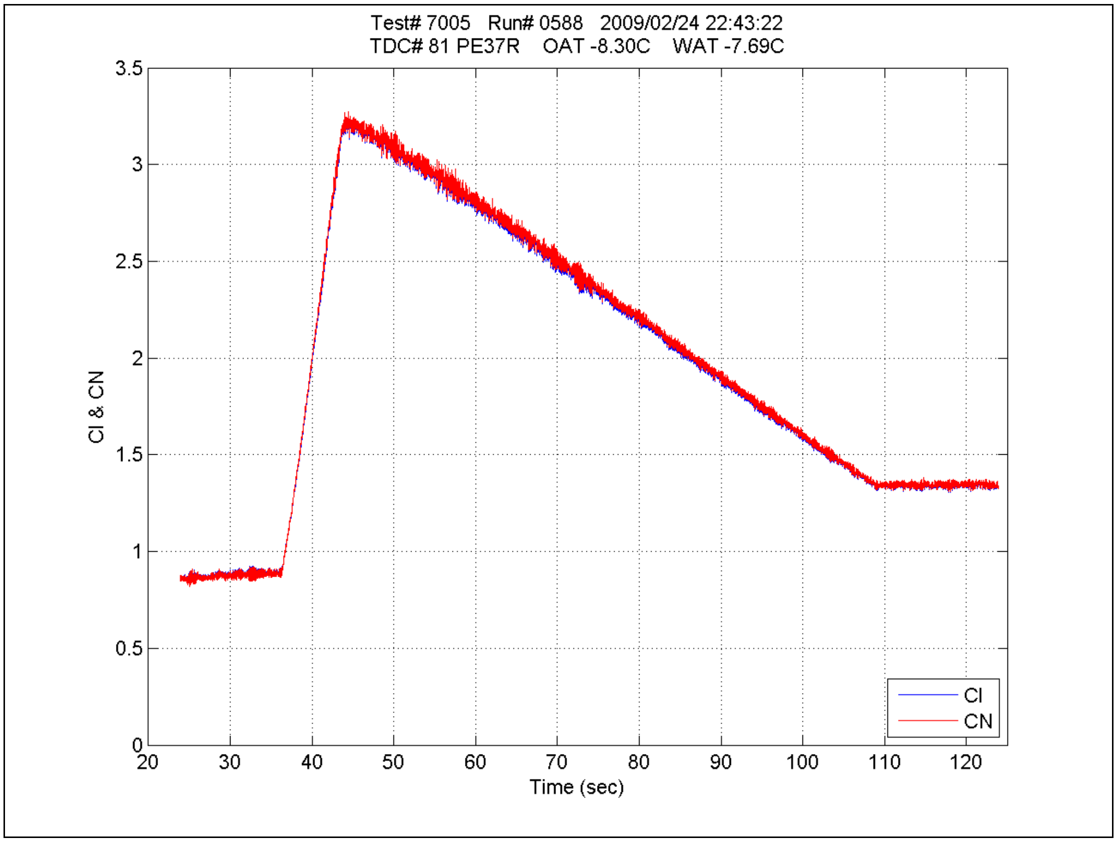

Test# 7005 Run# 0478 2009/02/05 21:19:41
TDC# 71 P62 (71 P62) OAT -15.31C WAT -14.12C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
10
20
30
40
50
60
70
80
90
100
110

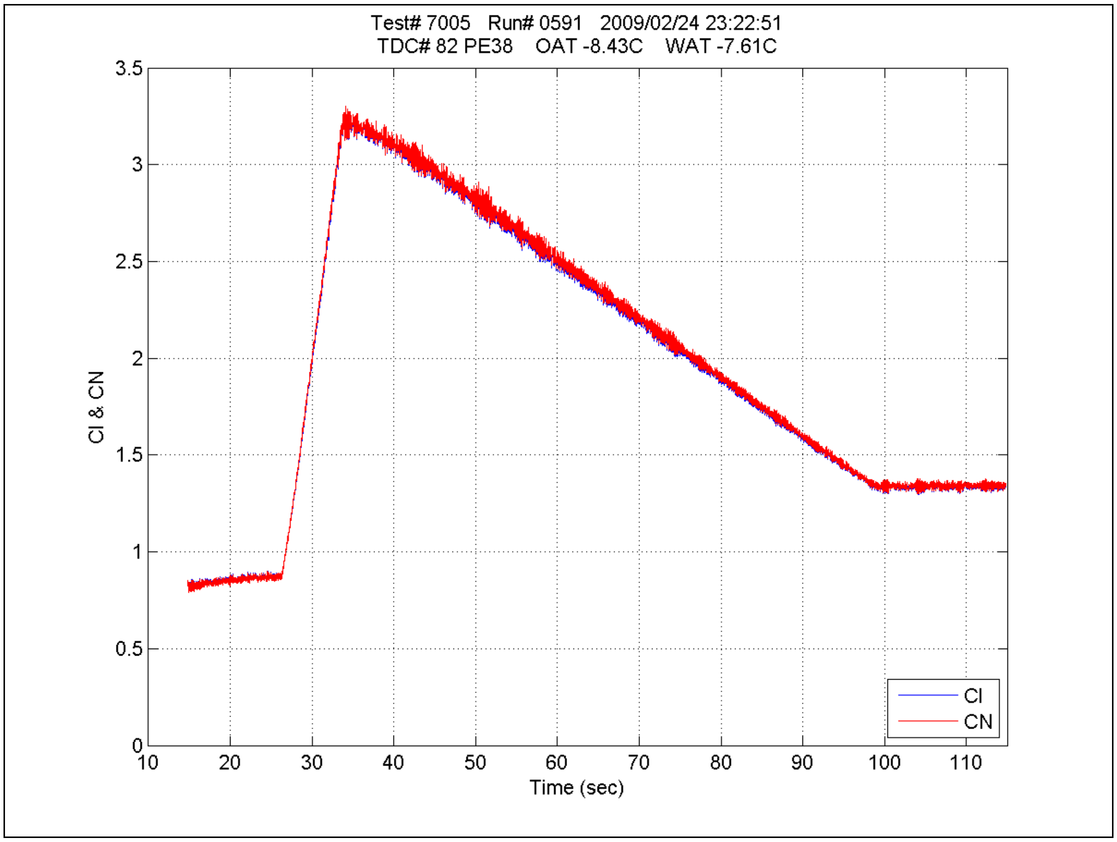

Test# 7005 Run# 0482 2009/02/05 22:40:48
TDC# 72 PE4 (72 PE4) OAT -15.32C WAT -14.56C
CI & CN
Time (sec)
CI
CN

