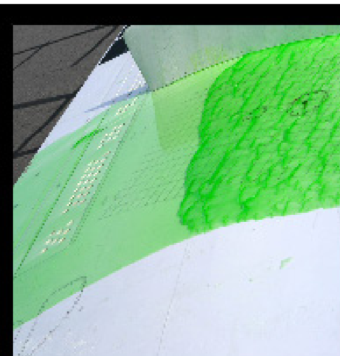
TP 14871E

Research for Further Development of Ice Pellet Allowance Times:

Aircraft Trials to Examine Anti-Icing Fluid Flow-Off Characteristics

Winter 2007-08



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Transportation Development Centre

In cooperation with

Civil Aviation
Transport Canada

and

The Federal Aviation Administration
William J. Hughes Technical Center

Prepared by

APS Aviation Inc.

March 2009
Final Version 1.0

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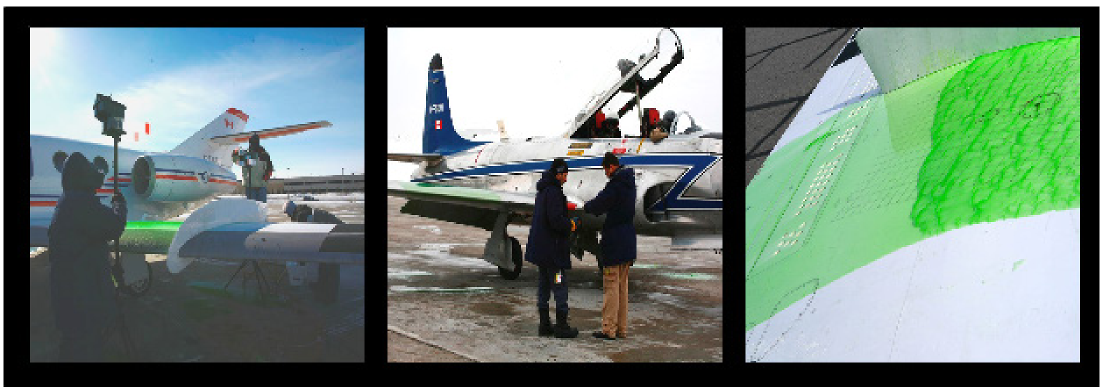

By:

Marco Ruggi

APS Aviation Inc.

March 2009
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The contents of this report reflect the views of APS Aviation Inc. and not necessarily the official view or opinions of the Transportation Development Centre of Transport Canada.

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

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Un sommaire français se trouve avant la table des matières.

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PREFACE

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

- To develop holdover time data for all newly-qualified de/anti-icing fluids;
- To examine the effect of heated fluids on Type II, III and IV fluid endurance times;
- To evaluate weather data from previous winters that can have an impact on the holdover time table format;
- To assist in the testing of flow of contaminated fluid from aircraft wings during takeoff;
- To validate the laboratory snow test protocol with Type II, III and IV fluids;
- To develop performance specifications for an integrated weather system that measures holdover time;
- To conduct general and exploratory de/anti-icing research;
- To conduct endurance time tests on non-aluminum plates;
- To conduct endurance time tests in frost on various test surfaces;
- To compile historical data for calculation of holdover times based on a small number of inputs; and
- To assist Department of National Defence Canada in evaluating the standards used at various Department of National Defence sites.

The research activities of the program conducted on behalf of Transport Canada during the winter of 2007-08 are documented in six reports. The titles of the reports are as follows:

- TP 14869E Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2007-08 Winter;
- TP 14870E Winter Weather Impact on Holdover Time Table Format (1995-2008);
- TP 14871E Research for Further Development of Ice Pellet Allowance Times: Aircraft Trials to Examine Anti-Icing Fluid Flow-Off Characteristics Winter 2007-08;
- TP 14872E Aircraft Ground Icing General Research Activities During the 2007-08 Winter;
- TP 14873E Regression Coefficients and Equations Used to Develop the Winter 2008-09 Aircraft Ground Deicing Holdover Time Tables; and
- TP 14874E Effect of Heat on Endurance Times of Anti-Icing Fluids.

In addition, the following three interim reports are being prepared:

- *Endurance Time Testing in Snow: Comparison of Indoor and Outdoor Data for 2007-08 and Other Artificial Snow Projects;*
- *Fluid Endurance Times Using Composite Surfaces; and*

- *Substantiation of Aircraft Ground Deicing Holdover Times in Frost Conditions.*

In addition, the following report was written for Department of National Defence as part of this contract; this report does not have a TP number:

- Development of the Canadian Forces Approved Ground Icing Program (AGIP), Evaluation Methods for Current Performance and Recommendations for Improvement Project: Report on Site Visit to 14 Wing Greenwood.

This report, TP 14871E, has the following objective:

- To conduct flat plate and aerodynamic full-scale testing to provide a basis for expanding the current ice pellet allowance times.

This objective was met by conducting small scale testing on flat plates, followed by a series of full-scale tests using the National Research Council Canada Falcon 20 and T-33 aircraft to examine the flow-off properties of both contaminated and uncontaminated anti-icing fluids during simulated low speed and high speed takeoff runs.

PROGRAM ACKNOWLEDGEMENTS

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

APS Aviation Inc. would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data. This includes the following people: George Balaban, Katrina Bell, Stephanie Bendickson, Michael Chaput, John D'Avirro, Peter Dawson, Benjamin Guthrie, Michael Hawdur, Eric Perocchio, Dany Posteraro, Marco Ruggi, Filippo Suriano, Joey Tiano, David Youssef and Victoria Zoitakis.

Special thanks are extended to Barry Myers, Frank Eyre and Yagusha Bodnar, who on behalf of the Transportation Development Centre, have participated, contributed and provided guidance in the preparation of these documents.

PROJECT ACKNOWLEDGEMENTS

The author of this report would like to acknowledge and thank Barry Myers (Transport Canada) and Warren Underwood (Federal Aviation Administration) whose individual specializations played a critical role in directing the experiments. The author would also like to acknowledge and thank the staff of the National Research Council Canada Institute for Aerospace Research, and the National Research Council Canada Climatic Engineering Facility, for their diligence and commitment in providing support to conduct the experiments.

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

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

16. Abstract

The objective of this study was to examine anti-icing fluid flow-off properties of both contaminated and uncontaminated anti-icing fluids during simulated low speed and high speed take-off runs with the NRC Falcon 20 and T-33 aircraft. High speed and low speed testing was primarily conducted with the Falcon 20 aircraft. Limited tests were conducted with the T-33 to validate the low speed results obtained using the Falcon 20 aircraft.

The results indicated that the effect of extended flaps seemed to improve fluid elimination at the time of rotation. The slatted leading edge did not have a significant effect on fluid flow-off. Testing to simulate different chord lengths demonstrated better fluid flow off for shorter chord length test sections. The aerodynamic performance of the new generation triozole-free fluids meets or exceeds the performance of the older generation fluids. Fluid flow-off as a result of the aircraft rotating or not rotating at the end of the acceleration profile demonstrated a general trend pointing towards greater residual fluid following the no-rotation test runs. Low speed testing with 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. Testing in mixed ice pellet and snow conditions at colder temperatures (below -5ºC) demonstrated difficulties in fluid elimination. Fluid elimination problems with Type IV fluids at lower rotation speeds appear to be a fluid issue rather than a contamination issue, however, the general trend indicated that as the speed was increased, fluid elimination was improved.

No changes were made to the Ice Pellet Allowance Time Guidelines for the winter of 2008-09. Although a significant amount of data was collected with the Falcon 20 and T-33 aircraft during the winter of 2007-08, further testing in the wind tunnel is required in order to obtain appropriate lift and drag data to confirm the results obtained with the Falcon 20 and T-33 aircraft. Wind tunnel testing should be conducted to further investigate lower rotation speeds, mixed ice pellet and snow conditions, and ice pellet testing with different fluid types, formulations, and conditions. In addition preliminary work should investigate effects of improper fluid application, differences between snow and snow pellets, reduced Type I holdover times on composite surfaces, and reduced anti-icing holdover times during frost conditions.

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

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

16. Résumé

Cette étude avait pour objectif d'examiner les propriétés de ruissellement de liquides d'antigivrage contaminés et non contaminés durant des simulations de course de décollage à basse et à haute vitesse avec les aéronefs T-33 et Falcon 20 du CNRC. Les essais à basse et à haute vitesse ont principalement été réalisés sur l'aéronef Falcon 20. Des tests limités ont été réalisés sur le T-33 afin de valider les résultats obtenus à basse vitesse avec l'aéronef Falcon 20.

Les résultats ont démontré que le déploiement des volets semblait améliorer l'élimination du liquide au moment de la rotation. Le déploiement des becs de bord d'attaque n'avait quant à lui aucun effet important sur le ruissellement du liquide. Les essais visant à simuler différentes longueurs de corde ont démontré un meilleur ruissellement du liquide sur les sections plus courtes. La performance aérodynamique des liquides sans triazole de nouvelle génération est égale ou supérieure à celle des liquides des générations précédentes. Le ruissellement du liquide engendré par la rotation ou non de l'aéronef à la fin de la courbe d'accélération a démontré en général une plus grande quantité de résidus à la fin des essais sans rotation. Les essais menés à basse vitesse avec du liquide de type III ont démontré un meilleur ruissellement que ceux menés à basse vitesse avec du liquide de type IV ; une quantité importante de liquide de type III demeurait toutefois présente à la fin des essais à basse vitesse. Des essais réalisés dans des conditions mixtes de granules de glace et de neige par temps plus froid (températures inférieures à -5 ºC) ont démontré la difficulté d'éliminer le liquide. Les problèmes d'élimination avec les liquides de type IV à basse vitesse de rotation semblaient causés par le liquide même plutôt que par la contamination ; toutefois, l'élimination du liquide s'est généralement améliorée à mesure que la vitesse augmentait.

Aucun changement n'a été apporté aux lignes directrices sur les marges de tolérance dans des conditions de granules de glace de l'hiver 2008-2009. Bien qu'une quantité considérable de données aient été recueillies avec les aéronefs Falcon 20 et T-33 durant l'hiver 2007-2008, il est nécessaire de procéder à d'autres essais dans la soufflerie afin d'obtenir des données appropriées sur la portance et la traînée et ainsi valider les résultats obtenus avec les aéronefs. Des essais dans la soufflerie devraient étudier davantage les basses vitesses de rotation, les conditions mixtes de granules de glace et de neige, de même que l'effet sur les granules de glace de liquides de différents types et de différentes formules dans différentes conditions. En outre, des travaux préliminaires devraient étudier l'effet d'une mauvaise application du liquide, les différences entre la neige et la neige roulée, les durées d'efficacité réduites du liquide de type I sur les surfaces composites et les durées d'efficacité réduites de l'antigivrage dans des conditions de gel.

17. Mots clés Granule de glace, marge de tolérance, rotation à basse vitesse, conditions mixtes, Falcon 20, T-33, adhérence de liquide, écoulement de liquide	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) of Transport Canada (TC), with support from the Federal Aviation Administration (FAA), and several fluid manufacturers, APS Aviation Inc. (APS) has undertaken a testing and research program to further advance aircraft ground de/anti-icing technology. The program has a number of objectives, and work completed to address these objectives is documented in a series of related reports. The objective of the project documented in this report was to examine anti-icing fluid flow-off properties of both contaminated and uncontaminated anti-icing fluids during simulated low speed and high speed takeoff runs with the National Research Council Canada (NRC) Falcon 20 and T-33 aircraft.

Background and Objective

Prior to the winter of 2005-06, 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.

During the winter of 2005-06, the FAA provided a 25-minute allowance as a preliminary guideline; TC remained status quo and did not issue any guidance material for operations in ice pellet conditions. 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 ice pellets alone (no mixed conditions).

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

During the winter of 2007-08, the TC and FAA provided allowance time guidance material for operations in mixed conditions with ice pellet guideline. These allowance times were based on the research conducted during the winter of 2006-07. The recommended allowance times were based on aerodynamic research conducted using the 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.

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. Full-scale aircraft testing was conducted in mixed conditions with ice pellets and in non-precipitation conditions. Testing was conducted with and without contamination. Research was conducted to investigate the following:

- Effect of Flaps;
- Effect of Slats;
- Effect of Chord Length;
- New Generation vs. Older Generation Fluid;
- Effect of Rotation;
- Type III fluid;
- Ice Pellets Mixed with Snow; and
- High Speed vs. Low Speed.

Data Collection and Testing

At the start of each aerodynamic test (both for the Falcon 20 and the T-33 tests), the test wing was treated with anti-icing fluid using a one-step operation. Simulated precipitation was then applied over the anti-iced test section until specified levels of contamination were achieved. Data such as fluid thickness, wing temperatures, and fluid freeze points were recorded. The aircraft was then operated through a simulated takeoff run excluding climb-out. The behaviour of the fluid during the simulated takeoff was documented with high-speed digital still cameras and video cameras.

General Observations

Effect of Flaps

The Falcon 20 and T-33 results indicated that residual thickness was equal to or greater than on the trailing edge during the retracted flap tests compared to the extended flap tests. Visually, fluid elimination seemed to improve with flaps extended for both aircraft.

Effect of Slats

The Falcon 20 results indicated that the residual fluid thickness on the trailing edge during the outboard extended slat tests was generally equal to the inboard fixed leading edge tests.

Effect of Chord Length

The results indicated that the residual thickness was greater (almost double in some cases) on the longer 3 m (10 ft)) chord test section when compared to the shorter 1.7 m (5 ft)) chord test section. The residual fluid on the trailing edge was comparable and within 0.1 mm when comparing the results of the 3 m (10 ft)) versus the 2.4 m (8 ft) chord test sections. The results demonstrated better fluid flow-off for shorter chord length test sections.

New Generation vs. Old Generation Fluid

The aerodynamic performance of the new fluids meets or exceeds the performance of the older generation fluids. ABC-S Plus demonstrated similar flow-off chracteristics to the older ABC-S fluid. EG 106 performed better than the older Ultra+ and generated less residual fluid post-run; the relationship between the results will need to be considered when comparing new data to historical data.

Effect of Rotation

The results indicated some differences in fluid flow-off properties as a result of the aircraft rotating at the end of the aircraft acceleration profile. The results from the Falcon 20 tests and the T-33 tests were not completely in agreement, however the general trend pointed towards greater residual fluid following the no-rotation test runs.

Type III Fluid

The preliminary 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. During the contaminated wing tests, the Type III fluid did an excellent job of eliminating the contamination by the time of rotation. The residual fluid on the contaminated wing tests was equal to or less than the baseline fluid-only wing tests.

Ice Pellets Mixed with Snow

The high speed testing results at colder temperatures (below -5°C) with Type IV fluid demonstrated greater residual fluid thickness on the trailing edge section of the wing during the contaminated test run compared to the fluid-only test run. The low speed testing conducted at warmer temperatures with Type III and Type IV fluid demonstrated similar residual fluid on both the contaminated and uncontaminated wing section. The results obtained were in accordance with previous aerodynamic data collected during the winter of 2006-07, which indicated potential fluid flow-off problems at colder temperatures with mixed ice pellet and snow conditions.

High Speed vs. Low Speed

Fluid elimination problems with Type IV fluids at lower rotation speeds appear to be a fluid issue rather than a contamination issue. Even fluid-only tests were demonstrating significant amounts of residual fluid post-run at low rotation speeds. Extended flaps significantly helped fluid elimination prior to rotation, however residual trailing edge fluid was still greater during the low speed runs by a factor of two or more when compared to the previous year's high speed test runs. The general trend indicated that as the speed was increased, fluid elimination was improved.

Future Work

No changes were made to the Ice Pellet Allowance Time Guidelines for the winter of 2008-09. Although a significant amount of data was collected with the Falcon 20 and T-33 aircraft during the winter of 2007-08, further testing in the wind tunnel is required in order to obtain appropriate lift and drag data to confirm the results obtained with the Falcon 20 and T-33 aircraft.

It is anticipated that wind tunnel testing will be conducted during the winter of 2008-09. Aerodynamic testing should investigate the effects on fluid flow-off as a result of lower rotation speeds, mixed ice pellet and snow conditions, and ice pellet testing with different fluid types, formulations, and conditions. In addition, preliminary aerodynamic research should investigate the effects on fluid flow-off as a result of improper fluid application, difference between snow and snow pellets, reduced Type I HOTs on composite surfaces, and reduced anti-icing HOTs during frost conditions.

SOMMAIRE

En vertu d'un contrat avec le Centre de développement des transports (CDT) de Transports Canada (TC), avec l'appui de la Federal Aviation Administration (FAA) et de plusieurs fabricants de liquides, APS Aviation Inc. (APS) a entrepris des essais et un programme de recherches visant à approfondir la technologie de dégivrage et d'antigivrage d'aéronefs au sol. Le programme poursuivait plusieurs objectifs et les travaux effectués pour atteindre ces objectifs sont documentés dans une suite de rapports connexes. Le projet documenté dans ce rapport avait pour objectif d'examiner les propriétés de ruissellement de liquides d'antigivrage contaminés et non contaminés durant des simulations de course de décollage à basse et à haute vitesse avec les aéronefs T-33 et Falcon 20 du Conseil national de recherches Canada (CNRC).

Contexte et objectif

Avant l'hiver 2005-2006, 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.

Au cours de l'hiver 2005-2006, la FAA a donné une marge de tolérance de 25 minutes à titre de ligne directrice préliminaire ; TC a maintenu le statu quo et n'a publié aucune ligne directrice concernant la navigation aérienne dans des conditions de granules de glace. 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 ; ces résultats ont été présentés à la réunion de la Society of Automotive Engineers (SAE), à Lisbonne en mai 2006. Afin de prendre en compte l'option d'inspection de contamination avant le décollage, la marge de tolérance proposée de 20 minutes a été prolongée à 25 minutes ; par conséquent, les inspections de contamination avant le 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 2007-08, 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. Les marges de tolérance recommandées étaient fondées sur la recherche aérodynamique menée à l'aide de la soufflerie à circuit ouvert du CNRC 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. Des essais sur des aéronefs pleine grandeur ont été menés dans des conditions mixtes avec granules de glace et en absence de précipitation. Les essais ont été effectués avec et sans contamination. L'étude avait pour but d'étudier ce qui suit :

- Effet des volets ;
- Effet des becs ;
- Effet de la longueur de corde ;
- Comparaison des liquides de nouvelle génération et d'ancienne génération ;
- Effet de la rotation ;
- Liquide de type III ;
- Conditions mixtes de granules de glace et de neige ; et
- Haute vitesse et basse vitesse.

Collecte de données et essais

Au début de chaque essai aérodynamique (tant sur le Falcon 20 que sur le T-33), l'aile testée était traitée au moyen d'un liquide d'antigivrage à l'aide d'une méthode en une étape. Des précipitations artificielles étaient ensuite appliquées par-dessus la section traitée par le liquide d'antigivrage jusqu'à ce que le taux de contamination déterminé soit atteint. Des données telles que l'épaisseur et le point de congélation du liquide et la température des ailes ont été recueillies. L'aéronef a ensuite effectué une course de décollage simulée, sans la montée initiale. Le comportement du liquide a été documenté durant la course au moyen d'appareils photographiques et de caméras vidéo numériques à grande vitesse.

Observations générales

Effet des volets

Les résultats obtenus avec le Falcon 20 et le T-33 ont indiqué que l'épaisseur de liquide résiduel sur le bord de fuite durant les essais avec volets rentrés était égale ou supérieure à celle observée durant les essais avec volets déployés. Visuellement, l'élimination du liquide semblait supérieure lorsque les volets étaient déployés, et ce, sur les deux aéronefs.

Effet des becs

Les résultats obtenus avec le Falcon 20 ont indiqué que l'épaisseur du liquide résiduel sur le bord de fuite durant les essais sur la partie externe des becs déployés était généralement égale à celle observée lors des essais sur la partie interne du bord d'attaque fixe.

Effet de la longueur de corde

Les résultats ont démontré que l'épaisseur du liquide résiduel était supérieure (près du double, dans certains cas) sur la section plus longue de la corde, soit 3 m (10 pi), comparativement à la section plus courte de la corde, soit 1,7 m (5 pi). L'épaisseur du liquide résiduel sur le bord de fuite était comparable, et inférieure à 0,1 mm, pour les sections de corde de 3 m (10 pi) et de 2,4 m (8 pi). Les résultats ont démontré un meilleur ruissellement du liquide sur les sections de corde plus courtes.

Comparaison des liquides de nouvelle génération et d'ancienne génération

La performance aérodynamique des nouveaux liquides est égale ou supérieure à celle des liquides des générations précédentes. Le liquide ABC-S Plus a démontré des caractéristiques de ruissellement semblables à celles de l'ancien liquide ABC-S. Le liquide EG106 s'est avéré plus efficace que l'ancienne version Ultra+ et a entraîné moins de résidus de liquide après la course ; le lien entre les résultats devra être pris en compte au moment de comparer les nouvelles données aux anciennes.

Effet de la rotation

Les résultats ont démontré quelques différences dans les propriétés de ruissellement du liquide en raison de la rotation de l'aéronef à la fin de sa courbe d'accélération.

Les résultats obtenus avec le Falcon 20 ne concordaient pas complètement avec ceux obtenus avec le T-33 ; ils tendaient toutefois généralement vers une plus grande quantité de liquide résiduel après les essais sans rotation.

Liquide de type III

Les résultats préliminaires obtenus avec le liquide de type III ont démontré un meilleur ruissellement que ceux obtenus avec le liquide de type IV lors d'essais à basse vitesse de rotation ; une quantité importante de liquide de type III demeurait toutefois présente à la fin des essais à basse vitesse. Durant les tests menés avec du liquide contaminé, le liquide de type III parvenait très bien à éliminer la contamination avant la rotation. La quantité de liquide résiduel sur les ailes durant les essais avec contamination était égale ou inférieure à celle durant les essais de référence avec du liquide non contaminé.

Conditions mixtes de granules de glace et de neige

Lors des essais à haute vitesse menés par temps froid (températures inférieures à -5 ºC) avec du liquide de type IV, l'épaisseur du liquide résiduel sur le bord de traînée de l'aile était supérieure en présence de contamination par rapport à celle observée avec du liquide non contaminé. Les essais à basse vitesse menés par temps plus chaud avec des liquides de type III et de type IV ont donné lieu à des épaisseurs de liquide résiduel semblables tant sur les sections d'aile contaminées que non contaminées. Les résultats obtenus concordaient avec les données aérodynamiques précédentes recueillies à l'hiver 2006-2007, lesquelles indiquaient d'éventuels problèmes de ruissellement du liquide par temps plus froid dans des conditions mixtes de granules de glace et de neige.

Haute vitesse et basse vitesse

Les problèmes d'élimination avec les liquides de type IV à basse vitesse de rotation semblaient causés par le liquide même plutôt que par la contamination. Même les essais réalisés avec du liquide non contaminé ont généré des quantités importantes de liquide résiduel après la course de décollage à basse vitesse de rotation. Le déploiement des volets a grandement contribué à l'élimination du liquide avant la rotation ; toutefois, la quantité de liquide résiduel sur le bord de fuite était toujours au moins deux fois plus grande durant les essais à basse vitesse par rapport aux résultats des essais à haute vitesse de l'année précédente. L'élimination du liquide s'est généralement améliorée à mesure que la vitesse augmentait.

Travaux à venir

Aucun changement n'a été apporté aux lignes directrices sur les marges de tolérance dans des conditions de granules de glace de l'hiver 2008-2009. Bien qu'une quantité considérable de données aient été recueillies avec les aéronefs Falcon 20 et T-33 durant l'hiver 2007-2008, il est nécessaire de procéder à d'autres essais dans la soufflerie afin d'obtenir des données appropriées sur la portance et la traînée et ainsi valider les résultats obtenus avec les aéronefs.

Des essais en soufflerie devraient avoir lieu à l'hiver 2008-2009. Des essais aérodynamiques devraient étudier les effets de basses vitesses de rotation et de conditions mixtes de granules de glace et de neige sur le ruissellement du liquide, de même que l'effet de liquides de différents types et de différentes formules dans différentes conditions sur les granules de glace. En outre, des essais aérodynamiques préliminaires devraient étudier l'effet d'une mauvaise application du liquide sur le ruissellement, les différences entre la neige et la neige roulée, les durées d'efficacité réduites du liquide de type I sur les surfaces composites et les durées d'efficacité réduites de l'antigivrage dans des conditions de gel.

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CONTENTS

Page

LIST OF APPENDICES

LIST OF TABLES Page

LIST OF FIGURES Page

LIST OF PHOTOS Page

GLOSSARY

APS	APS Aviation Inc.
CDU	Cockpit Display Unit
CSA	Canadian Space Agency
DND	Department of National Defence
EG	Ethylene Glycol
FAA	Federal Aviation Administration
GPS	Global Positioning System
HOT	Holdover Time
ILS	Instrument Landing System
LOUT	Lowest Operational Use Temperature
MLS	Microwave Landing System
MSC	Meteorological Service of Canada
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NRC	National Research Council Canada
OAT	Outside Air Temperature
PG	Propylene Glycol
PVC	Polyvinyl Chloride
SAE	Society of Automotive Engineers
TC	Transport Canada
TDC	Transportation Development Centre

UPS	United Parcel Service
VOR	VHF Omnidirectional Range
YOW	MacDonald-Cartier International Airport

1. INTRODUCTION

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

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

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

As part of a larger research program examining aircraft operations in ice pellets, APS conducted a series of small-scale plate tests and full-scale tests with the NRC Falcon 20 aircraft and T-33 aircraft to determine the flow-off characteristics of an anti-icing fluid with and without ice pellet contamination.

1.1 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 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) aircrafts in Louisville were grounded for several hours due to extended ice pellet conditions. Due to cargo aircraft configuration, pre-takeoff contamination checks by the onboard 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, the FAA provided a 25-minute allowance as a preliminary guideline; TC remained at the status quo of a 20-minute allowance. 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 ice pellets alone (no mixed conditions).

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

During the winter of 2007, 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 conducted during the winter of 2006-07. The recommended allowance times were based on aerodynamic research conducted using the 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.

During the winter of 2007-08, additional endurance time testing and aerodynamic research were conducted to support and further expand the ice pellet allowance times. Full-scale aircraft testing was conducted in mixed conditions with ice pellets and in non-precipitation conditions. Testing was conducted to simulate low rotation speed aircraft.

1.2 Program Objectives

A test program was developed for the winter of 2007-08 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 2007-08 to support and expand the guidance material in ice pellet and mixed conditions. Testing was conducted with and without contamination. Research was conducted to investigate the following:

- Effect of Flaps;
- Effect of Slats;
- Effect of Chord Length;
- New Generation vs. Older Generation Fluid;
- Effect of Rotation;
- Type III Fluid;
- Ice Pellets Mixed with Snow; and
- High Speed vs. Low Speed.

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

1.3 Previous Falcon 20 Full-Scale Testing

Previous trials 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 trials, 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 for the 1997/98 Winter* (1);
- TP 13479E, *Contaminated Aircraft Takeoff Tests for the 1998-99 Winter* (2);
- TP 13666E, *Contaminated Aircraft Simulated Takeoff Tests for the 1999-2000 Winter: Preparation and Procedures* (3);
- TP 13995E, *Aircraft Takeoff Test Program for Winter 2001-02: Testing to Evaluate the Aerodynamic Penalties of Clean or Partially Expended De/Anti-Icing Fluid* (4); 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* (5).

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:

- TP 14716E, *Falcon 20 Trials to Examine Fluid Removed from Aircraft During Takeoff with Ice Pellets* (6).

1.4 2006-07 NRC Wind Tunnel Full-Scale Testing

Previous trials to examine the 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 3 m x 6 m open-circuit wind tunnel. 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 trials, 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 for TC, TP 13426E, *Air-Flap Performance with De-Anti-Icing Fluids and Freezing Precipitation* (7).

During the winter of 2006-07, extensive testing was conducted in mixed ice pellet conditions in the NRC wind tunnel. 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. The Falcon 20 aircraft was used to validate the results obtained in the NRC wind tunnel by conducting a limited number of validation tests. This research is documented in detail in a report written by APS for TC:

- TP 14779E, *Development of Allowance Times for Aircraft Deicing Operations During Conditions with Ice Pellets* (8).

The details of the methodology used for this testing are documented in detail in a report written by APS for TC:

- TP 14778E, *Flow of Contaminated Fluid from Aircraft Wings: Feasibility Report* (9).

1.5 Overview of 2007-08 Testing

Testing during the winter of 2007-08 comprised small-scale testing conducted on flat plates and full-scale testing conducted with the NRC Falcon 20 aircraft and T-33 aircraft. It should be noted that the NRC wind tunnel was unavailable during the winter of 2007-08; therefore, a more extensive test plan was executed with the Falcon 20 aircraft and limited low-speed testing was conducted with the T-33 aircraft. The testing conducted is summarized below:

- Flat plate testing conducted to investigate fluid adherence in mixed ice pellet conditions (research geared to support aerodynamic research conducted):
  - Mixed light freezing rain and light ice pellets adherence testing with Type II and Type III fluids (April 2008 at the NRC).
- Aerodynamic research conducted to investigate fluid flow-off of uncontaminated fluid and contaminated fluid following simulated ice pellet and mixed conditions:
  - Low-speed and high-speed aerodynamic research with the Falcon 20 to expand the current ice pellet allowance times and to investigate various aircraft configuration parameters; and
  - Limited low-speed aerodynamic research with the T-33 aircraft to validate the simulated low-speed results obtained with the Falcon 20 aircraft (the Falcon 20 aircraft is a high rotation speed aircraft).

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 data, results, and observations regarding the effect of flaps on fluid flow-off;

e) Section 6 describes the data, results, and observations regarding the effect of slats on fluid flow-off;

f) Section 7 describes the data, results, and observations regarding the effect of the wing chord length on fluid flow-off;

g) Section 8 describes the data, results, and observations regarding the effect of the new generation triozole-free fluids;

h) Section 9 describes the data, results, and observations regarding the effect of the aircraft rotation on fluid flow-off;

i) Section 10 describes the data, results, and observations regarding the performance of Type III fluid for use with low-speed rotation aircraft;

j) Section 11 describes the data, results, and observations regarding the effect of mixed ice pellet and snow contamination on fluid flow-off;

k) Section 12 describes the data, results, and observations regarding the effect of the aircraft rotation speed on fluid flow-off;

l) Section 13 presents a summary of the current allowance times for ice pellet conditions; and

m) Section 14 lists recommendations for future testing.

2. METHODOLOGY

This section describes the test methodologies followed. The following list provides short descriptions of subsequent subsections:

- Subsection 2.1: Test methodologies and equipment specific to the full-scale aerodynamic tests with the Falcon 20 and T-33 aircraft; and
- Subsection 2.2: General testing methodologies and equipment.

2.1 Full-Scale Aerodynamic Tests

2.1.1 Test Site

The 2007-08 full-scale aerodynamic tests were performed at the MacDonald-Cartier International Airport (YOW) in Ottawa. Figure 2.1 provides a schematic of the airport showing the runways and the location of the NRC hangar and apron. Photo 2.1 shows the NRC hangar.

