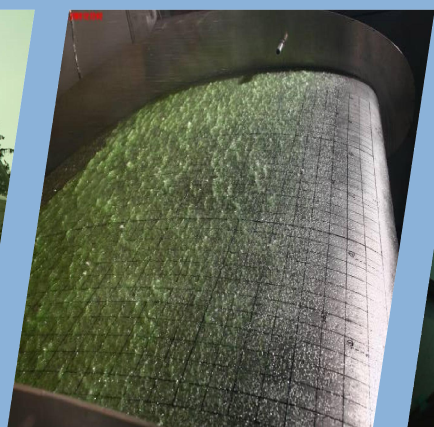
TP 14935E

Research for Further Development of Ice Pellet Allowance Times:

Wind Tunnel Trials to Examine Anti-Icing Fluid Flow-Off Characteristics

Winter 2008-09



Prepared for
Transportation Development Centre

In cooperation with

Civil Aviation
Transport Canada

and

The Federal Aviation Administration
William J. Hughes Technical Center

Prepared by:

APS Aviation Inc.

November 2009
Final Version 1.0

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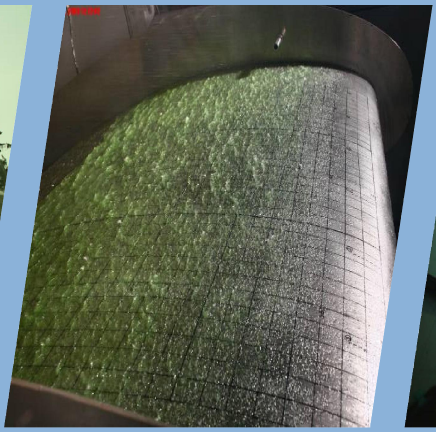


by

Marco Ruggi

November 2009
Final Version 1.0

APS Aviation Inc.

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

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

DOCUMENT ORIGIN AND APPROVAL RECORD

Prepared by:		January 18, 2018
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Approved by:	**	**
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Un sommaire français se trouve avant la table des matières.

***This report was prepared and signed by Marco Ruggi, reviewed and signed by John D'Avirro, and approved and signed by John Detombe in November 2009 as part of the first submission to Transport Canada (Final Draft 1.0). A final Transport Canada technical and editorial review was completed in December 2017; John Detombe was not available to participate in the final review or to sign the current version of this report.*

PREFACE

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

- To 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 NRC wind tunnel to further develop and expand ice pellet allowance times;
- To conduct various aerodynamic research activities at the NRC 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 Research General 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 Anti-Icing Fluid Flow-Off Characteristics Winter 2008-09.

In addition, an interim report entitled *Endurance Times Using Composite Surfaces* will be written.

This report, TP 14935E, has the following objective:

- To conduct flat plate and aerodynamic testing to substantiate and further develop the current ice pellet allowance times guidelines.

This objective was met by conducting small scale testing on flat plates, and a series of full-scale tests using the NRC open circuit wind tunnel to examine the flow-off properties of anti-icing fluids contaminated with simulated mixed conditions including ice pellets.

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 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 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 de-icing 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 NRC Open-Circuit Propulsion and Icing Wind Tunnel, and the NRC Climatic Engineering Facility, 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 (TDC). 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 (FAA).

16. Abstract

The objective of this study was to conduct flat plate and aerodynamic testing to substantiate and further develop the current ice pellet allowance times. A series of full-scale tests using the NRC open circuit wind tunnel was conducted to examine high speed and low speed flow-off properties of anti-icing fluids contaminated with simulated mixed conditions including ice pellets.

Type IV High Speed Allowance Times: The results indicated that all the cells of the Type IV high speed allowance time table were validated, however, some additional data is proposed for the -10 to -25ºC range for light and moderate ice pellets. A reduction to the light ice pellets mixed with moderate snow allowance time was issued for OAT above -5ºC. The testing conducted also allowed the expansion of the table to include a new 25 minute allowance time light ice pellets mixed with moderate rain for above -5ºC conditions, as well as a new 15 minute allowance time for "light ice pellets mixed with light snow for -5ºC to -10ºC conditions.

Type IV Low Speed Allowance Times: Testing supported the preliminary development of allowance times for low speed operations with Type IV fluid, however due to the limited data collected, further testing is recommended before a separate low speed allowance time table is published in the HOT guidelines.

Type III Low Speed Allowance Times: The results indicated a good potential for the use of Type III fluid during ice pellet conditions. A comprehensive preliminary allowance time table was developed, however the publication of the guidelines has been postponed until further data is collected.

Type II Allowance Times: The limited results indicate a good potential use for Type II fluids in mixed conditions with ice pellets, however further work is required to compile the necessary data to issue a separate Type II allowance time table.

A newly updated version of the Type IV allowance time table has been developed and adopted for the 2009-10 version of the HOT guidelines; this work was presented at the SAE G-12 meeting in Charleston in May 2009. Future work is recommended to further expand the current Type IV high speed table to include additional conditions. Testing to develop Type IV low speed, Type III, and Type II allowance time tables will be prioritized based on industry support and recommendations. It is recommended that testing during the winter of 2009-10 testing be conducted with a super-critical airfoil to provide a more aerodynamically sensitive model.

17. Key Words Ice Pellet, Allowance Time, High Speed Rotation, Low Speed Rotation, Type II, Type III, Type IV, Fluid Adherence, Fluid Flow-Off, Wind Tunnel	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 comptes rendus de recherche sur les essais de technologie de dégivrage et d'antigivrage des hivers précédents ont été produits pour Transports Canada. Ils sont disponibles au Centre de développement des transports (CDT). Plusieurs rapports ont été produits dans le cadre du programme de recherche de cet hiver. Leur objet est exposé à la préface. Le travail expliqué dans le présent rapport était en partie coparrainé par la Federal Aviation Administration (FAA).

16. Résumé

La présente étude avait pour objet de mener des essais aérodynamiques et sur plaque plane afin de confirmer et développer davantage les marges de tolérance actuelles dans des conditions de granules de glace. Des suites abstraites d'essais complets ont été menées avec la soufflerie à boucle ouverte du CNRC pour examiner les propriétés d'écoulement à basse et à haute vitesse de liquides d'antigivrage contaminés par des conditions simulées de précipitations avec granules de glace.

Marges de tolérance, liquide de type IV, haute vitesse : Les résultats ont validé toutes les cellules du tableau de marges de tolérance haute vitesse pour les liquides de type IV, mais des données additionnelles sont suggérées pour la plage de -10°C à -25°C pour les granules de glace légères ou modérées. Une réduction de marge de tolérance a été émise pour les granules de glace légères avec neige modérée, pour une température ambiante au-dessus de -5°C. Les essais ont aussi permis l'expansion du tableau par l'inclusion d'une nouvelle marge de tolérance de 25 minutes pour les conditions de granules de glace légères avec pluie modérée à des températures au-dessus de -5°C, ainsi qu'une nouvelle marge de tolérance de 15 minutes pour des conditions de granules de glace légères avec neige légère à des températures de la plage de -5°C à -10°C.

Marges de tolérance, liquide de type IV, basse vitesse : Les essais ont permis le développement préliminaire de marges de tolérance pour les liquides de type IV dans le cas d'opérations à basse vitesse mais, en raison de la quantité limitée de données recueillies, d'autre essais sont recommandés avant la publication d'un tableau de marges de tolérance séparé dans les lignes directrices sur les durées d'efficacité.

Marges de tolérance, liquide de type III, basse vitesse : Les résultats ont démontré un bon potentiel d'utilisation de liquide de type III dans des conditions de granules de glace. Un tableau préliminaire complet de marges de tolérance a été développé, mais la publication des lignes directrices a été reportée jusqu'à la collecte de données supplémentaires.

Marges de tolérance, liquide de type II : Les résultats limités démontrent le potentiel d'utilisation de liquide de type II dans des conditions mixtes avec granules de glace, mais du travail additionnel est requis pour compiler les données nécessaires à la publication d'un tableau séparé de marges de tolérance pour les liquides de type II.

Une version nouvellement actualisée du tableau de marges de tolérance pour les liquides de type IV a été développée et adoptée pour la version de 2009-2010 des lignes directrices sur les durées d'efficacité ; ces travaux ont été présentés à la réunion du G-12 de la SAE, à Charleston en mai 2009. D'autres travaux sont recommandés afin de développer davantage le tableau actuel pour les liquides de type IV, haute vitesse par l'ajout de conditions additionnelles. En conséquence de l'appui et des recommandations de l'industrie, la priorité sera accordée aux essais en vue du développement de tableaux de marges de tolérance pour les liquides de type IV, basse vitesse et pour les liquides de types II et III. Il est recommandé que les essais de l'hiver 2009-2010 soient effectués sur des surfaces portantes supercritiques, qui offrent un modèle aérodynamique plus sensible.

17. Mots clés Granule de glace, marge de tolérance, rotation à haute vitesse, rotation à basse vitesse, type II, type III, type IV, adhérence de liquide, écoulement de liquide, soufflerie	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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EXECUTIVE SUMMARY

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's (NRC) 3 m x 6 m Open-Circuit Propulsion and Icing Wind Tunnel (PIWT) to determine the flow-off characteristics of anti-icing fluid with and without mixed precipitation conditions with ice pellets.

Background and Objective

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

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

As a result of this costly incident, UPS set out to obtain experimental data to provide guidance and allow operations to continue in ice pellet conditions. During the winter of 2004-05, aerodynamic and endurance time testing were conducted in simulated ice pellet conditions. APS also conducted some preliminary flat plate research (see TP 14718E, *Preliminary Endurance Time Testing in Simulated Ice Pellet Conditions*) (1). Based on the preliminary data, an allowance of 20 minutes in light ice pellet conditions was proposed, however no changes to the HOT guidelines were made.

During the following winter of 2006-07, the FAA provided a 25 minute allowance time as a preliminary guideline; Transport Canada (TC) issued a note indicating that no changes would be made to the HOT guidelines. This allowance was based on the previous research conducted during the winter of 2005-06, primarily as a result of Falcon 20 aerodynamic research (see TP 14716E, *Falcon 20 Trials to Examine Fluid Removed From Aircraft During Takeoff With Ice Pellets*) (2); 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 targeted 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 ice pellets alone (no mixed conditions).

Due to the high occurrence of ice pellets combined with freezing rain or snow, 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 guideline. These allowance times were based on the research conducted during the winter of 2006-07 (see TP 14779E, *Development of Allowance Times for Aircraft Deicing Operations During Conditions with Ice Pellets*) (3). The recommended allowance times were based on aerodynamic research conducted using the PIWT and the NRC Falcon 20 aircraft; these results were presented at the SAE meeting in San Diego in May 2007. These allowance time guidelines were followed by a list of restrictions based on the results obtained through the research conducted, and the lack of data in specific conditions.

During the winter of 2007-08, additional endurance time testing and aerodynamic research was conducted to support and further expand the ice pellet allowance times (see TP 14871E, *Aircraft Trials to Examine Anti-Icing Fluid Flow-Off Characteristics: Ice Pellet Allowance Time Expansion Research*) (4). Full-scale testing with the NRC Falcon 20 and T-33 aircraft was conducted in mixed conditions with ice pellets and in non-precipitation conditions. Testing was primarily geared towards simulating low rotation speed aircraft. No changes to the allowance times were made as a result of this work as aerodynamic data were not available. It was recommended that additional testing be conducted in the PIWT during the winter of 2008-09 to validate and expand the results obtained.

A series of tests were designed and carried out during the winter of 2008-09 to validate and expand the current guidance material in ice pellet and mixed conditions. Testing was conducted with and without contamination. Research was conducted to validate and develop allowance times for the following applications:

- 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).

Conclusions and Observations

Type IV High Speed Allowance Times

Many of the cells of the allowance time table were validated, however, some additional data is proposed for the -10 to -25ºC range for light and moderate ice pellets. A reduction to the light ice pellets mixed with moderate snow allowance time was issued for Outside Air Temperature (OAT) above -5ºC: the allowance time was reduced from 25 minutes to 10 minutes. The testing conducted also allowed the expansion of the table to include a new 25 minute allowance time light ice pellets mixed with moderate rain for above -5ºC conditions, as well as a new 15 minute allowance time for light ice pellets mixed with light snow for -5ºC to -10ºC conditions. A newly updated version of the Type IV allowance time table has been developed and adopted for the 2009-10 version of the HOT Guidelines.

Type IV Low Speed Allowance Times

Testing was conducted for the preliminary development of allowance times for low speed operations with Type IV fluid. Allowance times were only developed for a limited number of cells due to issues observed with low speed fluid flow-off. Due to the limited tests and resulting lack of a comprehensive data set, it is recommended that further testing be conducted before a separate low speed allowance time table is published in the HOT guidelines. In addition, Type IV fluids are generally not certified (or do not qualify) for low speed takeoff; the resulting LOUT is not appropriate for operations. Modifications to the aerodynamic acceptance tests are required to better reflect the current generation of low speed aircraft and respective takeoff profiles (this work is currently ongoing and being performed by the SAE G-12 aerodynamic working group).

Type III Low Speed Allowance Times

Low speed allowance time testing with Type III fluid was conducted as a secondary objective during the winter of 2008-09, and as a result, only a limited amount of data were collected. The results indicated a good potential for the use of Type III fluid during ice pellet conditions. A comprehensive preliminary allowance time table was developed for Type III fluid applied at ambient temperature, however the publication of the guidelines has been postponed until further data is collected and until data for heated applications has been collected.

Type II Allowance Times

Allowance time testing with Type II fluid was conducted as a low priority objective during the winter of 2008-09, and as a result, only two tests were conducted. Although the results indicate a good potential use for Type II fluids in mixed conditions with ice pellets, further work is required to compile the necessary data to issue a separate Type II allowance time table.

Recommendations

New Type IV High Speed Allowance Time Table

A newly updated version of the Type IV allowance time table has been developed and adopted for the 2009-10 version of the HOT guidelines. This work was presented at the SAE G-12 meeting in Charleston in May 2009.

Future Work

Type IV High Speed Allowance Times

Historical winter weather data has indicated that a significant portion of "light ice pellets mixed with light snow" precipitation occurs below -10°C and "light ice pellets mixed with moderate snow" precipitation occurs below -5 to -10°C where no allowance times currently exist. It is recommended that future research target these conditions in order to allow greater flexibility to operators in conditions of mixed ice pellets and light or moderate snow. Some additional data is also proposed for the -10 to -25ºC range for light and moderate ice pellets; limited data were collected during the winter of 2008-09 due to lack of cold weather.

Type IV Low Speed Allowance Times

Preliminary testing indicated a potential to develop a Type IV low speed allowance time table. However, due to the limited data collected, as well as possible fluid flow issues observed with the low speed tests, it is recommended that further testing be conducted before a separate low speed allowance time table is published in the HOT guidelines.

Type IV fluids are generally not certified (or do not qualify) for low speed takeoff. Modifications to the aerodynamic acceptance tests are required to better reflect the current generation of low speed aircraft and respective takeoff profiles (this work is currently ongoing and being performed by the SAE G-12 aerodynamic working group). Until these modifications are issued and Type IV fluid is qualified for low speed operations with reasonable LOUT's, low speed allowance times for Type IV fluids should not be published.

Type III Low Speed Allowance Times

The preliminary results indicated a good potential for the use of Type III fluid during ice pellet conditions. Although a comprehensive data set was available for Type III fluid applied at ambient temperature, it was recommended that the preliminary Type III allowance time table not be published in the HOT guidelines for the winter of 2009-10 due to the limitations of the data set. Further testing is recommended to substantiate the current results, as well as to expand the data set to include heated Type III fluid applications, and high speed takeoff profiles.

Type II Allowance Times

The preliminary results indicated a good potential for the use of Type II fluid during ice pellet conditions. Due to the limited data collected, it is recommended that further testing be conducted before a separate allowance time table be published in the HOT guidelines.

In addition, there has not been a strong industry need to have allowance times developed for use with Type II fluids. Future work with Type II fluids should remain a lower priority in comparison to the Type III and Type IV high speed and low speed aerodynamic research.

Super-Critical Wing Research

The current generation of "regional jet" aircraft are developed with super-critical wing design. Some of these aircraft require strict maintenance procedures to ensure a polished leading edge, as minimal amounts of contamination (in the form of insects, 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 in the wind tunnel during the winter of 2009-10 to validate the current Type IV high speed allowance times for use with aircraft with super-critical wing designs.

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SOMMAIRE

En vertu d'un contrat avec le Centre de développement des transports (CDT) et avec le soutien financier de la Federal Aviation Administration (FAA), APS Aviation Inc. (APS) a entrepris des recherches visant à faire progresser la technologie de dégivrage et d'antigivrage d'aéronefs au sol. APS a mené une suite d'essais complets dans la soufflerie à propulsion à boucle ouverte (SPBOG) de 3 m x 6 m du Conseil national des recherches Canada (CNRC) pour identifier les caractéristiques du liquide d'antigivrage lorsqu'il s'écoule de la surface, avec ou sans condition de précipitation mixtes, incluant des granules de glace.

Contexte et objectif

Avant l'hiver 2006-2007, il n'y avait pas de lignes directrices sur les durées d'efficacité (HOT) dans des conditions de granules de glace, mais les aéronefs pouvaient quand même partir dans des conditions de granules de glace, après un dégivrage et une vérification de contamination avant le décollage. Ce protocole était acceptable pour les aéronefs de transport équipés de fenêtres d'issues de secours au-dessus du bord d'attaque de l'aile de l'aéronef; cependant, il causait un problème important dans le cas d'aéronefs de transport offrant une visibilité limitée des ailes à partir de la cabine.

Le 22 décembre 2004, les aéronefs de la United Parcel Service (UPS) de Louisville ont été retenus au sol durant plusieurs heures en raison de conditions prolongées de granules de glace. La configuration des aéronefs cargo ne permettait pas de vérifications de contamination à bord par l'équipage avant le décollage. FedEx a connu des problèmes semblables à Memphis. Suite à cet incident, la FAA a émis en octobre 2005 deux avis de restriction de décollage dans des conditions de granules de glace.

Par suite de cet incident coûteux, UPS s'est efforcée d'obtenir des données expérimentales qui donneraient des lignes directrices et permettraient la poursuite des opérations dans des conditions de granules de glace. Durant l'hiver 2004-2005, des essais aérodynamiques et de durées d'efficacité ont été menés dans des conditions simulées de granules de glace. APS a également mené des recherches sur plaque plane (voir le rapport TP 14718F , *Preliminary Endurance Time Testing in Simulated Ice Pellet Conditions*) (1). En fonction des données préliminaires, une durée de 20 minutes a été proposée pour les conditions de granules de glace légères, mais aucun changement n'a été apporté aux lignes directrices sur les durées d'efficacité.

Au cours de l'hiver 2006-2007, la FAA a donné une marge de tolérance de 25 minutes à titre de ligne directrice préliminaire; TC a émis une note précisant qu'aucun changement ne serait apporté aux lignes directrices sur les durées

d'efficacité. Cette marge se fondait sur des recherches antérieures menées au cours de l'hiver de 2005-2006, principalement suite à la recherche aérodynamique sur le Falcon 20 (voir la TP 14716F) (2); ces résultats ont été présentés à la réunion de la Society of Automotive Engineers (SAE), à Lisbonne en mai 2006. En considération de l'option de vérification de contamination avant décollage, la marge visée de 20 minutes a été prolongée à 25 minutes; les vérifications de contamination avant décollage ne s'appliqueraient plus. Cette marge était suivie d'une liste de conditions; l'une des restrictions s'appliquait aux opérations dans des conditions de granules de glace seulement (pas aux conditions mixtes).

En raison des conditions fréquentes de granules de glace combinées à la pluie verglaçante ou à la neige, l'industrie a demandé des lignes directrices additionnelles pour les opérations dans des conditions mixtes de granules de glace. Au cours de l'hiver 2006-2007, des recherches additionnelles aérodynamiques et sur les durées d'efficacité ont été menées dans des conditions simulées de granules de glace.

Au cours de l'hiver 2007-2008, TC et la FAA ont donné des lignes directrices sur les marges de tolérance pour les opérations dans des conditions mixtes avec granules de glace. Ces marges de tolérance étaient fondées sur la recherche menée au cours de l'hiver 2006-2007 (voir la TP 14779F) (3). Les marges de tolérance recommandées étaient fondées sur la recherche aérodynamique menée à l'aide de la SPBOG et sur l'aéronef Falcon 20 du CNRC; ces résultats ont été présentés à la réunion de la SAE, à San Diego en mai 2007. Ces lignes directrices sur les marges de tolérance ont été suivies d'une liste de restrictions fondées sur les résultats de la recherche et le manque de données dans des conditions spécifiques.

Au cours de l'hiver 2007-2008, des essais additionnels de durées d'efficacité et de la recherche aérodynamique ont été menés pour confirmer et compléter les marges de tolérance dans les granules de glace (voir la TP 14871F) (4). Des essais complets avec les aéronefs Falcon 20 et T-33 du CNRC ont été menés dans des conditions mixtes avec granules de glace et en absence de précipitation. Les essais visaient principalement la simulation d'aéronefs à basse vitesse de rotation. En l'absence de données aérodynamiques, aucun changement aux marges de tolérance n'a été apporté suite à ces travaux. Il a été recommandé que des essais additionnels soient menés dans la SPBOG durant l'hiver 2008-2009 pour valider et compléter les résultats.

Une suite d'essais ont été conçus et menés au cours de l'hiver 2008-2009 pour valider et compléter les lignes directrices actuelles pour les conditions mixtes avec granules de glace. Les essais ont été menés avec et sans contamination. Les recherches ont été menées pour valider et développer des marges de tolérance pour les applications suivantes :

- Liquide de type IV – Haute vitesse, aire de trafic (des marges de tolérance sont actuellement disponibles);
- Liquide de type IV – Basse vitesse, aire de trafic (des marges de tolérance ne sont pas disponibles);
- Liquide de type III – Basse vitesse, aire de trafic (des marges de tolérance ne sont pas disponibles); et
- Liquide de type II – (des marges de tolérance ne sont pas disponibles).

Conclusions et observations

Marges de tolérance, liquide de type IV, haute vitesse

Plusieurs cellules du tableau de marges de tolérance ont été validées, mais des données additionnelles sont proposées pour la plage de -10°C à -25°C dans des conditions de granules de glace légères et modérées. Une réduction applicable aux marges de tolérance pour les granules de glace légères avec neige modérée a été émise pour les températures ambiantes de plus de -5°C : les marges de tolérance ont été réduites de 25 minutes à 10 minutes. Les essais ont aussi permis de développer le tableau pour y inclure une nouvelle marge de tolérance de 25 minutes pour les granules de glace légères avec pluie modérée pour les températures supérieures à -5°C, de même qu'une nouvelle marge de tolérance de 15 minutes pour les granules de glace légères avec neige légère pour les températures de -5°C à -10°C. Une nouvelle version actualisée du tableau de marges de tolérance pour les liquides de type IV a été développée et adoptée pour la version de 2009-2010 des lignes directrices sur les durées d'efficacité.

Marges de tolérance, liquide de type IV, basse vitesse

Des essais ont été menés en vue du développement préliminaire de marges de tolérance des liquides de type IV pour les opérations à basse vitesse. Des marges de tolérance n'ont été développées que pour un nombre limité de cellules en raison des problèmes d'écoulement des liquides pour les opérations à basse vitesse. En raison du nombre limité d'essais et du manque conséquent d'un ensemble complet de données, il est recommandé de faire davantage d'essais avant de publier un tableau séparé de marges de tolérance basse vitesse dans les lignes directrices sur les durées d'efficacité. De plus, les liquides de type IV ne sont généralement pas certifiés (ou ne se qualifient pas) pour des décollages à basse vitesse; la température minimale d'utilisation opérationnelle (LOUT) qui en résulte ne convient pas aux opérations. Des modifications aux essais d'acceptabilité sur le plan aérodynamique sont nécessaires afin de mieux refléter la génération actuelle d'aéronefs à basse vitesse et leurs profils de décollage correspondants (ces travaux sont en cours et exécutés par le groupe de travail G-12 de la SAE sur l'aérodynamisme).

Marges de tolérance, liquide de type III, basse vitesse

Des essais de marges de tolérance basse vitesse avec du liquide de type III ont été menés à titre d'objectif secondaire au cour de l'hiver 2008-2009 et, en conséquence, seule une quantité limitée de données a été recueillie. Les résultats indiquaient un bon potentiel d'utilisation de liquide de type III dans des conditions de granules de glace. Un tableau préliminaire complet de marges de tolérance a été développé pour le liquide de type III appliqué à température ambiante, mais la publication des lignes directrices a été reportée à la collecte de davantage de données et jusqu'à ce que des données d'application chauffée soient recueillies.

Marges de tolérance, liquides de type II

Des essais sur les marges de tolérance de liquide de type II ont été menés à titre d'objectif de faible priorité au cours de l'hiver 2008-2009 et, en conséquence, deux essais seulement ont été effectués. Bien que les résultats indiquent un bon potentiel d'utilisation de liquide de type II dans des conditions mixtes avec granules de glace, davantage de travaux sont requis pour compiler les données nécessaires à la publication d'un tableau séparé de marges de tolérance pour les liquides de type II.

Recommandations

Nouveau tableau de marges de tolérance, liquide de type IV, haute vitesse

Une version nouvellement actualisée du tableau de marges de tolérance des liquides de type IV a été développée et adoptée pour la version de 2009-2010 des lignes directrices sur les durées d'efficacité. Ces travaux ont été présentés à la réunion du G-12 de la SAE, à Charleston en mai 2009.

Travaux à venir

Marges de tolérance, liquides de type IV, haute vitesse

Les données météorologiques hivernales historiques ont démontré qu'une partie importante des précipitations de « granules de glace légères avec neige légère » se produisent sous -10°C et que les « granules de glace légères avec neige modérée » se produisent entre -5 à -10°C, une plage où des marges de tolérance ne sont pas disponibles. Il est recommandé que les recherches futures portent sur ces conditions afin de permettre une plus grande flexibilité aux exploitants dans des conditions de granules de glace avec neige légère ou modérée. Des données additionnelles sont aussi recommandées pour les granules de glace légères ou modérées dans la plage de -10ºC à -25ºC; des données limitées ont été recueillies au cours de l'hiver 2008-2009 en raison de l'absence de températures froides.

Marges de tolérance, liquides de type IV, basse vitesse

Des essais préliminaires ont démontré la possibilité de développer un tableau de marges de tolérance pour les liquides de type IV et les basses vitesses. Cependant, en raison des données limitées recueillies, ainsi que des problèmes possibles d'écoulement des liquides observés lors des tests à basse vitesse, il est recommandé de mener d'autres essais avant de publier un tableau séparé de marges de tolérance pour les basses vitesses dans les lignes directrices sur les durées d'efficacité.

Les liquides de type IV ne sont généralement pas certifiés (ou ne se qualifient pas) pour les décollages à basse vitesse. Des modifications aux essais d'acceptabilité sur le plan aérodynamique sont nécessaires afin de mieux refléter la génération actuelle d'aéronefs à basse vitesse et leurs profils de décollage correspondants (ces travaux sont en cours et exécutés par groupe de travail G-12 de la SAE sur l'aérodynamisme). D'ici la publication de ces modifications et la qualification du liquide de type IV pour les opérations à basse vitesse avec des températures minimales d'utilisation opérationnelle, des marges de tolérance à basse vitesse pour les liquides de type IV ne devraient pas être publiées.

Marges de tolérances, liquides de type III, basse vitesse

Les résultats préliminaires ont indiqué un bon potentiel d'utilisation de liquide de type III dans des conditions de granules de glace. Bien qu'un ensemble complet de données était disponible pour les liquides de type III appliqués à la température ambiante, il a été recommandé de ne pas publier le tableau préliminaire de marges de tolérances pour les liquides de type III dans les lignes directrices sur les durées d'efficacité de l'hiver 2009-2010, en raison des limites de l'ensemble des données. De nouveaux essais sont recommandés afin de corroborer les résultats actuels, ainsi que pour enrichir l'ensemble de données et inclure les applications de liquide de type III chauffé et les profils de décollage à haute vitesse.

Marges de tolérance, liquides de type II

Les résultats préliminaires ont indiqué un bon potentiel d'utilisation de liquide de type II dans des conditions de granules de glace. En raison de la collecte limitée de données, il est recommandé de mener d'autres essais avant de publier un tableau séparé de marges de tolérance dans les lignes directrices sur les durées d'efficacité.

De plus, l'industrie n'a pas eu un grand besoin pour le développement de marges de tolérance pour les liquides de type II. Les travaux futurs sur les liquides de type II devraient mériter une moindre priorité, comparativement à la recherche aérodynamique sur les liquides de types III et IV, à basse et haute vitesse.

Recherche sur les ailes supercritiques

La génération actuelle d'aéronefs à réaction de transport régional comprend la conception d'ailes supercritiques. Certains de ces aéronefs exigent des procédures strictes d'entretien afin d'assurer un bord d'attaque poli, car de minuscules quantités de contamination (sous forme d'insectes, etc.) peuvent produire de sérieuses pénalités aérodynamiques. La même chose s'applique à la suppression de contamination sous forme de précipitation solide.

En raison de la popularité de ces aéronefs, il est recommandé de mener des recherches aérodynamiques dans la soufflerie au cours de l'hiver 2009-10 pour valider les marges de tolérance actuelles haute vitesse des liquides de type IV, à appliquer aux aéronefs équipés d'ailes supercritiques.

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GLOSSARY

APS	APS Aviation Inc.
EG	Ethylene Glycol
FAA	Federal Aviation Administration
HOT	Holdover Time
MSC	Meteorological Service of Canada
NASA	National Aeronautics and Space Administration
NRC	National Research Council Canada
NRCIAR	National Research Council Canada Institute for Aerospace Research
OAT	Outside Ambient Temperature
PET	Montréal–Pierre Elliott Trudeau International Airport
PG	Propylene Glycol
PIWT	3 m x 6 m Open-Circuit Propulsion and Icing Wind Tunnel
SAE	Society of Automotive Engineers
TC	Transport Canada
TDC	Transportation Development Centre
UPS	United Parcel Service

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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 little 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.

Over the past several years, 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 US 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.

As part of a larger research program examining de/anti-icing fluid flow-off during simulated aircraft takeoff, APS conducted a series of full-scale tests in the National Research Council Canada (NRC) 3 m x 6 m Open-Circuit Propulsion and Icing Wind Tunnel (PIWT) to determine the flow-off characteristics of anti-icing fluid with and without mixed precipitation conditions with ice pellets.

1.1 Background

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

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

As a result of this costly incident, UPS set out to obtain experimental data to provide guidance and allow operations to continue in ice pellet conditions. During the winter of 2004-05, aerodynamic and endurance time testing were conducted in simulated ice pellet conditions. APS also conducted some preliminary flat plate research (see TC report, *Preliminary Endurance Time Testing in Simulated Ice Pellet Conditions*, TP 14718E) (1). Based on the preliminary data, an allowance of 20 minutes in light ice pellet conditions was proposed, however no changes to the Holdover Time (HOT) guidelines were made.

During the following winter of 2006-07, the FAA provided a 25 minute allowance as a preliminary guideline; TC issued a note indicating that no changes would be made to the HOT guidelines. This allowance was based on the previous research conducted during the winter of 2005-06, primarily as a result of Falcon 20 aerodynamic research (see TC report, *Falcon 20 Trials to Examine Fluid Removed from Aircraft During Takeoff with Ice Pellets* TP 14716E) (2); 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 targeted 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 ice pellets alone (no mixed conditions).

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

During the winter of 2007-08, the TC and FAA provided allowance time guidance material for operations in mixed conditions with ice pellets guideline. These allowance times were based on the research conducted during the winter of 2006-07 (see TC report, *Development of Allowance Times for Aircraft Deicing Operations During Conditions with Ice Pellets* TP 14779E) (3). The recommended allowance times were based on aerodynamic research conducted using the PIWT and the NRC Falcon 20 aircraft; these results were presented at the SAE meeting in San Diego in May 2007. These allowance time guidelines were followed by a list of restrictions based on the results obtained through the research conducted, and the lack of data in specific conditions.

During the winter of 2007-08, additional endurance time testing and aerodynamic research was conducted to support and further expand the ice pellet allowance times (see TC report, *Aircraft Trials to Examine Anti-Icing Fluid Flow-Off*

Characteristics: Ice Pellet Allowance Time Expansion Research, TP 14871E) (4). Full-scale testing with the NRC Falcon 20 and T-33 aircraft was conducted in mixed conditions with ice pellets and in non-precipitation conditions. Testing was primarily geared towards simulating low rotation speed aircraft. No changes to the allowance times were made as a result of this work as aerodynamic data were not available. It was recommended that additional testing be conducted in the PIWT during the winter of 2008-09 to validate and expand the results obtained.

Table 1.1 describes the timeline of the developed allowance time guidance material.

Table 1.1: Timeline of Developed Allowance Time Guidance Material

Winter Testing	Research Conducted	FAA Allowance Time	TC Allowance Time	Report TP #	Related Winter HOT Guidelines
2004-05	UPS Research APS PMG Research	October 2005 Notices 8000.309 and 8000.313 (no takeoff in IP)	No Changes to Guidelines	Data available through UPS & TP 14718	2005-06
2005-06	APS Falcon 20	20 minutes targeted, 25 minutes reccomended *(to include 5 min PTCC)*	Note include indicating no changes to guidelines	TP 14716E	2006-07
2006-07	APS Wind Tunnel & Falcon 20	Allowance Time Table 1st Version	Allowance Time Table 1st Version (October 2007)	TP 14779E	2007-08
2007-08	APS Falcon 20	Allowance Time Table 1st Version	Allowance Time Table 1st Version	TP 14871E	2008-09
2008-09	APS Wind Tunnel	Allowance Time Table 2nd Version	Allowance Time Table 2nd Version	TP (08-09) 03	2009-10

1.2 Program Objectives

A test program was developed for the winter of 2008-09 in an attempt to substantiate and possibly expand the current ice pellet allowance times.

A series of tests were designed and carried out during the winter of 2008-09 to validate and expand the current guidance material in ice pellet and mixed conditions. Testing was conducted with and without contamination. Research was conducted to validate and develop allowance times for the following applications:

- 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).

The work statement for these tests is provided in Appendix A.

1.3 Previous Falcon 20 Full-Scale Testing

Previous tests to examine the elimination of failed SAE Type IV fluids from aircraft wings during takeoff were conducted during the 1997-98 and 1998-99 winter seasons. These tests, based on simulated takeoff tests using the NRC Falcon 20 aircraft, showed that the test approach was a viable one. The Falcon 20 test program conducted during the winters of 2001-02 and 2002-03 addressed the effects of unshed anti-icing fluid on aircraft takeoff performance.

This research is documented in detail in a series of five reports written by APS for TC:

- TP 13316E, *Contaminated Aircraft Takeoff Test 1997/98 Winter* (5);
- TP 13479E, *Contaminated Aircraft Takeoff Tests for the 1998-99 Winter* (6);
- TP 13666E, *Contaminated Aircraft Simulated Takeoff Tests for the 1999-2000 Winter: Preparation and Procedures* (7);
- TP 13995E, *Aircraft Take off Test Program for Winter 2001-02: Testing to Evaluate the Aerodynamic Penalties of Clean or Partially Expended De/Anti-Icing Fluid* (8); and
- TP 14147E, *Aircraft Takeoff Test Program for Winter 2002-03: Testing to Evaluate the Aerodynamic Penalties of Clean or Partially Expended De/Anti-Icing Fluid* (9).

Research was conducted during the winter of 2005-06 using the Falcon 20 aircraft to determine the maximum amount of ice pellet contamination that will flow-off an anti-iced aircraft at takeoff. This research is documented in detail in a report written by APS for TC (see TC report, TP 14716E, *Falcon 20 Trials to Examine Fluid Removed from Aircraft During Takeoff with Ice Pellets*) (2).

During the winter of 2006-07, extensive testing was conducted in mixed ice pellet conditions in the NRC PIWT. The Falcon 20 aircraft was used to validate the results obtained in the NRC PIWT by conducting a limited number of validation tests. This research is documented in detail in a report written by APS for TC (see TC report, TP 14779E, *Development of Allowance Times for Aircraft Deicing Operations During Conditions with Ice Pellets*) (3).

The details of the methodology used for this testing is documented in detail in a report written by APS for Transport Canada:

- *TP 14778E, Flow of Contaminated Fluid from Aircraft Wings: Feasibility Report (10).*

During the winter of 2007-08, the NRC PIWT was not available for testing during the winter months. The Falcon 20 aircraft was used to conduct simulated low rotation speed tests in mixed conditions with ice pellets. Two tests were also conducted with the NRC T-33 aircraft to validate the low rotation speed results obtained with the Falcon 20. This research is documented in detail in a report written by APS for Transport Canada (see TC report TP 14871E, *Aircraft Trials to Examine Anti-Icing Fluid Flow-Off Characteristics: Ice Pellet Allowance Time Expansion Research*) (4).

1.4 Previous NRC Wind Tunnel Full-Scale Testing

Previous tests to examine aerodynamic performance effects of de/anti-icing fluids that had been contaminated by varying quantities of freezing precipitation were conducted over three winter seasons at the NRC PIWT. The airfoil tested was a full-scale National Aeronautics and Space Administration (NASA) LS(1)-0417 section with a Fowler flap deployed at 15 degrees. A spray bar located in the wind tunnel settling chamber produced artificial snow. Takeoff was simulated by accelerating the test section wind speed, and aerodynamic data were obtained while pitching the airfoil to the stall. These tests, based on takeoff simulations, showed that the test approach was a viable one.

This research is documented in detail in a report written in May 1999 by the National Research Council Canada Institute for Aerospace Research (NRCIAR) for TC, TP 13426E, *Airfoil-Flap Performance with De/Anti-Icing Fluids and Freezing Precipitation* (11).

During the winter of 2006-07, extensive testing was conducted in simulated mixed ice pellet conditions in the NRC PIWT. Testing was primarily geared towards expansion of the 25 minute allowance time for ice pellets. Testing included mixed ice pellet conditions as well as preliminary testing in heavy snow conditions. This research is documented in detail in a report written by APS for TC, see TP 14779E, *Development of Allowance Times for Aircraft Deicing Operations During Conditions with Ice Pellets* (3).

The details of the methodology used for this testing is documented in detail in a report written by APS for TC, see TP 14778E, *Flow of Contaminated Fluid from Aircraft Wings: Feasibility Report* (10).

1.5 Overview of 2008-09 Testing

Testing during the winter of 2008-09 comprised of small scale testing conducted on flat plates and full-scale testing conducted using the NRC PIWT. The primary testing conducted is summarized below:

- Flat plate testing conducted to investigate fluid adherence in mixed ice pellet and light freezing rain conditions (research geared to support aerodynamic research conducted):
    - Testing with Type II, III, and IV Fluids (April 2009 at NRC).
- Aerodynamic research conducted to investigate fluid flow-off of contaminated fluid following simulated ice pellet and mixed conditions to substantiate and further develop the current ice pellet allowance times:
    - Type IV Fluid - High Speed Ramp (Allowance times currently exist);
    - Type IV Fluid - Low Speed Ramp (No Allowance time exist);
    - Type III Fluid - Low Speed Ramp (No Allowance time exist); and
    - Type II Fluid (No Allowance time exist).

In addition, some preliminary work was conducted as a lower priority to address current industry concerns. This work has been documented in the TC report, TP 14939E, *Exploratory Wind Tunnel Aerodynamic Research Examination of Anti-Icing Fluid Flow-Off Characteristics Winter 2008-09* (12).

Table 1.2 demonstrates the groupings for the global set of tests conducted at the wind tunnel during the winter of 2008-09. Only tests pertaining to ice pellet allowance times (groups 1 to 5) are described in this report. Table 1.3 demonstrates in greater detail the groupings for the secondary R&D objective tests.

Table 1.2: Summary of 2008-09 Wind Tunnel Tests by Objective

1. Type IV High Speed (Total: 24 Runs)	**4. Type IV Low Speed** (Total: 17 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	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)	**5. Baseline Fluid Only/Dry** (Total: 21 Runs)
23, 60	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)	**6. Secondary R&D Objectives** (Total: 34 Runs)
14, 16, 26, 47, 48, 57, 73, 74, 78, 100, 101	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 1.3: 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 Freeze 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

1.6 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 the results from the flat plate tests conducted in simulated mixed ice pellet conditions;
c) Section 4 describes data collected during the full-scale testing conducted;
d) Section 5 describes the analysis methodology used to evaluate the wind tunnel tests conducted;
e) Section 6 describes the data, results, and observations regarding the Type IV high speed allowance time testing;
f) Section 7 describes the data, results, and observations regarding the Type IV low speed allowance time testing;
g) Section 8 describes the data, results, and observations regarding the Type III low speed allowance time testing;
h) Section 9 describes the data, results, and observations regarding the Type II allowance time 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.

2.1 Wind Tunnel Test Site

The 2008-09 PIWT tests were performed at 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 fan at entry, permits contaminants associated with the test articles (such as heat, or de/anti-icing fluid) to discharge directly, without being recirculated or contacting the fan. The fan is normally driven electrically but high-speed operation can be accommodated by a gas turbine drive system. Due to the requirements of both high speed and low speed operation during the testing, the gas turbine was selected to allow for greater flexibility; the gas turbine drive can perform both low and high speed operations whereas the electric drive is limited to low speed operations.

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 set-up 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 results collected to date. Table 2.1 presents the calendar of wind tunnel tests performed in 2008-09. It should be noted that the tests listed include all the tests conducted including the tests not pertaining to the ice pellet allowance time objectives. At the beginning of each test day, a plan was developed which 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, FAA, and APS.

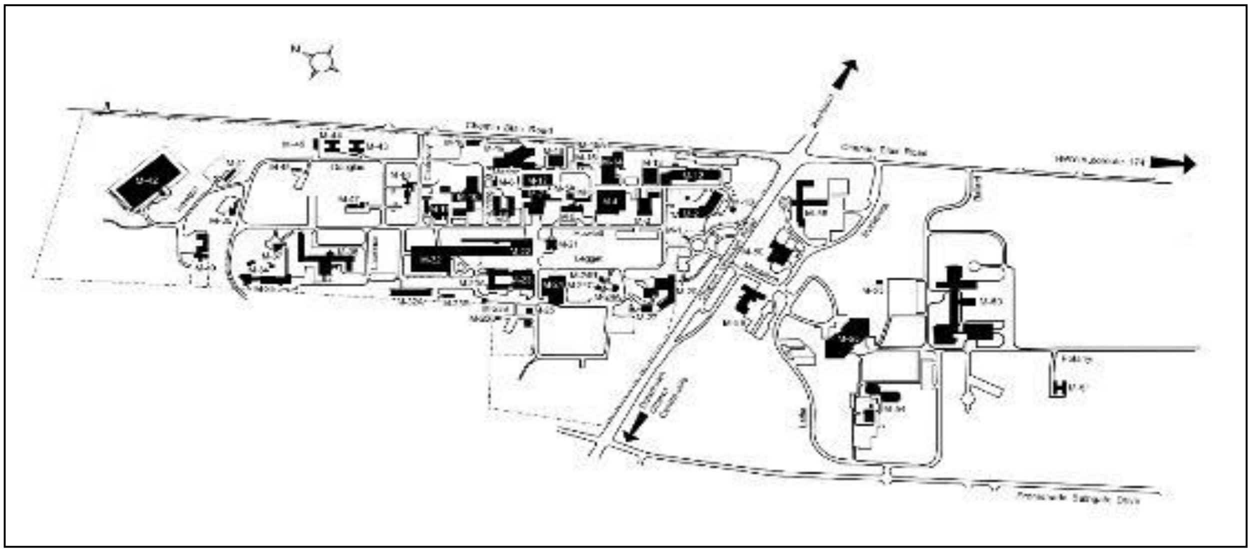

Figure 2.1: Schematic of NRC Montreal Road Campus

Table 2.1: Calendar of Tests

Date	Number of Test Runs	Test Numbers
15-Jan-09	Set-up	n/a
16-Jan-09	Set-up	n/a
21-Jan-07	Precipitation Calibration	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

2.3 Wind Tunnel Procedure

To satisfy the program objective, simulated takeoff and climb-out tests were performed with the NASA LS(1)-0417 wing section (a low speed airfoil fitted with a fowler flap), 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 reports TP 13426E, *Air-Flap Performance with De-Anti-Icing Fluids and Freezing Precipitation* (11) and *Experimental and Numerical Studies of the Effects of Upper Surface Roughness on Aileron Performance,* TP 14180E) (13).

The procedure for each test was as follows:

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; and

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

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

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

The length of each test (from start of set-up to end of last measurement) varied largely due to the length of exposure to precipitation (if applicable). Time required for set-up and teardown as well as preparing and configuring the aircraft stayed relatively the same from test to test. Figure 2.2 demonstrates a sample time line for a typical wind tunnel test. It should be noted that a precipitation exposure time of 30 minutes was used for demonstration purposes; this varied for each test depending on the objective.

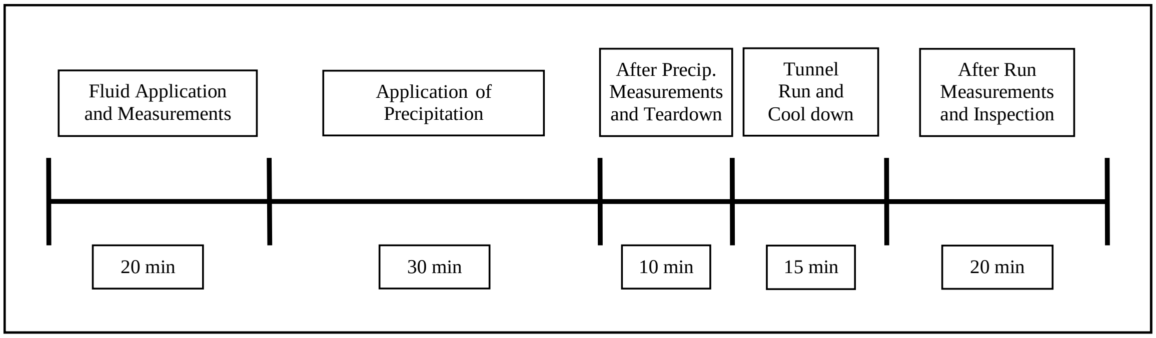

Figure 2.2: Typical Wind Tunnel Test Timeline

2.5 Wind Tunnel

The experiments were performed in the NRC PIWT. This facility is an open-circuit wind tunnel with the 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 to 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.

2.5.1 NASA LS(1)-0417 Wing Section

The wing section used for testing was a NASA LS(1)-0417 low speed airfoil 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 TC reports TP 13426E, *Flow of Contaminated Fluid from Aircraft Wings: Feasibility Report* (10) and TP 14180E, *Experimental and Numerical Studies of the Effects of Upper Surface Roughness on Aileron Performance*) (13).

2.5.2 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) Chord length not including flap: 1.8 m (6 ft.); and
b) Width: 2.4 m (8 ft.).

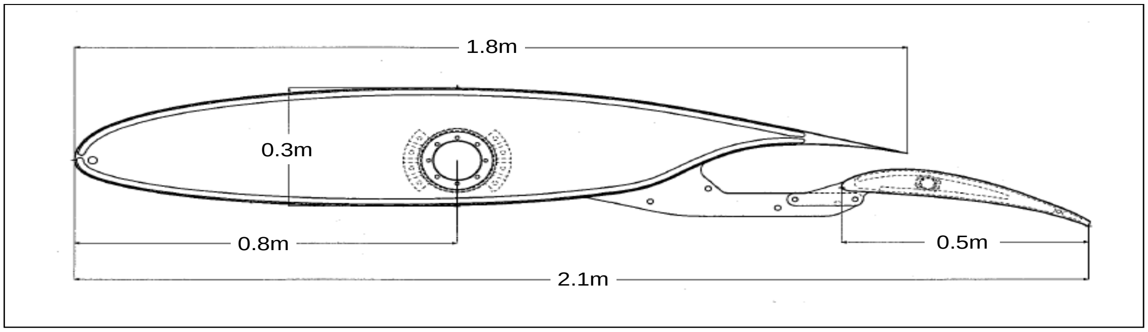

Figure 2.3: NASA LS(1)-0417 Wing Section

The wing section was fitted with a Fowler flap; however, the flap position was fixed at 15° and was not changed during testing. No moveable devices were available on the wing section. Detailed coordinates for this airfoil are included in Appendix C.

End plates were installed on the wing section to eliminate the "wall effects" from the wind tunnel walls (aerodynamic interference caused by the walls on an airfoil spanning the wind tunnel) 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.

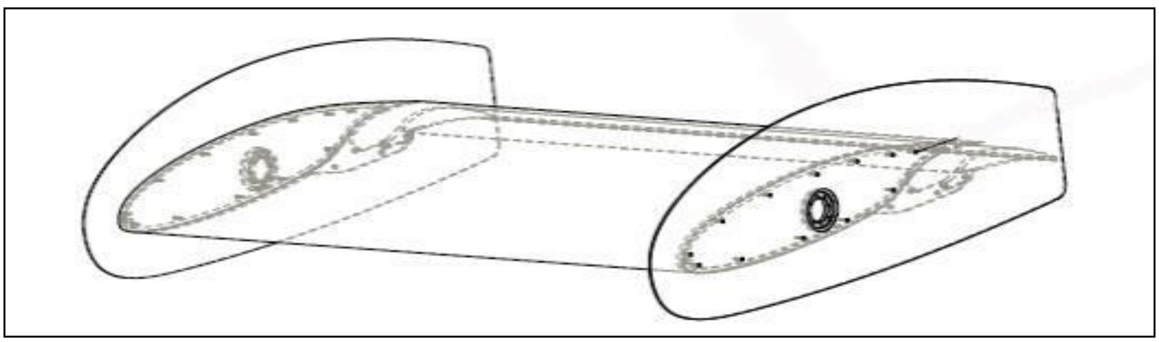

Figure 2.4: End Plates Installed on NASA LS(1)-0417 Wing Section

2.5.3 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. 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 data collected. The wing section was also equipped with three thermistor sensors (these were installed by NRC personnel) recording the skin temperature on the leading edge (two sensors) and on the trailing edge (one sensor). Theses thermistors were primarily used 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 handheld temperature probe by APS personnel and is described in Section 2.14.3.

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

- Ambient temperature inside the tunnel;
- Outside ambient temperature (OAT);
- Air pressure;
- Wind speed; and
- Relative humidity.

2.5.4 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. Additional notes can be found in Appendix C.

2.6 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.

2.7 Simulated Precipitation

2.7.1 Ice Pellets

In a previous analysis of natural ice pellet events, the diameter of ice pellets was measured. It was found that the ice pellets generally ranged from 1 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 to 4.0 mm to represent the most common ice pellet size 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 pellets size range. Handheld 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.

2.7.2 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 simulated snow versus natural snow. The simulated 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. Handheld motorized dispensers were used to dispense the snow. The snow was applied to the leading and trailing edges of the wing at the same time.

2.7.3 Freezing Rain/Rain

The same sprayer head and scanner used for HOT testing at the NRC climatic engineering facility 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.

2.8 Simulated Precipitation Related Equipment

2.8.1 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 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 15 x 15 cm, over an area 3.4 x 3.4 metres. Pre-measured amounts of IP/Snow were dispersed over this area and the amount collected by each pan was recorded. A distribution footprint of the dispenser was attained and efficiency for the dispenser was computed.

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

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

2.8.2 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 climatic engineering facility 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 two seconds are required for the sprayer to disperse across the 8′ 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.

2.9 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.

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;
- Moderate Freezing Drizzle: 5-13 g/dm²/h;
- Light Rain: 13-25 g/dm²/h;
- Moderate Rain: 25-75 g/dm²/h;
- Light Snow: 4-10 g/dm²/h; and
- Moderate Snow: 10-25 g/dm²/h.

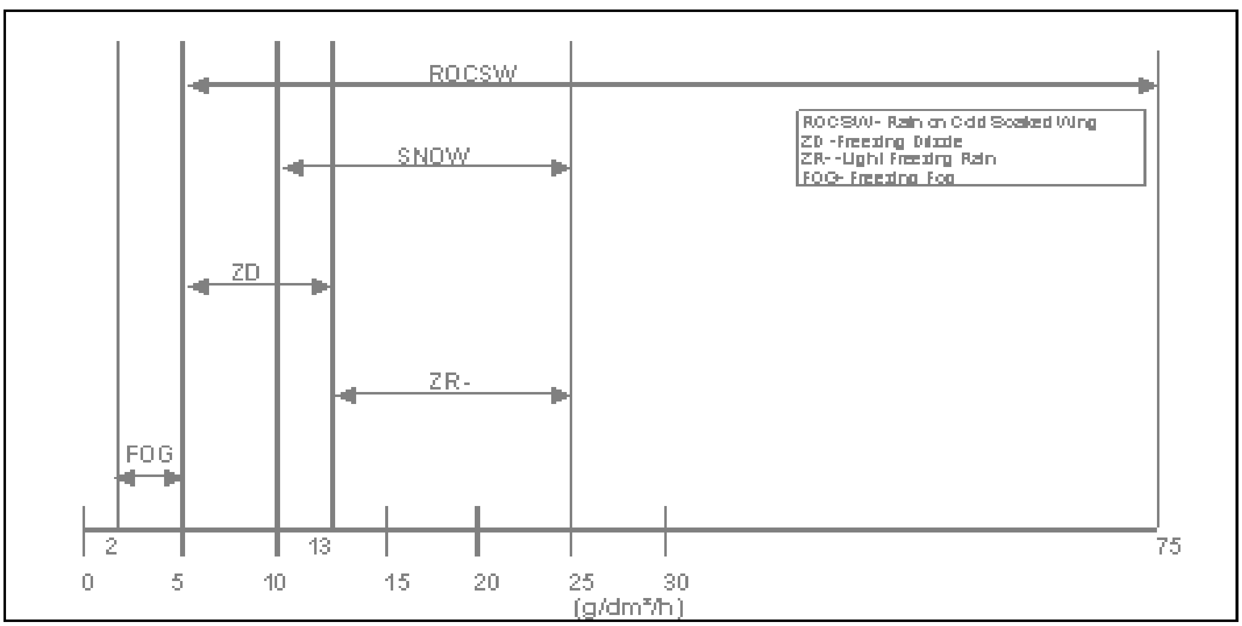

Figure 2.5: Precipitation Rate Breakdown

2.10 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 which could be used to measure and calculate the magnitude of the fluid waves and protruding contamination. Photo 2.9 and Photo 2.10 demonstrate the camera setup used for the testing period.

The cameras were positioned so as 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 camera primary focus was on the starboard section of the wing, whereas during the 2008-09 tests, the primary focus point was the center section of the wing; this was due to the restricted viewpoints 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 C.

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

2.11 Type III/III/IV Fluid Application Equipment

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

Type II/III/IV fluids were generally received in 20 litre containers. The fluid applied to the wing section by using smaller 2 L containers (see Photo 2.11). Approximately 16-20 L of fluid was applied to the wing section for each test; less fluid was required for the less viscous Type II and III fluids.

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

2.13 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. Representatives from 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).

2.14 Measurement of Test Parameters

2.14.1 Measurement Locations

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

a) Before fluid application;

b) After fluid application;

c) After application of contamination; and

d) After the simulated takeoff test.

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

- Wing Position 1: Approximately 10 cm up from the leading edge stagnation point;
- Wing Position 2: Approximately 25 cm up from the leading edge stagnation point;

- Wing Position 3: Approximately 40 cm up from the leading edge stagnation point;
- Wing Position 4: Approximately 55 cm up from the leading edge stagnation point;
- Wing Position 5: Approximately 70 cm up from the leading edge stagnation point;
- Wing Position 6: Approximately 30 cm from 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.

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

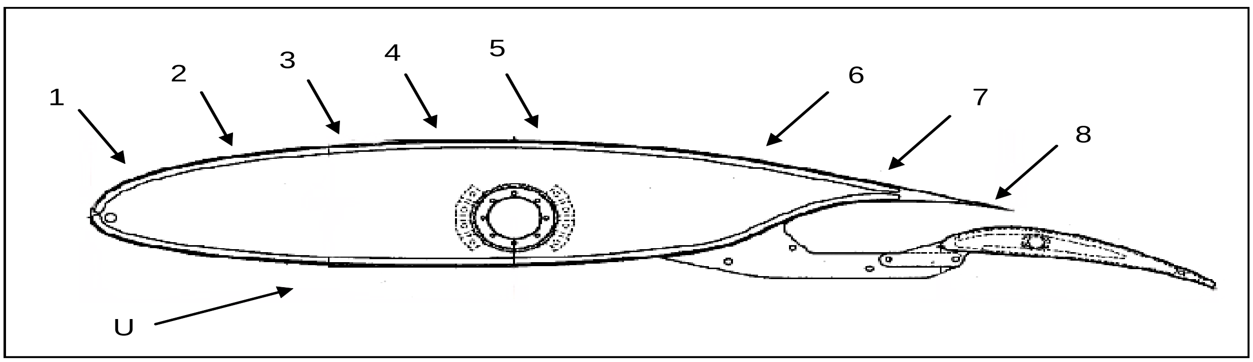

Figure 2.6: Measurement Locations Along Chord of NASA LS(1)-0417 Wing Section

2.14.2 Fluid Thickness

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

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

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

- Wing Position 1: Approximately 10 cm up from the leading edge stagnation point;
- Wing Position 2: Approximately 25 cm up from the leading edge stagnation point;
- Wing Position 3: Approximately 40 cm up from the leading edge stagnation point;
- Wing Position 4: Approximately 55 cm up from the leading edge stagnation point;
- Wing Position 5: Approximately 70 cm up from the leading edge stagnation point;
- Wing Position 6: Approximately 30 cm from 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.

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

2.14.3 Wing Skin Temperature

Wing temperatures were measured using a hand-held temperature probe at three locations 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 test.

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

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

- Underside: 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 (these were installed by NRC personnel) recording the skin temperature on the leading edge (two sensors) and on the trailing edge (one sensor). These thermistors were primarily used to monitor the skin temperature in real-time through the NRC data display system.

2.14.4 Fluid Brix

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

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

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

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

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

2.15 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.

2.16 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.

2.16.1 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 freeze points for the various fluids tested and relevant conversion tables:

- 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 illustrates the fluid freeze points for the Dow EG 106 fluid.

2.16.2 Temperature Sensor

Wing skin temperature and fluid temperature was 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.

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	FREEZE POINT
100 : 0	34.3 – 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

Safewing MP II 1951/Safewing MP II 2025 ECO/Safewing MP II FLIGHT

Refractive Index and Freezing Point Chart

MP II (50%PG) Refractive Index (+20°C)= 1,390

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			

Version: August 2006

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 Products Division
3401 Virginia Rd. • Cleveland, Ohio 44122 • (216) 831-1000

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					

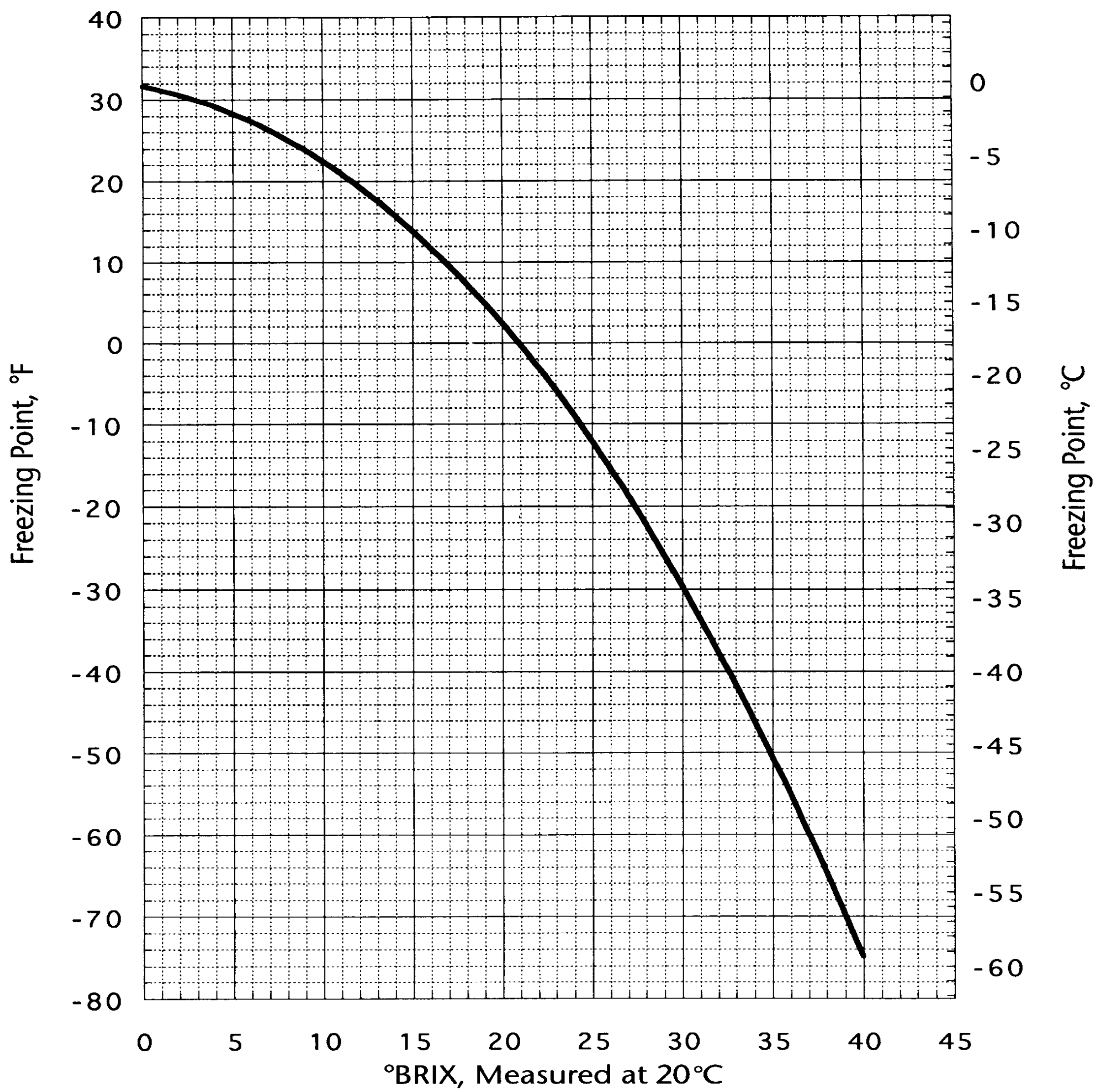

Figure 2.7: Freezing Point vs. Brix of Aqueous Solutions of Dow EG106

2.16.3 Thickness Gauges

Wet film thickness gauges, shown in Figure 2.8 and Photo 2.13, were used to measure fluid film thickness. These gauges were selected because they provide an adequate range of thickness (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 the corrected thickness values.

2.16.4 Viscometer

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

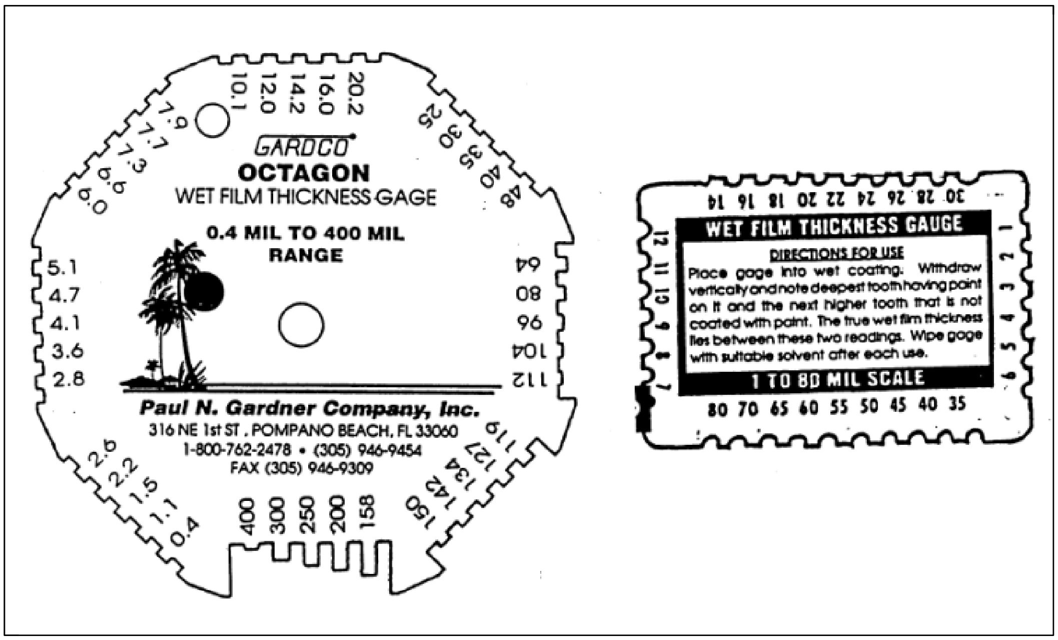

Figure 2.8: Thickness Gauges

2.16.5 Fluids

Six fluids were used during the wind tunnel tests conducted during the winter of 2008-09. The fluid used for testing was 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

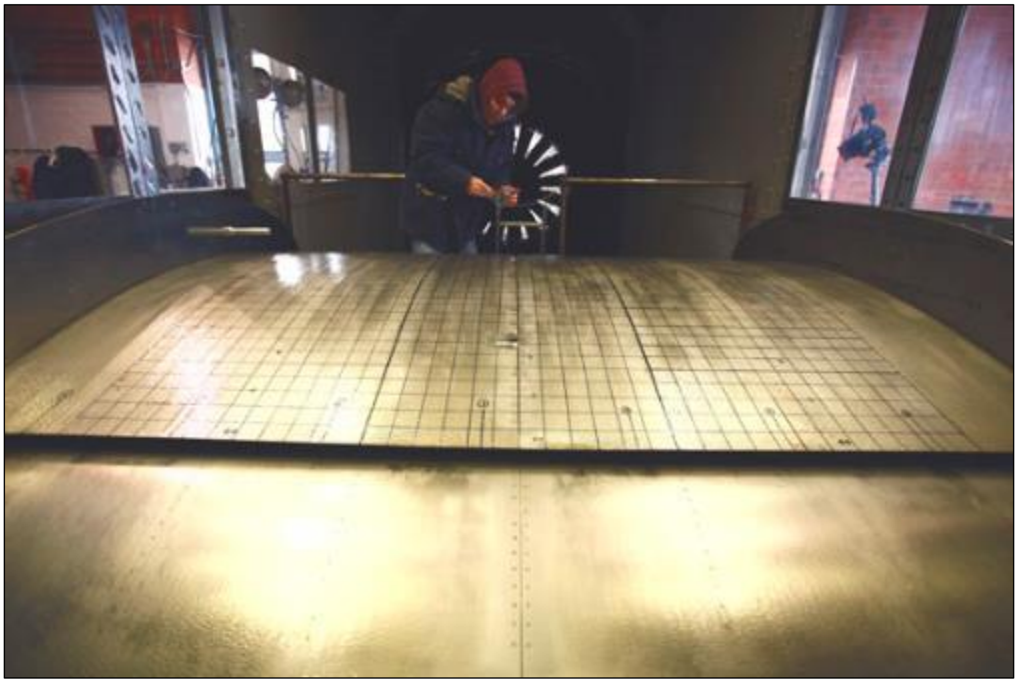

Photo 2.4: Grid Markings on NASA LS(1)-0417 Wing Section

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

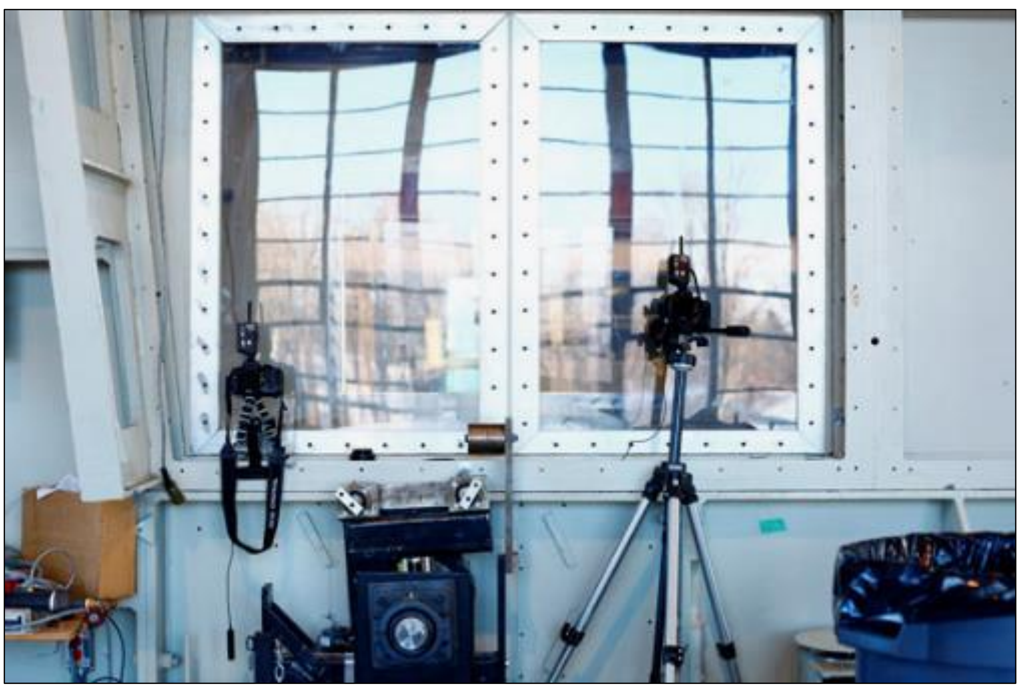

Photo 2.11: Fluid Pour Containers

Photo 2.12: 2008-09 Research Team

Photo 2.13: Wet Film Thickness Gauges

Photo 2.14: Hand-Held Temperature Probe

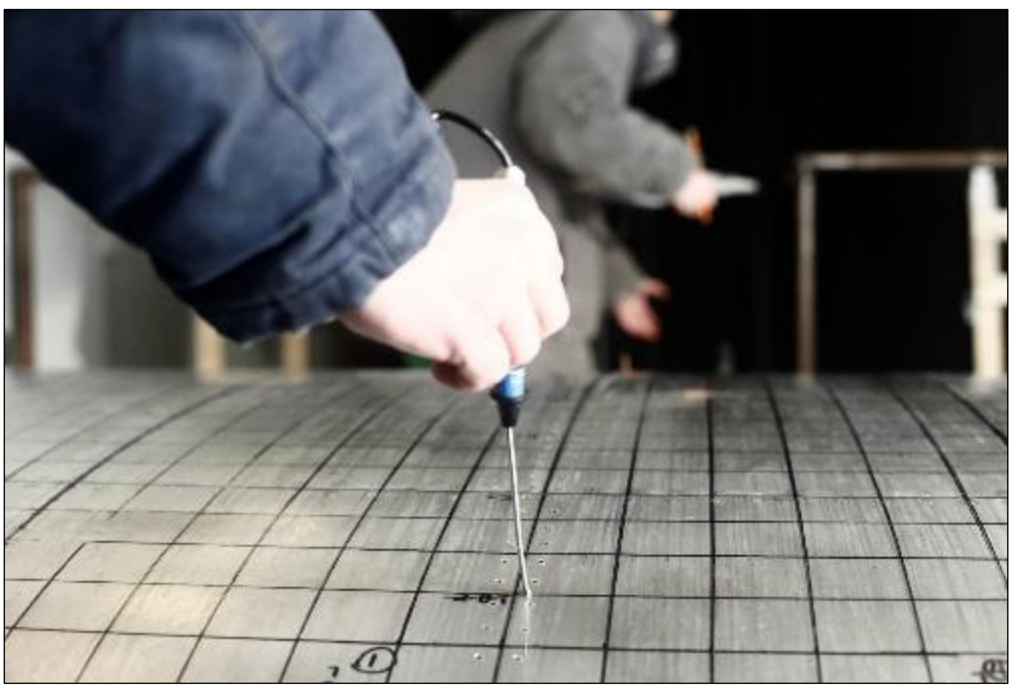

Photo 2.15: Hand-Held Brixometer (Misco 10431VP)

Photo 2.16: Brookfield Digital Viscometer Model DV-1+

3. FLAT PLATE TESTING RESULTS

Following the wind tunnel tests conducted during the winter of 2008-09, it was recommended that flat plate testing be conducted to further validate the results observed in the wind tunnel. It should be noted although the flat plate testing was conducted following the 2008-09 wind tunnel tests the data is being presented in Section 3 prior to the wind tunnel results.

3.1 Objective

The objective of this project was to verify the level of adhered contamination at the end of the allowance time for Type II, III, and IV fluids. It should be noted, that for the Type II, and Type III fluids, testing targeted proposed allowance times developed based on data collected at the wind tunnel during the winter of 2008-09. An additional five minutes was applied to the allowance time of all tests to investigate potential safety buffers in the allowance times.

3.2 Methodology

Details of the methodology used for testing can be found in the procedure *"Experimental Program – Adhesion of Aircraft De/Anti-icing Fluids on Aluminum Surfaces During Mixed Precipitation Conditions – Ice Pellets / Freezing Rain"* (see Appendix D).

Endurance time testing was conducted in March/April 2009 at the NRC Climatic Engineering Facility cold chamber using the standard flat plate HOT test procedure. Test plates were positioned directly underneath the simulated freezing precipitation sprayer assembly. The "Ice Pellet Dispenser" was positioned so as to dispense ice pellets on four test plates (test plate positions 1 and 2 and positions 5 and 6).

It should be noted that previous endurance time testing in simulated ice pellet conditions demonstrated that visual fluid failure was difficult to determine because ice pellets embed themselves in the fluid and take longer to dissolve compared to snow or other forms of precipitation For the purpose of this project, APS members monitored the level of adherence during the tests. Typically, levels of adherence beyond the 7.5 cm (3") line of a test plate indicate potential fluid flowoff issues on a wing.

3.2.1 Test Parameters Measured and Documented

1 L of fluid at OAT was poured onto the test plate. Fluid dilution, fluid thickness, surface temperature, and fluid adhesion were documented throughout the test. Photos of the test plates were taken every 5 minutes for the duration of the test. Ice pellet rate of precipitation was not measured during the tests, but was approximated based on previous calibration work was done at the APS Montréal-Pierre Elliott Trudeau International Airport (PET) test site. Testing immediately followed the standard HOT testing protocol; therefore there was no need to reconfirm light freezing rain precipitation rates.

3.3 Test Log

To facilitate the accessibility of the data collected, a log was created for the series of tests conducted by APS at the NRC research facility. The log presented in Table 3.1 provides relevant information for each of the endurance time tests conducted, as well as final values recorded. Each row contains data specific to one test.

3.4 General Observations

The following sections describe the observations and conclusions respective to each test condition.

3.4.1 Precipitation Rate Discrepancy

It should be noted that although a combined rate of 50 g/dm²/h was targeted (25 g/dm²/h ice pellets + 25 g/dm²/h freezing rain), the actual combined precipitation rate was 42 g/dm²/h; the ice pellet rate was actually 17 g/dm²/h instead of 25 g/dm²/h. This occurred as a result of technical error while operating the ice pellet dispensers and was only identified at the end of the testing period. This rate of 42 g/dm²/h applies for all the tests conducted.

The tests were not repeated because the difference in rate was not expected to have a significant impact on the results obtained, primarily because ice pellets are not as reactive as the light freezing rain in the condition tested.

Table 3.1: Test Log

Test #	Plate Location	Fluid Type	Fluid Brand (Neat)	Start Time	End Time	Total Time (min)	Target Allowance Time [min]	Test Temp. [°C]	Fluid Temp. [°C]	ZR + IP Precip Rate [g/dm²/h]	Time of Adh to 1" Line (min)	Adh at End of Test
IP1	1	IV	ABC-S	14:42	15:12	30.0	25+5	-5	-5	25 + 17	No Adh	No Adh
IP1A	6	IV	ABC-S	14:42	15:12	30.0	25+5	-5	-5	25 + 17	No Adh	No Adh
IP2	2	IV	Launch	14:42	15:12	30.0	25+5	-5	-5	25 + 17	26	Adh to 1" line
IP2A	5	IV	Launch	14:42	15:12	30.0	25+5	-5	-5	25 + 17	27	Adh to 1-3" line
IP3	1	II	Ecowing 26	15:42	16:07	25.0	20+5	-5	-5	25 + 17	20	Adh to 1-3" line
IP3A	6	II	Ecowing 26	15:42	16:07	25.0	20+5	-5	-5	25 + 17	20	Adh to 3-6" line
IP4	2	II	ABC-2000	15:42	16:07	25.0	20+5	-5	-5	25 + 17	20	Adh to 6-9" line
IP4A	5	II	ABC-2000	15:42	16:07	25.0	20+5	-5	-5	25 + 17	14	Adh to 6-9" line
IP5	1	III	2031	15:19	15:34	15.0	10+5	-5	-5	25 + 17	10 (3-6" Line)	Adh to 9" line
IP5A	6	III	2031	15:19	15:34	15.0	10+5	-5	-5	25 + 17	11 (3-6" Line)	Adh to 6-9" line
IP6	2	III	2031 (Heated)	15:19	15:34	15.0	10+5	-5	1L @ 20	25 + 17	10 (3" Line)	Adh to 6-9" line
IP6A	5	III	2031 (Heated)	15:19	15:34	15.0	10+5	-5	1L @ 20	25 + 17	11 (3-6" Line)	Adh to 6-9" line
IP7R	1	IV	ABC-S	12:36	12:51	15.0	10+5	-10	-10	25 + 17	No Adh	No Adh
IP7AR	6	IV	ABC-S	12:36	12:51	15.0	10+5	-10	-10	25 + 17	No Adh	No Adh
IP8R	2	IV	Launch	12:36	12:51	15.0	10+5	-10	-10	25 + 17	No Adh	No Adh
IP8AR	5	IV	Launch	12:36	12:51	15.0	10+5	-10	-10	25 + 17	No Adh	No Adh
IP9	1	II	Ecowing 26	13:06	13:21	15.0	10+5	-10	-10	25 + 17	No Adh	No Adh
IP9A	6	II	Ecowing 26	13:06	13:21	15.0	10+5	-10	-10	25 + 17	No Adh	No Adh
IP10	2	II	ABC-2000	13:06	13:21	15.0	10+5	-10	-10	25 + 17	10	Adh to 1-3" line
IP10A	5	II	ABC-2000	13:06	13:21	15.0	10+5	-10	-10	25 + 17	7	Adh to 3" line
IP11	1	III	2031	12:06	12:16	10.0	5+5	-10	-10	25 + 17	10	Adh to 1" line
IP11A	6	III	2031	12:06	12:16	10.0	5+5	-10	-10	25 + 17	10	Adh to 1" line
IP12	2	III	2031 (Heated)	12:06	12:16	10.0	5+5	-10	1L @ 20	25 + 17	5	Adh to 6-9" line
IP12A	5	III	2031 (Heated)	12:06	12:16	10.0	5+5	-10	1L @ 20	25 + 17	5	Adh to 6-9" line

Note: All tests were conducted on March 31, 2009.

3.4.2 Type IV Allowance Time Tests

Testing conducted at -10ºC demonstrated that the current allowance time of 10 minutes is appropriate. No adherence was observed at the end of the 15 minute exposure period.

Testing conducted at -5ºC demonstrated varying results with the different fluids tested, however both sets of tests indicated that the current allowance time of 25 minutes is appropriate. Two tests did not demonstrate signs of adherence following 30 minutes of exposure, and two tests demonstrated an acceptable level of adherence (between the 2.5 and 7.5 cm line) at the end of the 30 minutes of exposure.

During both the -10ºC and -5ºC tests, the allowance times provided a fair amount of buffer time to allow for protection against the adherence of contamination.

3.4.3 Type III Allowance Time Tests

Testing conducted at -10ºC demonstrated varying results with the different fluids tested, however both sets of tests indicated that the proposed allowance time of 10 minutes is appropriate. Two tests did not demonstrate signs of adherence following 15 minutes of exposure, and two tests demonstrated a marginal level of adherence (between the 2.5 and 7.5 cm line) at the end of the 15 minutes of exposure. Based on the results, a 10 minute allowance time is appropriate, however does not provide a large safety buffer.

Testing conducted at -5ºC demonstrated that the proposed allowance time of 20 minutes is appropriate but should be re-evaluated. Two tests demonstrated a marginal level of adherence (between the 2.5 and 15 cm line) at the end of the 25 minutes of exposure, and two tests demonstrated a severe level of adherence (between the 15 and 23 cm line) at the end of the 25 minutes of exposure. Based on the results, a 20 minute allowance time is appropriate, however the proposed allowance time provides little safety buffer.