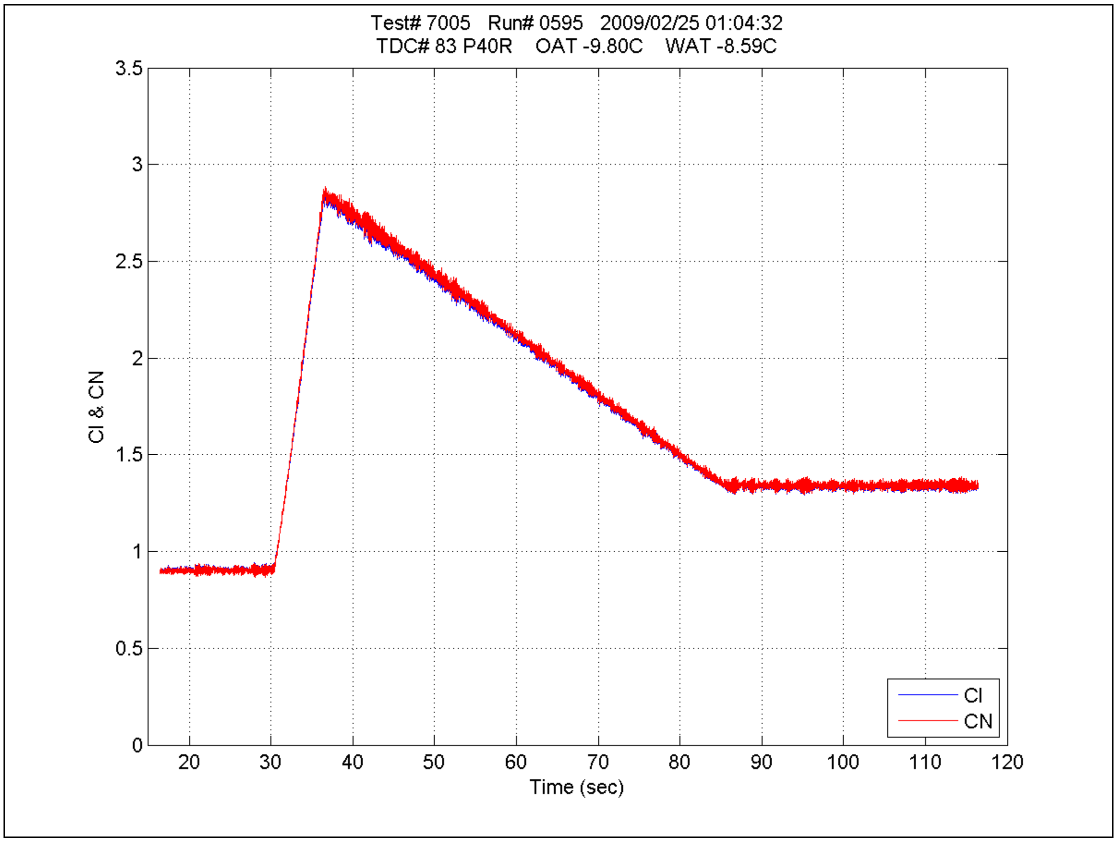

Test# 7005 Run# 0484 2009/02/05 22:51:23
TDC# 72A PE4 (72A PE4) OAT -15.51C WAT -14.77C
CI & CN
Time (sec)
CI
CN

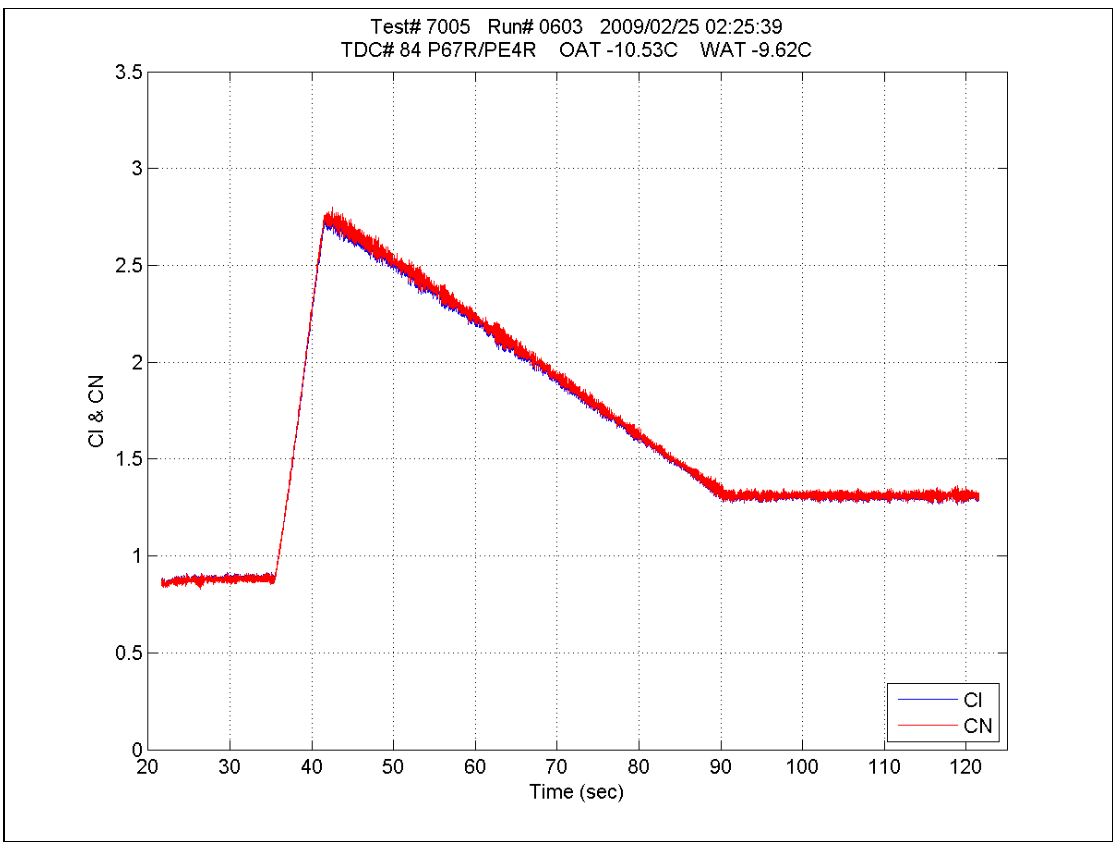

Test# 7005 Run# 0574 2009/02/24 05:42:58
TDC# 79 PE40 OAT -13.51C WAT -12.39C
CI & CN
Time (sec)
CI
CN
3.5
3
2.5
2
1.5
1
0.5
0
20
30
40
50
60
70
80
90
100
110
120