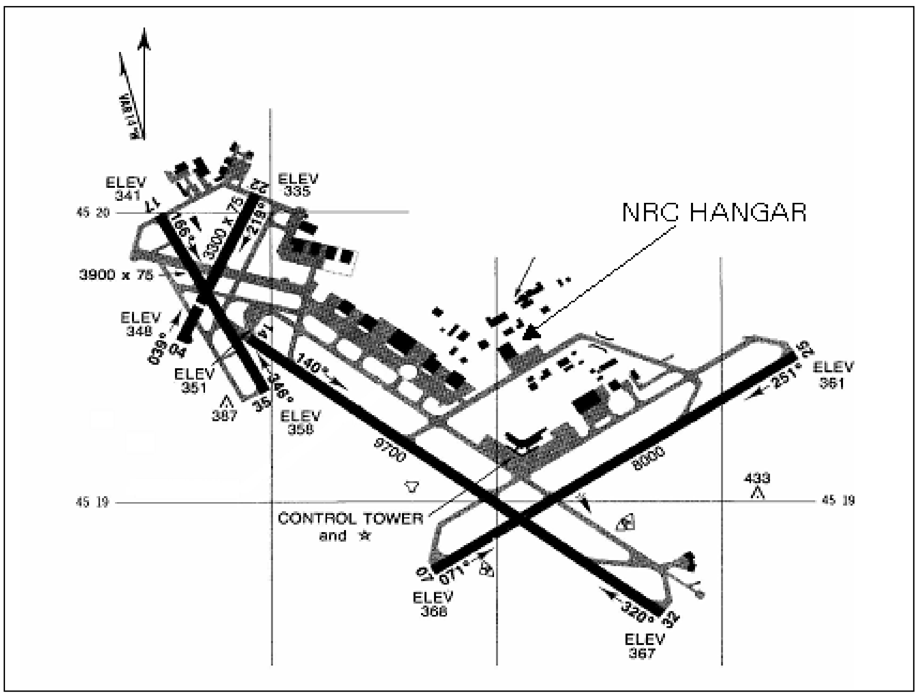

Figure 2.1: Schematic of Ottawa Airport

2.1.2 Test Schedule

Testing was scheduled for the period of February 25 to March 7, 2008. February 25 was scheduled as a setup day. A test plan was completed that allowed for modifications during the test period according to observations made during initial tests. During each test, fluid was applied to a pre-marked section on both port and starboard wings. During some tests with the Falcon 20, two strips of fluid were applied to each wing section; the second outboard sections were not exposed to contamination. Contamination was applied to the main test section of only one wing; the other wing sections remained uncontaminated and were used as baselines for the test. Table 2.1 presents the calendar of Falcon 20 and T-33 tests performed in 2008. For example, on February 27, 2008, two test runs were completed; Test #2 was done on both the port (Test #2P8) and starboard (Test #2S8) inboard wing sections. Similarly, Test #3 was also done on the two inboard wing sections (Tests #3P8 and #3S8); however, an additional test was conducted on the outboard starboard wing section (Test #3AS8). The number "8" at the end of the test number is used to identify 2008 data from the 2007 data. It should be noted that only two T-33 aircraft tests were conducted (Tests #17P/S8 and #18P/S8).

Table 2.1: Calendar of Tests

Date	Number of Test Runs	Test Numbers
25-Feb-08	Setup	n/a
26-Feb-08	1	1P8, 1S8
27-Feb-08	2	2P8, 2S8, 3P8, 3S8, 3AS8
28-Feb-08	4	4P8, 4S8, 5P8, 5S8, 6P8, 6S8, 7P8, 7S8
29-Feb-08	4	8P8, 8S8, 9P8, 9S8, 10P8, 10S8, 10AP8, 10AS8, 11P8, 11S8
4-Mar-08	2	12P8, 12S8, 12AP8, 12AS8, 13P8, 13S8, 13AP8, 13AS8
6-Mar-08	3	14P8, 14S8, 14AP8, 14AS8, 15P8, 15S8, 15AP8, 15AS8, 16P8, 16S8, 16AP8, 16AS8
7-Mar-08	2	17P8, 17S8, 18P8, 18S8

2.1.3 Falcon 20 Test Procedure

To satisfy the program objective, simulated takeoff tests were performed with the NRC Falcon 20 research aircraft, and different parameters, including fluid thickness, wing temperature, and fluid freezing point, were recorded at designated times during the tests.

The procedure for each test was as follows:

a) Designated test areas on the port and starboard wings were treated with Type III or Type IV fluid, poured in a one-step operation outside the NRC hangar;

b) Contamination, in the form of simulated ice pellets and snow, was applied to the inboard section of only one wing; the other wing sections were left uncontaminated and used as a baseline for comparison tests. Test parameters were measured at the beginning and end of the exposure to contamination;

c) At the end of the contamination period, the aircraft was taxied to the selected runway. Once at the button, APS personnel conducted an inspection of the contaminated wing section and measured selected test parameters; and

d) The aircraft was subsequently operated through a simulated takeoff test, excluding climb-out. The behaviour of the contaminated and uncontaminated fluid during the takeoff test was recorded with digital video cameras and digital high-speed still cameras.

2.1.4 T-33 Test Procedure

To satisfy the program objective, simulated takeoff tests were performed with the NRC T-33 research aircraft, and different parameters, including fluid thickness, wing temperature, and fluid freezing point, were recorded at designated times during the tests.

The procedure for each test was as follows:

a) A designated test area on the port and starboard wings was treated with Type IV fluid, poured in a one-step operation outside the NRC hangar;

b) Test parameters were measured following the application of fluid. No contamination was applied to the wing;

c) The aircraft was taxied to the selected runway. Only two NRC staff members were accommodated in the aircraft, the pilot and co-pilot, who would observe the test and photograph the test runs using a hand-held camera; and

d) The aircraft was subsequently operated through a simulated takeoff test, excluding climb-out. The behaviour of the uncontaminated fluid during the takeoff test was recorded with digital high-speed still cameras.

2.1.5 Falcon 20 Research Aircraft

The following subsections describe the Falcon 20 aircraft used to conduct the tests.

2.1.5.1 Dassault Falcon 20

The aircraft used for testing was a Dassault Falcon 20 twin-engine, mid-size business jet, operated by the NRC (see Photo 2.2). The aircraft is a multi-purpose platform that has been used in recent years for two major research programs:

a) The testing and evaluation of precision instrument approaches using augmented Global Positioning Systems (GPS) for guidance; and
b) The determination of aircraft performance characteristics on runways contaminated by winter precipitation.

With an extensive onboard data acquisition system, the aircraft can also be used for airborne geoscience studies, avionics research, and aircraft-based sensor research.

NRC acquired the Falcon 20 from the Department of National Defence (DND) in 1991. In partnership with the Canadian Space Agency (CSA) and TC, NRC originally instrumented the aircraft to support micro-gravity research and curved path (area navigation) capabilities and procedures. These capabilities still exist with the modified aircraft fuel and hydraulic systems in place to allow the aircraft to fly "zero-G" parabolic manoeuvres and with the modified aircraft guidance systems available to fly curved path precision approaches using GPS-based receivers.

In partnership with TC, NASA, and DND, the NRC Falcon 20 was used in a five-year research program directed at standardizing runway friction reporting procedures for winter contaminated runways and at determining aircraft landing and takeoff performance changes as a result of runway contaminants.

2.1.5.2 Falcon 20 Design Characteristics

A three-view diagram of the Falcon 20 aircraft has been included in Figure 2.2. Some of the pertinent dimensions of the Falcon 20 are:

a) Wingspan: 16.32 m (53 ft. 7 in.);
b) Wing surface area (both wings): 41 m^2 (441.33 $ft.^2$); and
c) Length: 17.15 m (56 ft. 3 in.).

The Falcon 20 has slotted slats outboard of the fence on each wing; the wing section inboard of the fence contains no moveable devices.

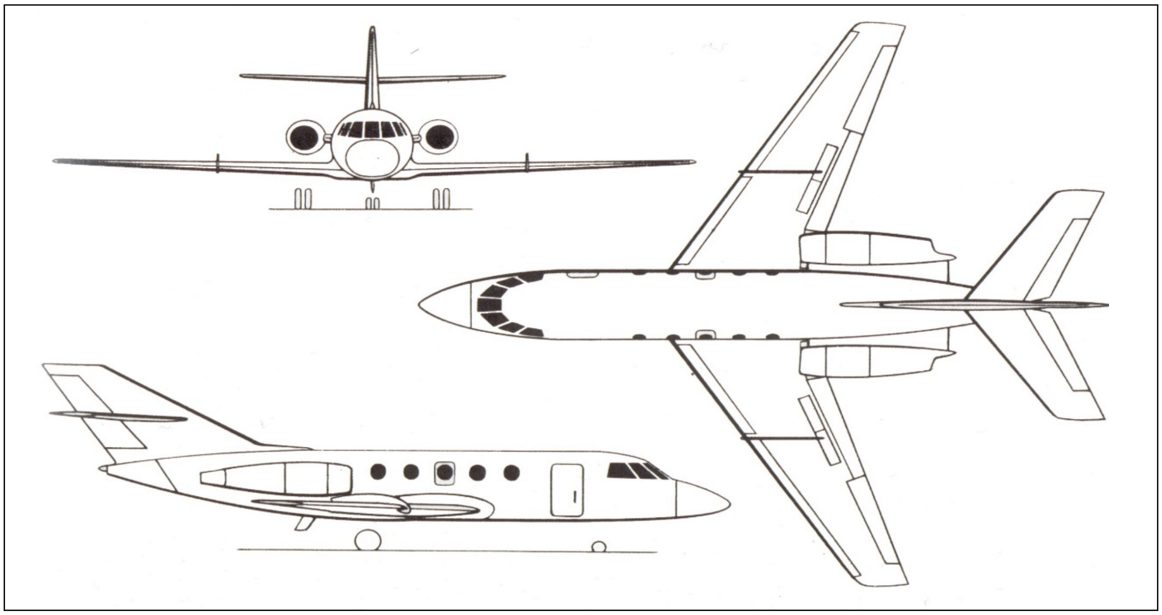

Figure 2.2: Schematic View of Dassault Falcon 20

2.1.5.3 Falcon 20 Onboard Installations

The NRC Falcon 20 research aircraft is equipped with the following onboard installations:

a) Engineering workstation containing computer with GPS receiver card, display, and interface with the data acquisition system;
b) Data acquisition system based on LSI 11/73 digital computer, with DAT tape and/or hard disk recording medium;
c) Multiple navigation sensors including VHF Omnidirectional Range (VOR), Instrument Landing System (ILS), Microwave Landing System (MLS), GPS, flight test differential GPS, and modified flight director; and
d) Cockpit mounted Cockpit Display Unit (CDU) to initiate GPS approaches and monitor selected test parameters.

2.1.5.4 Falcon 20 Measurement Capabilities

The NRC Falcon 20 research aircraft has the following measurement capabilities:

a) 3-axis accelerations and rates;
b) Aircraft attitude and heading;
c) Three-dimensional positions and velocities;
d) Static and dynamic pressures;
e) Outside air temperature; and
f) Flight director system signals.

2.1.5.5 Test Area

Areas on the port and starboard wings, just inboard of the fences, were selected to serve as the principal test surfaces on the Falcon 20 (denoted by the letter A in Figure 2.3). The test area was made large enough to be representative of the entire wing and, at the same time, to enable an ice pellet production rate that was reasonably achievable. The areas selected covered 1.1 m of the leading edge, inboard of the fence and the entire chord of the wing, as illustrated in Figure 2.3. The test surfaces had areas of 2.7 m^2 and were used for all tests.

In addition, some preliminary testing was conducted to investigate the effects of a shorter chord length on fluid flow-off. Test sections B and C in Figure 2.3 demonstrate the test areas used to represent a 2.4 m (8 ft.) chord and a 1.7 m (5.5 ft.) chord. These limited tests were in conjunction with the standard tests on the 2.9 m (9.5 ft.) chord section.

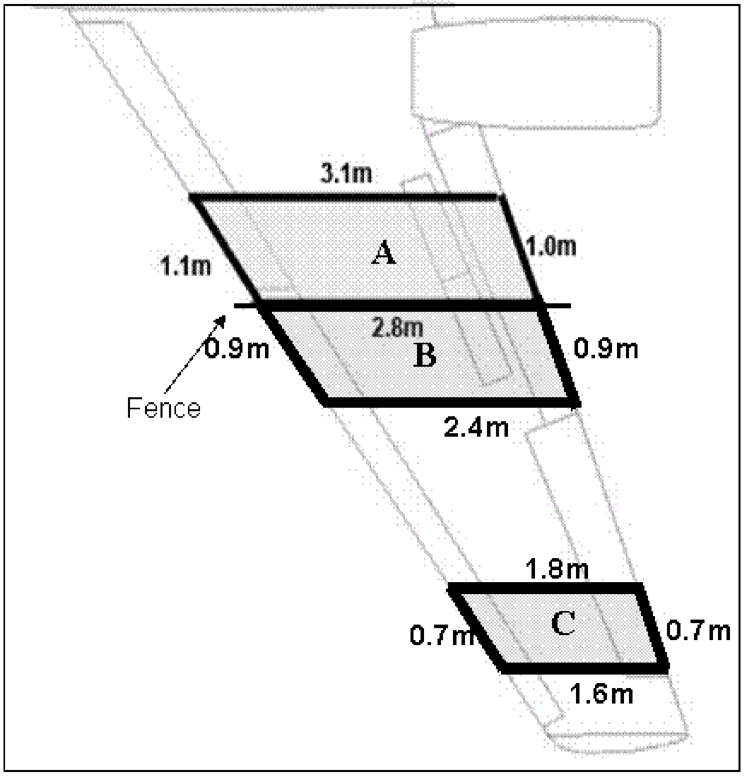

Figure 2.3: Test Area

2.1.5.6 Test Area Grid

Prior to the testing, NRC personnel used markers to draw a grid with dimensions of 0.61 m x 0.61 m (2 ft. x 2 ft.) just inside the fence on the port and starboard wings of the Falcon 20. Smaller grids with dimensions of 5.1 cm x 5.1 cm (2 in. x 2 in.) were then drawn inside the larger grid, perpendicular and parallel to the fence (see Photo 2.3). The grid was used to facilitate observations of the fluid shearing off the wing and the movement of ice pellets during takeoff.

The test area grid was only drawn on section A of the port and starboard wings (see Figure 2.3). Sections B and C did not have grid markings.

2.1.6 T-33 Research Aircraft

The following subsections describe the T-33 aircraft used to conduct the tests.

2.1.6.1 Lockheed Martin T-33 T-Bird/Shooting Star

The T-33 is a 1960s vintage "fighter" jet used extensively by the Canadian Armed Forces and Royal Canadian Air Force for flight training requirements. It is capable of high-performance, high-altitude operations with two pilots and a small instrument package. The T-33 has also been used by the NRC for convective and boundary layer turbulence studies. It is a rugged airplane that can handle harsh and adverse environments. The NRC T-33 aircraft is shown in Photo 2.4.

2.1.6.2 T-33 Design Characteristics

A three-view diagram of the T-33 aircraft has been included in Figure 2.4. Some of the pertinent dimensions of the T-33 are:

a) Wingspan: 11.85 m (38 ft. 10.5 in.); and
b) Length: 11.51 m (37 ft. 9 in.).

The T-33 comes equipped with wing "tip tanks." These tip tanks were removed during the testing.

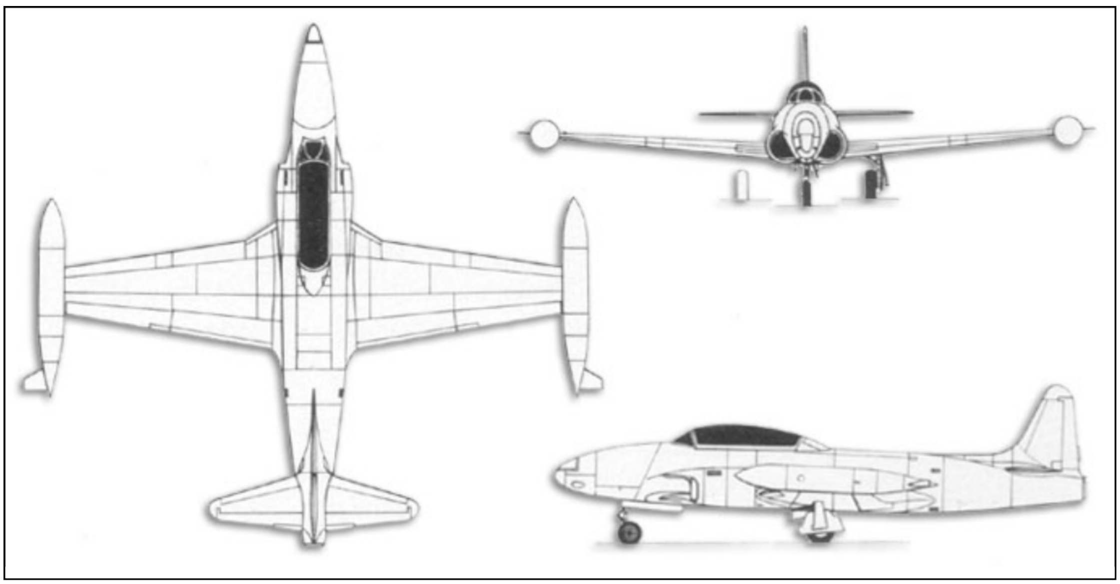

Figure 2.4: Schematic View of Lockheed Martin T-33

2.1.6.3 T-33 Onboard Installations

This high-speed (to 500 KIAS), high-G (-3.0 to +7.33), fully instrumented T-33 research aircraft is equipped for:

a) Pressure standard calibrations: precise in-flight static pressure measurement;
b) In-flight turbulence measurement: accurate 3-axis gust measurement; and

c) Flight mechanics research: accurate measurement of aircraft motion versus control input.

2.1.6.4 T-33 Measurement Capabilities

The NRC T-33 research aircraft has the following measurement capabilities:

a) 3-axis accelerations, attitudes, and rates;
b) Flight and engine control positions;
c) Longitudinal and lateral stick forces (rear cockpit);
d) Angles of attack and sideslip;
e) Static and dynamic pressures;
f) Total temperature; and
g) Provisions for additional sensors.

2.1.6.5 Test Area

The test areas on the T-33 port and starboard wings were chosen based on the chord length of 1.5 m (5 ft.). The areas selected covered 0.7 m of the leading edge and the entire chord of the wing, as illustrated in Figure 2.5.

It should be noted that due to the limited number of scheduled tests with the T-33, a test area grid was not drawn on the test sections. Small markings were made as reference points by APS personnel for taking Brix, thickness, and temperature measurements.

2.1.7 Simulated Precipitation Related Equipment

2.1.7.1 Ice Pellet Dispenser

Ice pellets were manufactured from ice cubes inside a rented refrigerated truck. The process required the use of blenders, calibrated sieves, and large Styrofoam containers.

Once produced, the ice pellets were stored in Styrofoam containers. They were applied over the test area using the modified motorized hand-held dispensers shown in Photo 2.5. Extensive calibration work was conducted prior to the full-scale testing to examine the dispensing footprint, eliminating the need to measure precipitation rates during the test runs.

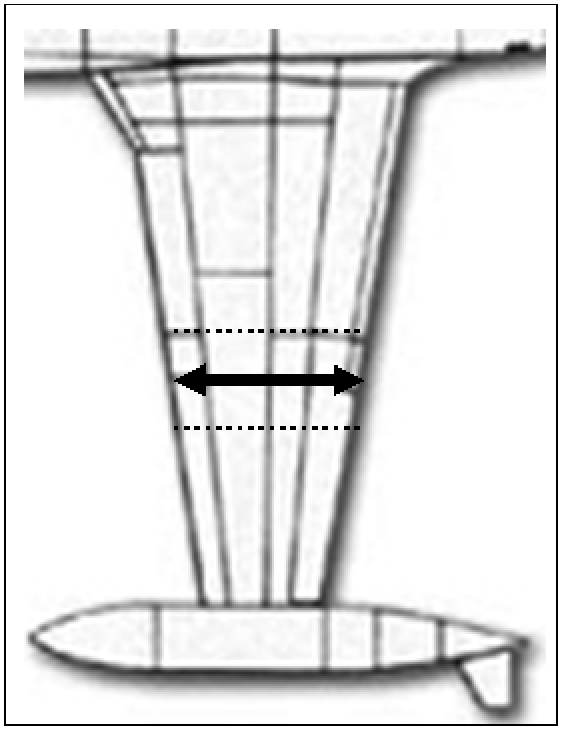

Figure 2.5: Test Area

2.1.7.2 Snow Dispenser

Snow was manufactured using a similar process used for the ice pellets. Once produced, the snow was stored in Styrofoam containers until applied over the test area using the ice pellet dispensers, modified to account for the finer snow particles. Extensive calibration work was conducted prior to the full-scale testing to examine the dispensing footprint, eliminating the need to measure precipitation rates during test runs.

2.1.7.3 Video and Photo Equipment

Four Canon Digital Rebel XTi digital still cameras (two per wing) were used to obtain high-speed, high-resolution photographs of the testing conducted with the Falcon 20 (only one hand-held camera was used during the T-33 tests). 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 two different lenses:

a) 18-55 mm standard lens for wide angle pictures; and
b) 105 mm macro lens for close-ups.

Still and video cameras were used to record visual observations of the testing. To create a consistent and stable setup for the cameras and video cameras, NRC personnel replaced both emergency exit doors of the Falcon 20 with a temporary structure that had camera-mounting capability (see Photo 2.6). A video camera and a still camera were fitted to both port and starboard emergency exit doors. The cameras were zoomed in to observe the behaviour of the fluid and contamination on the wing.

As testing progressed, the video cameras were replaced with additional still cameras, resulting in two still cameras per wing section. One still camera was focused to observe the leading edge of the principal test section and the other to observe the trailing edge of the principal test section. When fluid was applied to the secondary test section outboard of the fence during limited tests, one camera on the non-contamination wing side was repositioned to capture the outboard test section.

In addition to the images obtained from the cameras mounted on the aircraft, a professional photographer used a digital still camera to take pictures of the test setup and all phases of the takeoff tests.

2.1.8 Type III/IV Fluid Application Equipment

The Type III/IV fluids were kept at air temperature and applied to the aircraft outside the NRC hangar. 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 and the goal of minimizing the amount of fluid flowing off the wing.

Type III/IV fluids were applied to the aircraft wing surfaces using several polyvinyl chloride (PVC) pouring devices (Photo 2.7) manufactured for this purpose. Each 2.5 L device was fitted with pouring, refill, and breather holes, which permitted uniform fluid flow.

2.1.9 Waste Fluid Collection

A glycol mitigation plan was prepared for the Ottawa Airport Authority prior to the tests. This plan is shown in Appendix B.

Using a relatively small test area and applying the fluids by pouring minimized the amount of fluid falling off the aircraft wing. APS personnel used a vacuum to collect the fluid that did reach the ground immediately following the departure of the aircraft from the application area.

2.1.10 Personnel

NRC personnel operated the Falcon 20 and T-33 aircraft. Five APS staff members were required to conduct the tests, and three additional persons from Ottawa were hired to manufacture ice pellets. A professional photographer was retained to record digital images of the test setup and test runs. Representatives from the TDC and the FAA provided direction in testing and participated as observers. A group photo of the personnel involved in the Falcon 20 and T-33 testing is shown in Photo 2.8.

2.1.11 Measurement of Test Parameters

2.1.11.1 Fluid Thickness

For each test, the fluid thickness of the anti-icing fluid was generally measured at four locations along the centreline of the test area (see Photo 2.9). Measurements were typically taken at four stages in a typical test:

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

The fluid thickness measurement locations on the port wing of the Falcon 20 are shown in Figure 2.6; the same layout was used for the starboard wing. When testing on the outboard sections of the Falcon 20, or on the T-33, the layout for the measurement locations was approximated using the same relative locations to the main test sections of the Falcon 20. The locations designated for thickness measurement, identified in the data form, were the following:

- Wing Position 2: On the leading edge, 2.5 cm (1 in.) from the joint;
- Wing Position 5: As far as could be reached from the leading edge;
- Wing Position 7: Just behind the spoiler; and
- Wing Position 8: As far as could be reached from the trailing edge, halfway between the trailing edge and the joint.

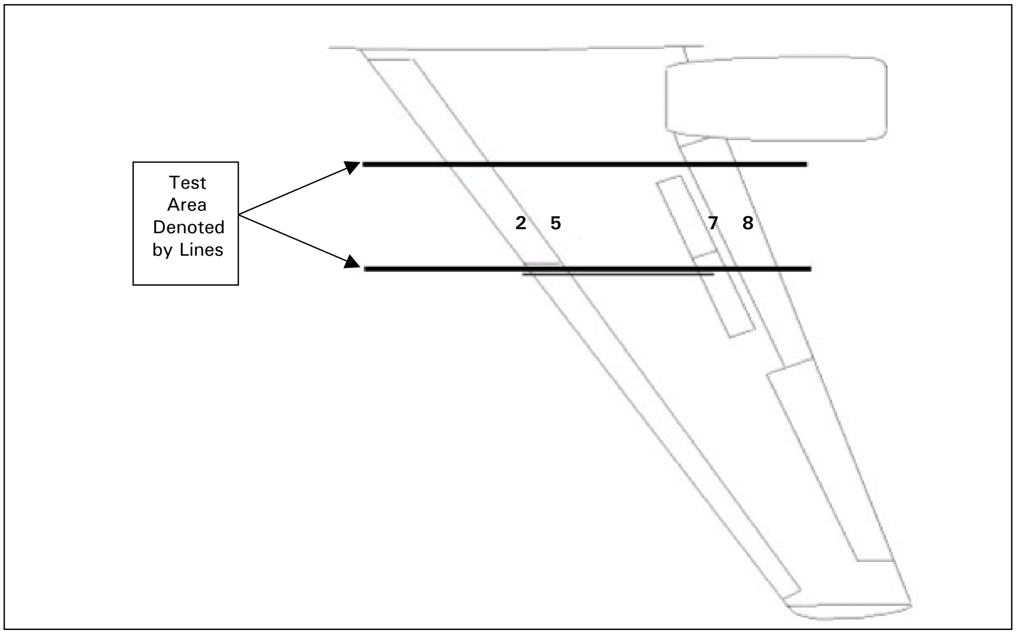

Figure 2.6: Fluid Thickness and Fluid Brix Measurement Locations

2.1.11.2 Fluid Brix

Fluid Brix was measured at the leading edge and the trailing edge using hand-held refractometers (Photo 2.10) at four stages in a typical test:

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

The locations designated for fluid Brix measurement, also shown in Figure 2.6, were the following:

- Wing Position 2: On the leading edge, 2.5 cm (1 in.) from the joint; and
- Wing Position 8: Halfway between the trailing edge and the joint.

2.1.11.3 Wing Skin Temperature

Wing skin temperature was measured at the leading edge and the trailing edge using hand-held temperature probes (Photo 2.11) at five stages in a typical test:

a) Before fluid application;
b) After fluid application;
c) After the ice pellet application;
d) Before the simulated takeoff test; and
e) After the simulated takeoff test.

Wing temperatures were measured at eight locations across the test area:

- Positions 1 and 2: On the leading edge;
- Positions 3 and 4: On the leading edge, 2.5 cm (1 in.) from the joint;
- Positions 5 and 6: As far as could be reached from the leading edge; and
- Positions 7 and 8: Halfway between the trailing edge and the joint.

Wing temperatures were read directly off the temperature probe and recorded on the appropriate data form. Figure 2.7 shows the location of each measurement position. When testing on the outboard sections of the Falcon 20, or on the T-33, the layout for the measurement locations was approximated using the same relative locations to the main test sections of the Falcon 20.

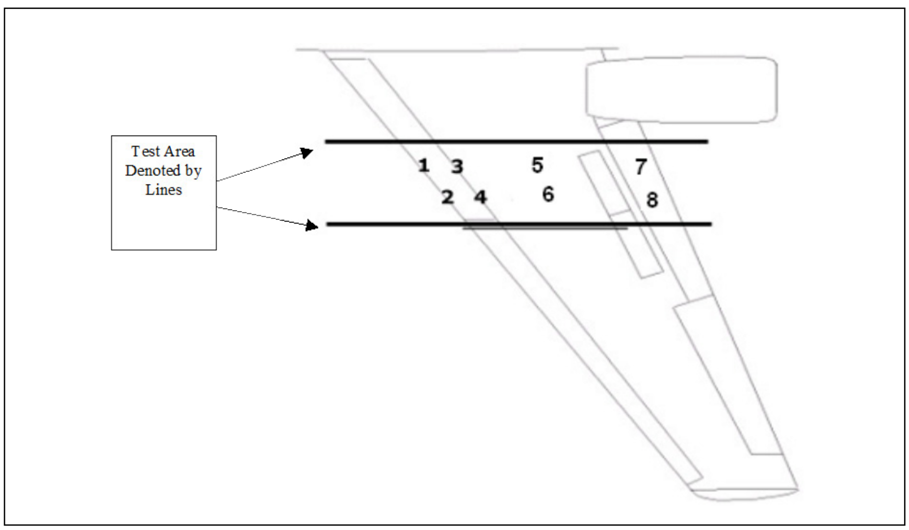

Figure 2.7: Wing Temperature Measurement Locations

2.1.12 Data Forms

Several different forms were used to facilitate the documentation of the various data collected for the Falcon 20 and T-33 tests. These forms include:

a) Fluid Receipt Form;
b) General Form (every test);
c) Fluid Thickness/Wing Temperature/Brix Form (Port Wing);
d) Fluid Thickness/Wing Temperature/Brix Form (Starboard Wing);
e) Freezing Rain/Snow Quantity Form;
f) Test Results Form;
g) Time Record of Operations; and
h) Nominal Test Conditions.

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

Completed data forms for the Falcon 20 and T-33 tests are also provided:

a) Time Record of Operations (Appendix D); and
b) Test Results Form (Appendix E).

2.2 General Methodology

This section describes equipment and general information used for both the Falcon 20 and T-33 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 C.

2.2.1 Viscometer

Viscosity measurements were carried out using a Brookfield viscometer (Model DV-1+, shown in Photo 2.12) fitted with a recirculating fluid bath and small sample adapter.

2.2.2 Fluid Freezing Point and Temperature Gauges

Fluid freezing points were measured using a hand-held Misco 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 fluid freezing point table for Kilfrost ABC-S and Kilfrost ABC-S Plus is shown in Table 2.2. The fluid freezing point curve for Dow Ultra+ and Dow EG106 is shown in Figure 2.8. Table 2.3 shows the fluid freezing points for Clariant MPIII 2031 ECO.

Wing temperatures were measured using hand-held Wahl surface temperature probes.

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

Conc. (% Vol)	BRIX (20°C)	RI (20°C)	Freezing Point (20°C)	Conc. (% Vol)	BRIX (20°C)	RI (20°C)	Freezing Point (20°C)	Conc. (% Vol)	BRIX (20°C)	RI (20°C)	Freezing Point (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				

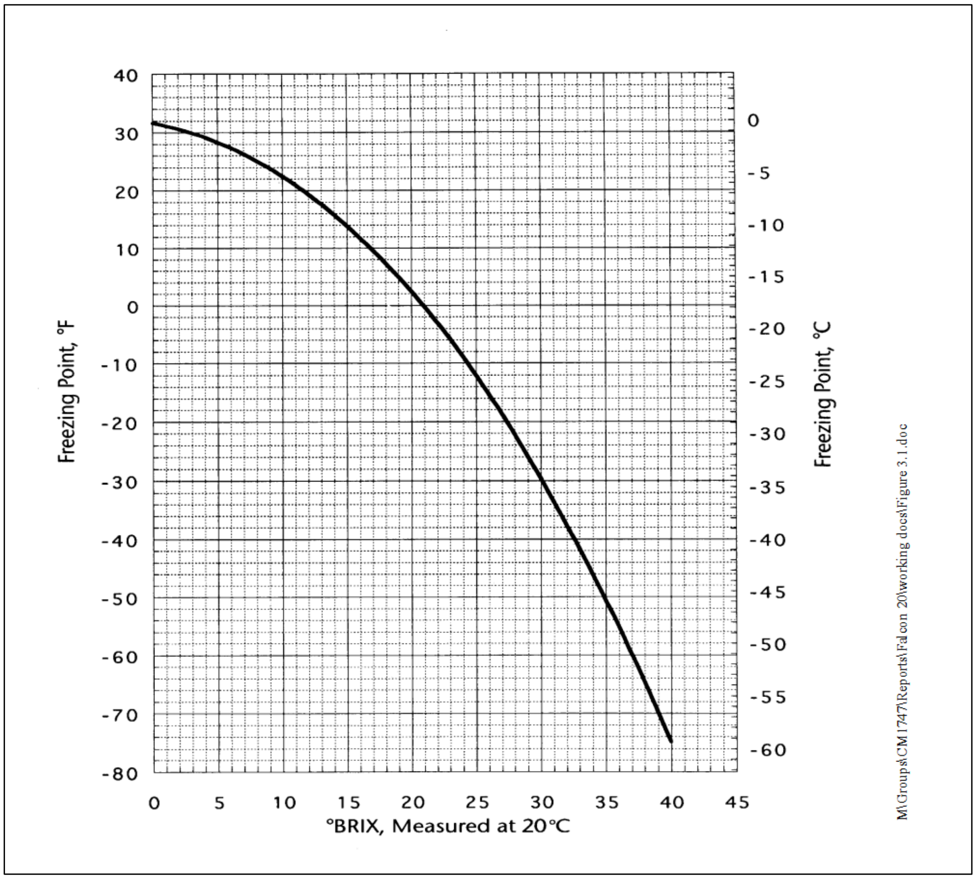

Figure 2.8: Freezing Point vs. Brix of Aqueous Solutions of Dow UCAR Ultra+ and Dow EG106

Table 2.3: Dilution Chart for Clariant MPIII 2031 ECO

	BRIX	FREEZING POINT
Dilution (v/v) Safewing : Water	MISCO 10431 VP	MISCO 7084 VP (˚C)
100 : 0	34.3 to 36.0	-31 to -34
95 : 5	33.4	-29
90 : 10	31.8	-26
85 : 15	30.2	-23
80 : 20	28.8	-21
75 : 25	27.2	-18
70 : 30	25.4	-16
65 : 35	24.0	-14
60 : 40	22.2	-12
55 : 45	20.4	-11
50 : 50	18.8	-10

2.2.3 Thickness Gauges

Wet film thickness gauges, shown in Figure 2.9, were used to measure fluid film thickness. These gauges were selected because they provide an adequate range of thicknesses (0.1 mm to 10.2 mm) for Type III/IV fluids. The rectangular gauge shown in Figure 2.9 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 2.4) was used to convert the recorded thickness values into the corrected thickness values.