3.4.4 Type III Mixed Precipitation Tests

Testing conducted at -10ºC demonstrated varying results for the heated and un-heated fluid application tests. The un-heated fluid tests demonstrated no adherence at the end of the proposed 5 minute allowance time, and adherence to the 2.5 cm line at the end of the 10 minutes of exposure. The heated fluid tests demonstrated adherence to the 2.5 cm line at the end of the proposed 5 minute allowance time, and adherence to the 15 and 23 cm line at the end of the 10 minutes of exposure. These results indicate that the proposed 5 minute allowance time is appropriate for Type III fluid applied at ambient, however, the 5 minute allowance time provides little safety buffer for heated Type III fluid applications.

Testing conducted at -5ºC demonstrated that the proposed allowance time of 10 minutes is marginal and should be reduced. Both heated and un-heated tests demonstrated adherence between the 7.5-15 cm line at the end of 10 minutes of exposure, and adherence between the 15-23 cm line at the end of the 15 minutes of exposure. Based on the results, it was recommended that the proposed allowance time be reduced to 7 minutes to account for the levels of adherence observed as well as to compensate for the discrepancy in the simulated rate of precipitation (as described in Section 3.4.1).

3.5 Future Work

It is recommended that testing with flat plates continue to be conducted to validate future allowance times developed through aerodynamic research. Flat plate testing has been used as the basis for developing HOT's and demonstrates a good correlation to fluid failure on the wing. Flat plate testing will provide further substantiation to future allowance times developed and are generally of lower cost as compared to full-scale aerodynamic research.

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4. FULL-SCALE DATA COLLECTED

4.1 Test Log

A detailed log of the tests conducted in the NRC PIWT is shown in Table 4.1; 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 4.1:

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 knots rotation) or low speed (80 knots rotation).
Rotation Angle:	Maximum angle of rotation obtained during simulated takeoff run; began testing with a max 8° rotation angle and increased to 20° as testing progressed.
Target OAT:	Target outside ambient 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 (°C):	Outside ambient temperature recorded just before the start of the simulated takeoff test, measured in degrees Celsius.
Tunnel Temp Before Test (°C):	Static tunnel ambient temperature recorded just before the start of the simulated takeoff test, measured in degrees Celsius.

Avg Wing Temp Before Test (ºC):	Average of the wing skin temperature measurements just before the start of the simulated takeoff test, recorded in degrees Celsius.
Precipitation Rate (Type: [g/dm²/h]):	Simulated freezing precipitation rate (or combination of different precipitation rates). N/A indicates that no precipitation was applied.
Exposure Time:	Simulated precipitation period, recorded in minutes.

The visual contamination ratings are described below. Visual contamination ratings were typically reported as the average of the 3 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 Section 5.1.

Visual Contamination Rating Before Takeoff (LE, TE):

Visual contamination rating determined before the start of the simulated takeoff:

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

Visual Contamination Rating at Rotation (LE, TE):

Visual contamination rating determined at the time of rotation:

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

Visual Contamination Rating After Takeoff (LE, TE):

Visual contamination rating determined at the end of the test:

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

C_L at 8º During Rotation:

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

C_L at Peak Angle of Rotation:

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

Table 4.1: Wind Tunnel Test Log

TEST #	8	9	10	11	12	13	14	16	20	21
Objective	IP Expansion	IP Expansion	IP Expansion	IP Expansion	Low Speed	IP Expansion	Type III	Type III	IP Validation	IP Validation
Test Condition	IP/SN	IP/SN	IP/SN	IP/SN	IP/SN	IP/SN	IP/SN	IP/SN	IP Mod	IP-
Fluid	ABC-S Plus	ABC-S Plus	Launch	ABC-S Plus	ABC-S Plus	Launch	2031	2031	ABC-S Plus	ABC-S Plus
Speed Profile	High	High	High	High	Low	High	Low	Low	High	High
Rotation Angle	8°	8°	8°	8°	8°	8°	8°	8°	8°	8°
Target OAT (ºC)	-10	-10	-10	-5	-5	-5	-5	-5	-5	-5
TEST PARAMETERS										
Date	26-Jan	26-Jan	26-Jan	27-Jan	27-Jan	27-Jan	27-Jan	27-Jan	28-Jan	28-Jan
Precipitation End Time	11:10	12:15	13:15	12:32	13:19	14:12	14:57	16:36	10:39	12:25
Tunnel Start Time	11:18	12:22	13:20	12:38	13:25	14:18	15:03	16:44	10:45	12:31
TEMPERATURES										
OAT Before Test (°C)	-21.6	-19.6	-18.2	-10	-9.2	-9	-9.1	-9.3	-12.1	-11.3
Tunnel Temp Before Test (°C)	-12.6	-8.4	-5.1	-5.9	-4.9	-5.3	-1.6	-1.2	-6.7	-8.5
Avg Wing Temp Before Test (°C)	-15.9	-12.1	-11.1	-6.5	-7.3	-5.8	-6.2	-7.3	-9.4	-8.3
PRECIPITATION										
Precipitation Rate (Type: [g/dm²/h])	IP:24, SN:24.5	IP:25, SN:25	IP:25, SN:25	IP:25, SN:25	IP:25, SN:25	IP:25, SN:25	IP:25, SN:25	IP:25, SN:25	IP:75	IP:25
Exposure Time (min)	10	10	10	10	10	10	10	15	25	50
OBSERVATIONS										
Visual Contamination Rating Before Take off (LE, TE)	3, 3	3, 3	3, 4	3, 3	3, 3	3, 3	2, 2	3, 4	3, 4	3, 3
Visual Contamination Rating At Rotation (LE, TE)	3, 3	2, 4	2, 3	1, 2	1, 2	1, 2	1, 1	1, 2	1, 2	1, 2
Visual Contamination Rating After Take off (LE, TE)	3, 3	2, 4	2, 3	1, 1	1, 1	1, 1	1, 1	1, 2	1, 1	1, 1
C_L at 0º Before Rotation	N/A	N/A	N/A	0.948	0.966	0.956	0.981	0.976	0.955	0.941
C_L at 8º During Rotation	N/A	N/A	N/A	1.76	1.762	1.77	1.779	1.78	1.758	1.755
C_L at Peak Angle of Rotation	N/A	N/A	N/A	1.76	1.762	1.77	1.779	1.78	1.758	1.755
C_L at 4º Following End of Rotation	N/A	N/A	N/A	1.308	1.309	1.313	1.324	1.32	1.305	1.299

Table 4.1: Wind Tunnel Test Log Test Log (cont'd)

TEST #	22	23	25	26	29	30	31	33	43	44
Objective	Low Speed	Low Speed	IP Validation/ Low Speed	Type III	IP Validation	IP Validation	Low Speed	IP Validation/ Low Speed	Low Speed	IP Expansion
Test Condition	IP/ZR	IP/ZR	IP/ZR	IP/ZR	IP Mod	IP-	IP/SN	IP/ZR	IP/SN	IP/SN
Fluid	Launch	Flight	ABC-S Plus	2031	EG 106	EG 106	EG 106	EG106	EG 106	EG 106
Speed Profile	Low	Low	Low	Low	High	High	Low	Low	Low	High
Rotation Angle	8°	8°	8°	8°	8°	8°	8°	8°	16°	16°
Target OAT (ºC)	-5	-5	-5	-5	-5	-5	-5	-5	-10	-10
TEST PARAMETERS										
Date	28-Jan	28-Jan	28-Jan	28-Jan	29-Jan	29-Jan	29-Jan	30-Jan	31-Jan	31-Jan
Precipitation End Time	15:55	17:08	19:11	21:10	17:15	18:45	20:35	9:55	4:50	5:48
Tunnel Start Time	16:04	17:16	19:18	21:18	17:23	18:53	20:44	10:03	4:59	5:56
TEMPERATURES										
OAT Before Test (°C)	-9.1	-8.3	-7.1	-7.9	-5.1	-5.6	-5.5	-7.9	-15.5	-17.1
Tunnel Temp Before Test (°C)	-5.5	-4.1	-3.6	-5.3	-2.6	-1.6	0.1	-2.7	-12.7	-12.3
Avg Wing Temp Before Test (°C)	-4.8	-5.1	-4.1	-3.1	-8.1	-5.4	-6	-5.6	N/A	-13.2
PRECIPITATION										
Precipitation Rate (Type: [g/dm²/h])	IP:25, ZR:25.5	IP:25, ZR:25.5	IP:25, ZR:25.5	IP:25, ZR:25.5	IP:75	IP:25	IP:25, SN:25	IP:25, ZR:25.5	IP:25, SN:25	IP:25, SN:25
Exposure Time (min)	25	25	25	25	25	50	25	25	10	15
OBSERVATIONS										
Visual Contamination Rating Before Take off (LE, TE)	3, 3	3, 3	2, 3	5, 5	2, 2	1.5, 2	1.5, 1.5	2, 2	2, 2	2, 2
Visual Contamination Rating At Rotation (LE, TE)	1, 2	1, 2	1, 2	5, 5	1, 1.5	1, 1	1, 1	1, 1	1, 1.5	1, 1
Visual Contamination Rating After Take off (LE, TE)	1, 1	1, 1	1, 1	5, 5	1, 1	1, 1	1, 1	1, 1	1, 1	1, 1
C_L at 0º Before Rotation	0.942	N/A	-	0.935	0.975	0.974	0.97	0.977	0.926	0.949
C_L at 8º During Rotation	1.753	N/A	-	1.704	1.794	1.793	1.779	1.776	1.729	1.746
C_L at Peak Angle of Rotation	1.753	N/A	-	1.704	1.794	1.793	1.779	1.776	2.743	2.774
C_L at 4º Following End of Rotation	1.304	N/A	1.301	1.258	1.322	1.32	1.32	1.317	1.3	1.293

Table 4.1: Wind Tunnel Test Log Test Log (cont'd)

TEST #	45	47	48	51	52	53	54	57	58	59
Objective	Low Speed	Type III	Type III	IP & Mod Rain	Low Speed/ IP Expansion	Low Speed	IP Expansion	Type III	IP Expansion	Low Speed
Test Condition	IP/SN	IP/SN	IP/SN	IP/R	IP/SN	IP/SN	IP/SN	IP/SN	IP/SN	IP/ZR
Fluid	ABC-S Plus	2031	2031	Launch	EG 106	ABC-S Plus	ABC-S Plus	2031	Launch	Launch
Speed Profile	Low	Low	Low	High	Low	Low	High	Low	High	Low
Rotation Angle	16°	16°	16°	16°	16°	16°	16°	16°	16°	16°
Target OAT (ºC)	-10	-10	-10	< -5	-5	-5	-5	-5	-5	-10
TEST PARAMETERS										
Date	31-Jan	31-Jan	31-Jan	2-Feb	2-Feb	3-Feb	3-Feb	3-Feb	3-Feb	3-Feb
Precipitation End Time	7:06	8:49	9:42	22:10	23:22	14:13	15:21	18:52	20:00	20:55
Tunnel Start Time	7:15	8:58	9:51	22:21	23:29	14:19	15:27	17:58	20:06	21:03
TEMPERATURES										
OAT Before Test (°C)	-18.4	-19	-18.2	-7.3	-7.8	-7.3	-6.9	-9.2	-11.4	-11.8
Tunnel Temp Before Test (°C)	-15.9	-17	-13.5	-1.6	-5.6	-3.4	0.4	-7.6	-6.3	-10.3
Avg Wing Temp Before Test (°C)	-13.1	-14.1	-13.5	-3.9	-8.6	-8	-7.9	-7.5	-9.2	-7.9
PRECIPITATION										
Precipitation Rate (Type: [g/dm²/h])	IP:25, SN:25	IP:25, SN:25	IP:25, SN:25	IP:25, R:50,	IP:25, SN:25	IP:25, SN:25	IP:25, SN:25	IP:25, SN:25	IP:25, SN:25	IP:25, ZR:25
Exposure Time (min)	10	10	5	25	25	25	25	10	25	10
OBSERVATIONS										
Visual Contamination Rating Before Take off (LE, TE)	2, 3	4, 4	2, 2	2, 2	3, 3	3, 4	2.5, 4	2, 2.5	3, 4	3, 3
Visual Contamination Rating At Rotation (LE, TE)	1.5, 2	2, 3	1, 2	1, 1	1, 2	1, 2	1, 2	1, 2	1, 2.5	1, 2.5
Visual Contamination Rating After Take off (LE, TE)	1, 2	2, 3	1, 1	1, 1	1, 1	1, 1	1, 1	1, 1	1, 2	1, 2
C_L at 0º Before Rotation	0.897	0.93	0.926	0.933	0.951	0.917	0.939	N/A	0.905	0.935
C_L at 8º During Rotation	1.67	1.707	1.719	1.738	1.75	1.713	1.744	N/A	1.706	1.723
C_L at Peak Angle of Rotation	2.632	2.691	2.711	2.748	2.752	2.716	2.768	N/A	2.706	2.7
C_L at 4º Following End of Rotation	1.265	1.277	1.284	1.285	1.299	1.289	1.301	N/A	1.279	1.292

Table 4.1: Wind Tunnel Test Log Test Log (cont'd)

TEST #	60	64	65	66	67	68	69	73	74	75
Objective	Low Speed	IP Validation	IP Validation	IP Validation	IP Validation	IP Validation	IP Validation	Type III	Type III	IP Expansion
Test Condition	IP/ZR	ZR/IP	ZR/IP	IP-	IP Mod	IP-	IP Mod	ZR/IP	ZR/IP	IP/SN-
Fluid	Flight	EG106	ABC-S Plus	Launch	Launch	EG 106	EG 106	2031	2031	ABC-S Plus
Speed Profile	Low	High	High	High	High	High	High	Low	Low	High
Rotation Angle	16°	16°	16°	16°	16°	16°	16°	20°	20°	16°
Target OAT (ºC)	-10	-10	-10	-25	-25	-25	-25	-10	-10	-10
TEST PARAMETERS										
Date	3-Feb	4-Feb	5-Feb	5-Feb	5-Feb	5-Feb	5-Feb	23-Feb	23-Feb	24-Feb
Precipitation End Time	21:53	23:35	0:24	1:41	2:27	3:31	4:31	22:48	23:40	0:39
Tunnel Start Time	22:01	23:42	0:32	1:46	2:33	3:37	4:39	22:57	23:47	0:47
TEMPERATURES										
OAT Before Test (°C)	-12.8	-16.5	-17	-18	-18.3	-18.5	-19.5	-10.3	-10.8	-11.1
Tunnel Temp Before Test (°C)	-11.3	-13.6	-12.8	-14.7	-16.2	-16.6	-17.9	-9.3	-9.3	-8.8
Avg Wing Temp Before Test (°C)	-8.1	-9.8	-11	-12.3	-13.7	-15	-14.9	-7	-7.1	-7.6
PRECIPITATION										
Precipitation Rate (Type: [g/dm²/h])	IP:25, ZR:25	IP:25, ZR:25	IP:25, ZR:25	IP:25	IP:75	IP:25	IP:75	IP:25, ZR:25	IP:25, ZR:25	IP:25, SN:10
Exposure Time (min)	10	10	10	30	10	30	10	10	5	10
OBSERVATIONS										
Visual Contamination Rating Before Take off (LE, TE)	3, 3	2, 2	3, 3	3, 3	4, 4	3, 3	3, 3	3, 3	2, 2	2, 2
Visual Contamination Rating At Rotation (LE, TE)	1, 2	1, 1	1, 2	1, 2	1, 3	1, 1	1, 1	2, 2	1, 2	1, 2
Visual Contamination Rating After Take off (LE, TE)	1, 1.5	1, 1	1, 1	1, 1	1, 1	1, 1	1, 1	1, 2	1, 1	1, 1
C_L at 0º Before Rotation	0.854	N/A	0.915	0.906	0.905	0.946	0.948	N/A	0.988	0.96
C_L at 8º During Rotation	1.707	N/A	1.725	1.707	1.706	1.752	1.741	N/A	1.798	1.77
C_L at Peak Angle of Rotation	2.688	N/A	2.726	2.705	2.712	2.779	2.774	N/A	3.285	2.758
C_L at 4º Following End of Rotation	1.297	N/A	1.277	1.286	1.285	1.295	1.288	N/A	1.346	1.337

Table 4.1: Wind Tunnel Test Log Test Log (cont'd)

TEST #	76	77	78	85	86	87	88	91
Objective	IP Expansion	IP Expansion	Type III	IP & Mod Rain	Low Speed	Low Speed	Low Speed	Low Speed
Test Condition	IP/SN-	IP/SN-	IP/SN-	IP/R	IP-	IP Mod	IP Mod	IP/SN-
Fluid	Launch	EG 106	2031	EG 106	ABC-S Plus	ABC-S Plus	ABC-S Plus	ABC-S Plus
Speed Profile	High	High	Low	High	Low	Low	Low	Low
Rotation Angle	16°	16°	20°	16°	20°	20°	20°	20°
Target OAT (ºC)	-10	-10	-10	>-5	-5	-5	-5	-10
TEST PARAMETERS								
Date	24-Feb	24-Feb	24-Feb	25-Feb	28-Feb	28-Feb	28-Feb	1-Mar
Precipitation End Time	1:39	3:10	3:58	3:51	22:15	23:19	0:14	3:30
Tunnel Start Time	1:47	3:20	4:05	3:58	22:21	23:25	0:20	3:36
TEMPERATURES								
OAT Before Test (°C)	-11.6	-12.4	-12.8	-12.1	-13.9	-14.9	-15.8	-16.5
Tunnel Temp Before Test (°C)	-9.8	-9.2	-10.7	-1.2	-9.3	-6.5	-6	-7.1
Avg Wing Temp Before Test (°C)	-8.8	-10.2	-9.1	-3.7	-9.9	-11.6	-11.1	-10
PRECIPITATION								
Precipitation Rate (Type: [g/dm²/h])	IP:25, SN:10	IP:25, SN:10	IP:25, SN:10	IP:25, R:75	IP:25	IP:75	IP:75	IP:25, SN:10
Exposure Time (min)	15	15	10	25	50	25	15	10
OBSERVATIONS								
Visual Contamination Rating Before Take off (LE, TE)	3, 3	2, 2	2, 2	1.5, 1.5	3.5, 3.5	3.5, 4	3, 3	3, 3
Visual Contamination Rating At Rotation (LE, TE)	1, 2	1, 1	1, 2	1, 1	1.5, 3	1.5, 3	1.5, 2.5	1, 2
Visual Contamination Rating After Take off (LE, TE)	1, 1	1, 1	1, 1	1, 1	1.5, 3	1.25, 2.5	1, 2	1, 2
C_L at 0º Before Rotation	0.977	1.003	0.985	1.011	0.91	0.892	0.872	0.925
C_L at 8º During Rotation	1.784	1.823	1.78	1.83	1.699	1.671	1.655	1.697
C_L at Peak Angle of Rotation	2.78	2.839	3.271	2.849	3.115	3.067	3.104	3.112
C_L at 4º Following End of Rotation	1.341	1.349	1.348	1.355	1.323	1.318	1.326	1.33

Table 4.1: Wind Tunnel Test Log Test Log (cont'd)

TEST #	92	95	99	100	101	106
Objective	Low Speed	IP & Mod Rain	Low Speed	Type III	Type III	Low Speed
Test Condition	IP/SN-	IP/R	IP-	IP Mod	IP-	IP Mod
Fluid	EG106	Type IV PG Launch	EG 106	2031	2031	EG 106
Speed Profile	Low	High	Low	Low	Low	Low
Rotation Angle	20°	16°	20°	20°	20°	20°
Target OAT (ºC)	-10	>-5	-5	-10	-10	-5
TEST PARAMETERS						
Date	1-Mar	1-Mar	2-Mar	2-Mar	2-Mar	2-Mar
Precipitation End Time	4:23	22:03	1:17	2:26	3:10	22:06
Tunnel Start Time	4:29	22:09	1:21	2:33	3:15	22:11
TEMPERATURES						
OAT Before Test (°C)	-17.6	-9.7	-11	-12.8	-13.2	-13.4
Tunnel Temp Before Test (°C)	-15.2	-1	-10.1	-11.2	-11.6	-9.4
Avg Wing Temp Before Test (°C)	-12	-2.9	-9.7	-9.7	-7.5	-13.2
PRECIPITATION						
Precipitation Rate (Type: [g/dm²/h])	IP:25, SN:10	IP:25, R:75	IP:25	IP:75	IP:25	IP:75
Exposure Time (min)	10	25	50	5	10	25
OBSERVATIONS						
Visual Contamination Rating Before Take off (LE, TE)	2, 2.5	2, 2	2, 3	3, 3	2.5, 3	3, 3
Visual Contamination Rating At Rotation (LE, TE)	1, 2	1, 2	1, 2	1, 2	1, 2	1, 2
Visual Contamination Rating After Take off (LE, TE)	1, 1	1, 1.5	1, 1	1, 1.25	1, 1	1, 1
C_L at 0º Before Rotation	0.885	0.912	0.916	0.977	0.963	N/A
C_L at 8º During Rotation	1.776	1.799	1.803	1.786	1.77	N/A
C_L at Peak Angle of Rotation	3.258	2.725	3.324	3.279	3.24	N/A
C_L at 4º Following End of Rotation	1.34	1.335	1.345	1.35	1.343	N/A

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5. ANALYSIS METHODOLOGY

This section provides an overview of the analysis methodology used to evaluate the wind tunnel tests conducted. Due to the large amount of data collected during each test, a methodology was developed in order to facilitate the analysis process.

5.1 Visual Contamination Ratings

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

Visual Contamination Ratings (1 to 5):

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

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

5.2 Lift Coefficient Data

The NRC collected various parameters during each of the wind tunnel test runs. The data were collected at a rate of 250 samples per second. Parameters such as lift force, normal force, drag force, wind speed, pitch angle, etc., were collected and used to calculate the lift, normal, and drag coefficients. For the purpose of the tests conducted, lift coefficient was primarily used as the evaluation criteria when analysing the fluid flow-off performance during the tests. Typically, the lift coefficient varied from 0.75 and 3.5 depending on the wing angle of attack which ranged from 0º to 20º. The lift coefficient data collected as part of the "ice pellet allowance time" research has been included in Appendix E.

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

Figure 5.1 demonstrates a comparison of a dry wing test vs. a fluid only test. The x-axis shows the time in seconds as of the start of the test; rotation begins at approximately 27 seconds, the wing rotates to a maximum angle of 16 degrees in approximately 6 seconds, and then is rotated back to 4 degrees over a period of approximately 48 seconds. The y-axis indicates the calculated lift coefficient. The dry wing profile indicates a steady lift coefficient in the ramp up to the time of rotation as compared to the fluid only case which incrementally increases as the fluid is shed and the aerodynamic performance of the wing is increased. The results indicate a lift loss associated with the fluid which is more prominent during the early periods of the test and rotation, and which decreases as fluid is shed.

5.3 Tunnel Measurement Sensitivity

The wind tunnel measurement sensitivity was evaluated in order to determine its applicability for the simulated takeoff tests. When comparing dry wing results to un-contaminated fluid results (as seen in Figure 5.1) a lift loss was apparent; lift loss associated with the fluid is more prominent during the early periods of the test and rotation, and decreases as fluid is shed. When comparing varying levels of contaminated fluid, the differences were primarily apparent prior to rotation and at the peak of the rotation.

Figure 5.2 demonstrates a comparison of a fluid covered wing with a level of contamination slightly beyond acceptable (Test 99), a dry wing with adhered freezing rain and ice pellet contamination simulating a severely contaminated and diluted fluid (Test 103), and a non-contaminated fluid only wing (Test 92). The x-axis shows 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 degrees in approximately 7.4 seconds, and then is rotated back to 4 degrees 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 a non-contaminated 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 as compared to a non-contaminated 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 demonstrates a stall at approximately the 16 degree rotation angle.

These results indicated that the wind tunnel equipment used to collect and monitor the aerodynamic performance of the wing are sensitive to the changes as a result of fluid application and the application of contamination.

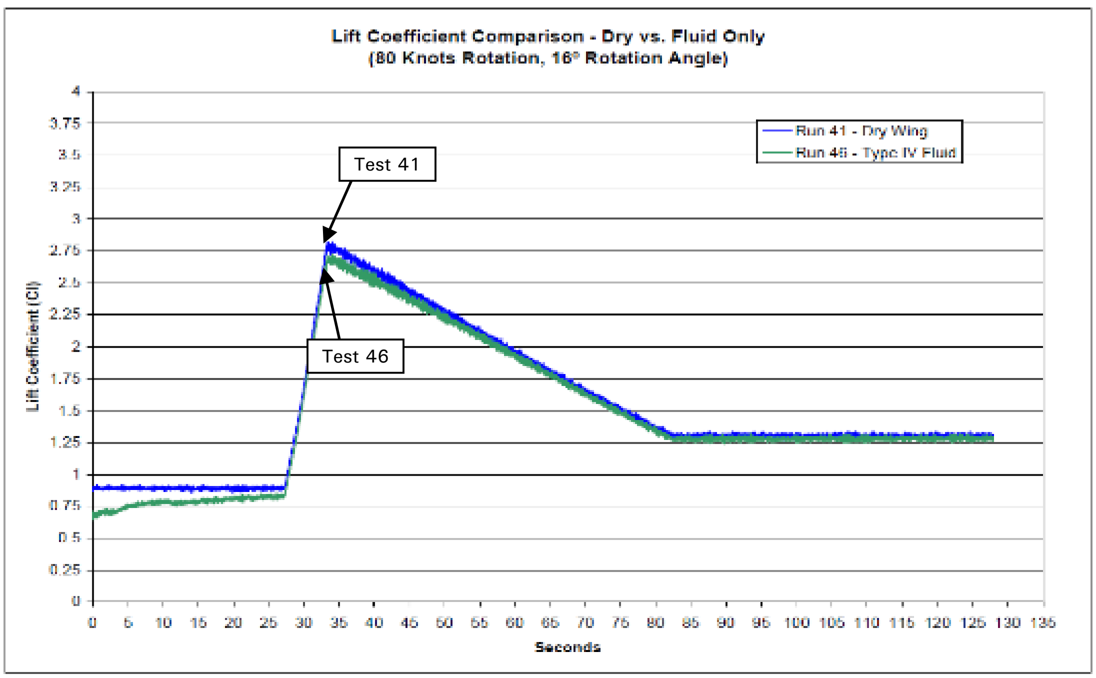

Figure 5.1: Lift Coefficient Comparison – Dry vs. Fluid Only

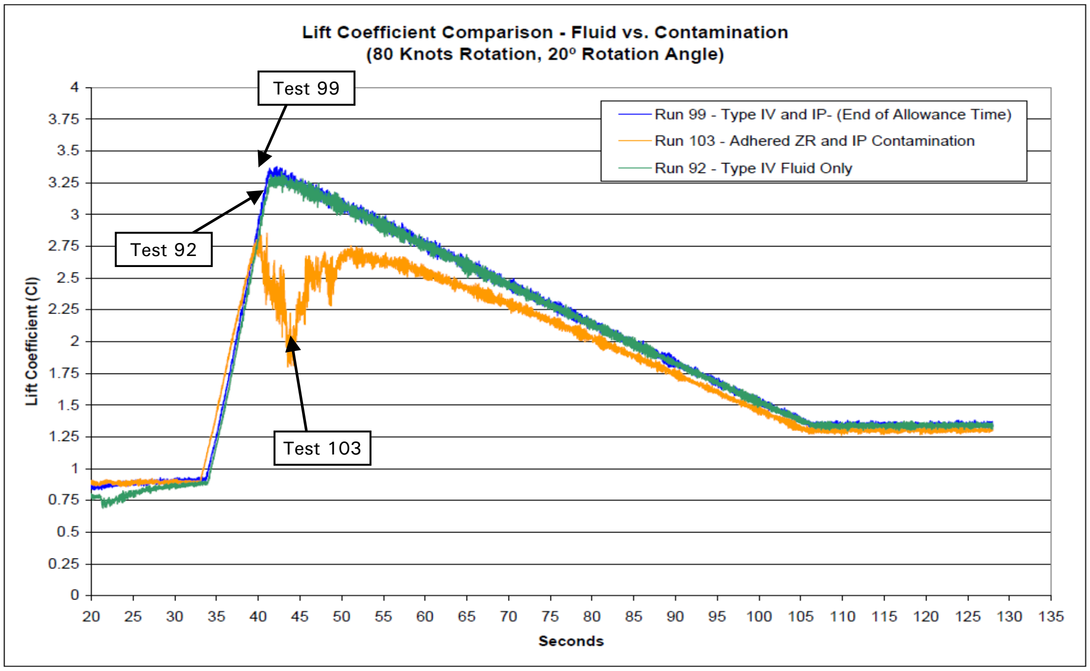

Figure 5.2: Lift Coefficient Comparison – Fluid vs. Contamination

5.4 Tunnel Measurement Repeatability

Testing conducted in the wind tunnel was based on comparative test runs, therefore it was necessary to evaluate the repeatability of the tests to validate the comparative test methodology. Two back-to-back tests were conducted in the wind tunnel with uncontaminated fluid. The lift coefficient data collected by the NRC was superimposed to identify any potential differences in the results obtained. Figure 5.3 demonstrates a comparison of two non-contaminated fluid tests. The x-axis shows the time in seconds as of the start of the test; rotation begins at approximately 35 seconds, the wing rotates to a maximum angle of 16 degrees in approximately 6 seconds, and the is rotated back to 4 degrees over a period of approximately 48 seconds. The y-axis indicates the calculated lift coefficient.

The results demonstrate that there was very little difference in the results obtained during the two separate tests. The graph demonstrates a similar aerodynamic improvement as the fluid sheds prior to rotation, and an almost identical lift coefficient profile following the time of rotation. It should be noted that the two tests were conducted in almost identical conditions. During tests with varying ambient conditions (i.e. OAT, humidity, etc) differences were observed and are primarily due to the differences in fluid dynamics and the resulting effects on aerodynamic performance.

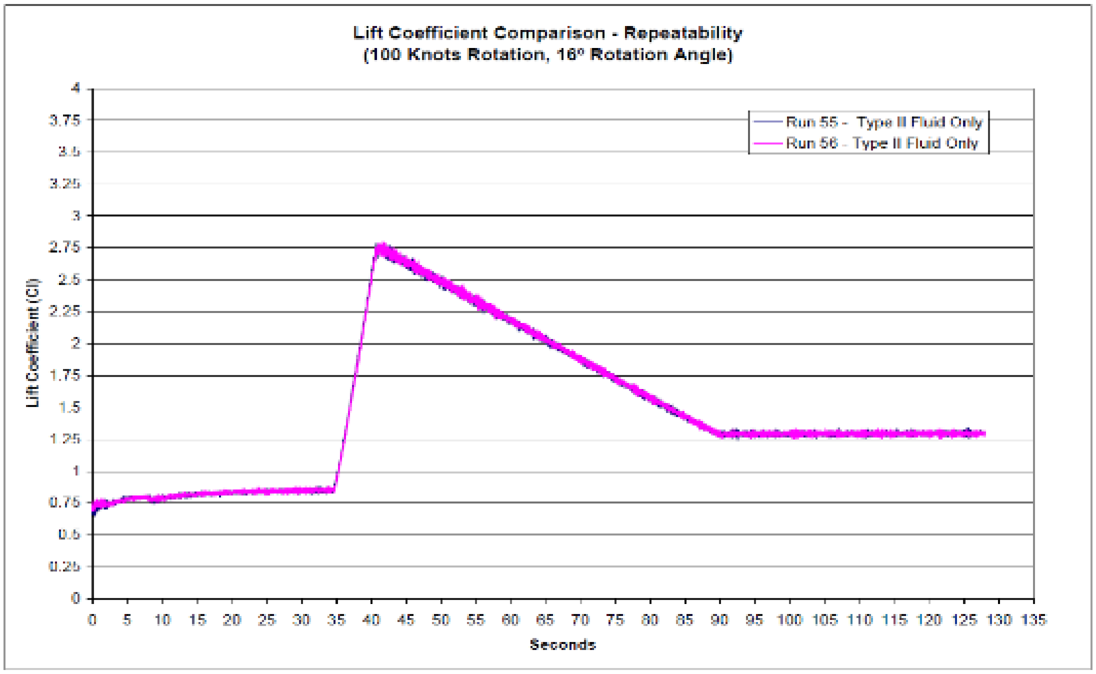

Figure 5.3: Lift Coefficient Comparison – Repeatability

5.5 Lift Coefficient Data vs. Visual Contamination Ratings

The evaluation of the test runs was based primarily on the visual observations which indicated the difficulty with which the fluid and contamination was eliminated from the airfoil during the simulated takeoff run. The correlation between the visual rating of the leading edge at the time of rotation and the lift coefficient calculated at the 8 degree angle of rotation were compared in order to determine cut-off criteria to be used for evaluation of the test runs. The lift data at 8 degree angle of rotation was selected to be representative based on expected aircraft and wing angle of attack at the time of rotation. The data set was separated according to high speed and low speed data. Figure 5.4 and Figure 5.5 demonstrate the results obtained.

Based on the visual contamination ratings, it was concluded that a clean leading edge (a visual rating of "1" on the leading edge) was the minimum acceptable criteria for an acceptable test run. When correlated against the recorded lift coefficient at 8 degrees, it was found that during the tests with visual ratings of "1", the recorded lift coefficient was 1.70 or greater at the 8 degree rotation angle.

It should be noted that this analysis was conducted with the lift coefficient recorded at the 8 degree rotation angle due to the fact that the maximum rotation angle was increased incrementally from 8 degrees up to 20 degrees as testing progressed. The 8 degree lift coefficient data were available for all tests and provided a common data point for comparison purposes. The linear regression line indicates an inversely proportional trend between the visual contamination ratings and the recorded lift coefficient at 8 degree rotation. Preliminary analysis of the correlation between the visual contamination ratings and the lift coefficient recorded at greater rotation angles (up to 20 degrees) showed similar trends.

This analysis was conducted based on the 8 degree rotation angle as many tests were not conducted at the greater rotation angles. The stall angle of the wing section used for testing was closer to 20 degrees. Test runs with higher angles of attack were mostly done for the low speed tests; there was a limitation on the NRC scale system and therefore high speed tests with higher angles of rotation were not possible. It is recommended that any further testing conducted in the wind tunnel simulate a rotation up to the stall angle of the wing; the wing will be more sensitive to lift losses and provide a better indication as to the severity of the contamination on the wing.

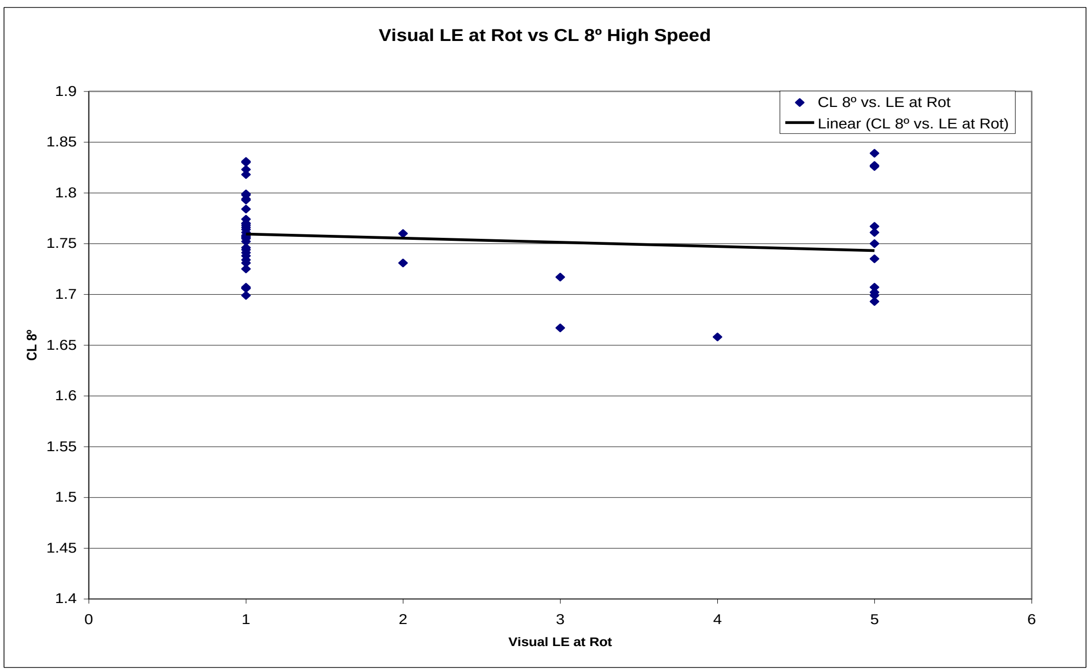

Figure 5.4: Visual Leading Edge Rating at Rotation vs. C_L 8º - High Speed Tests

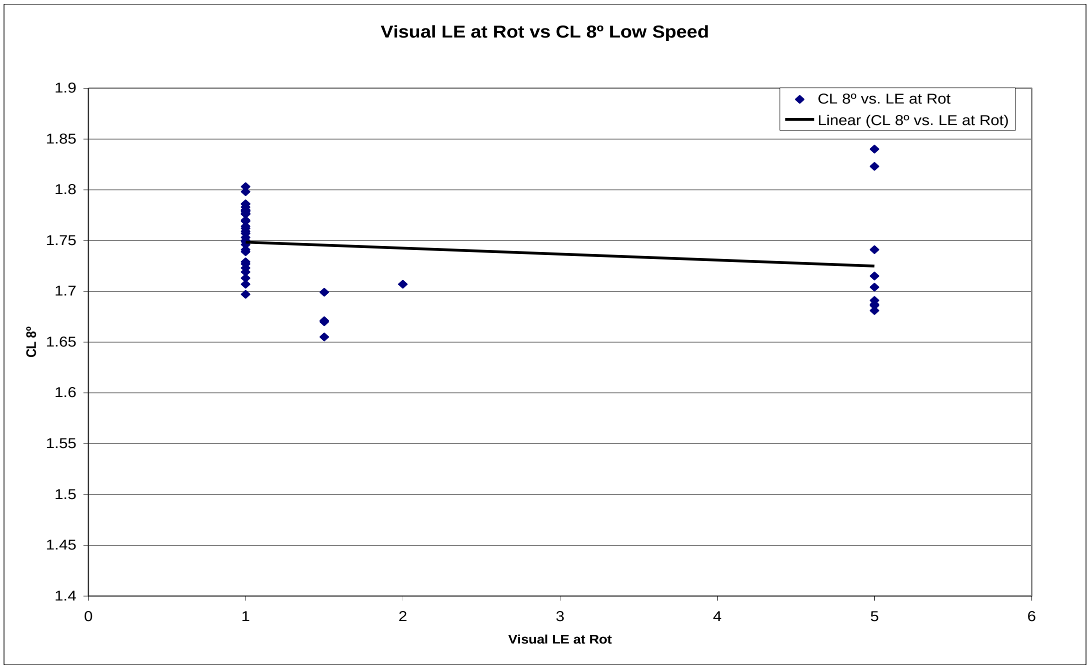

Figure 5.5: Visual Leading Edge Rating at Rotation vs. C_L 8º - Low Speed Tests

5.6 Analysis Summary Worksheets

Due to the large amount of data to be processed for each of the tests conducted, analysis worksheets were developed and completed for each of the tests to provide a summary regarding the status of each test. Figure 5.6 demonstrates a typical worksheet. Each worksheet comprised of eight rows: the first two rows indicated the test objective and test number, and the last six rows evaluated the status of the OAT, rate of precipitation, exposure time of precipitation, visual contamination ratings at the start of the test and time of rotation, calculated lift coefficient at 8 degree rotation, and finally provided an overall status summarizing the test. The evaluation grades included very good, good, fair, and bad, and were determined based on whether the criteria satisfied the test objective requirements or not. In the case of the OAT, Rate, and Exposure Time, these parameters were compared against the target parameters determined from the test plan i.e. a colder OAT than the target would constitute a more conservative test and was therefore good, whereas a warmer temperature would be fair or bad. The visual contamination ratings were evaluated based on pre-determined criteria; less than or equal to 3 on the leading and trailing edge at the start of the test was considered as “good” or “very good”, and equal to 1 on the leading edge at the time of rotation was also considered as “good” or “very good”. The calculated life coefficient at the 8 degree rotation angle was evaluated against the 1.7 cut-off (as described in Section 5.5). The overall status provided a summary of the test and indicated whether or not the test objective was met with successful results. A complete set of the analysis summary sheets for the ice pellet allowance time objectives has been included in Appendix F and separated according to test objective.

Objective	IP Validation TYPE IV HIGH SPEED	
Test # / Test Plan #	65 / PS1	
OAT	TARGET: -10°C -13°C very Good	
Rate	IP: 25 ZR: 25 Good	
Exposure Time	10 MINS Good	
Visual Contamination	AT START 3.3 Good AT ROT. 1.2	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	Good EXCEL 1.725	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	Good	

Figure 5.6: Typical Worksheet Used for Analysis

5.7 Comparison of Methodology Used for 2006-07 vs. 2008-09

During the 2008-09 testing, lift data collected from the NRC was monitored in real-time and was provided to APS at the end of each test run. This allowed TC/FAA/APS personnel to better assess and modify the test plan according to the results obtained. During the 2006-07 testing, data were only made available at the very end of the testing period, therefore, lift data were only used to confirm the visual observations and was not efficiently used as a decision making tool for planning during the testing.

As a result of the real-time availability of lift data, a more structured approach was employed during the 2008-09 testing which encompassed the critical aspects of the data collected (as demonstrated in the analysis summary sheets in Section 5.6). Marginal tests were more easily identified and were dealt with accordingly following the end of the test (in some cases marginal tests were re-run or modified in order to be able to satisfy test objectives). As compared to the 2006-07 testing, the analysis was ultimately based on the same evaluation criteria (visual and lift data) however the 2008-09 methodology was a more conservative analysis approach as a result of the real-time data provided by the NRC.

It is recommended that for future testing, data collected by the NRC should be provided in real-time to allow for on-site decision making based on the results obtained. In addition, each contaminated fluid test should be followed by, or preceded by a fluid only (un-contaminated) baseline test. This will allow for a direct comparison of the visual and lift results obtained. Ideally this should be performed for each tests conducted, but due to the large costs associated with this methodology, it may be more cost effective to use this methodology to help evaluate marginal tests.

5.8 Effect of Wing Surface Slope on Fluid Failure Mechanism

During tests with frozen precipitation, it was observed that the trailing edge section of the wing would show signs of failure earlier as compared to the leading edge. Upon closer investigation, it was found that there was a significant amount of fluid left on the trailing edge during these cases, and the failure observed was a result of the contamination bridging on the fluid surface. The leading edge, however, would show less signs of fluid failure but had less fluid present, especially close to the stagnation point. During these tests, a significant amount of fluid was observed on the highest point on the wing (at approximately 40 percent of the chord length). This “reserve” of fluid seemed to continually flow over and “feed” the leading edge removing any bridging contamination as the fluid diluted, whereas this was not observed on the trailing edge.

To investigate this phenomenon further, the geometry of the top wing surface was further analysed. Figure 5.7 demonstrates average slope of the wing leading and trailing edge, as well as a more detailed view of the wing leading edge. The first schematic in Figure 5.7 is derived based on the leading edge and trailing edge tip, as well as the highest point on the top wing surface. These dimensions were used to calculate an average slope for the leading edge and trailing edge of the wing. The results indicate that the leading edge had a steeper slope (14.7º) as compared to the trailing edge (9.9º) which may be a result for the fluid on the top of the wing surface “feeding” the leading edge.

The second schematic in Figure 5.7 represents the leading edge as a subdivision of two sections: the first third of the leading edge, and the rest of the leading edge. This was done to better represent the curvature on the leading edge. The results indicate that the leading edge had a shallow angle (5.4º) nearing the highest point of the wing, but the slope of the wing increased drastically over the first third of the wing (32.3º). This indicated that the fluid pooling on the shallow section of the wing would begin to flow over the leading edge as the contamination began to dilute the fluid. As a result, this would remove any bridging contamination on the leading edge. This was not observed on the trailing edge section due to the shallow angle of the wing surface which was fairly constant as of the highest point on the wing.

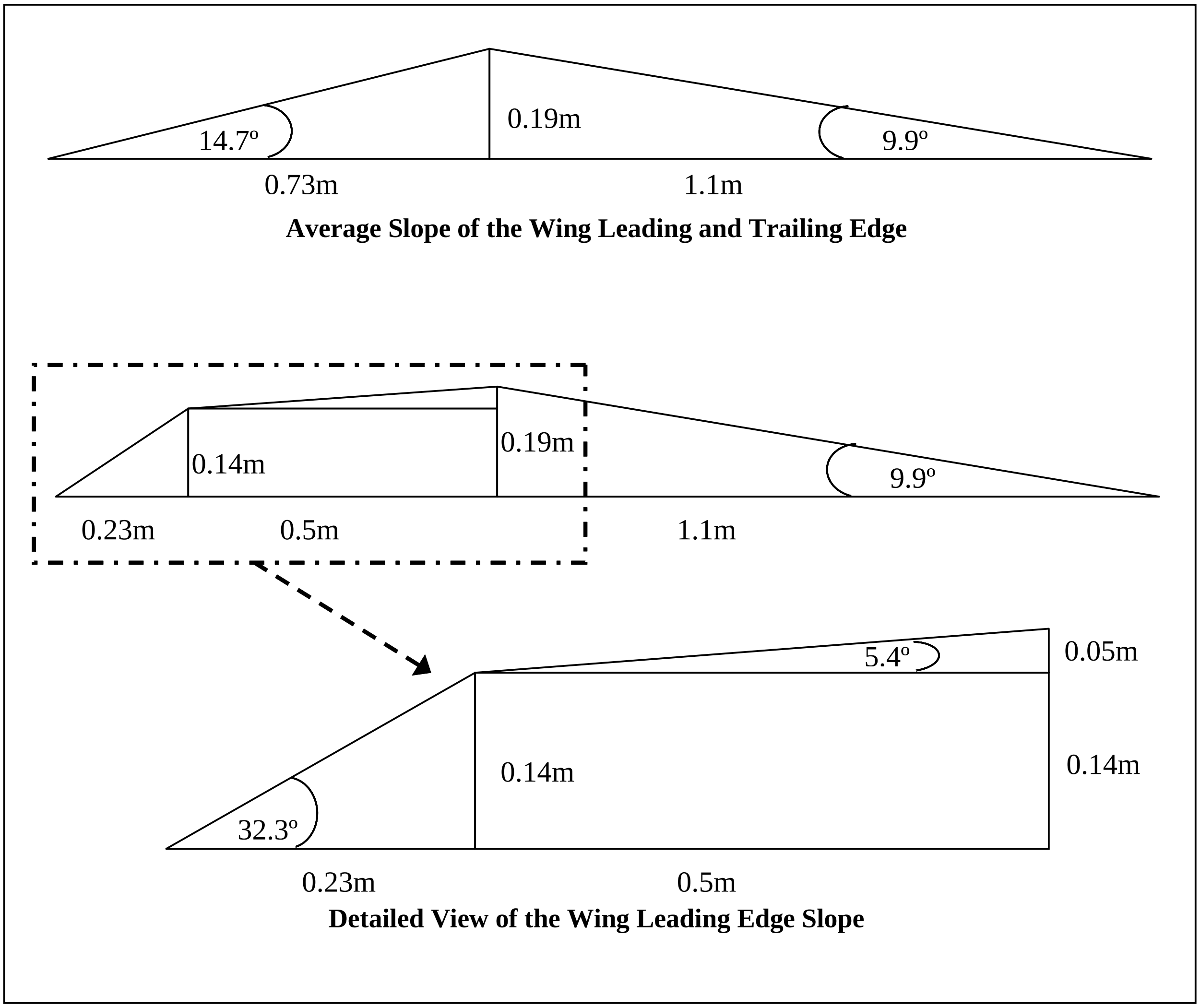

Figure 5.7: Wing Top Surface Slopes

6. TYPE IV FLUID ICE PELLET ALLOWANCE TIMES FOR HIGH SPEED AIRCRAFT

Aerodynamic testing was conducted to validate and further develop the Type IV high speed ice pellet allowance times in the NRC wind tunnel. Previous testing in 2006-07 consisted of wind tunnel tests and Falcon 20 aircraft tests to develop allowance times for mixed conditions with ice pellets. Due to the limitations of the data, some extrapolation of the results was required in order to develop a comprehensive table. It was recommended that testing be conducted at the most critical limits of the allowance times to validate the current guidance material. Additional testing was also required to provide guidance material where data were limited or non-existent.

This section provides an overview of each test conducted to substantiate and further develop the current high speed allowance times for Type IV fluids. The main objectives of this testing were as follows:

- Validation of the current Type IV high speed allowance times; and
- Expansion of the current Type IV high speed allowance times to include:
    - Mixed ice pellets and snow below -5°C conditions; and
    - Mixed ice pellets and moderate rain conditions.

Testing was conducted in simulated precipitation conditions. The parameters for each test are detailed and a description of the data collected during each test is provided.

6.1 Overview of Tests

A summary of the Type IV high speed 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 Section 4.1. 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 test, measured in degrees Celsius.

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

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

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

Visual Contamination Rating at Rotation (LE, TE): Visual contamination rating determined at the time of rotation:

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

Table 6.1: Summary of 2008-09 Type IV High Speed Testing

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
8	26-Jan-09	ABC-S Plus	IP/SN	25/25	10	-13	-15.9	3, 3	3, 3	N/A
9	26-Jan-09	ABC-S Plus	IP/SN	25/25	10	-8	-12.1	3, 3	2, 4	N/A
10	26-Jan-09	Launch	IP/SN	25/25	10	-5	-11.1	3, 4	2, 3	N/A
11	27-Jan-09	ABC-S Plus	IP/SN	25/25	10	-6	-6.5	3, 3	1, 2	1.760
13	27-Jan-09	Launch	IP/SN	25/25	10	-5	-5.8	3, 3	1, 2	1.770
20	28-Jan-09	ABC-S Plus	IP Mod	75	25	-7	-9.4	3, 4	1, 2	1.758
21	28-Jan-09	ABC-S Plus	IP-	25	50	-9	-8.3	3, 3	1, 2	1.755
29	29-Jan-09	EG106	IP Mod	75	25	-3	-8.1	2, 2	1, 1.5	1.794
30	29-Jan-09	EG106	IP-	25	50	-2	-5.4	1.5, 2	1, 1	1.793
44	31-Jan-09	EG106	IP/SN	25/25	15	-12	-13.2	2, 2	1, 1	1.746
51	2-Feb-09	Launch	IP/R	25/50	25	-2	-3.9	2, 2	1, 1	1.738
54	3-Feb-09	ABC-S Plus	IP/SN	25/25	25	0	-7.9	2.5, 4	1, 2	1.744
58	3-Feb-09	Launch	IP/SN	25/25	25	-6	-9.2	3, 4	1, 2.5	1.706
64	4-Feb-09	EG106	IP/ZR	25/25	10	-14	-9.8	2, 2	1, 1	N/A
65	5-Feb-09	ABC-S Plus	IP/ZR	25/25	10	-13	-11.0	3, 3	1, 2	1.725
66	5-Feb-09	Launch	IP-	25	30	-15	-12.3	3, 3	1, 2	1.707
67	5-Feb-09	Launch	IP Mod	75	10	-16	-13.7	4, 4	1, 3	1.706
68	5-Feb-09	EG106	IP-	25	30	-17	-15.0	3, 3	1, 1	1.752
69	5-Feb-09	EG106	IP Mod	75	10	-18	-14.9	3, 3	1, 1	1.741
75	24-Feb-09	ABC-S Plus	IP/SN-	25/10	10	-9	-7.6	2, 2	1, 2	1.770
76	24-Feb-09	Launch	IP/SN-	25/10	15	-10	-8.8	3, 3	1, 2	1.784
77	24-Feb-09	EG106	IP/SN-	25/10	15	-9	-10.2	2, 2	1, 1	1.823
85	25-Feb-09	EG106	IP/R	25/75	25	-1	-3.7	1.5, 1.5	1, 1	1.830
95	1-Mar-09	Launch	IP/R	25/75	25	-1	-2.9	2, 2	1, 1.5	1.799

6.2 Data Collected

6.2.1 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Section 2.14.2. Fluid thickness measurements were recorded at the following intervals:

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

Table 6.2 to Table 6.25 show the corrected fluid thickness measurements (in millimetres) collected during the tests.

Table 6.2: Test #8 Fluid Thickness Data

Test 8, ABC-S Plus, IP/SN, Tunnel OAT -12.6ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.8	1.1	0.0
2	0.8	1.1	0.0
3	1.1	1.3	0.1
4	1.2	1.2	0.0
5	1.5	1.2	0.0
6	1.0	1.3	1.0
7	1.1	1.5	1.1
8	1.0	1.3	1.2

Table 6.3: Test #9 Fluid Thickness Data

Test 9, ABC-S Plus, IP/SN, Tunnel OAT -8.4ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.0	0.8	0.0
2	1.0	1.0	0.0
3	1.2	1.2	0.1
4	1.3	1.2	0.1
5	1.6	1.7	0.1
6	1.1	1.3	0.6
7	1.1	1.3	0.6
8	1.1	1.2	0.7

Table 6.4: Test #10 Fluid Thickness Data

Test 10: Launch, IP/SN, Tunnel OAT -5.1ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.6	0.8	0.0
2	0.8	1.1	0.1
3	1.0	1.3	0.1
4	1.2	1.8	0.1
5	1.7	1.8	0.1
6	0.7	1.1	1.1
7	0.8	1.3	0.4
8	0.8	1.3	0.7

Table 6.5: Test #11 Fluid Thickness Data

Test 11, ABC-S Plus, IP/SN, Tunnel OAT -5.9ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.7	0.8	0.0
2	0.8	1.1	0.0
3	1.2	1.4	0.1
4	1.6	1.8	0.1
5	2.2	2.7	0.1
6	0.7	1.7	0.4
7	1.0	1.7	0.3
8	1.1	1.7	0.3

Table 6.6: Test #13 Fluid Thickness Data

Test 13, Launch, IP/SN, Tunnel OAT -5.3ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.7	0.8	0.0
2	0.8	1.1	0.0
3	1.2	1.4	0.0
4	1.6	1.8	0.1
5	2.5	2.5	0.1
6	1.0	2.2	0.3
7	1.2	2.2	0.2
8	1.0	1.8	0.3

Table 6.7: Test #20 Fluid Thickness Data

Test 20, ABC-S Plus, IP Mod, Tunnel OAT -6.7ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.8	1.4	0.0
2	1.1	1.8	0.0
3	1.5	3.1	0.0
4	1.8	3.7	0.0
5	2.7	4.5	0.0
6	1.3	5.7	0.1
7	1.2	4.5	0.3
8	1.3	4.5	0.3

Table 6.8: Test #21 Fluid Thickness Data

Test 21, ABC-S Plus, IP-, Tunnel OAT -8.5ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.8	Slush	0.0
2	1.0	1.8	0.0
3	1.5	2.9	0.0
4	1.8	3.3	0.0
5	2.7	3.9	0.0
6	1.2	1.8 (slush)	0.2
7	1.2	1.8 (slush)	0.2
8	1.5	1.8 (slush)	0.3

Table 6.9: Test #29 Fluid Thickness Data

Test 29, EG106, IP Mod, Tunnel OAT -2.6ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.8	1.1	0.0
2	2.5	1.8	0.0
3	3.3	3.7	0.0
4	4.5	4.5	0.0
5	4.5	5.7	0.0
6	2.2	2.2	0.1
7	2.2	1.8	0.1
8	1.8	slush	0.2

Table 6.10: Test #30 Fluid Thickness Data

Test 30, EG106, IP-, Tunnel OAT -1.6ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.8	0.6	0.0
2	2.7	1.0	0.0
3	3.7	1.8	0.0
4	4.5	2.2	0.0
5	4.5	4.5	0.0
6	2.5	1.1	0.0
7	2.2	0.8	0.1
8	2.2	0.8	0.1

Table 6.11: Test #44 Fluid Thickness Data

Test 44, EG106, IP/SN, Tunnel OAT -12.3ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.8	1.8	0.0
2	2.5	2.9	0.0
3	3.7	3.7	0.0
4	4.5	4.5	0.0
5	4.5	4.5	0.0
6	3.5	2.9	0.0
7	2.2	2.2	0.0
8	2.2	1.8	0.2

Table 6.12: Test #51 Fluid Thickness Data

Test 51, Launch, IP/R, Tunnel OAT -1.6ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.0	0.7	0.0
2	1.4	1.4	0.0
3	1.8	2.5	0.0
4	2.5	3.7	0.0
5	3.5	4.5	0.0
6	1.5	0.7	0.1
7	1.5	0.6	0.1
8	1.6	0.6	0.1

Table 6.13: Test #54 Fluid Thickness Data

Test 54, ABC-S Plus, IP/SN, Tunnel OAT 0.4ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.0	0.7	0.0
2	1.8	1.8	0.1
3	1.8	2.9	0.1
4	3.1	4.5	0.1
5	4.5	5.7	0.1
6	1.5	1.7	0.1
7	1.3	1.5	0.2
8	1.6	1.7	0.4

Table 6.14: Test #58 Fluid Thickness Data

Test 58, Launch, IP/SN, Tunnel OAT -6.3ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.7	0.8	0.0
2	1.0	2.2	0.0
3	1.4	2.9	0.0
4	2.2	3.5	0.0
5	3.1	3.7	0.0
6	1.2	1.6	0.1
7	1.2	1.3	0.1
8	1.3	1.3	0.2

Table 6.15: Test #64 Fluid Thickness Data

Test 64, EG106, IP/ZR, Tunnel OAT -13.6ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.8	1.1	0.0
2	2.9	1.8	0.0
3	3.5	2.9	0.0
4	4.5	3.5	0.0
5	4.5	3.9	0.0
6	2.5	1.4	0.0
7	2.5	1.8	0.0
8	2.2	1.8	0.1

Table 6.16: Test #65 Fluid Thickness Data

Test 65, ABC-S Plus, IP/ZR, Tunnel OAT -12.8ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.8	1.0	0.0
2	1.1	1.1	0.0
3	1.8	1.8	0.0
4	2.2	2.5	0.1
5	3.3	3.5	0.0
6	1.3	2.2	0.1
7	1.2	1.8	0.2
8	1.6	1.8	0.3

Table 6.17: Test #66 Fluid Thickness Data

Test 66, Launch, IP-, Tunnel OAT -14.7ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.8	0.8	0.1
2	0.8	1.8	0.1
3	1.2	2.2	0.1
4	1.2	2.7	0.1
5	1.8	3.3	0.0
6	1.0	2.2	0.1
7	1.0	1.8	0.1
8	1.1	1.4	0.2

Table 6.18: Test #67 Fluid Thickness Data

Test 67, Launch, IP Mod, Tunnel OAT -16.2ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.7	0.8	0.0
2	1.0	0.7	0.1
3	1.0	1.6	0.1
4	1.2	1.7	0.2
5	1.6	2.2	0.3
6	1.0	1.3	0.1
7	1.1	1.6	0.1
8	1.3	1.5	0.1

Table 6.19: Test #68 Fluid Thickness Data

Test 68, EG106, IP-, Tunnel OAT -16.6ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.7	1.1	0.0
2	2.2	1.7	0.0
3	3.3	3.3	0.1
4	4.5	4.5	0.1
5	4.5	4.5	0.1
6	1.8	1.8	0.3
7	1.7	1.7	0.4
8	1.5	1.5	0.2

Table 6.20: Test #69 Fluid Thickness Data

Test 69, EG106, IP Mod, Tunnel OAT -17.9ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.7	1.3	0.0
2	2.7	2.2	0.0
3	3.5	3.3	0.0
4	4.5	4.5	0.1
5	4.5	4.5	0.1
6	2.2	2.2	0.0
7	2.5	2.5	0.1
8	2.5	2.5	0.1

Table 6.21: Test #75 Fluid Thickness Data

Test 75, ABC-S Plus, IP/SN-, Tunnel OAT -8.8ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.1	1.1	0.0
2	1.4	1.7	0.1
3	2.9	2.7	0.1
4	3.5	3.5	0.1
5	4.5	4.5	0.1
6	1.3	1.7	0.1
7	1.3	1.6	0.2
8	1.6	1.3	0.5

Table 6.22: Test #76 Fluid Thickness Data

Test 76, Launch, IP/SN-, Tunnel OAT -9.8ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	2.9	1.0	0.0
2	2.2	1.8	0.1
3	1.4	1.8	0.1
4	1.1	2.5	0.1
5	1.0	2.9	0.1
6	1.1	1.3	0.2
7	1.1	1.3	0.3
8	1.3	1.2	0.3

Table 6.23: Test #77 Fluid Thickness Data

Test 77, EG106, IP/SN-, Tunnel OAT -9.2ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	4.5	1.2	0.0
2	3.9	1.8	0.0
3	3.1	3.1	0.1
4	1.8	3.9	0.1
5	1.4	4.5	0.1
6	2.2	1.8	0.2
7	2.2	1.4	0.2
8	2.2	1.0	0.2

Table 6.24: Test #85 Fluid Thickness Data

Test 85, EG106, IP/R, Tunnel OAT -1.2ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.8	0.5	0.0
2	2.2	0.6	0.0
3	3.5	0.7	0.0
4	4.5	1.4	0.0
5	4.5	2.2	0.0
6	2.2	0.3	0.0
7	2.2	0.3	0.0
8	2.2	0.4	0.0

Table 6.25: Test #95 Fluid Thickness Data

Test 95, Launch, IP/R, Tunnel OAT -1.0ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.1	1.6	0.0
2	1.4	1.8	0.0
3	1.4	3.9	0.0
4	1.8	3.9	0.0
5	3.7	4.5	0.0
6	1.2	1.3	0.3
7	1.2	0.6	0.3
8	1.3	0.6	0.4

6.2.2 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Section 2.14.3. Skin temperature measurements were recorded at the following intervals:

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

The wing temperatures measurements (in degrees Celsius) recorded during each test are shown in Table 6.26 to Table 6.49.

Table 6.26: Test #8 Wing Skin Temperature Data

Test 8, ABC-S Plus, IP/SN, Tunnel OAT -12.6ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-16.1	-17.7	-16.5	-15.1
T5	-15.9	-16.9	-14.9	-15.1
TU	-17.4	-17.7	-16.2	-16.4

Table 6.27: Test #9 Wing Skin Temperature Data

Test 9, ABC-S Plus, IP/SN, Tunnel OAT -8.4ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-12.8	-14.1	-13.2	-13.4
T5	-13.0	-14.2	-10.9	-12.6
TU	-13.7	-14.3	-12.1	-12.5

Table 6.28: Test #10 Wing Skin Temperature Data

Test 10, Launch, IP/SN, Tunnel OAT -5.1ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-12.4	-13.4	-12.4	-13.0
T5	-11.8	-13.2	-9.3	-12.5
TU	-11.8	-12.9	-11.7	-13.7

Table 6.29: Test #11 Wing Skin Temperature Data

Test 11, ABC-S Plus, IP/SN, Tunnel OAT -5.9ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-6.3	-8.8	-7.1	-8.0
T5	-6.0	-8.2	-6.3	-7.6
TU	-6.3	-8.2	-6.2	-8.3

Table 6.30: Test #13 Wing Skin Temperature Data

Test 13, Launch, IP/SN, Tunnel OAT -5.3ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-6.8	-6.5	-6.2	-5.7
T5	-6.7	-6.7	-5.8	-5.1
TU	-7.4	-6.2	-5.4	-5.1

Table 6.31: Test #20 Wing Skin Temperature Data

Test 20, ABC-S Plus, IP Mod, Tunnel OAT -6.7ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-5.1	-7.0	-10.0	-6.7
T5	-5.5	-7.2	-9.0	-6.4
TU	-6.0	-6.8	-9.3	-7.2

Table 6.32: Test #21 Wing Skin Temperature Data

Test 21, ABC-S Plus, IP-, Tunnel OAT -8.5ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-5.1	-6.7	-8.8	-6.0
T5	-5.2	-6.8	-7.8	-6.7
TU	-6.1	-6.9	-8.3	-7.5

Table 6.33: Test #29 Wing Skin Temperature Data

Test 29, EG106, IP Mod, Tunnel OAT -2.6ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-2.0	-1.4	-9.2	-2.5
T5	-1.7	-1.2	-6.7	-3.0
TU	-2.4	-2.0	-8.3	-3.8

Table 6.34: Test #30 Wing Skin Temperature Data

Test 30, EG106, IP-, Tunnel OAT -1.6ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-2.5	-2.6	-6.2	-2.6
T5	-3.0	-2.2	-5.3	-3.1
TU	-3.8	-3.0	-4.8	-3.4

Table 6.35: Test #44 Wing Skin Temperature Data

Test 44, EG 106, IP/SN, Tunnel OAT -12.3ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-12.8	-10.9	-13.7	-12.1
T5	-12.3	-10.6	-12	-12.6
TU	-13.8	-11.9	-13.9	-14.0

Table 6.36: Test #51 Wing Skin Temperature Data

Test 51, Launch, IP/R, Tunnel OAT -1.6ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-1.0	-2.5	-4.2	-4.0
T5	-1.0	-2.3	-3.4	-4.5
TU	-1.7	-2.4	-4.2	-5.0

Table 6.37: Test #54 Wing Skin Temperature Data

Test 54, ABC-S Plus, IP/SN, Tunnel OAT 0.4ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-4.7	-5.0	-8.5	-3.2
T5	-4.2	-5.8	-7.3	-4.0
TU	-5.5	-5.1	-8.0	-4.2

Table 6.38: Test #58 Wing Skin Temperature Data

Test 58, Launch, IP/SN, Tunnel OAT -6.3ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-6.0	-7.1	-9.6	-7.3
T5	-6.4	-6.8	-8.7	-7.9
TU	-7.4	-7.2	-9.4	-8.9

Table 6.39: Test #64 Wing Skin Temperature Data

Test 64, EG106, IP/ZR, Tunnel OAT -13.6ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-9.0	-10.7	-10.0	-11.3
T5	-9.0	-10.4	-8.3	-11.1
TU	-11.1	-10.7	-11.0	-12.7

Table 6.40: Test #65 Wing Skin Temperature Data

Test 65, ABC-S Plus, IP/ZR, Tunnel OAT -12.8ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-11.4	-11.9	-11.0	-12.4
T5	-11.5	-11.4	-10.1	-12.0
TU	-12.4	-12.4	-12.0	-13.1

Table 6.41: Test #66 Wing Skin Temperature Data

Test 66, Launch, IP-, Tunnel OAT -14.7ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-12.0	-12.0	-12.4	-13.4
T5	-11.8	-11.7	-12.0	-13.0
TU	-12.4	-12.4	-12.4	-13.7

Table 6.42: Test #67 Wing Skin Temperature Data

Test 67, Launch, IP Mod, Tunnel OAT -16.2ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-13.4	-13.1	-14.4	-14.6
T5	-13.0	-12.7	-14.1	-14.2
TU	-13.7	-13.2	-12.6	-15.3

Table 6.43: Test #68 Wing Skin Temperature Data

Test 68, EG106, IP-, Tunnel OAT -16.6ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-14.6	-14.0	-15.8	-14.1
T5	-14.2	-13.9	-14.9	-13.7
TU	-15.3	-14.0	-14.4	-14.8

Table 6.44: Test #69 Wing Skin Temperature Data

Test 69, EG106, IP Mod, Tunnel OAT -17.9ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-14.1	-14.5	-15.6	-15.5
T5	-13.7	-14.6	-14.1	-14.9
TU	-14.8	-14.8	-14.9	-16.1

Table 6.45: Test #75 Wing Skin Temperature Data

Test 75, ABC-S Plus, IP/SN-, Tunnel OAT -8.8ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-7.9	-7.4	-8.2	-7.4
T5	-7.6	-7.2	-7.5	-6.5
TU	-8.4	-7.5	-7.2	-7.9

Table 6.46: Test #76 Wing Skin Temperature Data

Test 76, Launch, IP/SN-, Tunnel OAT -9.8ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-7.4	-7.7	-9.6	-8.6
T5	-6.5	-7.6	-9.1	-7.7
TU	-7.9	-7.9	-7.6	-8.6

Table 6.47: Test #77 Wing Skin Temperature Data

Test 77, EG106, IP/SN-, Tunnel OAT -9.2ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-7.3	-7.0	-11.1	-9.0
T5	-6.2	-6.5	-9.2	-8.5
TU	-6.7	-7.2	-10.2	-9.6

Table 6.48: Test #85 Wing Skin Temperature Data

Test 85, EG106, IP/R, Tunnel OAT -1.2ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-1.7	-3.9	-3.8	-5.9
T5	-2.2	-3.9	-3.2	-4.2
TU	-1.3	-3.2	-4.2	-2.8

Table 6.49: Test #95 Wing Skin Temperature Data

Test 95, Launch, IP/R, Tunnel OAT -1.0ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-5.7	-5.2	-3.9	-4.6
T5	-5.2	-4.9	-3.6	-4.0
TU	-6.0	-5.5	-1.3	-5.5

6.2.3 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Section 2.14.4.

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

Table 6.50 to Table 6.73 show the fluid Brix measurements (in degrees Brix) collected during the test.

Table 6.50: Test #8 Fluid Brix Data

Test 8, ABC-S Plus, IP/SN, Tunnel OAT -12.6ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	38.00	25.50	24.00
8	37.25	22.50	21.00

Table 6.51: Test #9 Fluid Brix Data

Test 9, ABC-S Plus, IP/SN, Tunnel OAT -8.4ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.75	30.00	25.00
8	37.25	20.00	21.50

Table 6.52: Test #10 Fluid Brix Data

Test 10, Launch, IP/SN, Tunnel OAT -5.1ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.25	24.75	32.50
8	37.00	18.75	25.25

Table 6.53: Test #11 Fluid Brix Data

Test 11, ABC-S Plus, IP/SN, Tunnel OAT -5.9ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.25	27.50	33.50
8	37.25	13.50	26.25

Table 6.54: Test #13 Fluid Brix Data

Test 13, Launch, IP/SN, Tunnel OAT -5.3ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.00	24.00	34.25
8	36.25	21.25	26.00

Table 6.55: Test #20 Fluid Brix Data

Test 20, ABC-S Plus, IP Mod, Tunnel OAT -6.7ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.25	16.00	26.25
8	37.25	13.00	22.00

Table 6.56: Test #21 Fluid Brix Data

Test 21, ABC-S Plus, IP, Tunnel OAT -8.5ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.00	21.00	26.50
8	37.00	19.50	22.75

Table 6.57: Test #29 Fluid Brix Data

Test 29, EG106, IP Mod, Tunnel OAT -2.6ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	33.50	21.50	30.00
8	33.75	15.75	29.25

Table 6.58: Test #30 Fluid Brix Data

Test 30, EG106, IP-, Tunnel OAT -1.6ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	33.50	19.00	26.25
8	33.75	15.00	27.25

Table 6.59: Test #44 Fluid Brix Data

Test 44, EG106, IP/SN, Tunnel OAT -12.3ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	34.25	21.50	33.00
8	34.00	26.50	30.75

Table 6.60: Test #51 Fluid Brix Data

Test 51, Launch, IP/R, Tunnel OAT -1.6ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.25	14.50	36.00
8	36.25	9.50	25.25

Table 6.61: Test #54 Fluid Brix Data

Test 54, ABC-S Plus, IP/SN, Tunnel OAT 0.4ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.50	20.00	30.50
8	37.00	22.75	26.50

Table 6.62: Test #58 Fluid Brix Data

Test 58, Launch, IP/SN, Tunnel OAT -6.3ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.75	15.00	34.00
8	37.00	17.00	24.00

Table 6.63: Test #64 Fluid Brix Data

Test 64, EG106, IP/ZR, Tunnel OAT -13.6ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	34.75	28.00	34.50
8	34.25	23.25	32.00

Table 6.64: Test #65 Fluid Brix Data

Test 65, ABC-S Plus, IP/ZR, Tunnel OAT -12.8ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	38.00	30.00	29.50
8	37.25	26.50	28.50

Table 6.65: Test #66 Fluid Brix Data

Test 66, Launch, IP-, Tunnel OAT -14.7ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.00	22.00	34.50
8	36.50	22.50	27.75

Table 6.66: Test #67 Fluid Brix Data

Test 67, Launch, IP Mod, Tunnel OAT -16.2ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.50	35.50	35.00
8	36.75	34.00	29.00

Table 6.67: Test #68 Fluid Brix Data

Test 68, EG106, IP-, Tunnel OAT -16.6ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.00	27.50	38.00
8	34.50	27.00	29.50

Table 6.68: Test #69 Fluid Brix Data

Test 69, EG106, IP Mod, Tunnel OAT -17.9ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	35.00	29.50	34.50
8	34.25	31.50	29.50

Table 6.69: Test #75 Fluid Brix Data

Test 75, ABC-S Plus, IP/SN-, Tunnel OAT -8.8ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.75	33.00	32.75
8	36.50	35.75	30.75

Table 6.70: Test #76 Fluid Brix Data

Test 76, Launch, IP/SN-, Tunnel OAT -9.8ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.25	27.50	29.00
8	36.50	20.25	26.50

Table 6.71: Test #77 Fluid Brix Data

Test 77, EG106, IP/SN-, Tunnel OAT -9.2ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	33.75	25.00	36.25
8	33.75	26.50	32.50

Table 6.72: Test #85 Fluid Brix Data

Test 85, EG106, IP/R, Tunnel OAT -1.2ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	33.25	13.50	N/A
8	33.75	8.50	21.00

Table 6.73: Test #95 Fluid Brix Data

Test 95, Launch, IP/R, Tunnel OAT -1.0ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.00	13.00	33.00
8	37.00	9.25	21.75

6.3 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 test, a summary of the photos has been compiled comprising of four photos per camera angle:

- 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 4 degrees); and
- End of test.

Photo 6.1 to Photo 6.96 show the photo summaries of the tests conducted. A complete set of photos will be provided to TDC in electronic format.

6.4 General Observations

The following sections describe the observations regarding the testing conducted to validate and expand the current Type IV high speed allowance time table. The results have been separated according to the specific condition tested. Table 6.74 shows the tests conducted for each ice pellet condition as well as the ice pellet allowance times derived from the 2006-07 testing.

Table 6.74: Tests Conducted Separated According to Condition Tested

<table>
<tr><th></th><th>OAT -5°C and above</th><th>OAT less than -5°C to -10°C</th><th>OAT less than -10°C</th></tr>
<tr><td>Light Ice Pellets</td><td>50 minutes
Test # 21, 30</td><td>30 minutes
Test # 66, 68</td><td>30 minutes</td></tr>
<tr><td>Moderate Ice Pellets</td><td>25 minutes
Test # 20, 29</td><td>10 minutes
Test # 67, 69</td><td>10 minutes</td></tr>
<tr><td>Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle</td><td>25 minutes</td><td>10 minutes</td><td rowspan="6">Caution: No allowance times currently exist</td></tr>
<tr><td>Light Ice Pellets Mixed with Light Freezing Rain</td><td>25 minutes</td><td>10 minutes
Test # 64, 65</td></tr>
<tr><td>Light Ice Pellets Mixed with Light Rain</td><td>25 minutes</td><td rowspan="2"></td></tr>
<tr><td>Light Ice Pellets Mixed with Moderate Rain</td><td>Allowance Time N/A
Test # 51, 85, 95</td></tr>
<tr><td>Light Ice Pellets Mixed with Moderate Snow</td><td>25 minutes
Test # 10, 11, 13, 54, 58</td><td>Allowance Time N/A
Test # 8, 9, 44</td></tr>
<tr><td>Light Ice Pellets Mixed with Light Snow</td><td>25 minutes</td><td>Allowance Time N/A
Test # 75, 76, 77</td></tr>
</table>

6.4.1 Light Ice Pellets

6.4.1.1 OAT -5ºC and Above

Two tests were conducted: Test #21 and Test #30. Testing was conducted with a PG (Propylene Glycol) and an EG (Ethylene Glycol) fluid, respectively. The test results from Test #21 demonstrate positive visual ratings at the end of precipitation (equal to 3 on the leading and trailing edge) as well as at the time of rotation (less than 1 on the leading edge). The lift coefficient at the 8 degree angle of rotation was equal to 1.755, above the 1.70 identified as the pass-fail. The ambient temperature during the test was slightly below the target temperature, which was conservative, and the rate and exposure time of precipitation was appropriate according to the condition tested (this was a validation test). The overall status of this test was good, and demonstrated positive results. The details of this test (as well as all the other ice pellet allowance time tests conducted) can be found in Appendix F; all other tests were evaluated using the same methodology.

Similar results were obtained for Test #30; the visual and lift data results satisfied the pass-fail criteria. Both tests demonstrated positive results indicating that the current 50 minute allowance time for conditions of light ice pellets is acceptable and validated.

6.4.1.2 OAT less than -5ºC to -10ºC

Two tests were conducted: Test #66 and Test #68. Both tests demonstrated positive results indicating that the current 30 minute allowance time for conditions of light ice pellets is acceptable and validated.

6.4.1.3 OAT less than -10ºC

Testing at the lower limit of -25ºC was not possible to due to the lack of cold weather conditions during the testing period. Based on positive results from Test #66 and Test #68 which were conducted at -15ºC and -17ºC, the current allowance time of 30 minutes is acceptable, however further testing is recommended to obtain data at the -25ºC temperature range.

6.4.2 Moderate Ice Pellets

6.4.2.1 OAT -5ºC and Above

Two tests were conducted: Test #20 and Test #29. In the case of the PG fluid (Test #20), the visual contamination ratings at the start of the test were marginal (rating of 3.4), however the fluid flow-off results did not indicate any problems. Both tests demonstrated positive results indicating that the current 25 minute allowance time for conditions of moderate ice pellets is acceptable and validated.

6.4.2.2 OAT less than -5°C to -10°C

Two tests were conducted: Test #67 and Test #69. In the case of the PG fluid (Test #67), the visual contamination ratings at the start of the test were marginal (rating of 4.4), however the fluid flow-off results did not indicate any problems. Both tests demonstrated positive results indicating that the current 10 minute allowance time for conditions of moderate ice pellets is acceptable and validated.

6.4.2.3 OAT less than -10°C

Testing at the lower limit of -25°C was not possible to due to the lack of cold weather conditions during the testing period. Based on positive results from Test #67 and Test #69 which were conducted at -16°C and -18°C, the current allowance time of 10 minutes is acceptable, however further testing is recommended to obtain data at the -25°C temperature range.

6.4.3 Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle

Testing in this condition was not conducted in the wind tunnel. Allowance times were extrapolated from the "light ice pellets mixed with light freezing rain" condition (see Section 6.4.4 for results). This approach was deemed appropriate and conservative because light ice pellets mixed with light or moderate freezing drizzle is a less severe condition compared to light ice pellets mixed with light freezing rain.

6.4.4 Light Ice Pellets Mixed with Light Freezing Rain

6.4.4.1 OAT -5°C and Above

High speed testing in this condition was not conducted in the wind tunnel. Low speed testing in light ice pellets mixed with light freezing rain was conducted (see Section 7.4.4) and the results were applied for high speed takeoff as well; this is a conservative approach. The three low speed tests (Test # 22, 25 and 33) conducted demonstrated positive results indicating that the current 25 minute allowance time for conditions of light ice pellets mixed with light freezing rain is acceptable and validated.

In addition, flat plate testing at the NRC climatic engineering facility indicated that the current 25 minute allowance time for conditions of light ice pellets mixed with light freezing rain is acceptable and provides a sufficient safety buffer.

6.4.4.2 OAT less than -5°C to -10°C

Two tests were conducted: Test #64 and Test #65. The NRC lift data were not available for Test #64, but the visual observations did not indicate any potential flow-off problems. Both tests demonstrated positive results indicating that the current 10 minute allowance time for conditions of light ice pellets is acceptable and validated.

In addition, flat plate testing at the NRC climatic engineering facility indicated that the current 10 minute allowance time for conditions of light ice pellets mixed with light freezing rain is acceptable and provides a sufficient safety buffer.

6.4.5 Light Ice Pellets Mixed with Light Rain

6.4.5.1 OAT -5°C and Above

Testing in this condition was not conducted in the wind tunnel. Allowance times were extrapolated from the "light ice pellets mixed with light freezing rain" condition (see Section 6.4.4 for results). This approach was deemed appropriate and conservative because light ice pellets mixed with light rain is a less severe condition compared to light ice pellets mixed with light freezing rain.

Results from the testing in light ice pellets mixed with moderate rain condition (see Section 6.4.6) were positive and indicated a potential to expand the 25 minute allowance time for light ice pellets mixed with light rain. Additional testing is required to further expand the current 25 minute allowance time for light ice pellets mixed with light rain.