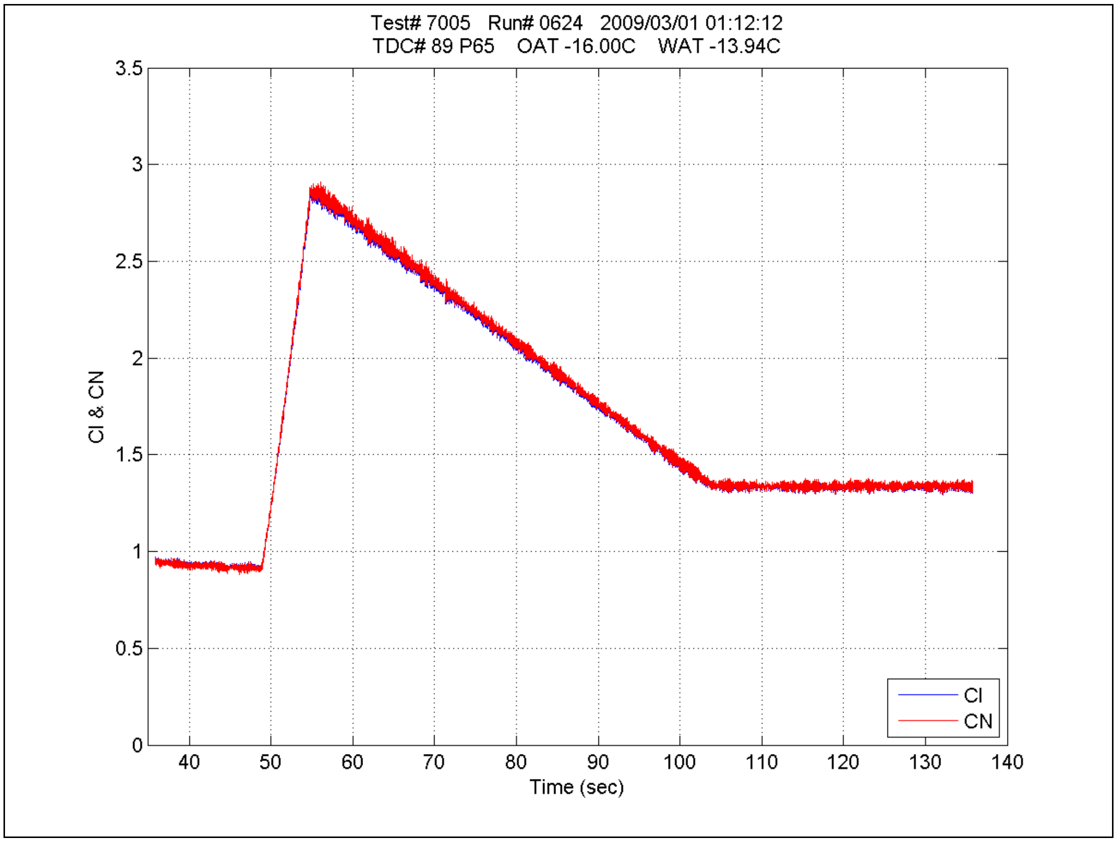

Test# 7005 Run# 0584 2009/02/24 21:52:31
TDC# 80 PE37 OAT -8.54C WAT -7.92C
CI & CN
Time (sec)
CI
CN
3.5
3
2.5
2
1.5
1
0.5
0
40
50
60
70
80
90
100
110
120
130
140