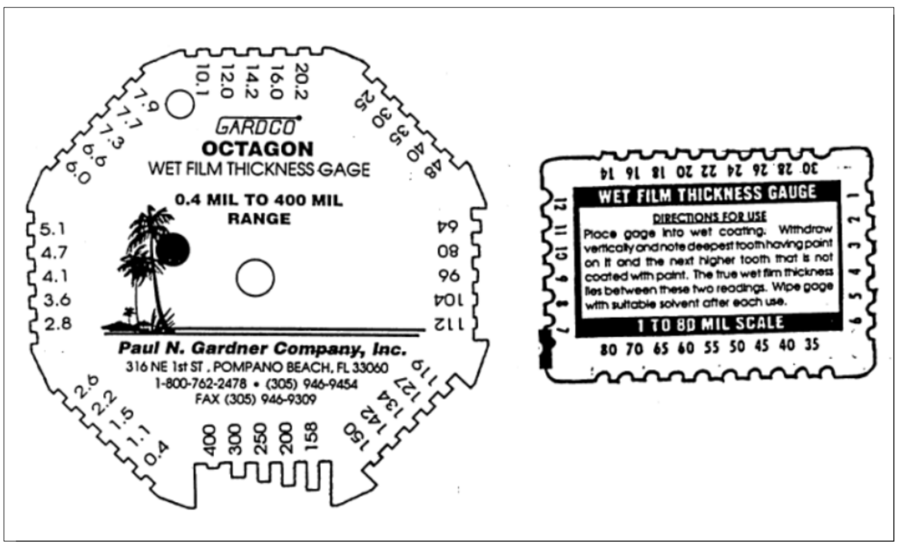

Figure 2.9: Thickness Gauges

Table 2.4: Film Thickness Conversion Table

RECTANGULAR GAUGE			OCTAGON GAUGE		
Reading* (mil)	Calculated Thickness (mil)	Calculated Thickness (mm)	Reading* (mil)	Calculated Thickness (mil)	Calculated Thickness (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.

2.2.4 Fluids

Five fluids were used in these tests: Clariant Safewing MP III 2031 ECO, Dow UCAR ADF/AAF Ultra+, Dow UCAR Endurance EG106, Kilfrost ABC-S, and Kilfrost ABC-S PLUS. The pertinent characteristics of these fluids are given in Table 2.5. It should be noted that Ultra+ and ABC-S fluids obtained the previous year were used for certain designated tests; the viscosity and condition of the fluids were found to be acceptable.

Table 2.5: Test Fluids

Fluid Name	Batch #	Received	Type	Formulation	Brix (°) of Neat Fluid	Viscosity (mPa.s)
Clariant Safewing MP III 2031 ECO	203573	Winter 07-08	III	PG	34.75	40
Dow UCAR ADF/AAF Ultra+	200601604-53	Winter 06-07	IV	EG	37.25	39,300
Dow UCAR Endurance EG106	VJ2601GKDR	Winter 07-08	IV	EG	31.25	31,650
Kilfrost ABC-S	10177	Winter 06-07	IV	PG	35	17,750
Kilfrost ABC-S PLUS	20368	Winter 07-08	IV	PG	35	18,550

2.2.5 Artificial Contamination

2.2.5.1 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 mm to 3 mm. During moderate to heavy ice pellet conditions, the diameter of the ice pellets measured up to 5 mm. Based on this observation, ice pellets were produced with diameters ranging from 1.0 mm to 4.0 mm to represent the most common ice pellet sizes observed during natural events.

The ice pellets were manufactured inside a refrigerated truck (see Photo 2.13). Cubes of ice were crushed and passed through calibrated sieves (see Photo 2.14) to obtain the required ice pellets size range. Hand-held motorized dispensers were used to dispense the ice pellets. The ice pellets were applied to the leading and trailing edges of the wing at the same time.

2.2.5.2 Snow

Snow was produced using the same method for producing ice pellets. The snow used consisted of small ice crystals measuring less than 1.3 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. Hand-held motorized dispensers were used to dispense the snow. The snow was applied to the leading and trailing edges of the wing at the same time.

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Photo 2.1: NRC YOW Institute for Aerospace Research Hangar

Photo 2.2: NRC Falcon 20 Aircraft

Photo 2.3: Reference Grid Drawn on Both Port and Starboard Wing Test Sections

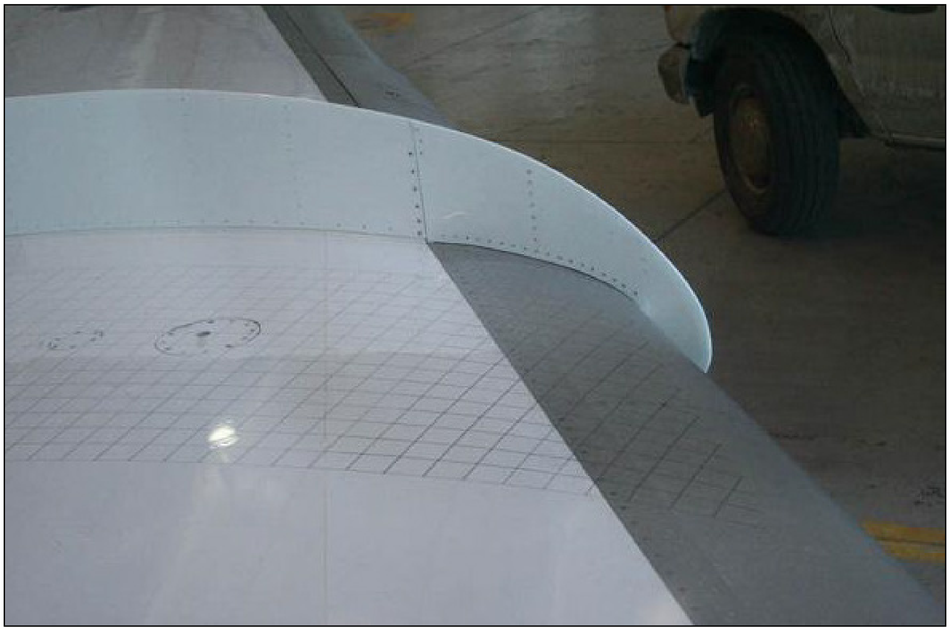

Photo 2.4: NRC T-33 Aircraft

Photo 2.5: Ice Pellet/Snow Dispenser Setup for Falcon 20 Tests

Photo 2.6: Camera Positioning in Emergency Exit Windows (View from Inside)

Photo 2.7: PVC Fluid Pouring Devices

Photo 2.8: Group Photo of Personnel

Photo 2.9: Fluid Thickness Measurement Using Wet Film Thickness Gauge

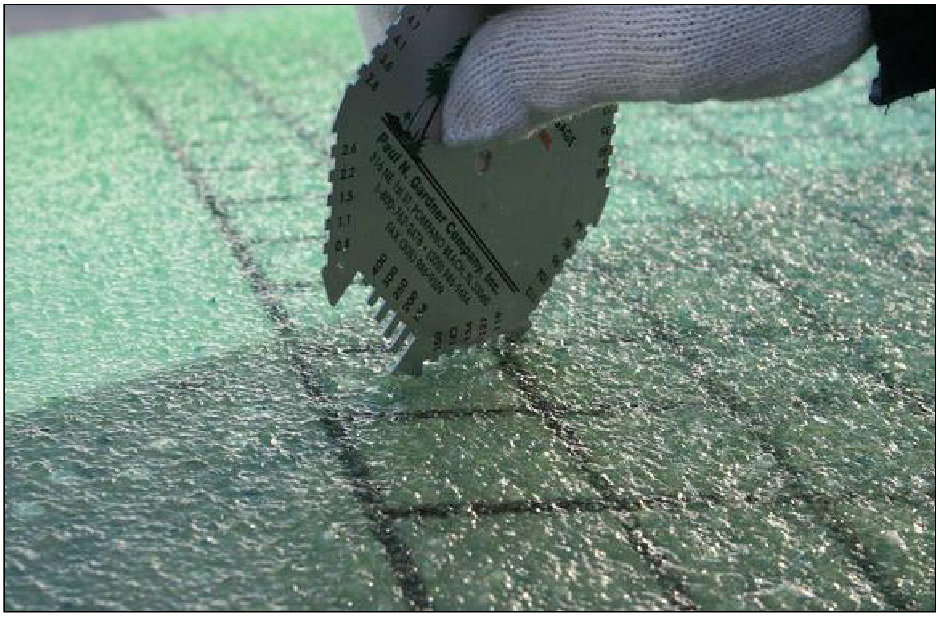

Photo 2.10: Fluid Freezing Point Measurement Using Hand-Held Brixometer

Photo 2.11: Wing Surface Temperature Measurement

Photo 2.12: Brookfield Digital Viscometer Model DV-1+

Photo 2.13: Refrigerated Truck Used for Manufacturing Ice Pellets

Photo 2.14: Calibrated Sieves Used to Obtain Desired Size Distribution

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3. FLAT PLATE TESTING

This section provides an overview of the flat plate testing conducted as part of the test program. The series of tests was performed with the objective of exploring specific ice pellet conditions with the aim of minimizing full-scale testing required.

3.1 Fluid Adherence in Mixed Ice Pellets and Freezing Rain Conditions - Type II and Type III Fluid Testing

3.1.1 Objective

The objective of this project was to investigate the level of ice pellet and freezing rain contamination required to cause fluid adherence to the test surface. Baseline testing was conducted in freezing rain conditions only. Testing was primarily conducted to investigate if the current allowance times for Type IV fluids could be expanded to include Type II and Type III fluids.

3.1.2 Methodology

Endurance time testing was conducted in April 2008 at the NRC Climatic Engineering Facility cold chamber using the standard flat plate HOT test procedure and surplus fluid inventory from HOT testing fluids. Test plates were positioned directly underneath the simulated freezing precipitation sprayer assembly. The "Ice Pellet Dispenser" was positioned to dispense ice pellets on two test plates (test plate positions 1 and 2).

3.1.3 General Observations

3.1.3.1 Type II Mixed Precipitation Tests

Testing conducted with the Type II fluid in mixed light ice pellets and light freezing rain demonstrated that the presence of ice pellets during the -5°C test shortened the time to first adherence compared to the -10°C test, during which the time to first adherence was comparable within 4 minutes to the baseline light freezing rain test. This may be due to the lower viscosity of the fluid at the warmer temperature, which is more conducive to melting and dissolving frozen precipitate.

Based on the results at -5ºC, the current mixed light freezing rain and light ice pellets 25-minute allowance time for Type IV fluids at -5ºC would not be appropriate for Type II fluids. Estimated failure occurred at 16 minutes; however, first adherence occurred at 25 minutes.

Based on the results at -10ºC, the current mixed light freezing rain and light ice pellets 10-minute allowance time for Type IV fluids at -10ºC seems appropriate for the Type II fluid that was tested. Estimated failure occurred at 12 minutes and adherence at 20 minutes, both exceeding the 10-minute allowance time for the condition for Type IV fluids.

3.1.3.2 Type III Mixed Precipitation Tests

Testing conducted with the Type III fluid demonstrated differences in the visual fluid failure call when comparing mixed conditions versus the baseline light freezing rain only test; mixed condition tests failed quicker. However, the time of first adherence was comparable (within 4 minutes) for both mixed and baseline tests. Due to the thin fluid layer of Type III fluid, ice pellets likely protrude further out of the fluid (compared to thickened Type II or Type IV fluid) causing early visual failure; however, the ice pellets likely do not significantly add to the occurrence of adherence.

Based on the results at -5ºC, the current mixed light freezing rain and light ice pellets 25-minute allowance time for Type IV fluids at -5ºC is not appropriate for Type III fluids. Estimated failure and adherence occurred at 10 minutes.

Based on the results at -10ºC, the current mixed light freezing rain and light ice pellets 10-minute allowance time for Type IV fluids at -10ºC is not appropriate for Type III fluids. Estimated failure and adherence occurred at 7 minutes.

A detailed test report was compiled upon completion of testing. This report is included in Appendix F.

4. FULL-SCALE DATA COLLECTED

4.1 Test Log

A detailed log of the tests conducted with the Falcon 20 and T-33 aircraft is shown in Table 4.1. The table provides relevant information for each of the tests, as well as final values used for the data analysis. Each column contains data specific to one test. The following is a brief description of the column headings for Table 4.1:

Run #:	Exclusive number identifying each test.
Aircraft:	NRC aircraft used during the test.
Target Takeoff Profile:	Target acceleration profile for the simulated takeoff run.
Actual Takeoff Profile:	Actual acceleration profile for the simulated takeoff run as recorded by the aircraft monitoring systems.
Test Objective:	Test objective describing test conditions.
Date:	Date when the test was conducted.
Actual OAT (test start) (ºC):	Outside air temperature recorded just before the start of the takeoff test, measured in degrees Celsius.
Takeoff test start time:	Start of the test, recorded in local time.
Rotation (yes or no):	Whether the aircraft underwent rotation once the desired top speed was achieved.
Number of Cameras:	Total number of high-speed digital cameras used during the conduct of the test.
Fluid:	Aircraft anti-icing fluid used during the test.
Precipitation Type:	Simulated freezing precipitation type (combination of ice pellets or snow). "N/A" indicates that no precipitation was applied.
IP Rate (g/dm²/h):	Simulated ice pellet precipitation rate, calculated in g/dm²/h.
SN Rate (g/dm²/h):	Simulated snow precipitation rate, calculated in g/dm²/h.
Exposure Time:	Simulated precipitation period, recorded in minutes.
Observation #1-3:	General observations made during or following the test.

Table 4.1: Falcon 20 and T-33 Test Log

RUN NO.	**1 P/S 8**	**2 P/S 8**	**3 P/S 8**	**3A S 8**	**4 P/S 8**	**5 P/S 8**	**6 P/S 8**	**7 P/S 8**
Aircraft	Falcon 20	Falcon 20	Falcon 20		Falcon 20	Falcon 20	Falcon 20	Falcon 20
Target Takeoff Profile	80 knots in 17 sec	80 knots in 17 sec	80 knots in 17 sec		120 knots in 25 sec	80 knots in 17 sec	80 knots in 17 sec	80 knots in 17 sec
Actual Takeoff Profile	78 knots in 21 sec	74 knots in 19 sec	75 knots in 18 sec		104 knots in 31 sec	66 knots in 18 sec	75 knots in 18 sec	74 knots in 19 sec
Objective	80 knots IP Expansion	80 knots IP Expansion	80 knots IP Expansion (repeat Run 1)	2.4 m (8 ft) chord	ABC-S vs. ABC-S Plus 120 knots	ABC-S vs. ABC-S Plus 80 knots	EG 106 vs. Ultra+	80 knots IP Expansion
TEST PARAMETERS								
Date	26-Feb	27-Feb	27-Feb		28-Feb	28-Feb	28-Feb	28-Feb
Actual OAT (test start)	-1°C	-13°C	-11°C		-19°C	-18°C	-16°C	-15°C
Approx Start Time	12:00	11:20	13:15		9:30	10:30	12:00	2:30
Rotation	no	no	no		no	no	no	no
Number of Cameras	2	2	2	0	4	4	4	4
PORT WING:	**1P8**	**2P8**	**3P8**	**N/A**	**4P8**	**5P8**	**6P8**	**7P8**
Fluid	ABC-S Plus	2031	EG106	N/A	ABC-S Plus	ABC-S Plus	EG106	ABC-S Plus
Precipitation Type	IP / Snow	IP	IP	N/A	N/A	N/A	N/A	IP
IP Rate (g/dm²/h)	77	26	75	N/A	N/A	N/A	N/A	75
Snow Rate (g/dm²/h)	7.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Exposure Time (min)	25	10	10	N/A	N/A	N/A	N/A	10
STARBOARD WING:	**1S8**	**2S8**	**3S8**	**3AS8**	**4S8**	**5S8**	**6S8**	**7S8**
Fluid	ABC-S Plus	2031	EG106	EG106	ABC-S	ABC-S	Ultra+	ABC-S Plus
Precipitation Type	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IP Rate (g/dm²/h)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Snow Rate (g/dm²/h)	7.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Exposure Time (min)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
COMMENTS								
Observation #1	Most contamination and fluid came off, but thickness of remanents were higher than 120 knots	Could have run with higher rate and/or time (didn't look like fluid would fail from contamination)	Not a contamination issue, there is a fluid aerodynamic issue. IP did not play a role.	Additional fluid applied to right side of fence to observe difference of shorter (8 ft) chord	No difference between final fluid thickness on port and starboard wings	No difference between final fluid thickness on port and starboard wings	Ultra+ fluid thicker than EG106	Limited ice pellets left on contaminated wing. IP aft of the LE to TE.
Observation #2	Could this be a problem for aerodynamics?	Significant amount of fluid remained on wing. Close to "aerodynamic edge".	Wind - approx 23 knots	8 ft vs 9.5 ft chord comparison of fluid without contamination showed no visual differences.	Low winds	Low winds	Increasing wind speed	Fluid left on both wings, contaminated (port) side showed thicker fluid thickness at end of run.
Observation #3	Fluid left on starboard wing. Fluid cleared 1/3 of wing on port side.	High winds (about 15 knots) pushed IP to trailing edge. Note IP not calibrated at this wind speed (>10 km)	Final thickness of this fluid was thinner than Kilfrost ABC-S Plus					Winds approx 15 km

Table 4.1: Falcon 20 and T-33 Test Log (cont'd)

RUN NO.	8 P/S 8	9 P/S 8	10 P/S 8	10A P/S 8	11 P/S 8	12 P/S 8	12A P/S 8
Aircraft	Falcon 20	Falcon 20	Falcon 20		Falcon 20	Falcon 20	
Target Takeoff Profile	120 knots in 25 sec	120 knots in 25 sec	100 knots in 21 sec		80 knots in 17 sec	80 knots in 17 sec	
Actual Takeoff Profile	112 knots in 29 sec	117 knots in 29 sec	90 knots in 22 sec		76 knots in 17 sec	72 knots in 22 sec	
Objective	ABC-S vs. ABC-S Plus with rotation	Allowance Time Expansion	100 knot rotation	5.1.7 m (5 ft) chord	80 knots with flaps	80 knots with flaps	
TEST PARAMETERS							
Date	29-Feb	29-Feb	29-Feb		29-Feb	4-Mar	
Actual OAT (test start)	-17°C	-15°C	-13°C		-12°C	-3°C	
Approx Start Time	9:48	11:10	12:25		14:00	10:25	
Rotation	yes	yes	no		no	no	
Number of Cameras	4	4	3	1	4	3	1
PORT WING:	**8P8**	**9P8**	**10P8**	**10AP8**	**11P8**	**12P8**	**12AP8**
Fluid	ABC-S Plus	ABC-S Plus	EG106	EG106	EG106	ABC-S Plus	Ultra+
Precipitation Type	N/A	IP/Snow	N/A	N/A	N/A	IP	N/A
IP Rate (g/dm²/h)	N/A	25	N/A	N/A	N/A	75	N/A
Snow Rate (g/dm²/h)	N/A	25	N/A	N/A	N/A	N/A	N/A
Exposure Time (min)	N/A	20	N/A	N/A	N/A	25	N/A
STARBOARD WING:	**8S8**	**9S8**	**10S8**	**10AS8**	**11S8**	**12S8**	**12AS8**
Fluid	ABC-S	ABC-S Plus	ABC-S Plus	ABC-S Plus	ABC-S Plus	ABC-S Plus	Ultra+
Precipitation Type	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IP Rate (g/dm²/h)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Snow Rate (g/dm²/h)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Exposure Time (min)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
COMMENTS							
Observation #1	Fluid very clean first 60% of chord. Acceleration time 29.70 seconds	Acceleration 29.36 seconds. Port side cleared 60% of chord. IP/fluid left on TE, but not a concern.	Outboard was thinner than inboard	10 L of fluid poured on outer wing; 5.5 ft chord	EG106 thinner than ABC-S Plus	Fluid came off test section (>2/3 at rotation)	Slats seemed to impose shearing of fluid outboard on 5.5 ft section
Observation #2	Both wings comparable, thinner than 120 knots w/o rotation, but flight profile was longer.	LE comparable thickness, port side TE thicker fluid.	EG106 thinner at end of test than ABC-S Plus		Flaps seemed to help fluid elimination. Visually approx 2/3 clean at rotation	Run was longer than usual (~21 seconds)	
Observation #3					Flaps 15 degrees		

Table 4.1: Falcon 20 and T-33 Test Log (cont'd)

RUN NO.	13 P/S 8	13A P/S 8	14 P/S 8	14A P/S 8	15 P/S 8	15A P/S 8	16 P/S 8	16 P/S 8
Aircraft	Falcon 20		Falcon 20		Falcon 20		Falcon 20	
Target Takeoff Profile	80 knots in 17 sec		120 knots in 25 sec		80 knots in 17 sec		80 knots in 17 sec	
Actual Takeoff Profile	71 knots in 19 sec		117 knots in 30 sec		77 knots in 19 sec		75 knots in 17 sec	
Objective	80 knots with flaps		120 knots with rotation, flaps down		80 knots no rotation, flaps down		80 knots no rotation, flaps down	
TEST PARAMETERS								
Date	4-Mar		6-Mar		6-Mar		6-Mar	
Actual OAT (test start)	-5°C		-9°C		-4°C		+1°C	
Approx Start Time	11:45		9:00		10:10		12:30	
Rotation	no		yes		no		no	
Number of Cameras	2	2	3	1	3	1	3	1
PORT WING:	**13P8**	**13AP8**	**14P8**	**14AP8**	**15P8**	**15AP8**	**16P8**	**16AP8**
Fluid	EG106	Ultra+	ABC-S+	ABC-S+	ABC-S+	ABC-S+	2031	2031
Precipitation Type	IP	N/A	IP/Snow	N/A	IP/Snow	N/A	IP/Snow	N/A
IP Rate (g/dm²/h)	75	N/A	25	N/A	25	N/A	25	N/A
Snow Rate (g/dm²/h)	N/A	N/A	25	N/A	25	N/A	25	N/A
Exposure Time (min)	25	N/A	20	N/A	20	N/A	20	N/A
STARBOARD WING:	**13S8**	**13AS8**	**14S8**	**14AS8**	**15S8**	**15AS8**	**16S8**	**16AS8**
Fluid	EG106	Ultra+	ABC-S+	ABC-S+	ABC-S+	ABC-S+	ABC-S+	ABC-S+
Precipitation Type	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IP Rate (g/dm²/h)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Snow Rate (g/dm²/h)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Exposure Time (min)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
COMMENTS								
Observation #1	>2/3 of wing cleared at rotation		Thickness greater on 5.5 ft section than inboard section on S/B wing as compared to inboard section, especially on TE		S/B: Thickness greater on outboard section than on inboard section		IP melting in the dispensers, therefore amount actually dispensed is probably lower (see precip rate data form).	
Observation #2	Slatted section sheared <1/2 of wing at rotation		Some contamination on TE on port wing		Port: Fluid completely eliminated some minimal contamination left on TE.		S/B: Similar results for inboard vs. outboard	
Observation #3	No contamination left at end of run				Temp >0°C so contamination mostly melted		Port: Outboard dry - no movement at rotation. Inboard cleared at rotation. Ice contamination removed at rotation	

Table 4.1: Falcon 20 and T-33 Test Log (cont'd)

RUN NO.	16 P/S 8	16 P/S 8	17 P/S 8	18 P/S 8
Aircraft	Falcon 20		T-33	T-33
Target Takeoff Profile	80 knots in 17 sec		85 knots in 17 sec	85 knots in 17 sec
Actual Takeoff Profile	75 knots in 17 sec		92 knots in 29 sec	92 knots in 29 sec
Objective	80 knots no rotation, flaps down		85 knots with rotation, flaps down	85 knots with rotation, flaps down
TEST PARAMETERS				
Date	6-Mar		7-Mar	7-Mar
Actual OAT (test start)	+1°C		0°C	0°C
Approx Start Time	12:30		9:30	9:30
Rotation	no		yes	yes
Number of Cameras	3	1	1	1
PORT WING:	**16P8**	**16AP8**	**17P8**	**18P8**
Fluid	2031	2031	EG106	EG106
Precipitation Type	IP/Snow	N/A	N/A	N/A
IP Rate (g/dm²/h)	25	N/A	N/A	N/A
Snow Rate (g/dm²/h)	25	N/A	N/A	N/A
Exposure Time (min)	20	N/A	N/A	N/A
STARBOARD WING:	**16S8**	**16AS8**	**17S8**	**18S8**
Fluid	ABC-S+	ABC-S+	ABC-S+	ABC-S+
Precipitation Type	N/A	N/A	N/A	N/A
IP Rate (g/dm²/h)	N/A	N/A	N/A	N/A
Snow Rate (g/dm²/h)	N/A	N/A	N/A	N/A
Exposure Time (min)	N/A	N/A	N/A	N/A
COMMENTS				
Observation #1	IP melting in the dispensers, therefore amount actually dispensed is probably lower (see precip rate data form).		Fluid thickness similar on both wings	EG106 cleared before ABC-S+
Observation #2	S/B: Similar results for inboard vs. outboard		EG106 seems to have more ripples in residual fluid. Likely illusion of different dyes in fluids	Thickness thinner on TE port vs. TE S/B
Observation #3	Port: Outboard dry - no movement at rotation. Inboard cleared at rotation. Ice contamination removed at rotation			Flaps seemed to help flow-off on the half section (visual observation)

4.2 Precipitation Rate Measurement and Calibration

4.2.1 Ice Pellets and Snow

APS conducted testing to determine the footprint of the ice pellet and snow dispersers. Calibration work was conducted at the APS test site situated at the Pierre-Elliot Trudeau International Airport in Montreal.

To measure the footprint of the dispensers, collection pans measuring 17.8 cm x 17.8 cm were laid out in a matrix of 11 pans by 11 pans for a total of 121 collection pans. The dispenser location relative to the matrix of pans was recorded. A designated weight of simulated ice pellets or simulated snow was placed into the dispenser and the dispenser was run. The dispensers were re-filled with measured weights of ice pellets or snow every 5 minutes for the duration of the test when all the contents were emptied. At test end, the individual collection pans were then weighed to calculate the dispenser distribution.

It was found that the distribution efficiency of the dispensing system varied depending on the surface dimensions. As a result, a dispensing efficiency was calculated specifically for the Falcon 20 test section dimensions. The dispensing efficiency and location of the dispensers with respect to the test section varied based on the wind speeds during the test.

4.2.2 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 4.1 demonstrates the HOT testing rate precipitation breakdown.

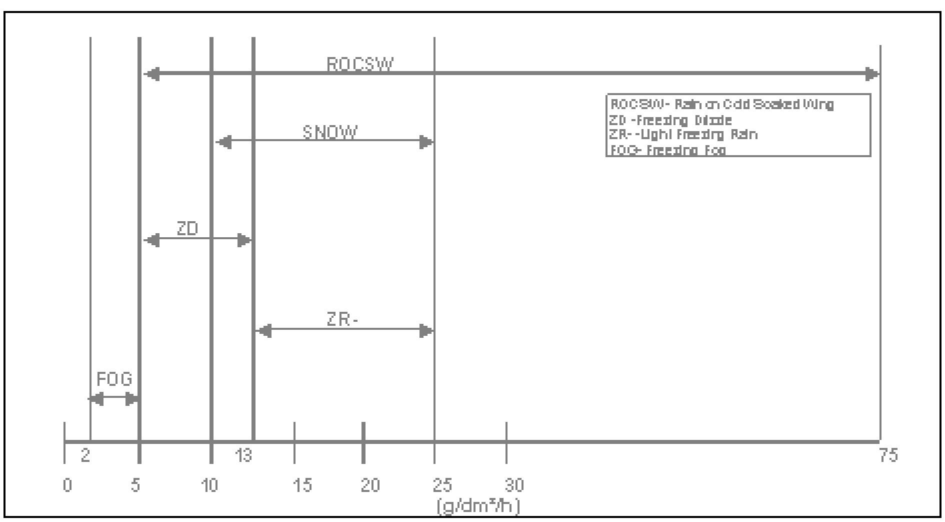

Figure 4.1: Precipitation Rate Breakdown

HOT testing protocol for ice pellets does not currently exist. As a result, ice pellet precipitation rate limits were based upon the freezing rain rate breakdown. The following precipitation rates were used for the full-scale and flat plate testing conducted during the winter of 2007-08:

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

4.3 Test Sequence

For both the Falcon 20 and T-33 tests, the test sequence followed the same critical path. The length of each test (from start of setup to end of last measurement) varied largely due to the length of exposure to precipitation (if applicable). Time required for setup and teardown as well as preparing and configuring the aircraft stayed relatively the same from test to test. Figure 4.2 demonstrates a sample timeline for a typical Falcon 20 and T-33 test. It should be noted that in both figures, a precipitation exposure time of 60 minutes was used for demonstration purposes; this varied for each test depending on the objective.

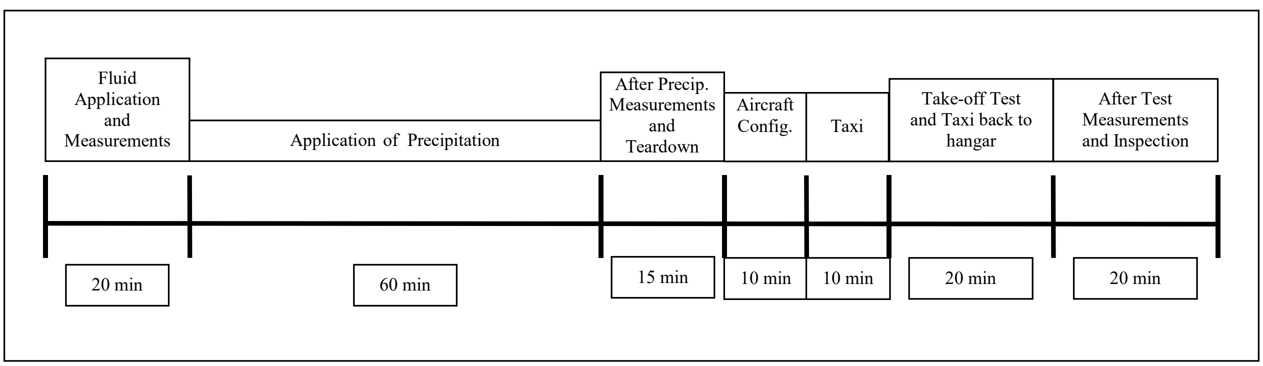

Figure 4.2: Typical Falcon 20 and T-33 Test Timeline

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5. EFFECT OF FLAPS

Previous testing conducted during the winter of 2006-07 indicated that residual fluid observed on the trailing edge of the National Advisory Committee for Aeronautics (NACA) 23012 wing section may have been largely due to the design of the wing; there was no trailing edge flap. The validation testing conducted using the Falcon 20 aircraft during the winter of 2006-07 required the aircraft to be configured in standard takeoff configuration with extended flaps. Consequently, the results with the Falcon 20 demonstrated better fluid flow-off results on the trailing edge. It was recommended that work be conducted to investigate the effect of the trailing edge flaps on the anti-icing fluid flow-off at the time of takeoff.

This section provides an overview of each test conducted as part of the test program to evaluate the effect of trailing edge flaps (either extended or retracted) on the flow-off behaviour of anti-icing fluid. Testing was conducted with fluid only applied to the test sections; no contamination was applied. The parameters for each test are detailed, and a description of the data collected during each test is provided.

5.1 Overview of Tests

A summary of the baseline tests conducted using the Falcon 20 and T-33 aircraft is shown in Table 5.1. The table provides relevant information for each of the tests, as well as the final values used for the data analysis. Each row contains data specific to one test. A more detailed test log of all conditions tested using the Falcon 20 aircraft is provided in Subsection 4.1. The following is a brief description of the column headings for Table 5.1:

Run #: Exclusive number identifying each run.

Aircraft: Aircraft used for the test.

Date: Date when the test was conducted.

Fluid: Aircraft deicing fluid specified by product name.

Condition: Simulated precipitation condition.