6.4.6 Light Ice Pellets Mixed with Moderate Rain

6.4.6.1 OAT -5°C and Above

Three tests were conducted: Test #51, Test #85, and Test #95. The first test, Test #51, demonstrated positive results, however the precipitation rate generated was not at the upper limit; the rain rate produced was 50 g/dm²/h rather than 75 g/dm²/h. Test #85 produced positive results. Test #95 demonstrated positive fluid flow-off results; however, due to the large temperature differential between the tunnel ambient temperature and the outside ambient temperature, some freezing occurred on the leading edge at the time of rotation which was removed by the end of the test. It was concluded that had the outside temperature been closer to the tunnel ambient temperature during Test #95, the ice formations would not have occurred. The three tests demonstrated positive results indicating that a 25 minute allowance time for conditions of light ice pellets mixed with moderate rain is acceptable.

6.4.7 Light Ice Pellets Mixed with Moderate Snow

6.4.7.1 OAT -5°C and Above

Five tests were conducted with PG fluids: Test #10, Test #11, Test #13, Test #54, and Test #58. Results indicated fluid flow-off issues for PG fluids at the colder temperatures. 25 minute exposure tests conducted at the warmer temperatures (Test #54 and Test #58) generated positive results, whereas 10 minute tests conducted at the lower temperature limit (Test #10, Test #11, and Test #13) generated mixed results with positive lift data and marginal visual contamination results; testing with intermediary exposure times was not attempted. As the current guidelines included a 25 minute allowance time based on previous wind tunnel and Falcon 20 research, it was recommended that the allowance time be reduced to 10 minutes based on this year's results obtained at the lower temperatures. Additional testing should be conducted to try and substantiate an allowance time of 15 or 20 minutes for this condition.

6.4.7.2 OAT -5°C to -10°C

Three tests were conducted: Test #8, Test #9, and Test #44. The objective was to develop guidance material, as prior to this testing allowance times for this condition did not exist. The results demonstrated a discrepancy in the results obtained with the PG fluid vs. the EG fluid. Test #44 conducted with the EG fluid demonstrated good fluid flow-off and positive results whereas Test #8 and Test #9 conducted with the PG fluid demonstrated poor fluid flow-off. As limited testing was conducted with 10 minute exposure times, allowance times for these conditions were not recommended. Additional testing should be conducted to target 5 or 8 minute allowance times.

6.4.8 Light Ice Pellets Mixed with Light Snow

Due to the stringent allowance times issued with the light ice pellets mixed with moderate snow condition, it was recommended to separate the mixed condition into "light ice pellets mixed with moderate snow" and "light ice pellets mixed with light snow" in order to provide greater flexibility to operators.

6.4.8.1 OAT -5ºC and Above

Testing was not conducted as data from previous years was available and substantiated the current 25 minute allowance time. Based on the previous results, as well as the data collected this year in the -5ºC to -10ºC temperature range, additional testing should be conducted to try and expand the current allowance time to approximately 40 minutes.

6.4.8.2 OAT -5ºC to -10ºC

Three tests were conducted Test #75, Test #76, and Test #77. The exposure times for these tests were 10 minutes, 15 minutes, and 15 minutes respectively. All the tests demonstrated good fluid flow-off and had positive results. A 15 minute allowance time was recommended for this condition based on these tests. Additional testing should be conducted to potentially expand the allowance time to 18 minutes or greater.

6.5 Summary of Results

6.5.1 Allowance Time Validation

Based on the testing conducted during the winter of 2008-09, all the cells of the allowance time table were validated, however, some additional data is recommended for the following conditions:

- Light Ice Pellets below -10ºC (close to the -25ºC temperature limit); and
- Moderate Ice Pellets below -10ºC (close to the -25ºC temperature limit).

In addition, the following restrictive change was made to the current allowance time table:

- Light Ice Pellets Mixed with Moderate Snow above -5ºC: Allowance time reduced from 25 minutes to 10 minutes.

6.5.2 Allowance Time Expansion

Based on the testing conducted during the winter of 2008-09, some changes were recommended to allow greater flexibility to operators. The following is a list of the recommended changes:

- New 25 minute allowance time for light ice pellets mixed with moderate rain for above -5°C conditions; and
- Separation of the light ice pellets mixed with light or moderate snow row:
  - New 15 minute allowance time for "light ice pellets mixed with light snow for the -5°C to -10°C conditions.

Based on these results, a newly updated version of the Type IV Allowance time table has been developed and proposed for the 2009-10 version of the HOT Guidelines. The new table will include the above mentioned changes to reflect the results obtained during the testing conducted in 2008-09.

A summary of the newly developed allowance times is shown in Table 6.75. The respective tests used to validate or develop the respective cells have also been indicated.

6.6 Probability of Ice Pellet Occurrences for use with Allowance Times

Ice pellet precipitation data were acquired from instruments located at six stations in Quebec, Canada from the Meteorological Service of Canada (MSC). This data were collected as part of an ongoing study to evaluate the suitability of the current format of the HOT tables [see TP 14934E, *Winter Weather Impact on Holdover Time Table Format (1995-2009*)] (14). The results were translated into likelihood of ice pellet occurrence in each cell of the allowance time table. The outcome is shown in Table 6.75.

Values in italics in Table 6.76 indicate conditions where no allowance times currently exist. Based on this limited data, it appears a significant portion of "light ice pellets mixed with light snow" precipitation occurs below -10°C and "light ice pellets mixed with moderate snow" precipitation occurs below -5 to -10°C where no allowance times currently exist. It is recommended that future research target these conditions in order to allow greater flexibility to operators in conditions of mixed ice pellets and light or moderate snow.

Table 6.75: Type IV High Speed Ice Pellet Allowance Times for Winter 2009-10

	OAT -5°C and above	OAT less than -5°C to -10°C	OAT less than -10°C
Light Ice Pellets	**50 minutes** *Test # 21, 30*	**30 minutes** *Test # 66, 68*	**30 minutes**
Moderate Ice Pellets	**25 minutes** Test # 20, 29	**10 minutes** Test # 67, 69	**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** ↑ *Test # 64, 65*	
Light Ice Pellets Mixed with Light Rain	**25 minutes**		
Light Ice Pellets Mixed with Moderate Rain	**25 minutes** ↓ *Test # 51, 85, 95*		
Light Ice Pellets Mixed with Moderate Snow	**10 minutes** *Test # 10, 11, 13, 54, 58*	**0 minutes** *Test # 8, 9, 44*	
Light Ice Pellets Mixed with Light Snow	**25 minutes**	**15 minutes** *Test # 75, 76, 77*	

⟶ Extrapolated Allowance Times

Table 6.76: Likelihood of Occurrence for use with Ice Pellet Allowance Times

Condition	Possible Rate	OAT -5°C and above	OAT less than -5°C to -10°C	OAT less than -10°C	Total
Light Ice Pellets	(0 to 25 g/dm²/h)	88.8%	7.2%	0.0%	**100%**
Moderate Ice Pellets	(25 to 75 g/dm²/h)	4.0%	0.0%	0.0%	
***Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle**	(0 to 38 g/dm²/h)	90.4%	9.6%	*0.0%*	**100%**
***Light Ice Pellets Mixed with Light Freezing Rain**	(0 to 50 g/dm²/h)				
***Light Ice Pellets Mixed with Light Rain**	(0 to 50 g/dm²/h)	99.5%(1)	*0.0%*	*0.0%*	
***Light Ice Pellets Mixed with Moderate Rain**	(25 to 100 g/dm²/h)	9.5%(2)	*0.0%*	*0.0%*	
***Light Ice Pellets Mixed with Light Snow**	(0 to 35 g/dm²/h)	55.80%	20.40%(3)	*18.90%*	
***Light Ice Pellets Mixed with Moderate Snow**	(10 to 50 g/dm²/h)	14.45%(4)	*11.45%*	*1.09%*	

*Analysis based upon a cumulative rate of both precipitation types and assumes ice pellet intensity does not exceed "light" or 25 g/dm²/h

FOOTNOTES

(1) There is a 99.5% likelihood of light ice pellets mixed with light rain with a possible rate from 0 to 50 g/dm²/h (at OAT -5°C and above) if the weather report is ice pellets mixed with rain.

(2) There is a 9.5% likelihood of light ice pellets mixed with moderate rain with a possible rate from 25 to 100 g/dm²/h (at OAT -5°C and above) if the weather report is ice pellets mixed with rain.

(3) There is a 20.4% likelihood of light ice pellets mixed with light snow with a possible rate from 0 to 35 g/dm²/h (at OAT -5°C to -10°C) if the weather report is ice pellets mixed with snow.

(4) There is a 14.45% likelihood of light ice pellets mixed with moderate snow with a possible rate from 10 to 50 g/dm²/h (at OAT -5°C and above) if the weather report is ice pellets mixed with snow.

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Photo 6.1: Test #8 – Start of Test

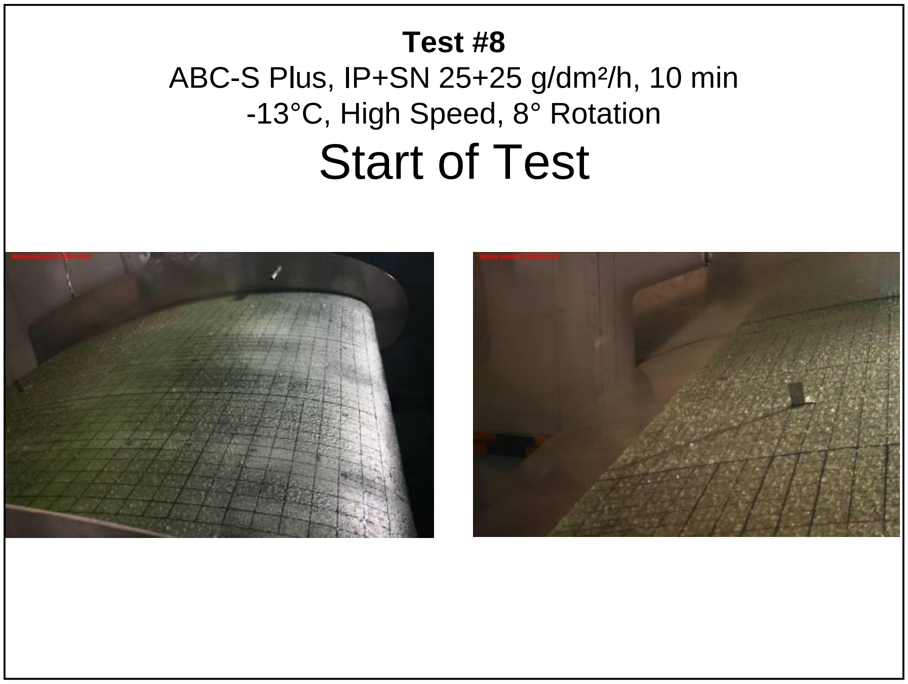


Photo 6.2: Test #8 – Before Rotation

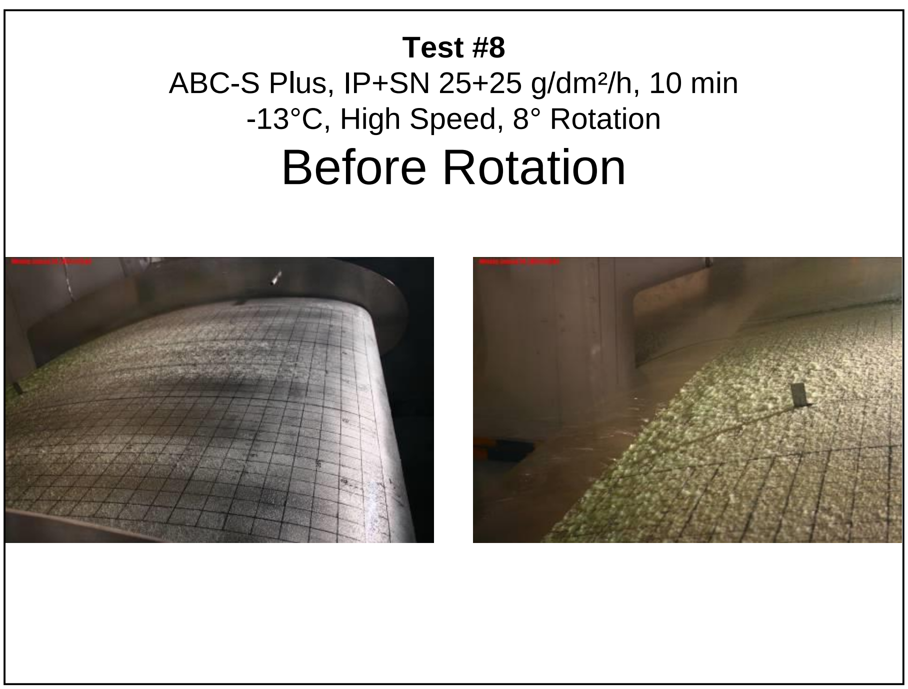


Photo 6.3: Test #8 – End of Rotation

Test #8
ABC-S Plus, IP+SN 25+25 g/dm²/h, 10 min
-13°C, High Speed, 8° Rotation
End of Rotation

Photo 6.4: Test #8 – End of Test

Test #8
ABC-S Plus, IP+SN 25+25 g/dm²/h, 10 min
-13°C, High Speed, 8° Rotation
End of Test

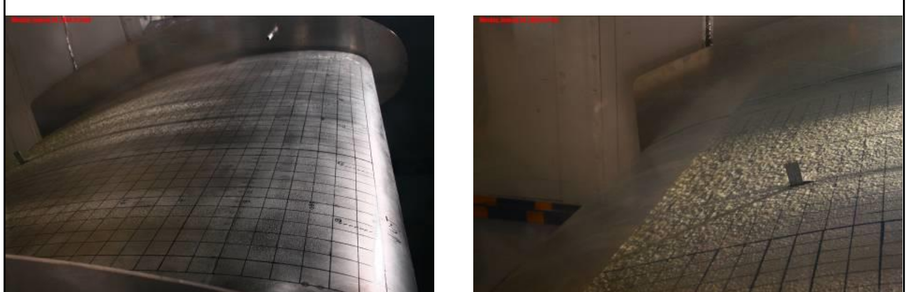


Photo 6.5: Test #9 – Start of Test

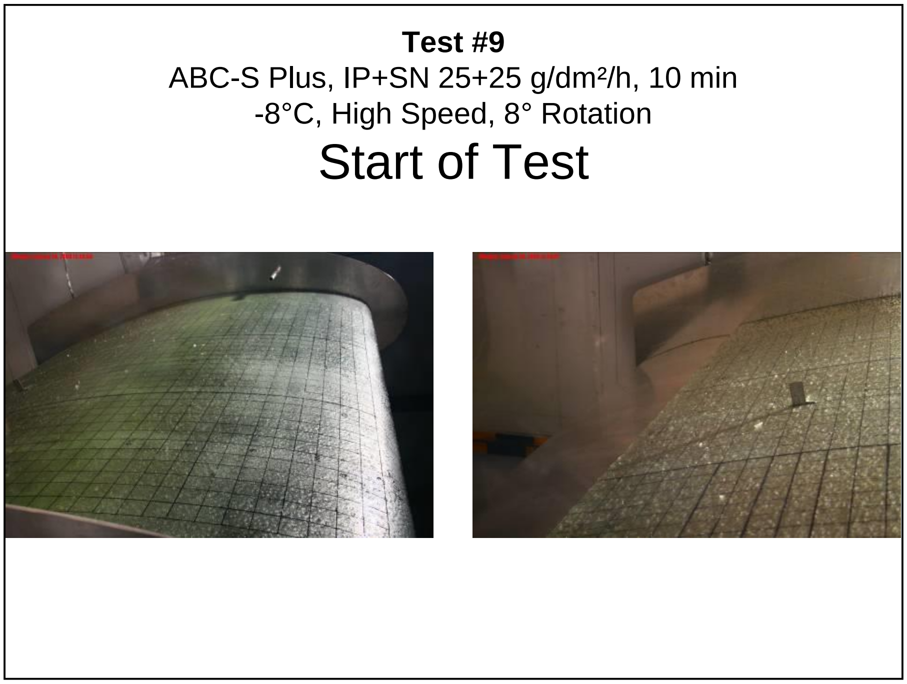


Photo 6.6: Test #9 – Before Rotation

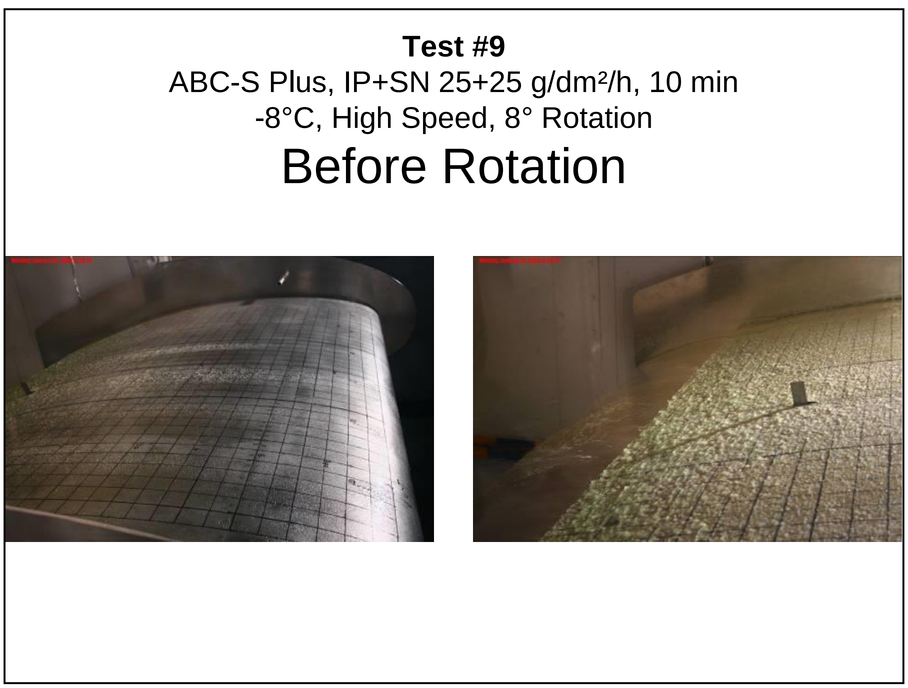


Photo 6.7: Test #9 – End of Rotation

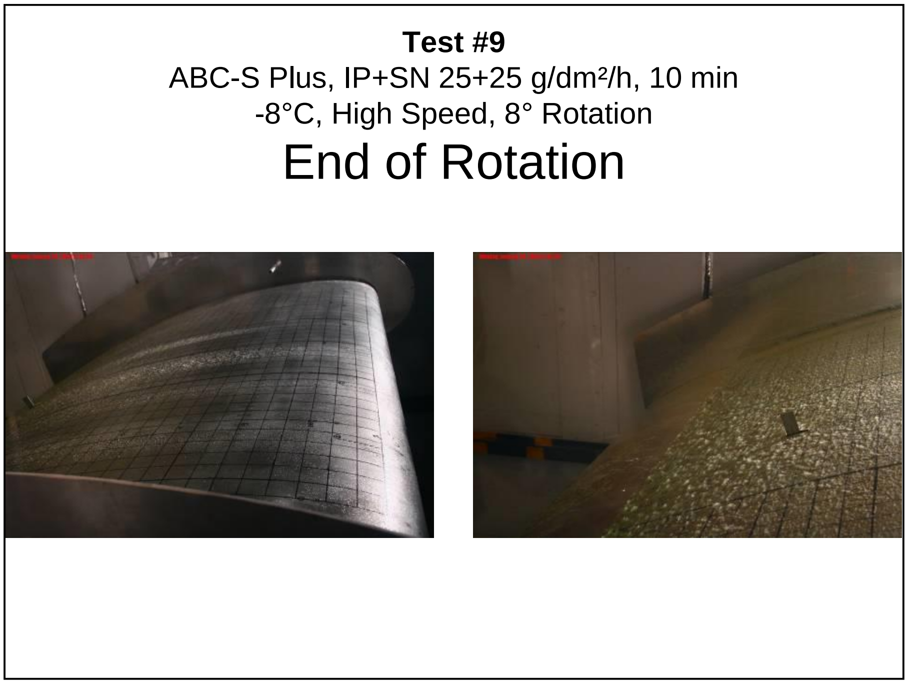


Photo 6.8: Test #9 – End of Test

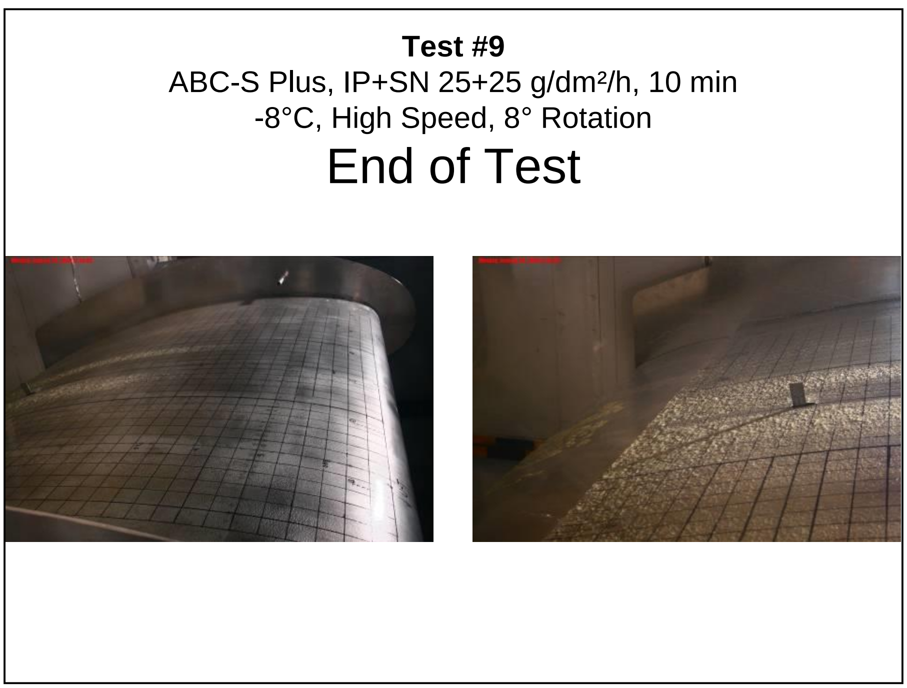


Photo 6.9: Test #10 – Start of Test

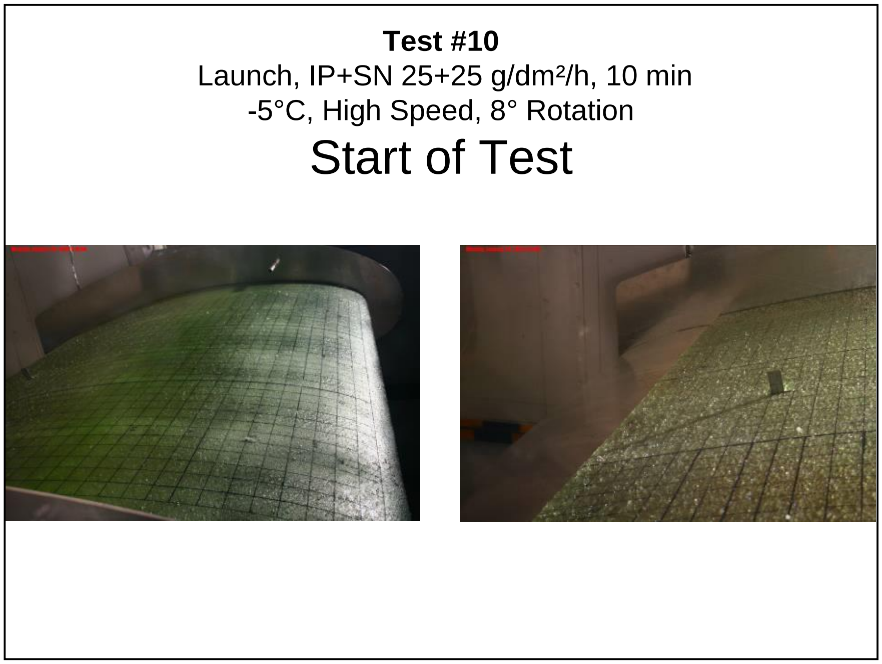


Photo 6.10: Test #10 – Before Rotation

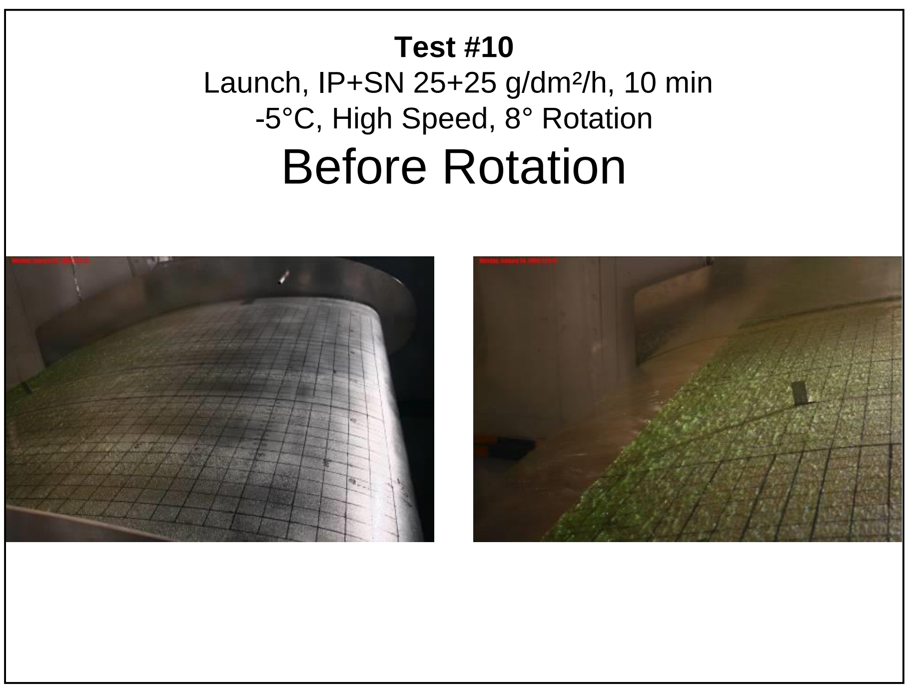


Photo 6.11: Test #10 – End of Rotation

Test #10
Launch, IP+SN 25+25 g/dm²/h, 10 min
-5°C, High Speed, 8° Rotation
End of Rotation

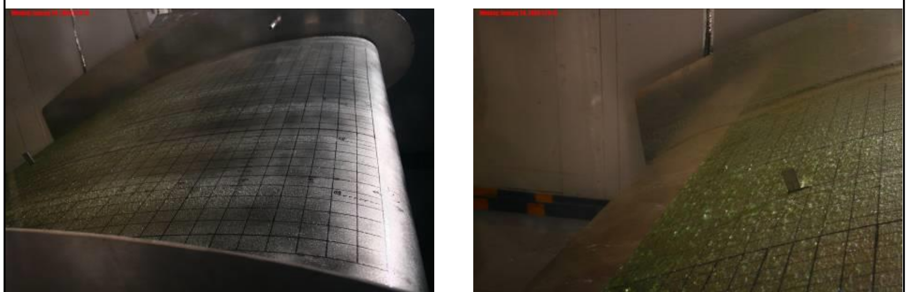


Photo 6.12: Test #10 – End of Test

Test #10
Launch, IP+SN 25+25 g/dm²/h, 10 min
-5°C, High Speed, 8° Rotation
End of Test

Photo 6.13: Test #11 – Start of Test

Test #11
ABC-S Plus, IP+SN 25+25 g/dm²/h, 10 min
-6°C, High Speed, 8° Rotation
Start of Test

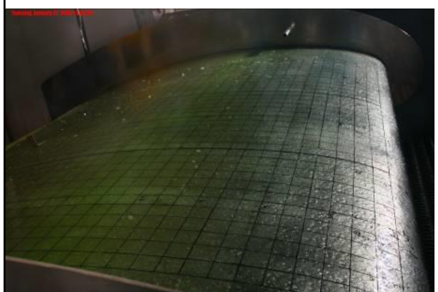
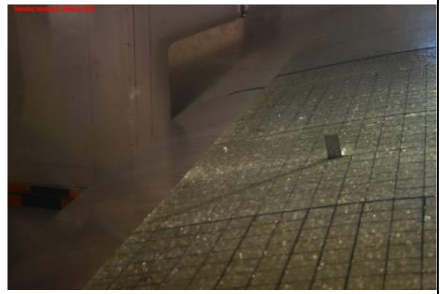



Photo 6.14: Test #11 – Before Rotation

Test #11
ABC-S Plus, IP+SN 25+25 g/dm²/h, 10 min
-6°C, High Speed, 8° Rotation
Before Rotation

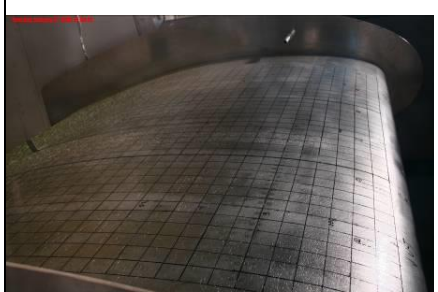



Photo 6.15: Test #11 – End of Rotation

Test #11
ABC-S Plus, IP+SN 25+25 g/dm²/h, 10 min
-6°C, High Speed, 8° Rotation
End of Rotation

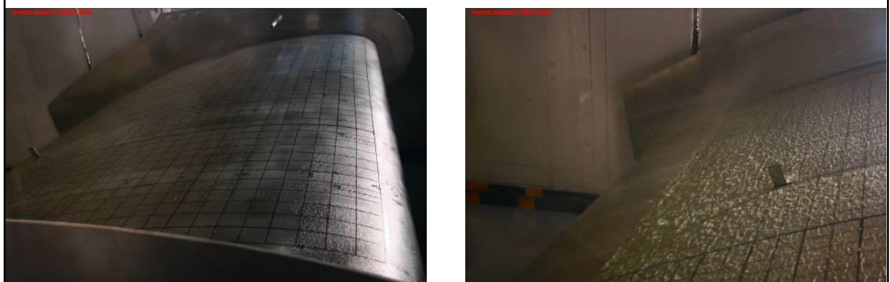


Photo 6.16: Test #11 – End of Test

Test #11
ABC-S Plus, IP+SN 25+25 g/dm²/h, 10 min
-6°C, High Speed, 8° Rotation
End of Test

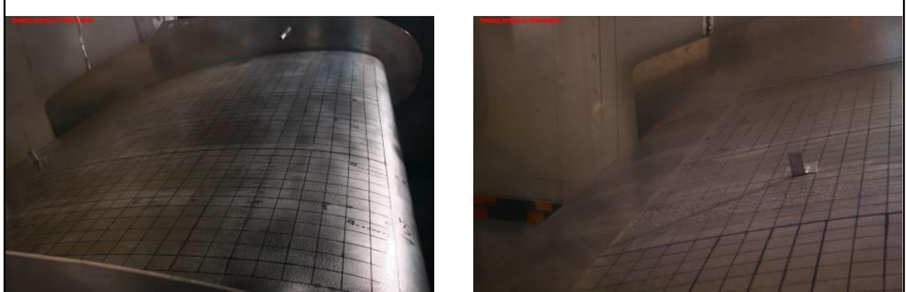


Photo 6.17: Test #13 – Start of Test

Test #13
Launch, IP+SN 25+25 g/dm²/h, 10 min
-5°C, High Speed, 8° Rotation
Start of Test

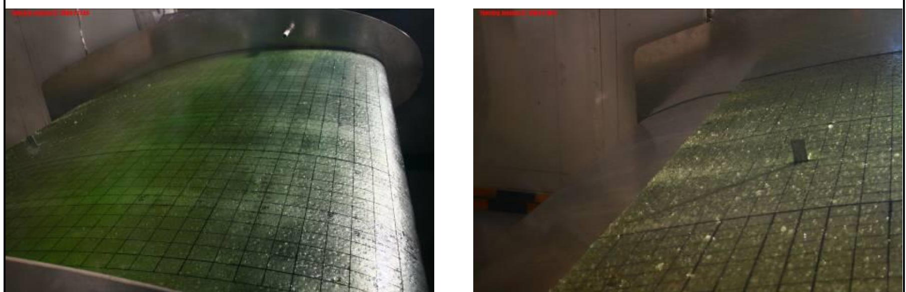


Photo 6.18: Test #13 – Before Rotation

Test #13
Launch, IP+SN 25+25 g/dm²/h, 10 min
-5°C, High Speed, 8° Rotation
Before Rotation

Photo 6.19: Test #13 – End of Rotation

Test #13
Launch, IP+SN 25+25 g/dm²/h, 10 min
-5°C, High Speed, 8° Rotation
End of Rotation

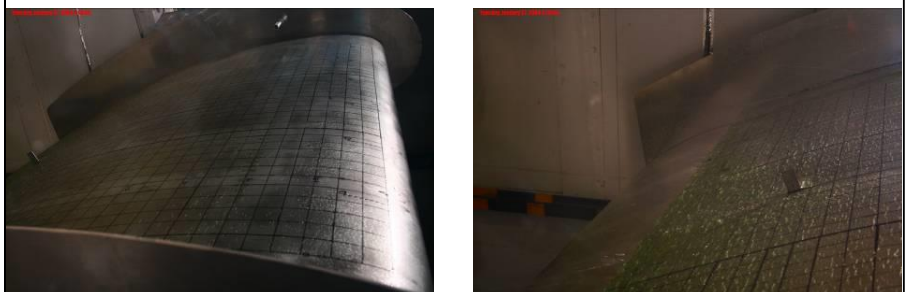


Photo 6.20: Test #13 – End of Test

Test #13
Launch, IP+SN 25+25 g/dm²/h, 10 min
-5°C, High Speed, 8° Rotation
End of Test

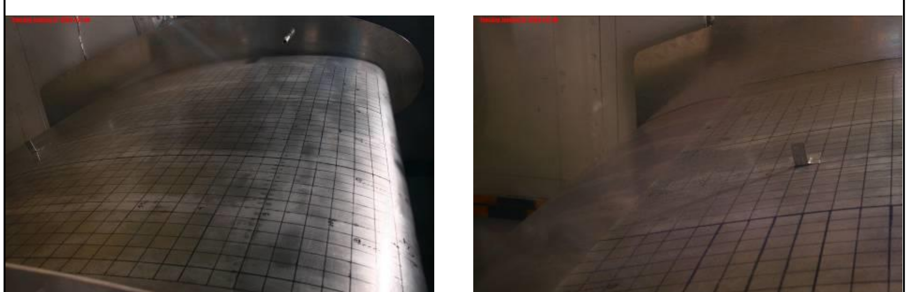


Photo 6.21: Test #20 – Start of Test

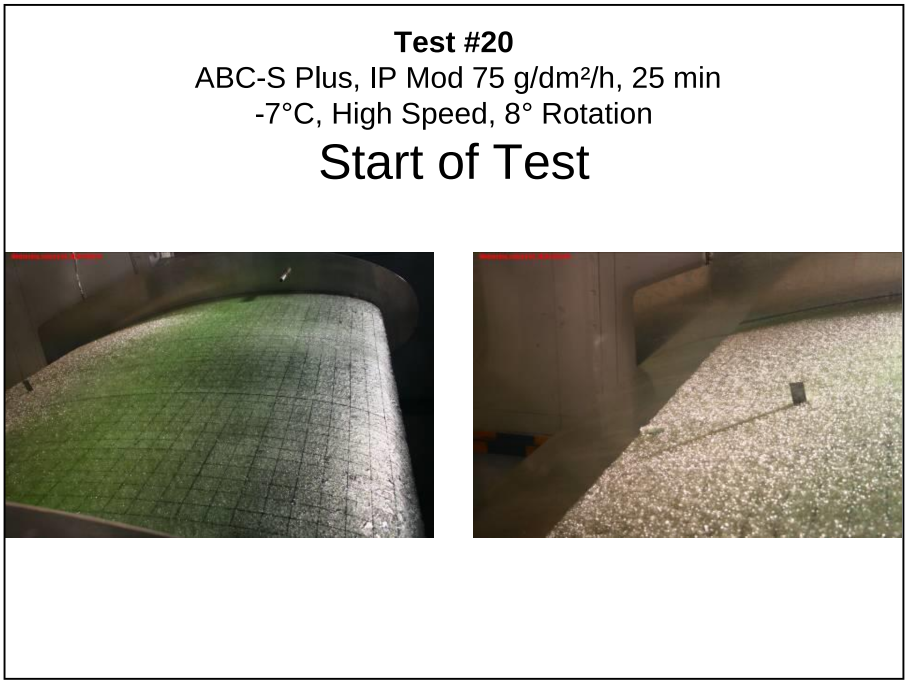


Photo 6.22: Test #20 – Before Rotation

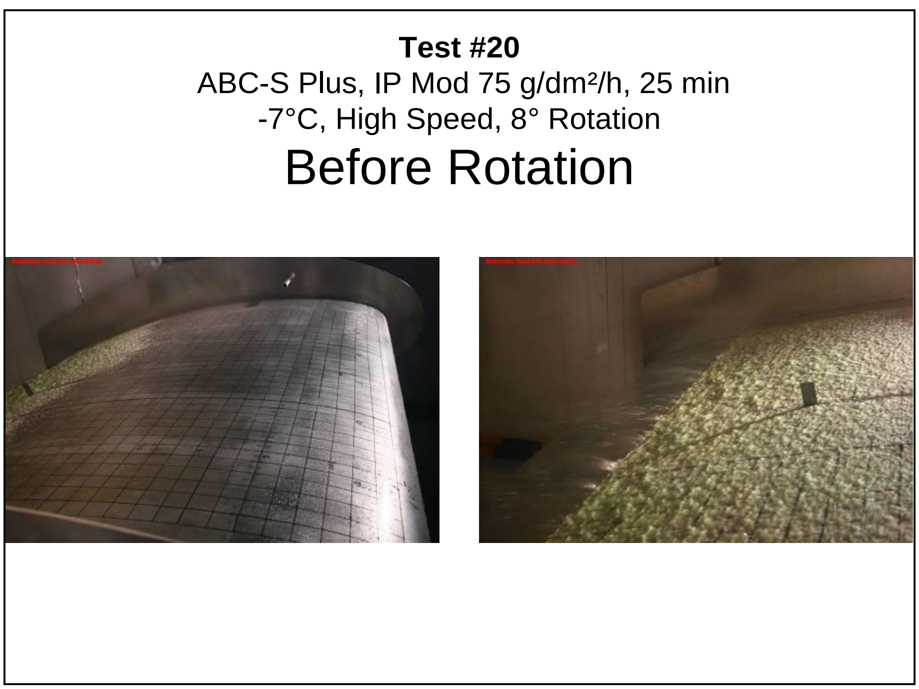


Photo 6.23: Test #20 – End of Rotation

Test #20
ABC-S Plus, IP Mod 75 g/dm²/h, 25 min
-7°C, High Speed, 8° Rotation
End of Rotation

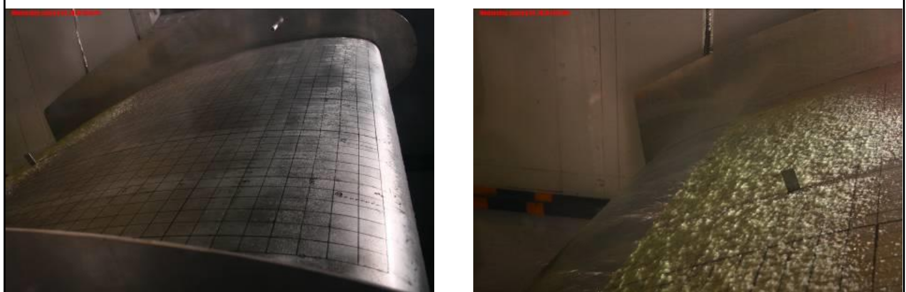


Photo 6.24: Test #20 – End of Test

Test #20
ABC-S Plus, IP Mod 75 g/dm²/h, 25 min
-7°C, High Speed, 8° Rotation
End of Test

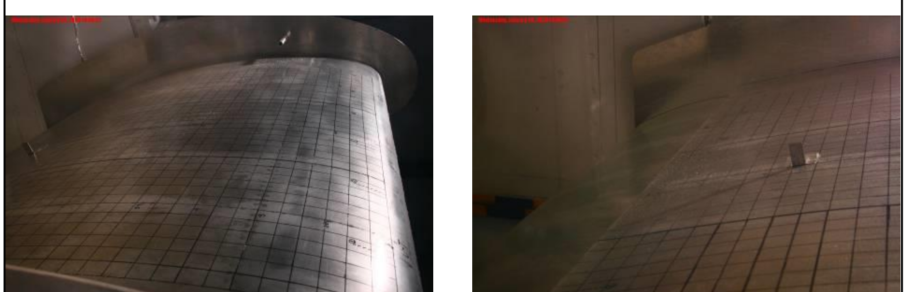


Photo 6.25: Test #21 – Start of Test

Test #21
ABC-S Plus, IP- 25 g/dm²/h, 50 min
-9°C, High Speed, 8° Rotation
Start of Test

Photo 6.26: Test #21 – Before Rotation

Test #21
ABC-S Plus, IP- 25 g/dm²/h, 50 min
-9°C, High Speed, 8° Rotation
Before Rotation

Photo 6.27: Test #21 – End of Rotation

Test #21
ABC-S Plus, IP- 25 g/dm²/h, 50 min
-9°C, High Speed, 8° Rotation
End of Rotation

Photo 6.28: Test #21 – End of Test

Test #21
ABC-S Plus, IP- 25 g/dm²/h, 50 min
-9°C, High Speed, 8° Rotation
End of Test

Photo 6.29: Test #29 – Start of Test

Test #29
EG106, IP Mod 75 g/dm²/h, 25 min
-3°C, High Speed, 8° Rotation
Start of Test

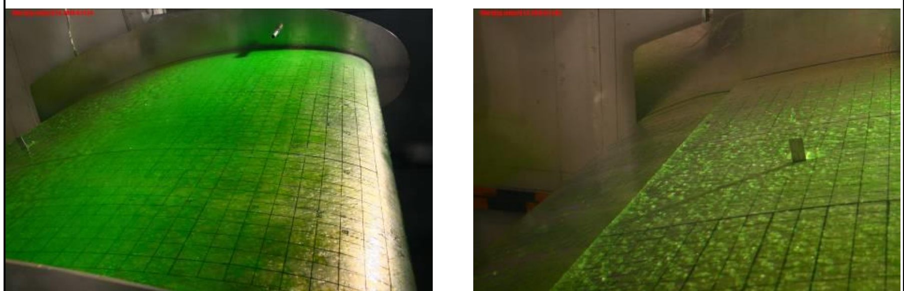
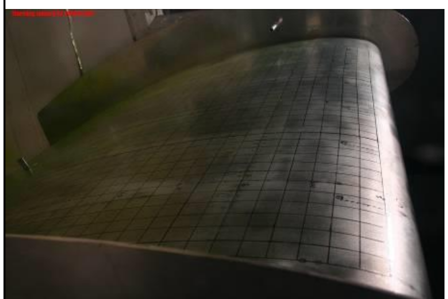


Photo 6.30: Test #29 – Before Rotation

Test #29
EG106, IP Mod 75 g/dm²/h, 25 min
-3°C, High Speed, 8° Rotation
Before Rotation

Photo 6.31: Test #29 – End of Rotation

Test #29
EG106, IP Mod 75 g/dm²/h, 25 min
-3°C, High Speed, 8° Rotation
End of Rotation



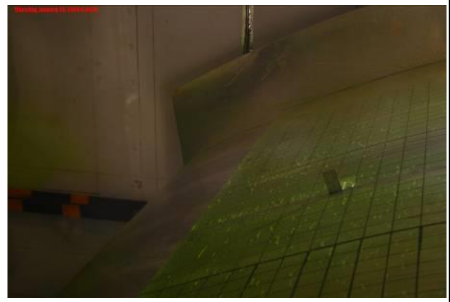


Photo 6.32: Test #29 – End of Test

Test #29
EG106, IP Mod 75 g/dm²/h, 25 min
-3°C, High Speed, 8° Rotation
End of Test

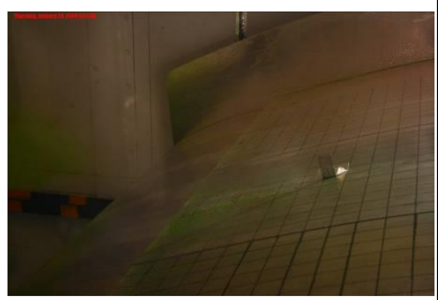


Photo 6.33: Test #30 – Start of Test

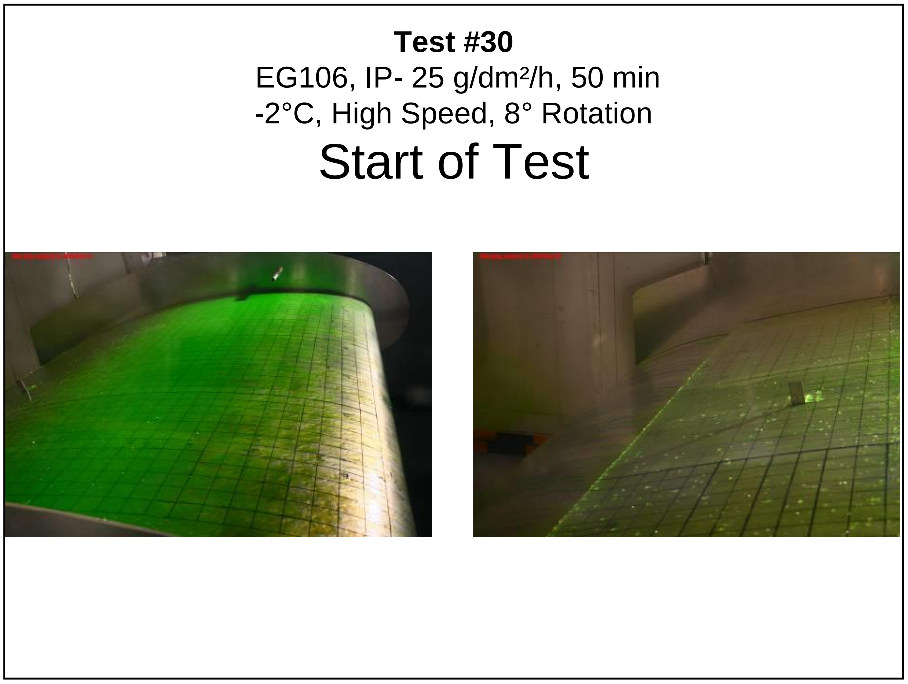


Photo 6.34: Test #30 – Before Rotation

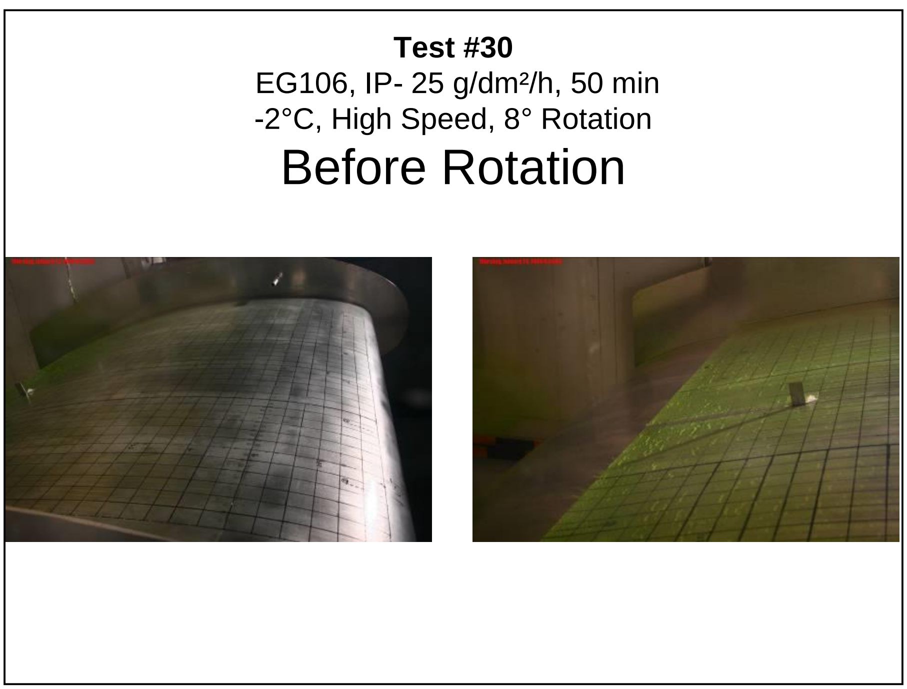


Photo 6.35: Test #30 – End of Rotation

Test #30
EG106, IP- 25 g/dm²/h, 50 min
-2°C, High Speed, 8° Rotation
End of Rotation

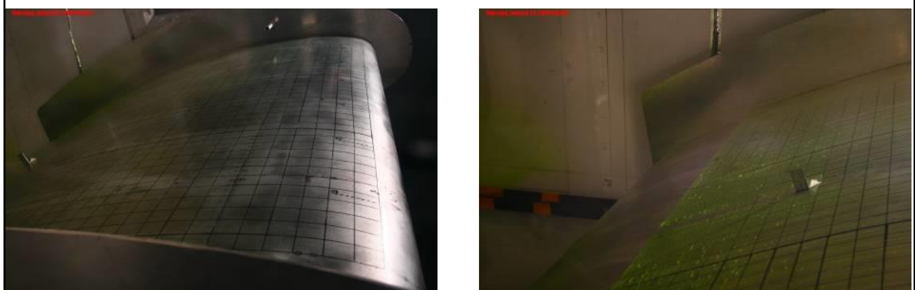
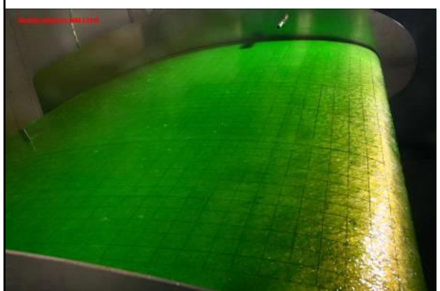


Photo 6.36: Test #30 – End of Test

Test #30
EG106, IP- 25 g/dm²/h, 50 min
-2°C, High Speed, 8° Rotation
End of Test

Photo 6.37: Test #44 – Start of Test

Test #44
EG106, IP+SN 25+25 g/dm²/h, 15 min
-12°C, High Speed, 16° Rotation
Start of Test



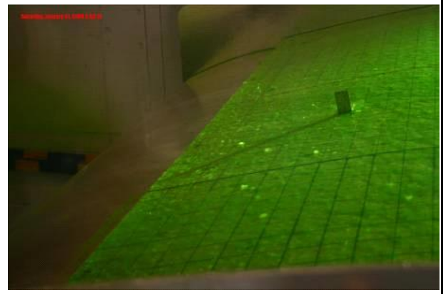
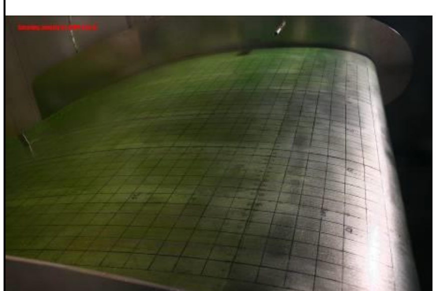


Photo 6.38: Test #44 – Before Rotation

Test #44
EG106, IP+SN 25+25 g/dm²/h, 15 min
-12°C, High Speed, 16° Rotation
Before Rotation



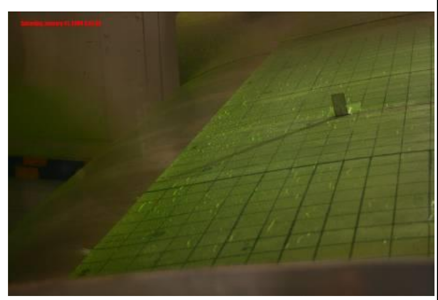


Photo 6.39: Test #44 – End of Rotation

Test #44
EG106, IP+SN 25+25 g/dm²/h, 15 min
-12°C, High Speed, 16° Rotation
End of Rotation

Photo 6.40: Test #44 – End of Test

Test #44
EG106, IP+SN 25+25 g/dm²/h, 15 min
-12°C, High Speed, 16° Rotation
End of Test

Photo 6.41: Test #51 – Start of Test

Test #51
Launch, IP+R 25+50 g/dm²/h, 25 min
-2°C, High Speed, 16° Rotation
Start of Test

Photo 6.42: Test #51 – Before Rotation

Test #51
Launch, IP+R 25+50 g/dm²/h, 25 min
-2°C, High Speed, 16° Rotation
Before Rotation

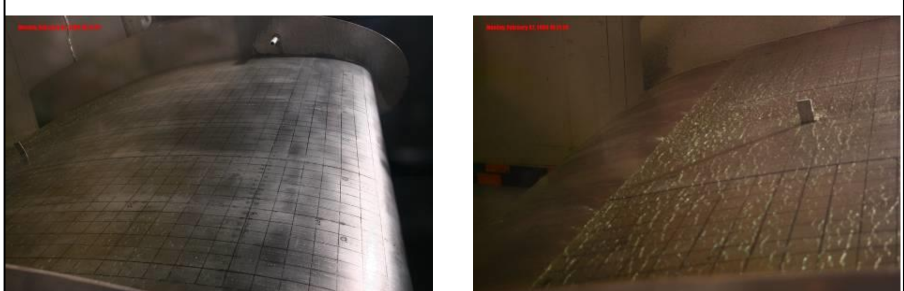


Photo 6.43: Test #51 – End of Rotation

Test #51
Launch, IP+R 25+50 g/dm²/h, 25 min
-2°C, High Speed, 16° Rotation
End of Rotation

Photo 6.44: Test #51 – End of Test

Test #51
Launch, IP+R 25+50 g/dm²/h, 25 min
-2°C, High Speed, 16° Rotation
End of Test

Photo 6.45: Test #54 – Start of Test

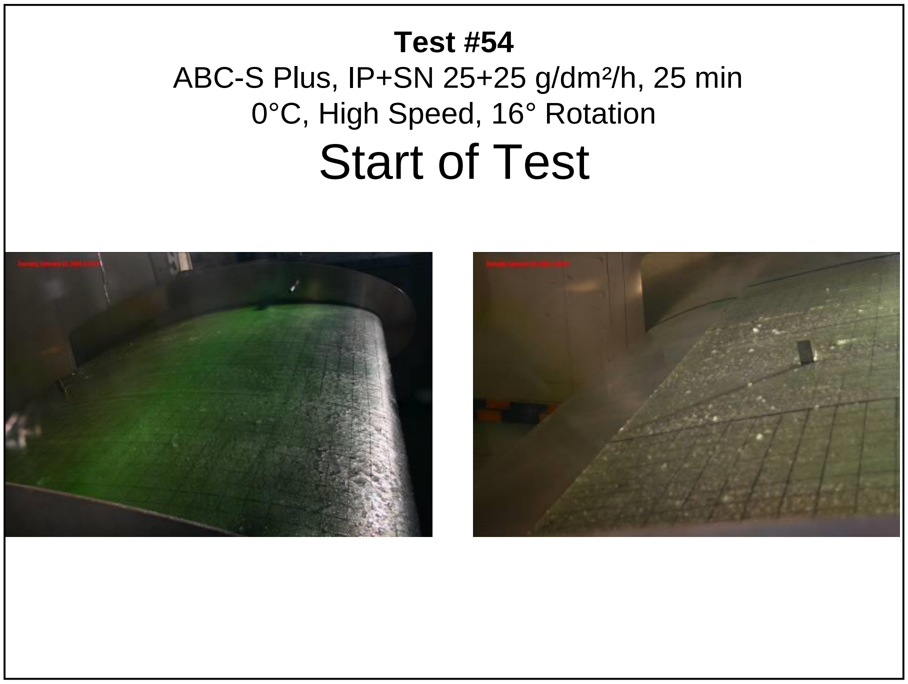


Photo 6.46: Test #54 – Before Rotation

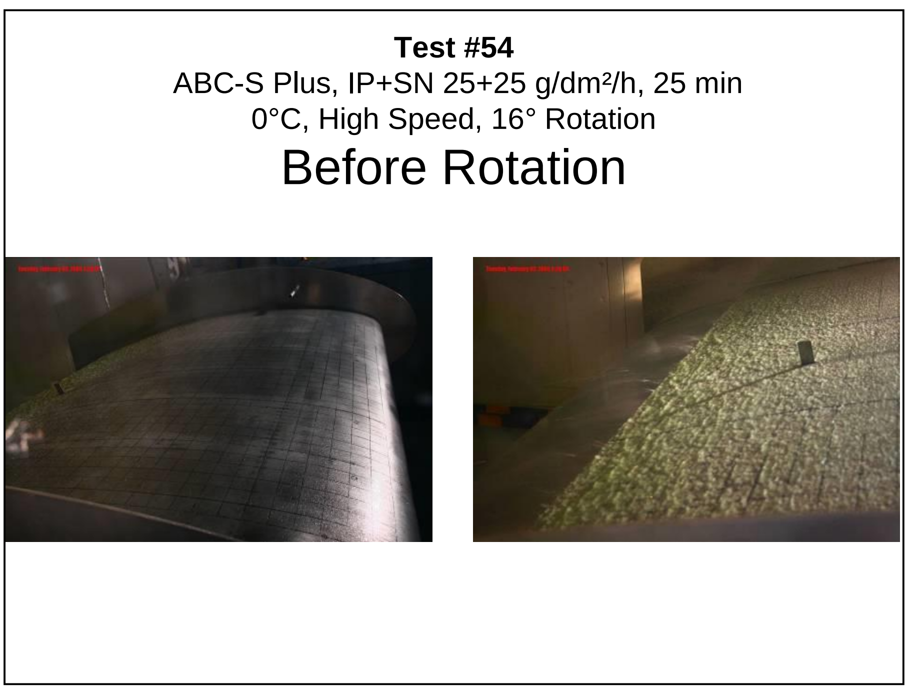


Photo 6.47: Test #54 – End of Rotation

Test #54

ABC-S Plus, IP+SN 25+25 g/dm²/h, 25 min

0°C, High Speed, 16° Rotation

End of Rotation

Photo 6.48: Test #54 – End of Test

Test #54

ABC-S Plus, IP+SN 25+25 g/dm²/h, 25 min

0°C, High Speed, 16° Rotation

End of Test

Photo 6.49: Test #58 – Start of Test

Test #58
Launch, IP+SN 25+25 g/dm²/h, 25 min
-6°C, High Speed, 16° Rotation

Start of Test

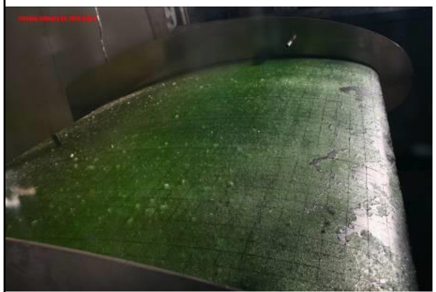



Photo 6.50: Test #58 – Before Rotation

Test #58
Launch, IP+SN 25+25 g/dm²/h, 25 min
-6°C, High Speed, 16° Rotation

Before Rotation

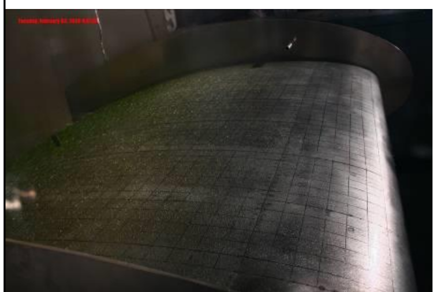



Photo 6.51: Test #58 – End of Rotation

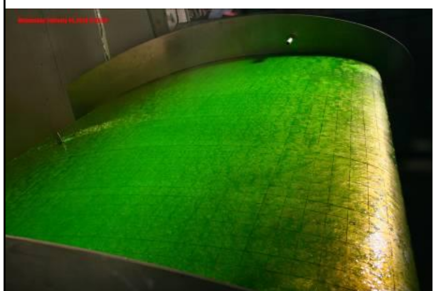
Test #58
Launch, IP+SN 25+25 g/dm²/h, 25 min
-6°C, High Speed, 16° Rotation
End of Rotation

Photo 6.52: Test #58 – End of Test

Test #58
Launch, IP+SN 25+25 g/dm²/h, 25 min
-6°C, High Speed, 16° Rotation
End of Test

Photo 6.53: Test #64 – Start of Test

Test #64
EG106, IP+ZR 25+25 g/dm²/h, 10 min
-14°C, High Speed, 16° Rotation
Start of Test



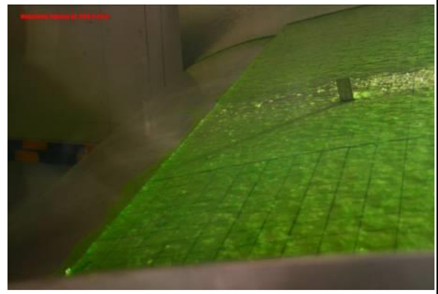


Photo 6.54: Test #64 – Before Rotation

Test #64
EG106, IP+ZR 25+25 g/dm²/h, 10 min
-14°C, High Speed, 16° Rotation
Before Rotation

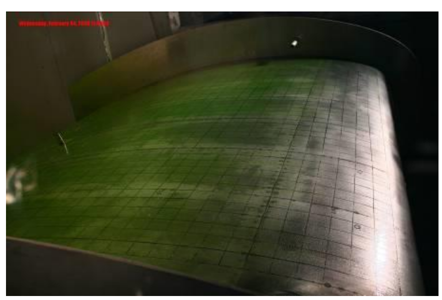


Photo 6.55: Test #64 – End of Rotation

Test #64
EG106, IP+ZR 25+25 g/dm²/h, 10 min
-14°C, High Speed, 16° Rotation
End of Rotation

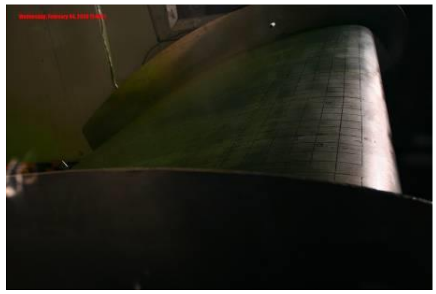


Photo 6.56: Test #64 – End of Test

Test #64
EG106, IP+ZR 25+25 g/dm²/h, 10 min
-14°C, High Speed, 16° Rotation
End of Test

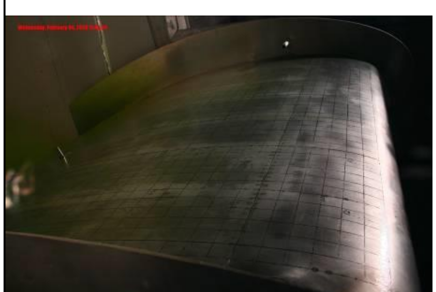


Photo 6.57: Test #65 – Start of Test

Test #65
ABC-S Plus, IP+ZR 25+25 g/dm²/h, 10 min
-13°C, High Speed, 16° Rotation
Start of Test

Photo 6.58: Test #65 – Before Rotation

Test #65
ABC-S Plus, IP+ZR 25+25 g/dm²/h, 10 min
-13°C, High Speed, 16° Rotation
Before Rotation

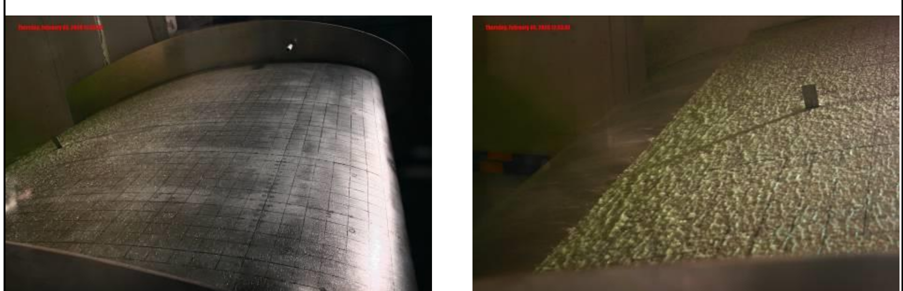


Photo 6.59: Test #65 – End of Rotation

Test #65
ABC-S Plus, IP+ZR 25+25 g/dm²/h, 10 min
-13°C, High Speed, 16° Rotation
End of Rotation

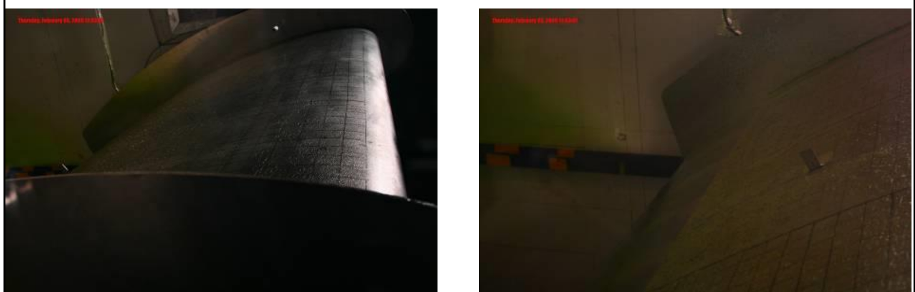


Photo 6.60: Test #65 – End of Test

Test #65
ABC-S Plus, IP+ZR 25+25 g/dm²/h, 10 min
-13°C, High Speed, 16° Rotation
End of Test

Photo 6.61: Test #66 – Start of Test

Test #66
Launch, IP- 25 g/dm²/h, 30 min
-15°C, High Speed, 16° Rotation
Start of Test

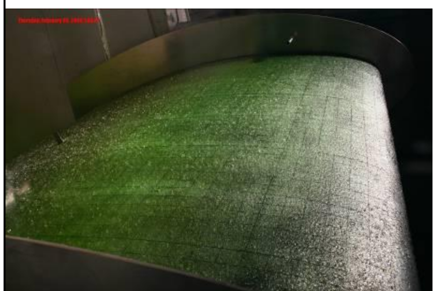


Photo 6.62: Test #66 – Before Rotation

Test #66
Launch, IP- 25 g/dm²/h, 30 min
-15°C, High Speed, 16° Rotation
Before Rotation

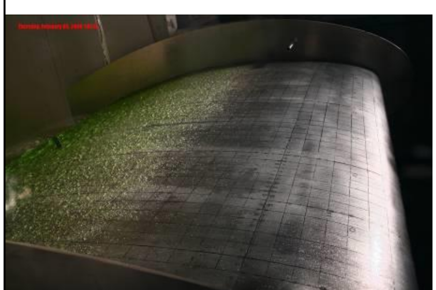


Photo 6.63: Test #66 – End of Rotation

Test #66
Launch, IP- 25 g/dm²/h, 30 min
-15°C, High Speed, 16° Rotation
End of Rotation

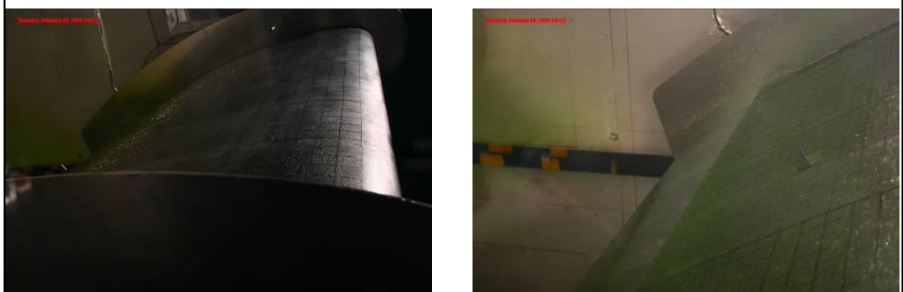


Photo 6.64: Test #66 – End of Test

Test #66
Launch, IP- 25 g/dm²/h, 30 min
-15°C, High Speed, 16° Rotation
End of Test

Photo 6.65: Test #67 – Start of Test

Test #67
Launch, IP Mod 75 g/dm²/h, 10 min
-16°C, High Speed, 16° Rotation
Start of Test

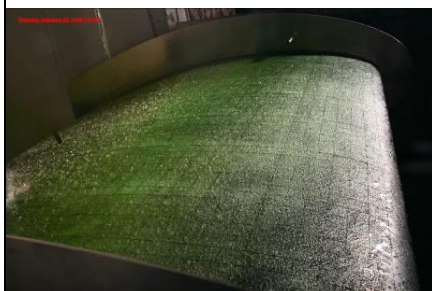


Photo 6.66: Test #67 – Before Rotation

Test #67
Launch, IP Mod 75 g/dm²/h, 10 min
-16°C, High Speed, 16° Rotation
Before Rotation

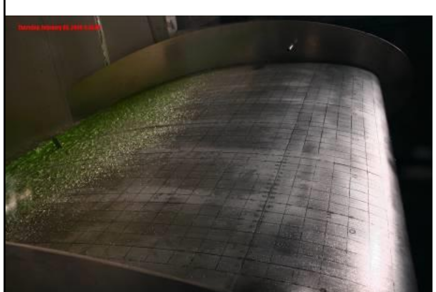


Photo 6.67: Test #67 – End of Rotation

Test #67
Launch, IP Mod 75 g/dm²/h, 10 min
-16°C, High Speed, 16° Rotation
End of Rotation

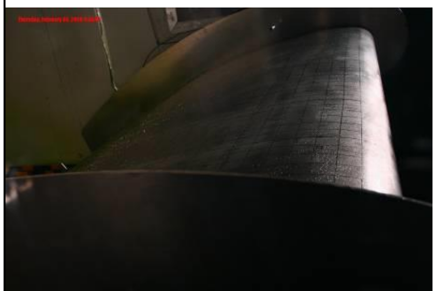


Photo 6.68: Test #67 – End of Test

Test #67
Launch, IP Mod 75 g/dm²/h, 10 min
-16°C, High Speed, 16° Rotation
End of Test

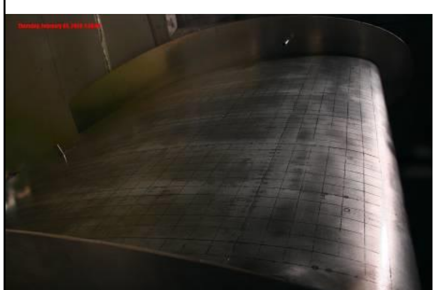


Photo 6.69: Test #68 – Start of Test

Test #68
EG106, IP- 25 g/dm²/h, 30 min
-17°C, High Speed, 16° Rotation
Start of Test

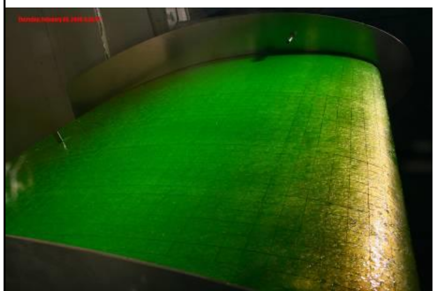
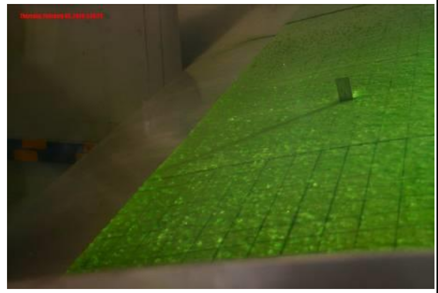



Photo 6.70: Test #68 – Before Rotation

Test #68
EG106, IP- 25 g/dm²/h, 30 min
-17°C, High Speed, 16° Rotation
Before Rotation

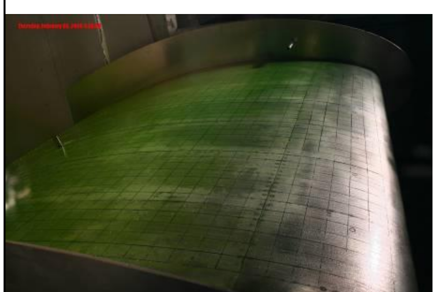



Photo 6.71: Test #68 – End of Rotation

Test #68
EG106, IP- 25 g/dm²/h, 30 min
-17°C, High Speed, 16° Rotation
End of Rotation

Photo 6.72: Test #68 – End of Test

Test #68
EG106, IP- 25 g/dm²/h, 30 min
-17°C, High Speed, 16° Rotation
End of Test

Photo 6.73: Test #69 – Start of Test

Test #69
EG106, IP Mod 75 g/dm²/h, 10 min
-18°C, High Speed, 16° Rotation
Start of Test

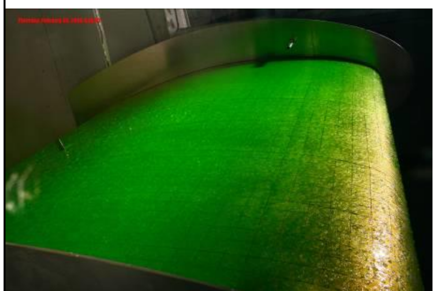
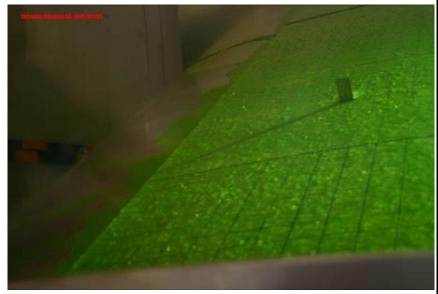



Photo 6.74: Test #69 – Before Rotation

Test #69
EG106, IP Mod 75 g/dm²/h, 10 min
-18°C, High Speed, 16° Rotation
Before Rotation

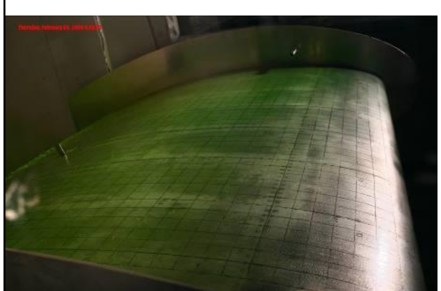
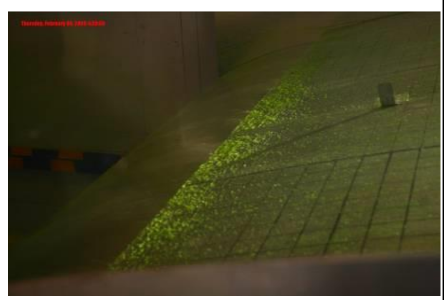



Photo 6.75: Test #69 – End of Rotation

Test #69
EG106, IP Mod 75 g/dm²/h, 10 min
-18°C, High Speed, 16° Rotation
End of Rotation

Photo 6.76: Test #69 – End of Test

Test #69
EG106, IP Mod 75 g/dm²/h, 10 min
-18°C, High Speed, 16° Rotation
End of Test

Photo 6.77: Test #75 – Start of Test

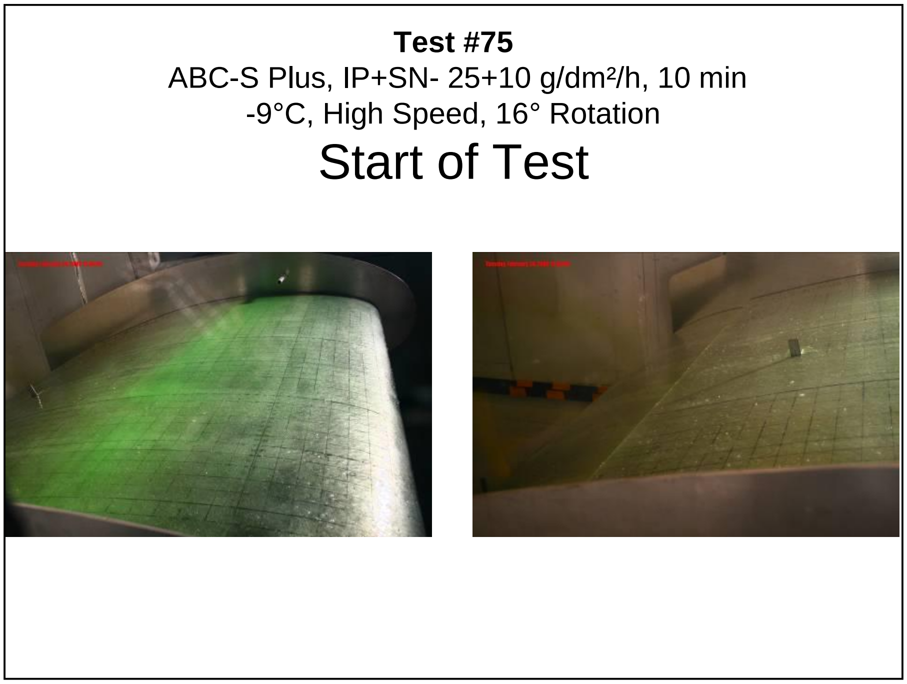


Photo 6.78: Test #75 – Before Rotation

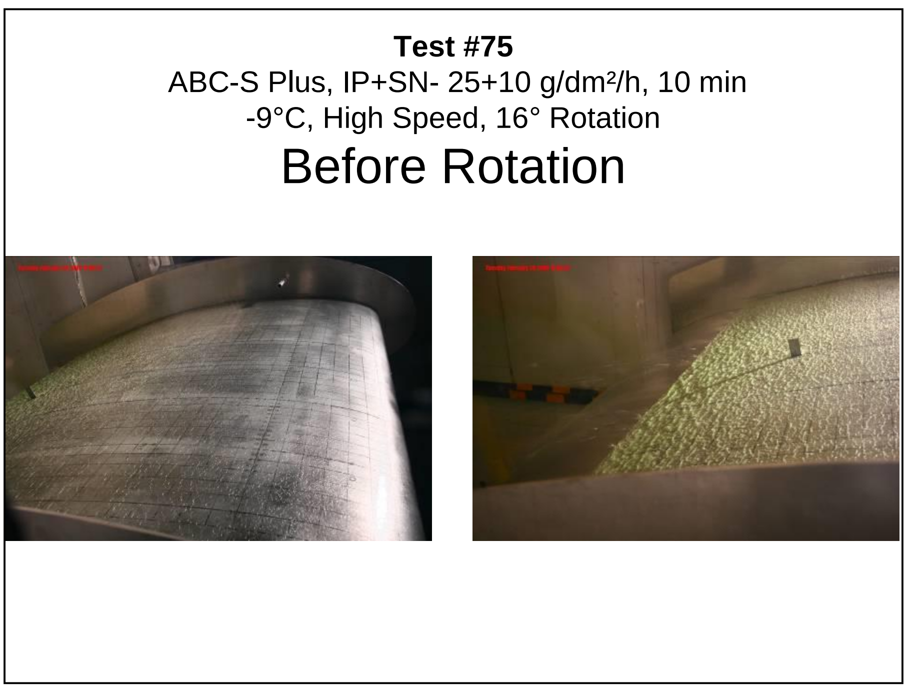


Photo 6.79: Test #75 – End of Rotation

Test #75
ABC-S Plus, IP+SN- 25+10 g/dm²/h, 10 min
-9°C, High Speed, 16° Rotation
End of Rotation

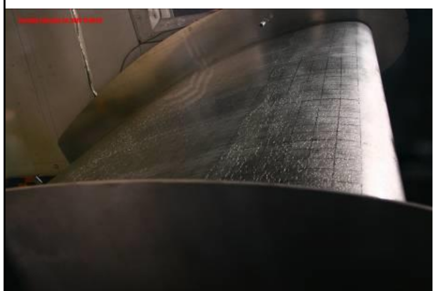


Photo 6.80: Test #75 – End of Test

Test #75
ABC-S Plus, IP+SN- 25+10 g/dm²/h, 10 min
-9°C, High Speed, 16° Rotation
End of Test

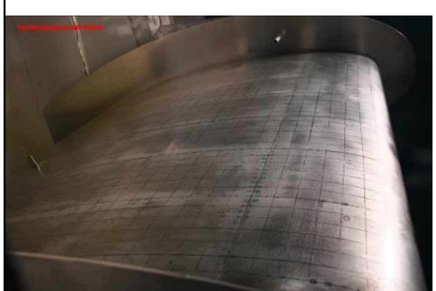


Photo 6.81: Test #76 – Start of Test

Test #76
Launch, IP+SN- 25+10 g/dm²/h, 15 min
-10°C, High Speed, 16° Rotation
Start of Test

Photo 6.82: Test #76 – Before Rotation

Test #76
Launch, IP+SN- 25+10 g/dm²/h, 15 min
-10°C, High Speed, 16° Rotation
Before Rotation