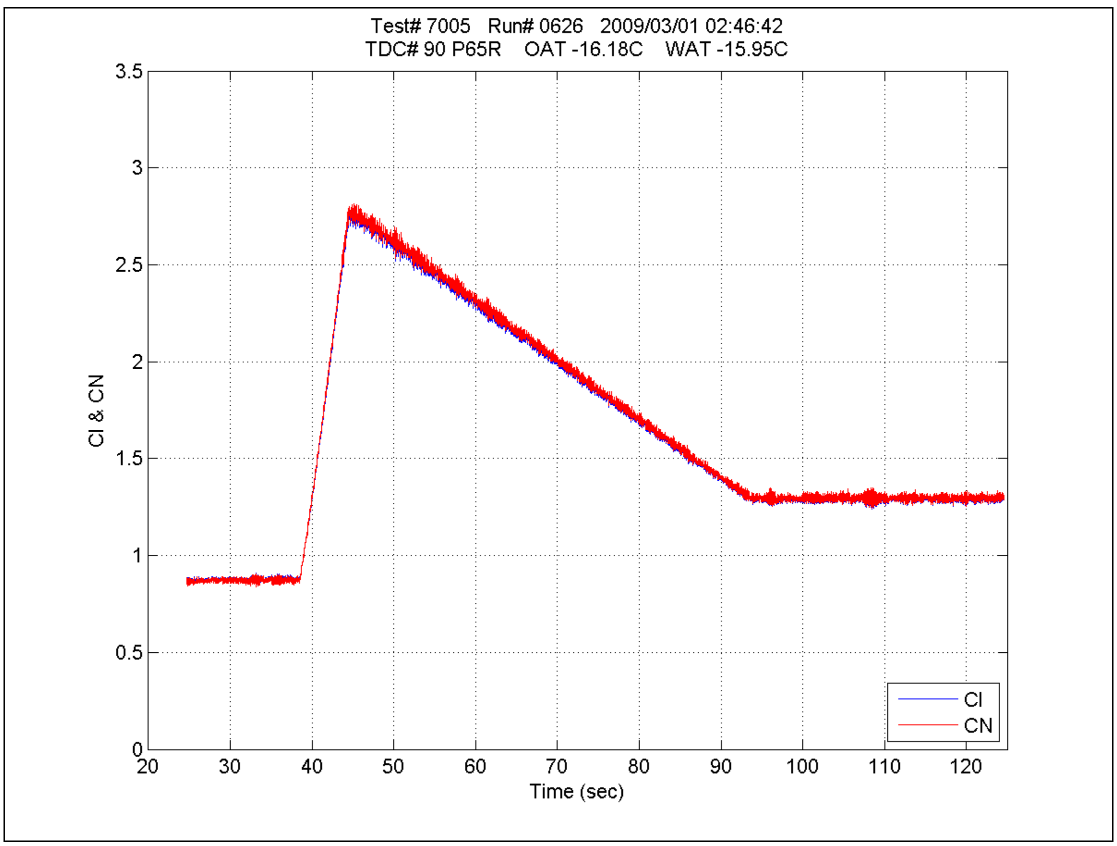

Test# 7005 Run# 0588 2009/02/24 22:43:22
TDC# 81 PE37R OAT -8.30C WAT -7.69C
CI & CN
Time (sec)
CI
CN

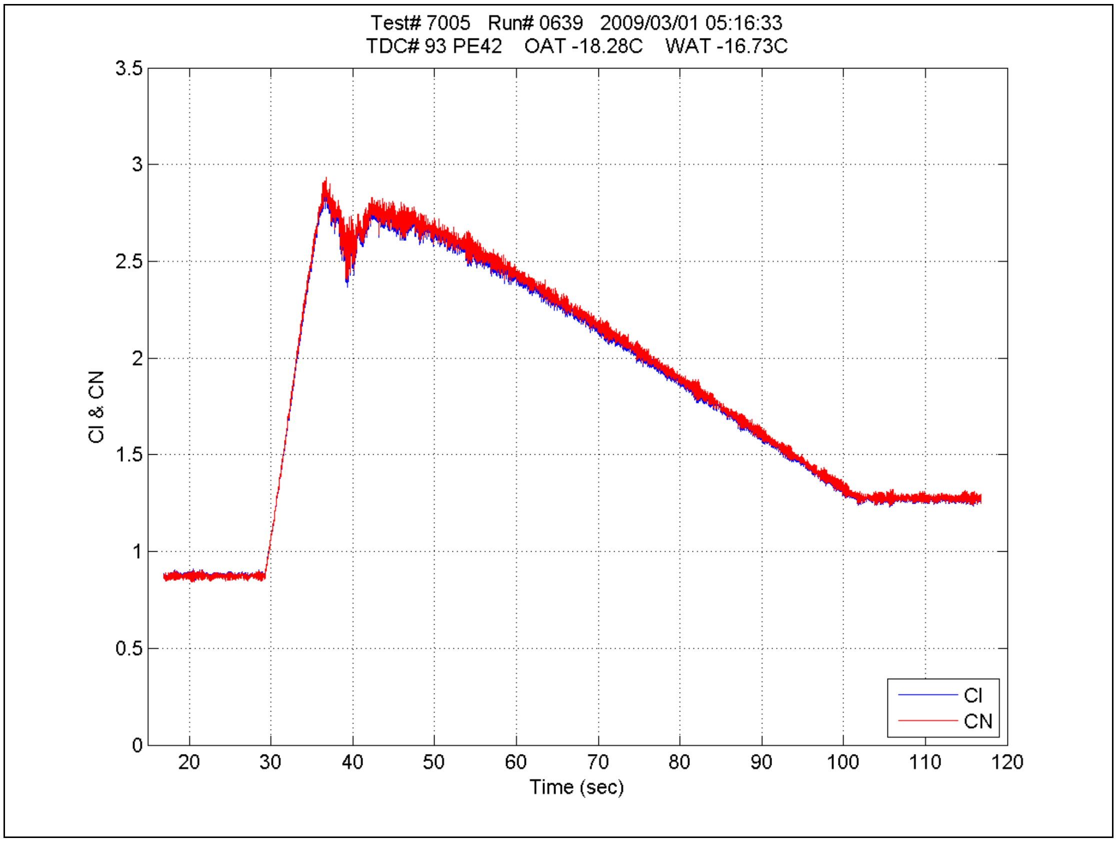

Test# 7005 Run# 0591 2009/02/24 23:22:51
TDC# 82 PE38 OAT -8.43C WAT -7.61C
CI & CN
Time (sec)
CI
CN