IP Rate (g/dm²/h): Average simulated ice pellet precipitation rate, measured in g/dm²/h.

SN Rate (g/dm²/h): Average simulated snow precipitation rate, measured in g/dm²/h.*Precip. Time (min.):* Total time of exposure to simulated precipitation.

OAT at Start of Test (°C): The outside air temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.

Avg. Wing Temp.: Average wing skin temperature.

After Fluid Appl. (°C): Wing temperature following fluid application, measured in degrees Celsius.

Takeoff Profile: Description of the takeoff acceleration and velocity of the aircraft during the test run.

Comments: General comments regarding the objective of the test.

Table 5.1: Summary of 2007-08 Effect of Flaps Testing with Falcon 20 and T-33 Aircraft

Run No.	Aircraft	Date	Fluid	Condition	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Precip. Time (min.)	OAT at Start of Test (°C)	AVG Wing Temp. After Fluid Appl. (°C)	Takeoff Profile	Comments
3S8	Falcon 20	27-Feb-08	EG106	Baseline	N/A	N/A	N/A	-11	-2.6	75 knots in 18 sec	Retracted Flap
5P8	Falcon 20	28-Feb-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-18	-8.7	66 knots in 18 sec	Retracted Flap
6P8	Falcon 20	28-Feb-08	EG106	Baseline	N/A	N/A	N/A	-16	-2.8	75 knots in 18 sec	Retracted Flap
7S8	Falcon 20	28-Feb-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-15	-7.5	74 knots in 19 sec	Retracted Flaps
11P8	Falcon 20	29-Feb-08	EG106	Baseline	N/A	N/A	N/A	-12	-3.8	76 knots in 17 sec	Extended Flap
11S8	Falcon 20	29-Feb-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-12	-3.2	76 knots in 17 sec	Extended Flap
17P8	T-33	7-Mar-08	EG106	Baseline	N/A	N/A	N/A	0	8.5	92 knots in 29 sec	Inboard - Extended Flap Outboard - No Flap
17S8	T-33	7-Mar-08	ABC-S Plus	Baseline	N/A	N/A	N/A	0	7	92 knots in 29 sec	
18P8	T-33	7-Mar-08	EG106	Baseline	N/A	N/A	N/A	1	6.7	85 knots in 20 sec	Inboard - Extended Flap Outboard - No Flap
18S8	T-33	7-Mar-08	ABC-S Plus	Baseline	N/A	N/A	N/A	1	6.5	85 knots in 20 sec	

5.2 Data Collected

5.2.1 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the Falcon 20 and T-33 tests are described in Subsection 2.1.11.1. Fluid thickness measurements were recorded at the following intervals:

- Falcon 20 Tests:
  - Approximately 5 minutes after fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

Tables 5.2 to 5.11 show the fluid thickness measurements collected during the tests.

Table 5.2: Test #3S8 Fluid Thickness Data

RUN 3S8: EG 106, fluid only, OAT -11°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.5	N/A	N/A	0.3
5	3.9	N/A	N/A	0.3
7	1.8	N/A	N/A	0.6
8	2.2	N/A	N/A	0.7

Table 5.3: Test #5P8 Fluid Thickness Data

RUN 5P8: ABC-S+, fluid only, OAT -18°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	N/A	N/A	0.3
5	4.5	N/A	N/A	0.5
7	2.9	N/A	N/A	1.8
8	2.7	N/A	N/A	2.2

Table 5.4: Test #6P8 Fluid Thickness Data

RUN 6P8: EG 106, fluid only, OAT -16ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.5	N/A	N/A	0.3
5	4.5	N/A	N/A	0.4
7	2.2	N/A	N/A	0.8
8	2.9	N/A	N/A	1.1

Table 5.5: Test #7S8 Fluid Thickness Data

RUN 7S8: ABC-S+, fluid only, OAT -15ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.3
5	4.5	N/A	N/A	0.4
7	1.8	N/A	N/A	1.4
8	1.8	N/A	N/A	1.4

Table 5.6: Test #11P8 Fluid Thickness Data

RUN 11P8: EG 106, fluid only, OAT -12ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	N/A	N/A	0.2
5	3.1	N/A	N/A	0.3
7	1.8	N/A	N/A	0.6
8	2.2	N/A	N/A	0.5

Table 5.7: Test #11S8 Fluid Thickness Data

RUN 11S8: ABC-S+, fluid only, OAT -12°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	0.5	N/A	N/A	0.3
5	4.5	N/A	N/A	0.4
7	2.5	N/A	N/A	0.8
8	2.9	N/A	N/A	0.7

Table 5.8: Test #17P8 (Inboard and Outboard) Fluid Thickness Data

RUN 17P8 Inboard: EG 106, fluid only, OAT 0°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.2
5	2.5	N/A	N/A	0.2
5A	2.2	N/A	N/A	0.2
6A	2.2	N/A	N/A	0.3
7	2.2	N/A	N/A	0.3
8	2.2	N/A	N/A	0.6

RUN 17P8 Outboard: EG 106, fluid only, OAT 0°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.2
5	2.2	N/A	N/A	0.2
5A	2.2	N/A	N/A	0.2
6A	2.2	N/A	N/A	0.2
7	1.8	N/A	N/A	0.4
8	1.8	N/A	N/A	0.5

Table 5.9: Test #17S8 (Inboard and Outboard) Fluid Thickness Data

RUN 17S8 Inboard: ABC-S+, fluid only, OAT 0ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	N/A	N/A	0.2
5	2.9	N/A	N/A	0.3
5A	4.5	N/A	N/A	0.3
6A	1.8	N/A	N/A	0.3
7	0.7	N/A	N/A	0.5
8	1.4	N/A	N/A	0.5

RUN 17S8 Outboard: ABC-S+, fluid only, OAT 0ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	N/A	N/A	0.2
5	3.3	N/A	N/A	0.3
5A	4.5	N/A	N/A	0.3
6A	1.8	N/A	N/A	0.2
7	1.4	N/A	N/A	0.6
8	1.4	N/A	N/A	0.5

Table 5.10: Test #18P8 (Inboard and Outboard) Fluid Thickness Data

RUN 18P8 Inboard: EG 106, fluid only, OAT +1ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.2
5	3.3	N/A	N/A	0.3
5A	3.1	N/A	N/A	0.3
6A	2.7	N/A	N/A	0.3
7	2.2	N/A	N/A	0.4
8	2.2	N/A	N/A	0.4

RUN 18P8 Outboard: EG 106, fluid only, OAT +1ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.2
5	2.9	N/A	N/A	0.3
5A	2.7	N/A	N/A	0.2
6A	2.5	N/A	N/A	0.3
7	2.2	N/A	N/A	0.4
8	2.2	N/A	N/A	0.4

Table 5.11: Test #18S8 (Inboard and Outboard) Fluid Thickness Data

RUN 18S8 Inboard: ABC-S+, fluid only, OAT +1°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	N/A	N/A	0.3
5	3.1	N/A	N/A	0.2
5A	5.7	N/A	N/A	0.2
6A	2.2	N/A	N/A	0.3
7	1.8	N/A	N/A	0.5
8	1.8	N/A	N/A	0.5

RUN 18S8 Outboard: ABC-S+, fluid only, OAT +1°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	N/A	N/A	0.2
5	3.1	N/A	N/A	0.3
5A	4.5	N/A	N/A	0.2
6A	1.8	N/A	N/A	0.3
7	1.8	N/A	N/A	0.6
8	1.8	N/A	N/A	0.5

5.2.2 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the Falcon 20 and T-33 tests are described in Subsection 2.1.11.3. Skin temperature measurements were recorded at the following intervals:

- Falcon 20 Tests;
  - Before fluid application;
  - After fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

The wing temperature measurements recorded during each test are shown in Tables 5.12 to 5.21.

Table 5.12: Test #3S8 Wing Skin Temperature Data

RUN 3S8: EG 106, fluid only, OAT -11°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-7.2	-5.9	N/A	N/A	-6.8
T2	-7.0	-6.5	N/A	N/A	-6.8
T3	-4.2	-3.1	N/A	N/A	-4.6
T4	-4.5	-3.0	N/A	N/A	-4.6
T5	-5.5	-2.9	N/A	N/A	-5.5
T6	-5.5	-2.2	N/A	N/A	-5.8
T7	-4.2	-1.1	N/A	N/A	-5.2
T8	-3.3	-0.3	N/A	N/A	-8.2

Table 5.13: Test #5P8 Wing Skin Temperature Data

RUN 5P8: ABC-S+, fluid only, OAT -18°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	N/A	N/A	N/A	-10.3
T2	N/A	N/A	N/A	N/A	-11
T3	N/A	N/A	N/A	N/A	-5.9
T4	N/A	N/A	N/A	N/A	-6.7
T5	N/A	N/A	N/A	N/A	-7.1
T6	N/A	N/A	N/A	N/A	-8.2
T7	N/A	N/A	N/A	N/A	-5.3
T8	N/A	N/A	N/A	N/A	-5.9

Table 5.14: Test #6P8 Wing Skin Temperature Data

RUN 6P8: EG 106, fluid only, OAT -16°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-6.3	-3.0	N/A	N/A	-5.2
T2	-6.8	-2.7	N/A	N/A	-6.1
T3	-3.9	-1.3	N/A	N/A	-2.7
T4	-4.8	-2.1	N/A	N/A	-3.4
T5	-7.6	-3.0	N/A	N/A	-5.5
T6	-8.7	-5.1	N/A	N/A	-7.2
T7	-8.5	-2.3	N/A	N/A	-3.0
T8	-9.2	-3.2	N/A	N/A	-3.8

Table 5.15: Test #7S8 Wing Skin Temperature Data

RUN 7S8: ABC-S+, fluid only, OAT -15°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-9.9	-8.8	N/A	N/A	-8.1
T2	-10.8	-8.8	N/A	N/A	-8.8
T3	-5.5	-3.7	N/A	N/A	-4.0
T4	-6.2	-4.2	N/A	N/A	-4.6
T5	-6.9	-4.6	N/A	N/A	-5.1
T6	-7.3	-4.6	N/A	N/A	-5.3
T7	-13.3	-11.6	N/A	N/A	-11.8
T8	-14.0	-13.5	N/A	N/A	-12.5

Table 5.16: Test #11P8 Wing Skin Temperature Data

RUN 11P8: EG 106, fluid only, OAT -12°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	-7.1	N/A	N/A	-5.7
T2	N/A	-7.0	N/A	N/A	-6.0
T3	N/A	-3.9	N/A	N/A	-5.1
T4	N/A	-3.5	N/A	N/A	-5.1
T5	N/A	-3.5	N/A	N/A	-6.7
T6	N/A	-3.9	N/A	N/A	-6.8
T7	N/A	-0.7	N/A	N/A	-6.5
T8	N/A	-0.6	N/A	N/A	-6.0

Table 5.17: Test #11S8 Wing Skin Temperature Data

RUN 11S8: ABC-S+, fluid only, OAT -12°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	-5.8	N/A	N/A	-5.9
T2	N/A	-5.5	N/A	N/A	-5.8
T3	N/A	-2.6	N/A	N/A	-4.5
T4	N/A	-2.0	N/A	N/A	-4.4
T5	N/A	-3.8	N/A	N/A	-5.8
T6	N/A	-3.0	N/A	N/A	-5.7
T7	N/A	-1.9	N/A	N/A	-5.1
T8	N/A	-0.8	N/A	N/A	-4.7

Table 5.18: Test #17P8 (Inboard and Outboard) Wing Skin Temperature Data

RUN 17P8 Inboard: EG 106, fluid only, OAT 0°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	N/A	N/A	N/A	N/A
T2	8.2	7.2	N/A	N/A	6.3
T3	N/A	N/A	N/A	N/A	N/A
T5	8.6	7.1	N/A	N/A	6.0
T5A	8.9	8.1	N/A	N/A	6.6
T6A	11.0	9.0	N/A	N/A	7.6
T7	11.5	9.3	N/A	N/A	7.7
T8	12.4	9.5	N/A	N/A	7.4

RUN 17P8 Outboard: EG 106, fluid only, OAT 0°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	N/A	N/A	N/A	N/A
T2	7.5	7.2	N/A	N/A	6.3
T3	N/A	N/A	N/A	N/A	N/A
T5	8.8	7.2	N/A	N/A	6.2
T5A	9.9	7.8	N/A	N/A	6.8
T6	11.5	9.5	N/A	N/A	8.2
T7	12.3	9.6	N/A	N/A	7.9
T8	12.3	9.6	N/A	N/A	7.9

Table 5.19: Test #17S8 (Inboard and Outboard) Wing Skin Temperature Data

RUN 17S8 Inboard: ABC-S+, fluid only, OAT 0ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	N/A	N/A	N/A	N/A
T2	7.7	5.8	N/A	N/A	5.6
T3	N/A	N/A	N/A	N/A	N/A
T4	8.1	6.5	N/A	N/A	5.5
T5	11.2	7.0	N/A	N/A	6.1
T6	11.5	7.5	N/A	N/A	7.0
T7	11.7	7.4	N/A	N/A	6.8
T8	12.9	7.6	N/A	N/A	7.2

RUN 17S8 Outboard: ABC-S+, fluid only, OAT 0ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	N/A	N/A	N/A	N/A
T2	7.8	6.2	N/A	N/A	5.7
T3	N/A	N/A	N/A	N/A	N/A
T5	9.5	6.3	N/A	N/A	5.7
T5A	10.7	6.4	N/A	N/A	6.0
T6	12.6	7.8	N/A	N/A	7.3
T7	13.0	7.4	N/A	N/A	7.0
T8	15.4	7.8	N/A	N/A	8.4

Table 5.20: Test #18P8 (Inboard and Outboard) Wing Skin Temperature Data

RUN 18P8 Inboard: EG 106, fluid only, OAT +1°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	N/A	N/A	N/A	N/A
T2	6.3	6.3	N/A	N/A	10.4
T3	N/A	N/A	N/A	N/A	N/A
T5	6.0	6.2	N/A	N/A	8.9
T5A	6.6	6.7	N/A	N/A	9.5
T6A	7.6	6.8	N/A	N/A	9.3
T7	7.7	6.7	N/A	N/A	9.4
T8	7.4	7.0	N/A	N/A	9.3

RUN 18P8 Outboard: EG 106, fluid only, OAT +1°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	N/A	N/A	N/A	N/A
T2	6.3	6.5	N/A	N/A	9.6
T3	N/A	N/A	N/A	N/A	N/A
T5	6.2	6.6	N/A	N/A	9.0
T5A	6.8	6.5	N/A	N/A	9.6
T6	8.2	7.0	N/A	N/A	9.6
T7	7.9	6.8	N/A	N/A	9.6
T8	7.9	6.8	N/A	N/A	9.5

Table 5.21: Test #18S8 (Inboard and Outboard) Wing Skin Temperature Data

RUN 18S8 Inboard: ABC-S+, fluid only, OAT +1°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	N/A	N/A	N/A	N/A
T2	5.6	6.1	N/A	N/A	9.1
T3	N/A	N/A	N/A	N/A	N/A
T4	5.5	6.0	N/A	N/A	7.9
T5	6.1	5.9	N/A	N/A	8.3
T6	7.0	6.8	N/A	N/A	9.3
T7	6.8	6.4	N/A	N/A	8.9
T8	7.2	6.7	N/A	N/A	9.2

RUN 18S8 Outboard: ABC-S+, fluid only, OAT +1°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	N/A	N/A	N/A	N/A
T2	7.8	6.2	N/A	N/A	5.7
T3	N/A	N/A	N/A	N/A	N/A
T5	9.5	6.3	N/A	N/A	5.7
T5A	10.7	6.4	N/A	N/A	6.0
T6	12.6	7.8	N/A	N/A	7.3
T7	13.0	7.4	N/A	N/A	7.0
T8	15.4	7.8	N/A	N/A	8.4

5.2.3 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the Falcon 20 and T-33 tests are described in Subsection 2.1.11.2. Fluid Brix measurements were recorded at the following intervals:

- Falcon 20 and T-33 Tests:
  - After fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

Tables 5.22 to 5.31 show the fluid Brix measurements collected during the tests.

Table 5.22: Test #3S8 Fluid Brix Data

RUN 3S8: EG 106, fluid only, OAT -11°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	34	N/A	N/A	36.5
B8	34	N/A	N/A	35

Table 5.23: Test #5P8 Fluid Brix Data

RUN 5P8: ABC-S+, fluid only, OAT -18°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37.75	N/A	N/A	38
B8	37.5	N/A	N/A	37.5

Table 5.24: Test #6P8 Fluid Brix Data

RUN 6P8: EG 106, fluid only, OAT -16°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	33.5	N/A	N/A	35.5
B8	33.75	N/A	N/A	34.25

Table 5.25: Test #7S8 Fluid Brix Data

RUN 7S8: ABC-S+, fluid only, OAT -15°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37.5	N/A	N/A	38
B8	37.5	N/A	N/A	38

Table 5.26: Test #11P8 Fluid Brix Data

RUN 11P8: EG 106, fluid only, OAT -12°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	33.5	N/A	N/A	35
B8	33.5	N/A	N/A	34

Table 5.27: Test #11S8 Fluid Brix Data

RUN 11S8: ABC-S+, fluid only, OAT -12°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37.5	N/A	N/A	38.25
B8	37.25	N/A	N/A	37.5

Table 5.28: Test #17P8 (Inboard and Outboard) Fluid Brix Data

RUN 17P8 Inboard: EG 106, fluid only, OAT 0°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	N/A	N/A	N/A	34.5
B8	N/A	N/A	N/A	34.5

RUN 17P8 Outboard: EG 106, fluid only, OAT 0°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	N/A	N/A	N/A	N/A
B8	N/A	N/A	N/A	N/A

Table 5.29: Test #17S8 (Inboard and Outboard) Fluid Brix Data

RUN 17S8 Inboard: ABC-S+, fluid only, OAT 0°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	N/A	N/A	N/A	37.25
B8	N/A	N/A	N/A	37

RUN 17S8 Outboard: ABC-S+, fluid only, OAT 0°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	N/A	N/A	N/A	N/A
B8	N/A	N/A	N/A	N/A

Table 5.30: Test #18P8 (Inboard and Outboard) Fluid Brix Data

RUN 18P8 Inboard: EG 106, fluid only, OAT +1°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	33.23	N/A	N/A	35
B8	33	N/A	N/A	33.5

RUN 18P8 Outboard: EG 106, fluid only, OAT +1°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	N/A	N/A	N/A	N/A
B8	N/A	N/A	N/A	N/A

Table 5.31: Test #18S8 (Inboard and Outboard) Fluid Brix Data

RUN 18S8 Inboard: ABC-S+, fluid only, OAT +1°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	36.5	N/A	N/A	38
B8	36.5	N/A	N/A	37.25

RUN 18S8 Outboard: ABC-S+, fluid only, OAT +1°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	N/A	N/A	N/A	N/A
B8	N/A	N/A	N/A	N/A

5.3 Photos

High-speed digital photographs of each test were taken; photos were taken of the leading edge, the trailing edge, or both. For each test, photo summaries have been compiled comprising four stages:

- Start of test;
- 17 seconds after start of test;
- Time of rotation; and
- End of test.

Photos 5.1 to 5.40 show the photo summaries for Tests #3S8, #5P8, #6P8, #7S8, #11P8, #11S8, #17P8, #17S8, #18P8, and #18S8. During the tests where photos were not taken, a note has been included indicating "No Photo Documentation Available." A compilation of selected high-speed photos taken during Test #7S8 are included in Appendix G. A complete set of photos will be provided to the TDC.

5.4 General Observations

5.4.1 Falcon 20 General Observations

A comparison of the residual fluid thickness at the end of the Falcon 20 test runs has been compiled and is demonstrated in Table 5.32. The residual fluid thickness during the extended flaps tests was compared to the residual thickness of the retracted flaps tests. The shaded cells indicate measurements where the fluid thickness during the retracted flaps test was greater in comparison to the extended flaps test. The results indicated that the residual thickness was up to three times greater on the trailing edge during the retracted flap tests compared to the extended flap tests. Residual fluid thickness on the leading edge was generally comparable.

Table 5.32: Comparison of Falcon 20 Residual Fluid Thicknesses

Wing Position	Fluid Thickness After Takeoff Run (mm)					
	Run #11P8	Run #3S8	Run #6P8	**Run #11S8**	Run #5P8	Run #7S8
	Extended Flap	*Retracted Flap*	*Retracted Flap*	***Extended Flap***	*Retracted Flap*	*Retracted Flap*
2	**0.2**	0.3	0.3	**0.3**	0.3	0.3
5	**0.3**	0.3	0.4	**0.4**	0.5	0.4
7	**0.6**	0.6	0.8	**0.8**	1.8	1.4
8	**0.5**	0.7	1.1	**0.7**	2.2	1.4

Visually, fluid elimination seemed to greatly improve with flaps extended. At the time of rotation, the fluid generally sheared to 1/3 of the wing aft of the leading edge with flaps retraced, whereas fluid generally sheared to 2/3 of the wing aft of the leading edge with flaps extended. The fluid thickness measurements confirmed the visual observations.

5.4.2 T-33 General Observations

A comparison of the residual fluid thickness at the end of the T-33 test runs has been compiled and is demonstrated in Table 5.33. It should be noted that these comparison tests were conducted on the same wing section with one strip of fluid; half of the fluid strip was applied to the flapped section (outboard) and the other half was applied to the fixed wing section (inboard). The residual fluid thickness on the extended flap sections was compared to the residual thickness on the fixed wing no flap sections. The shaded cells indicate measurements where the fluid thickness on the fixed wing section was greater in comparison to the extended flap section. The results indicated that the residual thickness was generally comparable in both conditions. The discrepancy in the T-33 results versus the Falcon 20 results may have been due to the proximity of the T-33 test areas with each other.

Table 5.33: Comparison of T-33 Residual Fluid Thicknesses

Wing Position	Fluid Thickness After Takeoff Run (mm)							
	Run #17P8 Outboard	Run #17P8 **Inboard**	**Run #17S8 Outboard**	Run #17S8 **Inboard**	**Run #18P8 Outboard**	Run #18P8 **Inboard**	**Run #18S8 Outboard**	Run #18S8 **Inboard**
	Extended Flap	*No Flap*	***Extended Flap***	*No Flap*	***Extended Flap***	*No Flap*	***Extended Flap***	*No Flap*
2	**0.2**	0.2	**0.2**	0.2	**0.2**	0.2	**0.2**	0.3
5	**0.2**	0.2	**0.3**	0.3	**0.3**	0.3	**0.3**	0.2
7	**0.4**	0.3	**0.6**	0.5	**0.4**	0.4	**0.6**	0.5
8	**0.5**	0.6	**0.5**	0.5	**0.4**	0.4	**0.5**	0.5

Visually, fluid elimination seemed to slightly improve with flaps extended; however, the fluid thickness measurements did not confirm drastic differences, as seen with the Falcon 20.

5.4.3 Conclusions and Recommendations for Future Work

The results from the Falcon 20 and T-33 aircraft testing demonstrated that the extended flaps on a wing section will generally allow for better fluid flow-off; the flaps will pull the air stream downwards on the trailing edge, aiding in shedding the fluid. In addition, it is normal for aircraft to be configured with extended flaps prior to takeoff. Therefore, future testing should be conducted using extended flaps on the wing test surfaces to be operationally representative. An LS(1)-0417 flapped wing section was previously used during icing tests in the wind tunnel. This wing section should be used for future wind tunnel testing.

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Photo 5.1: Test #3S8 – Start of Test