Photo 6.83: Test #76 – End of Rotation

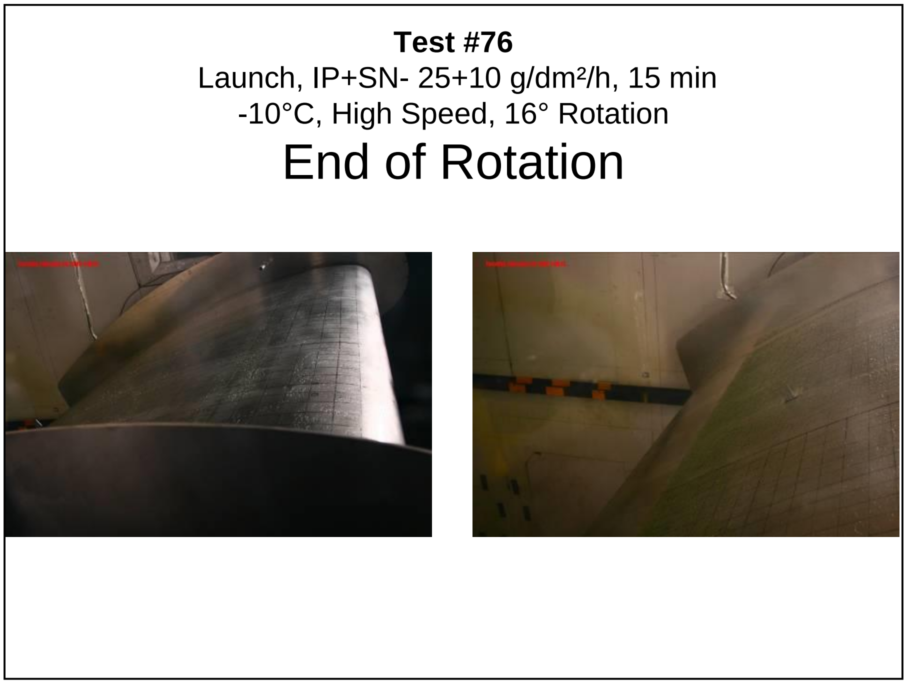


Photo 6.84: Test #76 – End of Test

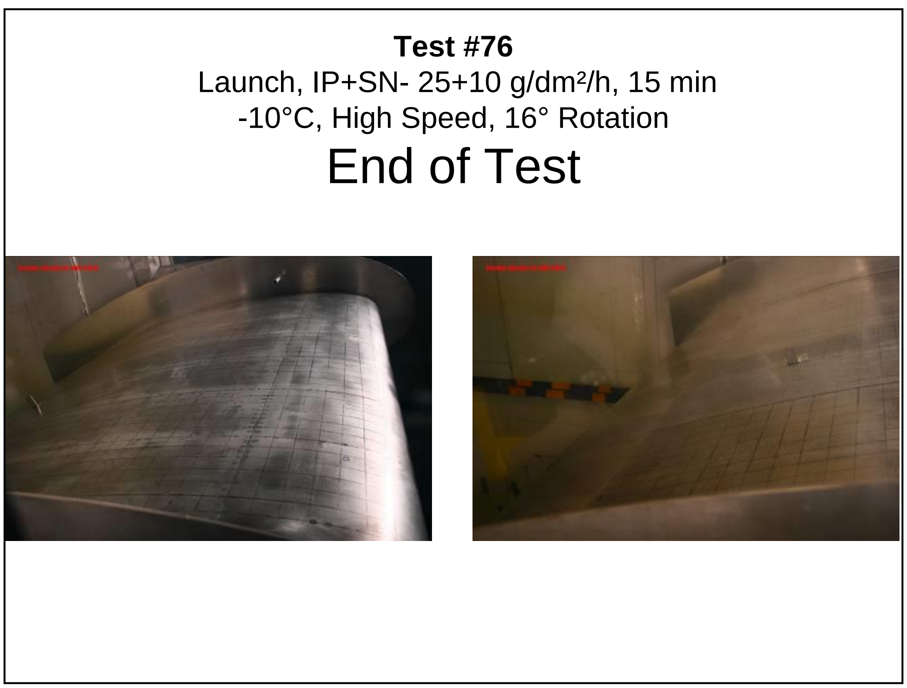


Photo 6.85: Test #77 – Start of Test

Test #77
EG106, IP+SN- 25+10 g/dm²/h, 15 min
-9°C, High Speed, 16° Rotation
Start of Test

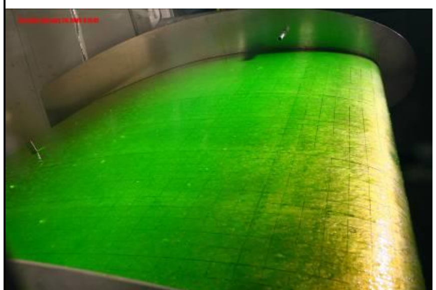
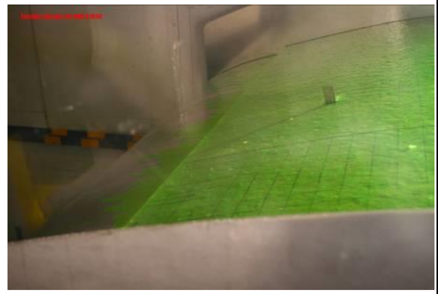



Photo 6.86: Test #77 – Before Rotation

Test #77
EG106, IP+SN- 25+10 g/dm²/h, 15 min
-9°C, High Speed, 16° Rotation
Before Rotation

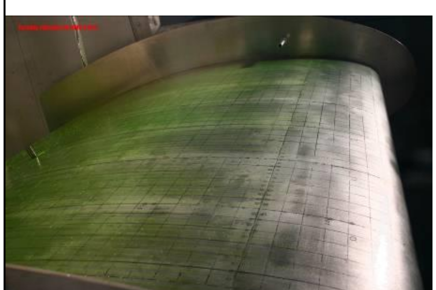
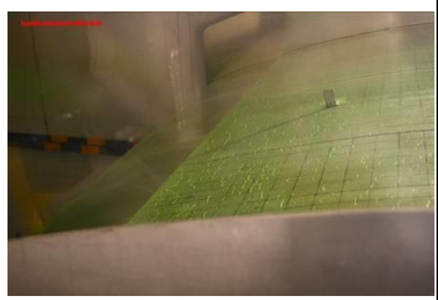



Photo 6.87: Test #77 – End of Rotation

Test #77
EG106, IP+SN- 25+10 g/dm²/h, 15 min
-9°C, High Speed, 16° Rotation

End of Rotation

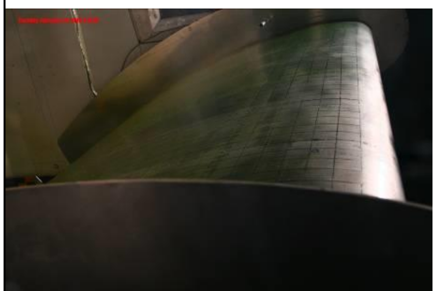



Photo 6.88: Test #77 – End of Test

Test #77
EG106, IP+SN- 25+10 g/dm²/h, 15 min
-9°C, High Speed, 16° Rotation

End of Test

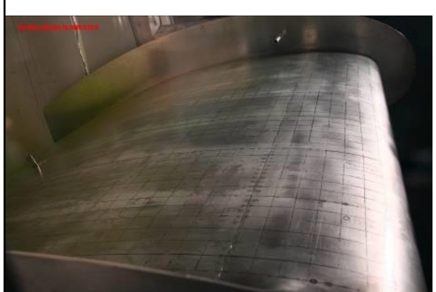
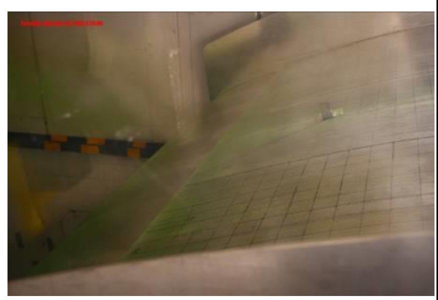



Photo 6.89: Test #85 – Start of Test

Test #85
EG106, IP+R 25+75 g/dm²/h, 25 min
-1°C, High Speed, 16° Rotation
Start of Test

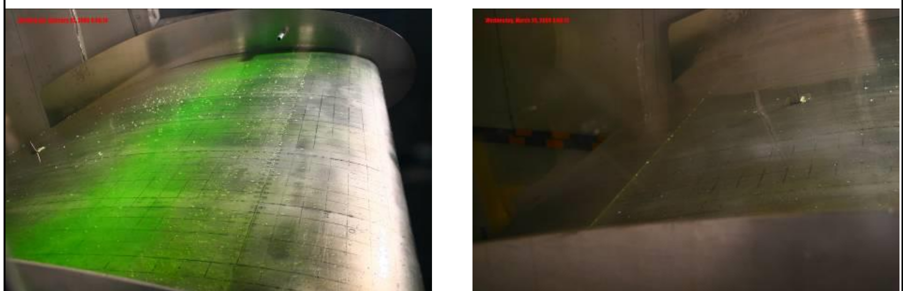


Photo 6.90: Test #85 – Before Rotation

Test #85
EG106, IP+R 25+75 g/dm²/h, 25 min
-1°C, High Speed, 16° Rotation
Before Rotation

Photo 6.91: Test #85 – End of Rotation

Test #85
EG106, IP+R 25+75 g/dm²/h, 25 min
-1°C, High Speed, 16° Rotation
End of Rotation

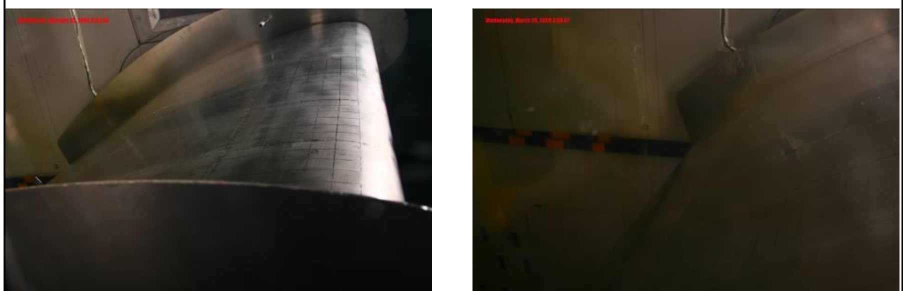


Photo 6.92: Test #85 – End of Test

Test #85
EG106, IP+R 25+75 g/dm²/h, 25 min
-1°C, High Speed, 16° Rotation
End of Test

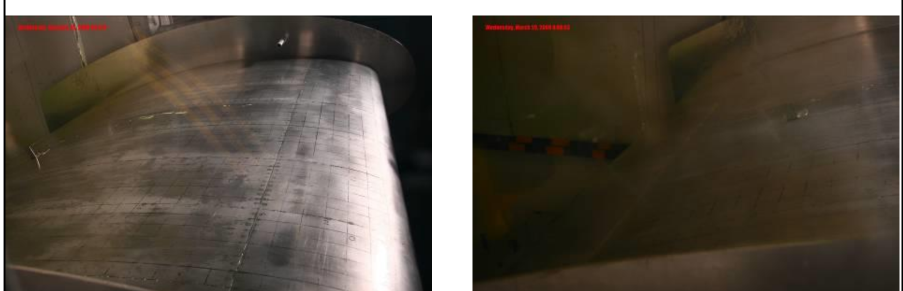


Photo 6.93: Test #95 – Start of Test

Test #95
Launch, IP+R 25+75 g/dm²/h, 25 min
-1°C, High Speed, 16° Rotation
Start of Test

Photo 6.94: Test #95 – Before Rotation

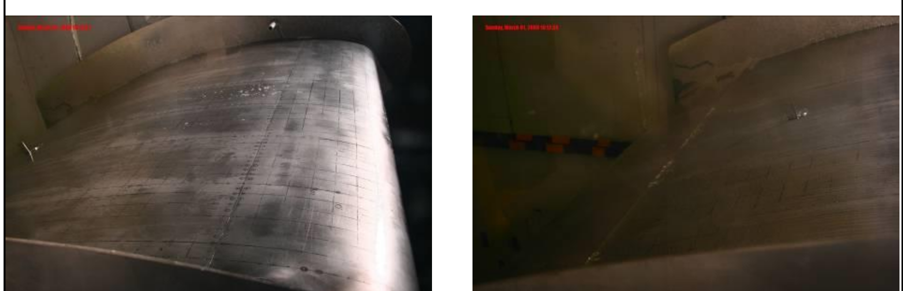
Test #95
Launch, IP+R 25+75 g/dm²/h, 25 min
-1°C, High Speed, 16° Rotation
Before Rotation

Photo 6.95: Test #95 – End of Rotation

Test #95
Launch, IP+R 25+75 g/dm²/h, 25 min
-1°C, High Speed, 16° Rotation
End of Rotation

Photo 6.96: Test #95 – End of Test

Test #95
Launch, IP+R 25+75 g/dm²/h, 25 min
-1°C, High Speed, 16° Rotation
End of Test



7. TYPE IV FLUID ICE PELLET ALLOWANCE TIMES FOR LOW SPEED AIRCRAFT

The testing conducted during the winter of 2008-09 was geared towards investigating the possibility of expanding the current ice pellet allowance times to include low rotation speed aircraft. Previous aerodynamic research conducted during the winter of 2006-07 using the NRC wind tunnel and Falcon 20 aircraft simulated high speed rotation aircraft (acceleration to 120 knots in approximately 25 seconds). Type IV anti-icing fluid is not recommended by the fluid manufacturers for use on low rotation speed aircraft. Some airframe manufacturers have approved the use of Type IV fluid on their low rotation speed turbo-prop 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-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. The 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. Low speed testing (acceleration to 80 knots in approximately 17 seconds) was recommended to verify the fluid flow-off properties of anti-icing fluid both in ice pellet, and no precipitation conditions.

Preliminary work was conducted during the winter of 2007-08 with the Falcon 20 aircraft and T-33 aircraft to investigate the fluid flow-off performance of un-contaminated and contaminated Type IV fluids; contamination consisted of mixed conditions with ice pellets. The results demonstrated fluid elimination problems with Type IV fluids at lower rotation speeds; however the problems appeared to be a fluid issue rather than a contamination issue. As aerodynamic data were not collected, wind tunnel work was recommended to further investigate the results obtained.

This section provides an overview of each test conducted to investigate the potential development of low speed allowance times for Type IV fluid during operations in conditions mixed with ice pellets. Testing was conducted in simulated precipitation conditions. The parameters for each test are detailed and a description of the data collected during each test is provided.

7.1 Overview of Tests

A summary of the Type IV fluid low speed 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 Section 4.1. The following is a brief description of the column headings for Table 7.1:

Test #:	Exclusive number identifying each test.
Date:	Date when the test was conducted.
Fluid:	Aircraft deicing fluid specified by product name; all fluids were in the "neat" 100/0 dilution.
Condition:	Simulated precipitation condition.
Precipitation Rate (g/dm²/h):	Simulated freezing precipitation rate (or combination of different precipitation rates). N/A indicates that no precipitation was applied.
Precip. Time (min.):	Total time of exposure to simulated precipitation.
Tunnel Temp at Start of Test (°C):	The tunnel ambient temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.
Avg Wing Temp before Test (°C):	Average of the wing skin temperature measurements just before the start of the simulated takeoff test, recorded in degrees Celsius.
Visual Contamination Rating Before Take off (LE, TE):	Visual contamination rating determined before the start of the simulated takeoff: 1. Contamination not very visible, fluid still clean; 2. Contamination is visible, but lots of fluid still present; 3. Contamination visible, spots of bridging contamination; 4. Contamination visible, lots of dry bridging present; and 5. Contamination visible, adherence of contamination.
Visual Contamination Rating at Rotation (LE, TE):	Visual contamination rating determined at the time of rotation: 1. Contamination not very visible, fluid still clean; 2. Contamination is visible, but lots of fluid still present; 3. Contamination visible, spots of bridging contamination; 4. Contamination visible, lots of dry bridging present; and 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 NRC.

7.2 Data Collected

7.2.1 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Section 2.14.2. Fluid thickness measurements were recorded at the following intervals:

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

Table 7.2 to Table 7.18 show the fluid thickness measurements collected during the tests.

Table 7.1: Summary of 2008-09 Type IV Low Speed Testing

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
12	27-Jan-09	ABC-S Plus	IP/SN	25/25	10	-5	-7.3	3, 3	1, 2	1.762
22	28-Jan-09	Launch	IP/ZR	25/25	25	-6	-4.8	3, 3	1, 2	1.753
25	28-Jan-09	ABC-S Plus	IP/ZR	25/25	25	-4	-4.1	2, 3	1, 2	N/A
31	29-Jan-09	EG106	IP/SN	25/25	25	0	-6.0	1.5, 1.5	1, 1	1.779
33	30-Jan-09	EG106	IP/ZR	25/25	25	-3	-5.6	2, 2	1, 1	1.776
43	31-Jan-09	EG106	IP/SN	2525	10	-13	N/A	2, 2	1, 1.5	1.729
45	31-Jan-09	ABC-S Plus	IP/SN	25/25	10	-16	-13.1	2, 3	1.5, 2	1.670
52	2-Feb-09	EG106	IP/SN	25/25	25	-6	-8.6	3, 3	1, 2	1.750
53	3-Feb-09	ABC-S Plus	IP/SN	25/25	25	-3	-8.0	3, 4	1, 2	1.713
59	3-Feb-09	Launch	IP/ZR	25/25	10	-10	-7.9	3, 3	1, 2.5	1.723
86	28-Feb-09	ABC-S Plus	IP-	25	50	-9	-9.9	3.5, 3.5	1.5, 3	1.699
87	28-Feb-09	ABC-S Plus	IP Mod	75	25	-7	-11.6	3.5, 4	1.5, 3	1.671
88	28-Feb-09	ABC-S Plus	IP Mod	75	15	-6	-11.1	3, 3	1.5, 2.5	1.655
91	1-Mar-09	ABC-S Plus	IP/SN-	25/10	10	-7	-10.0	3, 3	1, 2	1.697
92	1-Mar-09	EG106	IP/SN-	25/10	10	-15	-12.0	2, 2.5	1, 2	1.776
99	2-Mar-09	EG106	IP-	25	50	-10	-9.7	2, 3	1, 2	1.803
106	2-Mar-09	EG106	IP Mod	75	25	-9	-13.2	3, 3	1, 2	N/A

Table 7.2: Test #12 Fluid Thickness Data

Test 12, ABC-S Plus, IP/SN, Tunnel OAT -4.9ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Take off Run
1	0.8	1.2	0.0
2	1.1	1.7	0.0
3	1.5	1.7	0.1
4	1.8	1.8	0.2
5	2.7	2.5	0.3
6	1.2	1.6	0.4
7	1.2	1.6	0.4
8	1.2	1.8	0.6

Table 7.3: Test #22 Fluid Thickness Data

Test 22, Launch, IP/ZR, Tunnel OAT -5.5ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.8	0.8 (slush)	0.0
2	1.0	1.8 (slush)	0.0
3	1.5	2.9	0.0
4	1.8	3.5	0.0
5	2.9	4.5	0.0
6	1.3	1.4 (slush)	0.3
7	1.3	0.8 (slush)	0.4
8	1.6	slush	0.6

Table 7.4: Test #25 Fluid Thickness Data

Test 25, ABC-S Plus, IP/ZR, Tunnel OAT -3.6ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.0	1.1 (slush)	0.0
2	1.5	2.2	0.0
3	2.2	2.9	0.1
4	3.3	4.5	0.1
5	4.5	5.7	0.1
6	1.6	1.3 (slush)	0.3
7	1.6	1.2 (slush)	0.4
8	1.8	1.2 (slush)	0.7

Table 7.5: Test #31 Fluid Thickness Data

Test 31, EG106, IP/SN, Tunnel OAT 0.1ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.8	1.0	0.0
2	2.5	1.8	0.0
3	3.5	3.3	0.0
4	4.5	3.7	0.0
5	4.5	4.5	0.0
6	2.5	1.8	0.3
7	2.5	1.1	0.3
8	2.2	1.8	0.6

Table 7.6: Test #33 Fluid Thickness Data

Test 33, EG106, IP/ZR, Tunnel OAT -2.7ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.8	1.1	0.0
2	2.5	1.8	0.0
3	3.9	3.3	0.0
4	4.5	3.9	0.0
5	4.5	4.5	0.0
6	3.1	1.8	0.3
7	2.9	0.8	0.4
8	3.1	1.0	0.6

Table 7.7: Test #43 Fluid Thickness Data

Test 43, EG106, IP/SN, Tunnel OAT -12.7ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.8	1.4	0.0
2	2.2	2.2	0.0
3	3.1	3.3	0.1
4	4.5	4.5	0.1
5	5.7	4.5	0.1
6	2.5	2.9	0.3
7	2.7	2.7	0.3
8	2.5	2.5	0.3

Table 7.8: Test #45 Fluid Thickness Data

Test 45, ABC-S Plus, IP/SN, Tunnel OAT -15.9ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.8	0.8	0.0
2	1.1	1.1	0.0
3	1.8	1.8	0.0
4	2.2	2.2	0.1
5	3.5	3.3	0.1
6	1.7	1.6	0.5
7	1.3	1.1	0.4
8	1.5	1.1	0.5

Table 7.9: Test #52 Fluid Thickness Data

Test 52, EG106, IP/SN, Tunnel OAT -5.6ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.4	0.3	0.0
2	2.7	2.7	0.0
3	3.9	3.5	0.0
4	4.5	4.5	0.0
5	4.5	4.5	0.0
6	2.5	1.1	0.1
7	2.2	1.0	0.3
8	2.2	1.0	0.3

Table 7.10: Test #53 Fluid Thickness Data

Test 53, ABC-S Plus, IP/SN, Tunnel OAT -3.4ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.8	0.8	0.0
2	1.4	1.4	0.1
3	1.8	2.9	0.1
4	2.9	4.5	0.2
5	3.7	4.5	0.3
6	1.5	1.6	0.1
7	1.3	1.7	0.2
8	1.6	1.7	0.2

Table 7.11: Test #59 Fluid Thickness Data

Test 59, Launch, IP/ZR, Tunnel OAT -10.3ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.7	0.8	0.0
2	1.2	1.4	0.1
3	1.4	1.8	0.1
4	1.8	2.5	0.2
5	2.5	2.9	0.2
6	1.1	slush	0.1
7	1.1	slush	0.2
8	1.2	slush	0.3

Table 7.12: Test #86 Fluid Thickness Data

Test 86, ABC-S Plus, IP-, Tunnel OAT -9.3ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.8	1.1	0.0
2	1.4	2.2	0.0
3	1.8	3.7	0.1
4	2.2	4.5	0.2
5	3.7	4.5	0.2
6	1.2	2.5	slush
7	1.2	2.2	slush
8	1.6	1.8	slush

Table 7.13: Test #87 Fluid Thickness Data

Test 87, ABC-S Plus, IP Mod, Tunnel OAT -6.5ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.0	slush	0.0
2	1.1	slush	0.1
3	1.8	slush	0.1
4	2.5	slush	0.1
5	4.5	slush	0.1
6	1.5	slush	slush
7	1.5	slush	slush
8	1.6	slush	slush

Table 7.14: Test #88 Fluid Thickness Data

Test 88, ABC-S Plus, IP Mod, Tunnel OAT -6.0ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.4	slush	0.0
2	1.0	slush	0.1
3	1.8	slush	0.2
4	2.5	slush	0.2
5	4.5	4.5	0.2
6	1.3	slush	slush
7	1.5	slush	slush
8	1.5	slush	slush

Table 7.15: Test #91 Fluid Thickness Data

Test 91, ABC-S Plus, IP/SN-, Tunnel OAT -7.1ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.7	0.8	0.1
2	1.1	1.1	0.1
3	0.7	0.7	0.1
4	2.2	2.2	0.1
5	3.1	3.3	0.1
6	1.8	1.8	0.2
7	0.7	0.7	0.1
8	0.7	2.2	0.2

Table 7.16: Test #92 Fluid Thickness Data

Test 92, EG106, IP/SN-, Tunnel OAT -15.2ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.8	1.0	0.0
2	2.2	2.2	0.1
3	3.1	3.1	0.1
4	4.5	3.9	0.1
5	4.5	4.5	0.1
6	2.5	2.2	0.4
7	2.7	2.2	0.4
8	2.7	2.5	0.4

Table 7.17: Test #99 Fluid Thickness Data

Test 99, EG106, IP-, Tunnel OAT -10.1ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.8	0.7	0.0
2	2.2	0.7	0.0
3	3.1	1.8	0.0
4	3.9	2.9	0.0
5	4.5	3.9	0.0
6	2.5	1.1	0.1
7	2.5	1.2	0.0
8	2.7	1.2	0.0

Table 7.18: Test #106 Fluid Thickness Data

Test 106, EG 106, IP Mod, Tunnel OAT -9.4ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.8	1.0	0.0
2	2.5	1.8	0.0
3	3.7	3.7	0.0
4	4.5	4.5	0.0
5	4.5	5.7	0.0
6	2.2	1.8	0.0
7	2.2	1.8	0.0
8	2.2	1.8	0.0

7.2.2 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Section 2.14.3. Skin temperature measurements were recorded at the following intervals:

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

The wing temperatures measurements recorded during each test are shown in Table 7.19 to Table 7.35.

Table 7.19: Test #12 Wing Skin Temperature Data

Test 12, ABC-S Plus, IP/SN, Tunnel OAT -4.9°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-8.0	-8.8	-7.6	-6.8
T5	-7.6	-8.7	-7.0	-6.7
TU	-8.3	-8.5	-7.3	-7.4

Table 7.20: Test #22 Wing Skin Temperature Data

Test 22, Launch, IP/ZR, Tunnel OAT -5.5ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-4.7	-5.8	-4.4	-3.6
T5	-4.1	-5.8	-4.5	-3.8
TU	-4.7	-5.7	-5.5	-4.5

Table 7.21: Test #25 Wing Skin Temperature Data

Test 25, ABC-S Plus, IP/ZR, Tunnel OAT -3.6ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-2.4	-3.5	-4.4	-3.5
T5	-3.0	-4.0	-3.2	-3.2
TU	-4.2	-3.5	-4.7	-3.5

Table 7.22: Test #31 Wing Skin Temperature Data

Test 31, EG106, IP/SN, Tunnel OAT 0.1ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-2.0	-2.0	-7.5	-3.3
T5	-1.7	-1.6	-4.4	-2.7
TU	-2.5	-2.5	-6.1	-2.5

Table 7.23: Test #33 Wing Skin Temperature Data

Test 33, EG106, IP/ZR, Tunnel OAT -2.7ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-2.0	-3.9	-6.2	-3.9
T5	-3.0	-3.7	-4.6	-4.1
TU	-1.8	-3.5	-6.0	-4.9

Table 7.24: Test #43 Wing Skin Temperature Data

Test 43, EG106, IP/SN, Tunnel OAT -12.7ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-11.3	-10.1	-11.5	-12.8
T5	-11.0	-10.0	-10.6	-12.3
TU	-12.5	-11.0	-11.3	-13.8

Table 7.25: Test #45 Wing Skin Temperature Data

Test 45, ABC-S Plus, IP/SN, Tunnel OAT -15.9ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-13.3	-11.6	-13.0	-15.0
T5	-12.9	-11.3	-12.8	-14.6
TU	-13.9	-12.1	-13.5	-15.5

Table 7.26: Test #52 Wing Skin Temperature Data

Test 52, EG106, IP/SN, Tunnel OAT -5.6ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-4.0	-3.9	-9.2	-5.8
T5	-4.5	-4.0	-7.1	-5.9
TU	-5.0	-4.0	-9.5	-6.7

Table 7.27: Test #53 Wing Skin Temperature Data

Test 53, ABC-S Plus, IP/SN, Tunnel OAT -3.4ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-1.7	-4.1	-8.4	-4.7
T5	-2.2	-4.2	-6.7	-4.2
TU	-2.6	-3.9	-8.9	-5.5

Table 7.28: Test #59 Wing Skin Temperature Data

Test 59, Launch, IP/ZR, Tunnel OAT -10.3ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-7.3	-8.1	-8.0	-9.0
T5	-7.9	-7.6	-7.3	-8.0
TU	-8.9	-8.3	-8.5	-9.2

Table 7.29: Test #86 Wing Skin Temperature Data

Test 86, ABC-S Plus, IP-, Tunnel OAT -9.3ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	N/A	-8.3	-10.1	-10.1
T5	N/A	-8.1	-9.8	-8.5
TU	N/A	-8.3	-9.9	-10.0

Table 7.30: Test #87 Wing Skin Temperature Data

Test 87, ABC-S Plus, IP Mod, Tunnel OAT -6.5ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-10.1	-8.0	-12.0	-8.6
T5	-8.5	-8.3	-11.0	-8.2
TU	-10.0	-7.2	-11.9	-7.1

Table 7.31: Test #88 Wing Skin Temperature Data

Test 88, ABC-S Plus, IP Mod, Tunnel OAT -6.0ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-8.6	-7.4	-11.1	-10.6
T5	-8.2	-8.3	-10.6	-10.2
TU	-7.1	-7.0	-11.5	-11.5

Table 7.32: Test #91 Wing Skin Temperature Data

Test 91, ABC-S Plus, IP/SN-, Tunnel OAT -7.1ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-12.4	-11.0	-9.8	-11.0
T5	-12.1	-11.4	-10.2	-10.5
TU	-12.9	-11.1	-10.1	-10.6

Table 7.33: Test #92 Wing Skin Temperature Data

Test 92, EG106, IP/SN-, Tunnel OAT -15.2ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-11.0	-9.5	-11.5	-12.5
T5	-10.5	-9.5	-10.0	-11.8
TU	-10.6	-10.0	-14.4	-12.5

Table 7.34: Test #99 Wing Skin Temperature Data

Test 99, EG106, IP-, Tunnel OAT -10.1ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-6.0	-6.3	-9.9	-8.2
T5	-5.5	-5.9	-9.3	-7.9
TU	-6.7	-6.3	-9.8	-8.3

Table 7.35: Test #106 Wing Skin Temperature Data

Test 106, EG106, IP Mod, Tunnel OAT -9.4ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-9.7	-9.0	-12.0	-9.4
T5	-8.4	-8.7	-13.8	-8.7
TU	-9.8	-9.2	-13.9	-9.5

7.2.3 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Section 2.14.4.

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

Table 7.36 to Table 7.52 show the fluid Brix measurements collected during the test.

Table 7.36: Test #12 Fluid Brix Data

Test 12, ABC-S Plus, IP/SN, Tunnel OAT -4.9ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.25	20.25	26.00
8	37.00	25.25	27.00

Table 7.37: Test #22 Fluid Brix Data

Test 22, Launch, IP/ZR, Tunnel OAT -5.5ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.75	18.00	24.50
8	36.25	16.50	21.50

Table 7.38: Test #25 Fluid Brix Data

Test 25, ABC-S Plus, IP/ZR, Tunnel OAT -3.6ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.25	21.25	24.25
8	36.75	14.00	25.50

Table 7.39: Test #31 Fluid Brix Data

Test 31, EG106, IP/SN, Tunnel OAT 0.1ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	33.25	19.25	25.50
8	33.50	18.25	30.50

Table 7.40: Test #33 Fluid Brix Data

Test 33, EG106, IP/ZR, Tunnel OAT -2.7ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	33.50	26.50	26.50
8	34.00	20.00	30.75

Table 7.41: Test #43 Fluid Brix Data

Test 43, EG106, IP/SN, Tunnel OAT -12.7ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	34.75	32.75	33.00
8	34.00	27.75	31.00

Table 7.42: Test #45 Fluid Brix Data

Test 45, ABC-S Plus, IP/SN, Tunnel OAT -15.9ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	38.00	30.00	30.00
8	37.00	29.00	20.00

Table 7.43: Test #52 Fluid Brix Data

Test 52, EG106, IP/SN, Tunnel OAT -5.6ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	34.00	44.50	30.25
8	33.75	21.50	30.00

Table 7.44: Test #53 Fluid Brix Data

Test 53, ABC-S Plus, IP/SN, Tunnel OAT -3.4ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.25	19.50	23.00
8	37.25	26.50	25.00

Table 7.45: Test #59 Fluid Brix Data

Test 59, Launch, IP/ZR, Tunnel OAT -10.3ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.00	27.50	29.00
8	37.00	29.00	25.00

Table 7.46: Test #86 Fluid Brix Data

Test 86, ABC-S Plus, IP-, Tunnel OAT -9.3ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.00	20.75	22.50
8	36.75	21.50	20.00

Table 7.47: Test #87 Fluid Brix Data

Test 87, ABC-S Plus, IP Mod, Tunnel OAT -6.5ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.50	22.75	25.25
8	37.00	19.75	16.25

Table 7.48: Test #88 Fluid Brix Data

Test 88, ABC-S Plus, IP Mod, Tunnel OAT -6.0ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.50	21.50	31.50
8	37.00	18.50	24.50

Table 7.49: Test #91 Fluid Brix Data

Test 91, ABC-S Plus, IP/SN-, Tunnel OAT -7.1ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.50	33.75	29.25
8	37.00	25.00	29.25

Table 7.50: Test #92 Fluid Brix Data

Test 92, EG106, IP/SN-, Tunnel OAT -15.2ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	34.00	23.50	30.50
8	34.00	23.50	31.25

Table 7.51: Test #99 Fluid Brix Data

Test 99, EG106, IP-, Tunnel OAT -10.1ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	33.75	19.00	25.00
8	34.00	18.00	24.00

Table 7.52: Test #106 Fluid Brix Data

Test 106, EG106, IP Mod, Tunnel OAT -9.4ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	33.50	31.50	24.50
8	34.25	19.00	27.50

7.3 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 test, a summary of the photos has been compiled comprising of four photos per camera angle:

- 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 4 degrees); and
- End of test.

Photo 7.1 to Photo 7.68 show the photo summaries of the tests conducted. A complete set of photos will be provided to TDC.

7.4 General Observations

The following sections describe the observations regarding the testing conducted to support the potential development of a Type IV low speed allowance time table. The results have been separated according to the specific condition tested. Table 7.53 shows the tests conducted for each ice pellet condition as well as the Type IV high speed allowance time derived from the 2006-07 testing (included as a reference only).

7.4.1 Light Ice Pellets

7.4.1.1 OAT -5ºC and Above

No testing was conducted in this condition.

7.4.1.2 OAT less than -5ºC to -10ºC

Two tests were conducted: Test #86 and Test #99. Test #86 conducted with PG fluid demonstrated both poor visual fluid elimination and lift coefficient results, whereas the EG fluid showed positive results. The results indicate a fluid issue for PG fluids which needs to be investigated further. It should be noted that the tests originally targeted the -5ºC and above temperature range, whereas the OAT was actually closer to -10ºC, therefore the exposure time was almost twice as long as the current Type IV high speed allowance time for OAT less than -5ºC to -10ºC. Based on the results obtained, it was not possible to develop an ice pellet allowance time for low speed takeoff with Type IV fluid for this condition.

7.4.1.3 OAT less than -10ºC

No testing was conducted in this condition.

Table 7.53: Tests Conducted Separated According to Condition Tested

	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 *Test # 86, 99*	30 minutes
Moderate Ice Pellets	25 minutes *Test # 87, 88*	10 minutes *Test # 106*	10 minutes
Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle	25 minutes	10 minutes	
Light Ice Pellets Mixed with Light Freezing Rain	25 minutes *Test # 22, 25, 33*	10 minutes *Test # 59*	
Light Ice Pellets Mixed with Light Rain	25 minutes		**Caution: No allowance times currently exist**
Light Ice Pellets Mixed with Moderate Snow	25 minutes *Test # 12, 31, 52, 53*	Allowance Time N/A *Test #43, 45*	
Light Ice Pellets Mixed with Light Snow	25 minutes	Allowance Time N/A *Test #91, 92*	

7.4.2 Moderate Ice Pellets

7.4.2.1 OAT -5°C and Above

Two tests were conducted: Test #87 and Test #88. Both tests were conducted with PG fluid and both demonstrated poor visual fluid elimination and lift coefficient results. Similar to the results from the low speed light ice pellets testing, the results indicate a fluid issue for PG fluids which needs to be investigated further. Based on the results obtained, it was not possible to develop an ice pellet allowance time for low speed takeoff with Type IV fluid for this condition.

7.4.2.2 OAT less than -5°C to -10°C

One test was conducted: Test #106. The test conducted with EG fluid demonstrated positive results. It should be noted that the tests originally targeted the -5°C and above temperature range, whereas the OAT was actually closer to -10°C, therefore the exposure time was more than twice as long as the current Type IV high speed allowance time for OAT less than -5°C to -10°C.

7.4.2.3 OAT less than -10°C

No testing was conducted in this condition.

7.4.3 Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle

Testing in this condition was not conducted in the wind tunnel. Allowance times will be extrapolated from the "light ice pellets mixed with light freezing rain" condition (see Section 7.4.4 for results). This approach was deemed appropriate and conservative because light ice pellets mixed with light or moderate freezing drizzle is a less severe condition compared to light ice pellets mixed with light freezing rain.

7.4.4 Light Ice Pellets Mixed with Light Freezing Rain

7.4.4.1 OAT -5°C and Above

Two tests using PG fluid (Tests #22 and # 25) and one test using EG fluid (Test #33) were conducted. The results from all three tests demonstrated positive visual fluid elimination and lift coefficient results. Based on these results, the current 25 minute high speed allowance time for Type IV fluids seems appropriate for low speed operations as well.

In addition, flat plate testing at the NRC climatic engineering facility indicated that the current 25 minute allowance time for conditions of light ice pellets mixed with light freezing rain is acceptable and provides a sufficient safety buffer.

7.4.4.2 OAT less than -5°C to -10°C

One test was conducted: Test #59. The 10 minute exposure time test demonstrated marginal positive results. Due to the limited data collected, a 5 minute allowance time was recommended until further testing can be conducted to support a 10 minute allowance time.

In addition, flat plate testing at the NRC climatic engineering facility indicated that the current 10 minute allowance time for conditions of light ice pellets mixed with light freezing rain is acceptable and provides a sufficient safety buffer, however due to the limited aerodynamic data collected, a 5 minute allowance time is more conservative and appropriate.

7.4.5 Light Ice Pellets Mixed with Light Rain

7.4.5.1 OAT -5°C and Above

Testing in this condition was not conducted in the wind tunnel. Allowance times will be extrapolated from the “light ice pellets mixed with light freezing rain” condition (see Section 7.4.4 for results). This approach was deemed appropriate and conservative because light ice pellets mixed with light rain is a less severe condition compared to light ice pellets mixed with light freezing rain.

7.4.6 Light Ice Pellets Mixed with Moderate Snow

7.4.6.1 OAT -5°C and Above

Four tests were conducted: Test #12, Test #31, Test #52, and Test #53. Test #12 conducted with PG fluid for a 10 minute exposure time demonstrated positive results. Test #31 and #52, both conducted with EG fluid for an exposure time of 25 minutes demonstrated positive results as well. However, Test #53 conducted with PG fluid for an exposure time of 25 minutes demonstrated marginal visual contamination results and positive lift coefficient results. Due to the lack of the data collected in the 10 to 25 minute range, a 10 minute allowance time was proposed as a conservative allowance time for low speed operations with Type IV for this condition.

7.4.6.2 OAT -5°C to -10°C

Two tests were conducted: Test #43, and Test #45. The results demonstrated a discrepancy in the results obtained with the PG fluid vs. the EG fluid. Test #43 conducted with the EG fluid demonstrated positive results. Test #45 conducted with the PG fluid demonstrated poor fluid flow-off. Similar results were obtained during the high speed runs as well. As limited testing was conducted with 10 minute exposure times, allowance times for this condition were not recommended. Additional testing should be conducted to target 5 or 8 minute allowance times.

7.4.7 Light Ice Pellets Mixed with Light Snow

7.4.7.1 OAT -5°C and Above

Testing in this condition was not conducted in the wind tunnel. Allowance times will be extrapolated from the “light ice pellets mixed with moderate snow” condition (see Section 7.10 for results). This approach was deemed appropriate and conservative because light ice pellets mixed with light snow is a less severe condition compared to light ice pellets mixed with moderate snow.

7.4.7.2 OAT -5°C to -10°C

Two tests were conducted Test #91, and Test #92. Both tests targeted a 10 minute exposure time. Test #91 conducted with a PG fluid demonstrated marginal results (visual fluid flow-off seemed acceptable; however the lift coefficient data indicated lift losses). However, the EG fluid (Test #92) demonstrated positive results. Based on the limited data collected and the discrepancy between the PG and EG results obtained, no allowance times were proposed until additional testing can be conducted.

7.5 Summary of Results

7.5.1 Allowance Time Table Development

Based on the testing conducted during the winter of 2008-09, the following summary of potential allowance times for the preliminary development of the low speed Type IV fluid allowance time table has been compiled:

- 25 minute allowance time for "light ice pellets mixed with light freezing rain" for above -5°C conditions. This allowance time is also applicable to:
  - "light ice pellets mixed with light or moderate freezing drizzle;"
  - "light ice pellets mixed with light rain."
- 10 minute allowance time for "light ice pellets mixed with light freezing rain" for below -5°C to -10°C conditions. This allowance time is also applicable to:
  - "light ice pellets mixed with light or moderate freezing drizzle."
- 10 minute allowance time for "light ice pellets mixed with moderate snow" for above -5°C conditions. This allowance time is also applicable to:
  - "light ice pellets mixed with light snow."

Due to the limited data collected, as well as potential fluid flow issues observed with the low speed tests (especially with PG type fluids), it is recommended that further testing be conducted before a separate low speed allowance time table is published in the HOT Guidelines.

In addition, Type IV fluids are generally not certified (or do not qualify) for low speed takeoff. Therefore, until modifications to the aerodynamic acceptance tests are issued and Type IV fluid is certified for low speed operations, low speed allowance times for Type IV fluids should not be published.

A summary of the preliminary potential allowance times is shown in Table 7.54. The respective tests used to validate or develop the respective cells have also been indicated.

Table 7.54: Type IV Low Speed Preliminary Development of Ice Pellet Allowance Times For Winter 2009-10

	OAT -5°C and above	OAT less than -5°C to -10°C	OAT less than -10°C
Light Ice Pellets	No Tests Conducted	Tests inconclusive *Test # 86, 99*	No Tests Conducted
Moderate Ice Pellets	Tests inconclusive *Test # 87, 88*	Tests inconclusive *Test # 106*	No Tests Conducted
Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle	25 minutes ↑	5 minutes ↑	**Caution: No allowance times currently exist**
Light Ice Pellets Mixed with Light Freezing Rain	25 minutes *Test # 22, 25, 33*	5 minutes *Test # 59*	
Light Ice Pellets Mixed with Light Rain	↓ 25 minutes		
Light Ice Pellets Mixed with Moderate Snow	10 minutes *Test # 12, 31, 52, 53*	Tests Inconclusive *Test #43, 45*	
Light Ice Pellets Mixed with Light Snow	↓ 10 minutes	Tests Inconclusive *Test #91, 92*	

→ Extrapolated Allowance Times

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Photo 7.1: Test #12 – Start of Test

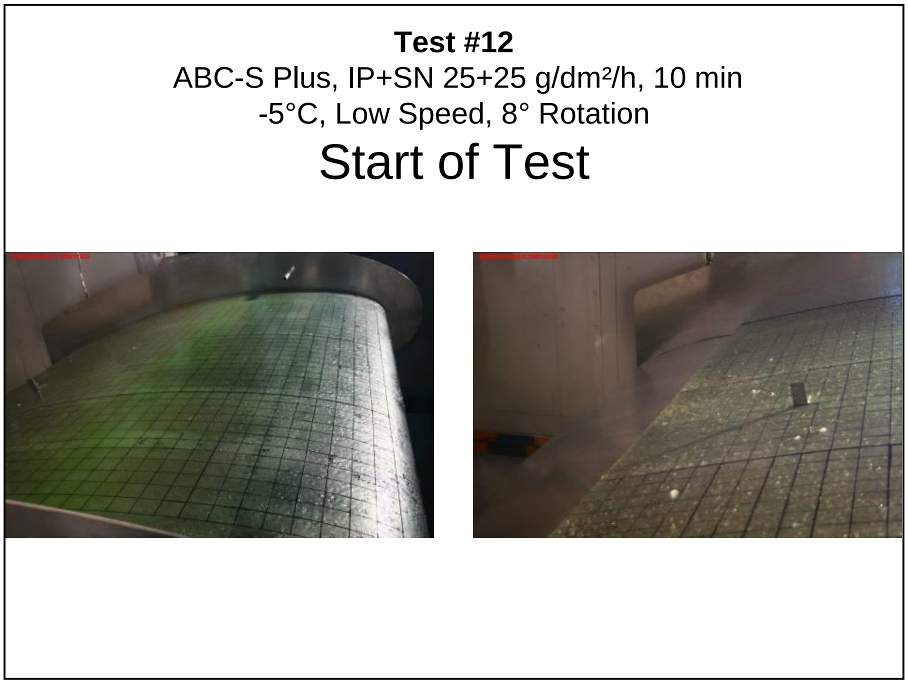


Photo 7.2: Test #12 – Before Rotation

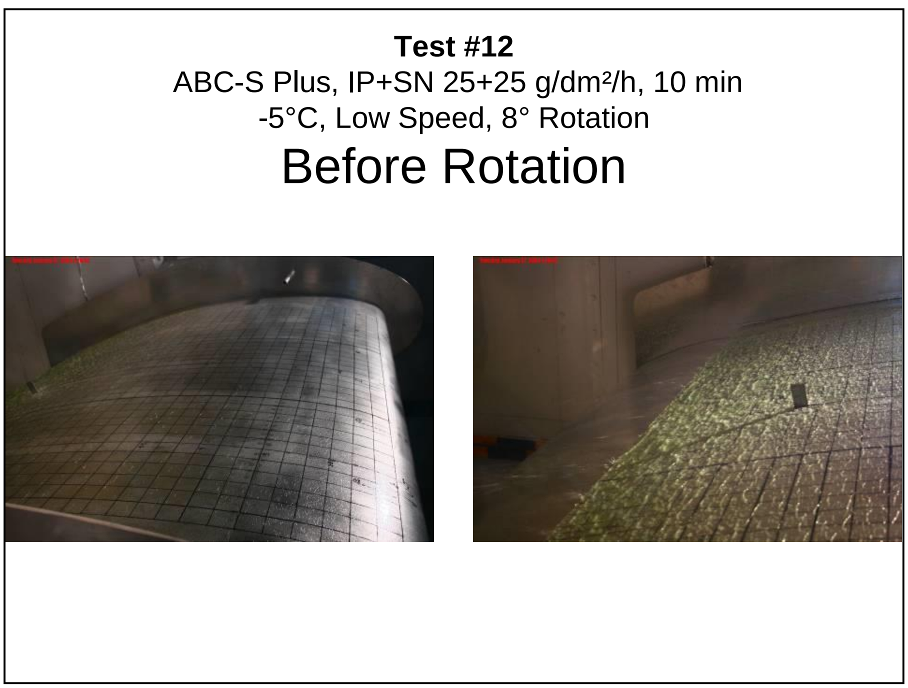


Photo 7.3: Test #12 – End of Rotation

Test #12
ABC-S Plus, IP+SN 25+25 g/dm²/h, 10 min
-5°C, Low Speed, 8° Rotation
End of Rotation

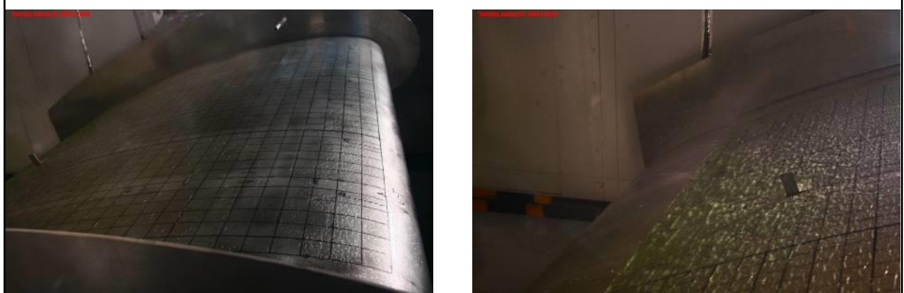


Photo 7.4: Test #12 – End of Test

Test #12
ABC-S Plus, IP+SN 25+25 g/dm²/h, 10 min
-5°C, Low Speed, 8° Rotation
End of Test

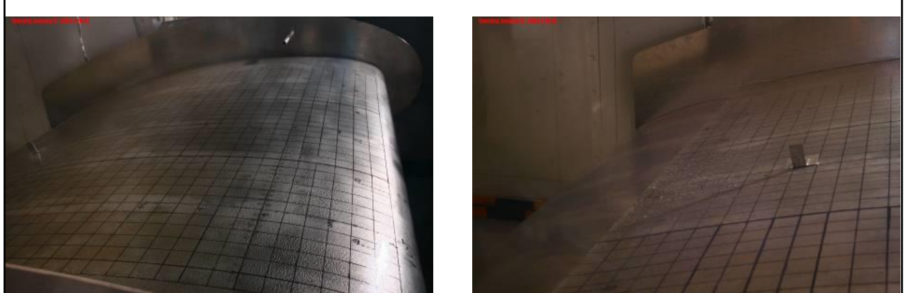


Photo 7.5: Test #22 – Start of Test

Test #22
Launch, IP+ZR, 25+25 $g/dm^2/h$, 25 min
-6°C, Low Speed, 8° Rotation
Start of Test

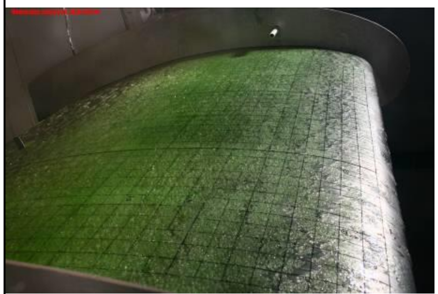


Photo 7.6: Test #22 – Before Rotation

Test #22
Launch, IP+ZR, 25+25 $g/dm^2/h$, 25 min
-6°C, Low Speed, 8° Rotation
Before Rotation

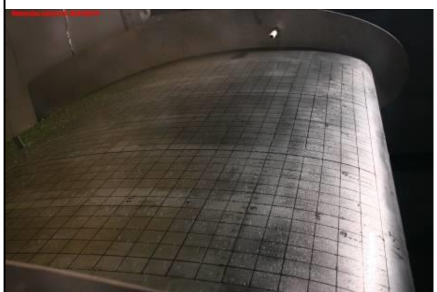


Photo 7.7: Test #22 – End of Rotation

Test #22
Launch, IP+ZR, 25+25 g/dm²/h, 25 min
-6°C, Low Speed, 8° Rotation
End of Rotation

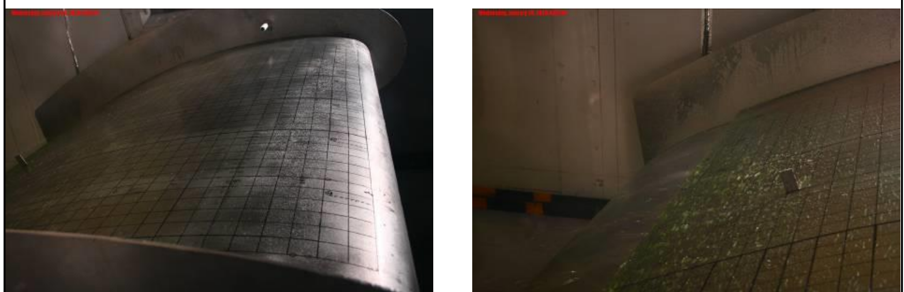


Photo 7.8: Test #22 – End of Test

Test #22
Launch, IP+ZR, 25+25 g/dm²/h, 25 min
-6°C, Low Speed, 8° Rotation
End of Test

Photo 7.9: Test #25 – Start of Test

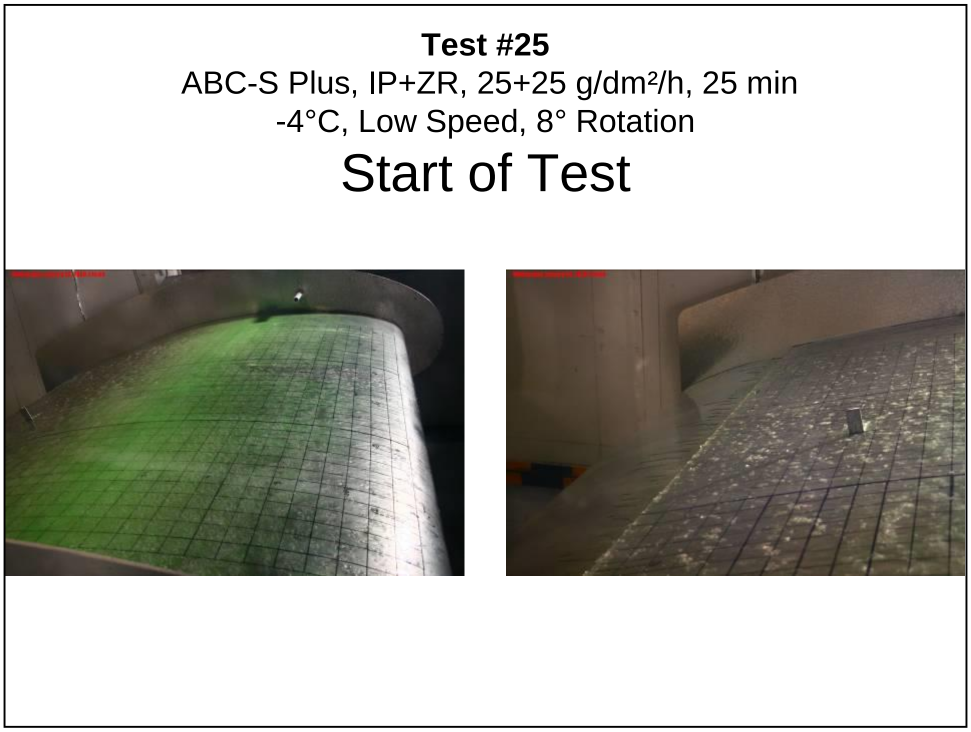


Photo 7.10: Test #25 – Before Rotation

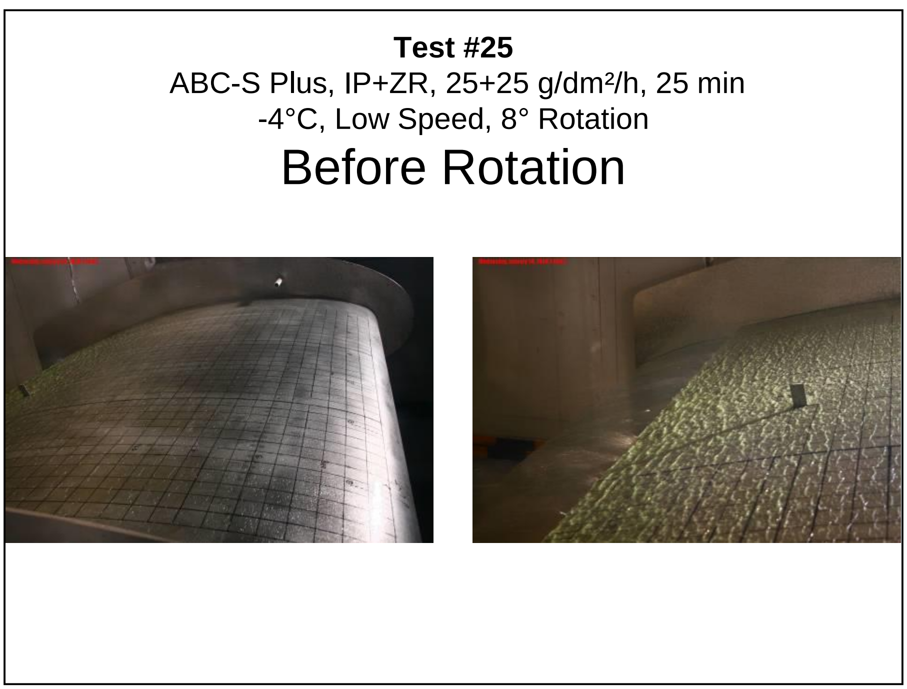


Photo 7.11: Test #25 – End of Rotation

Test #25
ABC-S Plus, IP+ZR, 25+25 g/dm²/h, 25 min
-4°C, Low Speed, 8° Rotation
End of Rotation

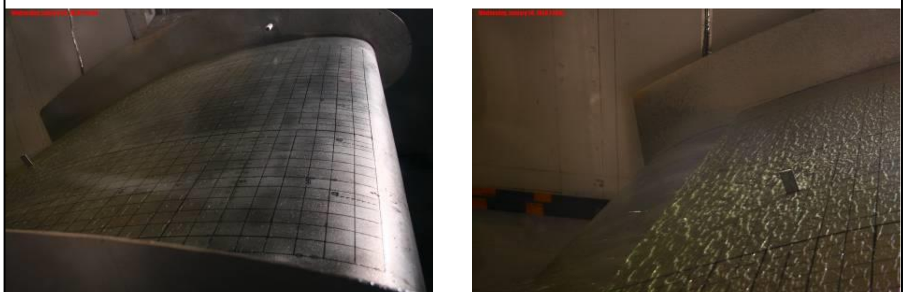


Photo 7.12: Test #25 – End of Test

Test #25
ABC-S Plus, IP+ZR, 25+25 g/dm²/h, 25 min
-4°C, Low Speed, 8° Rotation
End of Test

Photo 7.13: Test #31 – Start of Test

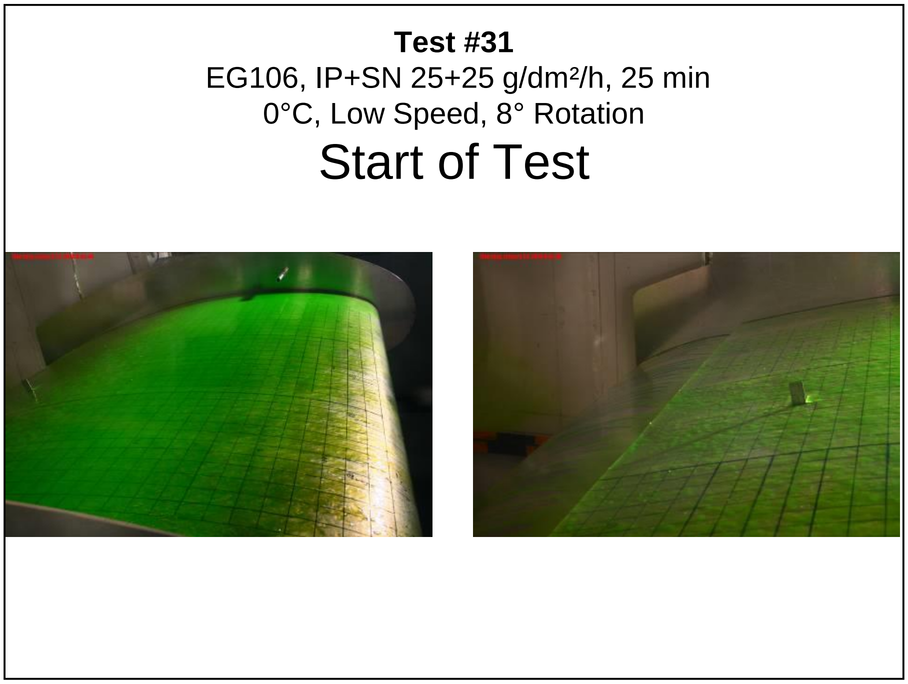


Photo 7.14: Test #31 – Before Rotation

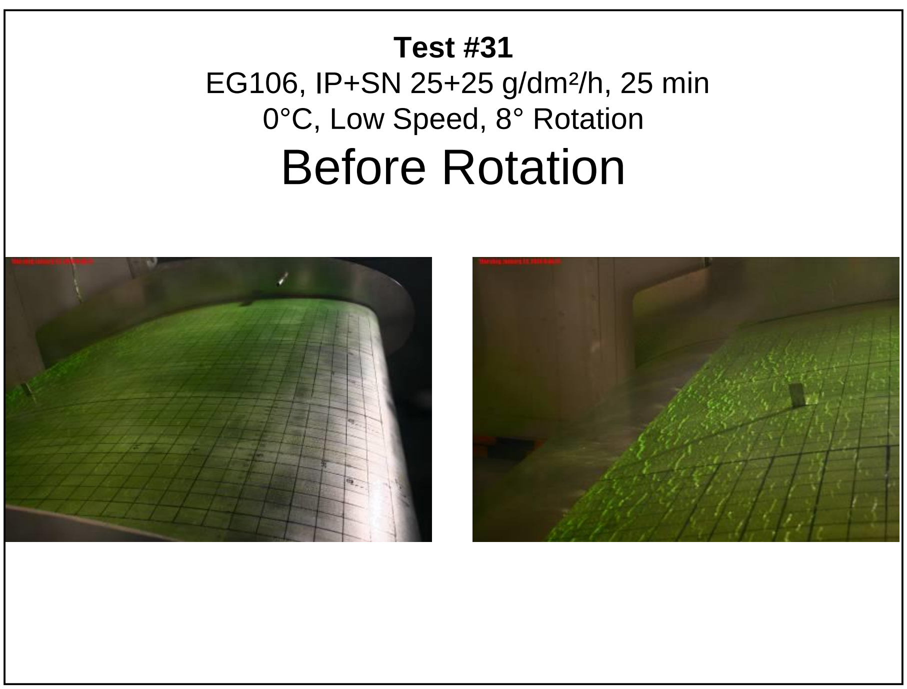


Photo 7.15: Test #31 – End of Rotation

Test #31
EG106, IP+SN 25+25 g/dm²/h, 25 min
0°C, Low Speed, 8° Rotation
End of Rotation

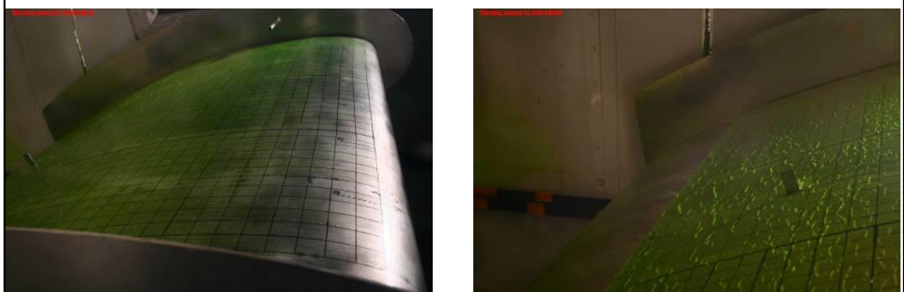


Photo 7.16: Test #31 – End of Test

Test #31
EG106, IP+SN 25+25 g/dm²/h, 25 min
0°C, Low Speed, 8° Rotation
End of Test

Photo 7.17: Test #33 – Start of Test

Test #33
EG106, IP+ZR 25+25 g/dm²/h, 25 min
-3°C, Low Speed, 8° Rotation
Start of Test

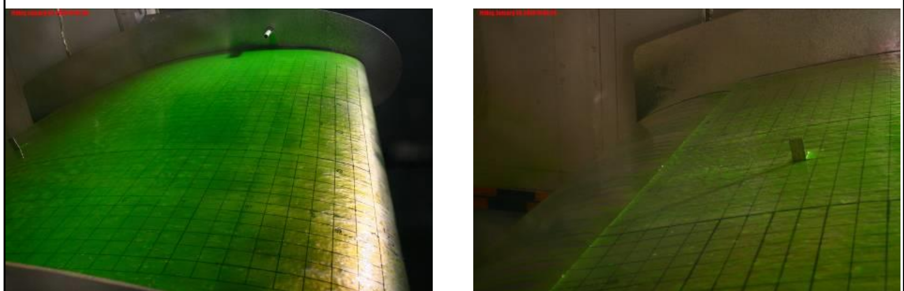


Photo 7.18: Test #33 – Before Rotation

Test #33
EG106, IP+ZR 25+25 g/dm²/h, 25 min
-3°C, Low Speed, 8° Rotation
Before Rotation

Photo 7.19: Test #33 – End of Rotation

Test #33
EG106, IP+ZR 25+25 g/dm²/h, 25 min
-3°C, Low Speed, 8° Rotation
End of Rotation

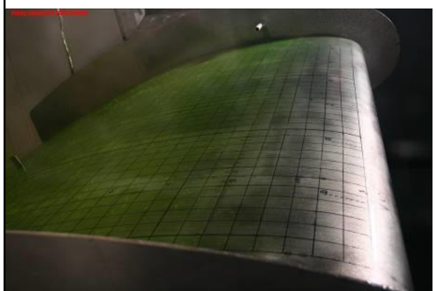
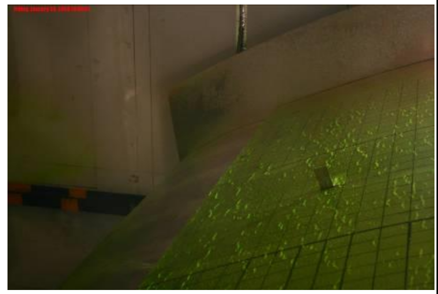



Photo 7.20: Test #33 – End of Test

Test #33
EG106, IP+ZR 25+25 g/dm²/h, 25 min
-3°C, Low Speed, 8° Rotation
End of Test

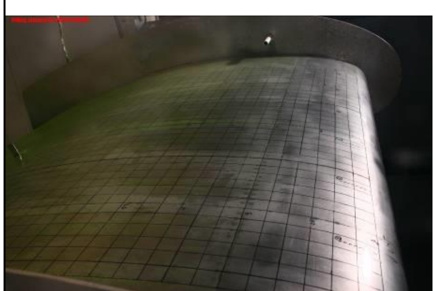
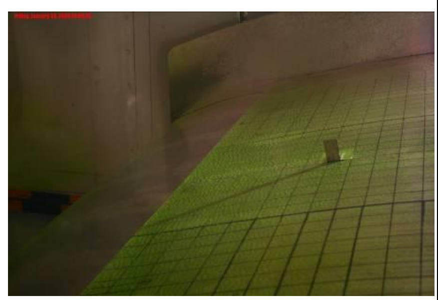



Photo 7.21: Test #43 – Start of Test

Test #43
EG106, IP+SN 25+25 g/dm²/h, 10 min
-13°C, Low Speed, 16° Rotation
Start of Test

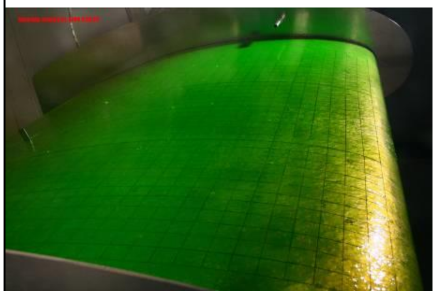
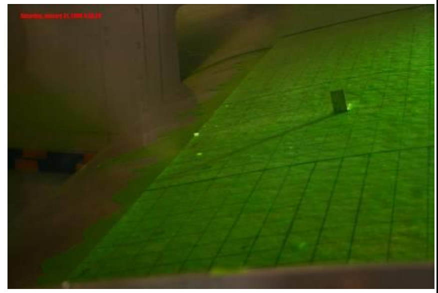



Photo 7.22: Test #43 – Before Rotation

Test #43
EG106, IP+SN 25+25 g/dm²/h, 10 min
-13°C, Low Speed, 16° Rotation
Before Rotation

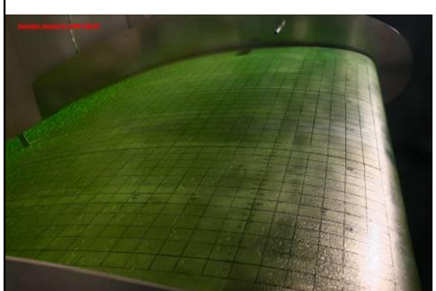
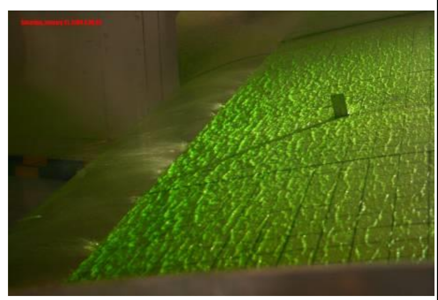



Photo 7.23: Test #43 – End of Rotation

Test #43
EG106, IP+SN 25+25 g/dm²/h, 10 min
-13°C, Low Speed, 16° Rotation
End of Rotation

Photo 7.24: Test #43 – End of Test

Test #43
EG106, IP+SN 25+25 g/dm²/h, 10 min
-13°C, Low Speed, 16° Rotation
End of Test

Photo 7.25: Test #45 – Start of Test

Test #45
ABC-S Plus, IP+SN 25+25 g/dm²/h, 10 min
-16°C, Low Speed, 16° Rotation

Start of Test

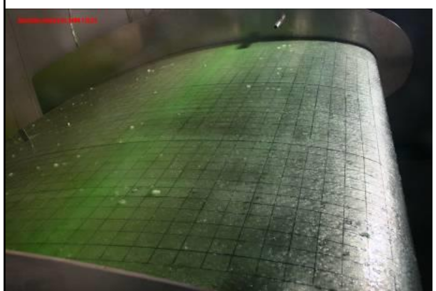


Photo 7.26: Test #45 – Before Rotation

Test #45
ABC-S Plus, IP+SN 25+25 g/dm²/h, 10 min
-16°C, Low Speed, 16° Rotation

Before Rotation

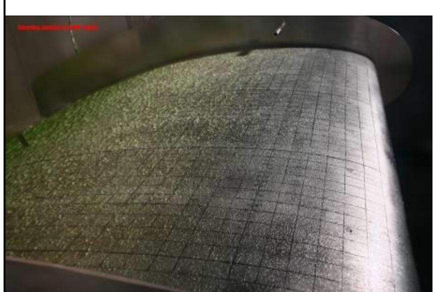
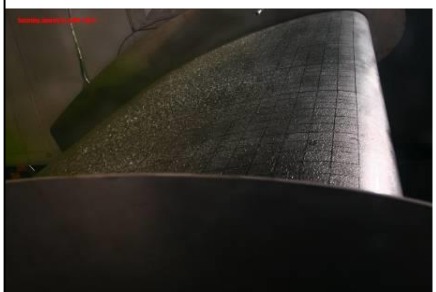


Photo 7.27: Test #45 – End of Rotation

Test #45
ABC-S Plus, IP+SN 25+25 g/dm²/h, 10 min
-16°C, Low Speed, 16° Rotation
End of Rotation



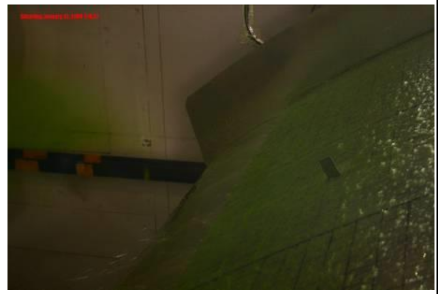


Photo 7.28: Test #45 – End of Test

Test #45
ABC-S Plus, IP+SN 25+25 g/dm²/h, 10 min
-16°C, Low Speed, 16° Rotation
End of Test

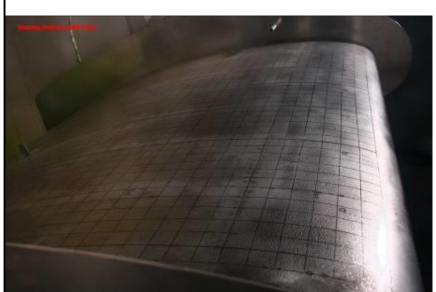


Photo 7.29: Test #52 – Start of Test

Test #52
EG106, IP+SN 25+25 g/dm²/h, 25 min
-6°C, Low Speed, 16° Rotation
Start of Test

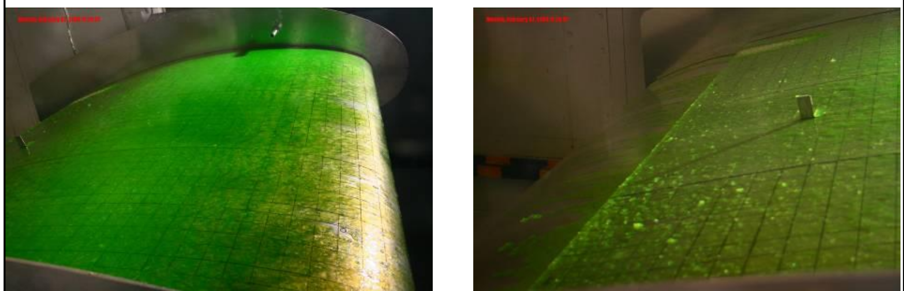


Photo 7.30: Test #52 – Before Rotation

Test #52
EG106, IP+SN 25+25 g/dm²/h, 25 min
-6°C, Low Speed, 16° Rotation
Before Rotation

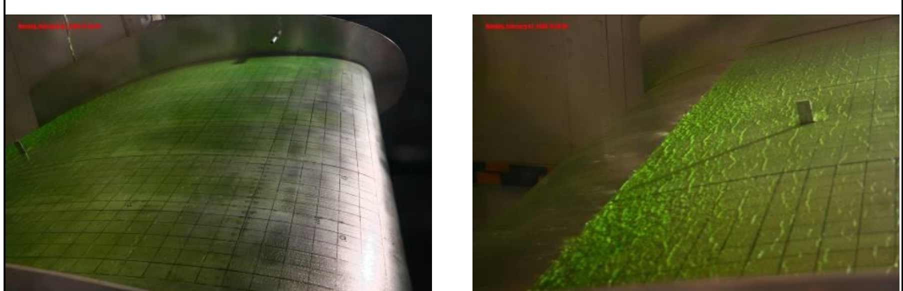


Photo 7.31: Test #52 – End of Rotation

Test #52
EG106, IP+SN 25+25 g/dm²/h, 25 min
-6°C, Low Speed, 16° Rotation
End of Rotation

Photo 7.32: Test #52 – End of Test

Test #52
EG106, IP+SN 25+25 g/dm²/h, 25 min
-6°C, Low Speed, 16° Rotation
End of Test

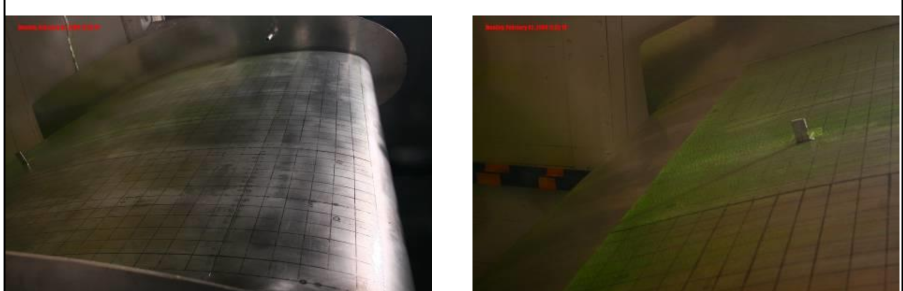


Photo 7.33: Test #53 – Start of Test

Test #53
ABC-S Plus, IP+SN 25+25 g/dm²/h, 25 min
-3°C, Low Speed, 16° Rotation
Start of Test

Photo 7.34: Test #53 – Before Rotation

Test #53
ABC-S Plus, IP+SN 25+25 g/dm²/h, 25 min
-3°C, Low Speed, 16° Rotation
Before Rotation

Photo 7.35: Test #53 – End of Rotation

Test #53
ABC-S Plus, IP+SN 25+25 g/dm²/h, 25 min
-3°C, Low Speed, 16° Rotation
End of Rotation

Photo 7.36: Test #53 – End of Test

Test #53
ABC-S Plus, IP+SN 25+25 g/dm²/h, 25 min
-3°C, Low Speed, 16° Rotation
End of Test

Photo 7.37: Test #59 – Start of Test

Test #59
Launch, IP+ZR 25+25 g/dm²/h, 10 min
-10°C, Low Speed, 16° Rotation
Start of Test

Photo 7.38: Test #59 – Before Rotation

Test #59
Launch, IP+ZR 25+25 g/dm²/h, 10 min
-10°C, Low Speed, 16° Rotation
Before Rotation

Photo 7.39: Test #59 – End of Rotation

Test #59
Launch, IP+ZR 25+25 g/dm²/h, 10 min
-10°C, Low Speed, 16° Rotation
End of Rotation

Photo 7.40: Test #59 – End of Test

Test #59
Launch, IP+ZR 25+25 g/dm²/h, 10 min
-10°C, Low Speed, 16° Rotation
End of Test

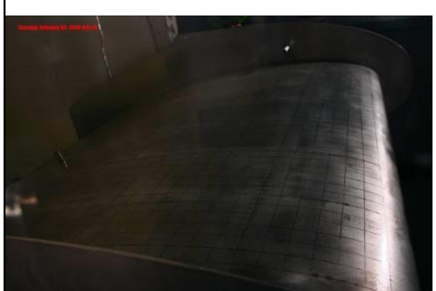


Photo 7.41: Test #86 – Start of Test

Test #86
ABC-S Plus, IP- 25 g/dm²/h, 50 min
-9°C, Low Speed, 20° Rotation
Start of Test


Photo 7.42: Test #86 – Before Rotation

Test #86
ABC-S Plus, IP- 25 g/dm²/h, 50 min
-9°C, Low Speed, 20° Rotation
Before Rotation


Photo 7.43: Test #86 – End of Rotation

Test #86
ABC-S Plus, IP- 25 g/dm²/h, 50 min
-9°C, Low Speed, 20° Rotation
End of Rotation

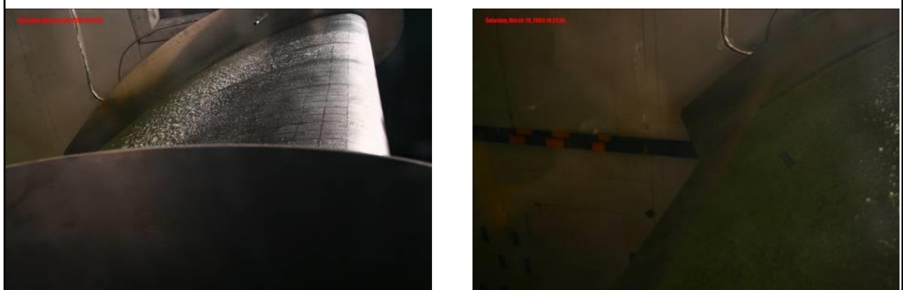


Photo 7.44: Test #86 – End of Test

Test #86
ABC-S Plus, IP- 25 g/dm²/h, 50 min
-9°C, Low Speed, 20° Rotation
End of Test

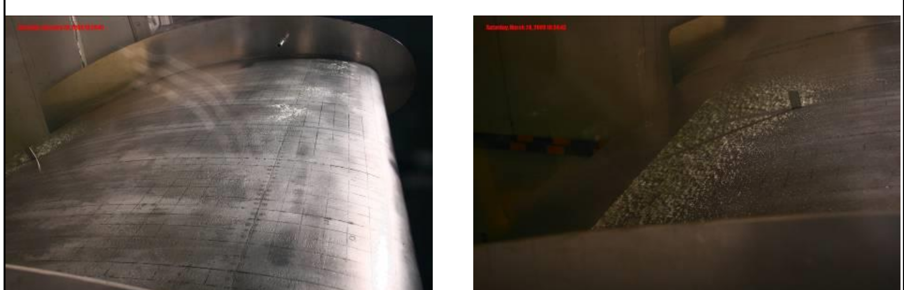


Photo 7.45: Test #87 – Start of Test

Test #87
ABC-S Plus, IP Mod 75 g/dm²/h, 25 min
-7°C, Low Speed, 20° Rotation
Start of Test


Photo 7.46: Test #87 – Before Rotation

Test #87
ABC-S Plus, IP Mod 75 g/dm²/h, 25 min
-7°C, Low Speed, 20° Rotation
Before Rotation


Photo 7.47: Test #87 – End of Rotation

Test #87
ABC-S Plus, IP Mod 75 g/dm²/h, 25 min
-7°C, Low Speed, 20° Rotation
End of Rotation

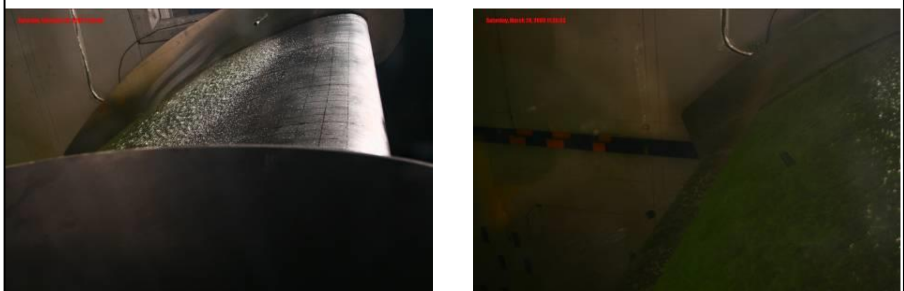


Photo 7.48: Test #87 – End of Test

Test #87
ABC-S Plus, IP Mod 75 g/dm²/h, 25 min
-7°C, Low Speed, 20° Rotation
End of Test