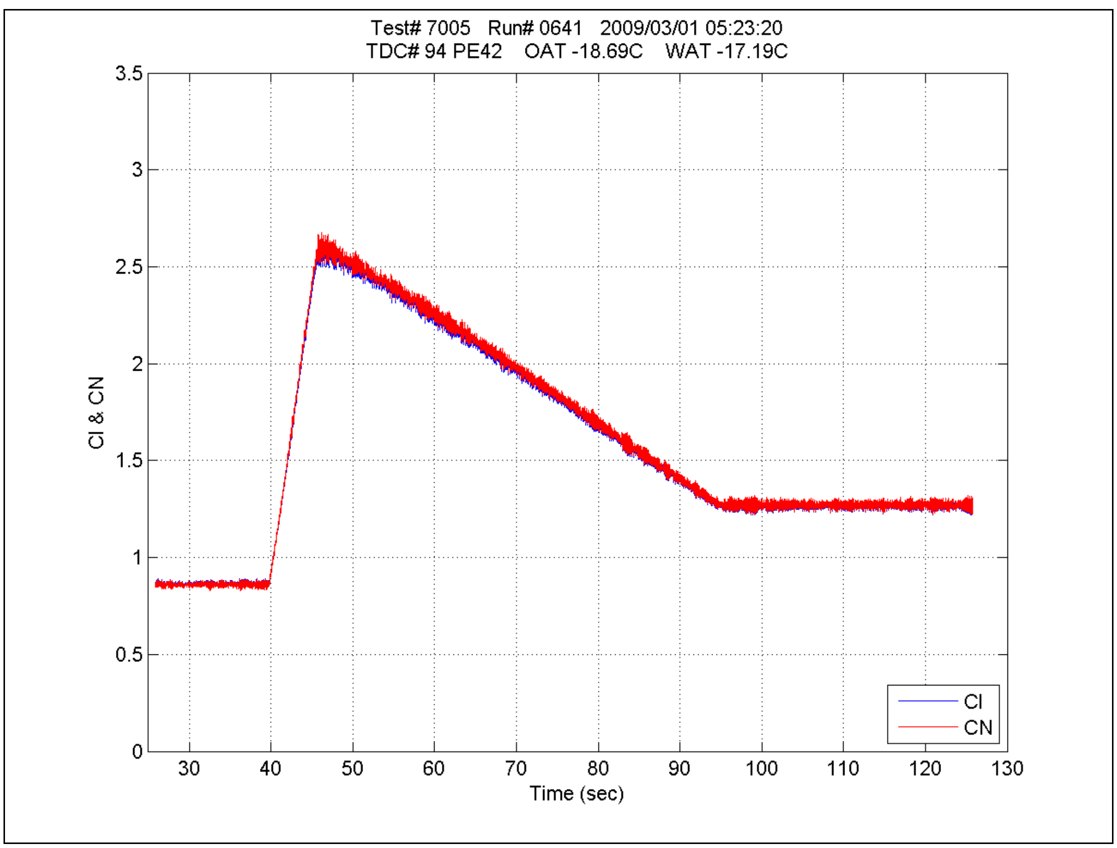

Test# 7005 Run# 0595 2009/02/25 01:04:32
TDC# 83 P40R OAT -9.80C WAT -8.59C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
20
30
40
50
60
70
80
90
100
110
120

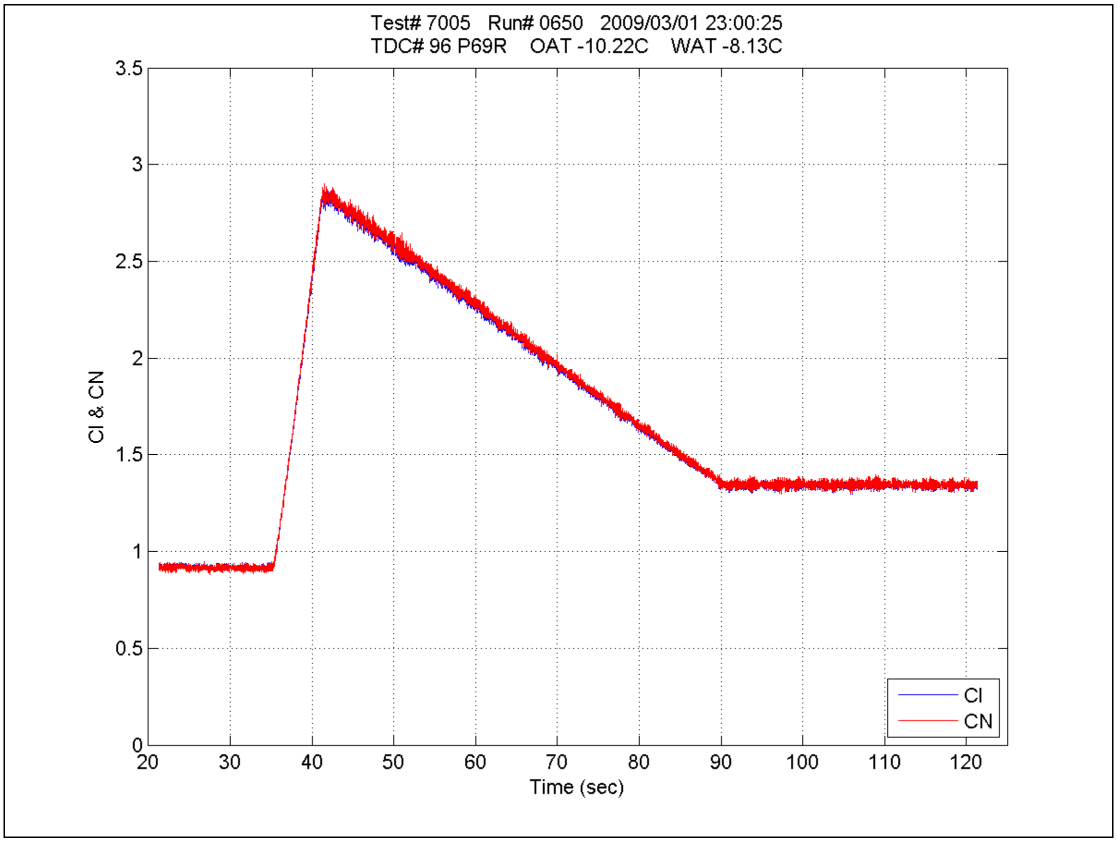

Test# 7005 Run# 0603 2009/02/25 02:25:39
TDC# 84 P67R/PE4R OAT -10.53C WAT -9.62C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
20
30
40
50
60
70
80
90
100
110
120