Photo 5.2: Test #3S8 – 17 Seconds

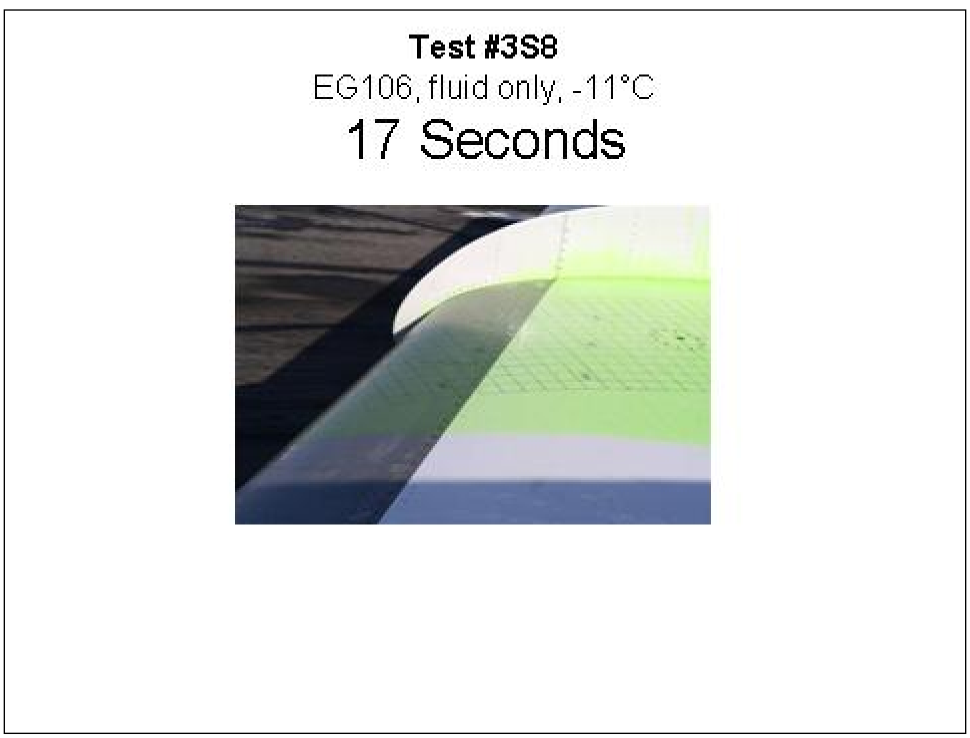

Photo 5.3: Test #3S8 – Rotation

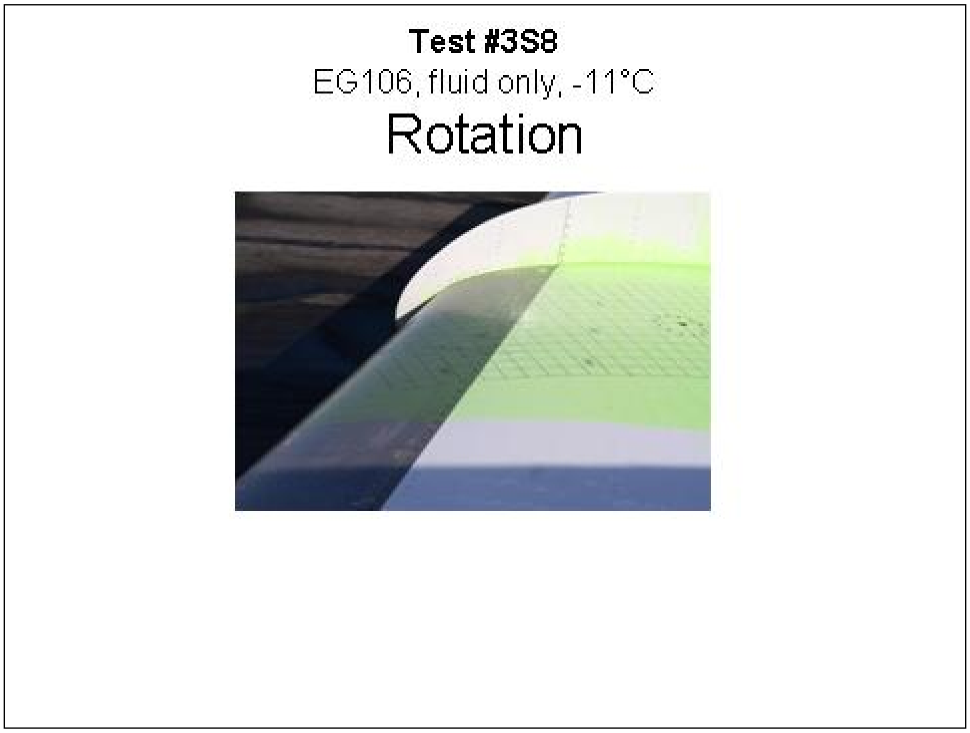

Photo 5.4: Test #3S8 – End of Test

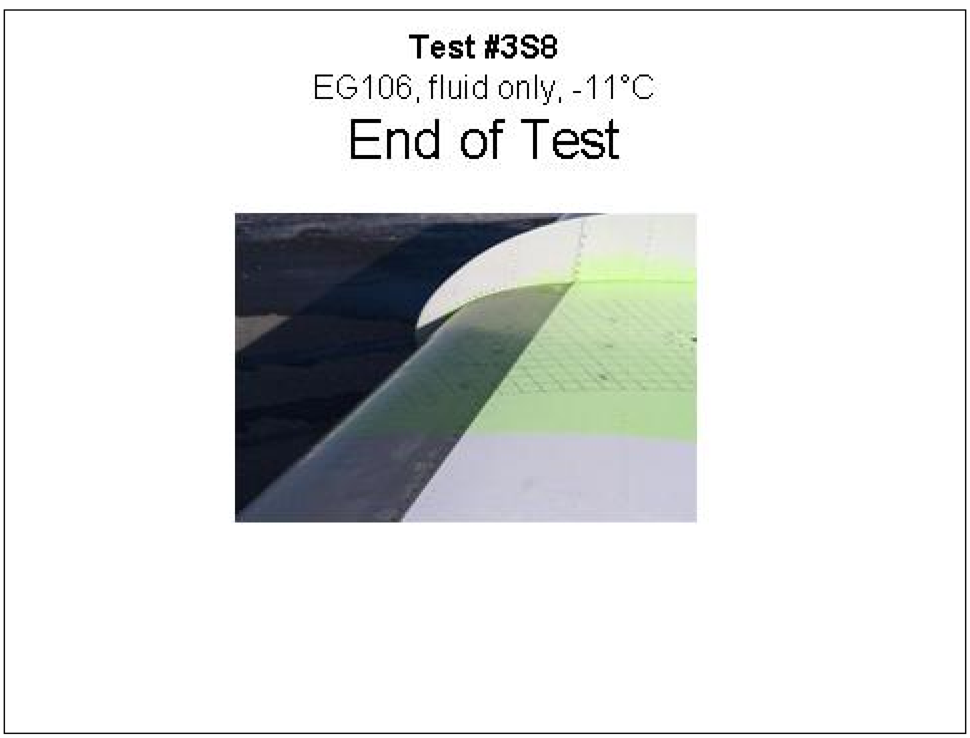

Photo 5.5: Test #5P8 – Start of Test

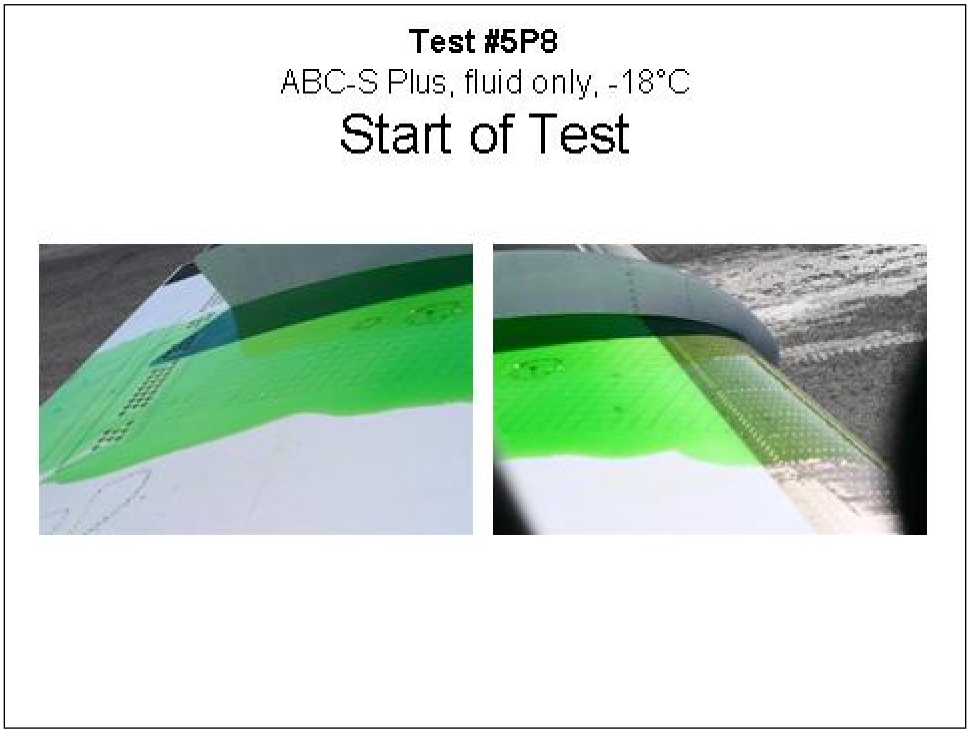

Photo 5.6: Test #5P8 – 17 Seconds

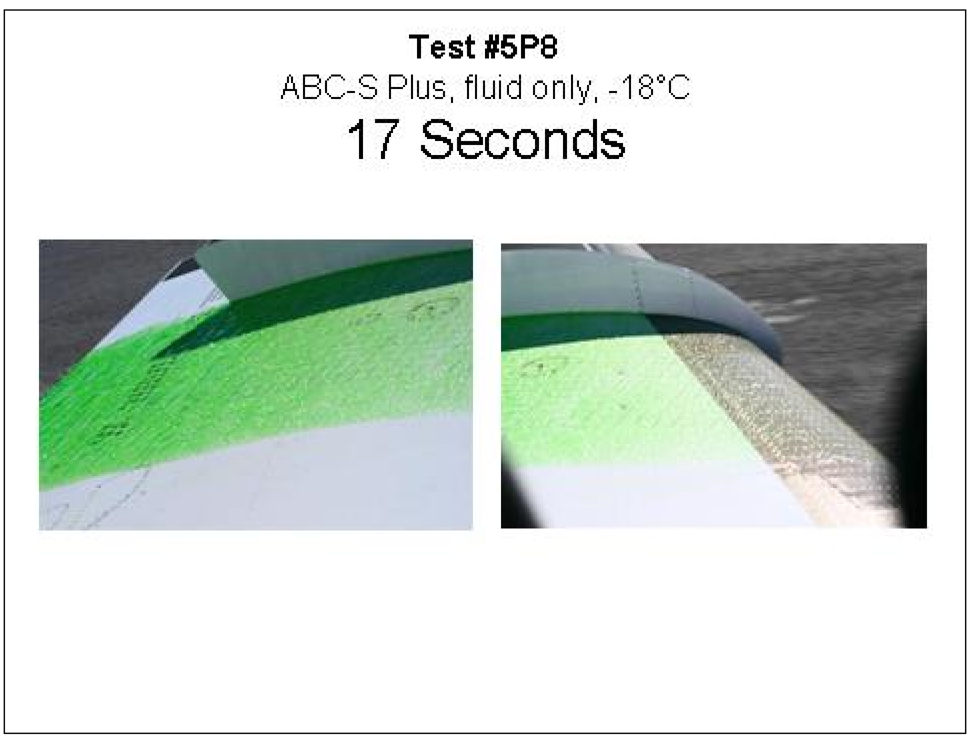

Photo 5.7: Test #5P8 – Rotation

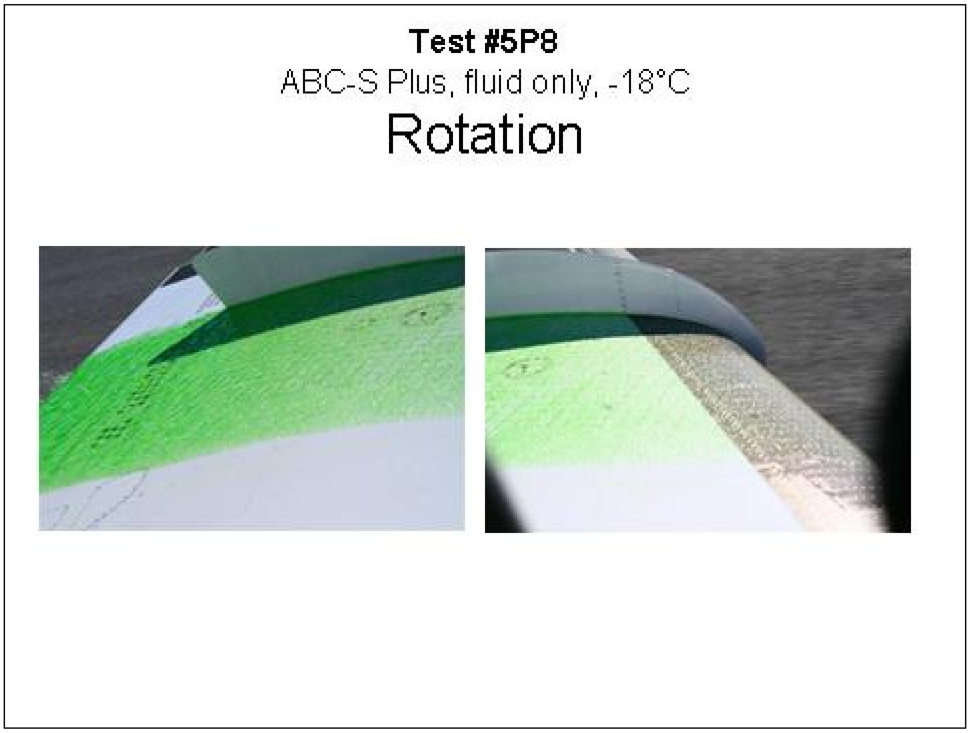

Photo 5.8: Test #5P8 – End of Test

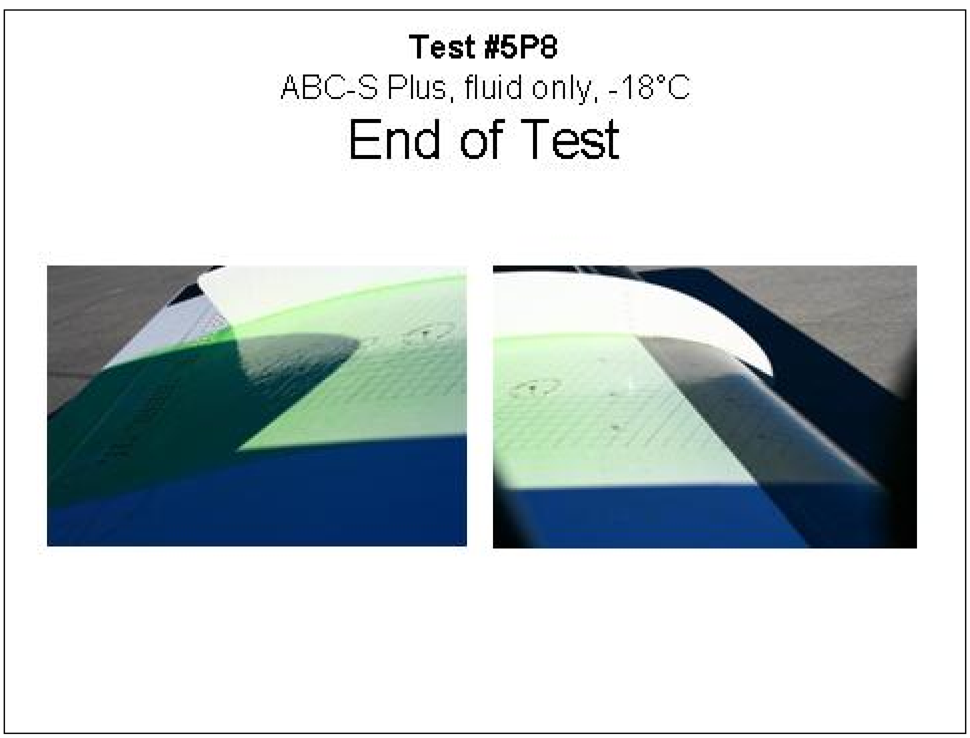

Photo 5.9: Test #6P8 – Start of Test

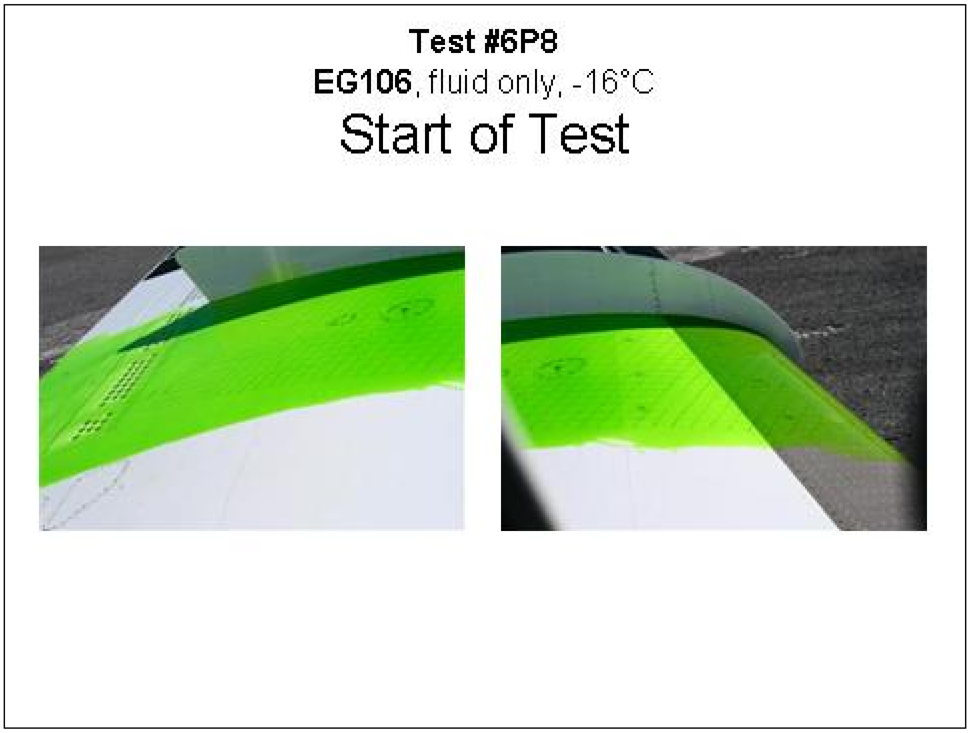

Photo 5.10: Test #6P8 – 17 Seconds

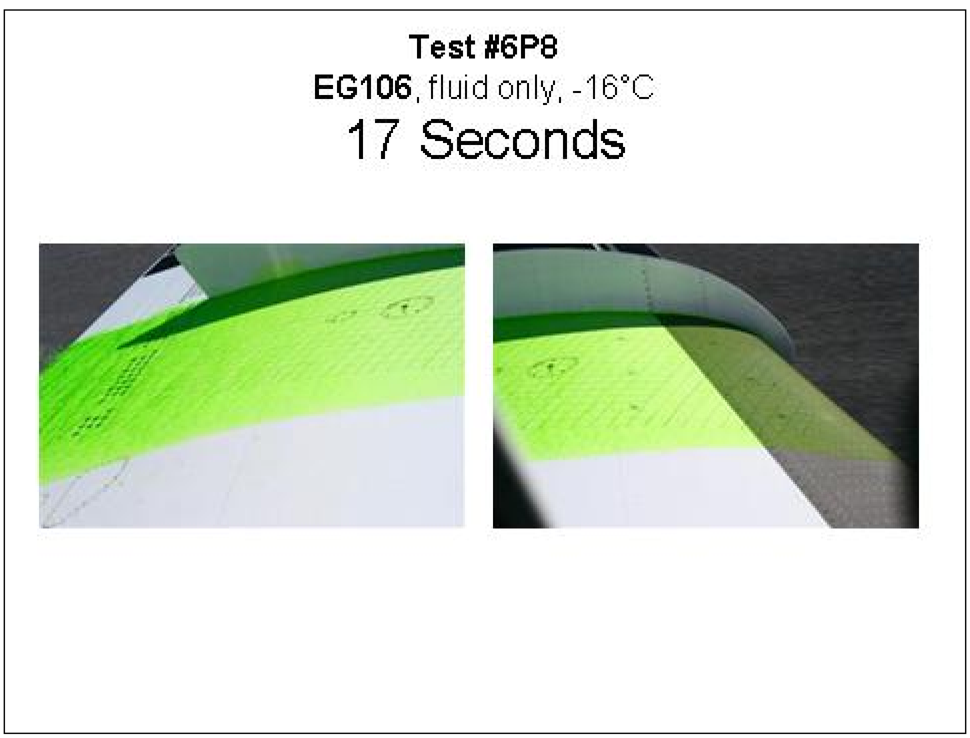

Photo 5.11: Test #6P8 – Rotation

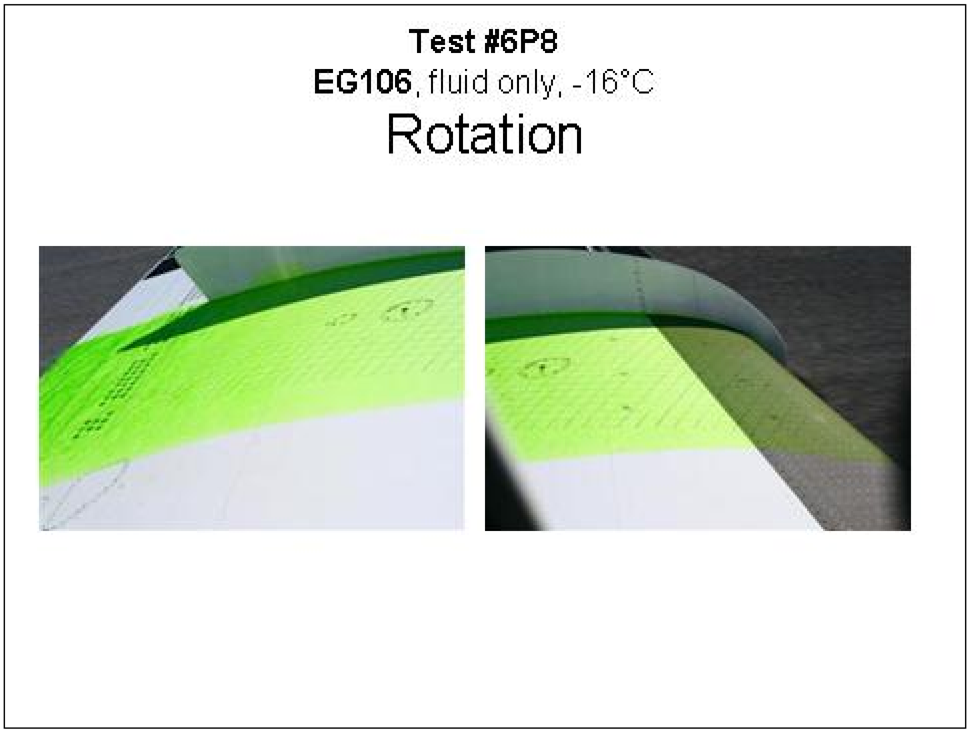

Photo 5.12: Test #6P8 – End of Test

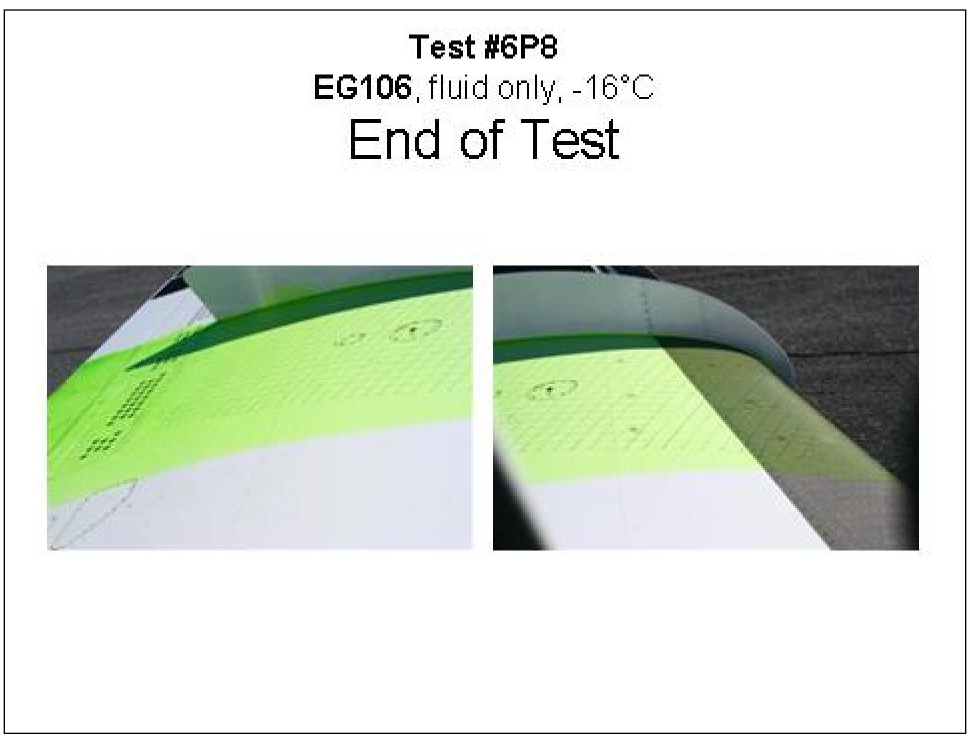

Photo 5.13: Test #7S8 – Start of Test

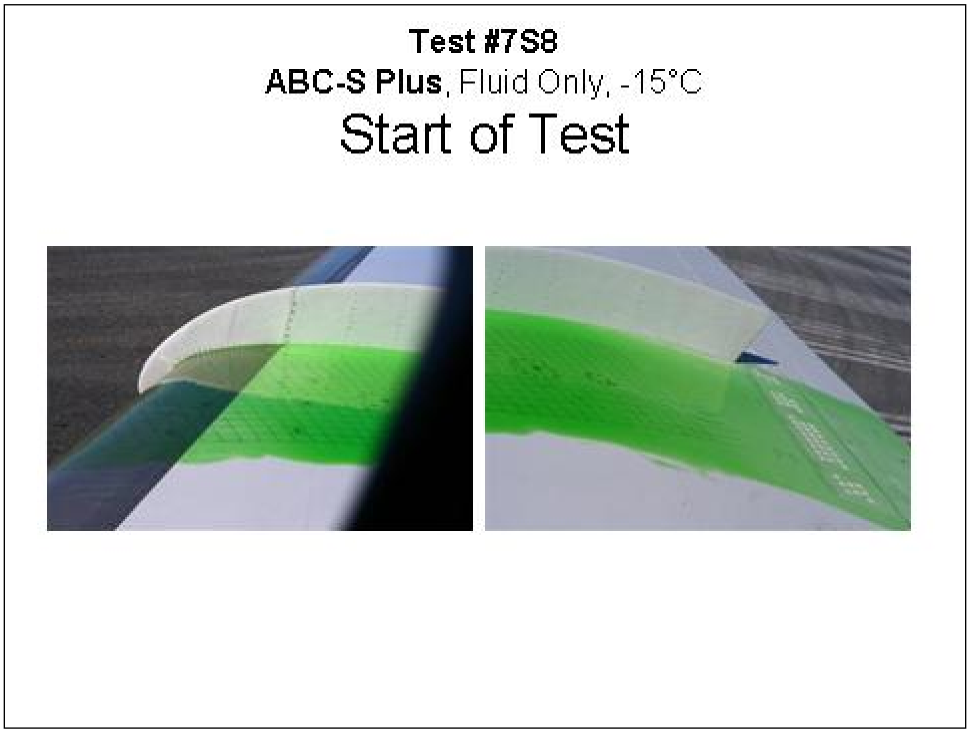

Photo 5.14: Test #7S8 – 17 Seconds

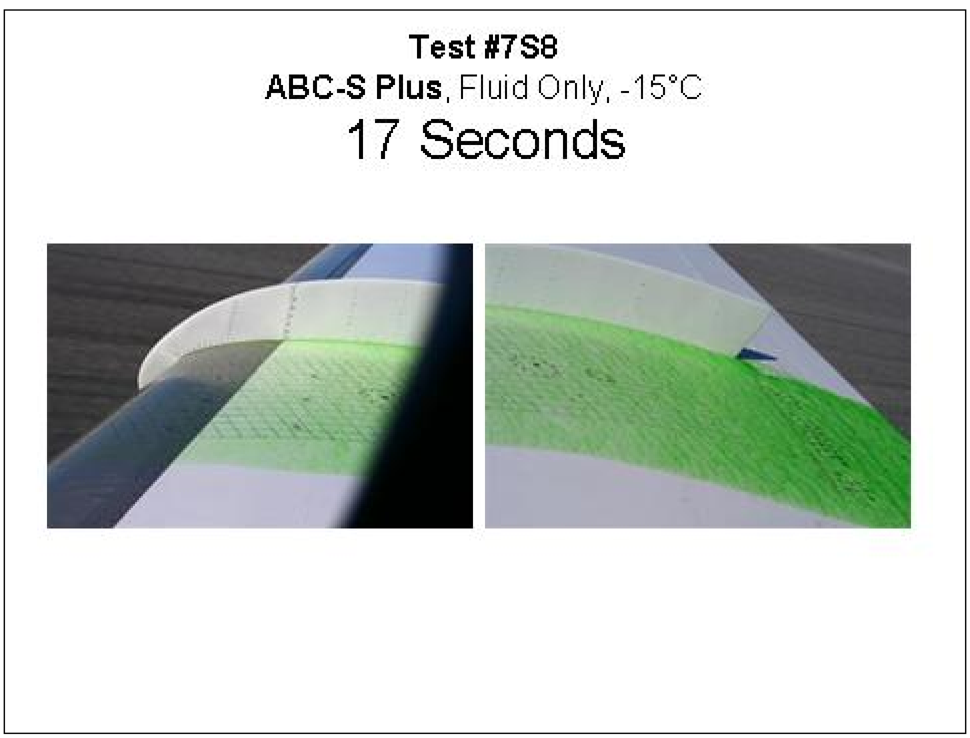

Photo 5.15: Test #7S8 – Rotation

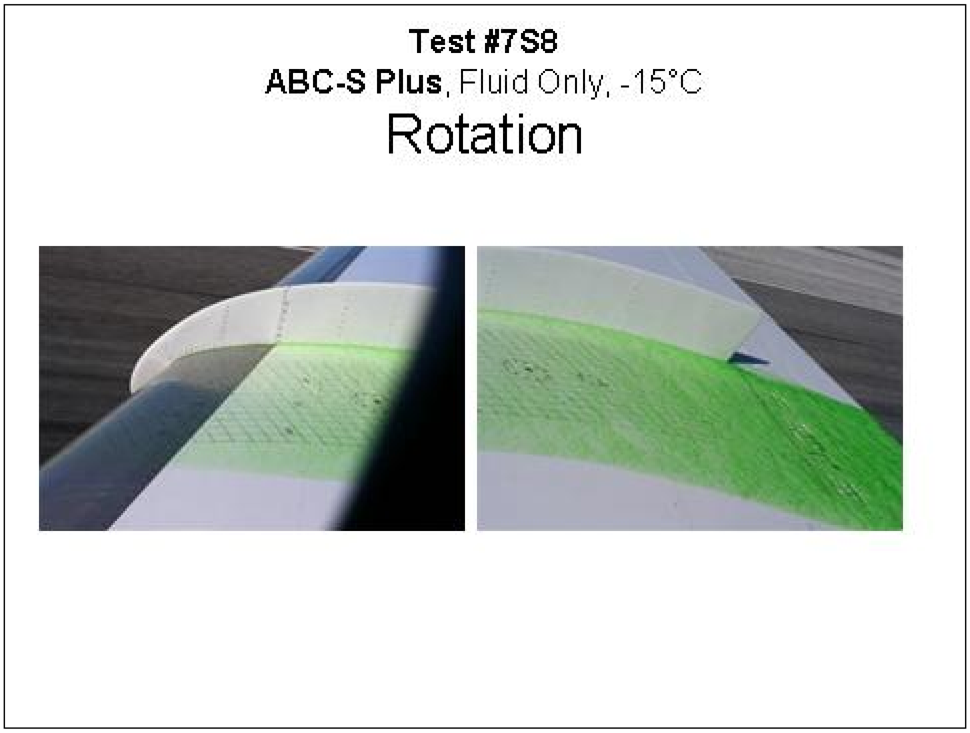

Photo 5.16: Test #7S8 – End of Test

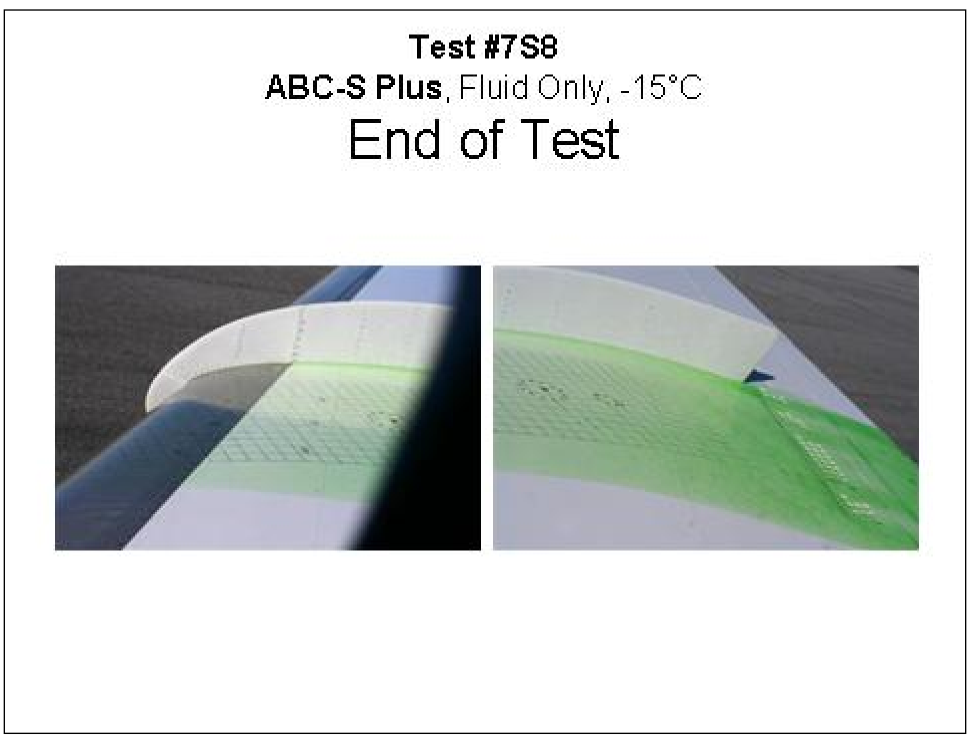

Photo 5.17: Test #11P8 – Start of Test

Photo 5.18: Test #11P8 – 17 Seconds

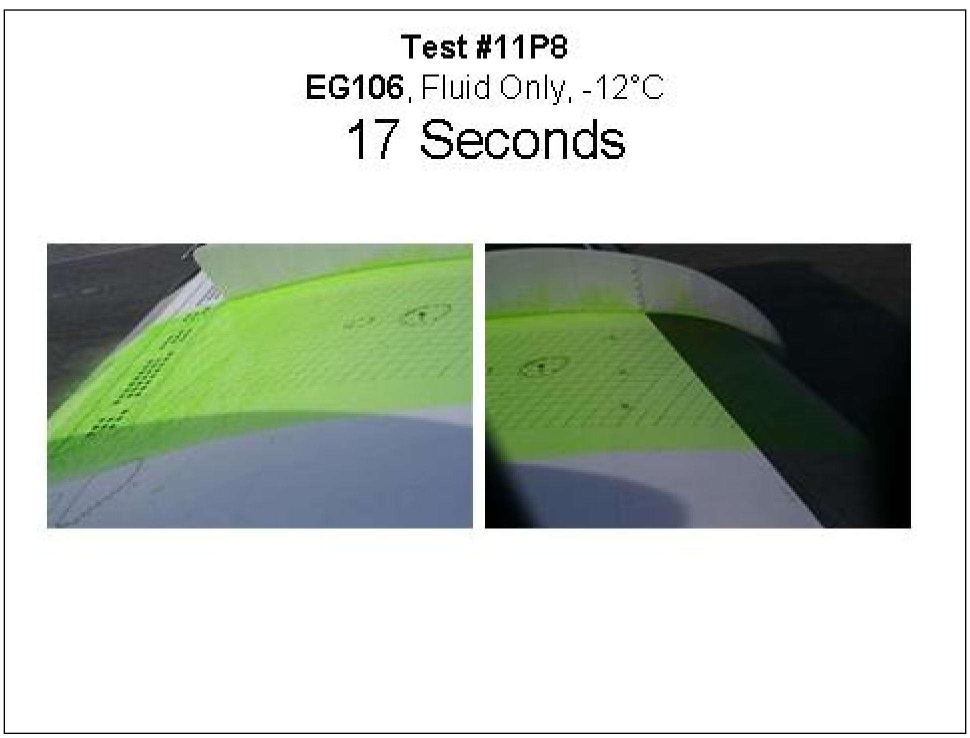

Photo 5.19: Test #11P8 – Rotation

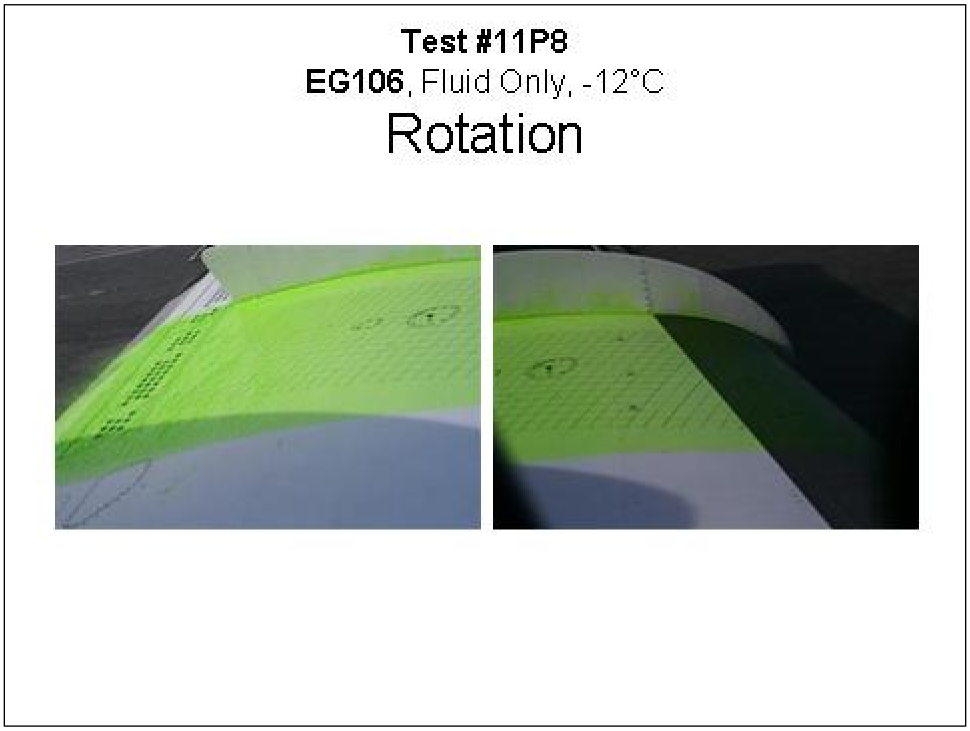

Photo 5.20: Test #11P8 – End of Test

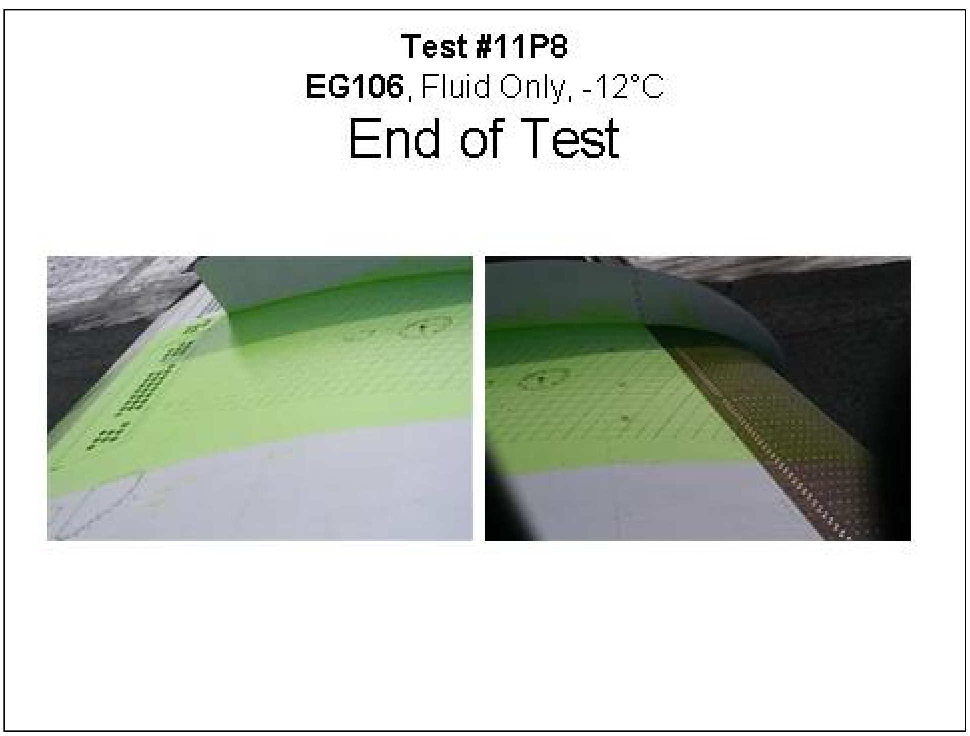

Photo 5.21: Test #11S8 – Start of Test

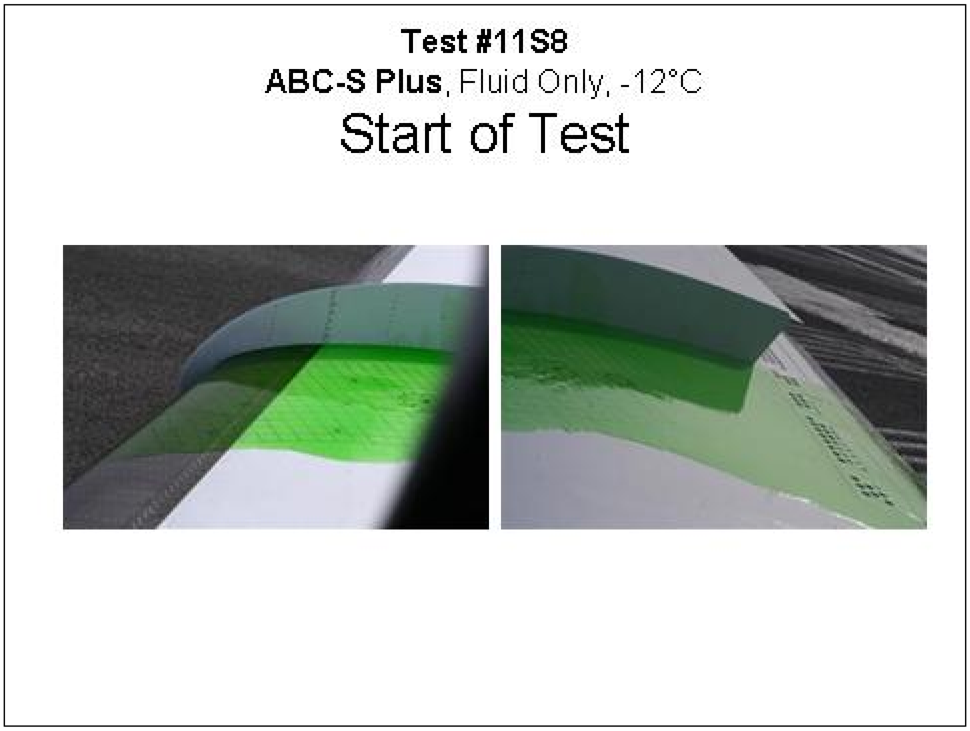

Photo 5.22: Test #11S8 – 17 Seconds

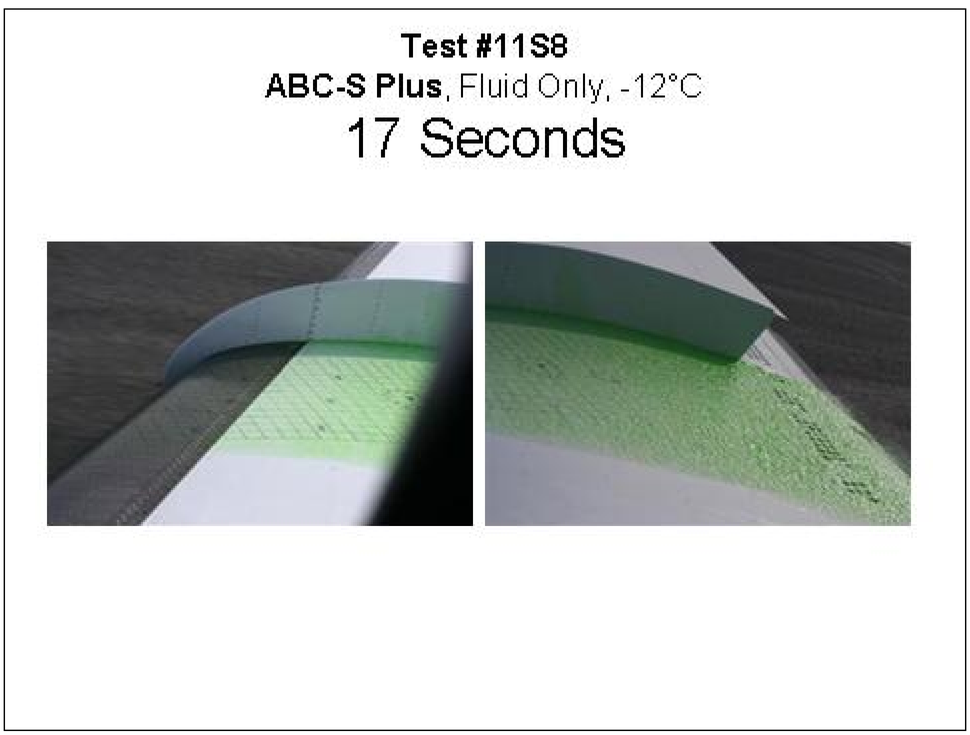

Photo 5.23: Test #11S8 – Rotation

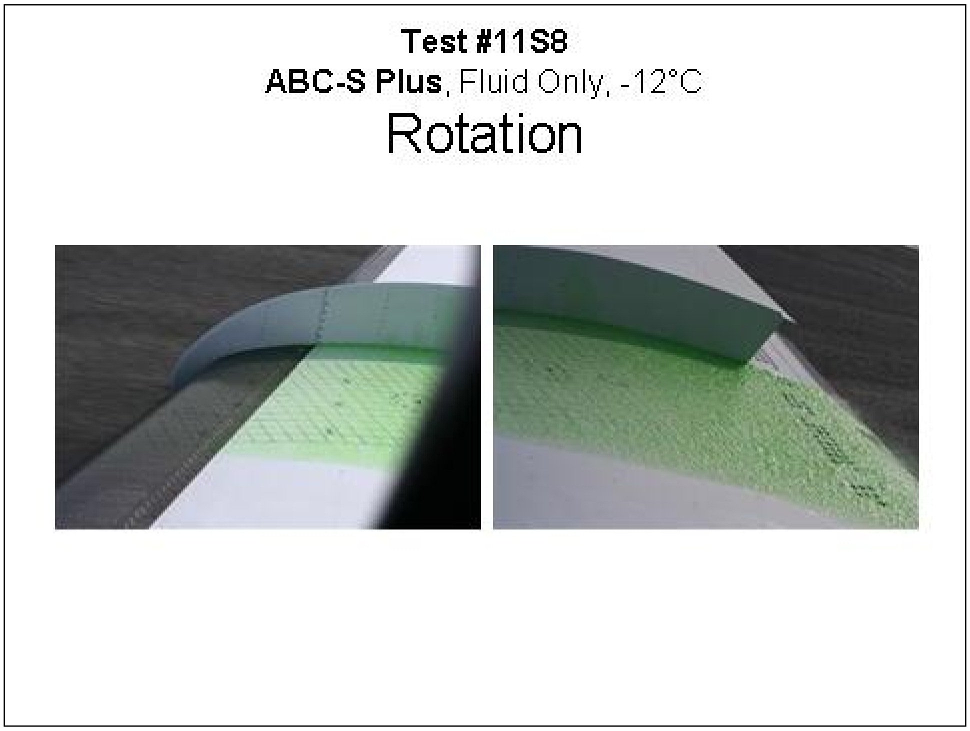

Photo 5.24: Test #11S8 – End of Test

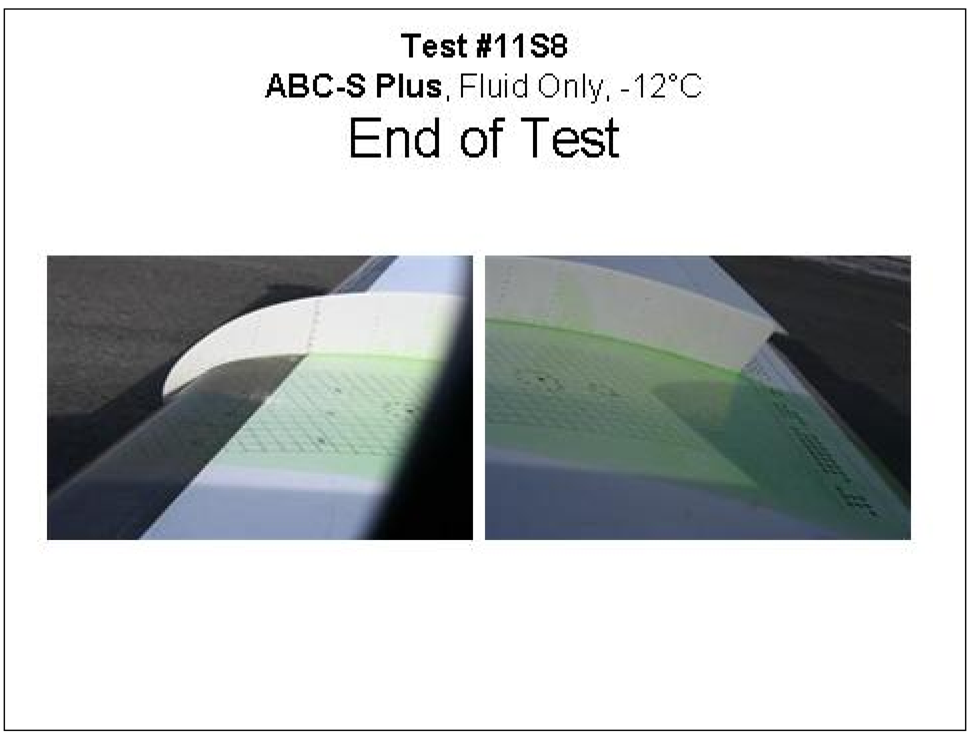

Photo 5.25: Test #17P8 – Start of Test

Photo 5.26: Test #17P8 – 17 Seconds

Photo 5.27: Test #17P8 – Rotation

Photo 5.28: Test #17P8 – End of Test

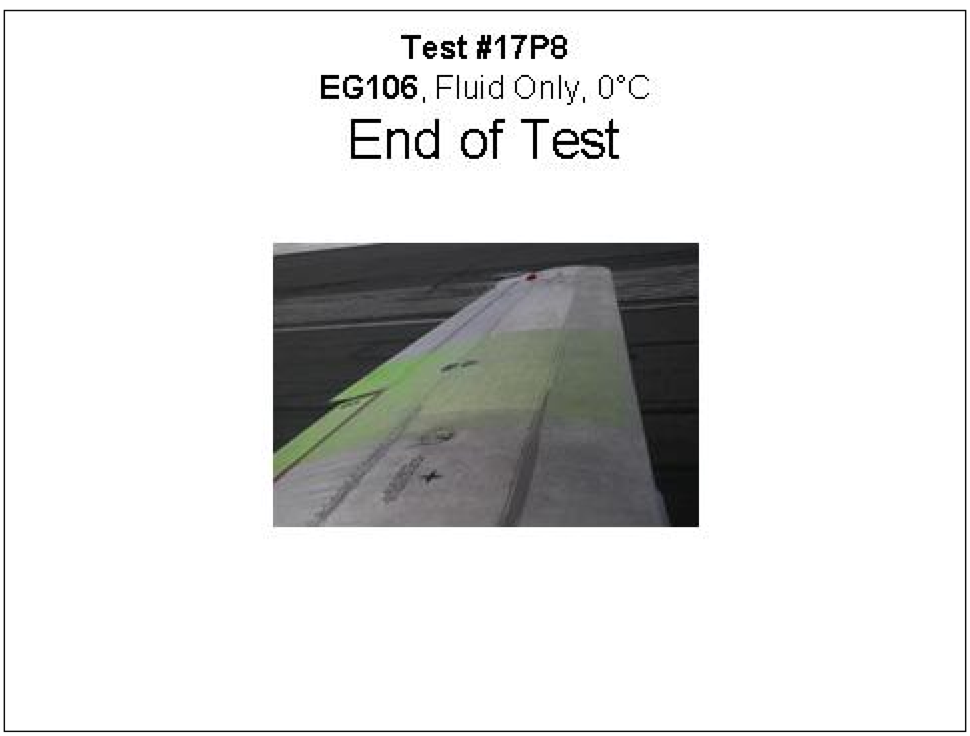

Photo 5.29: Test #17S8 – Start of Test

No Photo Documentation Available

Photo 5.30: Test #17S8 – 17 Seconds

No Photo Documentation Available

Photo 5.31: Test #17S8 – Rotation

No Photo Documentation Available

Photo 5.32: Test #17S8 – End of Test

No Photo Documentation Available

Photo 5.33: Test #18P8 – Start of Test

Photo 5.34: Test #18P8 – 17 Seconds

Photo 5.35: Test #18P8 – Rotation

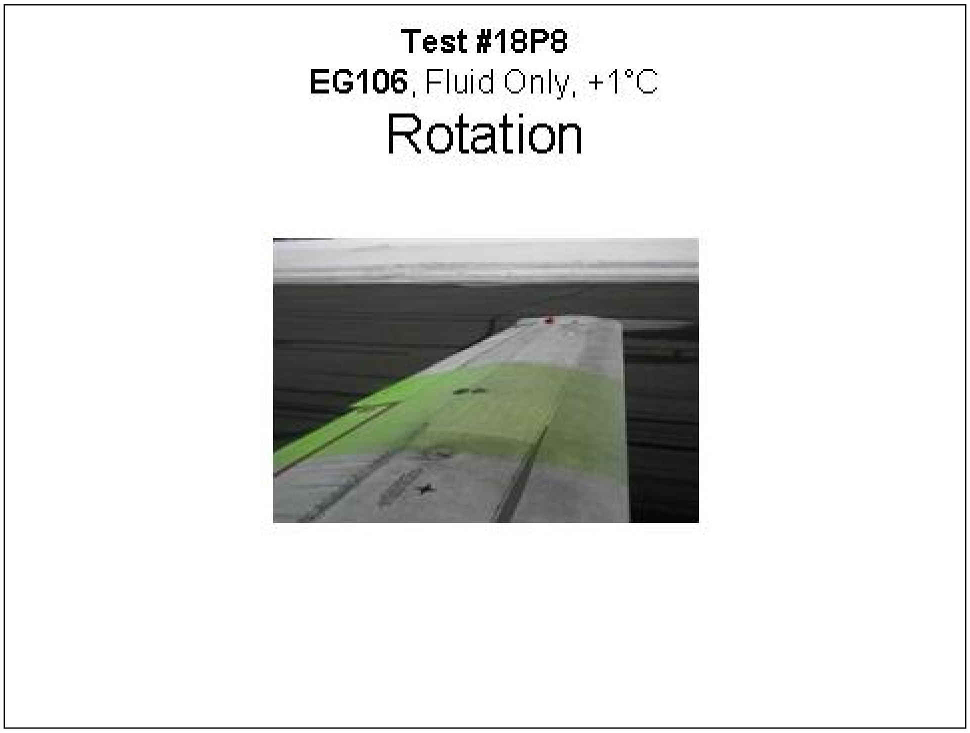

Photo 5.36: Test #18P8 – End of Test

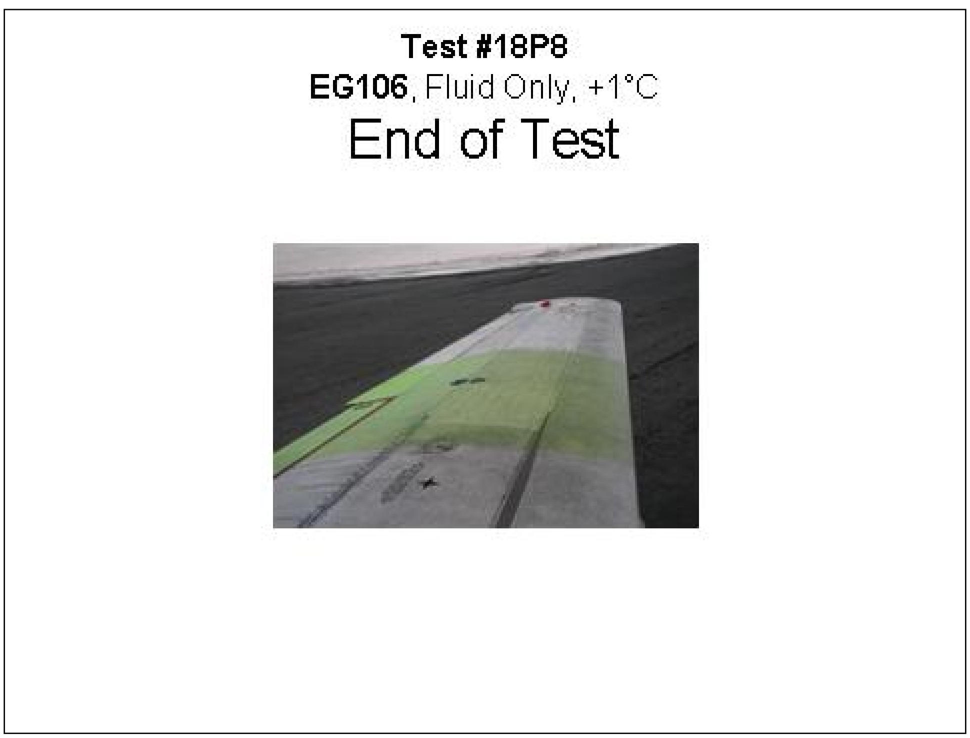

Photo 5.37: Test #18S8 – Start of Test

No Photo Documentation Available

Photo 5.38: Test #18S8 – 17 Seconds

No Photo Documentation Available

Photo 5.39: Test #18S8 – Rotation

No Photo Documentation Available

Photo 5.40: Test #18S8 – End of Test

No Photo Documentation Available

6. EFFECT OF SLATS

Aerodynamic testing conducted to develop and validate ice pellet allowance times has been conducted with the Falcon 20 aircraft and in the NRC wind tunnel using a NACA 23012 wing section. The test sections used for this research had a fixed leading edge and did not include moving leading edge devices (i.e., slatted wings). As many operational jet aircraft have slatted wings, there is a need to investigate the effects of slatted leading edges on the fluid flow-off of both contaminated and uncontaminated fluids.

This section provides an overview of each Falcon 20 aircraft test conducted to evaluate the effect of slats (either extended or retracted) on the flow-off behaviour of anti-icing fluid. It should be noted that no comparable outboard wing extended slats versus retracted slats tests were performed. Rather, the outboard slatted section of the wing was compared to the inboard flapped (but without leading edge slats) section of the wing; the fixed leading edge of the flapped section was treated as a retracted slat for analysis. Testing was conducted in non-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 baseline tests conducted using the Falcon 20 aircraft is shown in Table 6.1. The table provides relevant information for each of the tests, as well as the final values used for the data analysis. Each row contains data specific to one test. A more detailed test log of all conditions tested using the Falcon 20 aircraft is provided in Subsection 4.1. The following is a brief description of the column headings for Table 6.1:

Run #: Exclusive number identifying each run.

Date: Date when the test was conducted.

Fluid: Aircraft deicing fluid specified by product name.

Condition: Simulated precipitation condition.

IP Rate (g/dm²/h): Average simulated ice pellet precipitation rate, measured in g/dm²/h.

SN Rate (g/dm²/h): Average simulated snow precipitation rate, measured in g/dm²/h.

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

OAT at Start of Test (°C): The outside air temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.

Avg. Wing Temp.: Average wing skin temperature.

After Fluid Appl. (°C): Wing temperature following fluid application, measured in degrees Celsius.

Takeoff Profile: Description of the takeoff acceleration and velocity of the aircraft during the test run.

Comments: General comments regarding the objective of the test.

Table 6.1: Summary of 2007-08 Effect of Slats Testing with Falcon 20 Aircraft

Run No.	Date	Fluid	Condition	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Precip. Time (min.)	OAT at Start of Test (°C)	AVG Wing Temp. After Fluid Appl. (°C)	Takeoff Profile	Comments
14S8	6-Mar-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-9	-5.1	117 knots in 30 sec	Extended Slat
14AP8	6-Mar-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-9	-3.9	117 knots in 30 sec	Retracted Slat
14AS8	6-Mar-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-9	-4.8	117 knots in 30 sec	Retracted Slat
15S8	6-Mar-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-4	-1.4	77 knots in 19 sec	Extended Slat
15AP8	6-Mar-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-4	2.4	77 knots in 19 sec	Retracted Slat
15AS8	6-Mar-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-4	0	77 knots in 19 sec	Retracted Slat

6.2 Data Collected

6.2.1 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the Falcon 20 tests are described in Subsection 2.1.11.1. Fluid thickness measurements were recorded at the following intervals:

- Falcon 20 Tests:
  - Approximately 5 minutes after fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

Tables 6.2 to 6.7 show the fluid thickness measurements collected during the tests.

Table 6.2: Test #14S8 Fluid Thickness Data

RUN 14S8: ABC-S+, fluid only, OAT -9°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.2
5	4.5	N/A	N/A	0.2
7	2.5	N/A	N/A	0.3
8	2.5	N/A	N/A	0.3

Table 6.3: Test #14AP8 Fluid Thickness Data

RUN 14AP8: ABC-S+, fluid only, OAT -9°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.4	N/A	N/A	0.1
5	3.9	N/A	N/A	0.2
5A	4.5	N/A	N/A	0.3
6A	3.1	N/A	N/A	0.4
7	2.9	N/A	N/A	0.4
8	2.2	N/A	N/A	0.4

Table 6.4: Test #14AS8 Fluid Thickness Data

RUN 14AS8: ABC-S+, fluid only, OAT -9°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	N/A	N/A	0.1
5	3.7	N/A	N/A	0.2
5A	4.5	N/A	N/A	0.3
6A	3.1	N/A	N/A	0.4
7	2.9	N/A	N/A	0.4
8	2.2	N/A	N/A	0.6

Table 6.5: Test #15S8 Fluid Thickness Data

RUN 15S8: ABC-S+, fluid only, OAT -4°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.5
5	4.5	N/A	N/A	0.4
7	2.7	N/A	N/A	0.7
8	2.9	N/A	N/A	0.7

Table 6.6: Test #15AP8 Fluid Thickness Data

RUN 15AP8: ABC-S+, fluid only, OAT -4°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.4	N/A	N/A	0.2
5	3.1	N/A	N/A	0.4
5A	4.5	N/A	N/A	0.4
6A	2.9	N/A	N/A	0.6
7	2.7	N/A	N/A	0.6
8	2.2	N/A	N/A	0.6

Table 6.7: Test #15AS8 Fluid Thickness Data

RUN 15AS8: ABC-S+, fluid only, OAT -4°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.4	N/A	N/A	0.2
5	2.9	N/A	N/A	0.5
5A	5.7	N/A	N/A	0.4
6A	3.5	N/A	N/A	0.6
7	3.1	N/A	N/A	0.8
8	2.7	N/A	N/A	0.8