Photo 7.49: Test #88 – Start of Test

Test #88
ABC-S Plus, IP Mod 75 g/dm²/h, 15 min
-6°C, Low Speed, 20° Rotation
Start of Test

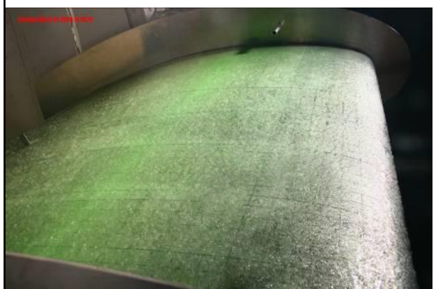
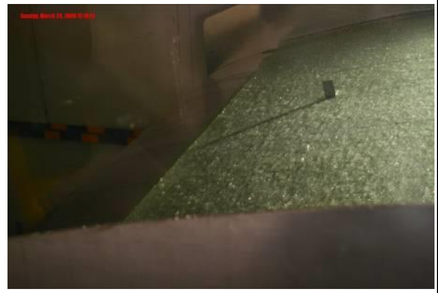



Photo 7.50: Test #88 – Before Rotation

Test #88
ABC-S Plus, IP Mod 75 g/dm²/h, 15 min
-6°C, Low Speed, 20° Rotation
Before Rotation


Photo 7.51: Test #88 – End of Rotation

Test #88
ABC-S Plus, IP Mod 75 g/dm²/h, 15 min
-6°C, Low Speed, 20° Rotation
End of Rotation


Photo 7.52: Test #88 – End of Test

Test #88
ABC-S Plus, IP Mod 75 g/dm²/h, 15 min
-6°C, Low Speed, 20° Rotation
End of Test

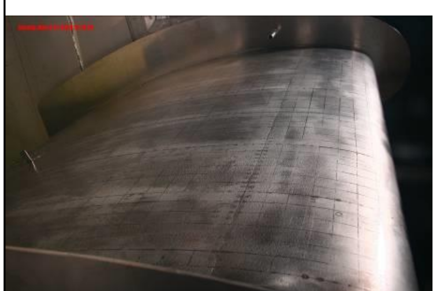



Photo 7.53: Test #91 – Start of Test

Test #91
ABC-S Plus, IP+SN- 25+10 g/dm²/h, 10 min
-7°C, Low Speed, 20° Rotation
Start of Test

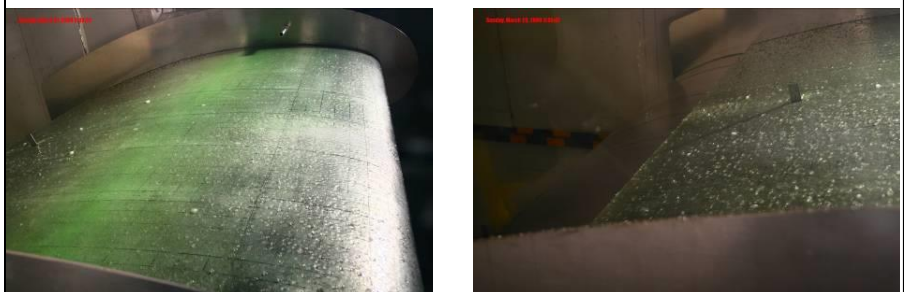


Photo 7.54: Test #91 – Before Rotation

Test #91
ABC-S Plus, IP+SN- 25+10 g/dm²/h, 10 min
-7°C, Low Speed, 20° Rotation
Before Rotation

Photo 7.55: Test #91 – End of Rotation

Test #91
ABC-S Plus, IP+SN- 25+10 g/dm²/h, 10 min
-7°C, Low Speed, 20° Rotation
End of Rotation

Photo 7.56: Test #91 – End of Test

Test #91
ABC-S Plus, IP+SN- 25+10 g/dm²/h, 10 min
-7°C, Low Speed, 20° Rotation
End of Test

Photo 7.57: Test #92 – Start of Test

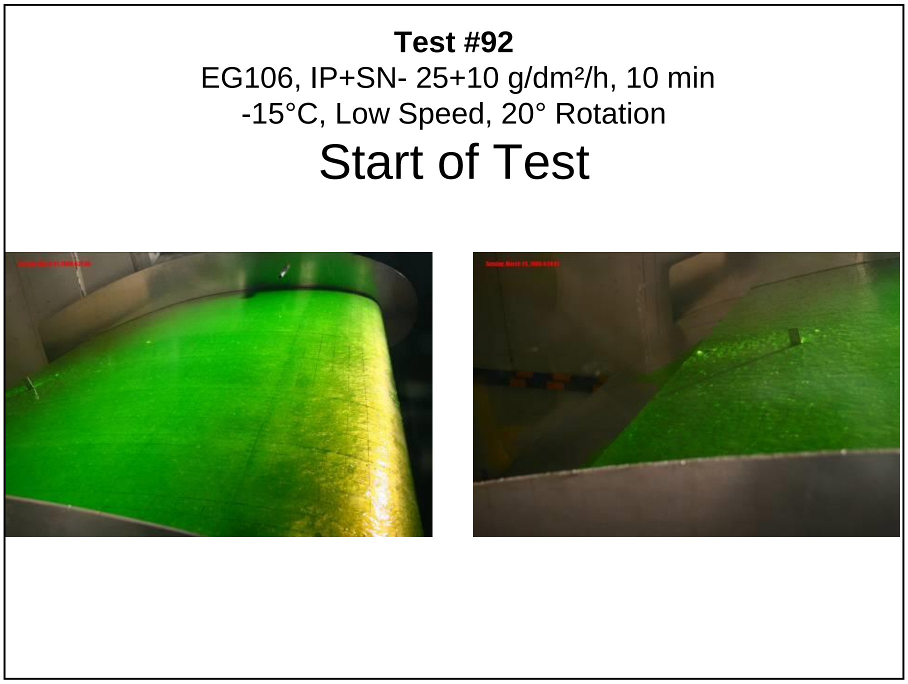


Photo 7.58: Test #92 – Before Rotation

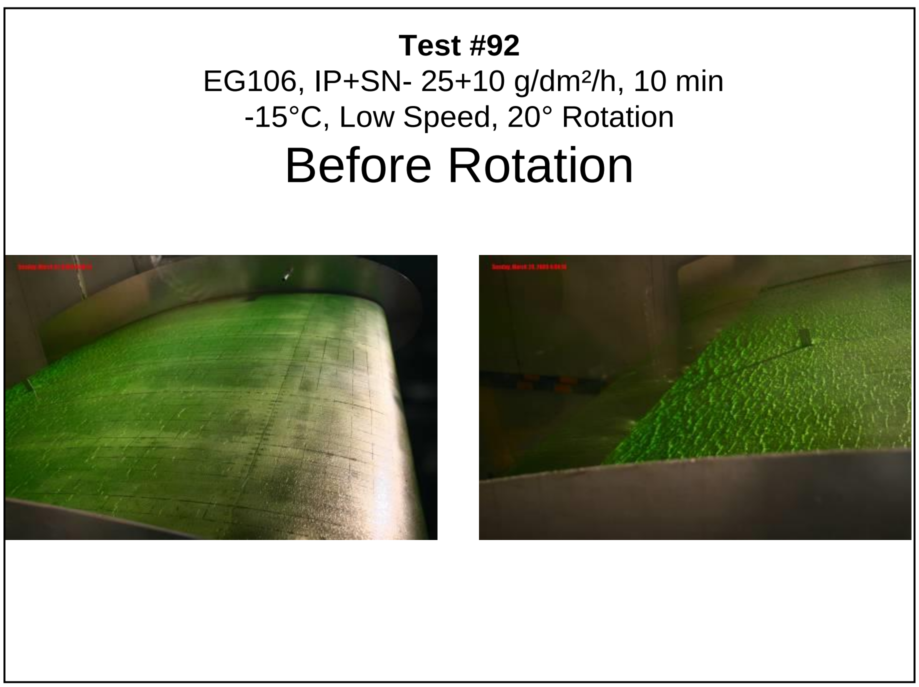
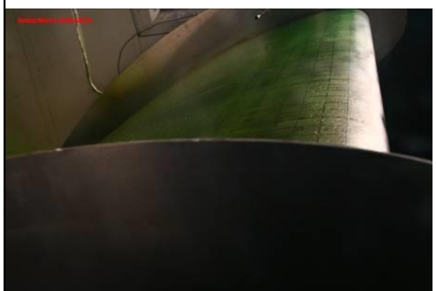


Photo 7.59: Test #92 – End of Rotation

Test #92
EG106, IP+SN- 25+10 g/dm²/h, 10 min
-15°C, Low Speed, 20° Rotation
End of Rotation



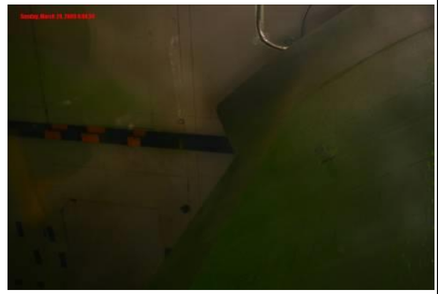


Photo 7.60: Test #92 – End of Test

Test #92
EG106, IP+SN- 25+10 g/dm²/h, 10 min
-15°C, Low Speed, 20° Rotation
End of Test

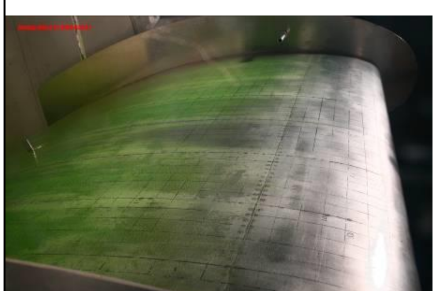


Photo 7.61: Test #99 – Start of Test

Test #99
EG106, IP- 25 g/dm²/h, 50 min
-10°C, Low Speed, 20° Rotation
Start of Test

Photo 7.62: Test #99 – Before Rotation

Test #99
EG106, IP- 25 g/dm²/h, 50 min
-10°C, Low Speed, 20° Rotation
Before Rotation

Photo 7.63: Test #99 – End of Rotation

Test #99
EG106, IP- 25 g/dm²/h, 50 min
-10°C, Low Speed, 20° Rotation
End of Rotation

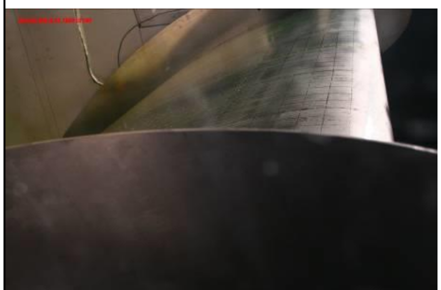


Photo 7.64: Test #99 – End of Test

Test #99
EG106, IP- 25 g/dm²/h, 50 min
-10°C, Low Speed, 20° Rotation
End of Test

Photo 7.65: Test #106 – Start of Test

Test #106
EG106, IP Mod 75 g/dm²/h, 25 min
-9°C, Low Speed, 20° Rotation
Start of Test

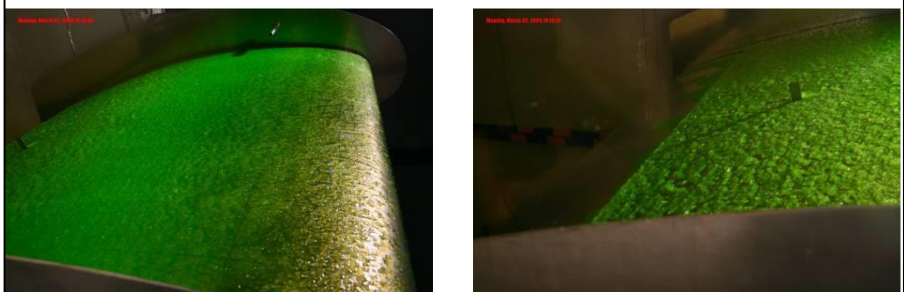


Photo 7.66: Test #106 – Before Rotation

Test #106
EG106, IP Mod 75 g/dm²/h, 25 min
-9°C, Low Speed, 20° Rotation
Before Rotation

Photo 7.67: Test #106 – End of Rotation

Test #106
EG106, IP Mod 75 g/dm²/h, 25 min
-9°C, Low Speed, 20° Rotation

End of Rotation

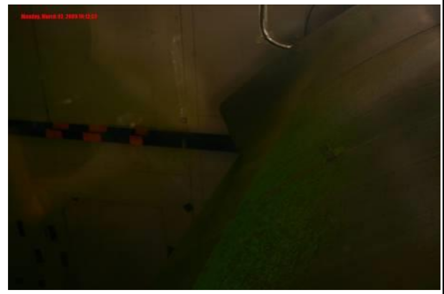
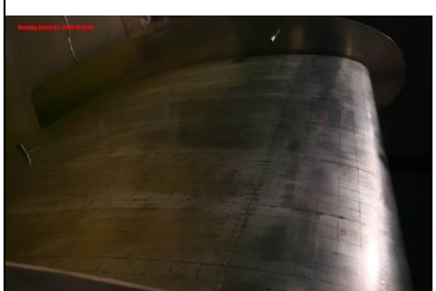


Photo 7.68: Test #106 – End of Test

Test #106
EG106, IP Mod 75 g/dm²/h, 25 min
-9°C, Low Speed, 20° Rotation

End of Test



8. TYPE III FLUID ICE PELLET ALLOWANCE TIMES FOR LOW SPEED AIRCRAFT

A secondary objective during the winter of 2008-09 was to investigate the possibility of expanding the current ice pellet allowance times for low rotation speed aircraft. However, Type IV anti-icing fluid is not recommended by the fluid manufacturers for use on low rotation speed aircraft. Some airframe manufacturers have approved the use of Type IV on their low rotation speed aircraft; however they have imposed speed penalties to compensate for the poor fluid flow-off at low speeds. The Clariant Type III fluid was specifically designed as an anti-icing fluid for low rotation speed aircraft. It was therefore recommended to investigate the performance of the Type III fluid during the low speed rotation test runs.

Preliminary work was conducted during the winter of 2007-08 with the Falcon 20 aircraft and T-33 aircraft to investigate the fluid flow-off performance of un-contaminated, and contaminated Type III fluids; contamination consisted of mixed conditions with ice pellets. The results obtained with the Type III fluid demonstrated better fluid flow-off when compared to Type IV fluids at low rotation speeds; however a significant amount of Type III fluid was still present at the end of the low speed test runs.

This section provides an overview of each test conducted to investigate the potential development of low speed and high speed allowance times for Type III fluid during operations in conditions mixed with ice pellets. The main objectives of this testing was the development of low speed allowance times for Type III fluids. Testing was conducted in simulated precipitation conditions. The parameters for each test are detailed and a description of the data collected during each test is provided.

8.1 Overview of Tests

A summary of the Type III fluid low speed 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 Section 4.1. 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 and applied at temperature close to the OAT.
Condition:	Simulated precipitation condition.
Precipitation Rate (g/dm²/h):	Simulated freezing precipitation rate (or combination of different precipitation rates). N/A indicates that no precipitation was applied.
Precip. Time (min.):	Total time of exposure to simulated precipitation.
Tunnel Temp at Start of Test (°C):	The tunnel ambient temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.
Avg. Wing Temp Before Test (°C):	Average of the wing skin temperature measurements just before the start of the simulated takeoff test, recorded in degrees Celsius.
Visual Contamination Rating Before Takeoff (LE, TE):	Visual contamination rating determined before the start of the simulated takeoff: 1. Contamination not very visible, fluid still clean; 2. Contamination is visible, but lots of fluid still present; 3. Contamination visible, spots of bridging contamination; 4. Contamination visible, lots of dry bridging present; and 5. Contamination visible, adherence of contamination.
Visual Contamination Rating at Rotation (LE, TE):	Visual contamination rating determined at the time of rotation: 1. Contamination not very visible, fluid still clean; 2. Contamination is visible, but lots of fluid still present; 3. Contamination visible, spots of bridging contamination; 4. Contamination visible, lots of dry bridging present; and 5. Contamination visible, adherence of contamination.
CL at 8° During Rotation:	Calculated lift coefficient at the 8° wing rotation angle position; data provided by NRC.

Table 8.1: Summary of 2008-09 Type III Low Speed Testing

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 Take off (LE, TE)	Visual Cont. Rating at Rotation (LE, TE)	C_L at 8° During Rotation
14	27-Jan-09	2031	IP/SN	25/25	10	-2	-6.2	2, 2	1, 1	1.779
16	27-Jan-09	2031	IP/SN	25/25	15	-1	-7.3	3, 4	1, 2	1.780
26	28-Jan-09	2031	IP/ZR	25/25	25	-5	-3.1	5, 5	5, 5	1.704
47	31-Jan-09	2031	IP/SN	25/25	10	-17	-14.1	4, 4	2, 3	1.707
48	31-Jan-09	2031	IP/SN	25/25	5	-14	-13.5	2, 2	1, 2	1.719
57	3-Feb-09	2031	IP/SN	25/25	10	-8	-7.5	2, 2.5	1, 2	N/A
73	23-Feb-09	2031	IP/ZR	25/25	10	-9	-7.0	3, 3	2, 2	N/A
74	23-Feb-09	2031	IP/ZR	25/25	5	-9	-7.1	2, 2	1, 2	1.798
78	24-Feb-09	2031	IP/SN-	25/10	10	-11	-9.1	2, 2	1, 2	1.780
100	2-Mar-09	2031	IP Mod	75	5	-11	-9.7	3, 3	1, 2	1.786
101	2-Mar-09	2031	IP-	25	10	-12	-7.5	2.5, 3	1, 2	1.770

8.2 Data Collected

8.2.1 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Section 2.14.2. Fluid thickness measurements were recorded at the following intervals:

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

Table 8.2 to Table 8.12 show the fluid thickness measurements collected during the tests.

Table 8.2: Test #14 Fluid Thickness Data

Test 14, 2031, IP/SN, Tunnel OAT -1.6ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.5	0.5	0.0
2	0.6	0.5	0.0
3	0.6	0.7	0.0
4	0.7	0.7	0.0
5	0.7	0.8	0.0
6	0.7	0.6	0.1
7	0.7	0.7	0.1
8	0.8	0.7	0.1

Table 8.3: Test #16 Fluid Thickness Data

Test 16, 2031, IP/SN, Tunnel OAT -1.2ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.6	1.0	0.0
2	0.8	1.2	0.0
3	1.1	1.3	0.1
4	0.7	1.7	0.0
5	1.5	1.8	0.1
6	0.7	1.3	0.1
7	0.7	1.1	0.1
8	0.8	1.2	0.1

Table 8.4: Test #26 Fluid Thickness Data

Test 26, 2031, IP/ZR, Tunnel OAT -5.3ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.6	slush	slush
2	0.7	slush	slush
3	1.0	slush	slush
4	1.1	slush	slush
5	0.6	slush	slush
6	0.7	slush	slush
7	0.7	slush	slush
8	0.8	slush	slush

Table 8.5: Test #47 Fluid Thickness Data

Test 47, 2031, IP/SN, Tunnel OAT -17.0ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.3	0.3 (slush)	0.0
2	0.4	0.4 (slush)	0.0
3	0.5	1.0 (slush)	0.0
4	0.5	0.7 (slush)	0.0
5	0.4	0.7 (slush)	0.0
6	0.7	0.5 (slush)	0.1
7	0.8	0.5 (slush)	0.1
8	0.8	0.4 (slush)	0.1

Table 8.6: Test #48 Fluid Thickness Data

Test 48, 2031, IP/SN, Tunnel OAT -13.5ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.6	0.7	0.0
2	0.8	0.7	0.0
3	1.0	1.1	0.1
4	1.2	1.8	0.1
5	1.7	1.4	0.1
6	0.7	1.1	0.2
7	0.7	0.7	0.3
8	0.8	0.5	0.2

Table 8.7: Test #57 Fluid Thickness Data

Test 57, 2031, IP/SN, Tunnel OAT -7.6ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.4	0.8	0.0
2	0.6	1.1	0.0
3	1.0	1.4	0.0
4	1.4	1.4	0.0
5	1.8	2.2	0.0
6	0.6	0.6	0.1
7	0.6	0.6	0.1
8	0.7	0.6	0.1

Table 8.8: Test #73 Fluid Thickness Data

Test 73, 2031, IP/ZR, Tunnel OAT -9.3ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.6	0.4	0.0
2	0.6	0.5	0.0
3	0.7	0.6	0.0
4	0.6	0.6	0.0
5	0.4	0.5	0.0
6	0.7	0.6	0.0
7	0.7	0.5	0.0
8	1.0	0.6	slush

Table 8.9: Test #74 Fluid Thickness Data

Test 74, 2031, IP/ZR, Tunnel OAT -9.3ºC			
FLUID THICKNESS (mm)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	2.2	0.6	0.0
2	1.3	0.7	0.0
3	1.0	1	0.0
4	0.7	1.8	0.0
5	N/A	4.5	0.0
6	0.7	1.7	0.2
7	0.7	1.6	0.2
8	0.8	1.6	0.3

Table 8.10: Test #78 Fluid Thickness Data

Test 78, 2031, IP/SN-, Tunnel OAT -10.7ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.7	0.7	0.0
2	0.7	1.0	0.0
3	1.1	1.1	0.0
4	1.4	1.4	0.0
5	2.2	2.5	0.1
6	0.6	1.1	0.1
7	0.7	0.7	0.1
8	0.7	0.8	0.1

Table 8.11: Test #100 Fluid Thickness Data

Test 100, 2031, IP Mod, Tunnel OAT -11.2ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.6	0.4	0.0
2	1.0	1.2	0.0
3	1.0	1.2	0.0
4	1.1	1.2	0.1
5	1.5	1.2	0.1
6	0.7	N/A	0.2
7	0.8	N/A	0.2
8	0.8	0.7	0.2

Table 8.12: Test #101 Fluid Thickness Data

Test 101, 2031, IP-, Tunnel OAT -11.6ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.6	N/A	0.0
2	0.7	0.8	0.0
3	1.0	1	0.0
4	1.3	N/A	0.1
5	1.8	2.2	0.1
6	0.6	slush	0.3
7	0.7	slush	0.2
8	0.6	slush	0.1

8.2.2 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Section 2.14.3. Skin temperature measurements were recorded at the following intervals:

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

The wing temperatures measurements recorded during each test are shown in Table 8.13 to Table 8.29

Table 8.13: Test #14 Wing Skin Temperature Data

Test 14, 2031, IP/SN, Tunnel OAT -1.6ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-5.7	-6.7	-7.0	-4.8
T5	-5.1	-6.0	-5.8	-4.2
TU	-5.1	-6.5	-5.8	-5.0

Table 8.14: Test #16 Wing Skin Temperature Data

Test 16, 2031, IP/SN, Tunnel OAT -1.2ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-5.1	-7.6	-8.2	-4.9
T5	-4.9	-7.0	-6.7	-3.6
TU	-5.3	-7.2	-7.1	-4.4

Table 8.15: Test #26 Wing Skin Temperature Data

Test 26, 2031, IP/ZR, Tunnel OAT -5.3ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-2.2	-4.2	-3.0	-5.2
T5	-2.3	-3.8	-2.5	-4.7
TU	-3.4	-4.2	-3.8	-4.6

Table 8.16: Test #47 Wing Skin Temperature Data

Test 47, 2031, IP/SN, Tunnel OAT -17.0ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-14.4	-13.0	-14.6	-14.1
T5	-13.9	-12.6	-13.0	-13.4
TU	-15.5	-13.4	-14.8	-14.4

Table 8.17: Test #33 Wing Skin Temperature Data

Test 33, EG106, IP/ZR, Tunnel OAT -2.7ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-2.0	-3.9	-6.2	-3.9
T5	-3.0	-3.7	-4.6	-4.1
TU	-1.8	-3.5	-6.0	-4.9

Table 8.18: Test #43 Wing Skin Temperature Data

Test 43, EG106, IP/SN, Tunnel OAT -12.7ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-11.3	-10.1	-11.5	-12.8
T5	-11.0	-10.0	-10.6	-12.3
TU	-12.5	-11.0	-11.3	-13.8

Table 8.19: Test #45 Wing Skin Temperature Data

Test 45, ABC-S Plus, IP/SN, Tunnel OAT -15.9ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-13.3	-11.6	-13.0	-15.0
T5	-12.9	-11.3	-12.8	-14.6
TU	-13.9	-12.1	-13.5	-15.5

Table 8.20: Test #52 Wing Skin Temperature Data

Test 52, EG106, IP/SN, Tunnel OAT -5.6ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-4.0	-3.9	-9.2	-5.8
T5	-4.5	-4.0	-7.1	-5.9
TU	-5.0	-4.0	-9.5	-6.7

Table 8.21: Test #53 Wing Skin Temperature Data

Test 53, ABC-S Plus, IP/SN, Tunnel OAT -3.4ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-1.7	-4.1	-8.4	-4.7
T5	-2.2	-4.2	-6.7	-4.2
TU	-2.6	-3.9	-8.9	-5.5

Table 8.22: Test #59 Wing Skin Temperature Data

Test 59, Launch, IP/ZR, Tunnel OAT -10.3ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-7.3	-8.1	-8.0	-9.0
T5	-7.9	-7.6	-7.3	-8.0
TU	-8.9	-8.3	-8.5	-9.2

Table 8.23: Test #48 Wing Skin Temperature Data

Test 48, 2031, IP/SN, Tunnel OAT -13.5ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-14.1	-13.2	-14.2	-14.4
T5	-13.4	-12.0	-12.8	-13.9
TU	-14.4	-13.9	-13.6	-15.2

Table 8.24: Test #57 Wing Skin Temperature Data

Test 57, 2031, IP/SN, Tunnel OAT -7.6ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-4.6	-6.0	-8.0	-5.2
T5	-5.0	-5.7	-6.8	-6.5
TU	-3.8	-5.7	-7.8	-6.5

Table 8.25: Test #73 Wing Skin Temperature Data

Test 73, 2031, IP/ZR, Tunnel OAT -9.3ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	N/A	-7.0	-7.3	-7.9
T5	N/A	-6.6	-6.2	-7.2
TU	N/A	-7.1	-7.4	-8.2

Table 8.26: Test #74 Wing Skin Temperature Data

Test 74, 2031, IP/ZR, Tunnel OAT -9.3ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-7.9	-6.1	-7.2	-7.9
T5	-7.2	-7.0	-6.7	-7.6
TU	-8.2	-7.5	-7.4	-8.4

Table 8.27: Test #78 Wing Skin Temperature Data

Test 78, 2031, IP/SN-, Tunnel OAT -10.7ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-9.0	-8.1	-9.2	-9.6
T5	-8.5	-8.2	-9.0	-8.9
TU	-9.6	-8.2	-9.0	-10.2

Table 8.28: Test #100 Wing Skin Temperature Data

Test 100, 2031, IP Mod, Tunnel OAT -11.2ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-7.3	-7.1	-10.8	-7.3
T5	-6.5	-7.1	-8.5	-6.3
TU	-8.3	-7.4	-9.8	-8.4

Table 8.29: Test #101 Wing Skin Temperature Data

Test 101, 2031, IP-, Tunnel OAT -11.6ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-7.3	-7.0	N/A	-9.9
T5	-6.3	-7.0	-7.5	-9.9
TU	-8.4	-7.2	N/A	-10.3

8.2.3 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Section 2.14.4.

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

Table 8.30 to Table 8.40 show the fluid Brix measurements collected during the test.

Table 8.30: Test #14 Fluid Brix Data

Test 14, 2031, IP/SN, Tunnel OAT -1.6ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.50	28.50	36.00
8	36.50	27.25	31.00

Table 8.31: Test #16 Fluid Brix Data

Test 16, 2031, IP/SN, Tunnel OAT -1.2ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.25	19.25	28.75
8	36.50	14.00	27.00

Table 8.32: Test #26 Fluid Brix Data

Test 26, 2031, IP/ZR, Tunnel OAT -5.3ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.00	7.00	7.00
8	36.50	7.00	8.50

Table 8.33: Test #47 Fluid Brix Data

Test 47, 2031, IP/SN, Tunnel OAT -17.0ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.25	14.00	31.00
8	36.75	25.00	26.75

Table 8.34: Test #48 Fluid Brix Data

Test 48, 2031, IP/SN, Tunnel OAT -13.5ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.25	29.75	32.75
8	37.00	29.75	31.00

Table 8.35: Test #57 Fluid Brix Data

Test 57, 2031, IP/SN, Tunnel OAT -7.6ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.25	24.00	35.00
8	37.25	26.75	27.50

Table 8.36: Test #73 Fluid Brix Data

Test 73, 2031, IP/ZR, Tunnel OAT -9.3ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.50	19.00	36.00
8	36.75	15.00	23.00

Table 8.37: Test #74 Fluid Brix Data

Test 74, 2031, IP/ZR, Tunnel OAT -9.3ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.00	28.00	29.50
8	36.75	27.00	29.50

Table 8.38: Test #78 Fluid Brix Data

Test 78, 2031, IP/SN-, Tunnel OAT -10.7ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.50	29.50	34.00
8	36.75	29.50	27.50

Table 8.39: Test #100 Fluid Brix Data

Test 100, 2031, IP Mod, Tunnel OAT -11.2ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.00	37.00	34.00
8	37.00	36.50	27.50

Table 8.40: Test #101 Fluid Brix Data

Test 101, 2031, IP-, Tunnel OAT -11.6ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.50	32.75	31.50
8	36.50	31.00	27.00

8.3 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 test, a summary of the photos has been compiled comprising of four photos per camera angle:

- 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 4 degrees); and
- End of test.

Photo 8.1 to Photo 8.44 show the photo summaries of the tests conducted. A complete set of photos will be provided to TDC.

8.4 General Observations

The following sections describe the observations regarding the testing conducted to support the potential development of a Type III low speed allowance time table. The results have been separated according to the specific condition tested. Table 8.41 shows the tests conducted for each ice pellet condition as well as the Type IV high speed allowance time derived from the 2006-07 testing (included as a reference only).

8.4.1 Light Ice Pellets

8.4.1.1 OAT -5ºC and Above

Testing in this condition was not conducted in the wind tunnel. Allowance times were extrapolated from the "light ice pellets, OAT less than -5ºC to -10ºC" condition (see Section 7.4.1 for results). This approach was deemed appropriate and conservative because the "OAT -5ºC and above" condition is a less severe compared to the "OAT less than -5ºC to -10ºC".

8.4.1.2 OAT less than -5ºC to -10ºC

One test was conducted: Test #101. Test #101 conducted with a 10 minute exposure time demonstrated positive results for visual fluid elimination as well as good lift coefficient results. 10 minutes was deemed an appropriate allowance time for this condition.

8.4.1.3 OAT less than -10ºC

No testing was conducted in this condition.

Table 8.41: Tests Conducted Separated According to Condition Tested

	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 *Test # 101*	30 minutes
Moderate Ice Pellets	25 minutes	10 minutes *Test # 100*	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 *Test # 26, 73*	10 minutes *Test # 74*	
Light Ice Pellets Mixed with Light Rain	25 minutes		
Light Ice Pellets Mixed with Moderate Snow	25 minutes *Test # 14, 16, 57*	Allowance Time N/A *Test # 47, 48*	
Light Ice Pellets Mixed with Light Snow	25 minutes	Allowance Time N/A *Test # 78*	

8.4.2 Moderate Ice Pellets

8.4.2.1 OAT -5°C and Above

Testing in this condition was not conducted in the wind tunnel. Allowance times were extrapolated from the "moderate ice pellets, OAT less than -5°C to -10°C" condition (see Section 7.4.2 for results). This approach was deemed appropriate and conservative because the "OAT -5°C and above" condition is a less severe compared to the "OAT less than -5°C to -10°C".

8.4.2.2 OAT less than -5°C to -10°C

One test was conducted: Test #100. Test #100 conducted with a 5 minute exposure time demonstrated positive results for visual fluid elimination as well as good lift coefficient results. 5 minutes was deemed an appropriate allowance time for this condition.

8.4.2.3 OAT less than -10°C

No testing was conducted in this condition.

8.4.3 Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle

Testing in this condition was not conducted in the wind tunnel. Allowance times will be extrapolated from the "light ice pellets mixed with light freezing rain" condition (see Section 7.4.4 for results). This approach was deemed appropriate and conservative because light ice pellets mixed with light or moderate freezing drizzle is a less severe condition compared to light ice pellets mixed with light freezing rain.

8.4.4 Light Ice Pellets Mixed with Light Freezing Rain

8.4.4.1 OAT -5°C and Above

Two tests were conducted: Test #26 and Test #73. Test #26 was conducted with an exposure time of 25 minutes which was well beyond the point of failure (the primary purpose of this test was to investigate the effects of adhered contamination and not allowance time development). Test #73 was conducted with a more appropriate 10 minute exposure time, however the results were marginal. Additional flat plate testing was conducted at the NRC climatic engineering facility, and the results indicated that 7 minutes would be more appropriate and offer an acceptable safety buffer to the presence of adherence. Based on these results, 7 minutes was deemed an appropriate allowance time for this condition.

8.4.4.2 OAT less than -5°C to -10°C

One test was conducted: Test #74. Test #74 conducted with a 5 minute exposure time demonstrated positive results for visual fluid elimination as well as good lift coefficient results. In addition, flat plate testing conducted at the NRC confirmed the results obtained in the wind tunnel. 5 minutes was deemed an appropriate allowance time for this condition

8.4.5 Light Ice Pellets Mixed with Light Rain

8.4.5.1 OAT -5°C and Above

Testing in this condition was not conducted in the wind tunnel. Allowance times will be extrapolated from the "light ice pellets mixed with light freezing rain" condition (see Section 7.4.4 for results). This approach was deemed appropriate and conservative because light ice pellets mixed with light rain is a less severe condition compared to light ice pellets mixed with light freezing rain.

8.4.6 Light Ice Pellets Mixed with Moderate Snow

8.4.6.1 OAT -5°C and Above

Three tests were conducted: Test #14, Test #16, and Test #57. Test #14 and #16 were conducted at warmer temperatures with exposure times of 10 minutes and 15 minutes, respectively. Test #14 (10 minute exposure time) demonstrated positive visual fluid elimination as well as good lift coefficient results, whereas Test #16 (15 minute exposure time) demonstrated an unacceptable amount of contamination present on the wing prior to the start of the test. Test #57 was a repeat of Test #14 at a colder temperature. The results again demonstrated positive visual fluid elimination as well as good lift coefficient results. Based on these results, 10 minutes was deemed an appropriate allowance time for this condition.

8.4.6.2 OAT -5ºC to -10ºC

Two tests were conducted: Test #47, and Test #48. Test #47 conducted with a 10 minute exposure time demonstrated poor visual fluid flow-off and marginal lift coefficient data. The test was repeated as Test #48 with half the exposure time (5 minute exposure time). The results from Test #48 demonstrated positive visual fluid elimination and lift coefficient results. Based on these results, 5 minutes was deemed an appropriate allowance time for this condition.

8.4.7 Light Ice Pellets Mixed with Light Snow

8.4.7.1 OAT -5ºC and Above

Testing in this condition was not conducted in the wind tunnel. Allowance times will be extrapolated from both the "light ice pellets mixed with moderate snow, OAT less than -5ºC to -10ºC" and the "light ice pellets mixed with light snow, OAT less than -5ºC to -10ºC" condition (see Sections 7.4.6 and 7.4.7 for results). This approach was deemed appropriate and conservative because "light ice pellets mixed with light snow, OAT -5ºC and above" is a less severe condition compared to the two above mentioned conditions.

8.4.7.2 OAT -5ºC to -10ºC

One test was conducted: Test #78. Test #78 conducted with a 10 minute exposure time demonstrated positive results for visual fluid elimination as well as good lift coefficient results. Based on these results, a 10 minute allowance time was deemed appropriate for this condition.

8.5 Summary of Results

8.5.1 Allowance Time Table Development

Based on the testing conducted during the winter of 2008-09, the following Type III allowance times were developed to allow greater flexibility to Type III fluid operators. The following is a list of the proposed allowance times for the preliminary development of the low speed Type III fluid allowance time table:

- 10 minute allowance time for "light ice pellets" for above -10ºC conditions;

- 5 minute allowance time for "moderate ice pellets" for above -10ºC conditions;
- 5 minute and 7 minute allowance time for "light ice pellets mixed with light freezing rain" for above -5ºC conditions, and -5 to -10ºC conditions;
  - These allowance times can also be applied to light ice pellets mixed with light or moderate freezing drizzle", and "light ice pellets mixed with light rain";
- 10 minute and 5 minute allowance time for "light ice pellets mixed with moderate snow" for above -5ºC conditions, and -5 to -10ºC conditions; and
- 10 minute allowance time for "light ice pellets mixed with moderate snow" for above -10ºC conditions.

Low speed allowance time testing with Type III fluid was conducted as a secondary objective during the winter of 2008-09, and as a result, only a limited amount of data were collected. The preliminary results indicated a good potential for the use of Type III fluid during ice pellet conditions.

The limitations of the current data collected include the following:

- Type III "heated" fluid applications were not tested. As this is understood to be a common practice with Type III fluid, this needs to be further investigated to determine any potential risk of adherence with the presence of ice pellets;
- Preliminary allowance times with fluid applied at ambient were developed based on a limited number of tests and would need to be further substantiated with additional testing; and
- Only low speed (80 knots rotation) data were collected, therefore the results would be applicable for high speed (100 knots) operations; this would be a conservative approach. High speed testing would be necessary to potentially get higher allowance times.

For these reasons, it was recommended that the preliminary Type III allowance time table not be published in the HOT Guidelines for the winter of 2009-10. Further testing should be conducted during the winter of 2009-10.

A summary of the preliminary allowance times is shown in Table 8.42. The respective tests used to validate or develop the respective cells have also been indicated.

Table 8.42: TYPE III (Applied At Ambient) Low Speed Preliminary Development of Ice Pellet Allowance Times for Winter 2009-10

	OAT -5°C and above	OAT less than -5°C to -10°C	OAT less than -10°C
Light Ice Pellets	10 minutes	10 minutes *Test # 101*	No Tests Conducted
Moderate Ice Pellets	5 minutes	5 minutes *Test # 100*	No Tests Conducted
Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle	7 minutes	5 minutes	**Caution: No allowance times currently exist**
Light Ice Pellets Mixed with Light Freezing Rain	7 minutes *Test # 26, 73*	5 minutes *Test # 74*	
Light Ice Pellets Mixed with Light Rain	7 minutes		
Light Ice Pellets Mixed with Moderate Snow	10 minutes *Test # 14, 16, 57*	5 minutes *Test # 47, 48*	
Light Ice Pellets Mixed with Light Snow	10 minutes	10 minutes *Test # 78*	

⟶ Extrapolated Allowance Times

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Photo 8.1: Test #14 – Start of Test

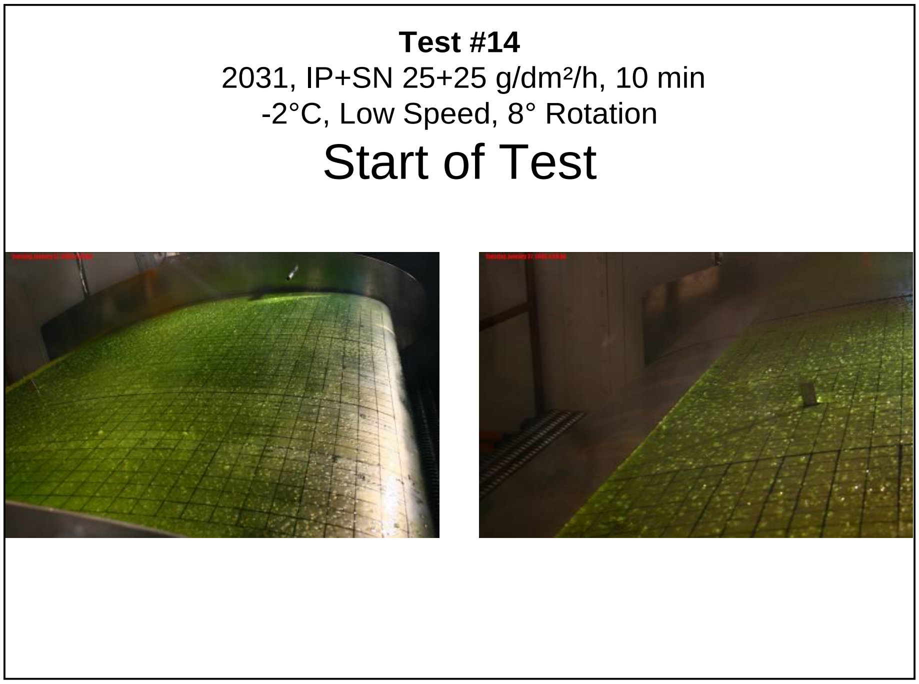


Photo 8.2: Test #14 – Before Rotation

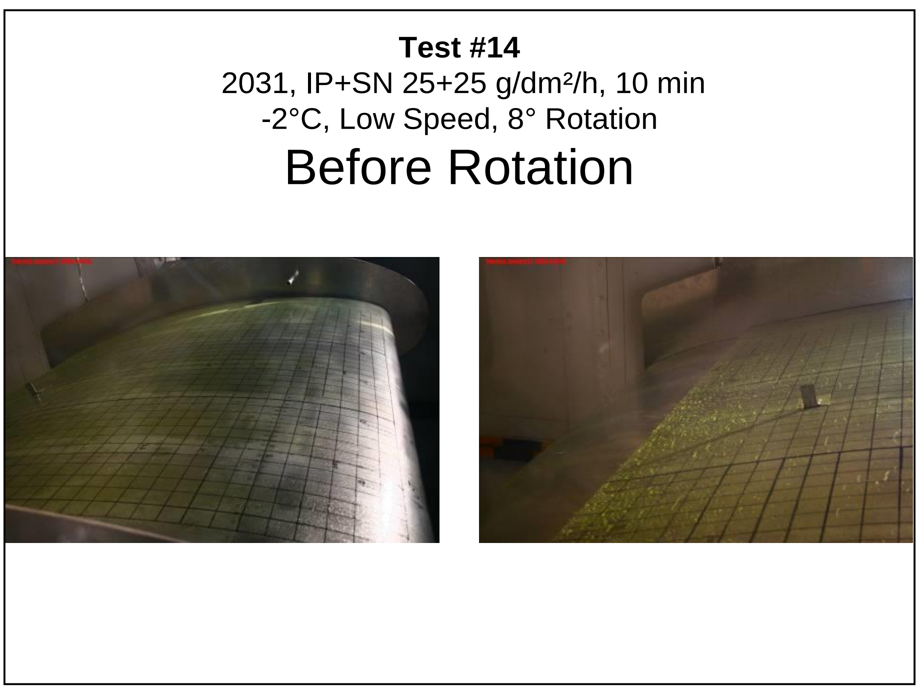


Photo 8.3: Test #14 – End of Rotation

Test #14
2031, IP+SN 25+25 g/dm²/h, 10 min
-2°C, Low Speed, 8° Rotation
End of Rotation

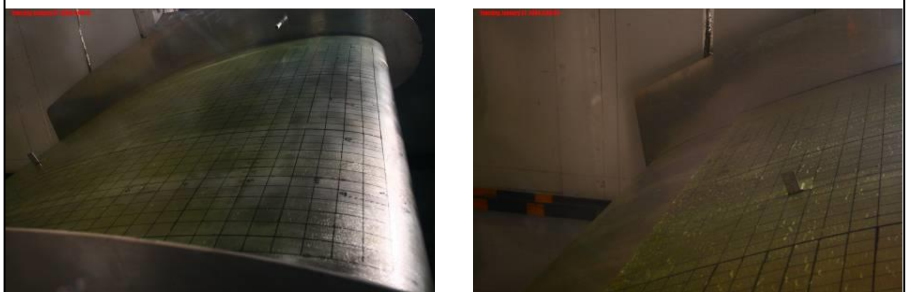


Photo 8.4: Test #14 – End of Test

Test #14
2031, IP+SN 25+25 g/dm²/h, 10 min
-2°C, Low Speed, 8° Rotation
End of Test

Photo 8.5: Test #16 – Start of Test

Test #16
2031, IP+SN 25+25 g/dm²/h, 15 min
-1°C, Low Speed, 8° Rotation
Start of Test

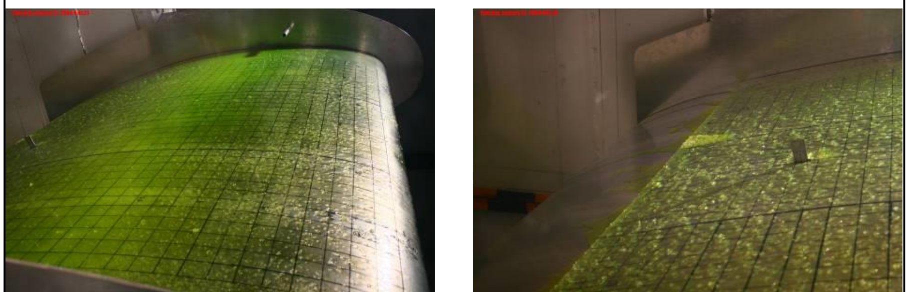


Photo 8.6: Test #16 – Before Rotation

Test #16
2031, IP+SN 25+25 g/dm²/h, 15 min
-1°C, Low Speed, 8° Rotation
Before Rotation

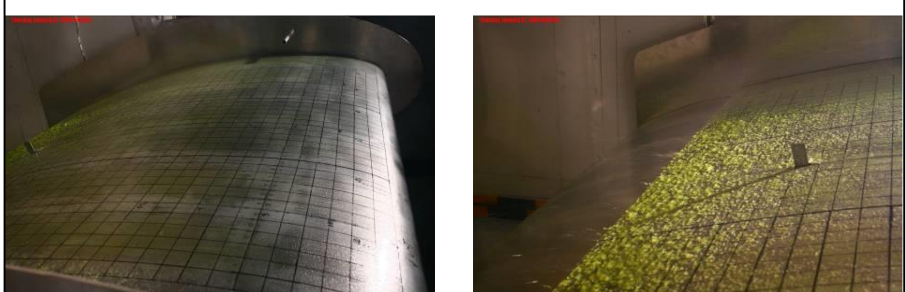


Photo 8.7: Test #16 – End of Rotation

Test #16
2031, IP+SN 25+25 g/dm²/h, 15 min
-1°C, Low Speed, 8° Rotation
End of Rotation

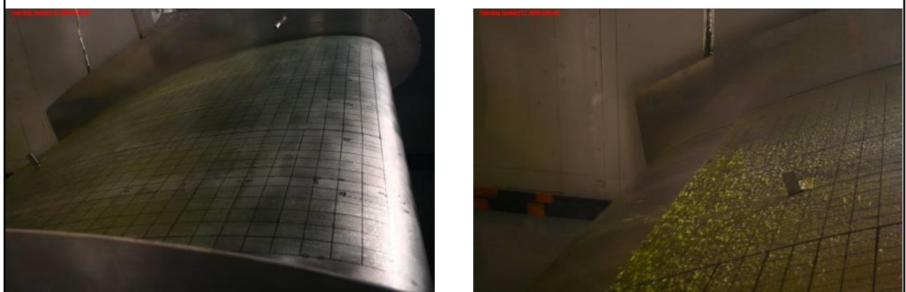


Photo 8.8: Test #16 – End of Test

Test #16
2031, IP+SN 25+25 g/dm²/h, 15 min
-1°C, Low Speed, 8° Rotation
End of Test

Photo 8.9: Test #26 – Start of Test

Test #26
2031, IP+ZR, 25+25 g/dm²/h, 25 min
-5°C, Low Speed, 8° Rotation
Start of Test

Photo 8.10: Test #26 – Before Rotation

Test #26
2031, IP+ZR, 25+25 g/dm²/h, 25 min
-5°C, Low Speed, 8° Rotation
Before Rotation

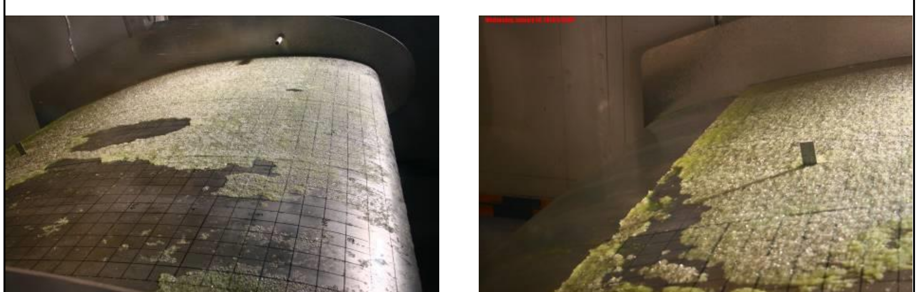


Photo 8.11: Test #26 – End of Rotation

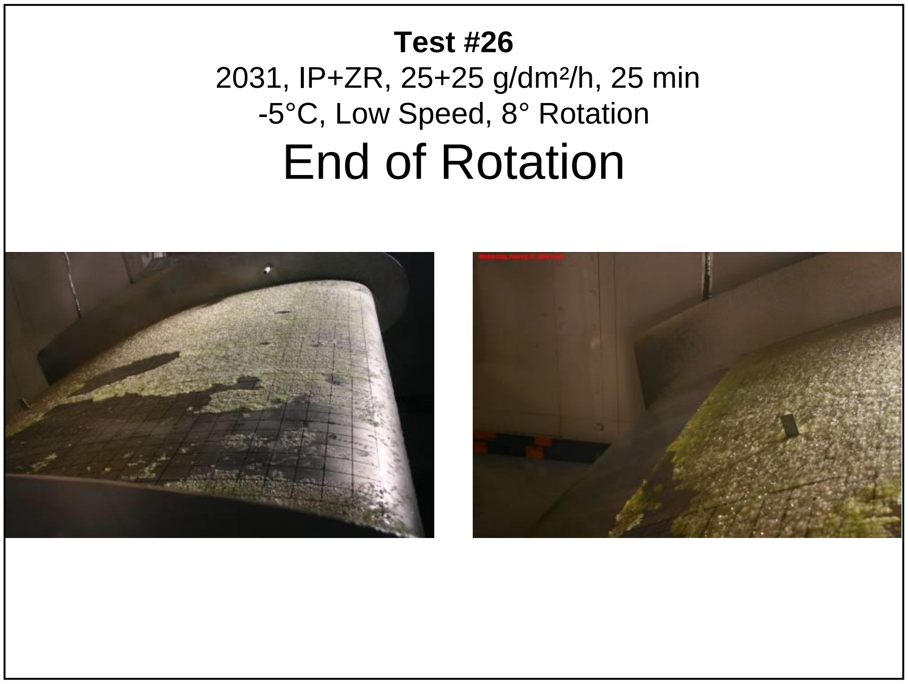


Photo 8.12: Test #26 – End of Test

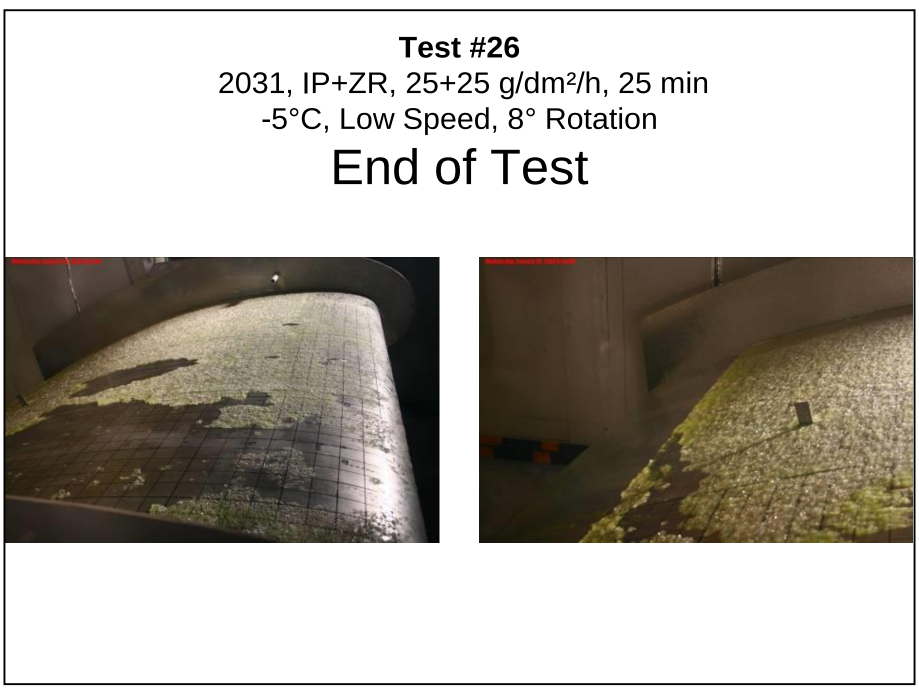


Photo 8.13: Test #47 – Start of Test

Test #47
2031, IP+SN 25+25 g/dm²/h, 10 min
-17°C, Low Speed, 16° Rotation
Start of Test

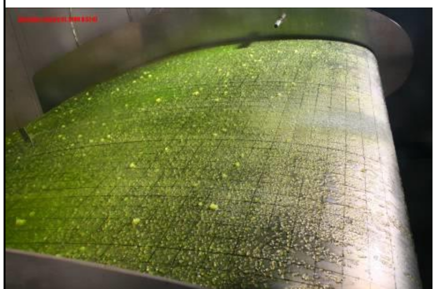


Photo 8.14: Test #47 – Before Rotation

Test #47
2031, IP+SN 25+25 g/dm²/h, 10 min
-17°C, Low Speed, 16° Rotation
Before Rotation

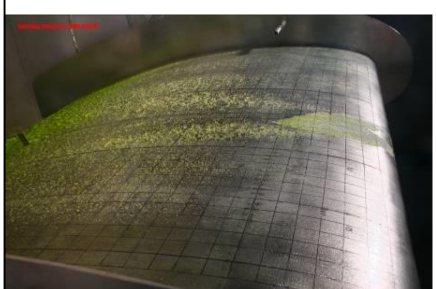


Photo 8.15: Test #47 – End of Rotation

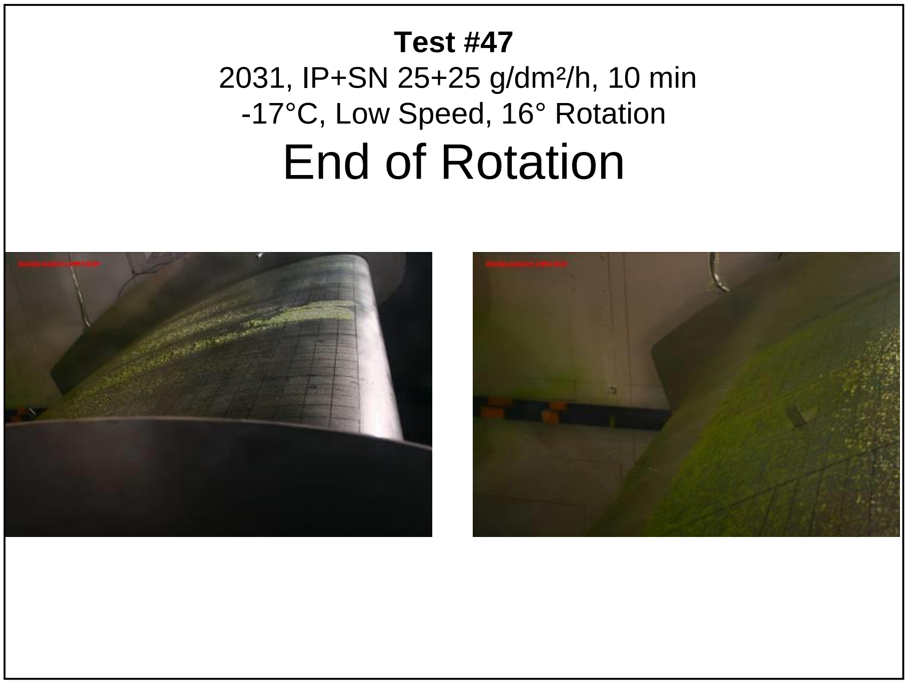


Photo 8.16: Test #47 – End of Test

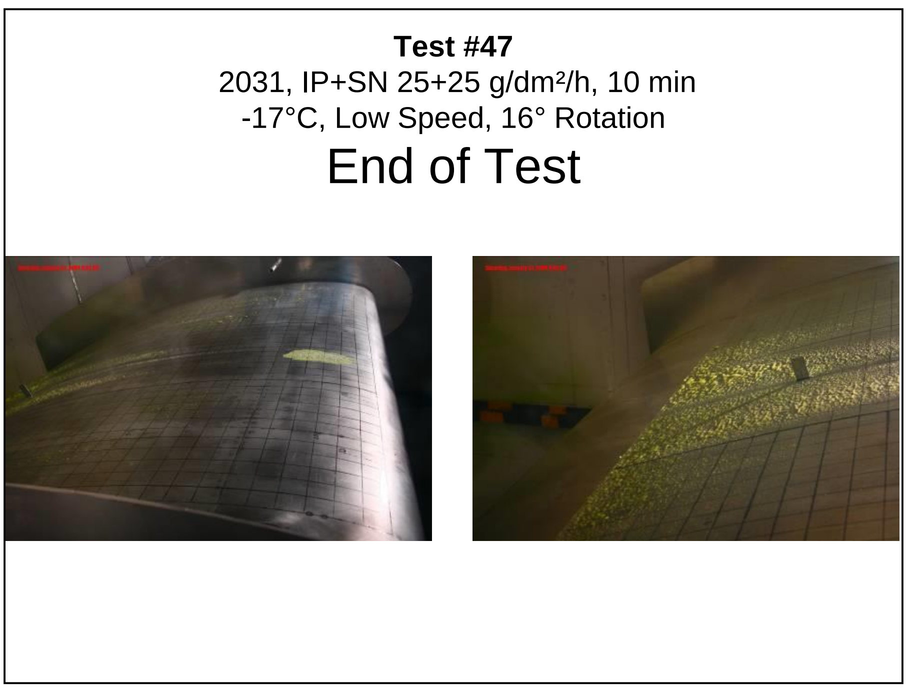
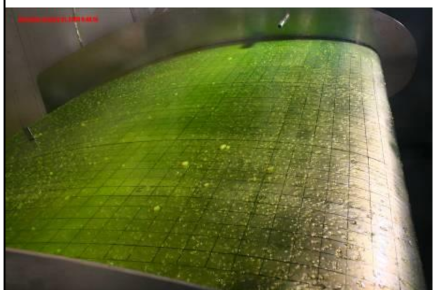


Photo 8.17: Test #48 – Start of Test

Test #48
2031, IP+SN 25+25 g/dm²/h, 5 min
-14°C, Low Speed, 16° Rotation
Start of Test



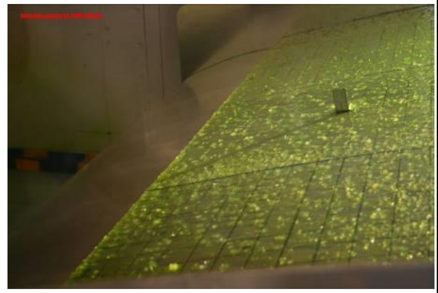
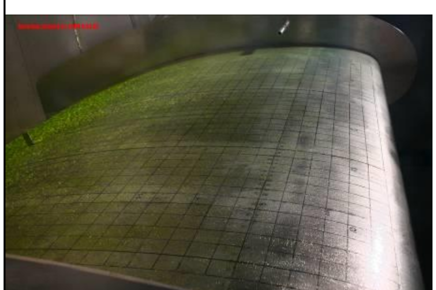


Photo 8.18: Test #48 – Before Rotation

Test #48
2031, IP+SN 25+25 g/dm²/h, 5 min
-14°C, Low Speed, 16° Rotation
Before Rotation



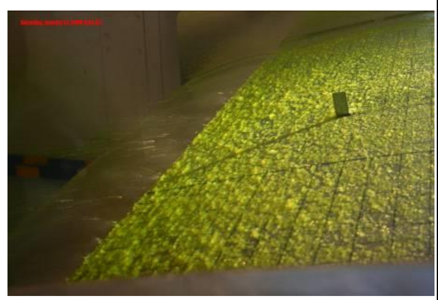


Photo 8.19: Test #48 – End of Rotation

Test #48
2031, IP+SN 25+25 g/dm²/h, 5 min
-14°C, Low Speed, 16° Rotation
End of Rotation

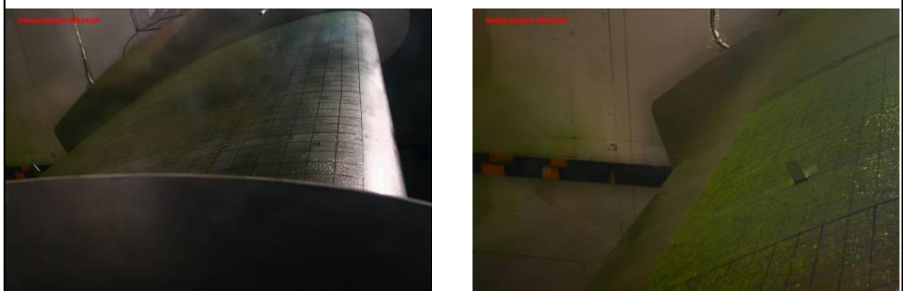


Photo 8.20: Test #48 – End of Test

Test #48
2031, IP+SN 25+25 g/dm²/h, 5 min
-14°C, Low Speed, 16° Rotation
End of Test

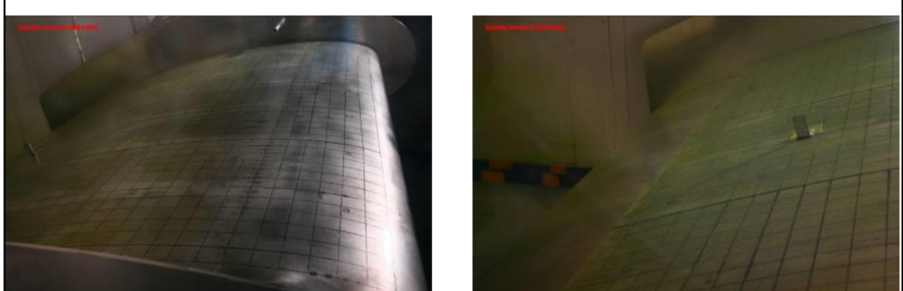


Photo 8.21: Test #57 – Start of Test

Test #57
2031, IP+SN 25+25 g/dm²/h, 10 min
-8°C, Low Speed, 16° Rotation
Start of Test

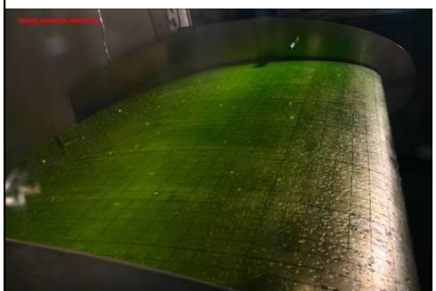
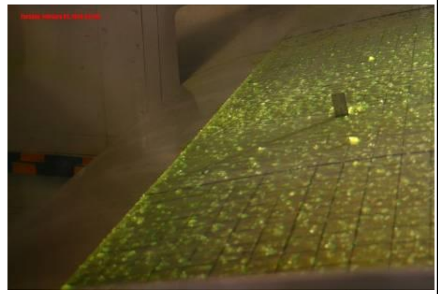



Photo 8.22: Test #57 – Before Rotation

Test #57
2031, IP+SN 25+25 g/dm²/h, 10 min
-8°C, Low Speed, 16° Rotation
Before Rotation

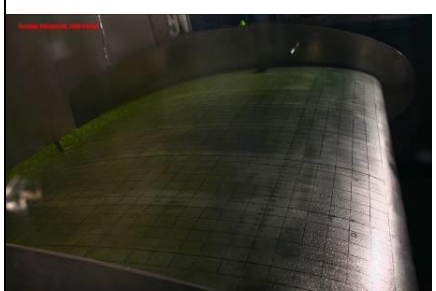
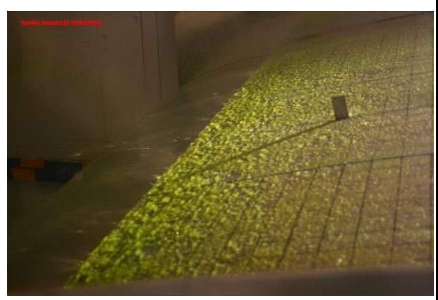



Photo 8.23: Test #57 – End of Rotation

Test #57
2031, IP+SN 25+25 g/dm²/h, 10 min
-8°C, Low Speed, 16° Rotation
End of Rotation

Photo 8.24: Test #57 – End of Test

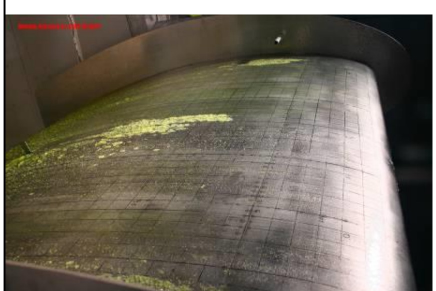
Test #57
2031, IP+SN 25+25 g/dm²/h, 10 min
-8°C, Low Speed, 16° Rotation
End of Test

Photo 8.25: Test #73 – Start of Test

Test #73
2031, IP+ZR 25+25 g/dm²/h, 10 min
-9°C, Low Speed, 20° Rotation
Start of Test

Photo 8.26: Test #73 – Before Rotation

Test #73
2031, IP+ZR 25+25 g/dm²/h, 10 min
-9°C, Low Speed, 20° Rotation
Before Rotation



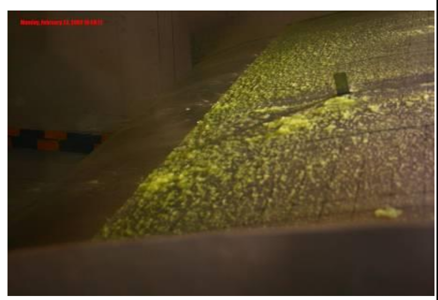


Photo 8.27: Test #73 – End of Rotation

Test #73
2031, IP+ZR 25+25 g/dm²/h, 10 min
-9°C, Low Speed, 20° Rotation
End of Rotation

Photo 8.28: Test #73 – End of Test

Test #73
2031, IP+ZR 25+25 g/dm²/h, 10 min
-9°C, Low Speed, 20° Rotation
End of Test

Photo 8.29: Test #74 – Start of Test

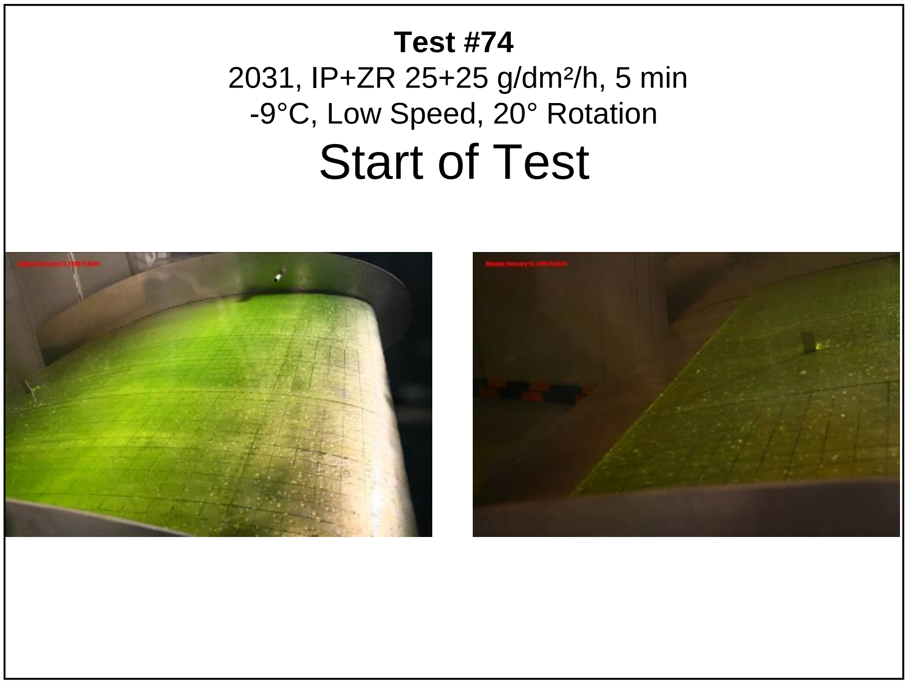


Photo 8.30: Test #74 – Before Rotation

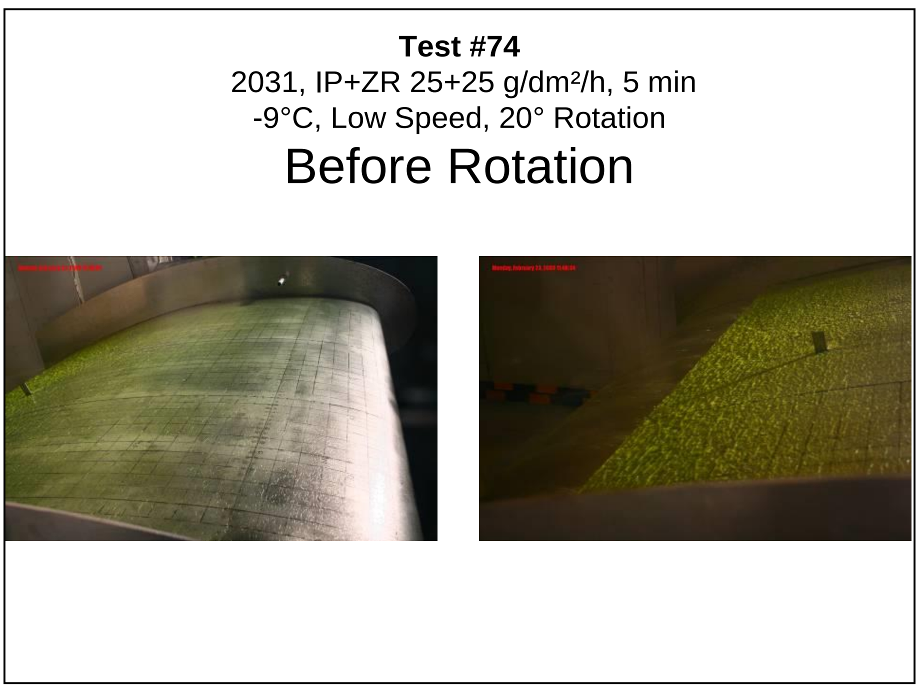


Photo 8.31: Test #74 – End of Rotation

Test #74
2031, IP+ZR 25+25 g/dm²/h, 5 min
-9°C, Low Speed, 20° Rotation
End of Rotation

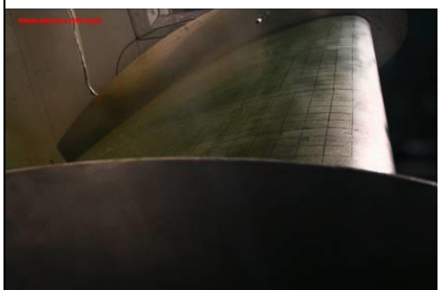
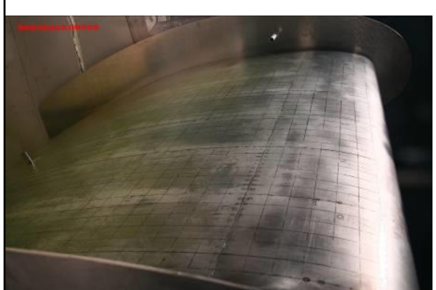


Photo 8.32: Test #74 – End of Test

Test #74
2031, IP+ZR 25+25 g/dm²/h, 5 min
-9°C, Low Speed, 20° Rotation
End of Test



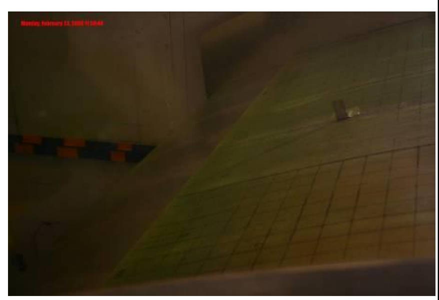


Photo 8.33: Test #78 – Start of Test

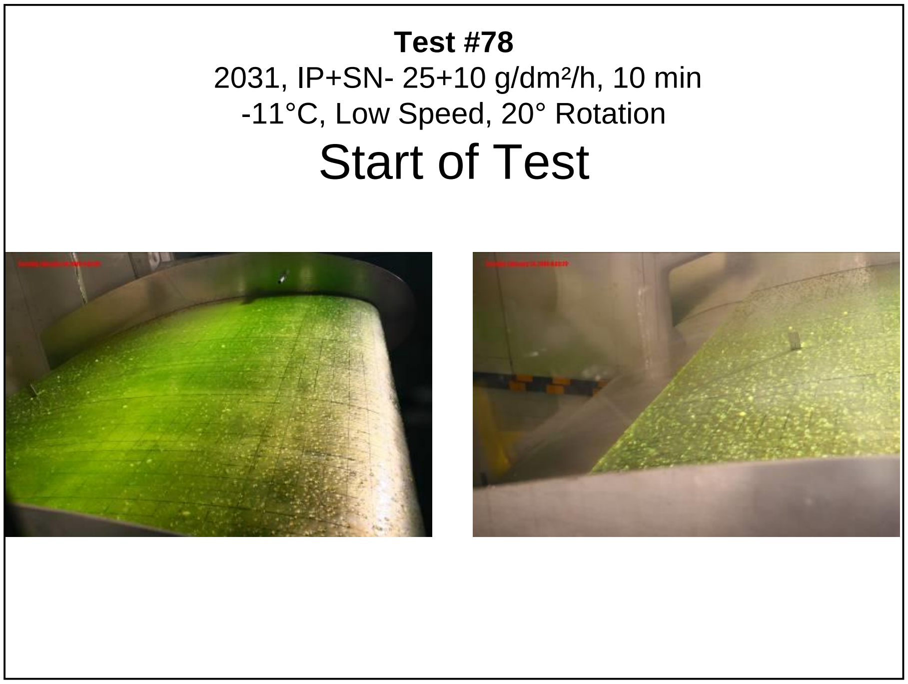


Photo 8.34: Test #78 – Before Rotation

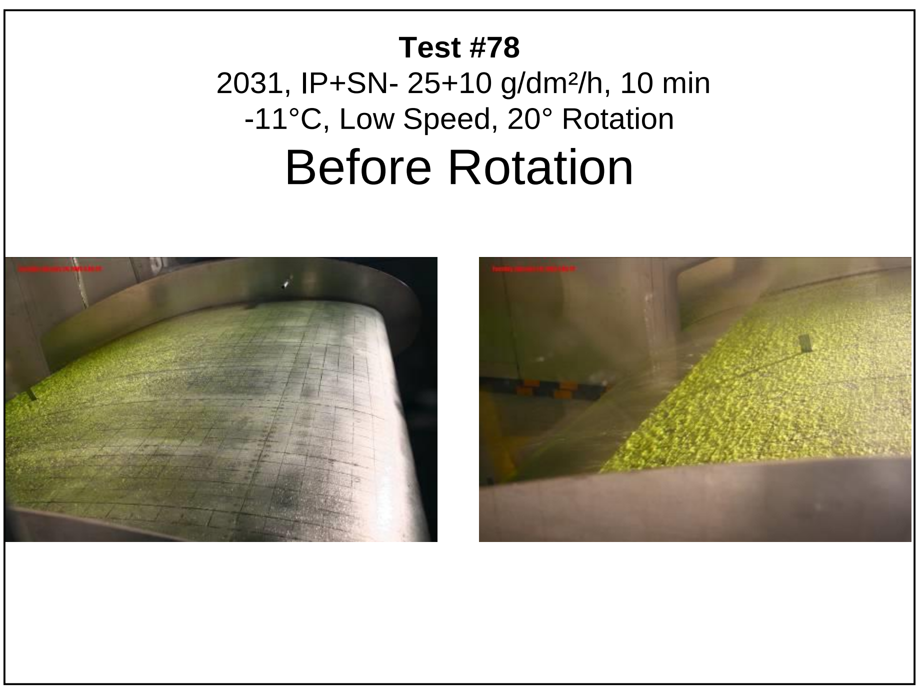


Photo 8.35: Test #78 – End of Rotation

Test #78
2031, IP+SN- 25+10 g/dm²/h, 10 min
-11°C, Low Speed, 20° Rotation
End of Rotation

Photo 8.36: Test #78 – End of Test

Test #78
2031, IP+SN- 25+10 g/dm²/h, 10 min
-11°C, Low Speed, 20° Rotation
End of Test

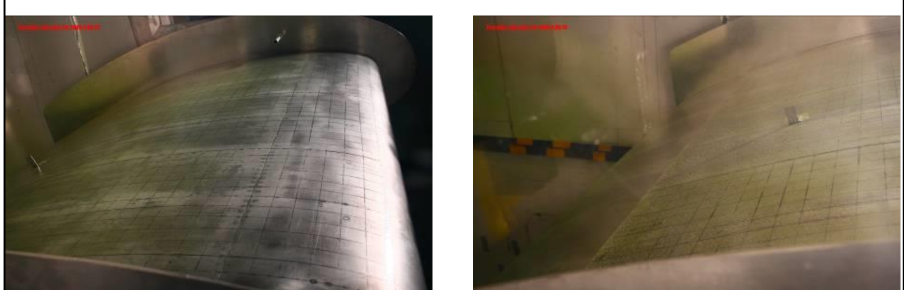


Photo 8.37: Test #100 – Start of Test

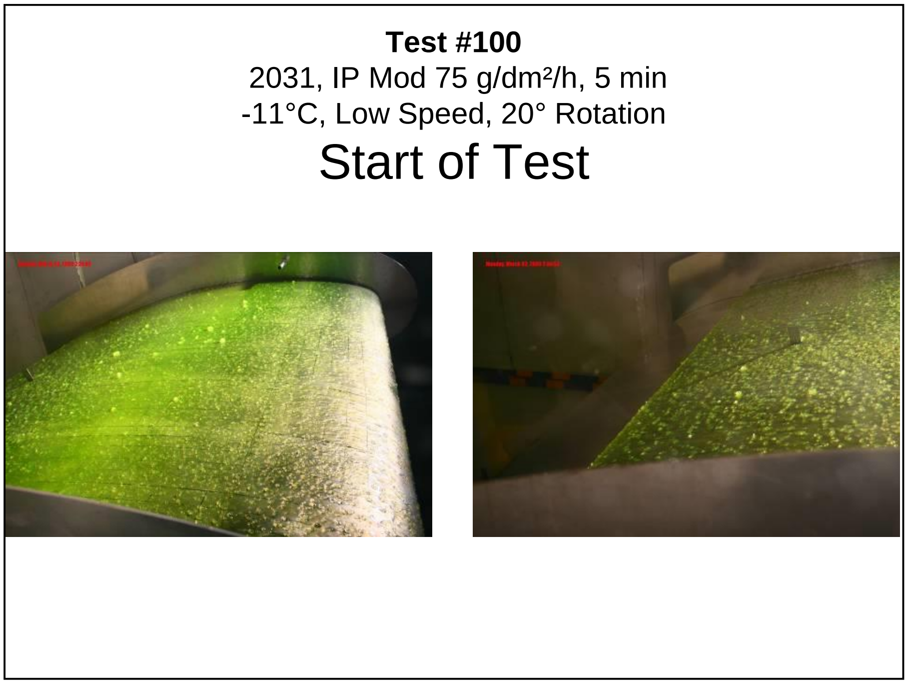


Photo 8.38: Test #100 – Before Rotation

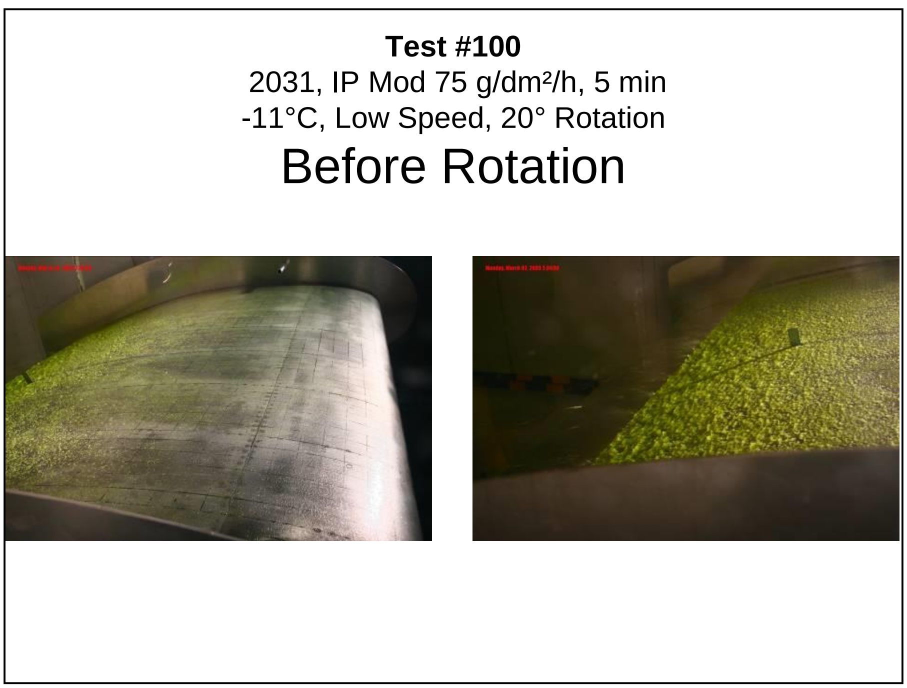


Photo 8.39: Test #100 – End of Rotation

Test #100
2031, IP Mod 75 g/dm²/h, 5 min
-11°C, Low Speed, 20° Rotation
End of Rotation

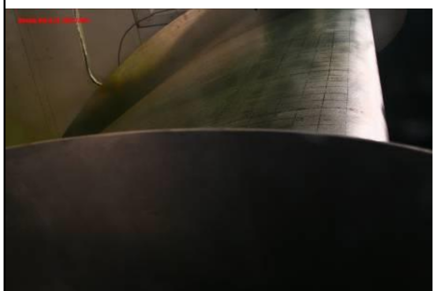
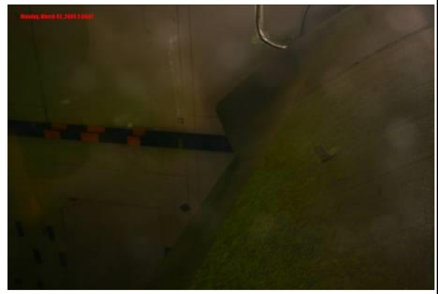



Photo 8.40: Test #100 – End of Test

Test #100
2031, IP Mod 75 g/dm²/h, 5 min
-11°C, Low Speed, 20° Rotation
End of Test

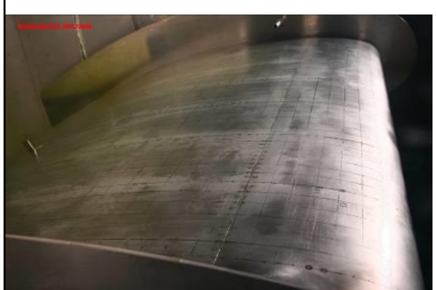



Photo 8.41: Test #101 – Start of Test

Test #101
2031, IP- 25 g/dm²/h, 10 min
-12°C, Low Speed, 20° Rotation
Start of Test

Photo 8.42: Test #101 – Before Rotation

Test #101
2031, IP- 25 g/dm²/h, 10 min
-12°C, Low Speed, 20° Rotation
Before Rotation

Photo 8.43: Test #101 – End of Rotation

Test #101
2031, IP- 25 g/dm²/h, 10 min
-12°C, Low Speed, 20° Rotation
End of Rotation

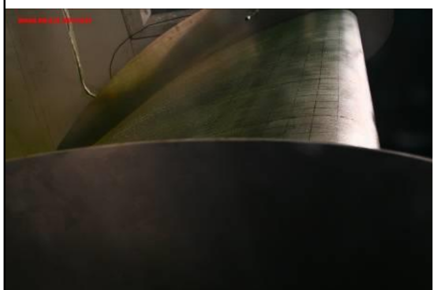
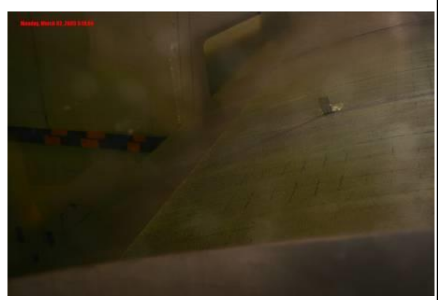



Photo 8.44: Test #101 – End of Test

Test #101
2031, IP- 25 g/dm²/h, 10 min
-12°C, Low Speed, 20° Rotation
End of Test

9. TYPE II FLUID

Previous ice pellet aerodynamic research conducted using the NRC wind tunnel and Falcon 20 aircraft focused on the development of ice pellet allowance times for use with undiluted Type IV fluid. As European operators primarily use Type II fluid for de/anti-icing operations, preliminary testing was conducted to investigate the potential development of ice pellet allowance times for use with Type II fluids. The current need for such guidance material has not been followed by strong industry pressure, therefore, the testing conducted during the winter of 2008-09 was limited and of lower priority.