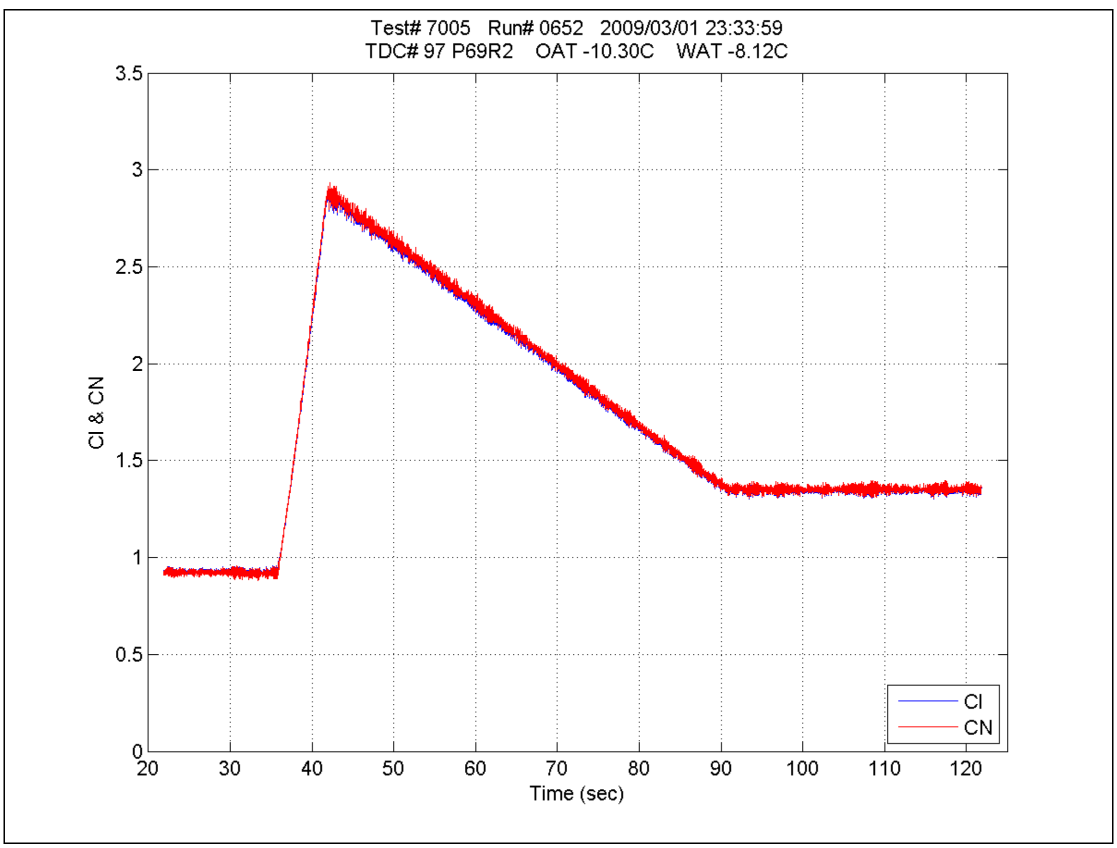

Test# 7005 Run# 0624 2009/03/01 01:12:12
TDC# 89 P65 OAT -16.00C WAT -13.94C
CI & CN
Time (sec)
CI
CN

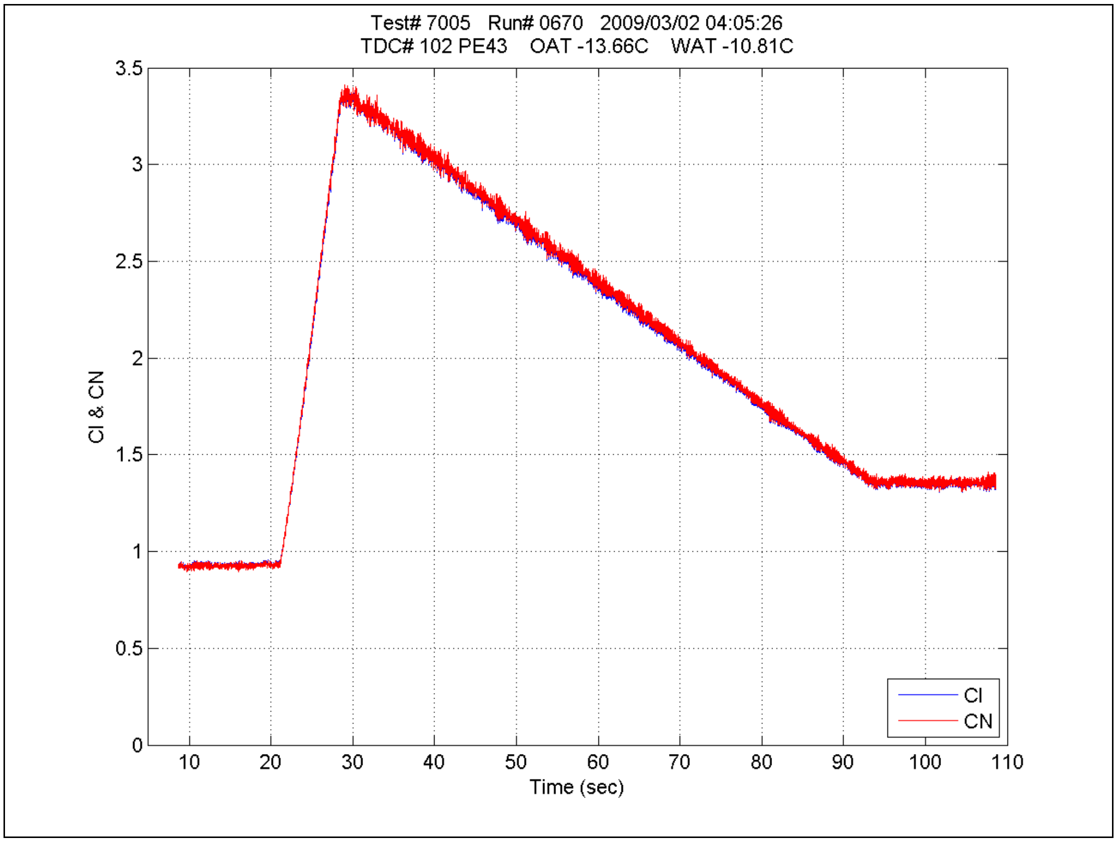

Test# 7005 Run# 0626 2009/03/01 02:46:42
TDC# 90 P65R OAT -16.18C WAT -15.95C
CI & CN
Time (sec)
CI
CN


Test# 7005 Run# 0639 2009/03/01 05:16:33
TDC# 93 PE42 OAT -18.28C WAT -16.73C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
20
30
40
50
60
70
80
90
100
110
120