6.2.2 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the Falcon 20 tests are described in Subsection 2.1.11.3. Skin temperature measurements were recorded at the following intervals:

- Falcon 20 Tests:
    - Before fluid application;

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

The wing temperature measurements recorded during each test are shown in Tables 6.8 to 6.13.

Table 6.8: Test #14S8 Wing Skin Temperature Data

RUN 14S8: ABC-S+, fluid only, OAT -9°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-8.2	-4.2	N/A	N/A	-2.2
T2	-7.9	-3.9	N/A	N/A	-2.0
T3	-8.2	-4.8	N/A	N/A	-1.4
T4	-8.2	-4.8	N/A	N/A	-1.3
T5	-8.9	-6.0	N/A	N/A	-3.6
T6	-9.1	-6.1	N/A	N/A	-3.8
T7	-8.8	-5.5	N/A	N/A	-3.3
T8	-8.7	-5.8	N/A	N/A	-3.6

Table 6.9: Test #14AP8 Wing Skin Temperature Data

RUN 14AP8: ABC-S+, fluid only, OAT -9ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-8.7	-4.5	N/A	N/A	-2.7
T2	-8.2	-4.0	N/A	N/A	-2.7
T3	-9.2	-5.5	N/A	N/A	-1.6
T4	-8.5	-4.2	N/A	N/A	-1.5
T5	-8.7	-4.9	N/A	N/A	0.2
T6	-7.5	-3.0	N/A	N/A	1.2
T7	-7.1	-2.5	N/A	N/A	0.3
T8	-7.4	-2.2	N/A	N/A	0.9

Table 6.10: Test #14AS8 Wing Skin Temperature Data

RUN 14AS8: ABC-S+, fluid only, OAT -9ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-8.6	-4.4	N/A	N/A	-3.0
T2	-8.8	-4.7	N/A	N/A	-2.7
T3	-8.8	-4.5	N/A	N/A	1.7
T4	-9.5	-5.5	N/A	N/A	-1.3
T5	-8.3	-3.8	N/A	N/A	0.2
T6	-9.1	-5.2	N/A	N/A	-0.1
T7	-8.6	-5.3	N/A	N/A	-3.3
T8	-8.5	-5.2	N/A	N/A	-3.7

Table 6.11: Test #15S8 Wing Skin Temperature Data

RUN 15S8: ABC-S+, fluid only, OAT -4ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	-0.9	N/A	N/A	3.2
T2	N/A	-0.8	N/A	N/A	3.6
T3	N/A	-0.9	N/A	N/A	4.0
T4	N/A	-0.7	N/A	N/A	3.5
T5	N/A	-2.4	N/A	N/A	1.2
T6	N/A	-2.0	N/A	N/A	1.4
T7	N/A	-2.0	N/A	N/A	2.0
T8	N/A	-1.4	N/A	N/A	2.6

Table 6.12: Test #15AP8 Wing Skin Temperature Data

RUN 15AP8: ABC-S+, fluid only, OAT -4ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	0.3	N/A	N/A	3.1
T2	N/A	0.6	N/A	N/A	2.7
T3	N/A	2.2	N/A	N/A	5.7
T4	N/A	2.5	N/A	N/A	5.4
T5	N/A	3.4	N/A	N/A	7.0
T6	N/A	4.5	N/A	N/A	8.3
T7	N/A	2.5	N/A	N/A	7.4
T8	N/A	3.0	N/A	N/A	6.3

Table 6.13: Test #15AS8 Wing Skin Temperature Data

RUN 15AS8: ABC-S+, fluid only, OAT -4°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	-0.4	N/A	N/A	3.2
T2	N/A	-0.6	N/A	N/A	3.5
T3	N/A	0.6	N/A	N/A	5.0
T4	N/A	0.5	N/A	N/A	5.4
T5	N/A	1.5	N/A	N/A	7.2
T6	N/A	1.2	N/A	N/A	6.8
T7	N/A	-1.4	N/A	N/A	3.5
T8	N/A	-1.4	N/A	N/A	3.7

6.2.3 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the Falcon 20 tests are described in Subsection 2.1.11.2. Fluid Brix measurements were recorded at the following intervals:

- Falcon 20 Tests:
  - After fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

Tables 6.14 to 6.19 show the fluid Brix measurements collected during the tests.

Table 6.14: Test #14S8 Fluid Brix Data

RUN 14S8: ABC-S+, fluid only, OAT -9ºC				
Wing Position	FLUID BRIX (º)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37	N/A	N/A	37.5
B8	37	N/A	N/A	37

Table 6.15: Test #14AP8 Fluid Brix Data

RUN 14AP8: ABC-S+, fluid only, OAT -9ºC				
Wing Position	FLUID BRIX (º)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37	N/A	N/A	N/A
B8	37	N/A	N/A	N/A

Table 6.16: Test #14AS8 Fluid Brix Data

RUN 14AS8: ABC-S+, fluid only, OAT -9ºC				
Wing Position	FLUID BRIX (º)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37	N/A	N/A	37
B8	37	N/A	N/A	37

Table 6.17: Test #15S8 Fluid Brix Data

RUN 15S8: ABC-S+, fluid only, OAT -4ºC				
Wing Position	FLUID BRIX (º)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37	N/A	N/A	37.5
B8	37	N/A	N/A	37.25

Table 6.18: Test #15AP8 Fluid Brix Data

RUN 15AP8: ABC-S+, fluid only, OAT -4°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37	N/A	N/A	N/A
B8	37	N/A	N/A	N/A

Table 6.19: Test #15AS8 Fluid Brix Data

RUN 15AS8: ABC-S+, fluid only, OAT -4°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37	N/A	N/A	N/A
B8	37	N/A	N/A	N/A

6.3 Photos

High-speed digital photographs of each test were taken; photos were taken of the leading edge, the trailing edge, or both. For each test, photo summaries have been compiled comprising four stages:

- Start of test;
- 17 seconds after start of test;
- Time of rotation; and
- End of test.

Photos 6.1 to 6.24 show the photo summaries for Tests #14S8, #14AP8, #14AS8, #15S8, #15AP8, and #15AS8. During the tests where photos were not taken, a note has been included indicating “No Photo Documentation Available.” A complete set of photos will be provided to the TDC.

6.4 General Observations

6.4.1 Falcon 20 General Observations

No comparable outboard slats extended versus slats retracted tests were performed. During each test run, the outboard slatted section of the wing was compared to the inboard flapped section of the wing. The wing configuration on the Falcon 20 requires both the flaps and slats to either be extended or retracted; they cannot be operated independently. The chord length of the slatted wing test section (Figure 2.3, test area C,) measured approximately 1.7 m (5.5 ft.), whereas the chord length of the flapped wing test section (Figure 2.3, test area A) measured approximately 3 m (10 ft.).

A comparison of the residual fluid thickness at the end of the Falcon 20 test runs has been compiled and is demonstrated in Table 6.20. The residual fluid thickness during the outboard extended slats tests was compared to the residual thickness of the inboard fixed leading edge section with extended flaps. The shaded cells indicate measurements where the fluid thickness during outboard extended slat test was greater in comparison to the inboard fixed leading edge section with extended flap test.

The results indicated that the residual thickness was generally equal on the trailing edge during the outboard extended slat tests compared to the inboard fixed leading edge tests with extended flaps. Differences in results were within 0.1 mm with the exception of Run #14AS8, which produced a residual fluid thickness on position 8 that was twice that of Run #14S8. Residual fluid thickness on the leading edge was generally comparable.

It should be noted that the outboard port wing surface was painted flat black as a result of previous unrelated testing conducted by the NRC. The black paint allowed for radiational heating on that section of the wing. This rise in temperature may have caused the discrepancy in results between Run #15AP8 and #15AS8; fluid would have been warmer and less viscous during Run #15AP8 and would have flowed off more easily.

Table 6.20: Comparison of Falcon 20 Residual Fluid Thicknesses

Wing Position	Fluid Thickness After Takeoff Run (mm)					
	Run #14S8	Run #14AP8	Run #14AS8	Run #15S8	Run #15AP8	Run #15AS8
	Extended Slat	*Retracted Slat*	*Retracted Slat*	*Extended Slat*	*Retracted Slat*	*Retracted Slat*
2	0.2	0.1	0.1	0.5	0.2	0.2
5	0.2	0.2	0.2	0.4	0.4	0.5
7	0.3	0.4	0.4	0.7	0.6	0.8
8	0.3	0.4	0.6	0.7	0.6	0.8

Visually, fluid elimination seemed to be hampered by the extended slats when compared to the inboard fixed wing extended flap section. The fluid shearing on the shorter-chord slatted section only began after the longer-chord flapped section had already begun shearing. The shorter slatted section sheared to approximately 1/2 of chord length at the time of rotation, in comparison to 2/3 on the longer flapped section. Considering the shorter length of the chord at the slatted section, smaller residual trailing edge thicknesses post-run were expected; however, they were equal in comparison to the longer flapped section.

6.4.2 Conclusions and Recommendations for Future Work

The results did not demonstrate significant differences in results due to leading edge slats. Future testing with fixed leading edge wing sections is recommended. If time and resources are available during future full-scale testing, the effect of slats should be revisited, particularly to investigate the effects of adhered contamination on the fluid flow-off on slatted wing sections.