This section provides an overview of each test conducted to investigate the potential development of allowance times for Type II fluid during operations in conditions mixed with ice pellets. Testing was conducted in simulated precipitation conditions. The parameters for each test are detailed and a description of the data collected during each test is provided.

9.1 Overview of Tests

A summary of the Type II tests conducted in the wind tunnel is shown in Table 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 Section 4.1. 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 test, measured in degrees Celsius.

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

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

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

Visual Contamination Rating at Rotation (LE, TE): Visual contamination rating determined at the time of rotation:

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

Table 9.1: Summary of 2008-09 Type II Low Speed Testing

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
23	28-Jan-09	Flight	IP/ZR	25/25	25	-4	-5.1	3, 3	1, 2	N/A
60	3-Feb-09	Flight	IP/ZR	25/25	10	-11	-8.1	3, 3	1, 2	1.707

9.2 Data Collected

9.2.1 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Section 2.14.2. Fluid thickness measurements were recorded at the following intervals:

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

Table 9.2 and Table 9.3 show the fluid thickness measurements collected during the tests.

Table 9.2: Test #23 Fluid Thickness Data

Test 23, Flight, IP/ZR, Tunnel OAT -4.1ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	1.0	1.3 (slush)	0.0
2	1.1	2.7 (slush)	0.0
3	1.8	3.1 (slush)	0.0
4	1.8	2.9 (slush)	0.0
5	3.3	4.5 (slush)	0.0
6	1.5	2.5 (slush)	0.3
7	1.3	2.9 (slush)	0.3
8	1.7	3.5 (slush)	0.6

Table 9.3: Test #60 Fluid Thickness Data

Test 60, Flight, IP/ZR, Tunnel OAT -11.3ºC			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
1	0.8	1.0	0.0
2	1.0	1.4	0.2
3	1.6	1.8	0.2
4	2.2	2.5	0.2
5	3.1	2.9	0.2
6	1.3	1.5	0.2
7	1.2	1.6	0.3
8	1.5	1.7	0.3

9.2.2 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Section 2.14.3. Skin temperature measurements were recorded at the following intervals:

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

The wing temperatures measurements recorded during each test are shown in Table 9.4 and Table 9.5.

Table 9.4: Test #23 Wing Skin Temperature Data

Test 23, 2031, IP/ZR, Tunnel OAT -4.1ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-7.3	-7.0	N/A	-9.9
T5	-6.3	-7.0	-7.5	-9.9
TU	-8.4	-7.2	N/A	-10.3

Table 9.5: Test #60 Wing Skin Temperature Data

Test 60, Flight, IP/ZR, Tunnel OAT -11.3ºC				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Run
T2	-7.6	-8.0	-8.1	-8.8
T5	-8.9	-8.0	-7.4	-8.4
TU	-9.0	-8.3	-8.9	-9.6

9.2.3 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the wind tunnel tests and Falcon 20 and T-33 tests are described in Section 2.14.4.

- Falcon 20 and T-33 Tests:
  - After fluid application;

- o After the application of contamination (on the test wing, not the fluid only wing);
- o Before the takeoff test; and
- o After the takeoff test (end of test).

Table 9.6 to Table 9.7 show the fluid Brix measurements collected during the test.

Table 9.6: Test #23 Fluid Brix Data

Test 23, Flight, IP/ZR, Tunnel OAT -4.1°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.75	20.50	21.00
8	36.00	16.25	21.25

Table 9.7: Test #60 Fluid Brix Data

Test 60, Flight, IP/ZR, Tunnel OAT -11.3ºC			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.00	31.00	29.25
8	37.50	30.00	25.00

9.3 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 test, a summary of the photos has been compiled comprising of four photos per camera angle:

- 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 4 degrees); and
- End of test.

Photo 9.1 to Photo 9.8 show the photo summaries of the tests conducted. A complete set of photos will be provided to TDC.

9.4 General Observations

The following sections describe the observations regarding the testing conducted to support the potential development of a Type II allowance time table. The results have been separated according to the specific condition tested. Table 9.8 shows the tests conducted for each ice pellet condition as well as the Type IV high speed allowance time derived from the 2006-07 testing (included as a reference only).

9.4.1 Light Ice Pellets

No testing was conducted in this condition.

9.4.2 Moderate Ice Pellets

No testing was conducted in this condition.

9.4.3 Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle

Testing in this condition was not conducted in the wind tunnel. Allowance times should be extrapolated from the "light ice pellets mixed with light freezing rain" condition (see Section 9.4.4 for results). This approach was deemed appropriate and conservative because light ice pellets mixed with light or moderate freezing drizzle is a less severe condition compared to light ice pellets mixed with light freezing rain.

9.4.4 Light Ice Pellets Mixed with Light Freezing Rain

9.4.4.1 OAT -5°C and Above

One test was conducted in this condition: Test #23. The 25 minute exposure time test demonstrated positive visual fluid elimination and lift coefficient results. Additional flat plate testing was conducted at the NRC climatic engineering facility indicated that a 25 minute allowance time for Type II fluids in this condition was marginal (due to the level of adherence observed). Based on the flat plate tests, a 20 minute allowance time was deemed more appropriate for this condition.

9.4.4.2 OAT less than -5°C to -10°C

One test was conducted in this condition: Test #60. The 10 minute exposure time test demonstrated positive visual fluid elimination and lift coefficient results. Additional flat plate testing was conducted at the NRC climatic engineering facility indicated that a 10 minute allowance time for Type II fluids in this condition was appropriate and provided a sufficient safety buffer. Based on these results, a 10 minute allowance time was deemed more appropriate for this condition.

Table 9.8: Tests Conducted Separated According to Condition Tested

	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 Test # 23	10 minutes Test # 60	
Light Ice Pellets Mixed with Light Rain	25 minutes		
Light Ice Pellets Mixed with Light or Moderate Snow	25 minutes		

9.4.5 Light Ice Pellets Mixed with Light Rain

9.4.5.1 OAT -5°C and Above

Testing in this condition was not conducted in the wind tunnel. Allowance times should be extrapolated from the "light ice pellets mixed with light freezing rain" condition (see Section 8.4.4 for results). This approach was deemed appropriate and conservative because light ice pellets mixed with light rain is a less severe condition compared to light ice pellets mixed with light freezing rain.

9.4.6 Light Ice Pellets Mixed with Moderate Snow

No testing was conducted in this condition.

9.4.7 Light Ice Pellets Mixed with Light Snow

No testing was conducted in this condition.

9.5 Summary of Results

9.5.1 Allowance Time Table Development

Based on the limited testing conducted during the winter of 2008-09, the following were proposed as preliminary allowance times for Type II fluids:

- 20 minute allowance time for "light ice pellets mixed with light freezing rain" for above -5°C conditions. This allowance time is also applicable to:
    - "light ice pellets mixed with light or moderate freezing drizzle;" and
    - "light ice pellets mixed with light rain."
- 10 minute allowance time for "light ice pellets mixed with light freezing rain" for below -5°C to -10°C conditions. This allowance time is also applicable to:
    - "light ice pellets mixed with light or moderate freezing drizzle."

Due to the limited data collected, it is recommended that further testing be conducted before a separate allowance time table is published in the HOT Guidelines.

In addition, there has not been a strong industry request to have allowance times developed for use with Type II fluids. Future work with Type II fluids should remain a lower priority in comparison to the Type III and Type IV high speed and low speed aerodynamic research.

A summary of the preliminary allowance times is shown in Table 9.9. The respective tests used to validate or develop the respective cells have also been indicated.

Table 9.9: Type II Preliminary Development of Ice Pellet Allowance Times For Winter 2009-10

	OAT -5°C and above	OAT less than -5°C to -10°C	OAT less than -10°C
Light Ice Pellets	No Tests Conducted	No Tests Conducted	No Tests Conducted
Moderate Ice Pellets	No Tests Conducted	No Tests Conducted	No Tests Conducted
Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle	↑ 20 minutes	↑ 10 minutes	**Caution: No allowance times currently exist**
Light Ice Pellets Mixed with Light Freezing Rain	20 minutes Test # 23	10 minutes Test # 60	
Light Ice Pellets Mixed with Light Rain	↓ 20 minutes		
Light Ice Pellets Mixed with Light or Moderate Snow	No Tests Conducted		

⟶ Extrapolated Allowance Times

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Photo 9.1: Test #23 – Start of Test

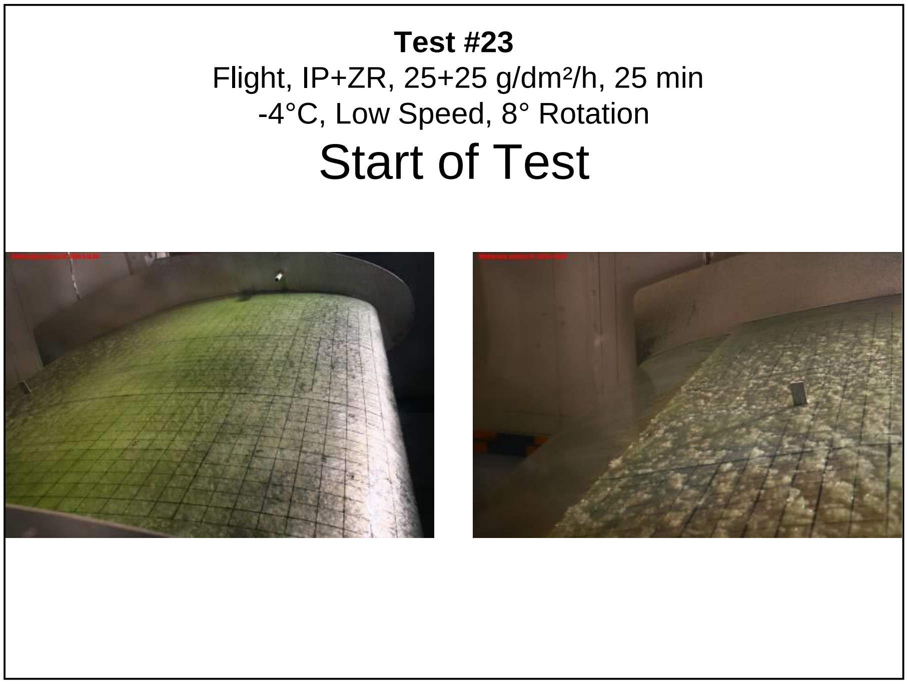


Photo 9.2: Test #23 – Before Rotation

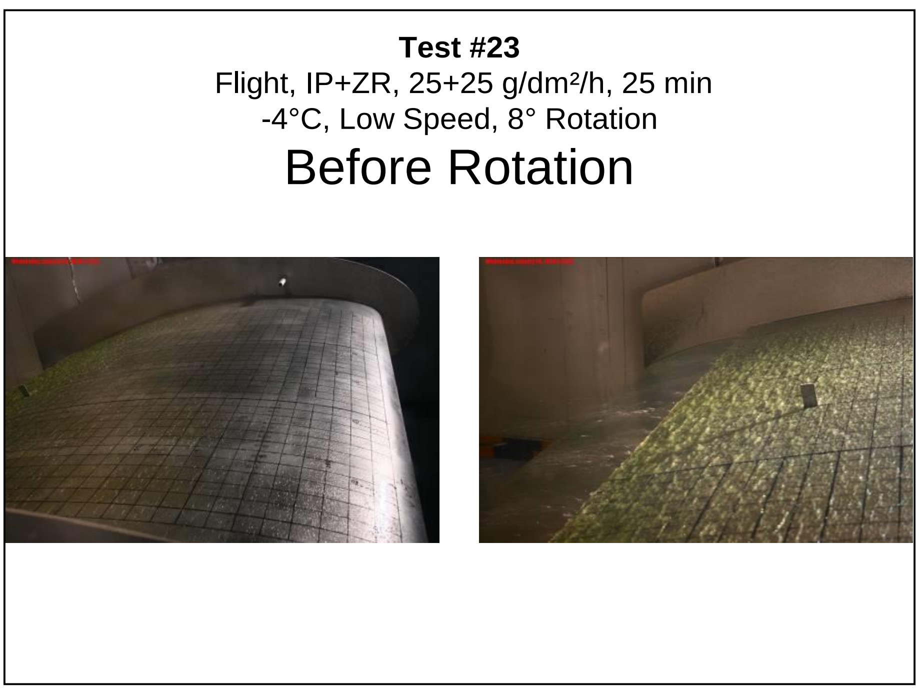


Photo 9.3: Test #23 – End of Rotation

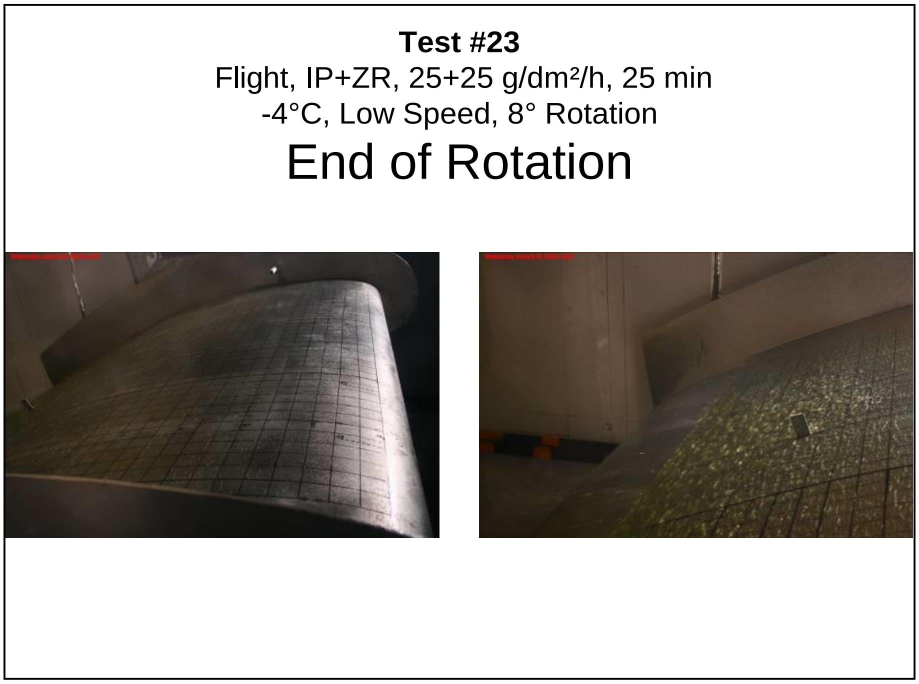


Photo 9.4: Test #23 – End of Test

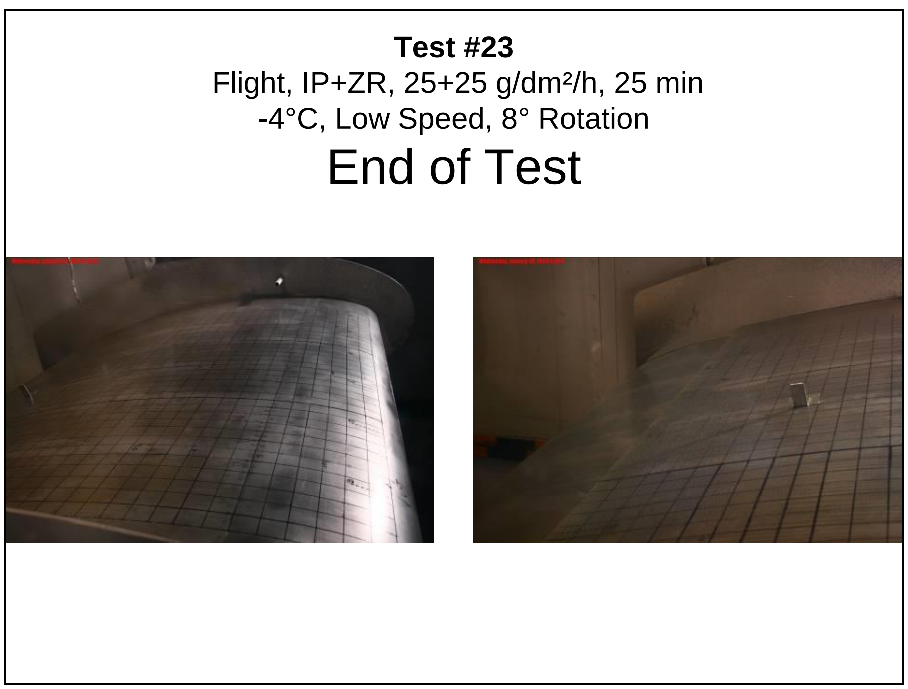


Photo 9.5: Test #60 – Start of Test

Test #60
Flight, IP+ZR 25+25 g/dm²/h, 10 min
-11°C, Low Speed, 16° Rotation
Start of Test

Photo 9.6: Test #60 – Before Rotation

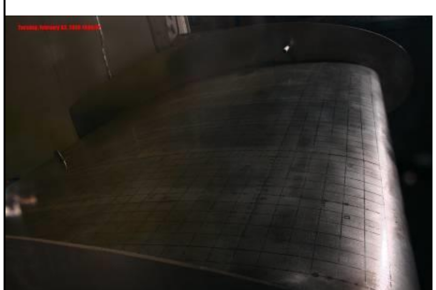
Test #60
Flight, IP+ZR 25+25 g/dm²/h, 10 min
-11°C, Low Speed, 16° Rotation
Before Rotation

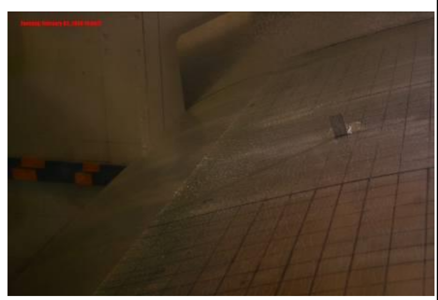
Photo 9.7: Test #60 – End of Rotation

Test #60
Flight, IP+ZR 25+25 g/dm²/h, 10 min
-11°C, Low Speed, 16° Rotation
End of Rotation

Photo 9.8: Test #60 – End of Test

Test #60
Flight, IP+ZR 25+25 g/dm²/h, 10 min
-11°C, Low Speed, 16° Rotation
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 Type IV High Speed Allowance Times

Many of the cells of the allowance time table were validated, however, some additional data is proposed for the -10 to -25°C range for light and moderate ice pellets. A reduction to the light ice pellets mixed with moderate snow allowance time was issued for OAT above -5°C: the allowance time was reduced from 25 minutes to 10 minutes. The testing conducted also allowed the expansion of the table to include a new 25 minute allowance time for light ice pellets mixed with moderate rain for above -5°C conditions, as well as a new 15 minute allowance time for light ice pellets mixed with light snow for -5°C to -10°C conditions. A newly updated version of the Type IV allowance time table has been developed and adopted for the 2009-10 version of the HOT Guidelines.

10.2 Type IV Low Speed Allowance Times

Testing was conducted for the preliminary development of allowance times for low speed operations with Type IV fluid. Allowance times were only developed for a limited number of cells due to issues observed with low speed fluid flowoff. Due to the limited tests and resulting lack of a comprehensive data set, it is recommended that further testing be conducted before a separate low speed allowance time table is published in the HOT guidelines. In addition, Type IV fluids are generally not certified (or do not qualify) for low speed takeoff. Therefore, until modifications to the aerodynamic acceptance tests are issued and Type IV fluid is certified for low speed operations, low speed allowance times for Type IV fluids should not be published.

10.3 Type III Low Speed Allowance Times

Low speed allowance time testing with Type III fluid was conducted as a secondary objective during the winter of 2008-09, and as a result, only a limited amount of data were collected. The results indicated a good potential for the use of Type III fluid during ice pellet conditions. A comprehensive preliminary allowance time table was developed for Type III fluid applied at ambient temperature, however the publication of the guidelines has been postponed until further data is collected.

The limitations of the current data collected include the following:

- Type III "heated" fluid applications were not tested. As this is understood to be a common practice with Type III fluid, this needs to be further investigated to determine any potential risk of adherence with the presence of ice pellets;
- Preliminary allowance times with fluid applied at ambient were developed based on a limited number of tests and would need to be further substantiated with additional testing; and
- Only low speed (80 knots rotation) data were collected, therefore the results would be applicable for high speed (100 knots) operations; this would be a conservative approach. High speed testing would be necessary to potentially get higher allowance times.

10.4 Type II Allowance Times

Allowance time testing with Type II fluid was conducted as a low priority objective during the winter of 2008-09, and as a result, only two tests were conducted. Although the results indicate a good potential use for Type II fluids in mixed conditions with ice pellets, further work is required to compile the necessary data to issue a separate Type II allowance time table. In addition, there has not been a strong industry request to have allowance times developed for use with Type II fluids. Future work with Type II fluids should remain a lower priority in comparison to the Type III and Type IV high speed and low speed aerodynamic research.

10.5 Correlation of Fluid Elimination and Visual Contamination Rating

In the examination of the thickness data on the trailing edge after the takeoff runs, the following observations are made:

- For most of the test runs, fluid was not completely eliminated from the trailing edge; for the Type IV high speed tests, about 0.2 mm remained on the trailing edge (measurement location 7) on average;
- For the low-speed Type III tests, a similar amount (approximately 0.2 mm on average) to the Type IV high speed tests remained on the trailing edge after the test run;
- The amount of fluid remaining on the trailing edge after the takeoff run is greatest for the low speed Type IV fluid tests; approximately by a factor of 2:1 when compared to the high speed Type IV fluid tests; and
- There appears to be a direct correlation of the trailing edge visual observation ratings at the time of rotation and the residual fluid thickness measurements on the trailing edge at the end of the takeoff run.

11. RECOMMENDATIONS

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

11.1 New Type IV High Speed Allowance Time Table

The testing conducted during the winter of 2008-09 validated, and expanded the current Type IV high speed allowance time table. Based on these results, a newly updated version of the Type IV allowance time table has been developed and adopted for the 2009-10 version of the HOT guidelines. This work was presented at the SAE G-12 meeting in Charleston in May 2009; a copy of the presentation is included in TC report TP 14936E, *Aircraft Ground Icing Research General Activities During the 2008-09 Winter* (15). The updated allowance time table is shown in Table 11.1.

Additional testing should be conducted to further expand the allowance times to allow greater flexibility to operators.

Table 11.1: 2009-10 Ice Pellet Allowance Time Table

<table>
<tr><th colspan="4">ICE PELLET ALLOWANCE TIMES FOR WINTER 2009-2010</th></tr>
<tr><th></th><th>OAT -5°C and above</th><th>OAT less than -5°C to -10°C</th><th>OAT less than -10°C</th></tr>
<tr><td>Light Ice Pellets</td><td>50 minutes</td><td>30 minutes</td><td>30 minutes</td></tr>
<tr><td>Moderate Ice Pellets</td><td>25 minutes</td><td>10 minutes</td><td>10 minutes</td></tr>
<tr><td>Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle</td><td>25 minutes</td><td>10 minutes</td><td rowspan="6">Caution: No allowance times currently exist</td></tr>
<tr><td>Light Ice Pellets Mixed with Light Freezing Rain</td><td>25 minutes</td><td>10 minutes</td></tr>
<tr><td>Light Ice Pellets Mixed with Light Rain</td><td>25 minutes</td><td rowspan="2"></td></tr>
<tr><td>Light Ice Pellets Mixed with Moderate Rain</td><td>25 minutes</td></tr>
<tr><td>Light Ice Pellets Mixed with Light Snow</td><td>25 minutes</td><td>15 minutes</td></tr>
<tr><td>Light Ice Pellets Mixed with Moderate Snow</td><td>10 minutes</td><td></td></tr>
</table>

11.2 Future Work

11.2.1 Type IV High Speed Allowance Times

Historical winter weather data has indicated that a significant portion of “light ice pellets mixed with light snow” precipitation occurs below -10°C and “light ice pellets mixed with moderate snow” precipitation occurs below -5 to -10°C where no allowance times currently exist. It is recommended that future research target these conditions in order to allow greater flexibility to operators in conditions of mixed ice pellets and light or moderate snow. Some additional data is also proposed for the -10 to -25ºC range for light and moderate ice pellets; limited data were collected during the winter of 2008-09 due to lack of cold weather.

In addition, industry requests have indicated a potential need for allowance times for conditions of ice pellets mixed with drizzle. Allowance times may be developed analytically however should be validated through full-scale testing in the wind tunnel.

11.2.2 Type IV Low Speed Allowance Times

Preliminary testing indicated a potential to develop a Type IV low speed allowance time table. However, due to the limited data collected, as well as possible fluid flow issues observed with the low speed tests, it is recommended that further testing be conducted before a separate low speed allowance time table is published in the HOT guidelines.

Type IV fluids are generally not certified (or do not qualify) for low speed takeoff. Modifications to the aerodynamic acceptance tests are required to better reflect the current generation of low speed aircraft and respective takeoff profiles (this work is currently ongoing and being performed by the SAE G-12 aerodynamic working group). Until these modifications are issued and Type IV fluid is qualified for low speed operations with reasonable LOUT’s, low speed allowance times for Type IV fluids should not be published.

11.2.3 Type III Low Speed Allowance Times

The preliminary results indicated a good potential for the use of Type III fluid during ice pellet conditions. Although a comprehensive data set was available as for Type III fluid applied at ambient temperature, it was recommended that the preliminary developed Type III allowance time table not be published in the HOT guidelines for the winter of 2009-10 due to the limitations of the data set. Further testing is recommended to substantiate the current results, as well as to expand the data set to include heated Type III fluid applications, and high speed takeoff profiles.

11.2.4 Type II Allowance Times

The preliminary results indicated a good potential for the use of Type II fluid during ice pellet conditions. Due to the limited data collected, it is recommended that further testing be conducted before a separate allowance time table be published in the HOT guidelines.

In addition, there has not been a strong industry request to have allowance times developed for use with Type II fluids. Future work with Type II fluids should remain a lower priority in comparison to the Type III and Type IV high speed and low speed aerodynamic research.

11.2.5 Super-Critical Wing Research

The current generation of “regional jet” aircraft are developed with super-critical wing design. Some of these aircraft require strict 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 in the wind tunnel during the winter of 2009-10 to validate the current Type IV high speed allowance times for use with aircraft with super critical wing designs.

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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

4.2 DE/ANTI-ICING FLUIDS RESEARCH (AND HOLDOVER TIME CREATION)

4.2.16 Testing in Mixed Ice Pellet Conditions with Supplemental Fluids

a) Review previously collected data;

b) Develop methodology and procedure for the conduct of tests. Attempts will be made to acquire lowest on-wing viscosity fluids;

c) Conduct endurance time testing with six anti-icing fluids in mixed ice pellet conditions. It is anticipate that 2 days of testing at the NRC will be required and will include baseline fluids tested previously;

d) Analyze data and results; and

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

4.3 AIRCRAFT PERFORMANCE RESEARCH

4.3.1 Wind Tunnel Testing to Refine Allowance Times

a) Meet with NRC personnel to arrange for access to the Propulsion Wind Tunnel (PWT) in M46 at the NRC Montreal Road facility in Ottawa;

b) Develop a procedure and test plan with the NRC staff that operates the PWT. It is anticipated that one week of setup will be required, followed by a three week test period, a two week analysis period, and finally by a two week testing period. It is anticipated that much of the testing will be conducted during overnight hours;

c) Perform wind tunnel tests to validate and possibly expand current allowance times published by TC and FAA;

d) Perform wind tunnel tests with an ethylene glycol and a propylene glycol anti-icing fluid at low temperatures;

e) Perform wind tunnel tests to simulate the slower rotation speeds of turboprop aircraft in accordance with the speed and angle of attack profiles provided by TDC;

f) Perform the wind tunnel tests on a wing with control surfaces included as provide by NRC and test with control at zero degrees and 15 degrees angle;

g) Collect the following data during the tests:

    i. Type and amount of fluid applied;
    ii. Type and rate of contamination applied; and
    iii. Extent of fluid contamination prior to the test run.

h) Take a series of high resolution photos of the fluid motion at the leading and trailing edges of the wing at a rate of about 3 frames per second, with lighting adequate to see the fluid waves and ripples of about 1mm in height, even when the wing is at 12 degrees angle of attack;

i) Document the appearance of fluid on the wing during the simulated takeoff run and climb of the aircraft by analyzing the photographic records; and

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

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).

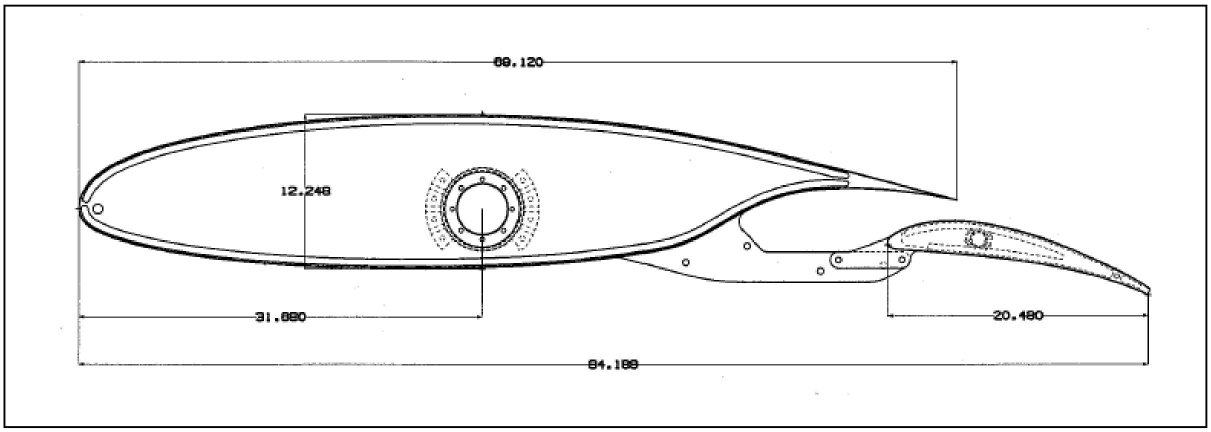

Figure 2.1: NASA LS(1)-0417 Wing Section

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.

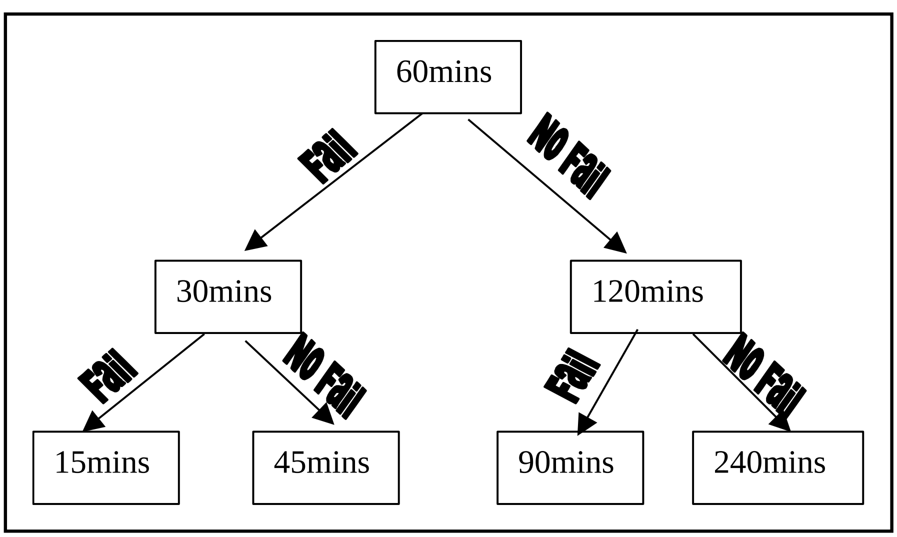

Figure 3.1: Decision Matrix for Each Test Series

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 (ºC)	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 (ºC)	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 (ºC)	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 (ºC)	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;
- Attachment XVI – Fluid Receipt Form (Generic form used by APS; will be used for this project as appropriate); and
- 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

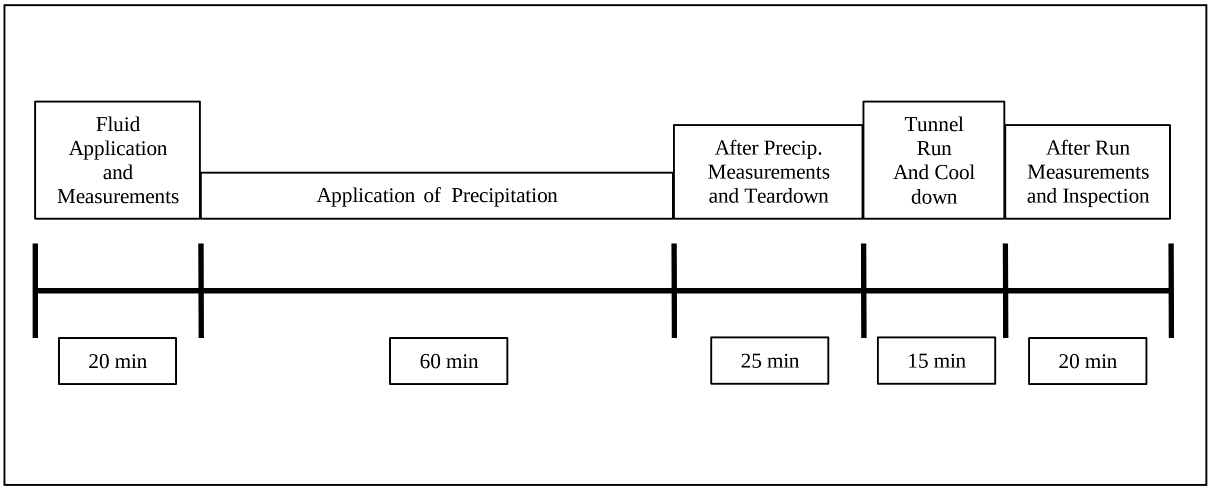

Figure 6.1: Typical Wind Tunnel Run Timeline

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)								
Degrees Celsius	Degrees Fahrenheit	Active Frost	Freezing Fog	Snow or Snow Grains[1]			Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[2]
				Very Light	Light	Moderate				
-3 and above	27 and above	45	11 – 17	18	11 – 18	6 – 11	9 – 13	4 – 6	2 – 5	CAUTION: No holdover time guidelines exist
below -3 to -6	below 27 to 21	45	8 – 13	14	8 – 14	5 – 8	5 – 9	4 – 6		
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.**

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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

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

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)									
Degrees Celsius	Degrees Fahrenheit	Type III Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Active Frost	Freezing Fog	Snow or Snow Grains: Very Light	Snow or Snow Grains: Light	Snow or Snow Grains: 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.**

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

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

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 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	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.**

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

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

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 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	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	CAUTION: No holdover time guidelines exist	
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.**

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

TABLE 4-C-Launch

CLARIANT TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 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 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	12:00	4:00 – 4:00	1:05 – 1:45	1:30 – 2:00	1:00 – 1:40	0:15 – 1:40	
		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	CAUTION: No holdover time guidelines exist	
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

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

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	

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:** ______________________

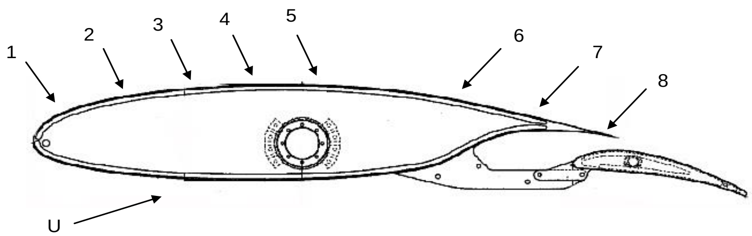
ATTACHMENT X – Wing Temperature, Fluid Thickness and Fluid Brix Form (to be filled by MP)

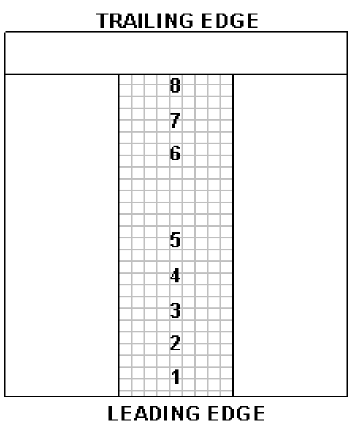
Date: ____________________ Run: ____________

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/dm²/h**
Duration	**5**	**minutes**

Footprint Rate	25	g/dm²/h
Stdev of Rate (+/-)	5	g/dm²/h
Effective Rate	23	g/dm²/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	$g/dm^2/h$
Stdev of Rate	10	$g/dm^2/h$
Effective Rate	22	$g/dm^2/h$

Snow needed per 5 minutes

In each position	60	g
In each Dispensor	240	g

Snow needed for entire test

In each Dispensor	240	g
Total Amount Snow Needed for Entire Test	960	g

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

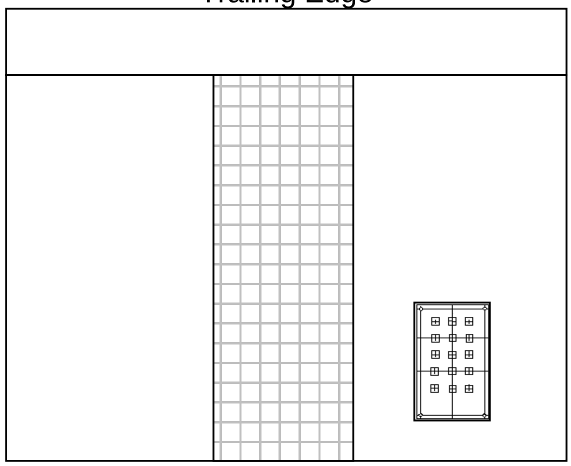
OBSERVER: ____________________

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 _____________________)

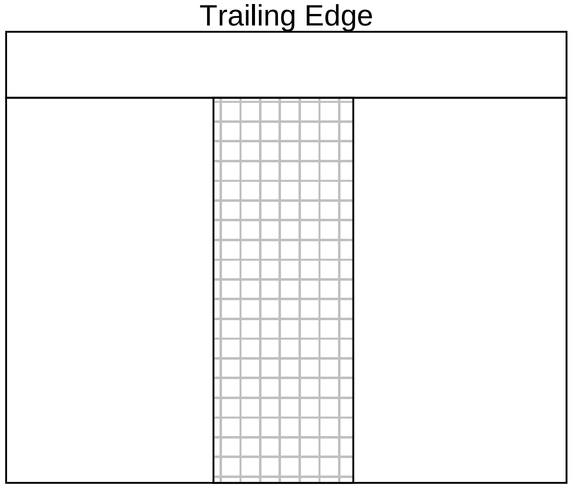
Trailing Edge



Leading Edge

Wing Condition After the Takeoff Run (Time: __________________________)

Trailing Edge



Leading Edge

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

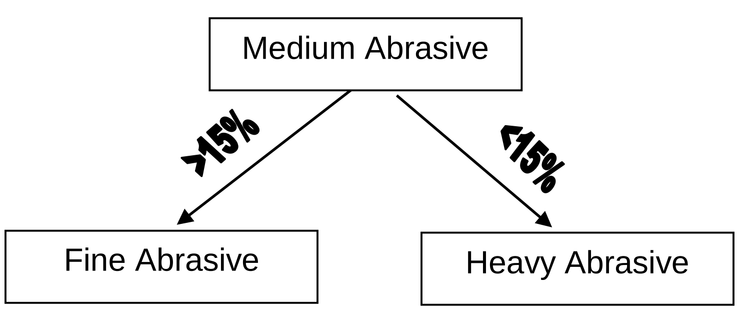
To investigate wing surface roughness and how it pertains to lift loss.

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 -24ºC;
- 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 -6º) 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 60ºC);
- 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 60ºC);
- 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.

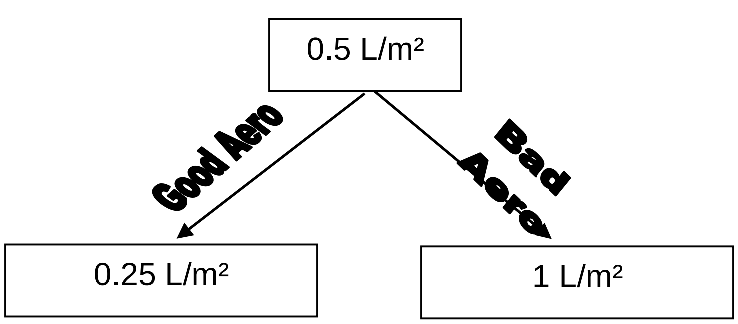
Methodology

- Perform a two step application of fluid;
- Apply heated Type I fluid to wing section (heated to 60ºC);
- 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.

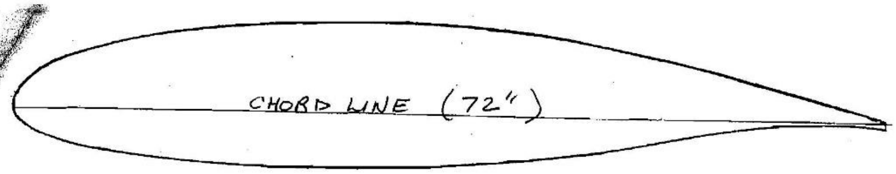
Test Plan

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



APPENDIX C

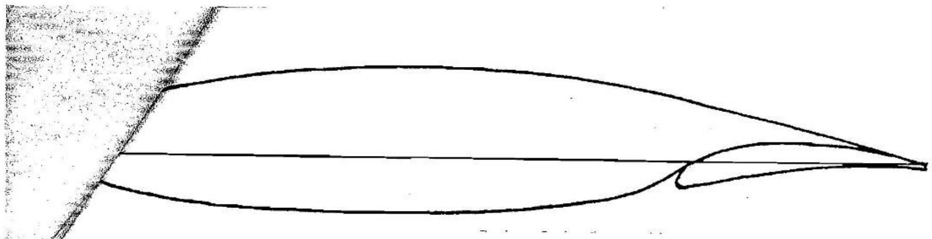
ADDITIONAL NOTES AND OBSERVATIONS AT NRC WIND TUNNEL



Upper Surface X / c	Upper Surface Z / c	Lower Surface X / c	Lower Surface Z / c
0.00000	0.00000	0.00000	0.00000
.00200	.01300	.00200	-.00930
.00500	.02040	.00500	-.01380
.01250	.03070	.01250	-.02050
.02500	.04170	.02500	-.02690
.03750	.04965	.03750	-.03190
.05000	.05589	.05000	-.03580
.07500	.06551	.07500	-.04210
.10000	.07300	.10000	-.04700
.12500	.07900	.12500	-.05100
.15000	.08400	.15000	-.05430
.17500	.08840	.17500	-.05700
.20000	.09200	.20000	-.05930
.25000	.09770	.25000	-.06270
.30000	.10160	.30000	-.06450
.35000	.10400	.35000	-.06520
.40000	.10491	.40000	-.06490
.45000	.10445	.45000	-.06350
.50000	.10258	.50000	-.06100
.55000	.09910	.55000	-.05700
.57500	.09668	.57500	-.05400
.60000	.09371	.60000	-.05080
.62500	.09006	.62500	-.04690
.65000	.08599	.65000	-.04280
.67500	.08136	.67500	-.03840
.70000	.07634	.70000	-.03400
.72500	.07092	.72500	-.02940
.75000	.06513	.75000	-.02490
.77500	.05907	.77500	-.02040
.80000	.05286	.80000	-.01600
.82500	.04646	.82500	-.01200
.85000	.03988	.85000	-.00860
.87500	.03315	.87500	-.00580
.90000	.02639	.90000	-.00360
.92500	.01961	.92500	-.00250
.95000	.01287	.95000	-.00260
.97500	.00609	.97500	-.00400
1.00000	-.00070	1.00000	-.00800

Figure 1 - GA(W)-1 Airfoil Coordinates (LATER RE-NAMED BY NASA AS LS(1)-0417)

TAKEN FROM NASA CR-2443
DEC. 1974



29%C Fowler Flap Coordinates

Upper Surface

X_f/c	Z_f/c
0.00000	-.02350
.00030	-.02000
.00200	-.01790
.00400	-.01550
.00800	-.01130
.01200	-.00780
.01800	-.00330
.02300	.00000
.02800	.00230
.03800	.00700
.04800	.01100
.05800	.01410
.06800	.01680
.07800	.01900
.08800	.02070
.09800	.02180
.10800	.02230
.11800	.02280
.12800	.02300
.13800	.02340
.14800	.02280
.15800	.02230
.16800	.02190
.19000	.01980
.21000	.01680
.23000	.01380
.25000	.00980
.27000	.00590
.29000	-.00070

Lower Surface

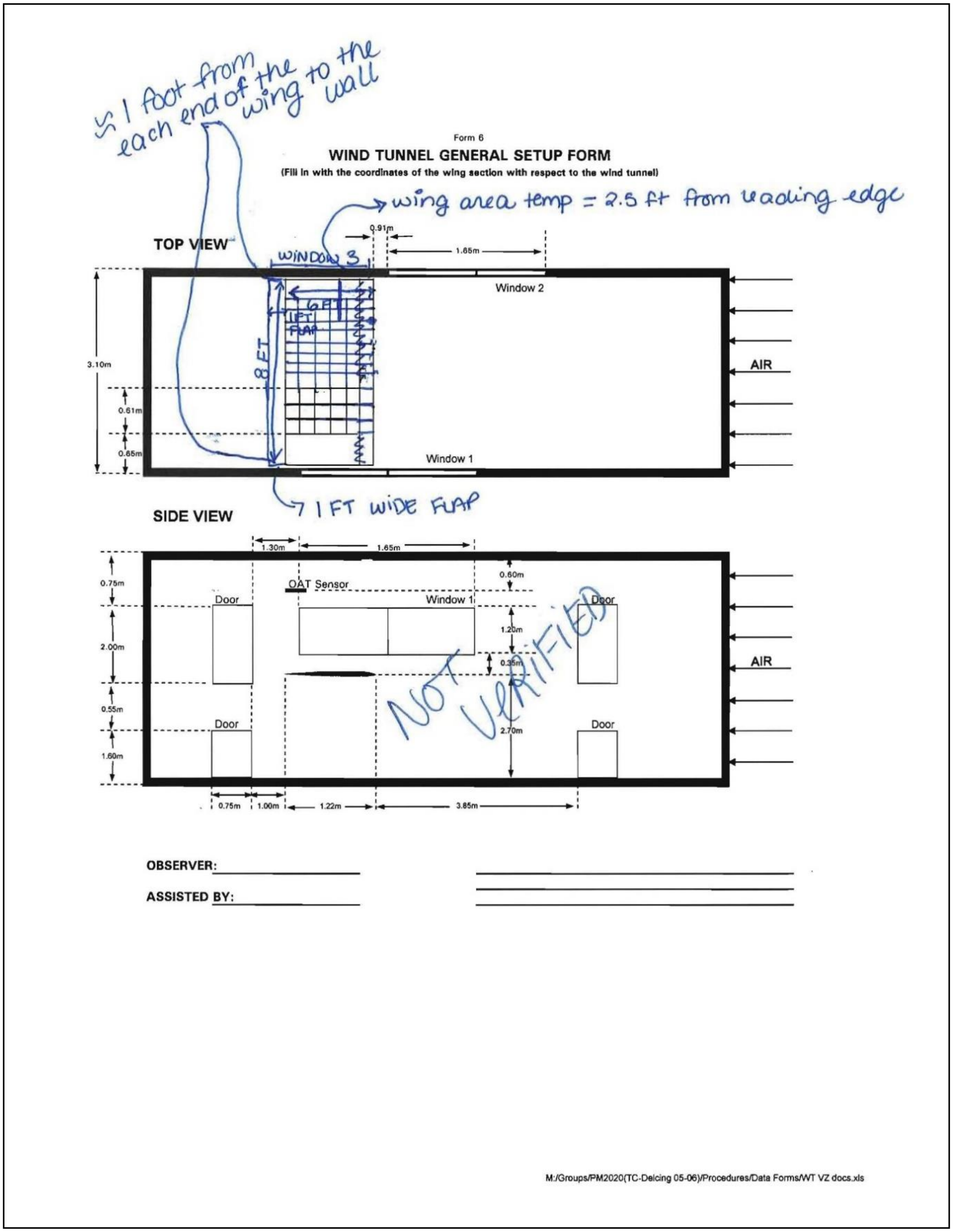
X_f/c	Z_f/c
0.00000	-.02350
.00100	-.02700
.00200	-.02880
.00400	-.03000
.00800	-.03100
.01200	-.03040
.02000	-.02880
.03000	-.02700
.05000	-.02350
.07000	-.01980
.09000	-.01600
.11000	-.01300
.13000	-.01000
.15000	-.00770
.17000	-.00580
.19000	-.00360
.21000	-.00270
.23000	-.00280
.25000	-.00350
.27000	-.00500
.29000	-.00800

Nose Radius = .0075c

Nose Radius Location $(X_f/c, Z_f/c) = (.0075, -.0235)$

Figure 1 - 29% c Fowler Flap Configuration
(CONT'D.)

FROM NASA CR-2443,
DEC. 1974



≈ 1 foot from each end of the wing to the wall
Form 6
WIND TUNNEL GENERAL SETUP FORM
(Fill in with the coordinates of the wing section with respect to the wind tunnel)
wing area temp = 2.5 ft from leading edge
TOP VIEW
WINDOW 3
0.91m
1.65m
Window 2
6FT
1FT FLAP
8FT
3.10m
0.61m
0.65m
AIR
Window 1
1 FT WIDE FLAP
SIDE VIEW
1.30m
1.65m
0.60m
0.75m
OAT Sensor
Door
Window 1
Door
1.20m
2.00m
0.35m
AIR
NOT VERIFIED
0.55m
Door
Door
2.70m
1.60m
0.75m
1.00m
1.22m
3.85m
OBSERVER:
ASSISTED BY:
M:/Groups/PM2020(TC-Deicing 05-06)/Procedures/Data Forms/WT VZ docs.xls

** note there is 16 cm between both windows

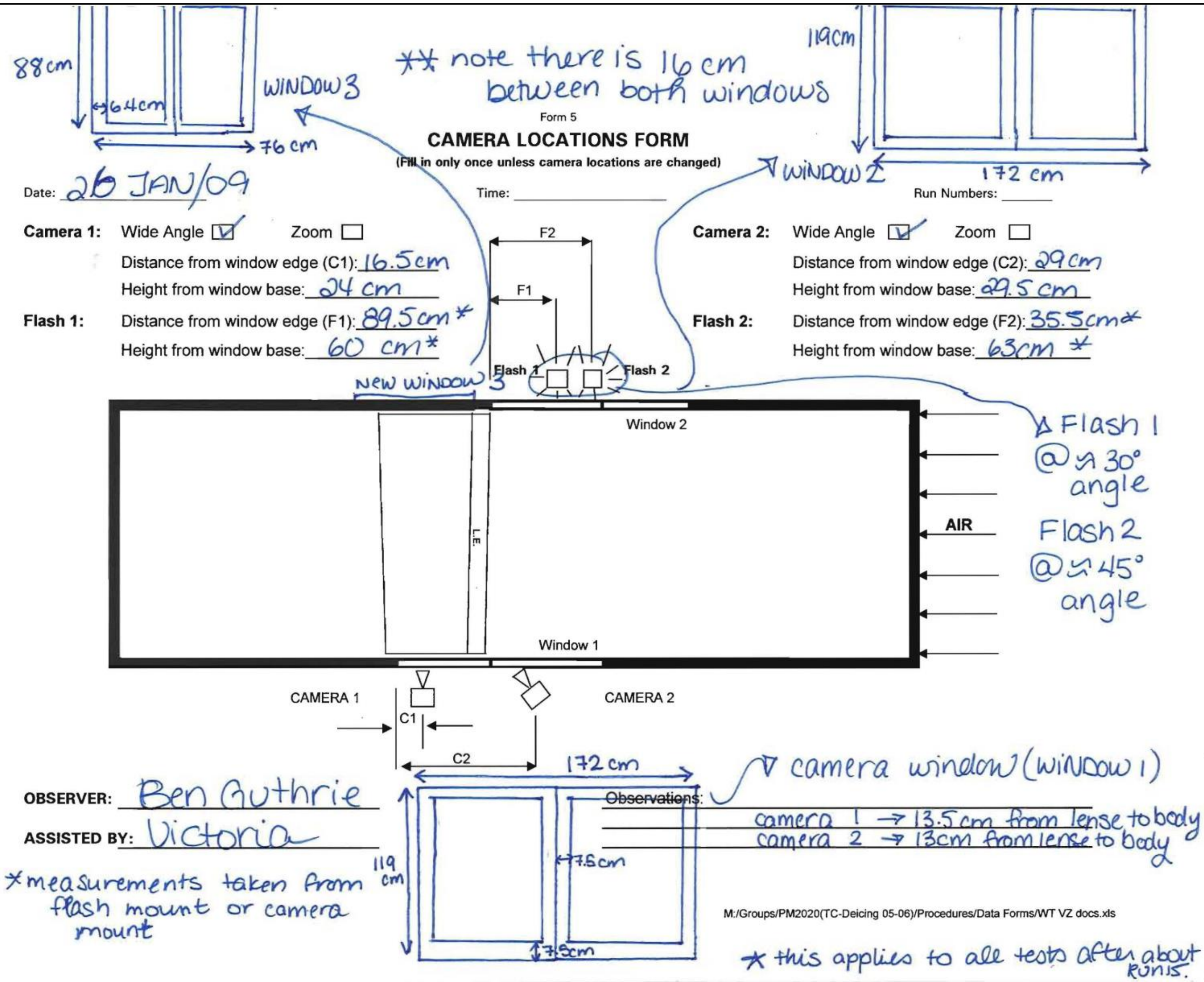
Form 5

CAMERA LOCATIONS FORM

(Fill in only once unless camera locations are changed)

Date: 26 JAN/09 Time: ______ Run Numbers: ______

Camera 1:	Wide Angle ☑ Zoom ☐		**Camera 2:**	Wide Angle ☑ Zoom ☐
	Distance from window edge (C1): 16.5cm			Distance from window edge (C2): 29 cm
	Height from window base: 24 cm			Height from window base: 29.5 cm
Flash 1:	Distance from window edge (F1): 89.5cm *		**Flash 2:**	Distance from window edge (F2): 35.5cm*
	Height from window base: 60 cm*			Height from window base: 63cm *



OBSERVER: Ben Guthrie

ASSISTED BY: Victoria

*measurements taken from flash mount or camera mount

Observations:

camera 1 → 13.5 cm from lense to body

camera 2 → 13cm from lense to body

M:/Groups/PM2020(TC-Deicing 05-06)/Procedures/Data Forms/WT VZ docs.xls

* this applies to all tests after about runs.

APPENDIX D

PROCEDURE
ADHESION OF AIRCRAFT DE/ANTI-ICING FLUIDS ON ALUMINUM SURFACES DURING MIXED PRECIPITATION CONDITIONS – ICE PELLETS / FREEZING RAIN

CM2020.002 (05-06)

EXPERIMENTAL PROGRAM
ADHESION OF AIRCRAFT DE/ANTI-ICING FLUIDS ON ALUMINUM SURFACES DURING MIXED PRECIPITATION CONDITIONS – ICE PELLETS / FREEZING RAIN

Fall 06

Prepared for

Transportation Development Centre
Transport Canada

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EXPERIMENTAL PROGRAM ADHESION OF AIRCRAFT DE/ANTI-ICING FLUIDS ON ALUMINUM SURFACES DURING MIXED PRECIPITATION CONDITIONS – ICE PELLETS / FREEZING RAIN

September 14, 2006

1. BACKGROUND

Preliminary endurance time testing during simulated ice pellet conditions was conducted by APS at the NRC research facility with the primary objective to investigate which conditions are most conducive to fluid adherence. A series of tests with the following objectives were conducted in simulated ice pellet conditions:

- Type I Heated Fluid Application Endurance Time Test;
- Type II/III/IV Fluid Application Endurance Time Test – Fluid at Room Temperature;
- Type II/III/IV Fluid Application Endurance Time Test – Fluid Heated to 60ºC;
- Type II/III/IV Fluid Application Endurance Time Test – Exceeded HOT; and
- Type II/III/IV Fluid Application Endurance Time Test – Mixed Precipitation (Ice Pellets and Freezing Rain / Drizzle).

Adherence occurred during tests conducted with Type I heated fluid in ice pellet conditions, and with Type IV fluid during mixed precipitation conditions.

As a result of the recent industry need to provide aircraft operators with holdover times for ice pellet conditions, the FAA provided a 25-minute allowance as a preliminary guideline. This allowance was followed by a list of conditions restricting operations, one condition being that the 25-minute allowance was acceptable in conditions with ice pellets alone. This recommendation was based on the previous research conducted during the winter of 2005-06, primarily as a result of Falcon 20 aerodynamic work. It is necessary to explore the worst-case mixed precipitation conditions in order to further evaluate the current recommendation.

Preliminary testing showed that adherence produced during ice pellet conditions in combination with freezing rain/drizzle is rough and "pimply". In comparison to adherence caused by freezing rain/drizzle alone, this is an aerodynamically more severe condition. It was recommended to conduct further endurance time testing during mixed precipitation conditions (ice pellets and freezing rain) to investigate if fluid adherence will occur during the first 20-30 minutes of exposure to precipitation with Type IV EG and PG fluid (testing will also be conducted with Type II fluid as a lesser priority test objective).

It should be noted that previous endurance time testing in simulated ice pellet conditions demonstrated that visual fluid failure was difficult to determine. For the purpose of this project, APS members will use their best judgment in approximating the fluid "failure time" based on the severity of the fluid condition. It should be noted that this is not the true fluid failure time as further work is ongoing in a separate project using wind tunnel simulations and full-scale aircraft to determine aerodynamic fluid failure.

2. OBJECTIVE

The objective of this project is to investigate if endurance time testing conducted during mixed precipitation conditions (ice pellets / freezing rain) will demonstrate signs of fluid adhesion to aluminum test surfaces during the first 20-30 minutes using Neat Type II and Type IV fluids.

3. TEST PLAN

A test plan summarizing the test objectives is shown in Table 3.1. A detailed test matrix is shown in Table 3.2. Fluids for the test matrix were chosen based on the fluid specific holdover times issued in the HOT Guidelines for light freezing rain conditions; worst case fluids were chosen for each temperature range. The failure times (estimated based on severity of fluid condition) on test surfaces will be recorded using the standard ET data form (Attachment I). Measurements will be continued beyond the failure time in an attempt to properly document the fluid adherence. Fluid type, fluid appearance, OAT, rate of precipitation and other factors will determine the duration of the test. After fluid failure, the test surface will be examined to determine whether or not adherence occurs. Progressive measurements will be conducted to help in reaching a decision. The methodology for measuring fluid adhesion is described in Section 4.6.

Table 3.1: Summary of Test Plan

Test #	Fluid	OAT (ºC)	Objective
1-4	Type II/IV	-3	High ZR / Low IP
Baseline 1-4	Type II/IV	-3	High ZR / Low IP
5-8	Type II/IV	-3	Equal ZR and IP
Baseline 5-8	Type II/IV	-3	Equal ZR and IP
9-12	Type II/IV	-10	High ZR / Low IP
Baseline 9-12	Type II/IV	-10	High ZR / Low IP
13-16	Type II/IV	-10	Equal ZR and IP
Baseline 13-16	Type II/IV	-10	Equal ZR and IP
17-20	Type II/IV	-6 *	High ZR / Low IP
21-24	Type II/IV	-6 *	Equal ZR and IP

*** OAT TBD and may be subject to change following results of tests 1-16**

Table 3.2: Test Matrix

Test #	Priority	Fluid Type	Fluid Brand	Dilution	Fluid Temp. [°C]	Precip Type	Test Temp. [°C]	Ice Pellet Precip Rate [g/dm²/h]	Freezing Rain Precip Rate [g/dm²/h]	Combined Precip Rate [g/dm²/h]	LZR HOT @ 25 g/dm²/h [min.]	LZR HOT @ 13 g/dm²/h [min.]	NRC Condition	Objective
1	1	IV	Octagon Maxflo	Neat	-3	ZR	-3	5	25	30	30	59	-3 / IP 5 / ZR 25	-3 / High ZR / Low IP
2	2	IV	Clariant MPIV 2012	Neat	-3	ZR	-3	5	25	30	26	47	-3 / IP 5 / ZR 25	-3 / High ZR / Low IP
3	1	IV	UCAR Ultra+	Neat	-3	ZR	-3	5	25	30	27	40	-3 / IP 5 / ZR 25	-3 / High ZR / Low IP
4	3	II	Clariant MPII 2025	Neat	-3	ZR	-3	5	25	30	27	34	-3 / IP 5 / ZR 25	-3 / High ZR / Low IP
Baseline 1	1	IV	Octagon Maxflo	Neat	-3	ZR	-3	N/A	25	25	30	59	-3 / ZR 25	Baseline Test
Baseline 2	2	IV	Clariant MPIV 2012	Neat	-3	ZR	-3	N/A	25	25	26	47	-3 / ZR 25	Baseline Test
Baseline 3	1	IV	UCAR Ultra+	Neat	-3	ZR	-3	N/A	25	25	27	40	-3 / ZR 25	Baseline Test
Baseline 4	3	II	Clariant MPII 2025	Neat	-3	ZR	-3	N/A	25	25	27	34	-3 / ZR 25	Baseline Test
5	1	IV	Octagon Maxflo	Neat	-3	ZR	-3	17	13	30	30	59	-3 / IP 17 / ZR 13	-3 / Equal ZR and IP
6	2	IV	Clariant MPIV 2012	Neat	-3	ZR	-3	17	13	30	26	47	-3 / IP 17 / ZR 13	-3 / Equal ZR and IP
7	1	IV	UCAR Ultra+	Neat	-3	ZR	-3	17	13	30	27	40	-3 / IP 17 / ZR 13	-3 / Equal ZR and IP
8	3	II	Clariant MPII 2025	Neat	-3	ZR	-3	17	13	30	27	34	-3 / IP 17 / ZR 13	-3 / Equal ZR and IP
Baseline 5	1	IV	Octagon Maxflo	Neat	-3	ZR	-3	N/A	13	13	30	59	-3 / ZR 13	Baseline Test
Baseline 6	2	IV	Clariant MPIV 2012	Neat	-3	ZR	-3	N/A	13	13	26	47	-3 / ZR 13	Baseline Test
Baseline 7	1	IV	UCAR Ultra+	Neat	-3	ZR	-3	N/A	13	13	27	40	-3 / ZR 13	Baseline Test
Baseline 8	3	II	Clariant MPII 2025	Neat	-3	ZR	-3	N/A	13	13	27	34	-3 / ZR 13	Baseline Test
9	1	IV	Kilfrost ABC-S	Neat	-10	ZR	-10	5	25	30	11	31	-10 / IP 5 / ZR 25	-10 / High ZR / Low IP
10	2	IV	Clariant MPIV 2012	Neat	-10	ZR	-10	5	25	30	17	26	-10 / IP 5 / ZR 25	-10 / High ZR / Low IP
11	1	IV	UCAR Ultra+	Neat	-10	ZR	-10	5	25	30	28	44	-10 / IP 5 / ZR 25	-10 / High ZR / Low IP
12	3	II	Kilfrost ABC-2000	Neat	-10	ZR	-10	5	25	30	12	29	-10 / IP 5 / ZR 25	-10 / High ZR / Low IP
Baseline 9	1	IV	Kilfrost ABC-S	Neat	-10	ZR	-10	N/A	25	25	11	31	-10 / ZR 25	Baseline Test
Baseline 10	2	IV	Clariant MPIV 2012	Neat	-10	ZR	-10	N/A	25	25	17	26	-10 / ZR 25	Baseline Test
Baseline 11	1	IV	UCAR Ultra+	Neat	-10	ZR	-10	N/A	25	25	28	44	-10 / ZR 25	Baseline Test
Baseline 12	3	II	Kilfrost ABC-2000	Neat	-10	ZR	-10	N/A	25	25	12	29	-10 / ZR 25	Baseline Test
13	1	IV	Kilfrost ABC-S	Neat	-10	ZR	-10	17	13	30	11	31	-10 / IP 17 / ZR 13	-10 / Equal ZR and IP
14	2	IV	Clariant MPIV 2012	Neat	-10	ZR	-10	17	13	30	17	26	-10 / IP 17 / ZR 13	-10 / Equal ZR and IP
15	1	IV	UCAR Ultra+	Neat	-10	ZR	-10	17	13	30	28	44	-10 / IP 17 / ZR 13	-10 / Equal ZR and IP
16	3	II	Kilfrost ABC-2000	Neat	-10	ZR	-10	17	13	30	12	29	-10 / IP 17 / ZR 13	-10 / Equal ZR and IP
Baseline 13	1	IV	Kilfrost ABC-S	Neat	-10	ZR	-10	N/A	13	13	11	31	-10 / ZR 13	Baseline Test
Baseline 14	2	IV	Clariant MPIV 2012	Neat	-10	ZR	-10	N/A	13	13	17	26	-10 / ZR 13	Baseline Test
Baseline 15	1	IV	UCAR Ultra+	Neat	-10	ZR	-10	N/A	13	13	28	44	-10 / ZR 13	Baseline Test
Baseline 16	3	II	Kilfrost ABC-2000	Neat	-10	ZR	-10	N/A	13	13	12	29	-10 / ZR 13	Baseline Test
17	1	IV	Kilfrost ABC-S	Neat	-6	ZR	-6	5	25	30	N/A	N/A	-6 / IP 5 / ZR 25	-6 / High ZR / Low IP
18	2	IV	Clariant MPIV 2012	Neat	-6	ZR	-6	5	25	30	N/A	N/A	-6 / IP 5 / ZR 25	-6 / High ZR / Low IP
19	1	IV	UCAR Ultra+	Neat	-6	ZR	-6	5	25	30	N/A	N/A	-6 / IP 5 / ZR 25	-6 / High ZR / Low IP
20	3	II	Kilfrost ABC-2000	Neat	-6	ZR	-6	5	25	30	N/A	N/A	-6 / IP 5 / ZR 25	-6 / High ZR / Low IP
21	4	IV	Kilfrost ABC-S	Neat	-6	ZR	-6	17	13	30	N/A	N/A	-6 / IP 17 / ZR 13	-6 / Equal ZR and IP
22	5	IV	Clariant MPIV 2012	Neat	-6	ZR	-6	17	13	30	N/A	N/A	-6 / IP 17 / ZR 13	-6 / Equal ZR and IP
23	4	IV	UCAR Ultra+	Neat	-6	ZR	-6	17	13	30	N/A	N/A	-6 / IP 17 / ZR 13	-6 / Equal ZR and IP
24	6	II	Kilfrost ABC-2000	Neat	-6	ZR	-6	17	13	30	N/A	N/A	-6 / IP 17 / ZR 13	-6 / Equal ZR and IP

Note: Repeat any test demonstrating adherence at the 1" line 20-30 minutes following fluid application.

The parameters to be measured during testing are the following: test surface temperature, fluid dilution (Brix), precipitation rate, fluid failure (estimated based on severity of fluid condition), and fluid adhesion. Photo documentation of each test will also be collected. Photos will be taken at set intervals during each test using a digital camera. All of these parameters are to be measured as the test progresses to gain a better understanding of the phenomena that take place as the fluid becomes diluted.

4. PROCEDURE

Endurance time testing will be conducted in the NRC cold chamber using the standard flat plate HOT test procedure . Test plates will be positioned directly underneath the simulated freezing precipitation sprayer assembly. The “Ice Pellet Dispenser” will be positioned approximately 1.2 m (4 ft.) away from, and 1.2 m above the test plate.

4.1 Type II/IV Fluid Application

1L of fluid at OAT will be poured onto the test plate. Fluid dilution, fluid thickness, surface temperature, fluid failure, and adhesion will be documented throughout the test. Photos of the test plate will be taken every 5 minutes for the duration of the test. Rate of precipitation will be verified just prior to the test and immediately following the end of the test.

4.2 Precipitation Rate

To verify that the appropriate rate of precipitation is being produced, the following procedure will be followed:

1. Adjust light freezing rain sprayer assembly to obtain desired rate;
2. Manually measure rate of precipitation on test plate (see indoor HOT procedure);
3. Verify that light freezing rain rate of precipitation is within a 1 $g/dm^2/h$ tolerance;
4. Adjust “Ice Pellet Dispenser” to obtain the desired rate;
5. Manually measure the combined rate of precipitation (ZR and IP) on test plate (see indoor HOT procedure); and
6. Verify that combined rate of precipitation is within a 2 $g/dm^2/h$ tolerance.

4.3 Surface Temperature

Test surface temperature logging is to be implemented using one thermistor probe mounted at the 15 cm (6") line on the underside of the test plate. The connection will be designed to last for the entire test season and to not impede the fluid flow. A SmartReader Eight-Channel temperature logger will be used to measure and record temperature. This temperature logger will run continuously and is independent of any external power supply or computer; the logger constantly measures and records readings from any enabled channels. The sampling rate (how often the logger takes readings) will be set to eight seconds, the smallest possible increment.

4.4 Fluid Dilution

Fluid dilution will be measured at the 15 cm (6") line, using a Misco 10431VP Brixometer. These measurements determine the concentration of the fluid on the test surface before and after fluid failure (estimate based on severity of fluid condition). The Brix value will originally be measured in the container before pouring. The second measurement will be taken right after pouring on the test surface, and at set intervals until fluid failure. After fluid failure the dilution measurements will be conducted every 5 minutes. Brix values and corresponding sample times will be recorded on the Brix/Thickness data form (Attachment II).

4.5 Fluid Failure

Previous endurance time testing in simulated ice pellet conditions demonstrated that visual fluid failure was difficult to determine. Fluid failure determination is not critical to this project. APS members will use their best judgment in approximating the fluid time of failure.

4.6 Fluid Adherence

The first occurrence of fluid adherence at any location on the surface of the plate will be recorded. Fluid adherence will be determined at the 5th crosshair immediately following failure at this location and at location B2 (see Attachment III). When the entire plate (15 crosshairs) has failed, again verify the fluid adherence at the 15 cm (6") line, and at all crosshairs B2, C2, D2, E2 and F2. Adherence will be noted by the plate observer on the Adherence of Fluid Failure data form (Attachment III). In addition to measuring adherence at the time of plate failure and complete plate failure, adherence will be measured progressively following fluid failure to determine the onset of adherence. A narrative description of the appearance of the fluid as it progresses toward failure will also be recorded.

In the absence of a recognized standard method or apparatus for measuring failure adhesion, the degree of bonding will be determined using an electronic dental flossing device. During operation, the device spins a thread of floss. The floss segment extends about 3 to 4 mm from the tip of the unit, and upon spinning could carve out a circle (or not, depending upon whether adhesion had occurred) 3 to 4 mm in radius on a failed surface element. In a layer of non-adhered fluid failure, the force of the spinning floss is sufficient to expose the surface of the test plate. As the rotation speed of the unit is fixed, the applied force will be constant for all tests, providing a basis of comparison among various test conditions, and between different stages of contamination for individual tests. This device proved to be the most satisfactory of the various approaches to establish whether an area had undergone surface bonding to the substrate and to give a measure of the strength of the bond formed.

An analysis of the shearing force exerted by this instrument (presented as Appendix C of the Transport Canada report, TP 14377E, *Adhesion of Aircraft Anti-Icing Fluids on Aluminum Surfaces (2003-04)*, December 2004) determined it to be in the range of 1.3×10^{-4} to 2.0×10^{-4} MPa.

4.7 Test Sequence

The steps to be followed are specific to each precipitation type.

1) Synchronize computer and test clocks to the atomic clock;

2) Prepare test plate and test stand;

3) Initiate temperature logging;

4) Prepare fluids for testing. The fluid types, fluid amounts and application temperatures are specific to each test;

5) Monitor precipitation rates;

6) Just before pouring the fluid, the test surface will be cleaned of all contamination with a scraper and a squeegee;

7) Apply the fluid to the test surfaces according to specific test procedure;

8) Determine failure time (estimated based on severity of fluid condition) on test surfaces, and record using standard ET data forms (Attachment I);

9) Measure Brix of the fluid and record on Brix/Thickness data form (Attachment II);

10) Determine fluid adherence and record on Adherence of Fluid Failure data form (Attachment III); and

11) At the end of the testing session save the temperature data on a memory stick or floppy disk. Label the diskette and place in the same envelope with the data forms.

5. EQUIPMENT AND FLUIDS

5.1 Equipment

The equipment to be used is, in general, the same as for the fluid holdover time tests. A comprehensive description of the equipment can be found in Transport Canada Report *Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2002-03 Winter*, TP 14144E, December 2004.

- Test plates and test stand;
- SmartReader Eight-Channel temperature logger and thermistor probes will be used for logging test surface temperatures;
- Wet film thickness gauges;
- Misco 10431VP brixometer will be utilized for fluid dilution rate measurements; and
- Ice Pellet Dispenser.

A detailed list of the equipment required for testing at the NRC facility is included in Attachment I.

5.2 Fluids

Tests shall be conducted using Type II/IV fluids as presented in Table 5.1. All fluids tested will be as close as possible to the lowest on wing viscosity and will conform to the viscosities stated in the HOT Guidelines.

Table 5.1: Fluid Required for Testing

Fluid Name	Fluid Type	Test Condition OAT [ºC]	Tentative # of Tests	Total Litres Required [L]
Clariant MPII 2025	2	-3	4	4
Kilfrost ABC-2000	2	-6, -10	6	6
Octagon Maxflo	4	-3	4	4
Kilfrost ABC-S	4	-6, -10	6	6
Clariant MPIV 2012	4	-3, -6, -10	10	10
UCAR Ultra+	4	-3, -6, -10	10	10

6. PERSONNEL

Six technicians are needed to conduct the tests:

- Technician one calls failure, and documents adherence;
- Technician two prepares fluids, measures precipitation rates and measures Brix and thickness;
- Technician three will be in charge of running the ice pellet dispenser system;
- Technician four will be in charge of managing the rate station; and
- Two technicians will be in charge of making simulated ice pellets.

7. DATA FORMS

Some of the same data forms from the procedure, *Adhesion Of Aircraft De/Anti-Icing Fluids On Aluminum Surfaces* (see Version 1.0 from November 13, 2003, located in Appendix B of TP 14144E) will be used for this project. Some fields of the data forms will not need to be filled out as they are not relevant to this project (refer to Section 3 for pertinent data). The following data forms are included in this procedure:

- End Condition data form (Attachment II);
- Fluid Brix/Thickness data form (Attachment III);
- Adherence of Fluid Failure data form (Attachment IV); and
- Position of Ice Pellet Dispenser System data form (Attachment V).

ATTACHMENT I
EQUIPMENT LIST

General	LOCATION	STATUS
Test Stands (2 x 6-plate stands)	Site	
4-plate stand (or 3-plate + 1-plate)	Site	
Desktop Computer x 1	Site	
Diskettes	Site	
Weigh Scale (Sartorius + NCAR) + wiring	Site	
Video camera x2	Site	
Anti-Slip Boards	Site	
Clamps x 12	Site	
VCR for time lapse	Site	
Monitor for time lapse	Site	
Plates (wing nuts) x15 (w/logging capability)	Site	
Insulation for weigh scale	Site	
Large Precipitation Pans x 100	Site	
Large calculator	Site	
Fluids	Site	
Clipboards x 6	Site	
Rubber squeegees x 4	Site	
Waste containers x 6	Site	
Funnels	Site	
Electrical Extension Cords	Site	
Wet vacuum	Site	
Storage bins for small equipment	Site	
Protective clothing (6)	Site	
Brixometer X 3	Site	
Tie wraps	Site	
Hand-held Temperture Probes (Wahl)	Site	
Thickness Gauges x 4 (both types)	Site	
Scrapers and Squeegees	Site	
Plate covers x 12	Site	
Spray paint	Site	
Tape measure	Site	
Thermistor Kit + Logger	Site	
Inclinometer (yellow level)	Site	
Printer Epson @ site	Site	
Washers	Site	
Pour Containers (2L) x4	Site	
Hard Water Chemicals	Site	
1 litre pour containers x 30 (if possible)	Site	
Large digital clock x 2	Site	
Anti-Slip Rubber Mats (all of them)	Site	
Laptop Computer	Site	
CD's	Site	
Heat Gun	Site	
Harmonica Folder	Site	
Sand or Grit	Purchase	
Batteries AA, 9V	Purchase	
Paper Towels (lots)	Purchase	
Cotton gloves	Purchase	
Pencils + pens + markers	Office	
Paper for printer (1 packs)	Office	
Fluid Reports + HOT Tables	Office	
Test Procedures X2	Office	
Procedures Data Forms (50x)	Office	
Black shelving units x 2	NRC?	
Flood Lights	NRC?	