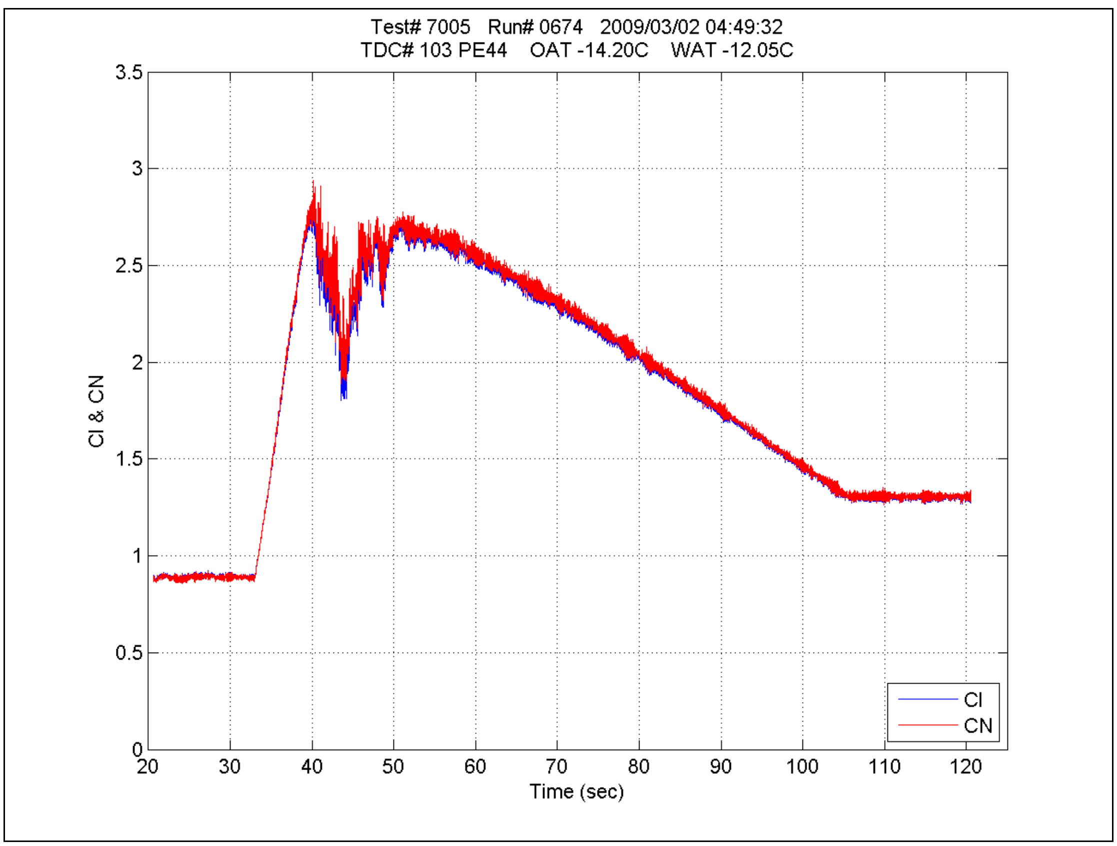

Test# 7005 Run# 0641 2009/03/01 05:23:20
TDC# 94 PE42 OAT -18.69C WAT -17.19C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
30
40
50
60
70
80
90
100
110
120
130


Test# 7005 Run# 0650 2009/03/01 23:00:25
TDC# 96 P69R OAT -10.22C WAT -8.13C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
20
30
40
50
60
70
80
90
100
110
120

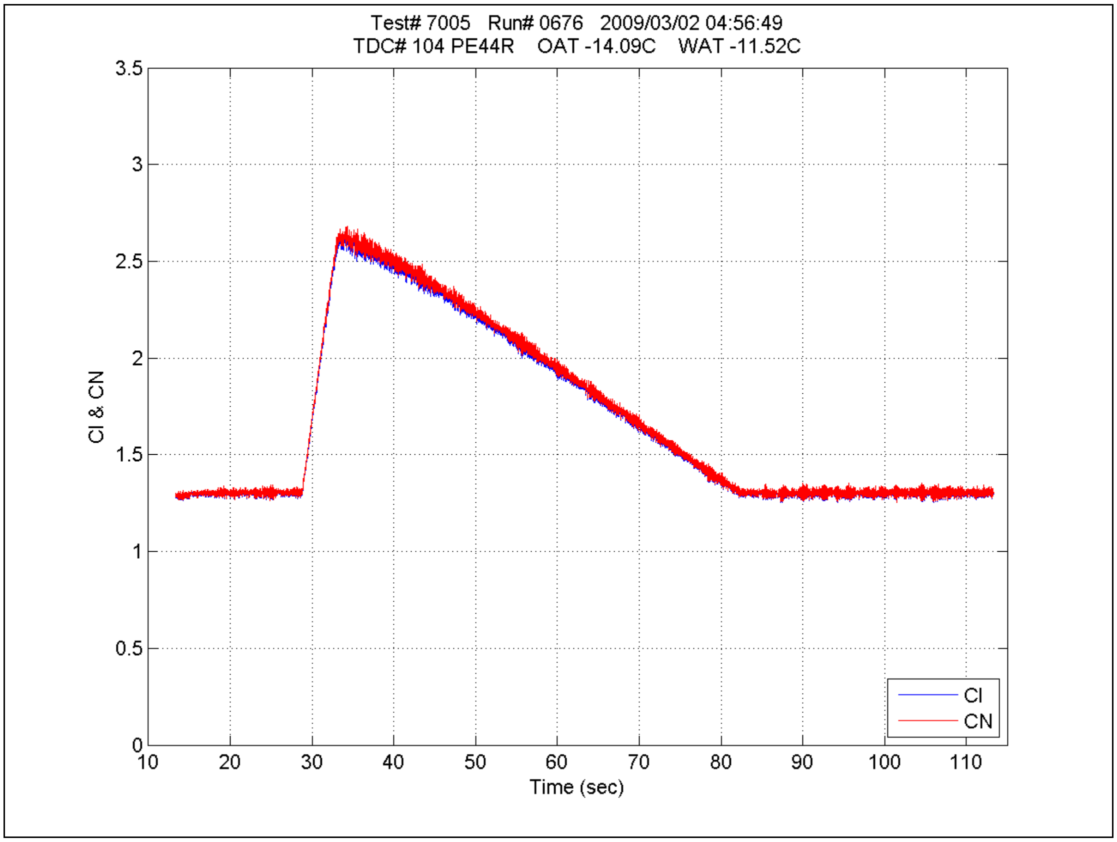

Test# 7005 Run# 0652 2009/03/01 23:33:59
TDC# 97 P69R2 OAT -10.30C WAT -8.12C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
20
30
40
50
60
70
80
90
100
110
120