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Photo 6.1: Test #14S8 – Start of Test

Photo 6.2: Test #14S8 – 17 Seconds

Photo 6.3: Test #14S8 – Rotation

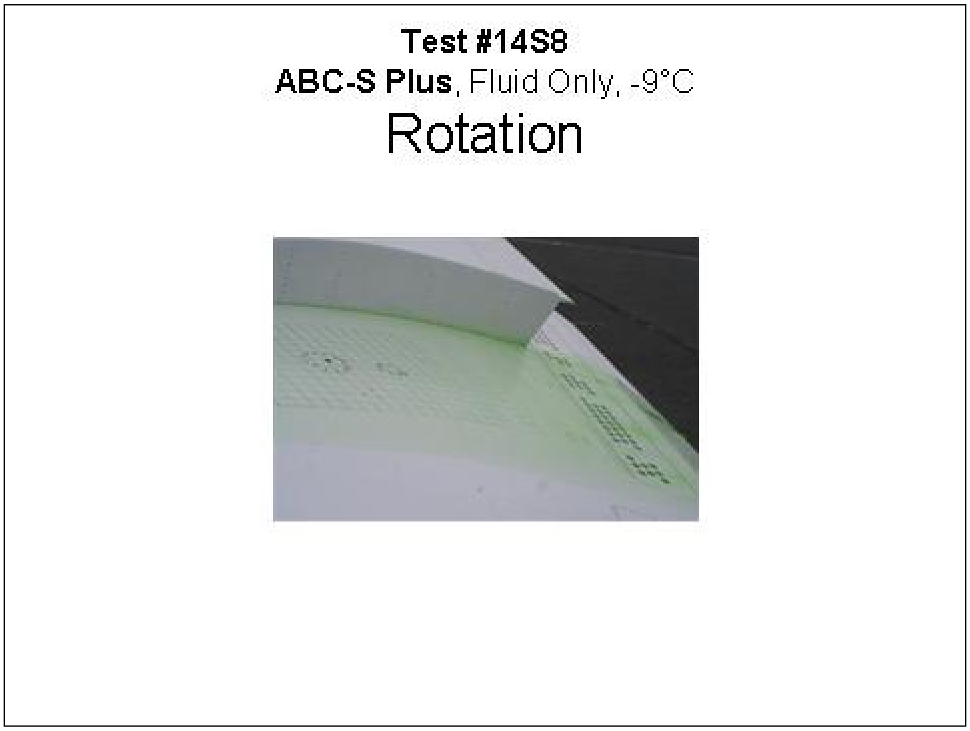


Photo 6.4: Test #14S8 – End of Test

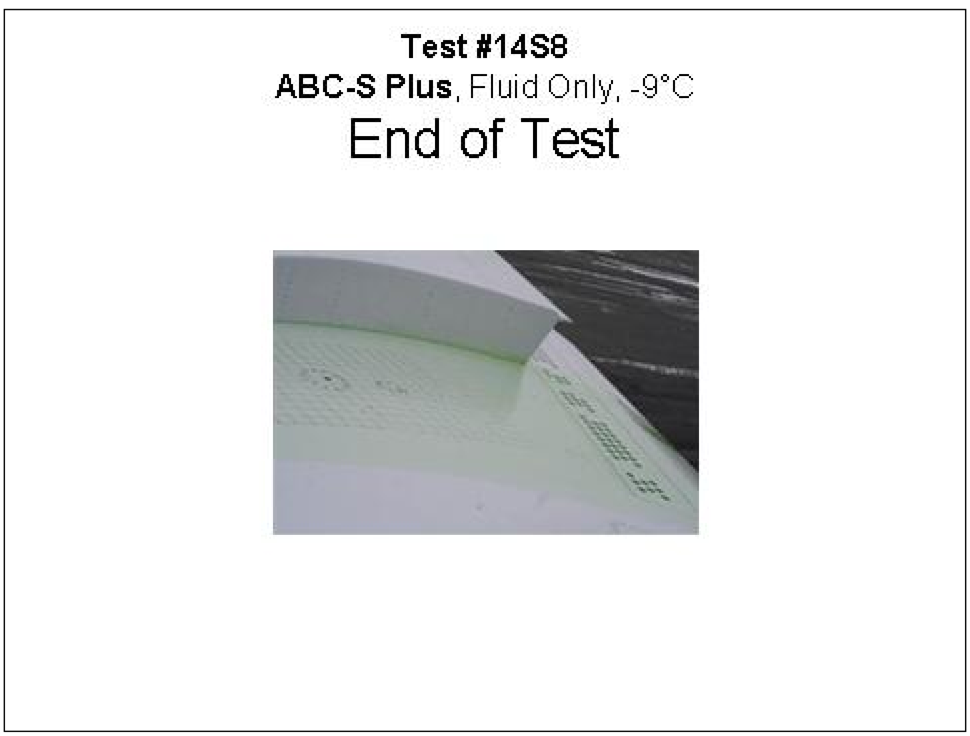


Photo 6.5: Test #14AP8 – Start of Test

No Photo Documentation Available

Photo 6.6: Test #14AP8 – 17 Seconds

No Photo Documentation Available

Photo 6.7: Test #14AP8 – Rotation

No Photo Documentation Available

Photo 6.8: Test #14AP8 – End of Test

No Photo Documentation Available

Photo 6.9: Test #14AS8 – Start of Test

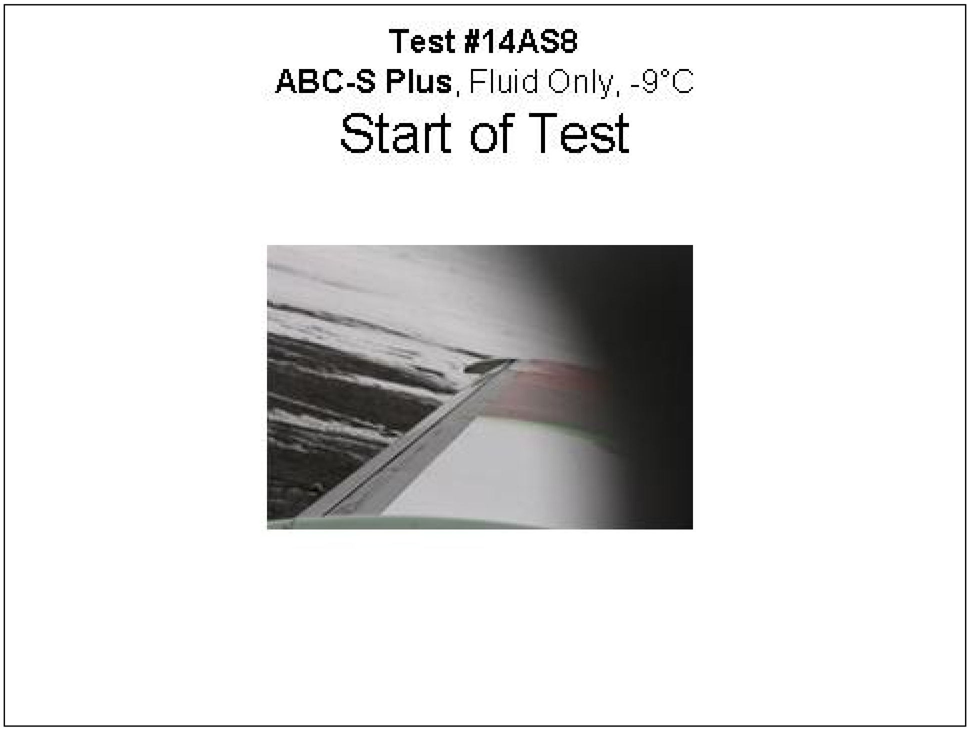


Photo 6.10: Test #14AS8 – 17 Seconds

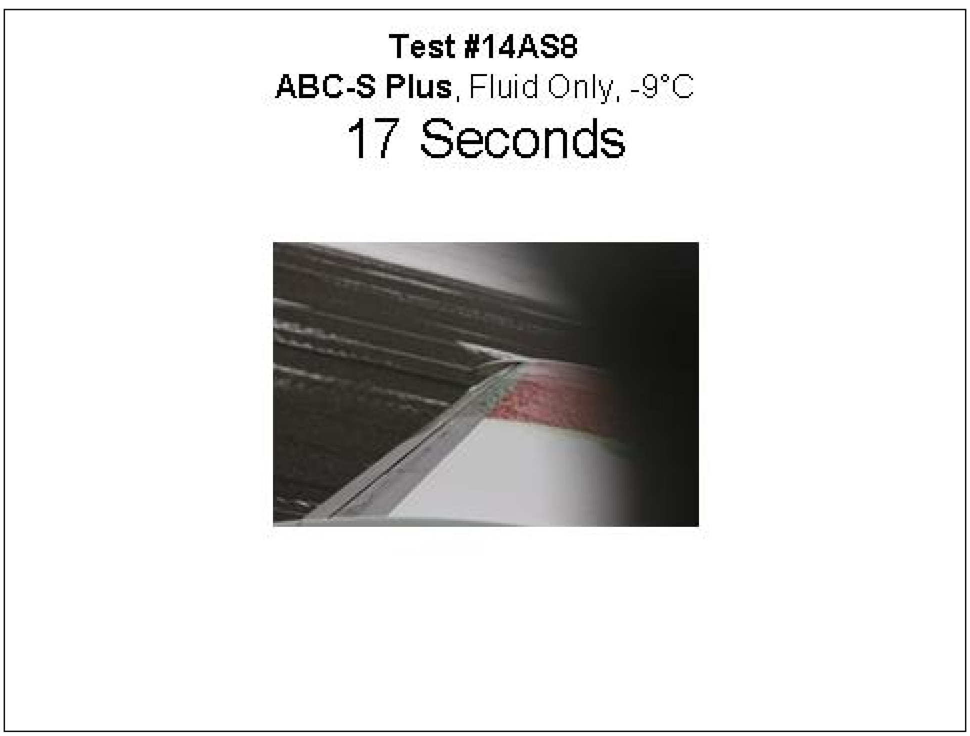


Photo 6.11: Test #14AS8 – Rotation

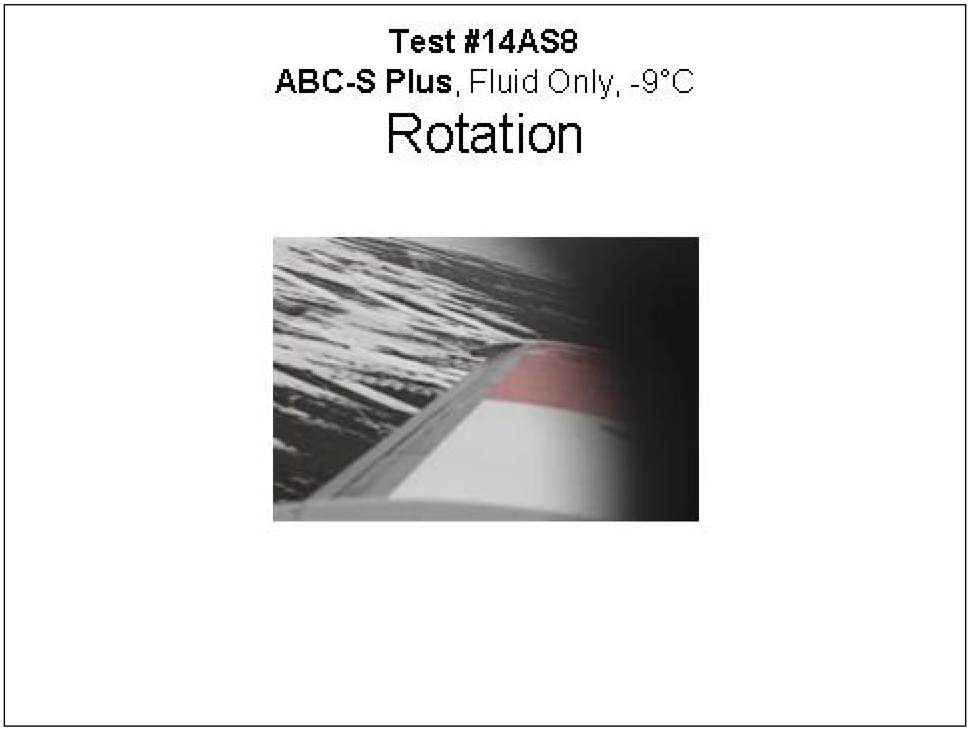


Photo 6.12: Test #14AS8 – End of Test

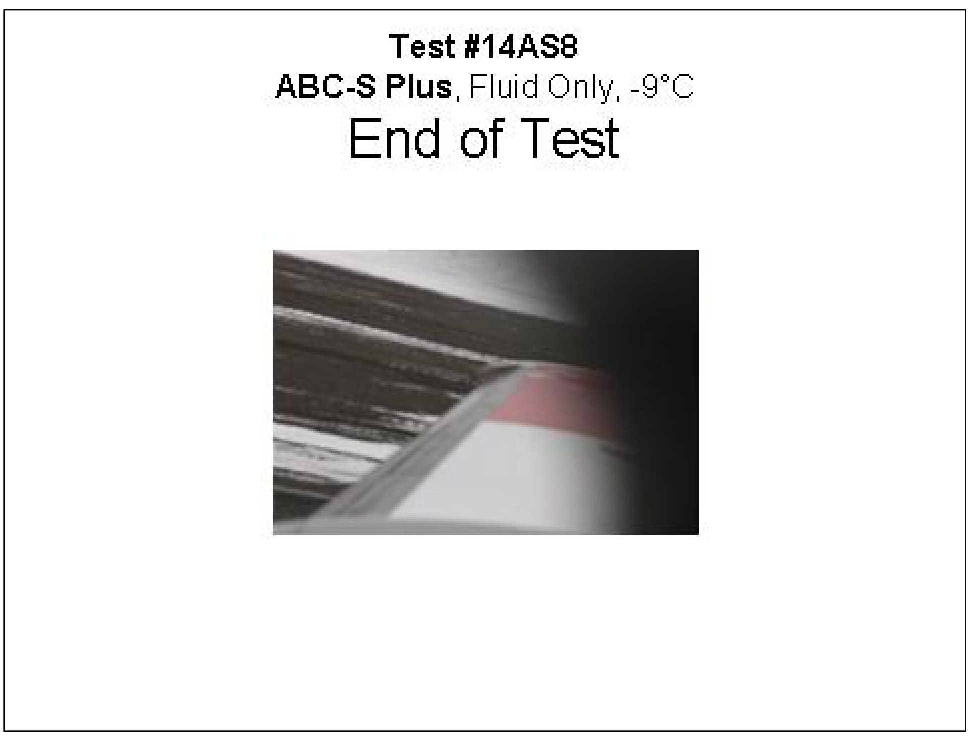


Photo 6.13: Test #15S8 – Start of Test

Photo 6.14: Test #15S8 – 17 Seconds

Photo 6.15: Test #15S8 – Rotation

Photo 6.16: Test #15S8 – End of Test

Photo 6.17: Test #15AP8 – Start of Test

No Photo Documentation Available

Photo 6.18: Test #15AP8 – 17 Seconds

No Photo Documentation Available

Photo 6.19: Test #15AP8 – Rotation

No Photo Documentation Available

Photo 6.20: Test #15AP8 – End of Test

No Photo Documentation Available

Photo 6.21: Test #15AS8 – Start of Test

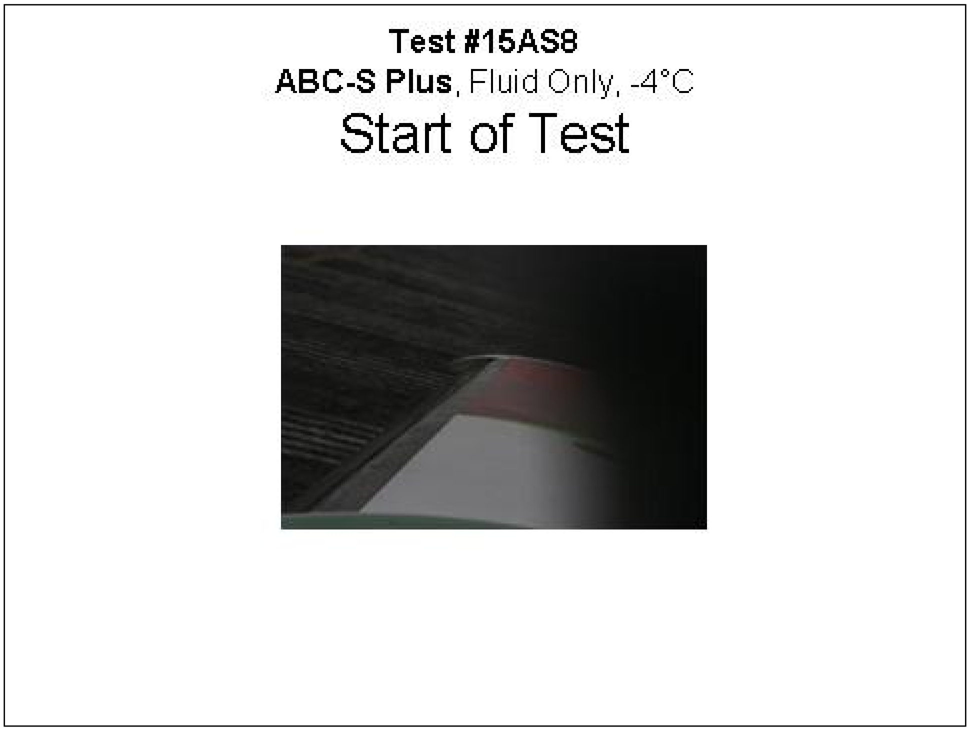


Photo 6.22: Test #15AS8 – 17 Seconds

Photo 6.23: Test #15AS8 – Rotation

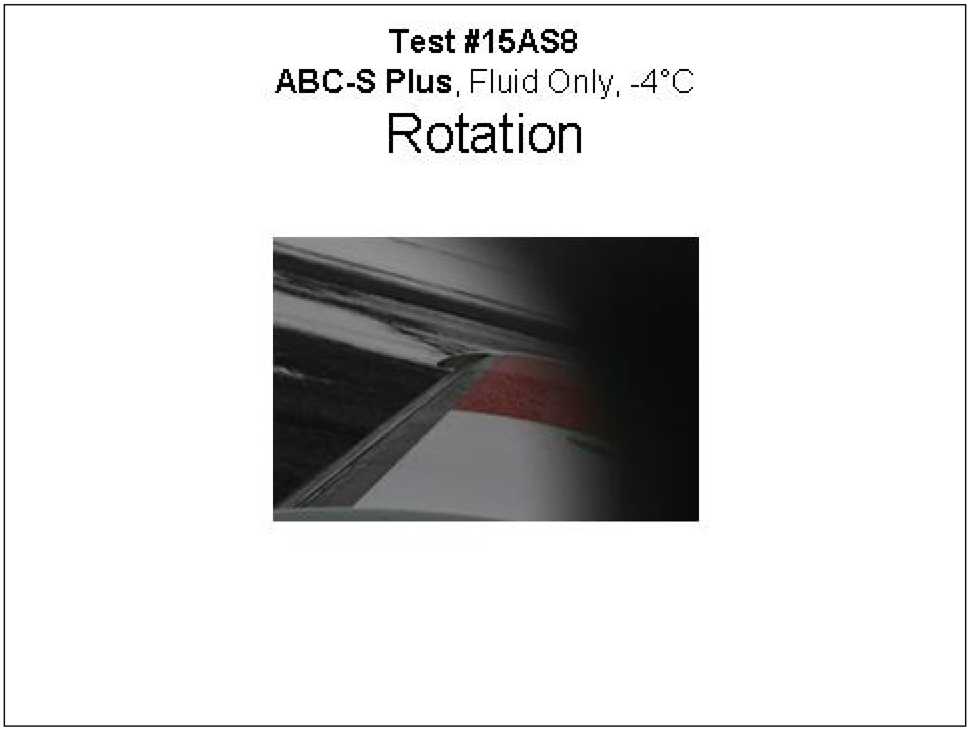
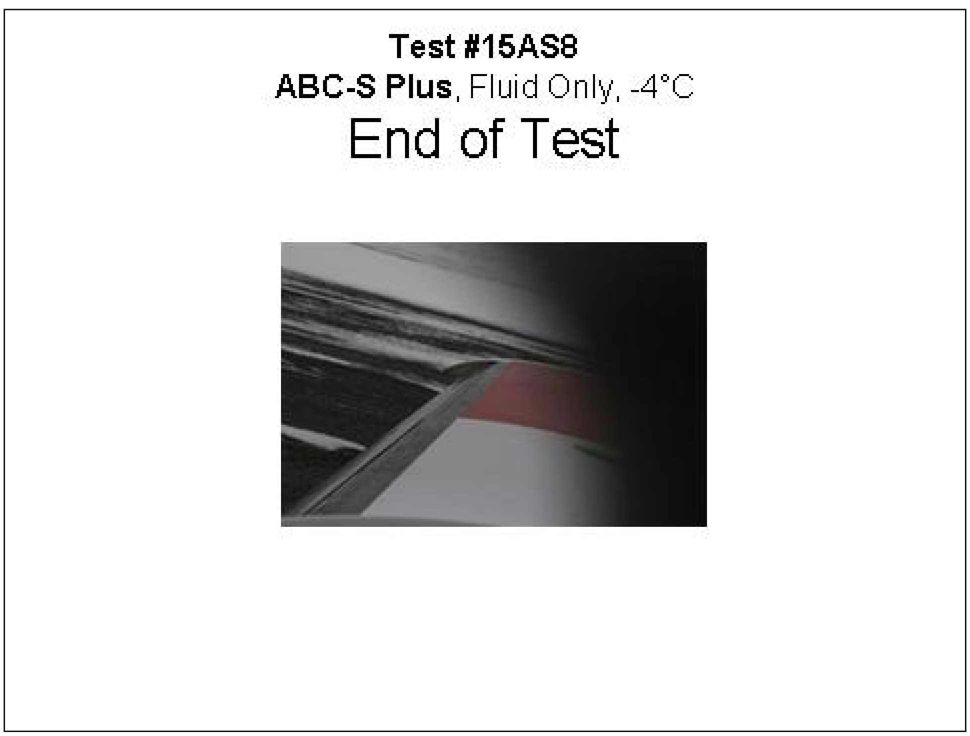


Photo 6.24: Test #15AS8 – End of Test



7. EFFECT OF CHORD LENGTH

The testing conducted during the winter of 2007-08 was geared towards investigating the possibility of expanding the current ice pellet allowance times for low rotation speed aircraft. Due to preliminary results that indicated problems with anti-icing fluid flow-off at low rotation speeds, it was suggested to investigate the infuence of chord length on fluid elimination at lower speeds. It was found that low rotation speed aircraft generally have shorter chord lengths in comparison to high-speed aircraft. The 2.4m (8 ft.) and 1.7m (5.5 ft.) chord test sections were chosen after common low-speed operational aircraft were researched; these chord lengths were deemed suitable and representative of the low-speed aircraft wing specifications. During these tests, the aircraft was configured with retracted flaps and slats to allow for a better comparison between inboard and outboard test sections.

This section provides an overview of each test conducted as part of the test program to evaluate the effect of the chord length on the flow-off behaviour of anti-icing fluid. Testing was conducted in non-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 baseline tests conducted using the Falcon 20 aircraft 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 Falcon 20 aircraft is provided in Subsection 4.1. The following is a brief description of the column headings for Table 7.1:

Run #: Exclusive number identifying each run.

Date: Date when the test was conducted.

Fluid: Aircraft deicing fluid specified by product name.

Condition: Simulated precipitation condition.

IP Rate (g/dm²/h): Average simulated ice pellet precipitation rate, measured in g/dm²/h.

SN Rate (g/dm²/h): Average simulated snow precipitation rate, measured in g/dm²/h.

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

OAT at Start of Test (°C): The outside air temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.

Avg. Wing Temp.: Average wing skin temperature.

After Fluid Appl. (°C): Wing temperature following fluid application, measured in degrees Celsius.

Takeoff Profile: Description of the takeoff acceleration and velocity of the aircraft during the test run.

Comments: General comments regarding the objective of the test.

Table 7.1: Summary of 2007-08 Effect of Chord Length Testing with Falcon 20 Aircraft

Run No.	Date	Fluid	Condition	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Precip. Time (min.)	OAT at Start of Test (°C)	AVG Wing Temp. After Fluid Appl. (°C)	Takeoff Profile	Comments
3S8	27-Feb-08	EG106	Baseline	N/A	N/A	N/A	-11	-3.1	75 knots in 18 sec	9.5 ft. Chord
3AS8	27-Feb-08	EG106	Baseline	N/A	N/A	N/A	-11	-3.1	75 knots in 18 sec	8 ft. Chord
10P8	29-Feb-08	EG106	Baseline	N/A	N/A	N/A	-13	-5	90 knots in 22 sec	9.5 ft. Chord
10AP8	29-Feb-08	EG106	Baseline	N/A	N/A	N/A	-13	1.2	90 knots in 22 sec	5.5 ft. Chord
10S8	29-Feb-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-13	-3.4	90 knots in 22 sec	9.5 ft. Chord
10AS8	29-Feb-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-13	-2.3	90 knots in 22 sec	5.5 ft. Chord

7.2 Data Collected

7.2.1 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the Falcon 20 tests are described in Subsection 2.1.11.1. Fluid thickness measurements were recorded at the following intervals:

- Falcon 20 Tests:
  - Approximately 5 minutes after fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

Tables 7.2 to 7.7 show the fluid thickness measurements collected during the tests.

Table 7.2: Test #3S8 Fluid Thickness Data

RUN 3S8: EG 106, fluid only, OAT -11°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.5	N/A	N/A	0.3
5	3.9	N/A	N/A	0.3
7	1.8	N/A	N/A	0.6
8	2.2	N/A	N/A	0.7

Table 7.3: Test #3AS8 Fluid Thickness Data

RUN 3AS8: EG 106, fluid only, OAT -11ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.2
5	3.9	N/A	N/A	0.3
7	1.8	N/A	N/A	0.6
8	1.8	N/A	N/A	0.6

Table 7.4: Test #10P8 Fluid Thickness Data

RUN 10P8: EG 106, fluid only, OAT -13ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.3
5	3.1	N/A	N/A	0.3
7	2.5	N/A	N/A	0.7
8	3.1	N/A	N/A	0.5

Table 7.5: Test #10AP8 Fluid Thickness Data

RUN 10AP8: EG 106, fluid only, OAT -13ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	N/A	N/A	0.3
5	3.1	N/A	N/A	0.2
5A	2.7	N/A	N/A	0.2
6A	2.7	N/A	N/A	0.4
7	3.3	N/A	N/A	0.3
8	3.3	N/A	N/A	0.4

Table 7.6: Test #10S8 Fluid Thickness Data

RUN 10S8: ABC-S+, fluid only, OAT -13°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.3
5	4.5	N/A	N/A	0.3
7	2.9	N/A	N/A	0.7
8	3.1	N/A	N/A	1.1

Table 7.7: Test #10AS8 Fluid Thickness Data

RUN 10AS8: ABC-S+, fluid only, OAT -13°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	N/A	N/A	0.3
5	3.1	N/A	N/A	0.3
5A	5.7	N/A	N/A	0.3
6A	3.9	N/A	N/A	0.5
7	3.5	N/A	N/A	0.5
8	2.5	N/A	N/A	0.5

7.2.2 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the Falcon 20 tests are described in Subsection 2.1.11.3. Skin temperature measurements were recorded at the following intervals:

- Falcon 20 Tests:
    - Before fluid application;
    - After fluid application;

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

The wing temperature measurements recorded during each test are shown in Tables 7.8 to 7.13.

Table 7.8: Test #3S8 Wing Skin Temperature Data

RUN 3S8: EG 106, fluid only, OAT -11°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-7.2	-5.9	N/A	N/A	-6.8
T2	-7.0	-6.5	N/A	N/A	-6.8
T3	-4.2	-3.1	N/A	N/A	-4.6
T4	-4.5	-3.0	N/A	N/A	-4.6
T5	-5.5	-2.9	N/A	N/A	-5.5
T6	-5.5	-2.2	N/A	N/A	-5.8
T7	-4.2	-1.1	N/A	N/A	-5.2
T8	-3.3	-0.3	N/A	N/A	-8.2

Table 7.9: Test #3AS8 Wing Skin Temperature Data

RUN 3AS8: EG 106, fluid only, OAT -11ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-7.2	-5.9	N/A	N/A	-6.8
T2	-7.0	-6.5	N/A	N/A	-6.8
T3	-4.2	-3.1	N/A	N/A	-4.6
T4	-4.5	-3.0	N/A	N/A	-4.6
T5	-5.5	-2.9	N/A	N/A	-5.5
T6	-5.5	-2.2	N/A	N/A	-5.8
T7	-4.2	-1.1	N/A	N/A	-5.2
T8	-3.3	-0.3	N/A	N/A	-8.2

Table 7.10: Test #10P8 Wing Skin Temperature Data

RUN 10P8: EG 106, fluid only, OAT -13ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	-5.8	N/A	N/A	-6.1
T2	N/A	-5.8	N/A	N/A	-6.5
T3	N/A	-3.9	N/A	N/A	-3.8
T4	N/A	-3.7	N/A	N/A	-4.1
T5	N/A	-4.8	N/A	N/A	-5.8
T6	N/A	-5.7	N/A	N/A	-6.3
T7	N/A	-6.2	N/A	N/A	-6.6
T8	N/A	-3.8	N/A	N/A	-4.4

Table 7.11: Test #10AP8 Wing Skin Temperature Data

RUN 10AP8: EG 106, fluid only, OAT -13ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	-4.4	N/A	N/A	-5.4
T2	N/A	-3.2	N/A	N/A	-4.7
T3	N/A	2.0	N/A	N/A	-1.5
T4	N/A	1.5	N/A	N/A	-1.7
T5	N/A	3.5	N/A	N/A	1.8
T6	N/A	3.8	N/A	N/A	2.0
T7	N/A	3.7	N/A	N/A	3.4
T8	N/A	2.4	N/A	N/A	3.9

Table 7.12: Test #10S8 Wing Skin Temperature Data

RUN 10S8: ABC-S+, fluid only, OAT -13ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	-3.4	N/A	N/A	-5.5
T2	N/A	-2.8	N/A	N/A	-5.7
T3	N/A	-2.0	N/A	N/A	-5.7
T4	N/A	-1.1	N/A	N/A	-2.4
T5	N/A	-4.9	N/A	N/A	-5.0
T6	N/A	-4.2	N/A	N/A	-4.4
T7	N/A	-4.7	N/A	N/A	-2.2
T8	N/A	-4.1	N/A	N/A	-3.0

Table 7.13: Test #10AS8 Wing Skin Temperature Data

RUN 10AS8: ABC-S+, fluid only, OAT -13°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	-3.0	N/A	N/A	-4.8
T2	N/A	-3.2	N/A	N/A	-5.2
T3	N/A	-0.7	N/A	N/A	-1.0
T4	N/A	-1.0	N/A	N/A	-0.6
T5	N/A	-0.2	N/A	N/A	0.6
T6	N/A	-0.4	N/A	N/A	1.5
T7	N/A	-4.9	N/A	N/A	-3.4
T8	N/A	-4.6	N/A	N/A	-3.4

7.2.3 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the Falcon 20 tests are described in Subsection 2.1.11.2. Fluid Brix measurements were recorded at the following intervals:

- Falcon 20 Tests:
  - After fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

Tables 7.14 to 7.19 show the fluid Brix measurements collected during the tests.

Table 7.14: Test #3S8 Fluid Brix Data

RUN 3S8: EG 106, fluid only, OAT -11°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	34	N/A	N/A	36.5
B8	34	N/A	N/A	35

Table 7.15: Test #3AS8 Fluid Brix Data

RUN 3AS8: EG 106, fluid only, OAT -11°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	N/A	N/A	N/A	N/A
B8	N/A	N/A	N/A	N/A

Table 7.16: Test #10P8 Fluid Brix Data

RUN 10P8: EG 106, fluid only, OAT -13°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	33.25	N/A	N/A	36.25
B8	33.5	N/A	N/A	34

Table 7.17: Test #10AP8 Fluid Brix Data

RUN 10AP8: EG 106, fluid only, OAT -13°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	N/A	N/A	N/A	N/A
B8	N/A	N/A	N/A	N/A

Table 7.18: Test #10S8 Fluid Brix Data

RUN 10S8: ABC-S+, fluid only, OAT -13ºC				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37.25	N/A	N/A	39.25
B8	37.25	N/A	N/A	38

Table 7.19: Test #10AS8 Fluid Brix Data

RUN 10AS8: ABC-S+, fluid only, OAT -13ºC				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	N/A	N/A	N/A	N/A
B8	N/A	N/A	N/A	N/A

7.3 Photos

High-speed digital photographs of each test were taken; photos were taken of the leading edge, the trailing edge, or both. For each test, photo summaries have been compiled comprising four stages:

- Start of test;
- 17 seconds after start of test;
- Time of rotation; and
- End of test.

Photos 7.1 to 7.24 show the photo summaries for Tests #3S8, #3AS8, #10P8, #10AP8, #10S8, and #10AS8. During the tests where photos were not taken, a note has been included indicating "No Photo Documentation Available." A complete set of photos will be provided to the TDC.