ICE PELLETS	LOCATION	STATUS
Ice Pellet Pitcher (2006)	Site	
Ice Pellet Pitcher (2005) as backup	Site	
Tripod for IP Pitcher	Site	
12 hole spreader (x1)	Site	
Type I EG Fluid (10L)	Site	
Hand Held IP Pitcher Backups (x4)	Site	
Camera tripods (x2)	Site	
20L Maxflo	Site	
Ice Pellets Stored in Freezer	Site	
Blender (x6) purchase if necessary	Site	
Sieves (x12)	Site	
Sieve collection dish (x2)	Site	
>5mm rectangular Screen	Site	
Big Table	Site	
Small table	Site	
1 litre measuring cups (x4)	Site	
Food Coloring (Blue and Red)	Site	
Extension Cables (x3)	Site	
Power bars (x2)	Site	
Microwave (x1)	Site	
Rubber gloves (x2)	Site	
Grey Duck Tape	Site	
Thermos (x6)	Site	
Thermos Carrier (x1)	Site	
Step Ladder	Site	
Oral B Flosser and Charger (x3)	Site	
Oral B Replacement Tips (lots)	Site	
New Dispenser w/ Batteries	Site	
Styrofoam Containers (x10)	Purchase	
Patio Umbrella	Purchase	
Canon Cameras (x2)	Office	
Canon Marco Camera (x1)	Office	
Storage freezer	NRC?	
Ice Cubes	NRC?	

ATTACHMENT II
END CONDITION DATA FORM

REMEMBER TO SYNCHRONIZE TIME

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

TIME TO FAILURE FOR INDIVIDUAL CROSSHAIRS (real time)

Time of Fluid Application:

Initial Plate Temperature (°C)
(NEEDS TO BE WITHIN 0.5°C OF AIR TEMP)

Initial Fluid Temperature (°C)
(NEEDS TO BE WITHIN 3°C OF AIR TEMP)

	Plate 1	Plate 2	Plate 3	Plate 4	Plate 5	Plate 6
FLUID NAME/BATCH						
B1 B2 B3						
C1 C2 C3						
D1 D2 D3						
E1 E2 E3						
F1 F2 F3						
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA						
FAILURE CALL (circle)	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy
HRZ. AIR VELOCITY * (circle)	A B C	A B C	A B C	A B C	A B C	A B C

Time of Fluid Application:

Initial Plate Temperature (°C)
(NEEDS TO BE WITHIN 0.5°C OF AIR TEMP)

Initial Fluid Temperature (°C)
(NEEDS TO BE WITHIN 3°C OF AIR TEMP)

	Plate 7	Plate 8	Plate 9	Plate 10	Plate 11	Plate 12
FLUID NAME/BATCH						
B1 B2 B3						
C1 C2 C3						
D1 D2 D3						
E1 E2 E3						
F1 F2 F3						
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA						
FAILURE CALL (circle)	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy
HRZ. AIR VELOCITY * (circle)	A B C	A B C	A B C	A B C	A B C	A B C

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

AMBIENT TEMPERATURE: ________ **°C**

COMMENTS:

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

LEADER / MANAGER: ________________________

ATTACHMENT III
FLUID BRIX/THICKNESS DATA FORM

DATE: ______________ **PERFORMED BY:** ______________

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

STAND: ______________ **LOCATION:** ______________

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

M:\Groups\CM (TC-Deicing 05-06)\Procedures\Data Forms\Fluid Brix Thickness Data Form

ATTACHMENT IV

ADHERENCE OF FLUID FAILURE

Date: ____________ Time: ______________ Plate Location: _________

Run #: ____________ Fluid Name: ______________ Fluid Dilution: _________

t =
1 2 3
B
C
D
E
F

t =
1 2 3
B
C
D
E
F

t =
1 2 3
B
C
D
E
F

t =
1 2 3
B
C
D
E
F

t =
1 2 3
B
C
D
E
F

t =
1 2 3
B
C
D
E
F

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ATTACHMENT V
POSITION OF ICE PELLET DISPENSER SYSTEM DATA FORM

DATE:______________________ CONDITION:_______________________ TIME:______________________

TYPE OF PRECIPITATION ON PLATE (circle precip.) type)

Pos. 1	Pos. 2	Pos. 3	Pos. 4	Pos. 5	Pos. 6
ZR	ZR	ZR	ZR	ZR	ZR
IP	IP	IP	IP	IP	IP
ZR/ IP	ZR/ IP	ZR/ IP	ZR/ IP	ZR/ IP	ZR/ IP

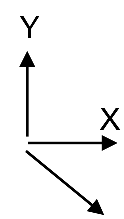
Pos. 7	Pos. 8	Pos. 9	Pos.10	Pos.11	Pos.12
ZR	ZR	ZR	ZR	ZR	ZR
IP	IP	IP	IP	IP	IP
ZR/ IP	ZR/ IP	ZR/ IP	ZR/ IP	ZR/ IP	ZR/ IP

MARK POSITION OF DISPENSER RELATIVE TO PLATES WITH AN "X" IN SPACE

OPERATIONAL TIME LOG OF ICE PELLET DISPENSER

IP DISPENSER ON	IP DISPENSER OFF	IP DISPENSER ON	IP DISPENSER OFF

POSITION[(1)] OF ICE PELLET DISPENSER



X___________

Y___________

Z___________

Z (height above ground)

(1) Origin is bottom left corner of stand

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APPENDIX E

LIFT COEFFICIENT AND NORMAL COEFFICIENT DATA PROVIDED BY NRC

LIST OF FIGURES

TYPE IV HIGH SPEED

Figure E1: Run #8

Run 8: No Data Available

Figure E2: Run #9

Run 9: No Data Available

Figure E3: Run #10

Run 10: No Data Available

Figure E4: Run #11

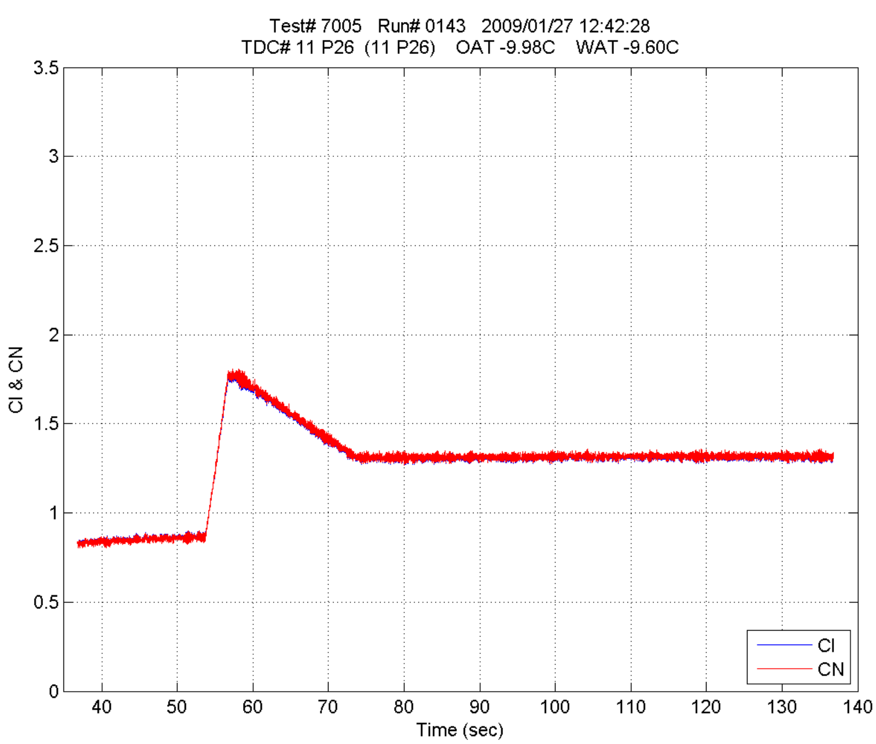


Figure E5: Run #13

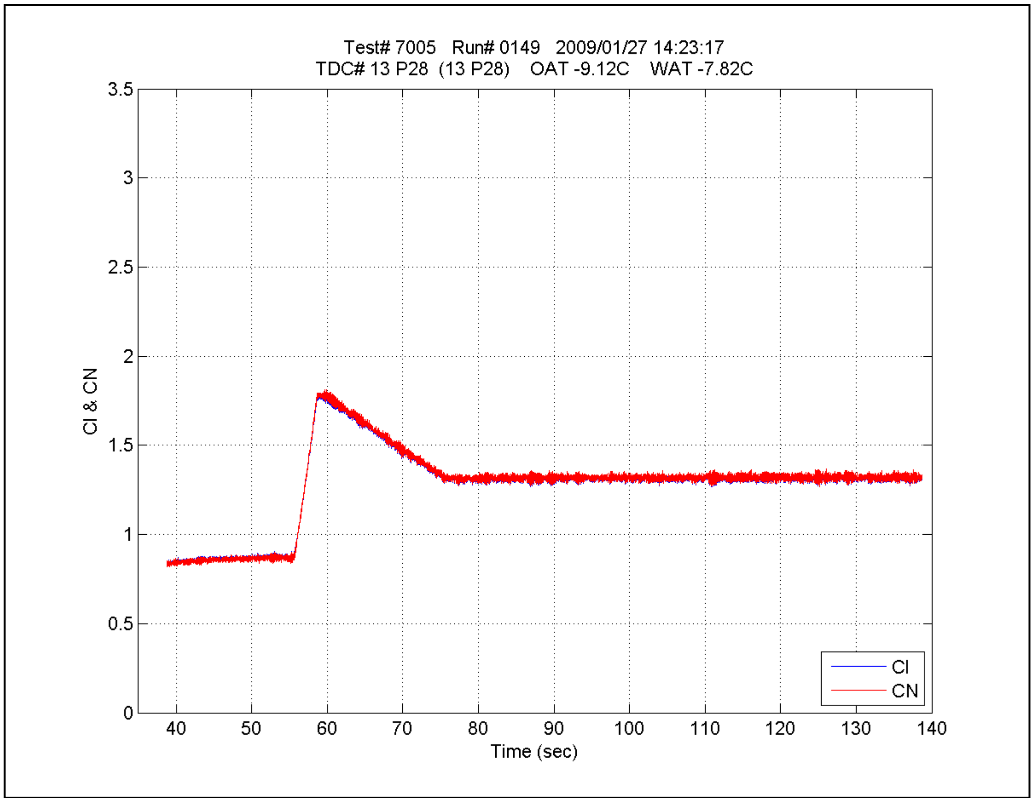


Figure E6: Run #20

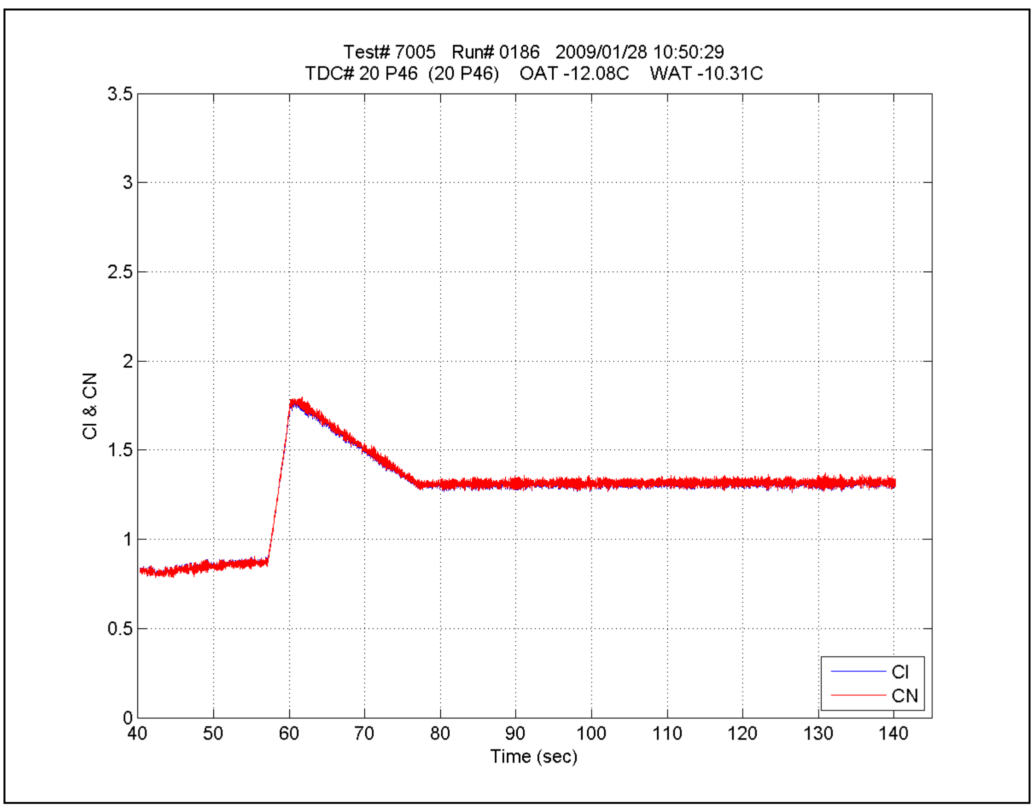


Figure E7: Run #21

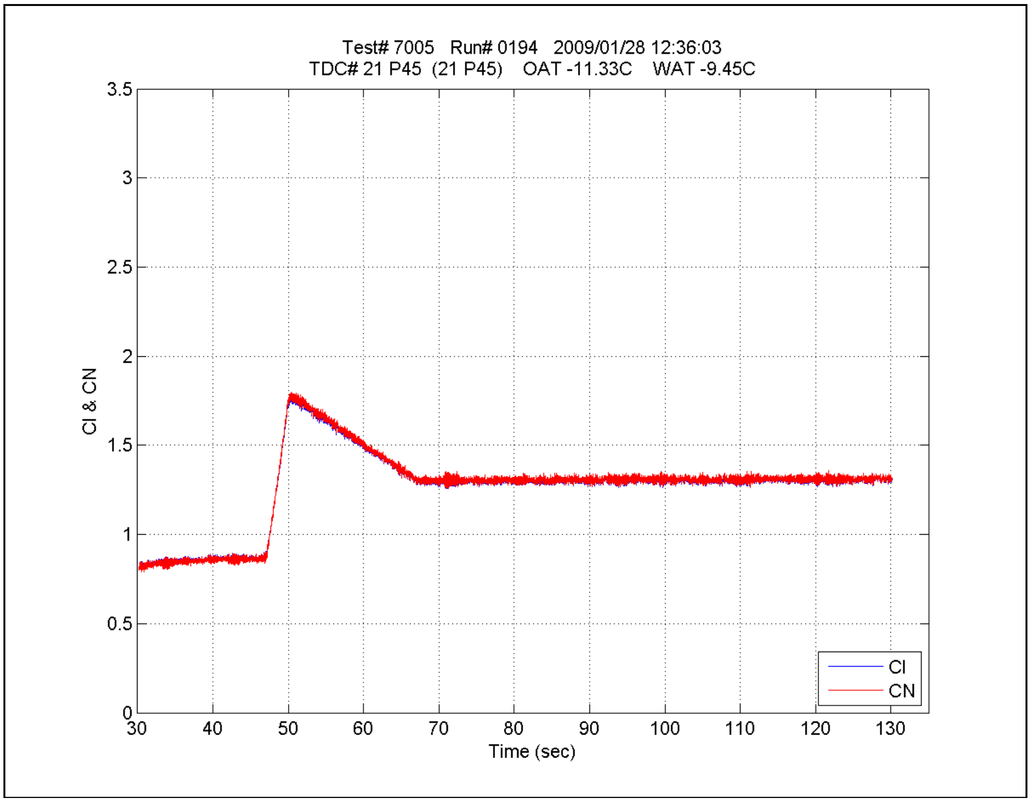


Figure E8: Run #29

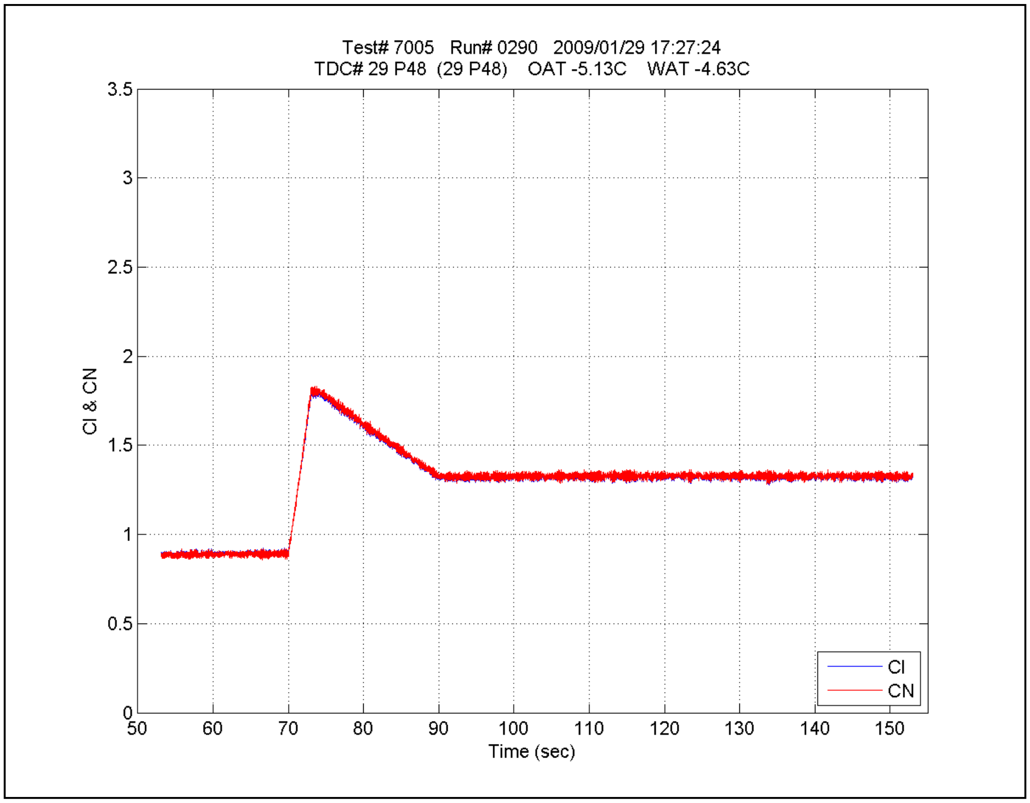


Figure E9: Run #30

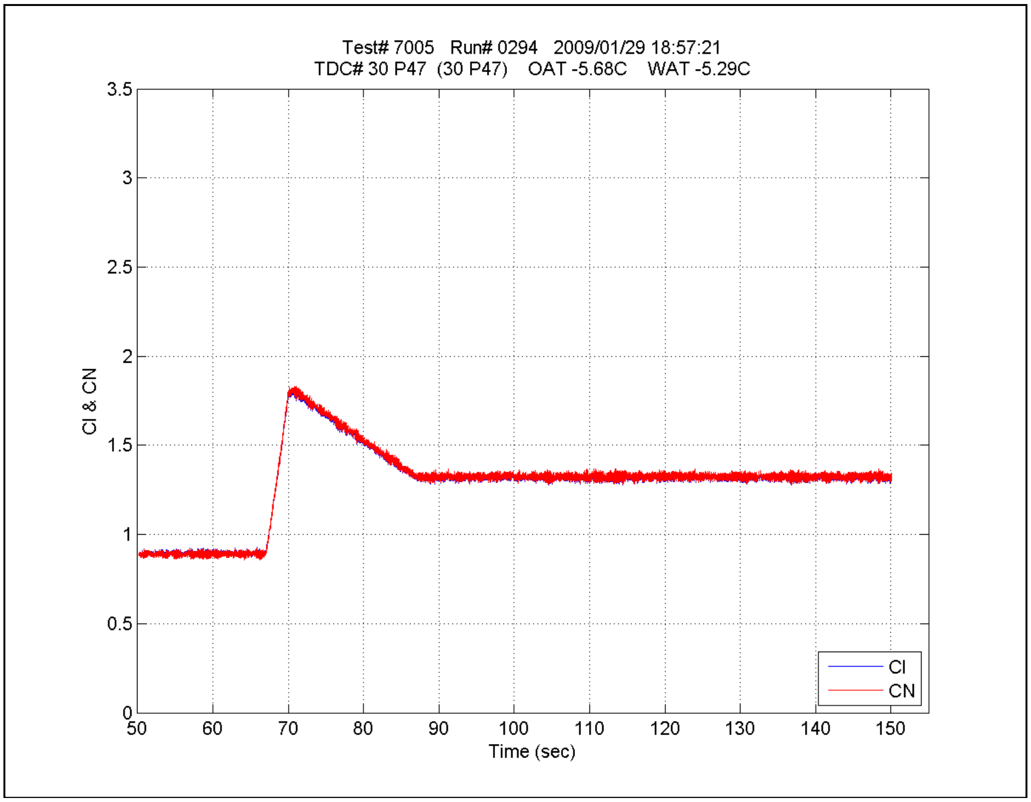


Figure E10: Run #44

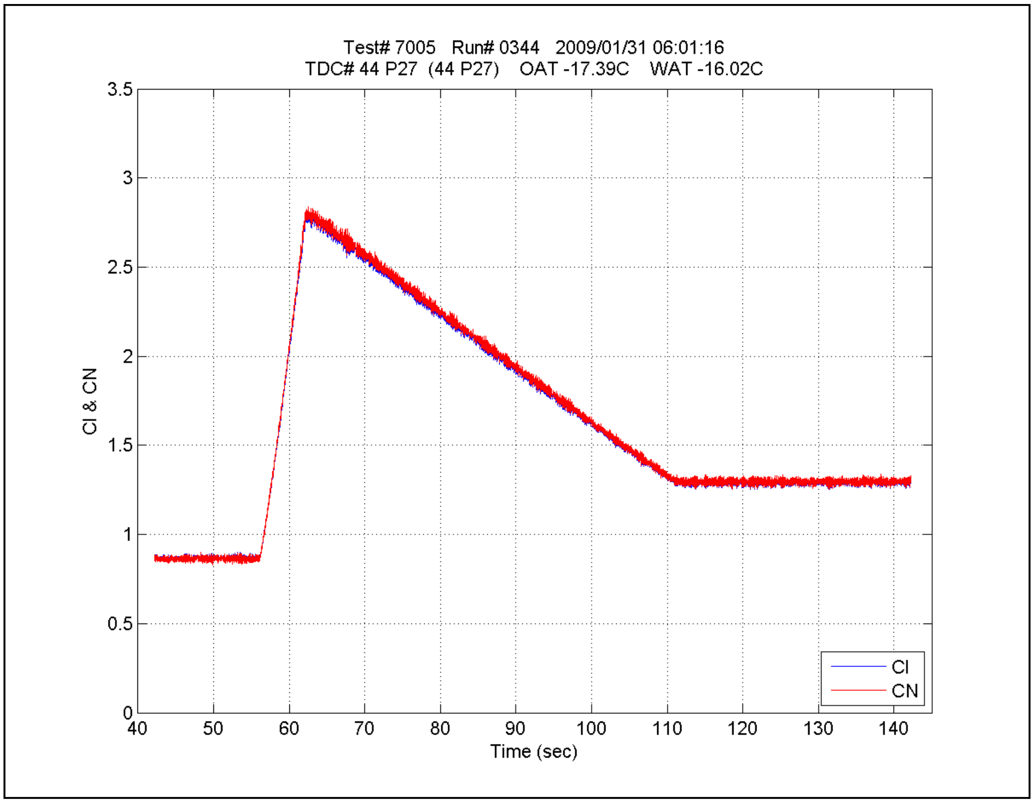


Figure E11: Run **#51**

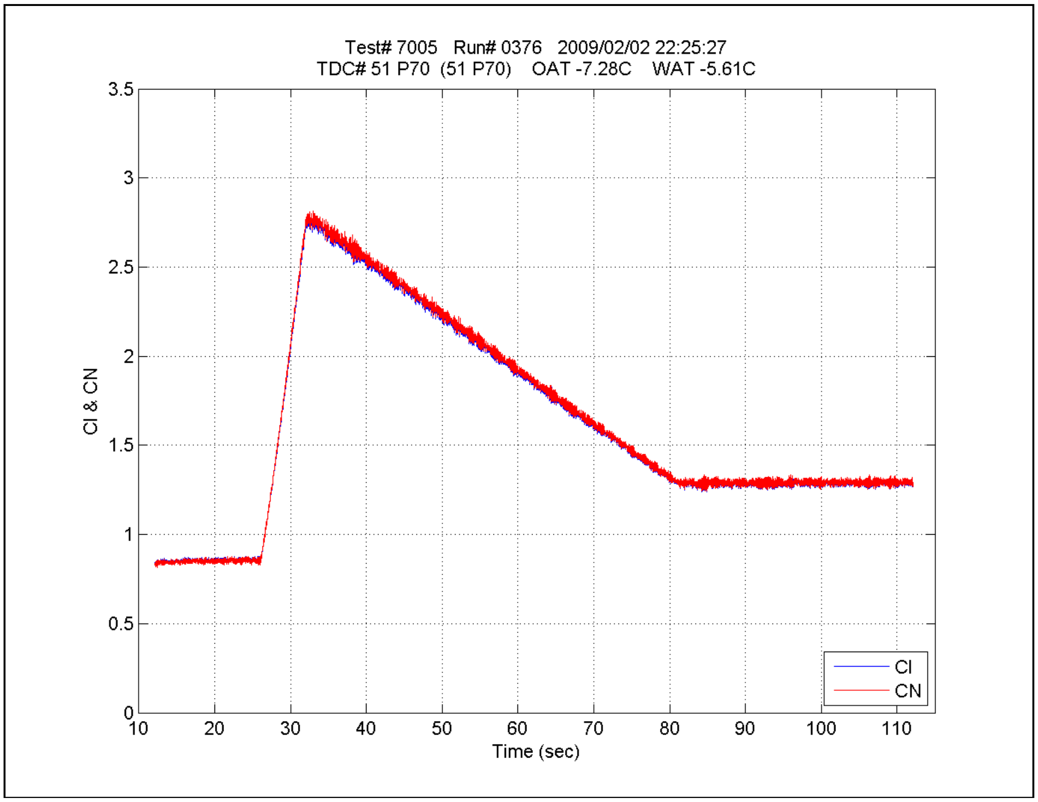


Figure E12: Run **#54**

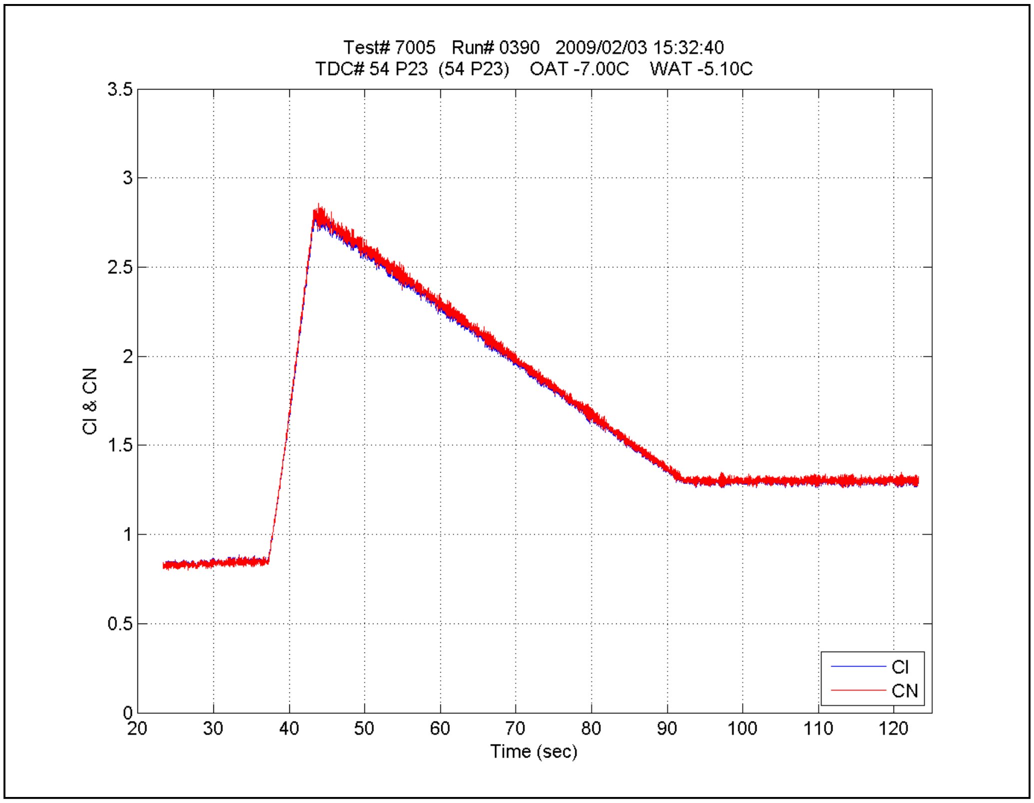


Figure E13: Run #58

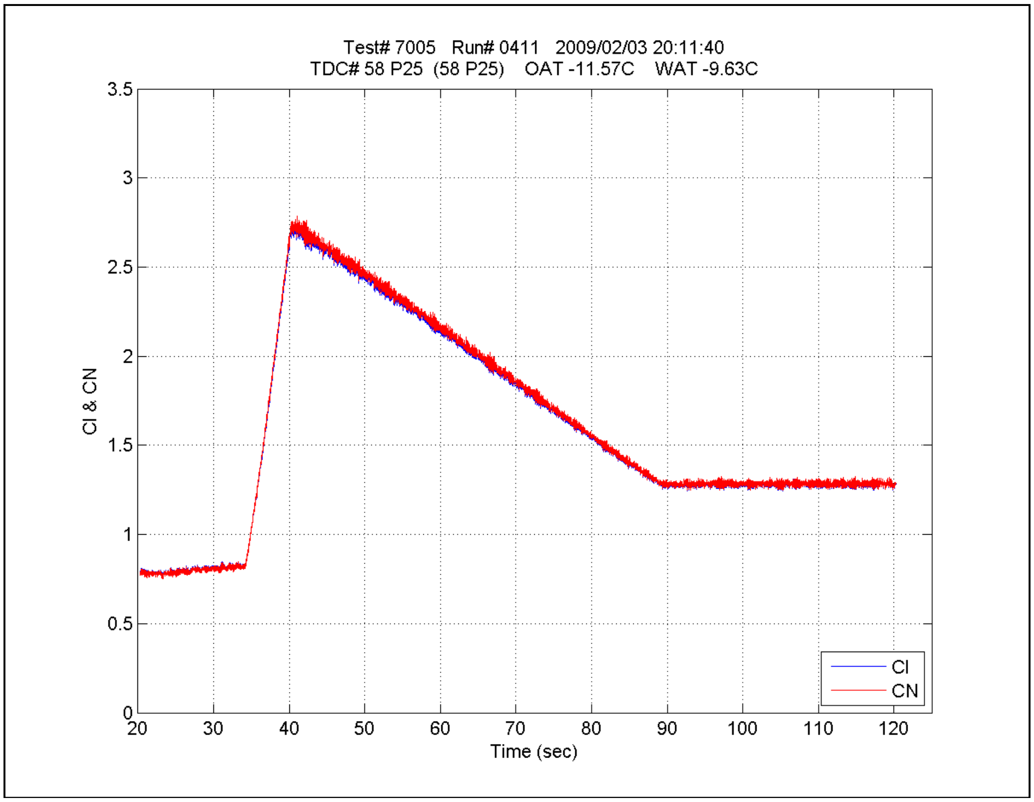


Figure E14: Run #64

Run 64: No Data Available

Figure E15: Run #65

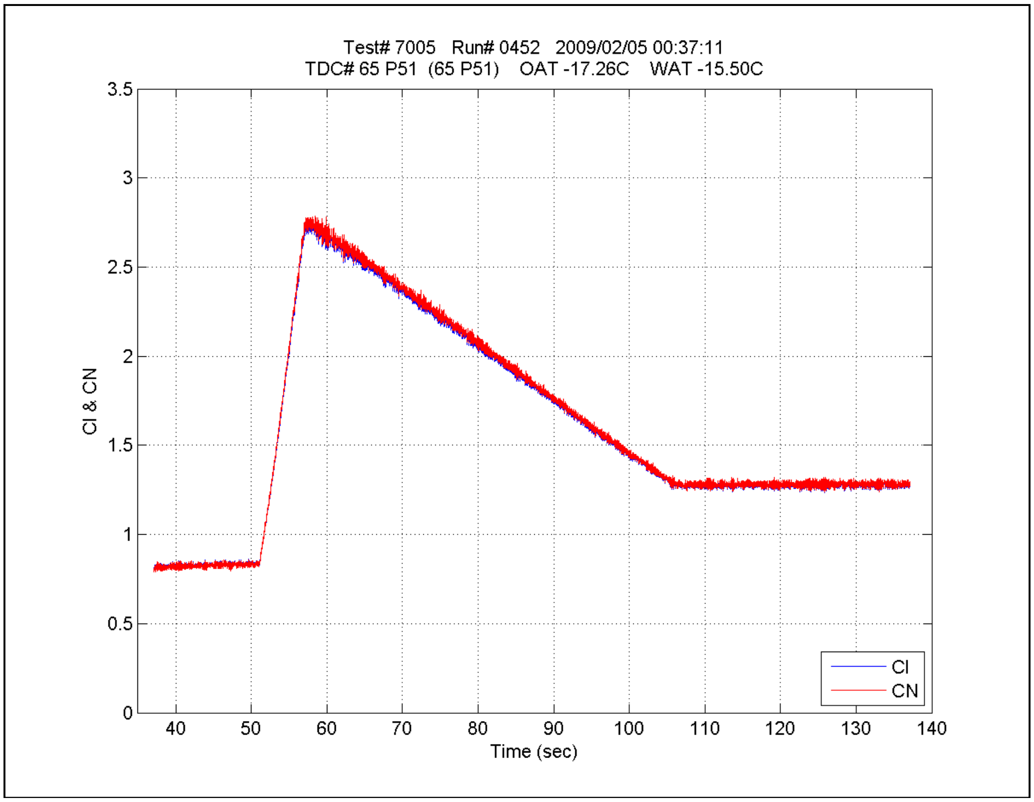


Figure E16: Run #66

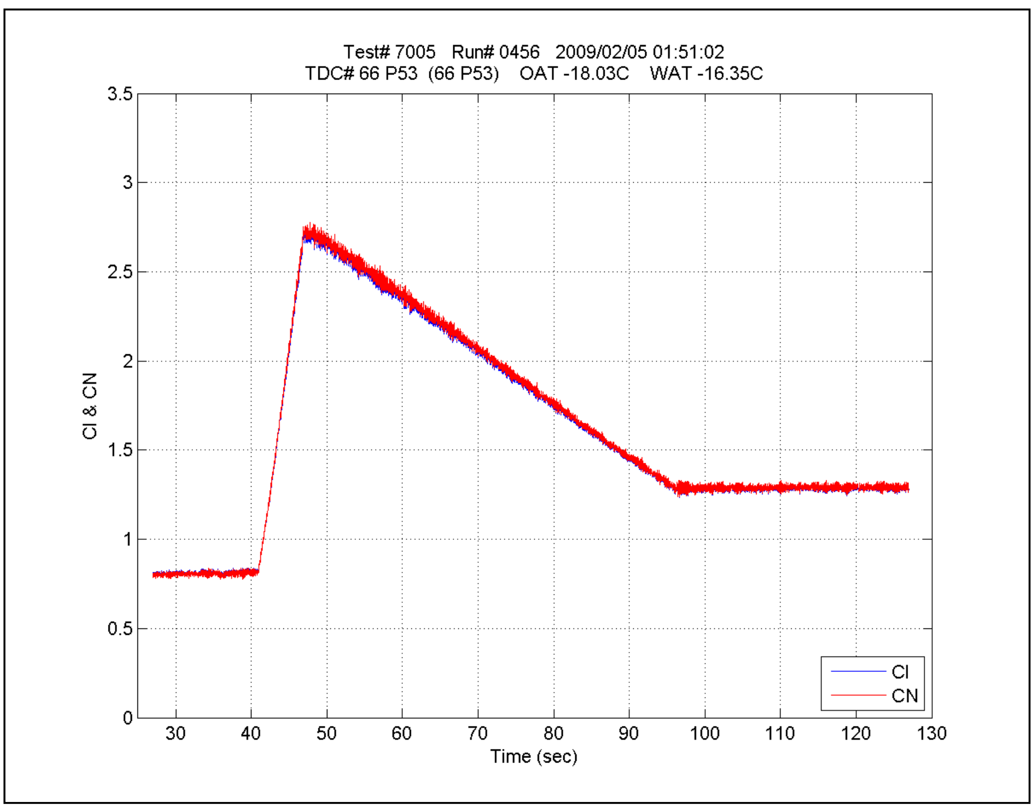


Figure E17: Run #67

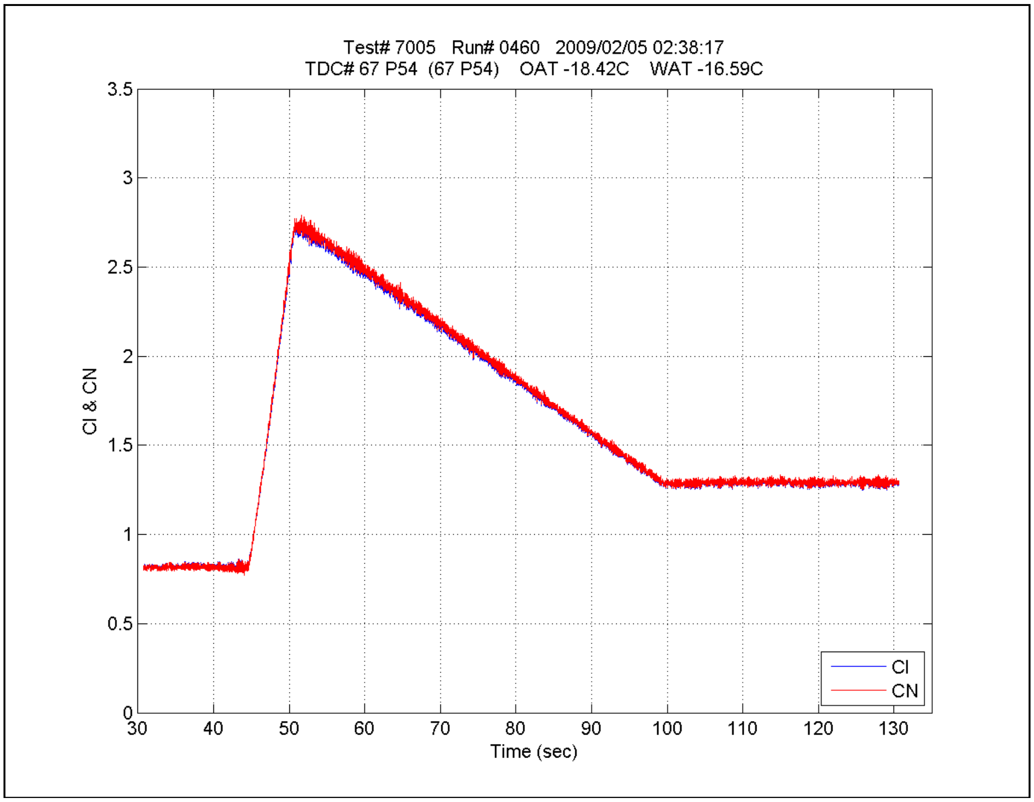


Figure E18: Run #68

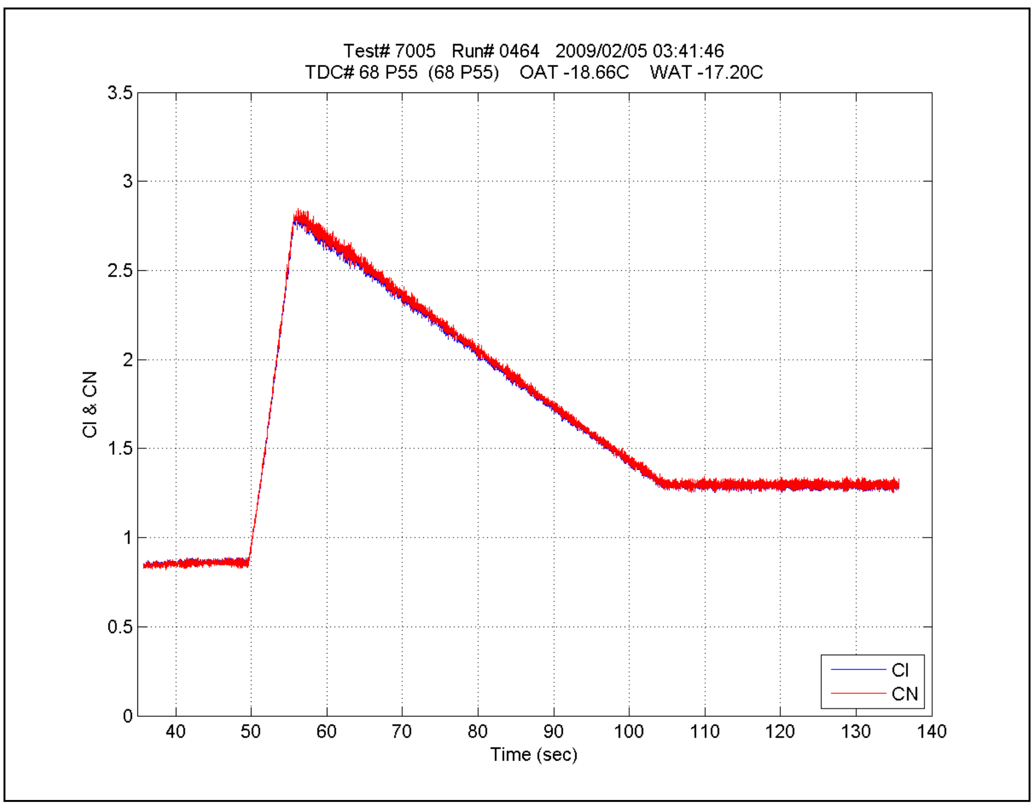


Figure E19: Run #69

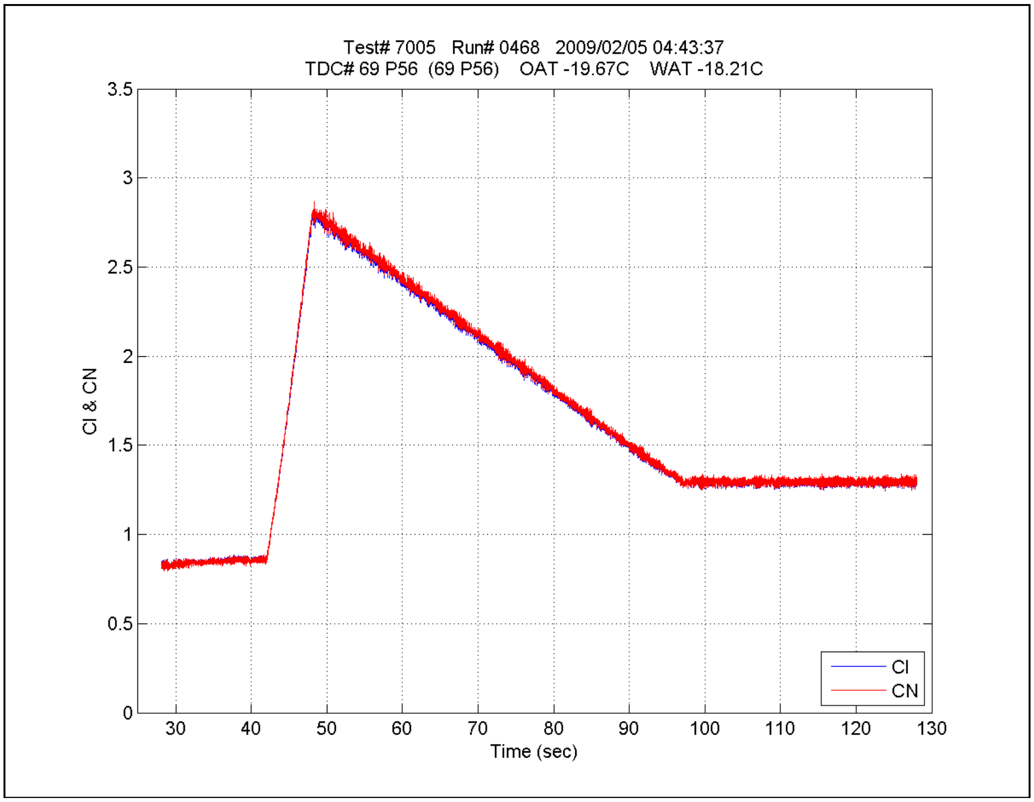


Figure E20: Run #75

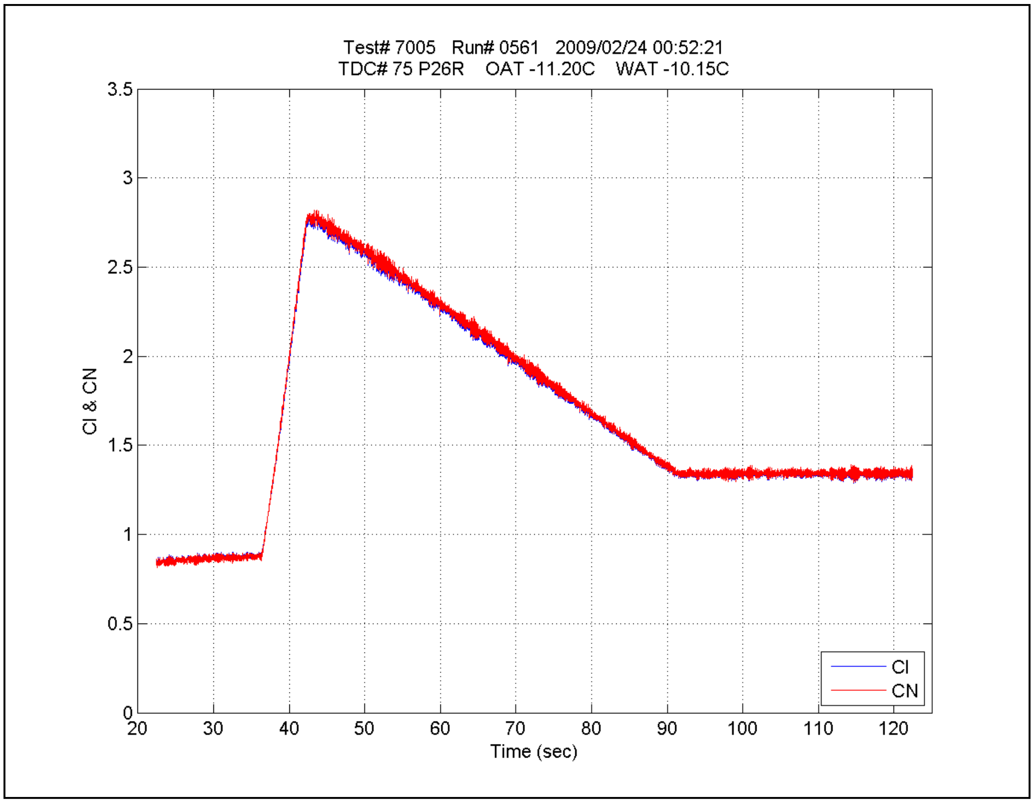


Figure E21: Run #76

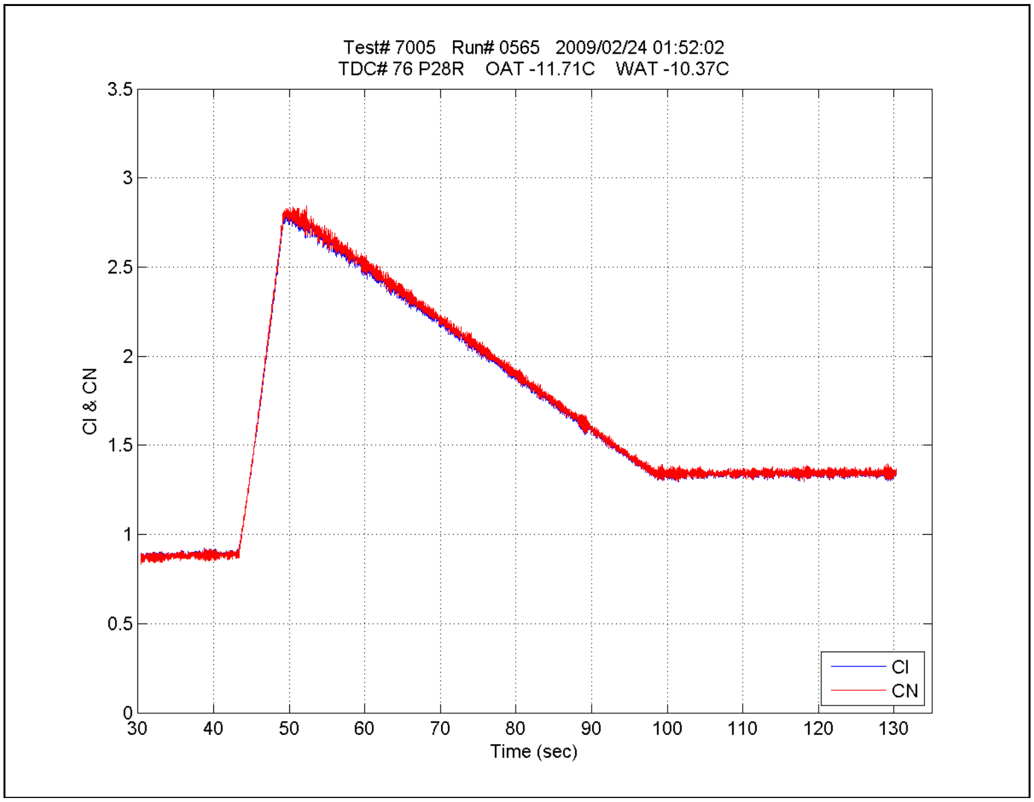


Figure E22: Run #77

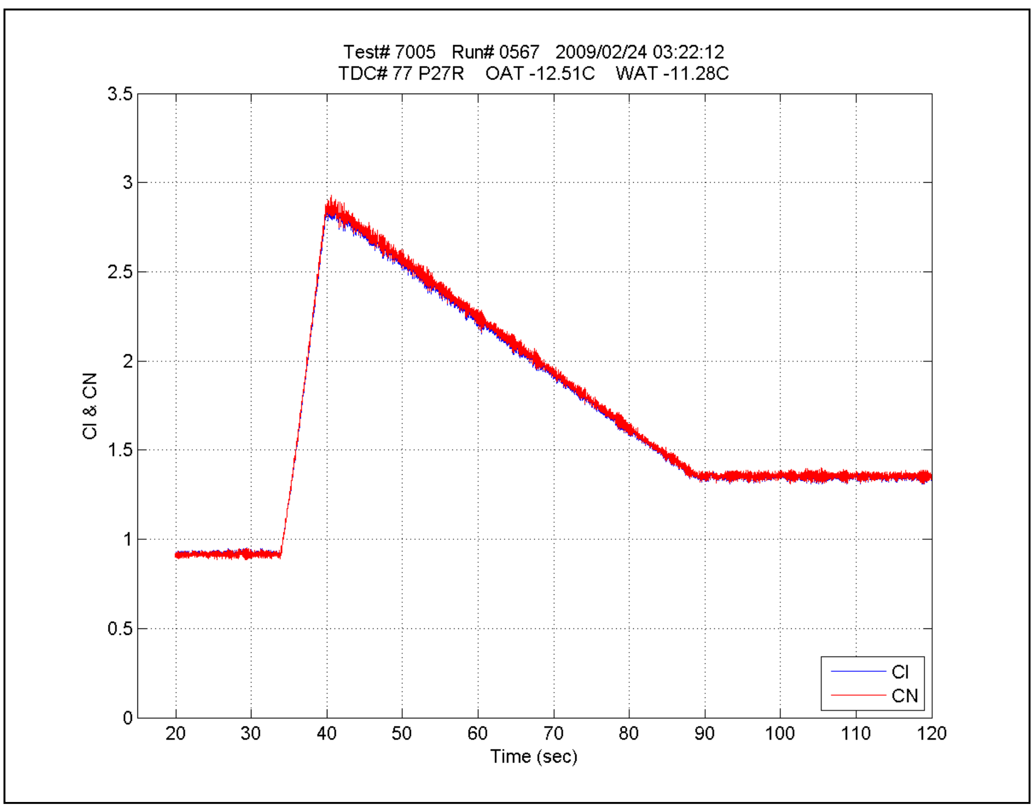


Figure E23: Run #85

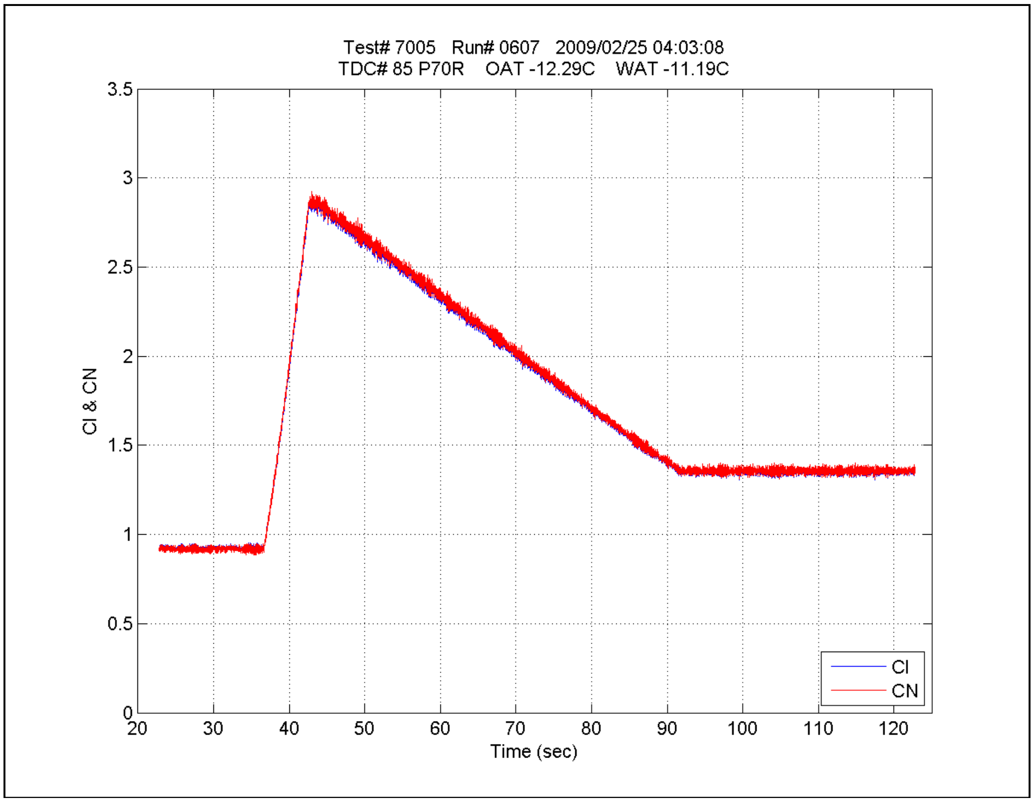
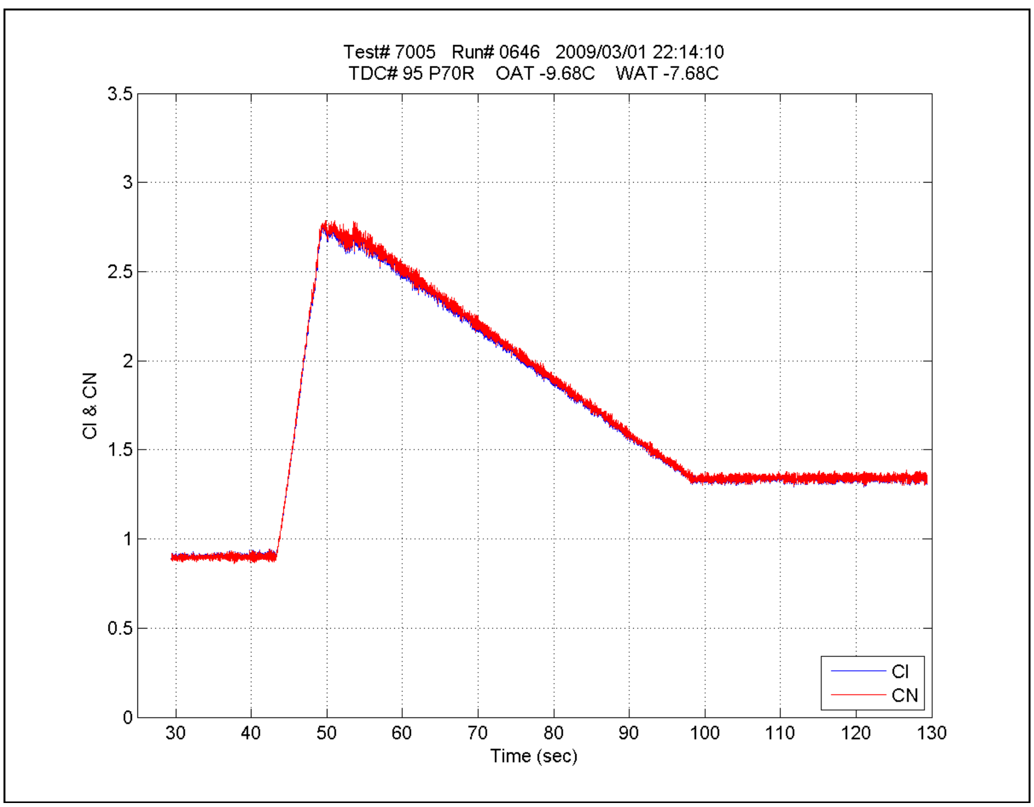