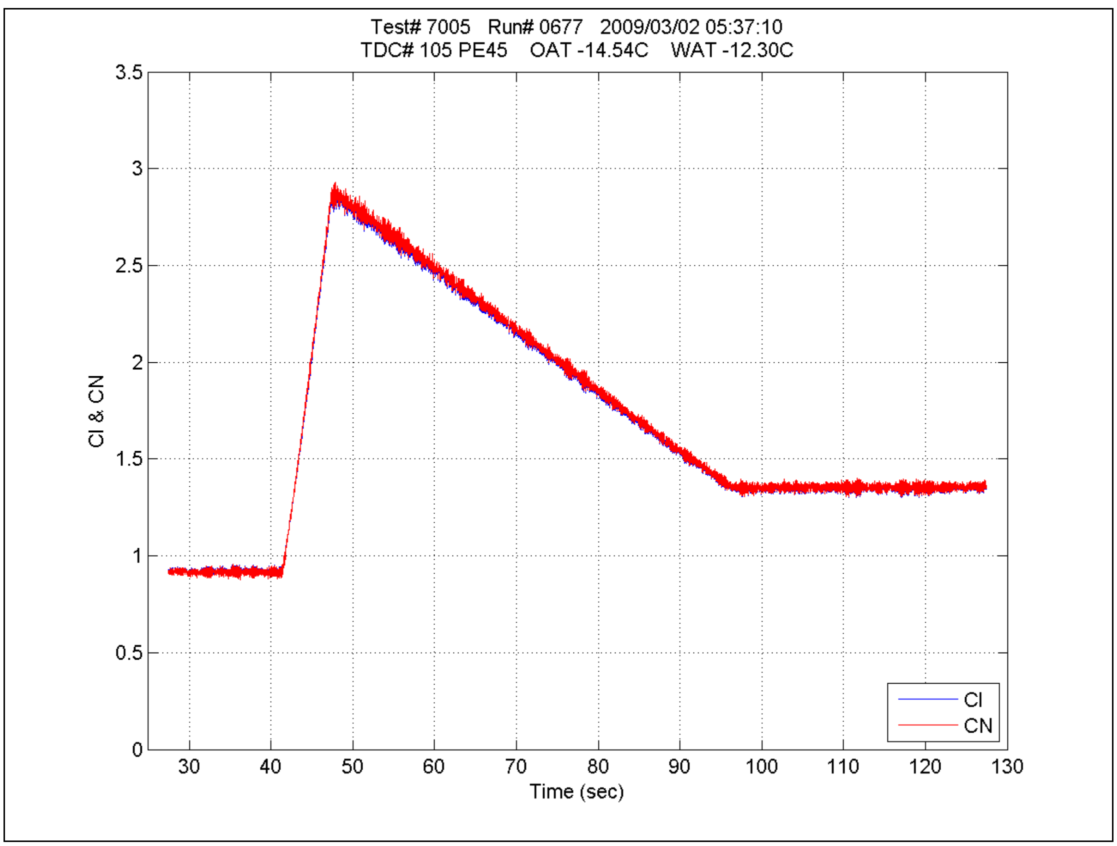


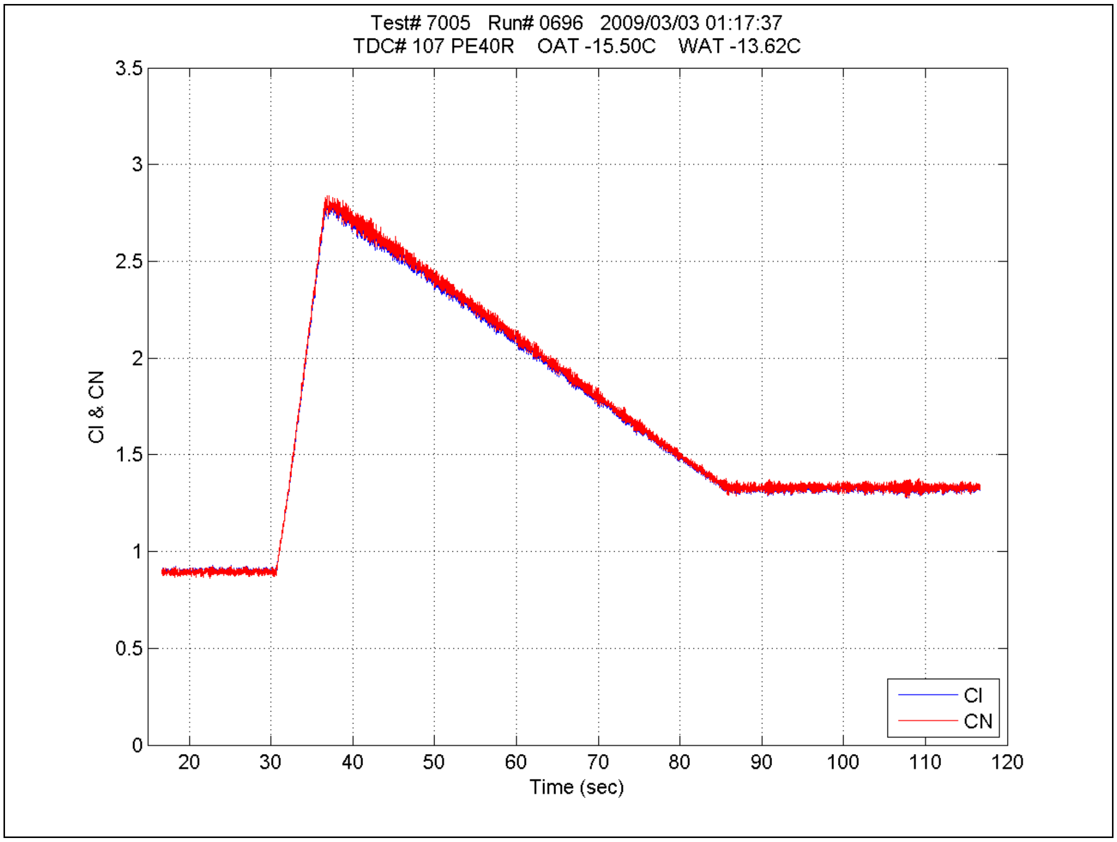
Test# 7005 Run# 0670 2009/03/02 04:05:26
TDC# 102 PE43 OAT -13.66C WAT -10.81C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
10
20
30
40
50
60
70
80
90
100
110



Test# 7005 Run# 0674 2009/03/02 04:49:32
TDC# 103 PE44 OAT -14.20C WAT -12.05C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
20
30
40
50
60
70
80
90
100
110
120


Test# 7005 Run# 0676 2009/03/02 04:56:49
TDC# 104 PE44R OAT -14.09C WAT -11.52C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
10
20
30
40
50
60
70
80
90
100
110


Test# 7005 Run# 0677 2009/03/02 05:37:10
TDC# 105 PE45 OAT -14.54C WAT -12.30C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
2
2.5
3
3.5
30
40
50
60
70
80
90
100
110
120
130


Test# 7005 Run# 0696 2009/03/03 01:17:37
TDC# 107 PE40R OAT -15.50C WAT -13.62C
CI & CN
Time (sec)
CI
CN
0
0.5
1
1.5
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2.5
3
3.5
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120

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