Figure E24: Run #95



TYPE IV LOW SPEED

Figure E25: Run #12

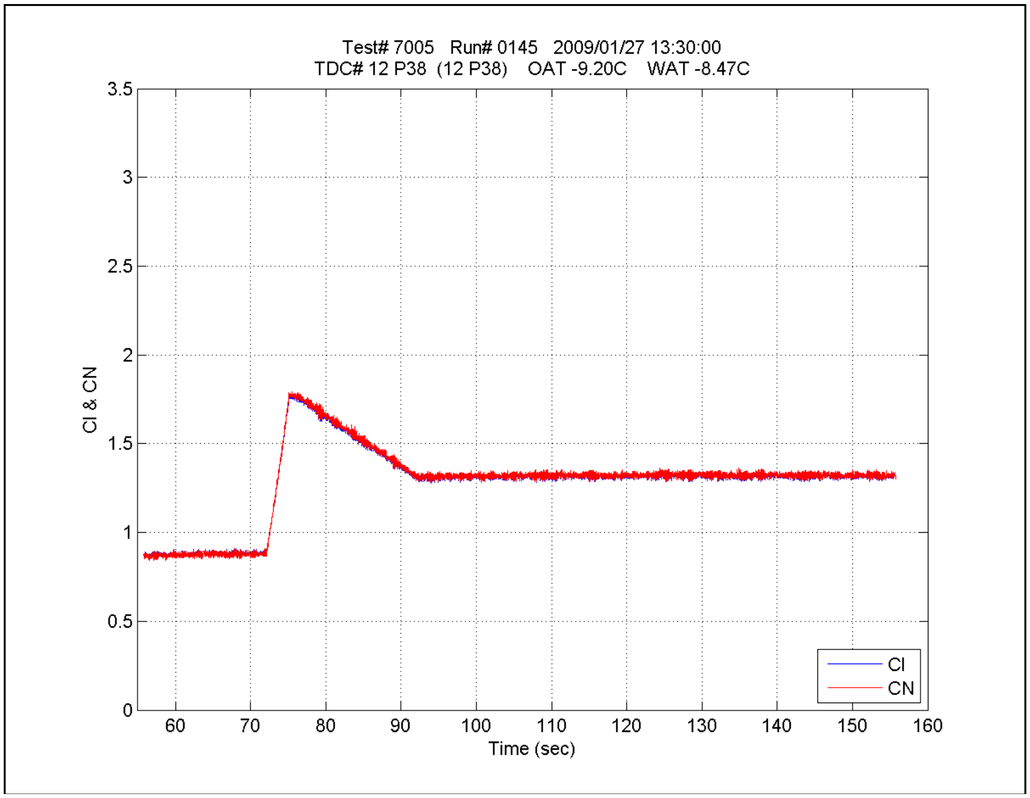


Figure E26: Run #22

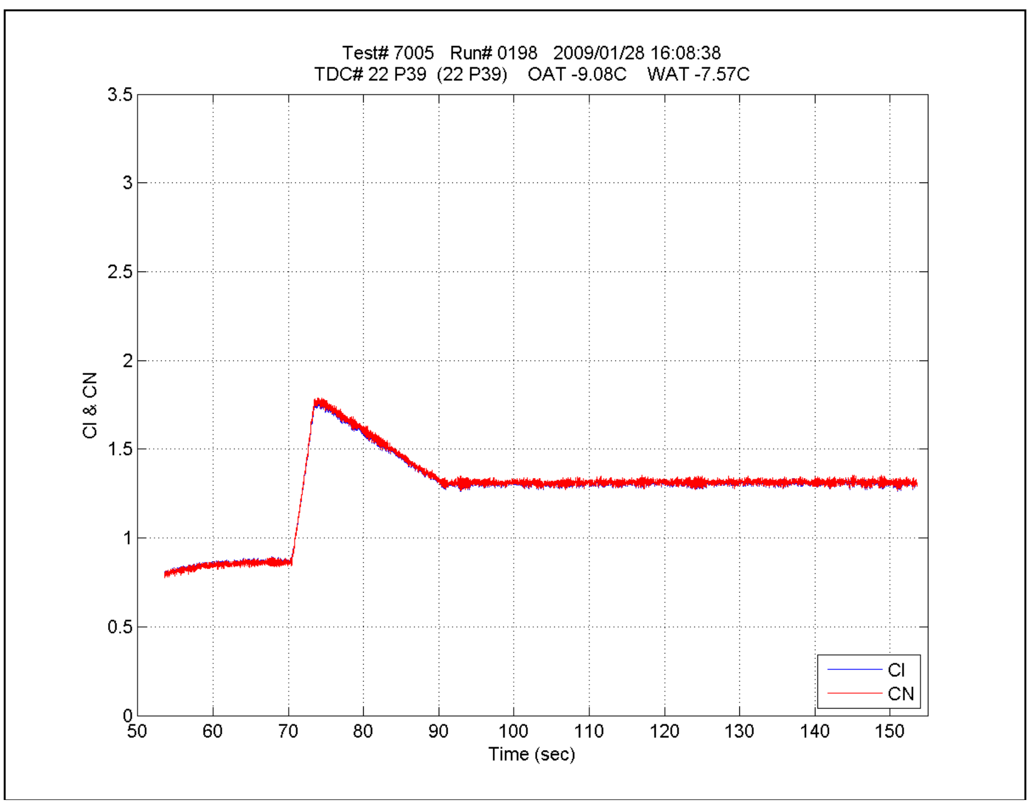


Figure E27: Run #25

Run 25: No Data Available

Figure E28: Run #31

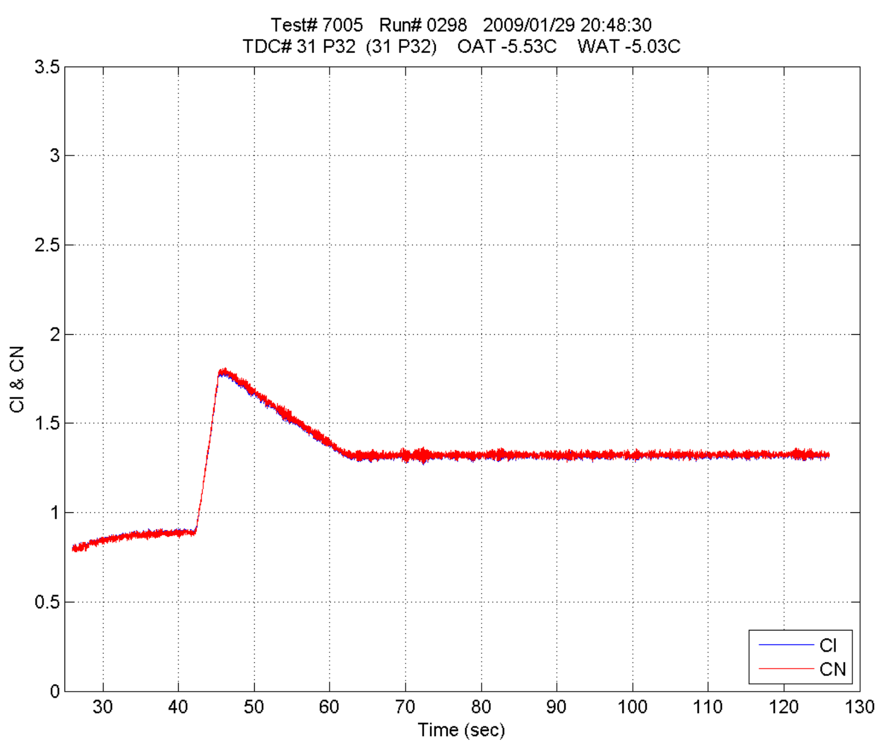


Figure E29: Run #33

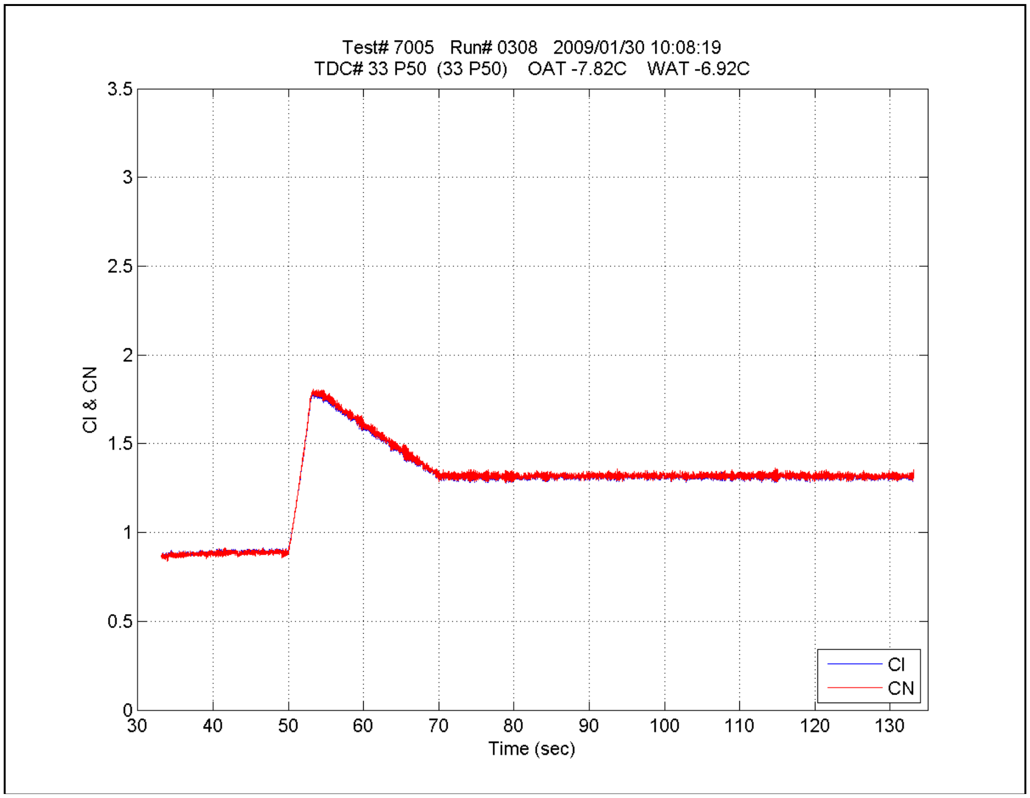


Figure E30: Run #43

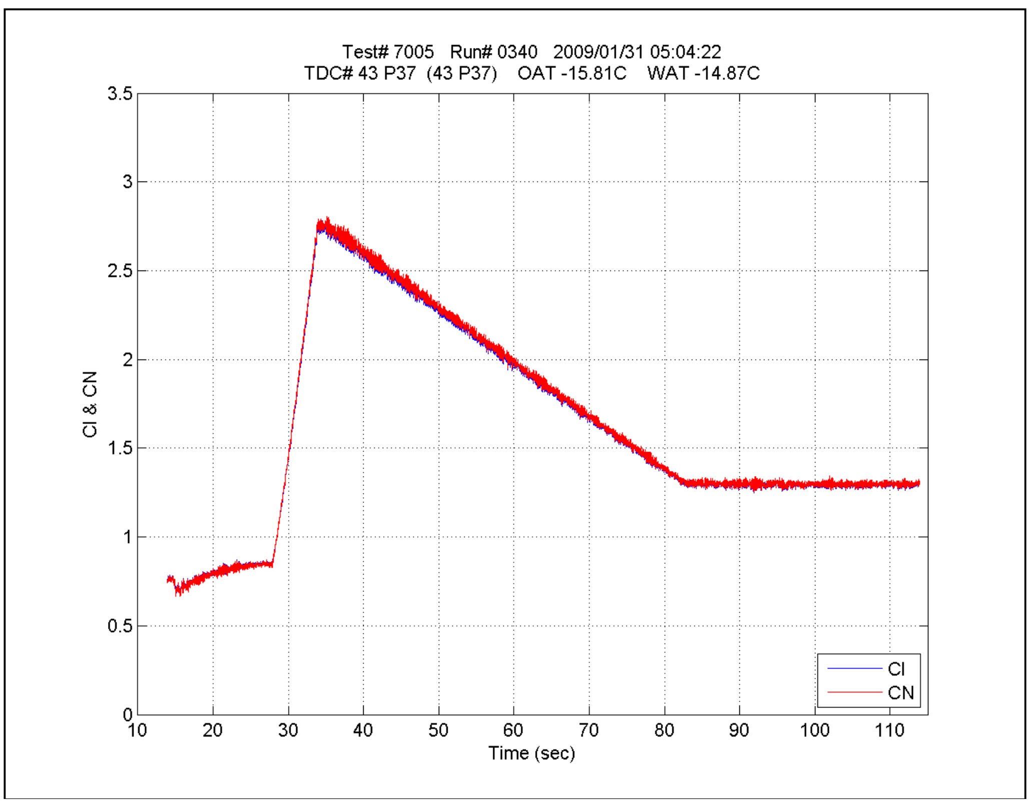


Figure E31: Run #45

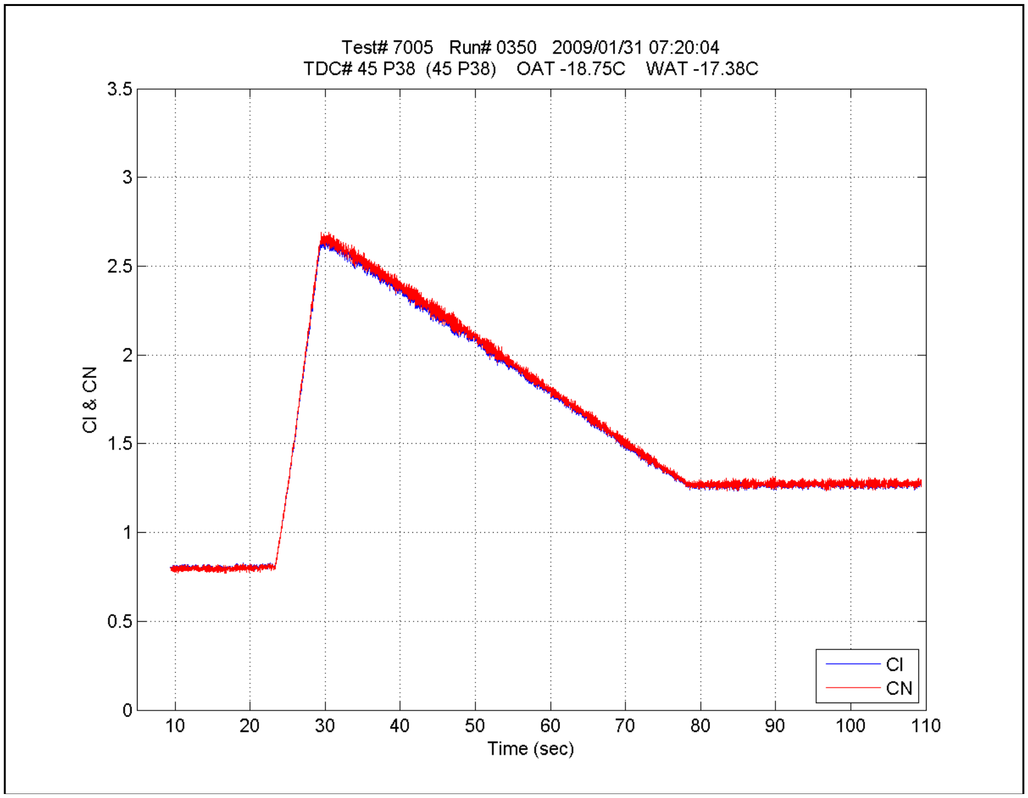


Figure E32: Run #52

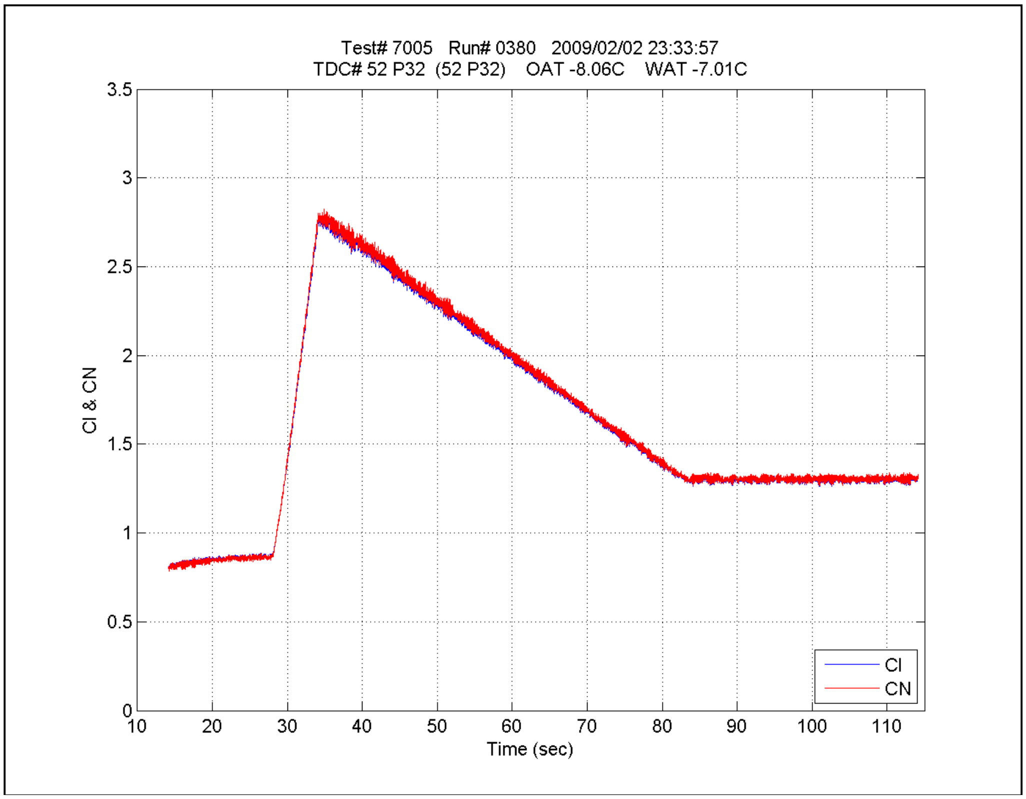


Figure E33: Run #53

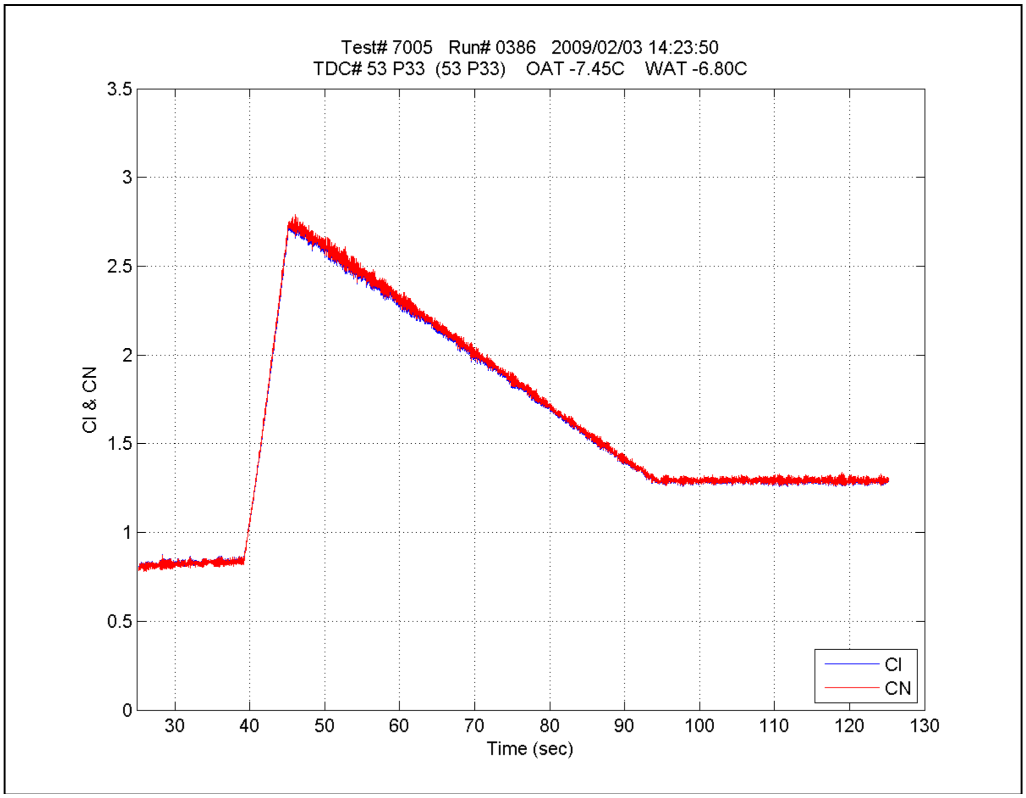


Figure E34: Run #59

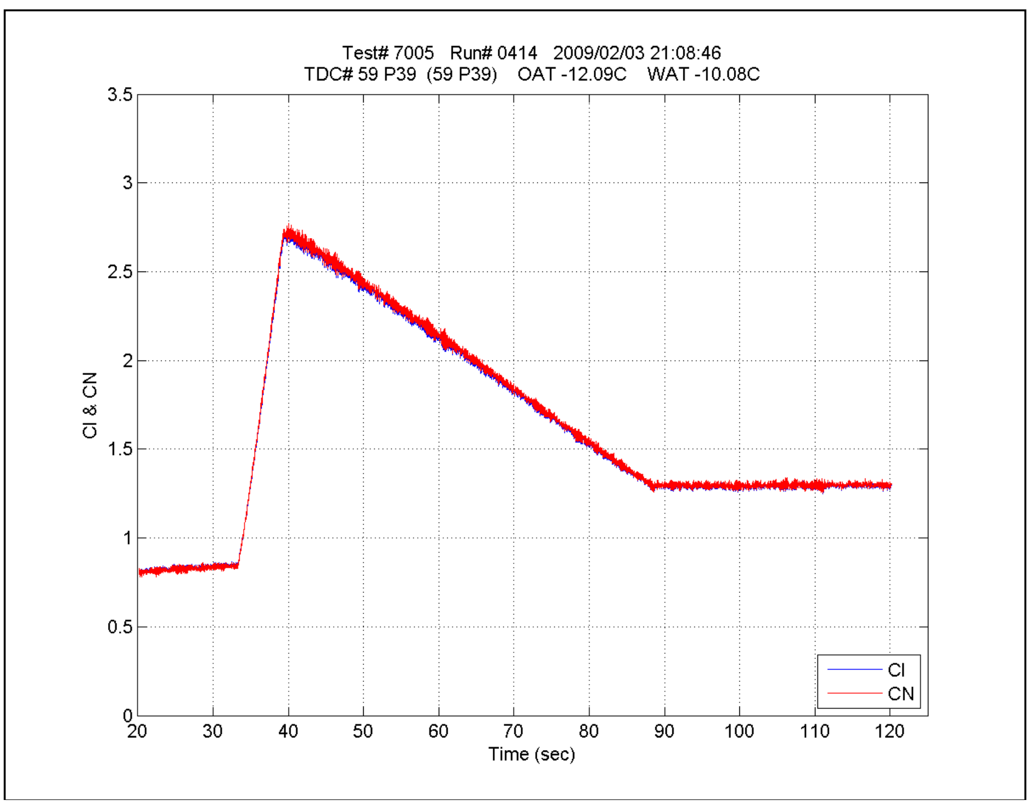


Figure E35: Run #86

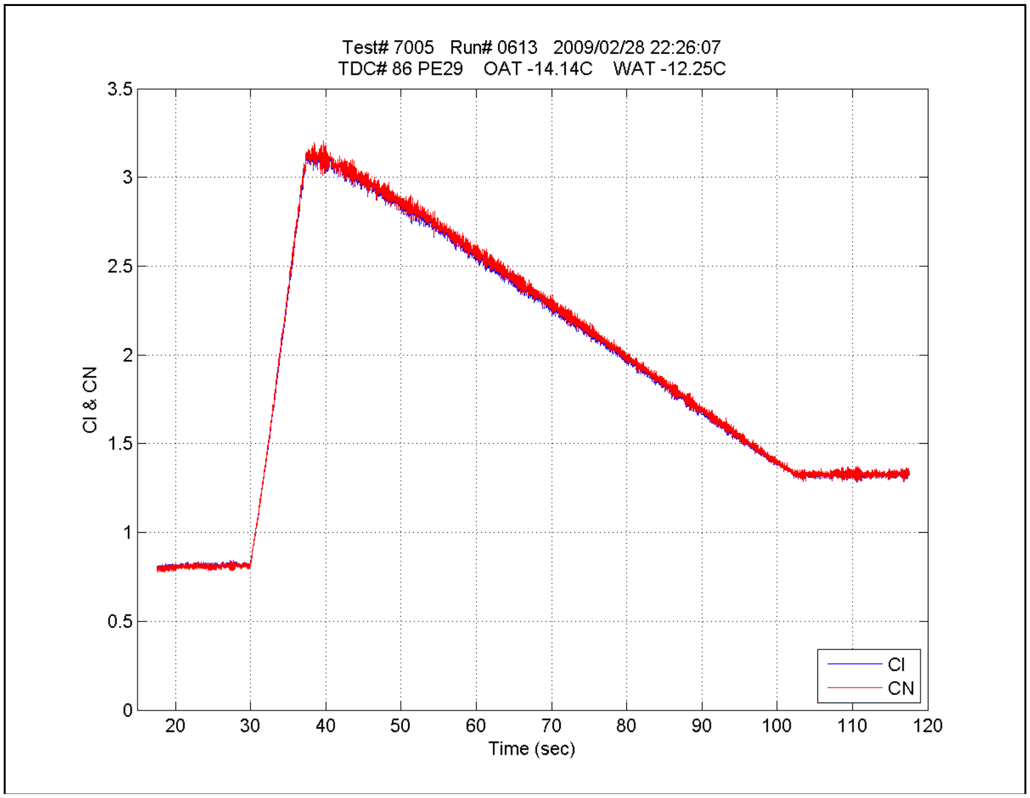


Figure E36: Run #87

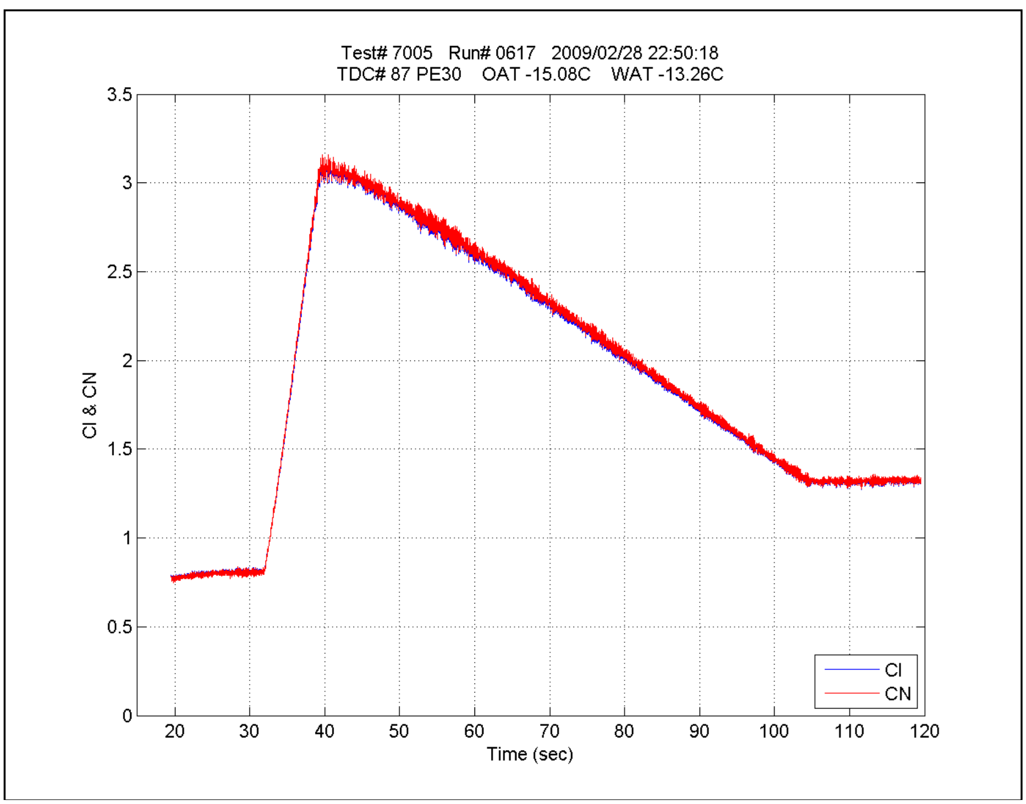


Figure E37: Run #88

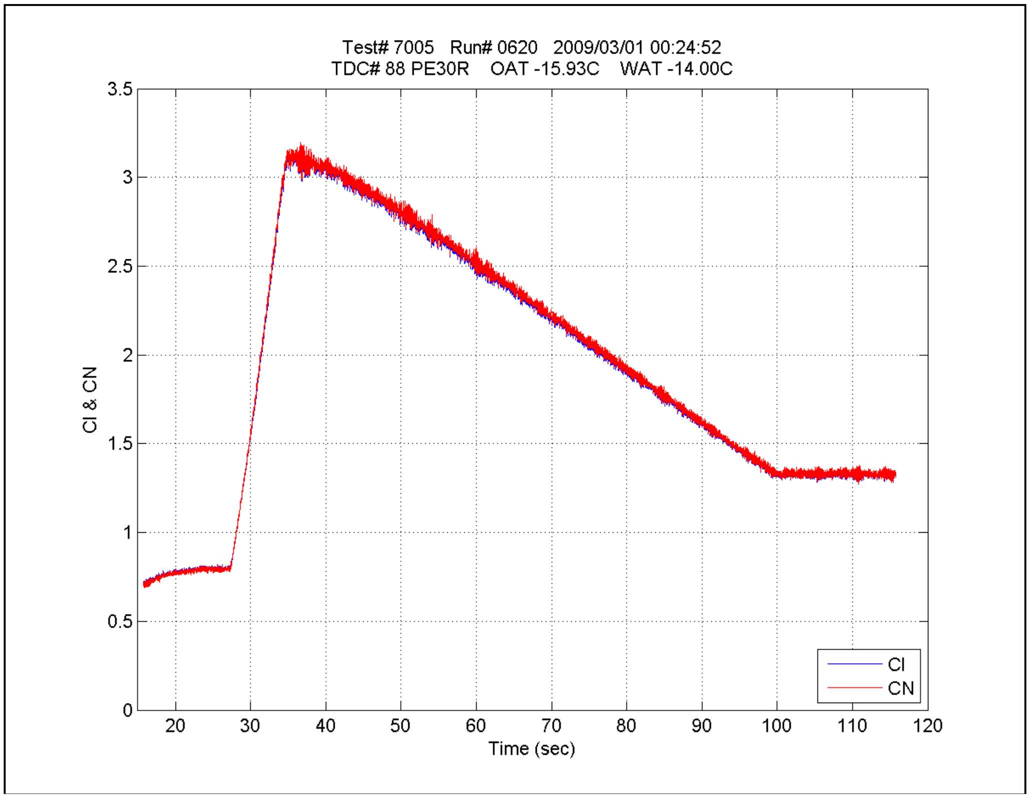


Figure E38: Run #91

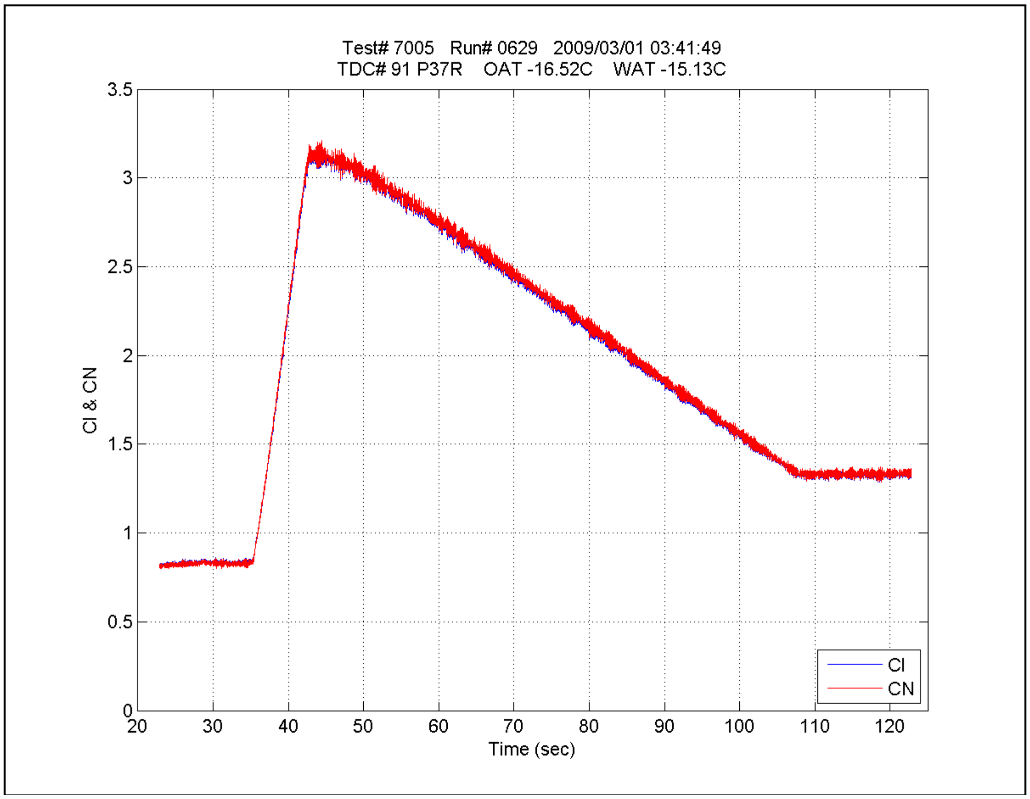


Figure E39: Run #92

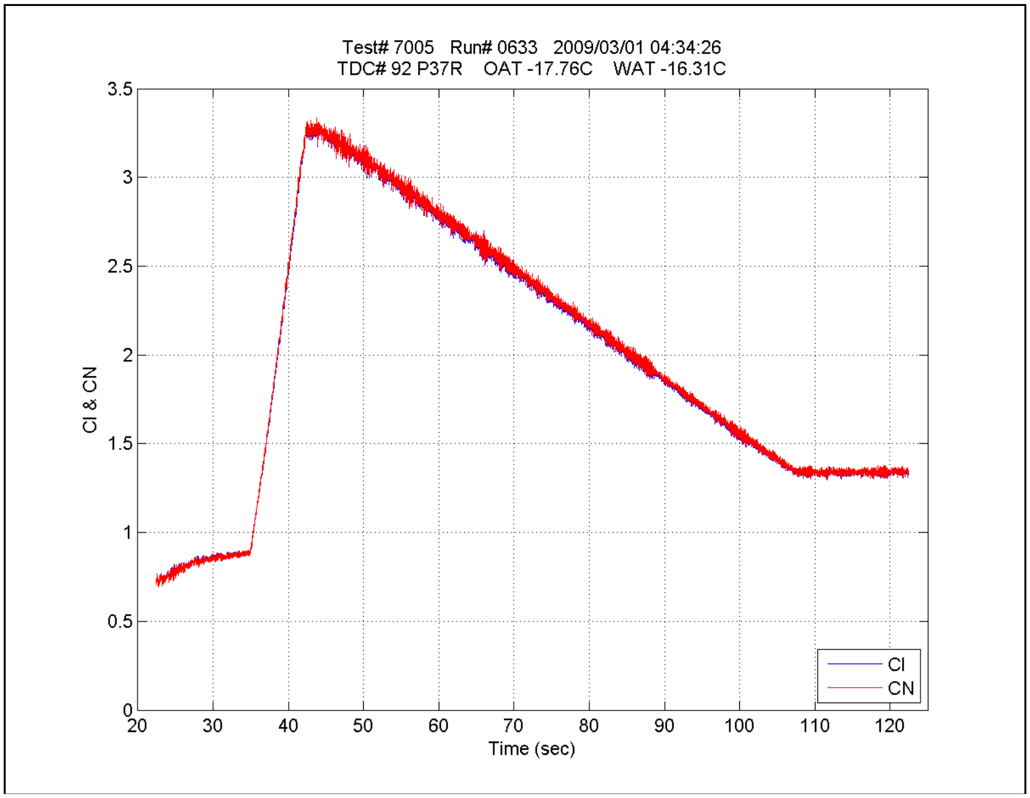


Figure E40: Run #99

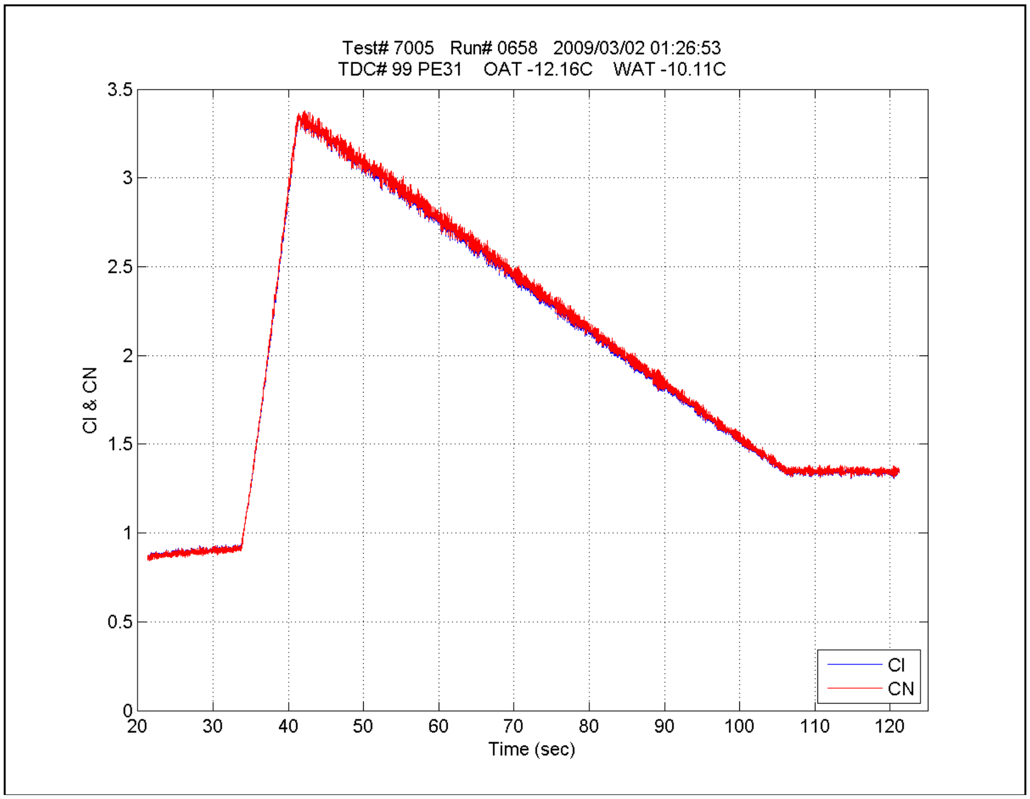


Figure E41: Run #106

Run 106: No Data Available

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TYPE III LOW SPEED

Figure E42: Run #14

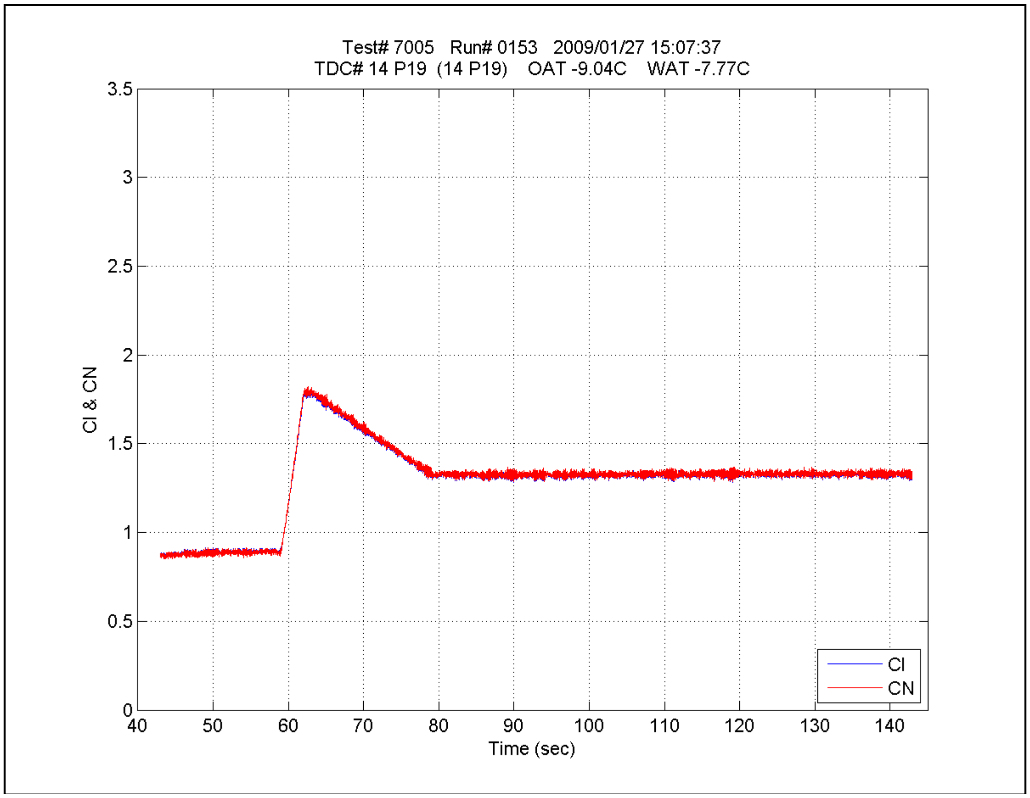


Figure E43: Run #16

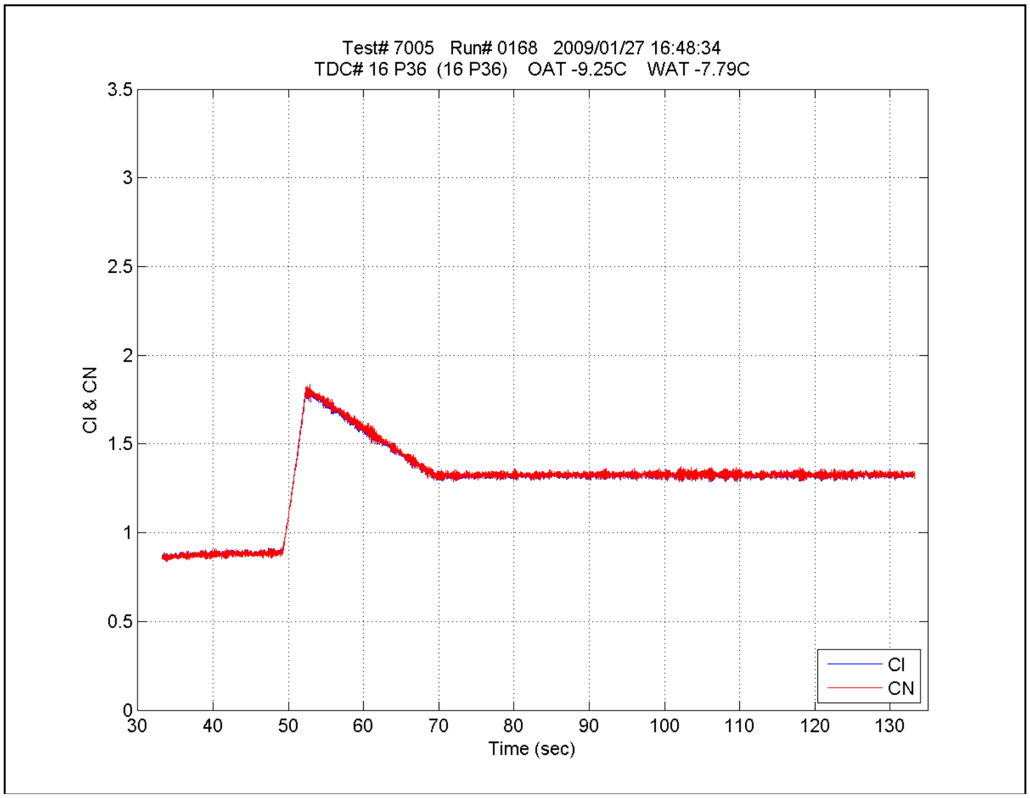


Figure E44: Run #26

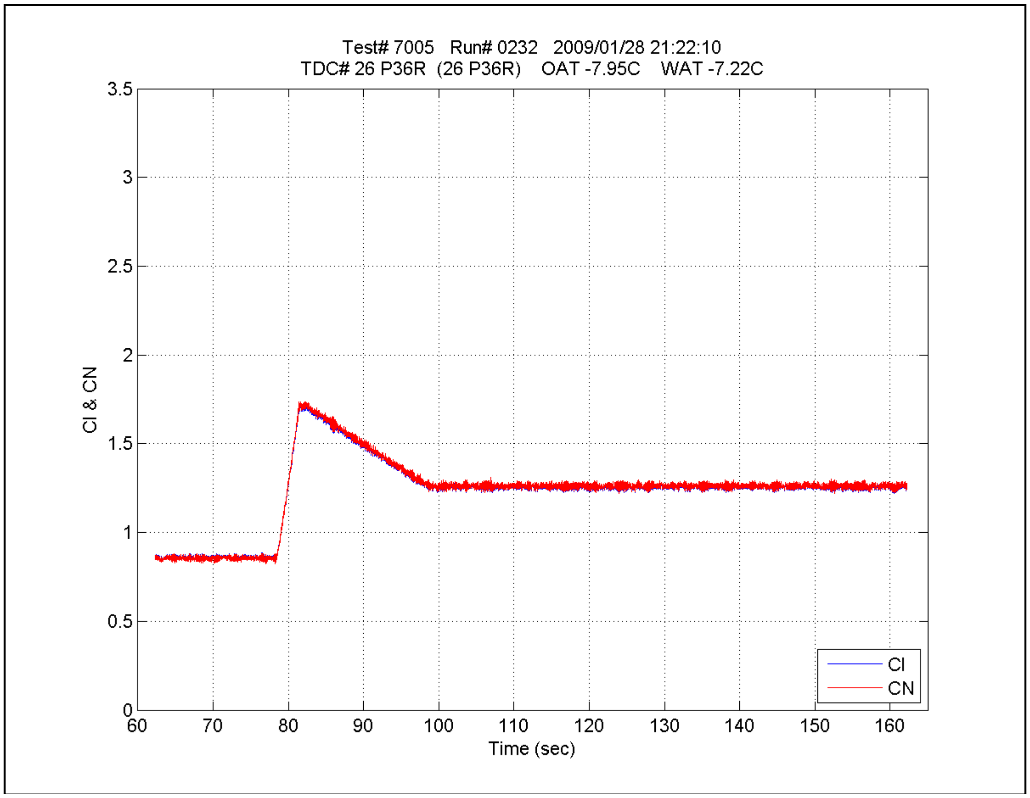


Figure E45: Run #47

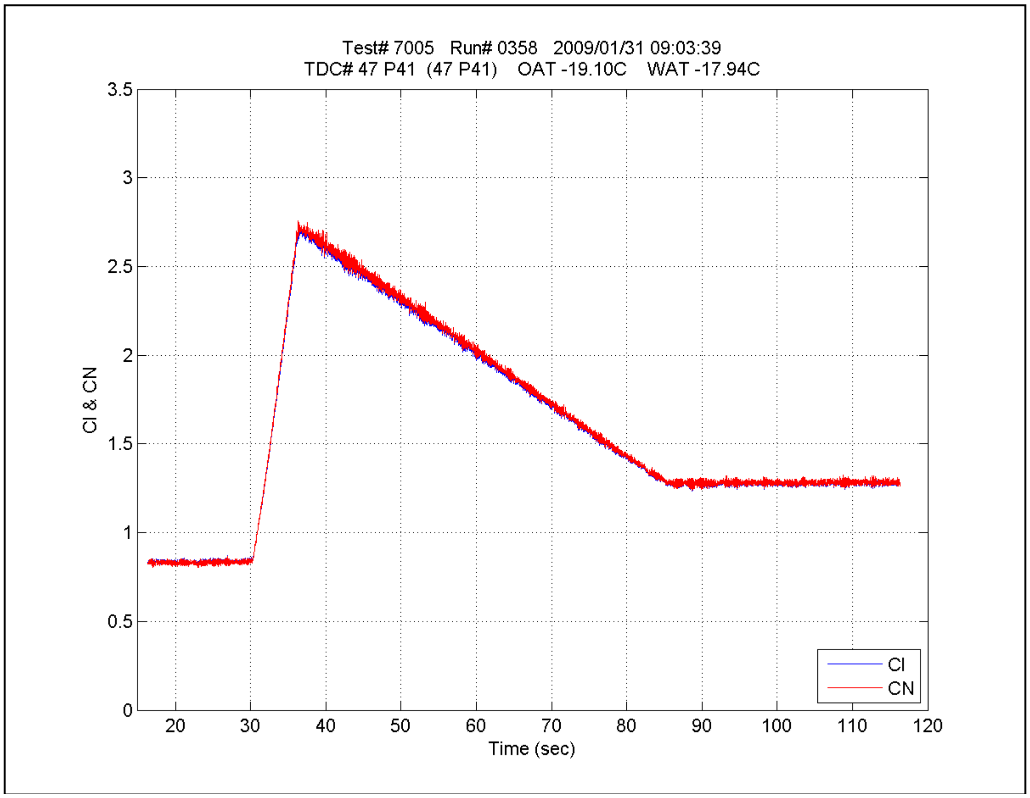


Figure E46: Run #48

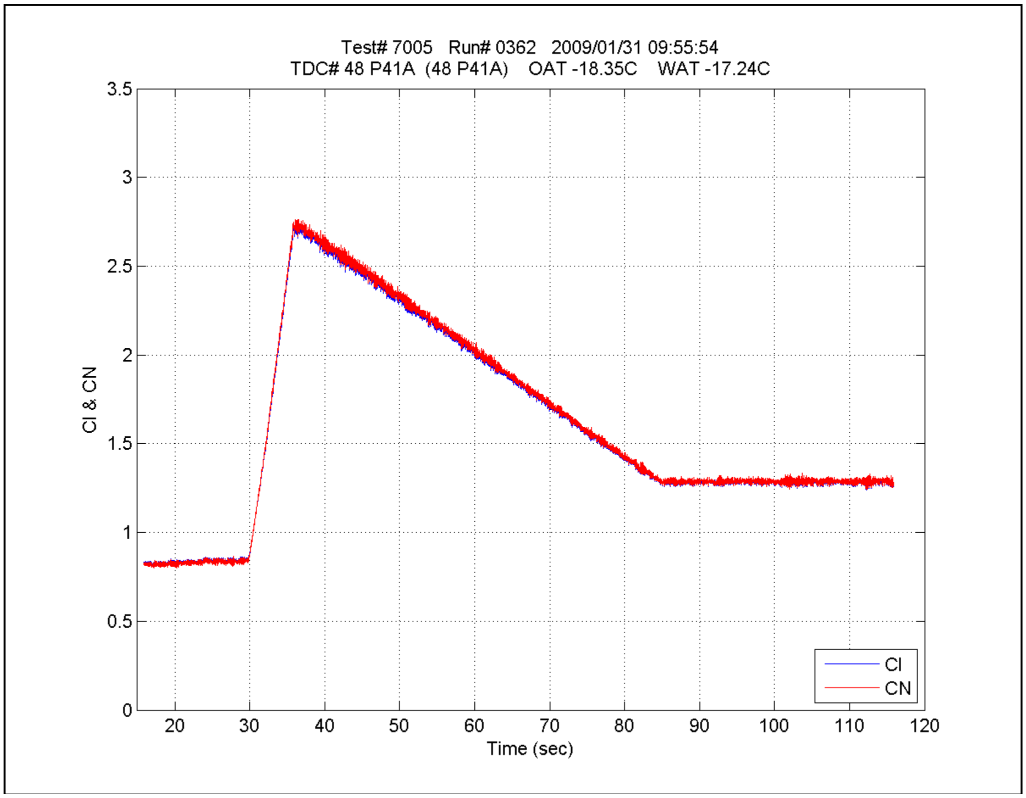


Figure E47: Run #57

Run 57: No Data Available

Figure E48: Run #73

Run 73: No Data Available

Figure E49: Run #74

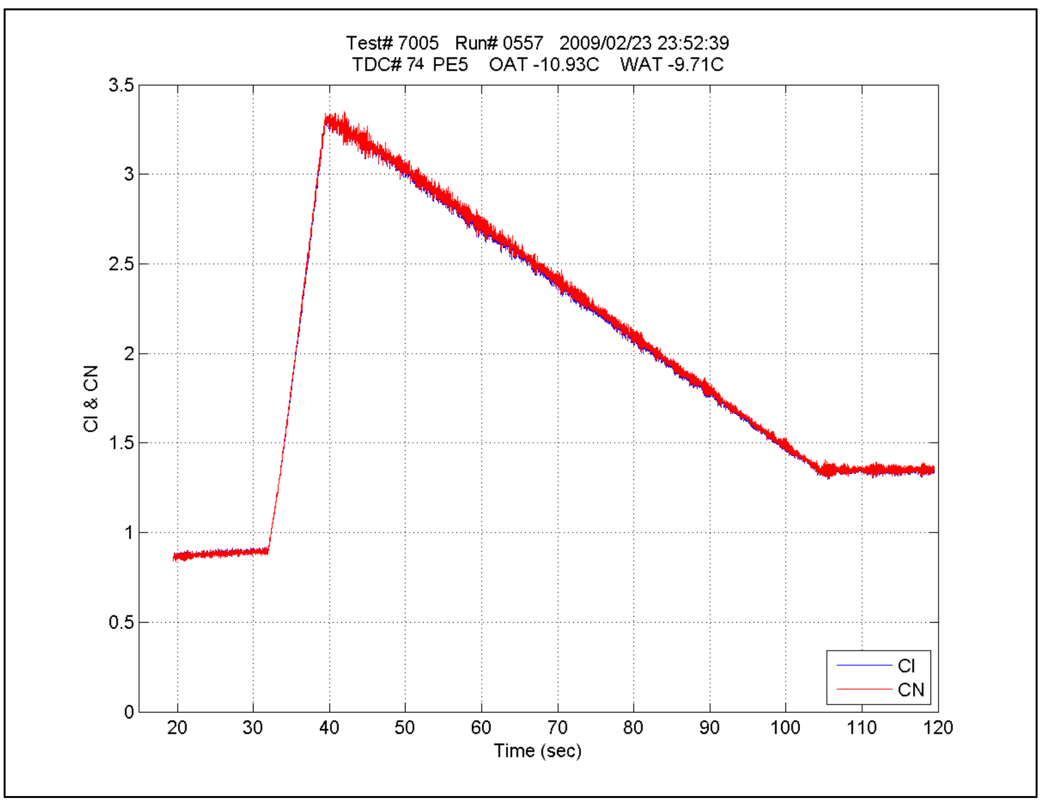


Figure E50: Run #78

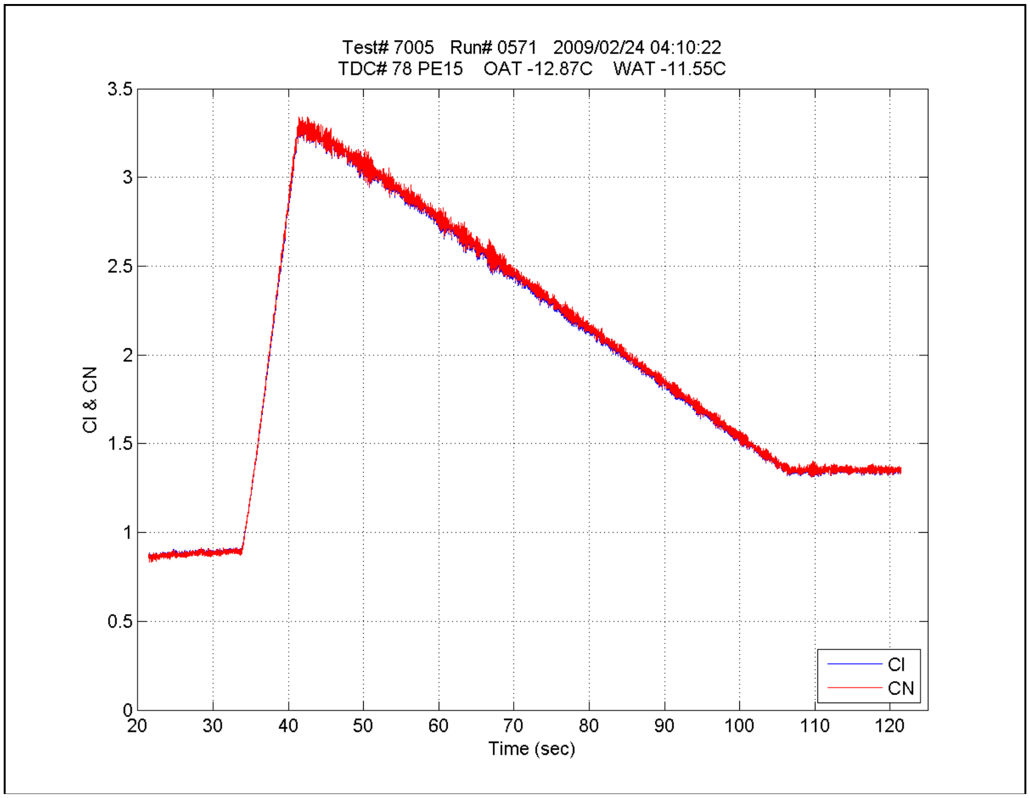


Figure E51: Run #100

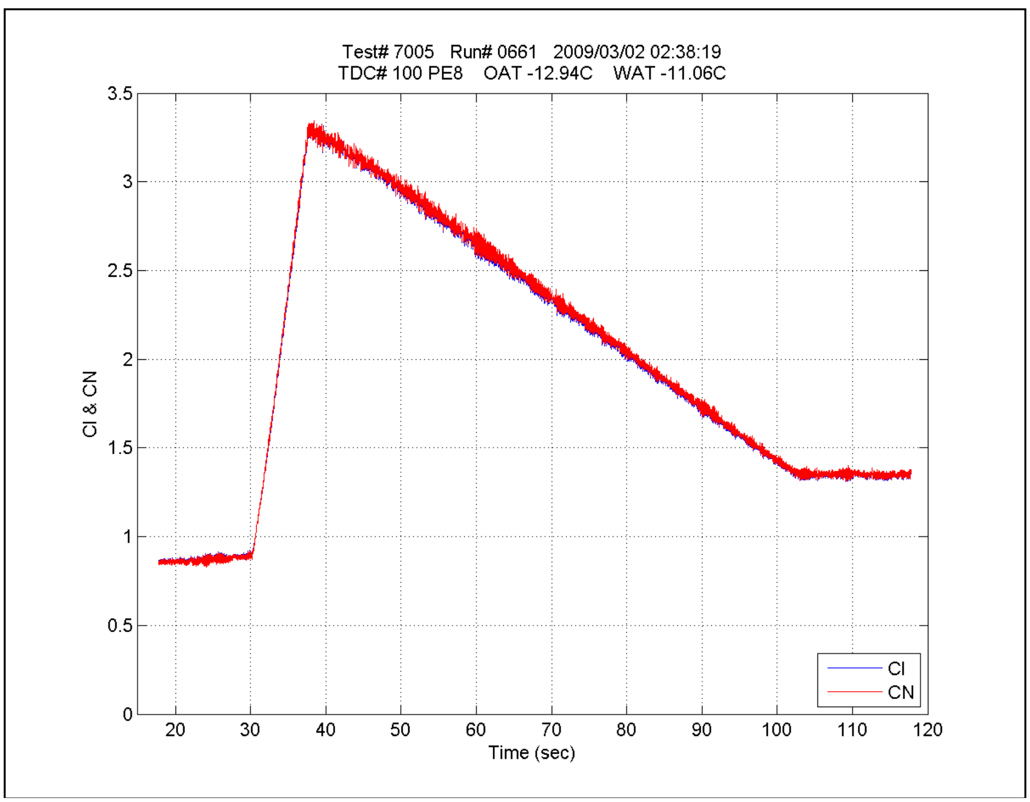
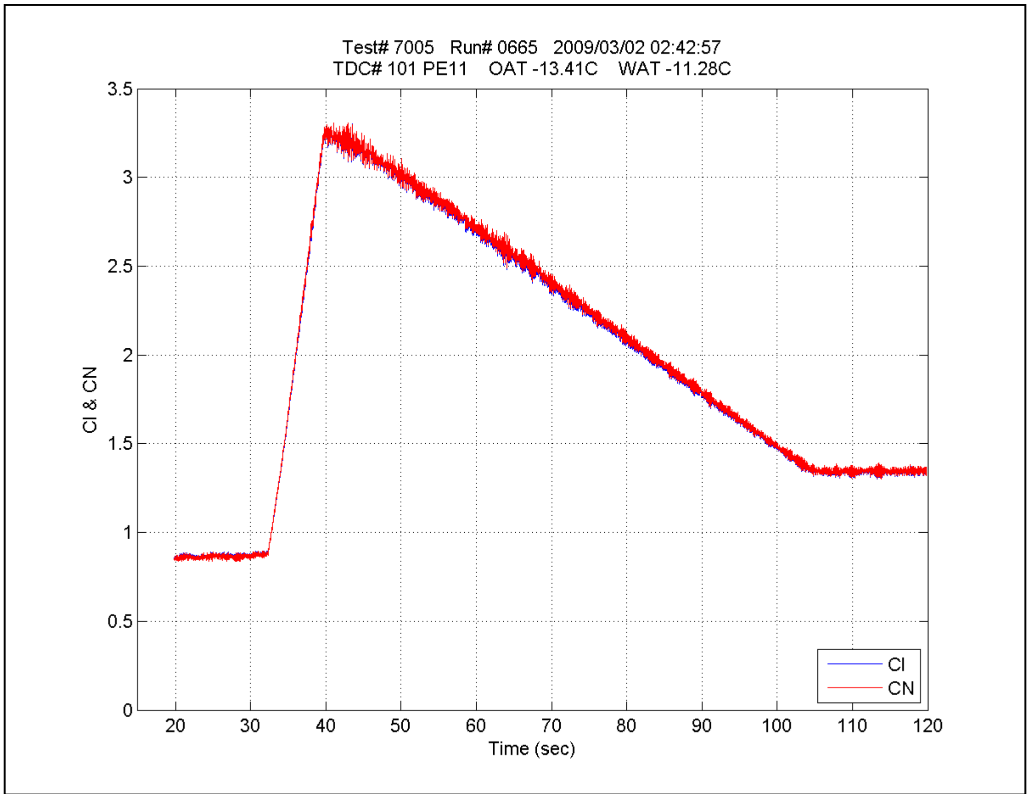


Figure E52: Run #101

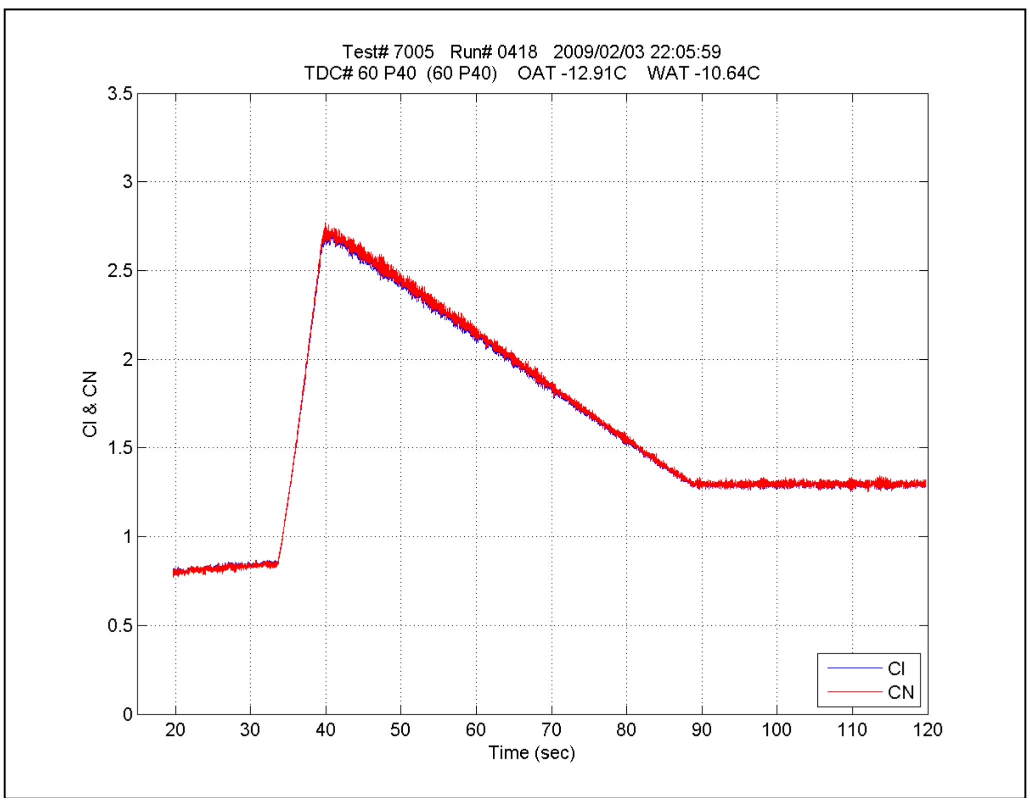


TYPE II LOW SPEED

Figure E53: Run #23

Run 23: No Data Available

Figure E54: Run #60



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APPENDIX F

ICE PELLET ALLOWANCE TIMES SUMMARY SHEETS

LIST OF FIGURES

TYPE IV HIGH SPEED

Figure F1: Run #8

Objective	IP Expansion/TYPE IV HS	FLUID ABC-S (PG)
Test # / Test Plan #	#8 / P26	
OAT	VERY GOOD -13°C TARGET: -10°C	
Rate	IP/SN (24/24.5) GOOD	
Exposure Time	(10 min) GOOD	
Visual Contamination	3 and 3 BAD After 3 and 3	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	NRC Data lost N/A	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	BAD	

(visual)

Figure F2: Run #9

Objective	IP Expansion/TYPE IV HS	FLUID ABC-S+ (PG)
Test # / Test Plan #	#9 / P26	
OAT	-8°C GOOD TARGET: -10°C	
Rate	IP/SN (25/25) GOOD	
Exposure Time	(60) GOOD	
Visual Contamination	3,3 BAD AT ROT. 2,4 2,4 (After)	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	N/A NRC Data lost	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	BAD	

(visual)

Figure F3: Run #10

Objective	IP Expansion/TYPE IV HS	FLUID
Test # / Test Plan #	#10 /P28	PG LAUNCH
OAT	-5C BAD TARGET: -10°C	
Rate	IP/SN (25/25) GOOD	
Exposure Time	(10 min) OK	
Visual Contamination	3,4 START BAD 2,3 ROT. 2,3 End	****** Not Based on photos ****** Visual at Start should be <=3 ****** Visual at Rot LE should be 1
Lift Coefficient	N/A NRC Data lost	****** Use baseline as basis until further analysis of data ****** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	BAD (OAT = BAD, (visual = BAD)	

Figure F4: Run #11

Objective	IP Expansion TYPE IV HIGH SPEED	FLUID
Test # / Test Plan #	#11 /P23	PG ABC-S†
OAT	-6 °C GOOD TARGET: -5°C	
Rate	(25/25) = OK IP/SN	
Exposure Time	(10 min) BAD	
Visual Contamination	AT START 3.3 GOOD AT ROT. 1.2	****** Not Based on photos ****** Visual at Start should be <=3 ****** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.80 GOOD EXCEL 1.76	****** Use baseline as basis until further analysis of data ****** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	Good but BAD (due to expansion)	

Figure F5: Run #13

Objective	IP Expansion TYPE IV HIGH SPEED	FLUID PG LAUNCH
Test # / Test Plan #	#13 / P25	
OAT	-5°C GOOD TARGET: -5°C	
Rate	IP/SN (25/25) GOOD	
Exposure Time	(10) BAD	
Visual Contamination	3.3 AT START GOOD 1.2 AT ROT.	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.79 GOOD EXCEL 1.77	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	Good but BAD (Exposure time should of been 25 min.)	

Figure F6: Run #20

Objective	IP validation TYPE IV HIGH SPEED	FLUID PG ABC-S +
Test # / Test Plan #	#20 / P46	
OAT	-7 good TARGET: -5°C	
Rate	good IP = 75	
Exposure Time	good 25 mins	
Visual Contamination	AT START 3,4 OK (based on photos) AT ROT. 1.2	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.77 GOOD EXCEL 1.75	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	OK	

Figure F7: Run #21

Objective	IP Validation / TYPE IV HS
Test # / Test Plan #	#21 / P45
OAT	VG ACTUAL: -8.5°C TARGET: -5°C
Rate	G IP=25
Exposure Time	G 50 MINS
Visual Contamination	AT START 3.3 G AT ROT. 1.2
Lift Coefficient	VISUAL 1.78 G EXCEL 1.755 Baseline 1.792-2 1.760-13
OVERALL STATUS (good, bad, or review)	G

FLUID
PG ABC-S +

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1

***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F8: Run #29

Objective	IP validation / TYPE IV HS
Test # / Test Plan #	29 / P48
OAT	-3 Fair TARGET: -5°C ACTUAL: -2.6°C
Rate	good IP=75
Exposure Time	good 25 MINS
Visual Contamination	AT START 2.2 good AT ROT. 1.1.5
Lift Coefficient	VISUAL 1.83 good EXCEL 1.794
OVERALL STATUS (good, bad, or review)	good.

FLUID
EG 106

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1

***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

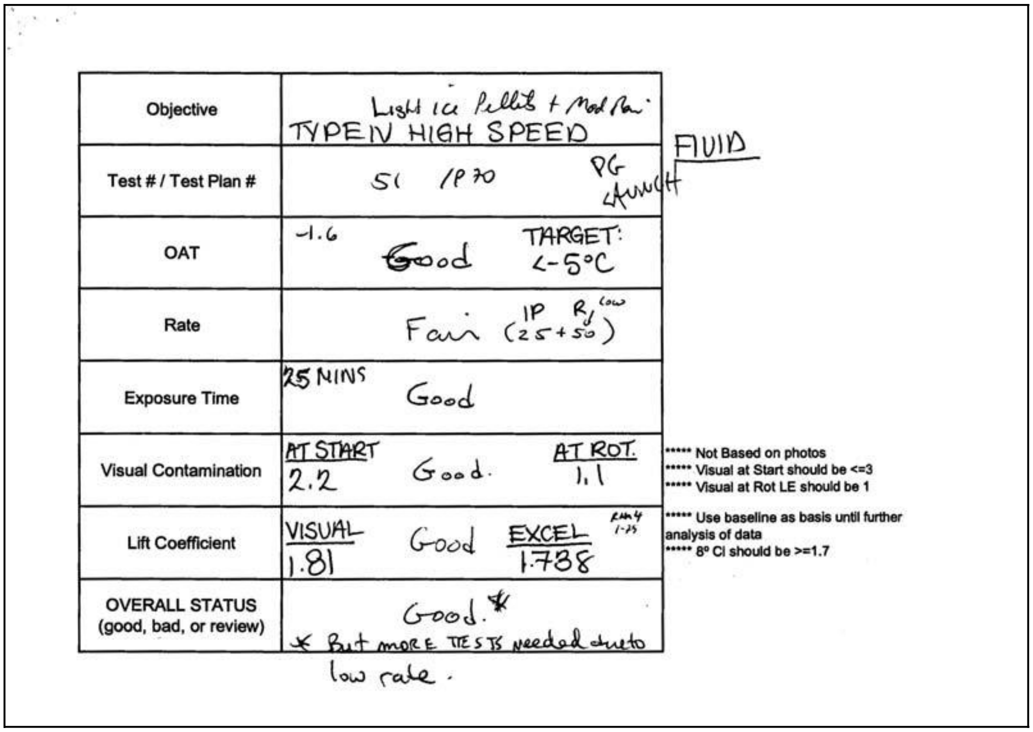
Figure F9: Run #30

Objective	IP validation / TYPE IV HS	FLUID EG106
Test # / Test Plan #	#30 / P47	
OAT	TARGET -5°C Fair ACTUAL=-1.6°C	
Rate	G IP:25	
Exposure Time	G 50 MINS	
Visual Contamination	AT START 1.5, 2 G AT ROT. 1.1	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.80 G EXCEL 1.793 Baseline 1.8	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	G	

Figure F10: Run #44

Objective	TYPE IV HS IP+S (-5 to -10)	FLUID EG106
Test # / Test Plan #	44 / p27	
OAT	-12.3 VG TARGET: -10°C	
Rate	IP: 25 SN: 25 VG (Moderate)	
Exposure Time	15 MINS G	
Visual Contamination	AT START 2.2 G AT ROT. 1.1	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient at 8°	VISUAL 1.80 G EXCEL 1.746 Run 42	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	G	

Figure F11: Run #51

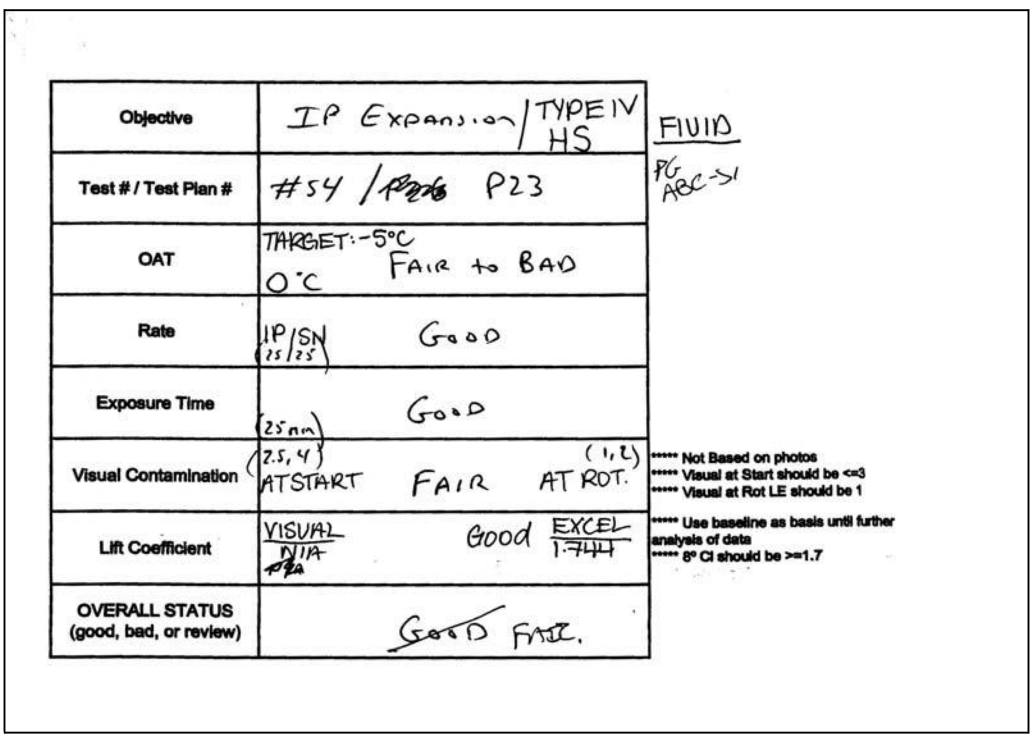


Objective	Light Ice Pellets + Mod Rain TYPE IV HIGH SPEED
Test # / Test Plan #	51 / P70
OAT	-1.6 Good TARGET: <-5°C
Rate	Fair (IP 25 + R 50 low)
Exposure Time	25 MINS Good
Visual Contamination	AT START 2.2 Good. AT ROT. 1.1
Lift Coefficient	VISUAL 1.81 Good EXCEL 1.788
OVERALL STATUS (good, bad, or review)	Good.* * But MORE TESTS needed due to low rate.

FLUID PG LAUNCH

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1
***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F12: Run #54



Objective	IP Expansion / TYPE IV HS
Test # / Test Plan #	#54 / ~~P26~~ P23
OAT	TARGET: -5°C 0°C FAIR to BAD
Rate	IP/SN (25/25) GOOD
Exposure Time	(25 min) GOOD
Visual Contamination	(2.5, 4) AT START FAIR (1, 2) AT ROT.
Lift Coefficient	VISUAL N/A Good EXCEL 1.744
OVERALL STATUS (good, bad, or review)	~~GOOD~~ FAIR.

FLUID PG ABC-S1

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1
***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F13: Run #58

Objective	TYPE IV HIGH SPEED IP Expansion	FLUID PG LAUNCH
Test # / Test Plan #	#58 / P25	
OAT	-6.3C GOOD TARGET -5°C	
Rate	IP / SN 25 / 25 GOOD	
Exposure Time	25 MINS GOOD	
Visual Contamination	3 and 4 (initial) BAD to FAIR 1 and 2.5 (After)	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.78 OK EXCEL 1.706	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	FAIR NEEDS Further Review with WARREN. due to initial visual of 3/4	

Figure F14: Run #64

Objective	Ice Pellet Validation TYPE IV HIGH SPEED	FLUID EG 106
Test # / Test Plan #	64 / P52	
OAT	-14°C Very Good TARGET -10°C	
Rate	IP : 25 ZR : 25 GOOD	
Exposure Time	10 MINS GOOD	
Visual Contamination	AT START 2.2 GOOD AT ROT. 1.1	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	Data Loss by NRC - Lost for ever - N/A	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	GOOD	

Figure F15: Run #65

Objective	IP Validation TYPE IV HIGH SPEED	FLUID PG ABC-S+
Test # / Test Plan #	65 / P51	
OAT	TARGET: –10°C -13°C very GOOD	
Rate	IP: 25 ZR: 25 GOOD	
Exposure Time	10 MINS GOOD	
Visual Contamination	AT START 3.3 GOOD AT ROT. 1.2	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.79 GOOD EXCEL 1.725	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	GOOD	

Figure F16: Run #66

Objective	~~68~~ TYPE IV HS. IP VALIDATION	FLUID PG [illegible]
Test # / Test Plan #	66 / P53	
OAT	-15°C Fair* TARGET -25°C	
Rate	IP: 25 G	
Exposure Time	30 MINS G	
Visual Contamination	AT START 3.3 G AT ROT. 1.2	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.785 OK EXCEL 1.707	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	Good *	

* Recommend tests at -25°C (Priority 3 (low).)

Figure F17: Run #67

Objective	JP Validation / TYPE IV HS
Test # / Test Plan #	67 / P54
OAT	-16 Fair * TARGET -25°C
Rate	good IP: 75
Exposure Time	good. 10 MINS
Visual Contamination	AT START 4.4 bad (>3 at start) AT ROT. 1.3
Lift Coefficient	VISUAL 1.77 OK EXCEL 1.706
OVERALL STATUS (good, bad, or review)	review *

FLUID
IG LAUNCH

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1

***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

* redo test at -25°C.

Figure F18: Run #68

Objective	JP Validation / TYPE IV HS
Test # / Test Plan #	68 / P55
OAT	-17°C Fair * TARGET -25°C
Rate	IP: 25 Good
Exposure Time	30 MINS good
Visual Contamination	AT START 3.3 good AT ROT. 1.1
Lift Coefficient	VISUAL 1.825 good EXCEL 1.752
OVERALL STATUS (good, bad, or review)	Good *

FLUID
EG106

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1

***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

* same recommendation as test 66 (only redo test

Figure F19: Run #69

Objective	IP validation. TYPE IV HS	FLUID
Test # / Test Plan #	69 / P56	EG106
OAT	-18 fair * TARGET -25°C	
Rate	IP: 75 good	
Exposure Time	10 MINS good.	
Visual Contamination	AT START 3.3 good; AT ROT. 1.1	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.85 good; EXCEL 1.741	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	* good to fair (due to OAT).	

* No need to redo because recommended to

Figure F20: Run #75

Objective	TYPE IV HIGH SPEED IP & SN-(IP EXPANSION)	FLUID ABC-S+ (PG)
Test # / Test Plan #	RUN #75 / P26R	
OAT	G; PG; TARGET: -10°C ACTUAL: -8.8°C	
Rate	G; IP=25 SN=10	
Exposure Time	G; 10 MINS	
Visual Contamination	@ START 2.2; G; @ ROT. 1.2	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.84; G; EXCEL 1.770	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	GOOD	

Figure F21: Run #76

Objective	TYPE IV HIGH SPEED IP & SN-(IP EXPANSION)	
Test # / Test Plan #	RUN # 76 / P28R	
OAT	G PG TARGET: -10°C ACTUAL: -9.8°C	
Rate	G IP = 25 SN = 10	
Exposure Time	VG 15 MINS	
Visual Contamination	@ START 3.3 G @ ROT 1.2	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.86 G EXCEL 1.784	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	GOOD	

FLUID
LAUNCH

Figure F22: Run #77

Objective	TYPE IV HIGH SPEED IP & SN-(IP EXPANSION)	
Test # / Test Plan #	RUN # 77 / P27R	
OAT	G EG TARGET: -10°C ACTUAL: -9.2°C	
Rate	G IP = 25 SN = 10	
Exposure Time	VG 15 MINS	
Visual Contamination	@ START 2.2 G @ ROT 1.1	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.86 G EXCEL 1.823	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	GOOD	

FLUID
EG 106

Figure F23: Run #85

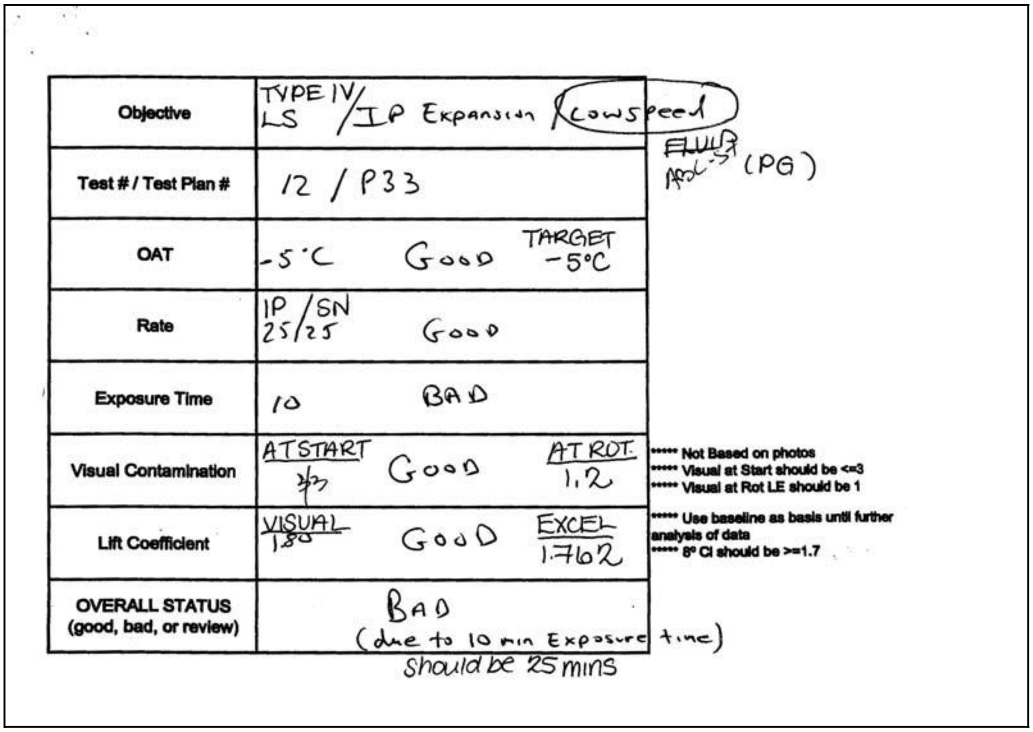
Objective	IP & MOD. RAIN / TYPE IV HS	
Test # / Test Plan #	RUN #85 | P70R2	FLUID EG106
OAT	G EG TARGET: >-5°C ACTUAL: -1.2°C	
Rate	G IP=25 R=75	
Exposure Time	G 25 MINS	
Visual Contamination	@ START 1.5, 1.5 G @ ROT. 1, 1	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.89 G EXCEL 1.830	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	GOOD	

Figure F24: Run #95

Objective	IP & MOD RAIN TYPE IV HIGH SPEED	
Test # / Test Plan #	RUN #95 | P70R	FLUID LAUNCH
OAT	G RC TARGET: >-5°C ACTUAL: -1°C	
Rate	G IP=25 R=75	
Exposure Time	G 25 MINS	
Visual Contamination	@ START 2, 2 Good @ ROT. 1, 1.5	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.82 G EXCEL 1.799	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	Good	

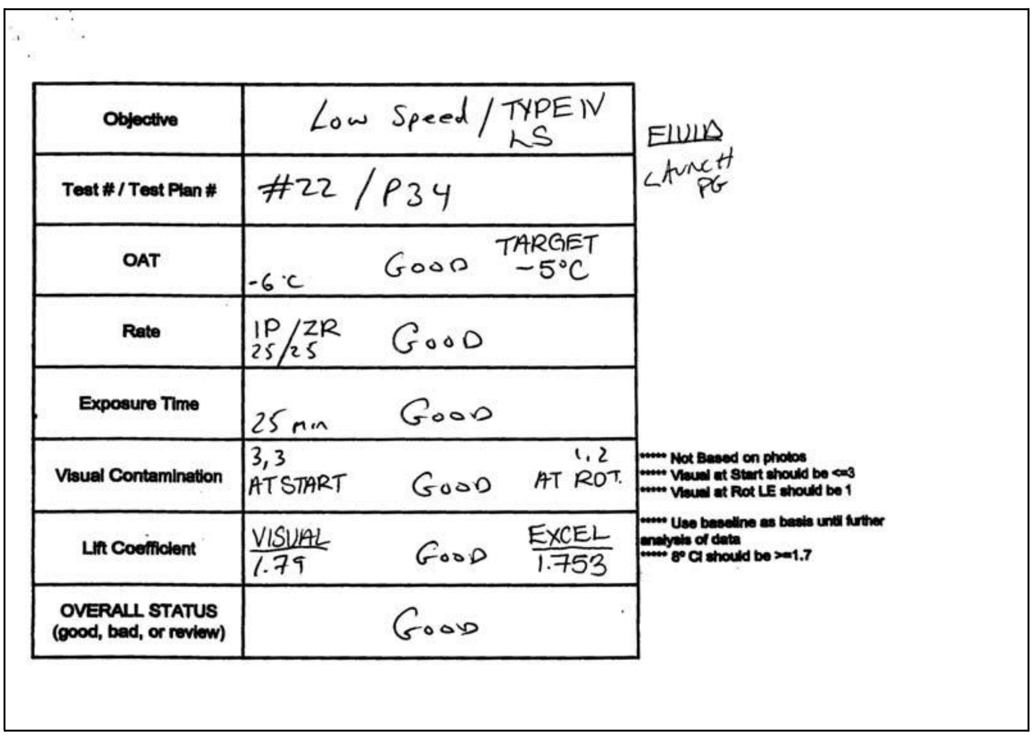
TYPE IV LOW SPEED

Figure F25: Run #12



Objective	TYPE IV LS / IP Expansion / Low speed	FLUID APOL-57 (PG)
Test # / Test Plan #	12 / P33	
OAT	-5°C Good TARGET -5°C	
Rate	IP/SN 25/25 Good	
Exposure Time	10 BAD	
Visual Contamination	AT START 3/3 Good AT ROT. 1.2	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.80 Good EXCEL 1.762	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	BAD (due to 10 min Exposure time) should be 25 mins	

Figure F26: Run #22



Objective	Low Speed / TYPE IV LS	FLUID LAUNCH PG
Test # / Test Plan #	#22 / P34	
OAT	-6°C Good TARGET -5°C	
Rate	IP/ZR 25/25 Good	
Exposure Time	25 min Good	
Visual Contamination	3,3 AT START Good 1.2 AT ROT.	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.79 Good EXCEL 1.753	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	Good	

Figure F27: Run #25

Objective	J P validation / LOW TYPE IV LS
Test # / Test Plan #	25 / P49R
OAT	-4 good TARGET -5°C
Rate	IP:25 ZR:25 good
Exposure Time	25 MINS good
Visual Contamination	AT START 2/3 good AT ROT 1/2
Lift Coefficient	DATA not available at this time N/A (START OF TAKE-OFF @ 7°)
OVERALL STATUS (good, bad, or review)	good (but review when lift data is available)

FLUID
PG
ABC-ST

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1
***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F28: Run #31

Objective	IP Expansion / Low Speed TYPE IV LOW SPEED
Test # / Test Plan #	#31 / P32
OAT	0°C BAD TARGET -5°C
Rate	IP/SN 25/25 GOOD
Exposure Time	25 MINS GOOD
Visual Contamination	AT START 1.5/1.5 GOOD AT ROT. 1/1
Lift Coefficient	VISUAL 1.80 GOOD EXCEL 1.779
OVERALL STATUS (good, bad, or review)	Good but BAD (due to OAT)

FLUID
EG106

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1
***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F29: Run #33

Objective	TYPE IV LOW SPEED IP validation. / Low	FLUID
Test # / Test Plan #	33 / P50	EG106
OAT	−3°C OK TARGET −5°C	
Rate	IP: 25 ZR: 25 GOOD / GOOD	
Exposure Time	25 MINS GOOD	
Visual Contamination	AT START 2/2 GOOD AT ROT 1/1	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.80 GOOD Low speed EXCEL 1.776	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	GOOD	

Figure F30: Run #43

−5 − −10

Objective	TYPE IV LOW SPEED Low Speed	FLUID
Test # / Test Plan #	#43 / P37	EG106
OAT	−13°C VERY GOOD TARGET −10°C	
Rate	IP / SN 25/25 GOOD	
Exposure Time	10 min GOOD	
Visual Contamination	2,2 AT START GOOD 1,1.5 AT ROT.	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.79 GOOD EXCEL 1.729	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	GOOD	

Figure F31: Run #45

Objective	TYPE IV LOW SPEED IP Expansion / Low Speed	FLUID PG ABC-S +
Test # / Test Plan #	#45 / P38	
OAT	-16°C VERY GOOD TARGET -10°C	
Rate	IP / SN 25 / 25 GOOD	
Exposure Time	10 GOOD	
Visual Contamination	2, 3 AT START FAIR 1.5 / 2 AT ROT. (Review with Warren)	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.75 BAD EXCEL 1.670	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	Fair to Bad. (lift)	

Figure F32: Run #52

Objective	TYPE IV / Low Speed	FLUID EG106
Test # / Test Plan #	#52 / P32	
OAT	-5.6°C GOOD TARGET -5°C	
Rate	IP / SN 25 / 25 GOOD	
Exposure Time	25 min GOOD	
Visual Contamination	3, 3 AT START GOOD 1, 2 AT ROT.	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.83 GOOD EXCEL 1.750	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	GOOD	

Figure F33: Run #53

J-S

Objective	TYPE IV Low Speed
Test # / Test Plan #	#53 / P33
OAT	-3°C OK TARGET -5°C
Rate	IP/SN 25/25 Good
Exposure Time	25 MINS Good
Visual Contamination	3,4 AT START FAIR (to Review with Warren) 1,2 AT ROT.
Lift Coefficient	VISUAL 1.80 Good EXCEL 1.713
OVERALL STATUS (good, bad, or review)	[illegible] to FAIR

FLUID ABL-S+

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1
***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

(Review Photos for bridging snow)
(to Review with Warren

Figure F34: Run #59

Objective	TYPE IV Low Speed
Test # / Test Plan #	[illegible] #59 / P39
OAT	-10.3°C Good TARGET -10°C
Rate	IP/ZR 25/25 Good
Exposure Time	10 min Good
Visual Contamination	3,3 AT START Good 1,2.5 AT ROT.
Lift Coefficient	VISUAL 1.80 Good EXCEL 1.723
OVERALL STATUS (good, bad, or review)	Good

FLUID LAUNCH PG

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1
***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F35: Run #86

Objective	LOW SPEED TYPE IV
Test # / Test Plan #	RUN #86 / PE29
OAT	BAD PG TARGET: -5°C ACTUAL: -9.3°C
Rate	GOOD IP- = 25
Exposure Time	BAD (30 min) 50 MINS
Visual Contamination	@ START 3.5, 3.5 BAD. @ ROT. 1.5, 3
Lift Coefficient	VISUAL 1.76 BAD EXCEL 1.699
OVERALL STATUS (good, bad, or review)	BAD (DUE TO EXPOSURE TIME)

FLUID
ABC-S+ (PG)

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1

***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F36: Run #87

Objective	LOW SPEED TYPE IV
Test # / Test Plan #	RUN #87 / PE30
OAT	G PG TARGET: -5°C ACTUAL: -6.5°C
Rate	G IP = 75
Exposure Time	G 25 MINS
Visual Contamination	@ START 3.5, 4 B @ ROT 1.5, 3
Lift Coefficient	VISUAL 1.74 B EXCEL 1.671
OVERALL STATUS (good, bad, or review)	BAD.

FLUID
ABC-S PLUS

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1

***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F37: Run #88

Objective	LOW SPEED TYPE IV
Test # / Test Plan #	RUN #88 / PE30R
OAT	G PG TARGET: -5°C ACTUAL: -6°C
Rate	G IP=75
Exposure Time	G 15 MINS
Visual Contamination	@ START 3,3 Bad @ ROT 1.5,2.5
Lift Coefficient	VISUAL 1.74 B EXCEL 1.655
OVERALL STATUS (good, bad, or review)	Bad. BUT REVIEW CL DATA

FLUID
ABC-S (PG)

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1

***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F38: Run #91

Objective	LOW SPEED TYPE IV
Test # / Test Plan #	RUN #91 / P38R2
OAT	OK PG TARGET: -10°C ACTUAL: -7.1°C
Rate	G IP=25 SN:10
Exposure Time	10 MINS G
Visual Contamination	@ START 3,3 G @ ROT 1,2
Lift Coefficient	VISUAL NEED TO REVIEW 1.76 EXCEL 1.697 BAD
OVERALL STATUS (good, bad, or review)	OK NEED TO REVIEW.

FLUID
ABC-S (PG)

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1

***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F39: Run #92

Objective	LOW SPEED TYPE IV
Test # / Test Plan #	RUN #92 / P37R
OAT	G EG TARGET: -10°C ACTUAL: -15.2°C
Rate	G IP=25 SN=10
Exposure Time	G 10 MINS
Visual Contamination	@ START 2.2.5 G @ ROT. 1.2
Lift Coefficient	VISUAL 1.85 G EXCEL 1.776
OVERALL STATUS (good, bad, or review)	GOOD

P + S

FLUID
EG106

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1
***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F40: Run #99

Objective	LOW SPEED TYPE IV
Test # / Test Plan #	RUN #99 / PE31
OAT	BAD (GOOD) EG TARGET: -5°C ACTUAL: -10.1°C
Rate	GOOD IP-=25
Exposure Time	BAD (GOOD) 50 MINS
Visual Contamination	@ START 2,3 GOOD @ ROT. 1,2
Lift Coefficient	VISUAL 1.88 GOOD. EXCEL 1.803
OVERALL STATUS (good, bad, or review)	GOOD

FLUID
EG106

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1
***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F41: Run #106

Objective	LOW SPEED TYPE IV
Test # / Test Plan #	RUN #106 / PE32
OAT	BAD EG TARGET: -5°C ACTUAL: -9.4°C
Rate	G IP = 75
Exposure Time	BAD 25 MINS
Visual Contamination	@ START 3,3 G @ ROT. 1,2
Lift Coefficient	N/A NRC DATA LOST
OVERALL STATUS (good, bad, or review)	GOOD.

FLUID
EG106 (EG)

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1

***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

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TYPE III LOW SPEED

Figure F42: Run #14

Objective	Type III / Low Speed
Test # / Test Plan #	#14 / P36
OAT	-2°C FAIR TARGET -5°C
Rate	IP/SN 25/25 Good
Exposure Time	10 ~~mins~~ Good
Visual Contamination	2,2 AT START Good 1,1 AT ROT. (check photo at rotation)
Lift Coefficient	VISUAL 1.80 Good EXCEL 1.779
OVERALL STATUS (good, bad, or review)	GOOD

FLUID 2031

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1
***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F43: Run #16

Objective	Type III / Low Speed
Test # / Test Plan #	16 / P36
OAT	-1.2°C FAIR TARGET -5°C
Rate	IP/SN 25/25 Good
Exposure Time	(15 mins) Good
Visual Contamination	3,4 START FAIR 1,2 ROT. (further review needed)
Lift Coefficient	VISUAL 1.80 Good EXCEL 1.780
OVERALL STATUS (good, bad, or review)	FAIR

FLUID 2031

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1
***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F44: Run #26

Objective	Type III Low Speed
Test # / Test Plan #	#26 / P36 R
OAT	-5 C Good TARGET -5°C
Rate	IP / ZR / 25 / 25 / [illegible] GOOD
Exposure Time	25 (allowance time ~~[illegible]~~ BAD) BAD
Visual Contamination	5.5, AT START BAD 5.5 AT ROT.
Lift Coefficient	VISUAL 1.72 FAIR EXCEL 1.704
OVERALL STATUS (good, bad, or review)	BAD

(same for 26A, 26B)

FLUID 2031

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1

***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F45: Run #47

Objective	Type III Low Speed
Test # / Test Plan #	#47 / P41 A
OAT	-17 C VERY GOOD TARGET -10°C
Rate	IP / SN 25 / 25 GOOD ~~FAIR~~
Exposure Time	[illegible] min FAIR
Visual Contamination	4.4 AT START BAD 2.3 AT ROT
Lift Coefficient	VISUAL 1.77 FAIR EXCEL 1.707
OVERALL STATUS (good, bad, or review)	FAIR (REVIEW)

FLUID 2031

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1

***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F46: Run #48

Objective	Type III / Low Speed
Test # / Test Plan #	#48 / P 41
OAT	-14°C VERY GOOD TARGET -10°C
Rate	IP/SN 25/25 GOOD
Exposure Time	5 min GOOD
Visual Contamination	2, 2 AT START Good 1, 2 AT ROT.
Lift Coefficient	VISUAL 1.82 Good EXCEL 1.719
OVERALL STATUS (good, bad, or review)	Good

FluID 2031

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1
***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F47: Run #57

Objective	Type III Low Speed
Test # / Test Plan #	#57 / P36
OAT	-8°C Very Good TARGET -5°C
Rate	IP/SN 25/25 Good
Exposure Time	10 min Good
Visual Contamination	2, 2.5 AT START Good 1, 2 AT ROT
Lift Coefficient	N/A NRC (DATA LOST)
OVERALL STATUS (good, bad, or review)	Good.

FluID 2031

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1
***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F48: Run #73

Objective	TYPE III / LOW SPEED
Test # / Test Plan #	RUN # 73 / PE6A
OAT	G TARGET: -10°C ACTUAL: -9.3°C
Rate	G IP=25 ZR=25
Exposure Time	G 10 MINS
Visual Contamination	@ START 3.3 BAD @ ROT. 2.2
Lift Coefficient	N/A NRC DATA LOST
OVERALL STATUS (good, bad, or review)	FAIR BUT REVIEW Cc

FLUID 2031

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1

***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F49: Run #74

Objective	TYPE III / LOW SPEED
Test # / Test Plan #	RUN # 74 / PE6
OAT	G TARGET: -10°C ACTUAL: -9.3°C
Rate	G IP=25 ZR=25
Exposure Time	G 5 MINS
Visual Contamination	@ START 2.2 G @ ROT. 1.2
Lift Coefficient	VISUAL 1.87 G EXCEL 1.798
OVERALL STATUS (good, bad, or review)	GOOD

FLUID 2031

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1

***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F50: Run #78

Objective	TYPE III / LOW SPEED	FLUID 2031
Test # / Test Plan #	RUN #78 / PE15	
OAT	G TARGET: -10°C ACTUAL: -10.7°C	
Rate	G IP=25 SN=10	
Exposure Time	G 10 MINS	
Visual Contamination	@ START 2.2 G @ ROT. 1,2	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.86 G EXCEL 1.780	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	GOOD.	

Figure F51: Run #100

Objective	TYPE III / LOW SPEED	FLUID 2031
Test # / Test Plan #	RUN #100 / PE8	
OAT	G TARGET: -10°C ACTUAL: -11.2°C	
Rate	G IP MOD = 75	
Exposure Time	G 5 MINS	
Visual Contamination	@ START 3.3 G @ ROT. 1,2	***** Not Based on photos ***** Visual at Start should be <=3 ***** Visual at Rot LE should be 1
Lift Coefficient	VISUAL 1.86 G EXCEL 1.786	***** Use baseline as basis until further analysis of data ***** 8° Cl should be >=1.7
OVERALL STATUS (good, bad, or review)	G	

Figure F52: Run #101

Objective	TYPE III / LOW SPEED	
Test # / Test Plan #	RUN # 101 / PE11	
OAT	TARGET: -10°C ACTUAL: -11.6°C	G
Rate	IP- = 25	G
Exposure Time	10 MINS	G
Visual Contamination	@ START 2.5, 3 ; @ ROT [illegible]	G
Lift Coefficient	VISUAL 1.85 ; EXCEL 1.770	G
OVERALL STATUS (good, bad, or review)		G

FLUID 2031

1, 2

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1

***** Use baseline as basis until further analysis of data
***** 8º Cl should be >=1.7

TYPE II LOW SPEED

Figure F53: Run #23

Objective	TYPE II Low Speed
Test # / Test Plan #	#23 / P35
OAT	-4°C Good TARGET: -5°C
Rate	IP/ZR 25/25 Good
Exposure Time	25 min Good
Visual Contamination	3,3 AT START Good 1,2 AT ROT.
Lift Coefficient	NRC DATA LOST (missing from NRC data) N/A
OVERALL STATUS (good, bad, or review)	Good

FLUID: PG Flight

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1
***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

Figure F54: Run #60

Objective	TYPE II Low Speed
Test # / Test Plan #	#60 / P40
OAT	-11°C Good TARGET: -10°C
Rate	IP/ZR 25/25 Good
Exposure Time	10 min Good
Visual Contamination	3,3 AT START Good 1,2 AT ROT.
Lift Coefficient	VISUAL 1.77 FAIR EXCEL 1.707
OVERALL STATUS (good, bad, or review)	Good to Fair.

FLUID PG FLIGHT

***** Not Based on photos
***** Visual at Start should be <=3
***** Visual at Rot LE should be 1
***** Use baseline as basis until further analysis of data
***** 8° Cl should be >=1.7

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