7.4 General Observations

7.4.1 Falcon 20 General Observations

Testing was conducted by simulating three different chord lengths: the 2.9 m (9.5 ft.) chord was inboard of the fence and was configured with retracted flaps, the 2.4 m (8 ft.) chord was just outboard of the fence and is a fixed wing section, and the 1.7 m (5.5 ft.) chord was located across the ailerons and was configured with retracted slats.

A comparison of the residual fluid thickness at the end of the Falcon 20 test runs has been compiled and is demonstrated in Table 7.20. The residual fluid thickness on the longer 2.9 m (9.5 ft.) chord was compared to the residual fluid thickness on the shorter 2.4 m (8 ft.) and 1.7 m (5.5 ft.) chords. The shaded cells indicate measurements where the fluid thickness measured on the shorter chord length sections was less in comparison to the longer chord length test sections.

The results indicated that the residual fluid thickness was greater (almost double in some cases) on the longer 2.9 m (9.5 ft.) chord test section compared to the shorter 1.7 m (5.5 ft.) chord test section. When comparing the results of the 2.9 m (9.5 ft.) versus the 2.4 m (8 ft.) chord test sections, residual fluid on the trailing edge was comparable and within 0.1 mm.

The length of the chord had a significant effect on fluid elimination; the shorter the chord, the better the fluid elimination. Visually, fluid began to shear at similar speeds; however, the 5.1.7 m (5 ft.) chord would have completely sheared at time of rotation, whereas the longer 2.9 m (9.5 ft.) chord would have sheared only between 1/2 to 2/3 of the chord. The 2.4 m (8 ft.) chord section did not show significant differences compared to the 2.9 m (9.5 ft.) chord section. Fluid thickness measurements confirmed the visual results.

Table 7.20: Comparison of Falcon 20 Residual Fluid Thicknesses

Wing Position	Fluid Thickness After Takeoff Run (mm)					
	Run #3S8	Run #3AS8	Run #10P8	Run #10AP8	Run #10S8	Run #10AS8
	10 ft. Chord	*8 ft. Chord*	*10 ft. Chord*	*5.5 ft. Chord*	*10 ft. Chord*	*5.5 ft. Chord*
2	0.3	0.2	0.3	0.3	0.3	0.3
5	N/A	0.3	0.3	0.2	0.3	0.3
7	0.6	0.6	0.7	0.3	0.7	0.5
8	0.7	0.6	0.5	0.4	1.1	0.5

7.4.2 Conclusions and Recommendations for Future Work

The results demonstrated better fluid flow-off for shorter chord length test sections. These results should be considered when conducting future low-speed aerodynamic testing. Although the shear forces may not be as great during low-speed takeoff, the shorter chord lengths on low-speed aircraft can facilitate anti-icing fluid flow-off. Aerodynamic lift data is required to quantify any potential lift losses associated with the residual fluid present at the time of takeoff for low-speed aircraft; this work should be conducted at the NRC wind tunnel during the winter of 2008-09.

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Photo 7.1: Test #3S8 – Start of Test

Photo 7.2: Test #3S8 – 17 Seconds

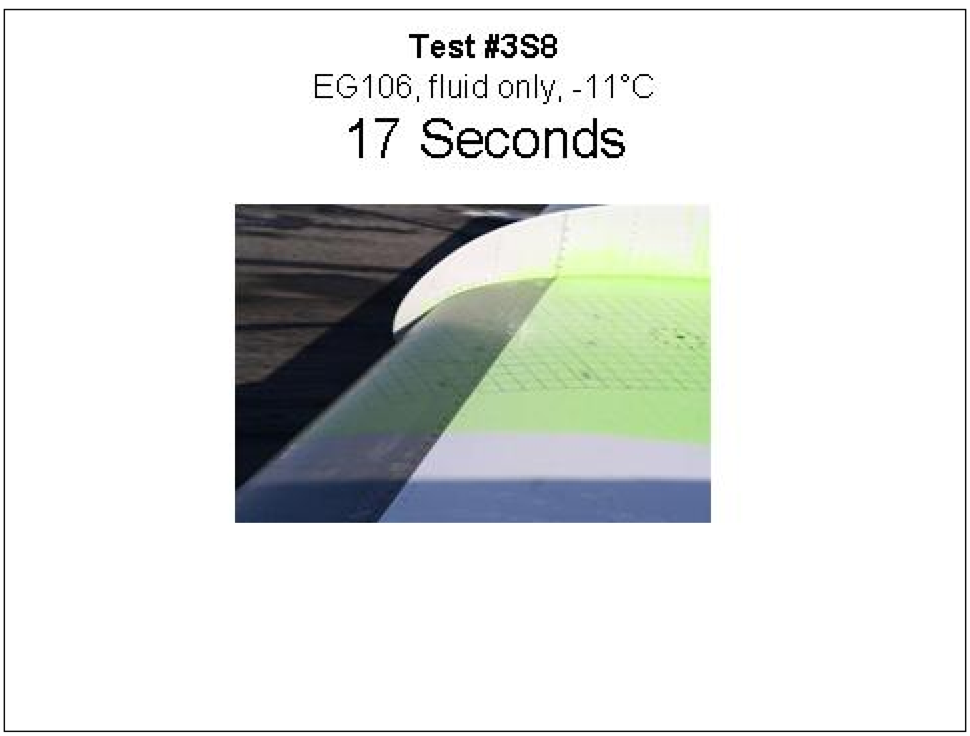


Photo 7.3: Test #3S8 – Rotation

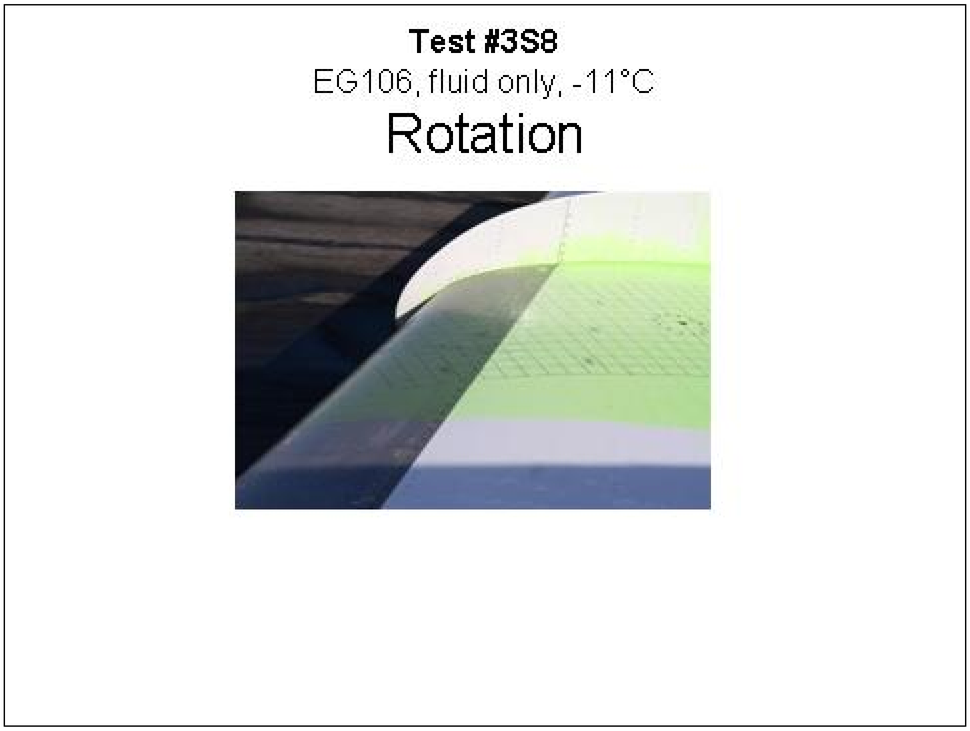


Photo 7.4: Test #3S8 – End of Test

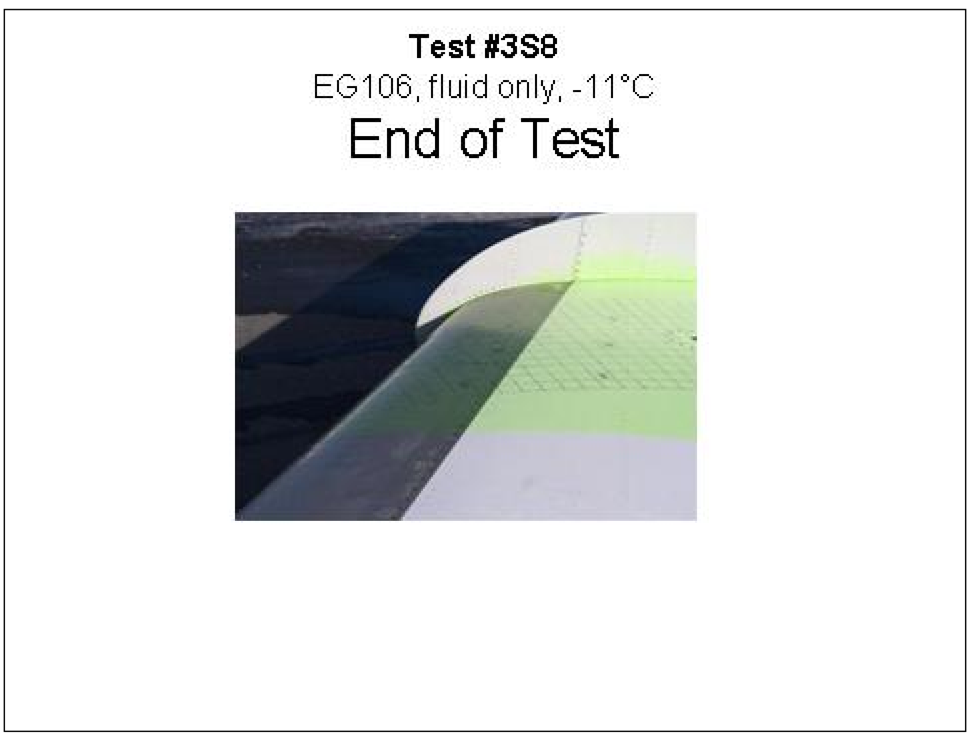


Photo 7.5: Test #3AS8 – Start of Test

No Photo Documentation Available

Photo 7.6: Test #3AS8 – 17 Seconds

No Photo Documentation Available

Photo 7.7: Test #3AS8 – Rotation

No Photo Documentation Available

Photo 7.8: Test #3AS8 – End of Test

No Photo Documentation Available

Photo 7.9: Test #10P8 – Start of Test

Photo 7.10: Test #10P8 – 17 Seconds

Photo 7.11: Test #10P8 – Rotation

Photo 7.12: Test #10P8 – End of Test

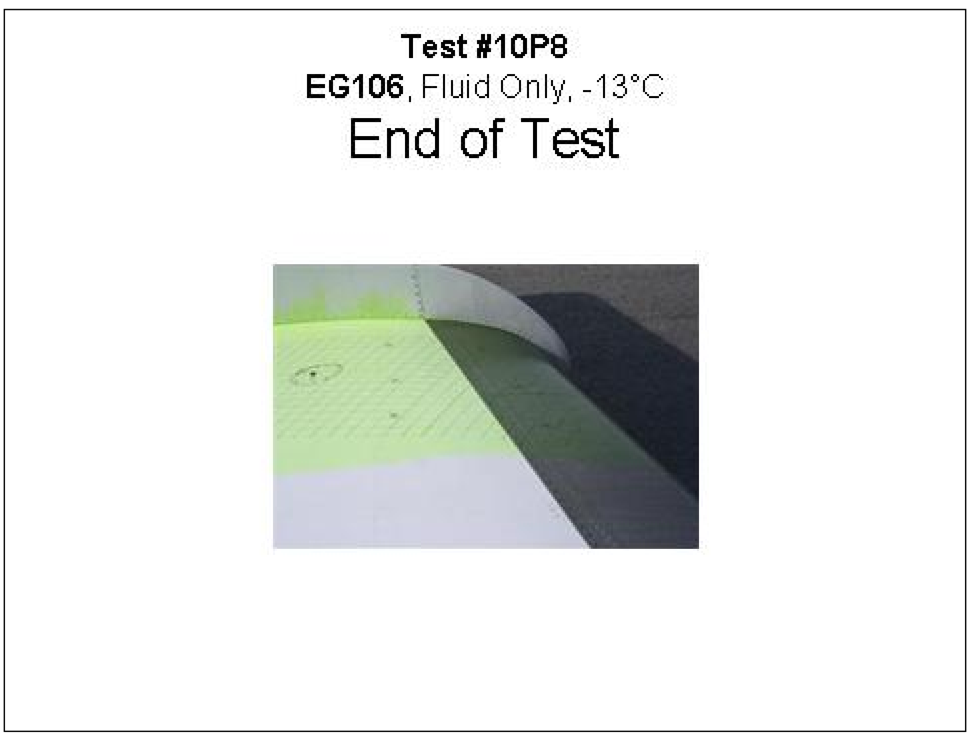


Photo 7.13: Test #10AP8 – Start of Test

Photo 7.14: Test #10AP8 – 17 Seconds

Photo 7.15: Test #10AP8 – Rotation

Photo 7.16: Test #10AP8 – End of Test

Photo 7.17: Test #10S8 – Start of Test

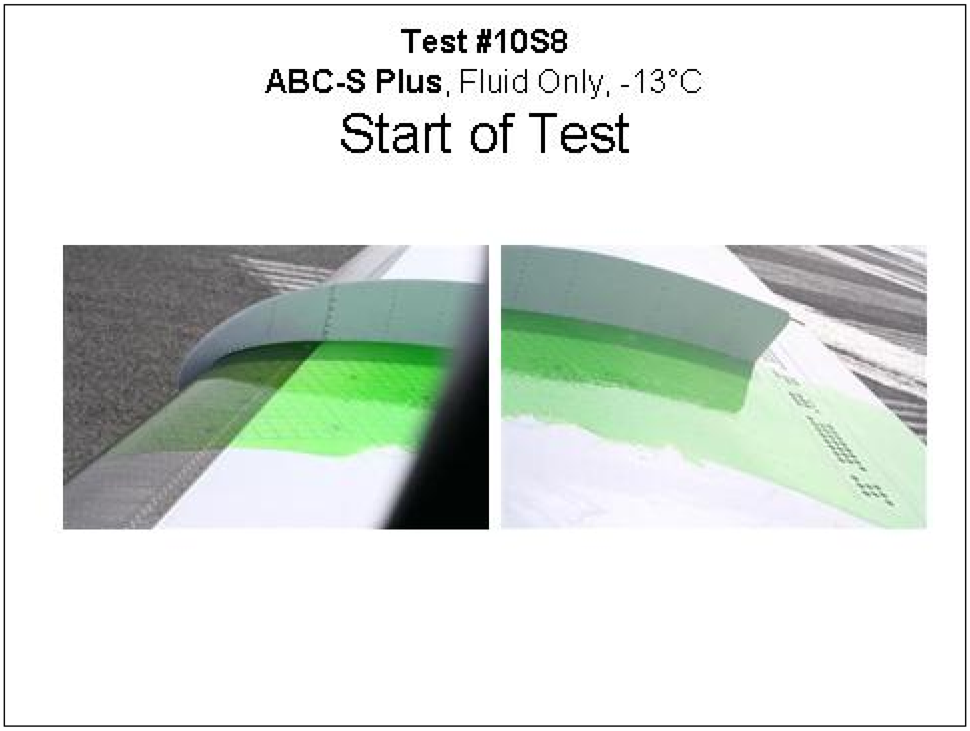


Photo 7.18: Test #10S8 – 17 Seconds

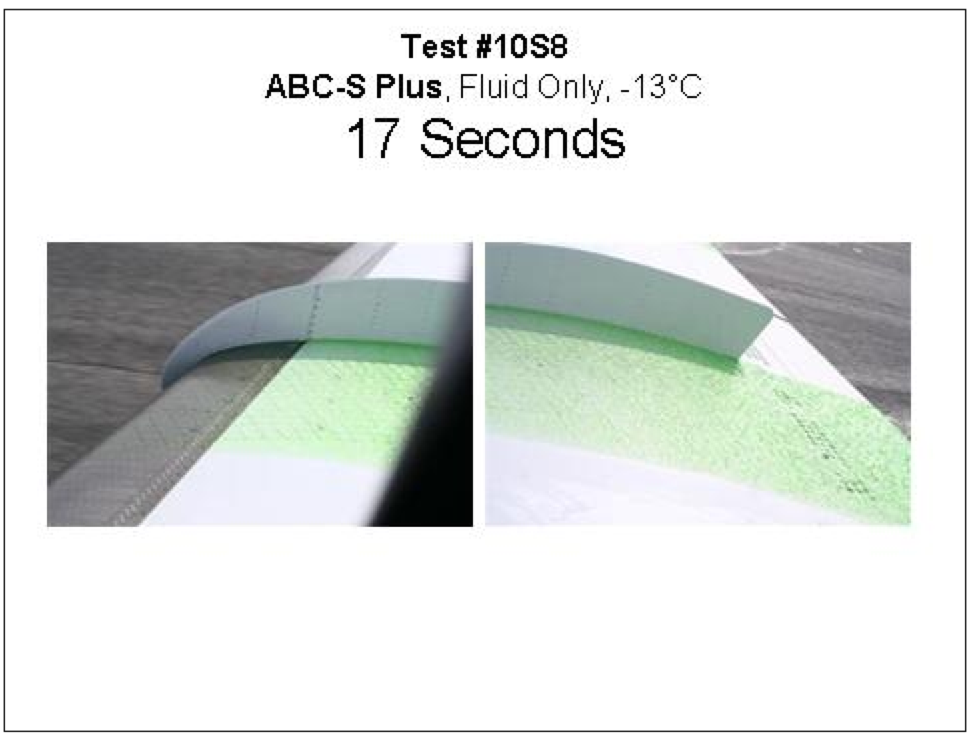


Photo 7.19: Test #10S8 – Rotation

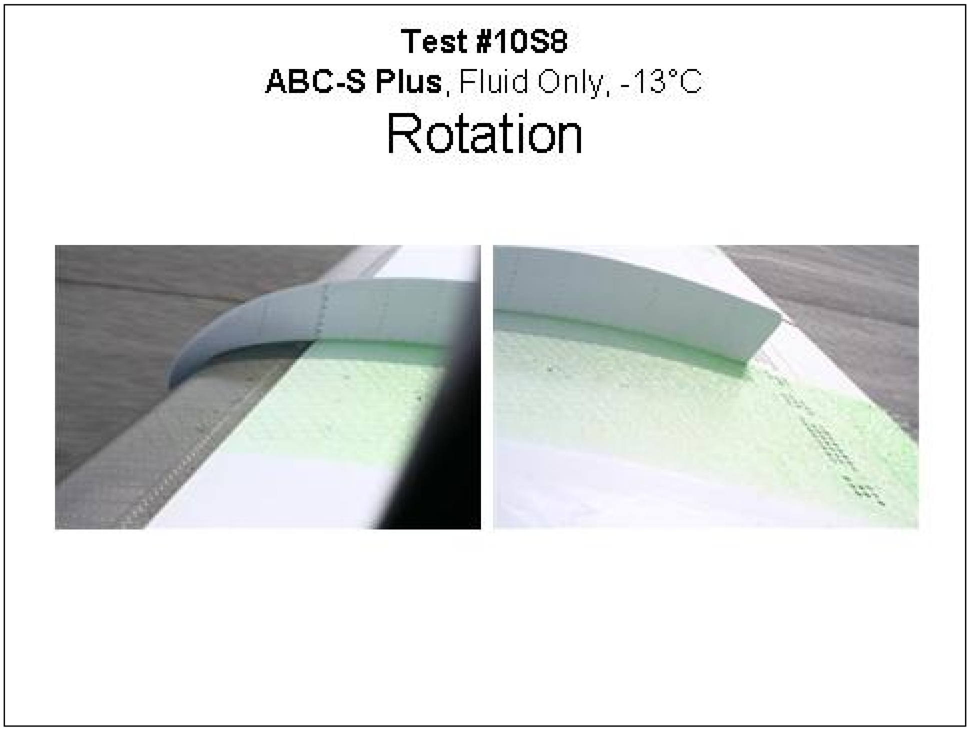


Photo 7.20: Test #10S8 – End of Test

Photo 7.21: Test #10AS8 – Start of Test

No Photo Documentation Available

Photo 7.22: Test #10AS8 – 17 Seconds

No Photo Documentation Available

Photo 7.23: Test #10AS8 – Rotation

No Photo Documentation Available

Photo 7.24: Test #10AS8 – End of Test

No Photo Documentation Available

8. NEW GENERATION VS. OLD GENERATION FLUID

Recently, fluid manufacturers have begun developing new generation anti-icing fluids. These new triazole-free formulations are designed to meet or exceed the performance characteristics of their predecessor fluids while meeting ever-increasing environmental demands. Dow UCAR has begun producing Endurance EG 106 as a substitute product for Ultra+, and Kilfrost has begun producing ABC-S Plus as a substitute for ABC-S. A significant amount of aerodynamic research to develop and support the ice pellet allowance time research has been conducted using the older generation fluids, Ultra+ and ABC-S. As the older generation fluids are slowly being removed from operations, testing was required to evaluate and determine any potential differences in the fluid flow-off properties of the new generation fluids (EG 106 and ABC-S Plus) to provide a link between the previous aerodynamic data collected and current and future work to be conducted.

This section provides an overview of each test conducted as part of the test program to evaluate the difference in the new generation triozole-free fluids in comparison to the older generation fluids by observing the flow-off behaviour of the anti-icing fluids. Testing was conducted in non-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 baseline tests conducted using the Falcon 20 aircraft 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 Falcon 20 aircraft is provided in Subsection 4.1. The following is a brief description of the column headings for Table 8.1:

Run #:	Exclusive number identifying each run.
Date:	Date when the test was conducted.
Fluid:	Aircraft deicing fluid specified by product name.
Condition:	Simulated precipitation condition.
IP Rate (g/dm²/h):	Average simulated ice pellet precipitation rate, measured in g/dm²/h.
SN Rate (g/dm²/h):	Average simulated snow precipitation rate, measured in g/dm²/h.

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

OAT at Start of Test (°C): The outside air temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.

Avg. Wing Temp.: Average wing skin temperature.

After Fluid Appl. (°C): Wing temperature following fluid application, measured in degrees Celsius.

Takeoff Profile: Description of the takeoff acceleration and velocity of the aircraft during the test run.

Comments: General comments regarding the objective of the test.

Table 8.1: Summary of 2007-08 New Generation vs. Old Generation Fluid Testing with Falcon 20 Aircraft

Run No.	Date	Fluid	Condition	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Precip. Time (min.)	OAT at Start of Test (°C)	AVG Wing Temp. After Fluid Appl. (°C)	Takeoff Profile	Comments
4P8	28-Feb-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-19	-10.5	104 knots in 31 sec	New Fluid
4S8	28-Feb-08	ABC-S	Baseline	N/A	N/A	N/A	-19	-11.1	104 knots in 31 sec	Old Fluid
5P8	28-Feb-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-18	-8.7	66 knots in 18 sec	New Fluid
5S8	28-Feb-08	ABC-S	Baseline	N/A	N/A	N/A	-18	-8.6	66 knots in 18 sec	Old Fluid
6P8	28-Feb-08	EG106	Baseline	N/A	N/A	N/A	-16	-2.8	75 knots in 18 sec	New Fluid
6S8	28-Feb-08	Ultra+	Baseline	N/A	N/A	N/A	-16	-6.8	75 knots in 18 sec	Old Fluid
8P8	29-Feb-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-17	-12.9	112 knots in 29 sec	New Fluid
8S8	29-Feb-08	ABC-S	Baseline	N/A	N/A	N/A	-17	-14.2	112 knots in 29 sec	Old Fluid

8.2 Data Collected

8.2.1 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the Falcon 20 tests are described in Subsection 2.1.11.1. Fluid thickness measurements were recorded at the following intervals:

- Falcon 20 Tests:
  - Approximately 5 minutes after fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

Tables 8.2 to 8.9 show the fluid thickness measurements collected during the tests.

Table 8.2: Test #4P8 Fluid Thickness Data

RUN 4P8: ABC-S+, fluid only, OAT -19°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	N/A	N/A	0.2
5	4.5	N/A	N/A	0.3
7	2.2	N/A	N/A	1
8	2.5	N/A	N/A	0.5

Table 8.3: Test #4S8 Fluid Thickness Data

RUN 4S8: ABC-S, fluid only, OAT -19°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	N/A	N/A	0.2
5	3.3	N/A	N/A	0.3
7	1.8	N/A	N/A	0.6
8	1.8	N/A	N/A	0.4

Table 8.4: Test #5P8 Fluid Thickness Data

RUN 5P8: ABC-S+, fluid only, OAT -18ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	N/A	N/A	0.3
5	4.5	N/A	N/A	0.5
7	2.9	N/A	N/A	1.8
8	2.7	N/A	N/A	2.2

Table 8.5: Test #5S8 Fluid Thickness Data

RUN 5S8: ABC-S, fluid only, OAT -18ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	N/A	N/A	0.3
5	3.7	N/A	N/A	0.5
7	2.2	N/A	N/A	1.8
8	2.5	N/A	N/A	1.8

Table 8.6: Test #6P8 Fluid Thickness Data

RUN 6P8: EG 106, fluid only, OAT -16ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.5	N/A	N/A	0.3
5	4.5	N/A	N/A	0.4
7	2.2	N/A	N/A	0.8
8	2.9	N/A	N/A	1.1

Table 8.7: Test #6S8 Fluid Thickness Data

RUN 6S8: ULTRA+, fluid only, OAT -16°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.3
5	4.5	N/A	N/A	0.4
7	3.1	N/A	N/A	1.8
8	3.1	N/A	N/A	1.8

Table 8.8: Test #8P8 Fluid Thickness Data

RUN 8P8: ABC-S+, fluid only, OAT -17°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.1	N/A	N/A	0.2
5	2.5	N/A	N/A	0.2
7	1.8	N/A	N/A	0.4
8	1.8	N/A	N/A	0.6

Table 8.9: Test #8S8 Fluid Thickness Data

RUN 8S8: ABC-S, fluid only, OAT -17°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.4	N/A	N/A	0.2
5	2.5	N/A	N/A	0.2
7	1.8	N/A	N/A	0.3
8	1.8	N/A	N/A	0.5

8.2.2 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the Falcon 20 tests are described in Subsection 2.1.11.3. Skin temperature measurements were recorded at the following intervals:

- Falcon 20 Tests:
  - Before fluid application;
  - After fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

The wing temperature measurements recorded during each test are shown in Tables 8.10 to 8.17.

Table 8.10: Test #4P8 Wing Skin Temperature Data

RUN 4P8: ABC-S+, fluid only, OAT -19°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-14.0	-14.6	N/A	N/A	-12.4
T2	-14.5	-14.3	N/A	N/A	-13.3
T3	-11.3	-9.6	N/A	N/A	-9.5
T4	-11.8	-9.1	N/A	N/A	-8.8
T5	-10.2	-8.1	N/A	N/A	-9.3
T6	-10.5	-7.7	N/A	N/A	-8.7
T7	-16.1	-11.2	N/A	N/A	-10.5
T8	-16.3	-9.5	N/A	N/A	-10.3

Table 8.11: Test #4S8 Wing Skin Temperature Data

RUN 4S8: ABC-S, fluid only, OAT -19°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-16.1	-14.6	N/A	N/A	-13.9
T2	-15.9	-15.1	N/A	N/A	-13.9
T3	-11.1	-9.6	N/A	N/A	-9.5
T4	-12.0	-9.6	N/A	N/A	-9.1
T5	-11.2	-8.5	N/A	N/A	-9.3
T6	-11.4	-8.0	N/A	N/A	-8.9
T7	-14.3	-9.9	N/A	N/A	-10.1
T8	-14.9	-13.7	N/A	N/A	-9.8

Table 8.12: Test #5P8 Wing Skin Temperature Data

RUN 5P8: ABC-S+, fluid only, OAT -18°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	N/A	N/A	N/A	-10.3
T2	N/A	N/A	N/A	N/A	-11
T3	N/A	N/A	N/A	N/A	-5.9
T4	N/A	N/A	N/A	N/A	-6.7
T5	N/A	N/A	N/A	N/A	-7.1
T6	N/A	N/A	N/A	N/A	-8.2
T7	N/A	N/A	N/A	N/A	-5.3
T8	N/A	N/A	N/A	N/A	-5.9

Table 8.13: Test #5S8 Wing Skin Temperature Data

RUN 5S8: ABC-S, fluid only, OAT -18°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	N/A	N/A	N/A	-12.6
T2	N/A	N/A	N/A	N/A	-12.7
T3	N/A	N/A	N/A	N/A	-7.1
T4	N/A	N/A	N/A	N/A	-7.5
T5	N/A	N/A	N/A	N/A	-7.6
T6	N/A	N/A	N/A	N/A	-7.6
T7	N/A	N/A	N/A	N/A	-6.8
T8	N/A	N/A	N/A	N/A	-13.8

Table 8.14: Test #6P8 Wing Skin Temperature Data

RUN 6P8: EG 106, fluid only, OAT -16°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-6.3	-3.0	N/A	N/A	-5.2
T2	-6.8	-2.7	N/A	N/A	-6.1
T3	-3.9	-1.3	N/A	N/A	-2.7
T4	-4.8	-2.1	N/A	N/A	-3.4
T5	-7.6	-3.0	N/A	N/A	-5.5
T6	-8.7	-5.1	N/A	N/A	-7.2
T7	-8.5	-2.3	N/A	N/A	-3.0
T8	-9.2	-3.2	N/A	N/A	-3.8

Table 8.15: Test #6SS8 Wing Skin Temperature Data

RUN 6S8: ULTRA+, fluid only, OAT -16ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-12.6	-10.0	N/A	N/A	-9.9
T2	-12.0	-10.4	N/A	N/A	-10.1
T3	-7.5	-4.5	N/A	N/A	-5.0
T4	-7.5	-4.7	N/A	N/A	-5.1
T5	-7.9	-4.7	N/A	N/A	-5.6
T6	-8.4	-4.2	N/A	N/A	-5.7
T7	-12.3	-5.4	N/A	N/A	-4.7
T8	-14.9	-10.7	N/A	N/A	-12.5

Table 8.16: Test #8P8 Wing Skin Temperature Data

RUN 8P8: ABC-S+, fluid only, OAT -17ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-14.3	-12.9	N/A	N/A	-11.1
T2	-14.6	-13.3	N/A	N/A	-10.8
T3	-14.3	-12.8	N/A	N/A	-12.0
T4	-14.6	-13.2	N/A	N/A	-9.3
T5	-15.5	-13.4	N/A	N/A	-13.3
T6	-15.5	-14.3	N/A	N/A	-13.0
T7	-15.5	-11.4	N/A	N/A	-13.6
T8	-15.4	-11.7	N/A	N/A	-13.5

Table 8.17: Test #8S8 Wing Skin Temperature Data

RUN 8S8: ABC-S, fluid only, OAT -17°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-16.3	-14.2	N/A	N/A	-5.2
T2	-16.2	-14.1	N/A	N/A	-5.2
T3	16.4	-14.0	N/A	N/A	-6.1
T4	-16.5	-14.1	N/A	N/A	-6.2
T5	-17.2	-14.3	N/A	N/A	-12.4
T6	-17.4	-14.4	N/A	N/A	-11.5
T7	-14.9	-14.3	N/A	N/A	-10.4
T8	-14.5	-14.2	N/A	N/A	-9.2

8.2.3 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the Falcon 20 tests are described in Subsection 2.1.11.2. Fluid Brix measurements were recorded at the following intervals:

- Falcon 20 Tests:
  - After fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

Tables 8.18 to 8.25 show the fluid Brix measurements collected during the tests.

Table 8.18: Test #4P8 Fluid Brix Data

RUN 4P8: ABC-S+, fluid only, OAT -19ºC				
Wing Position	FLUID BRIX (º)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37.75	N/A	N/A	38.5
B8	37.75	N/A	N/A	37.5

Table 8.19: Test #4S8 Fluid Brix Data

RUN 4S8: ABC-S, fluid only, OAT -19ºC				
Wing Position	FLUID BRIX (º)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37.5	N/A	N/A	39
B8	37.5	N/A	N/A	37.5

Table 8.20: Test #5P8 Fluid Brix Data

RUN 5P8: ABC-S+, fluid only, OAT -18ºC				
Wing Position	FLUID BRIX (º)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37.75	N/A	N/A	38
B8	37.5	N/A	N/A	37.5

Table 8.21: Test #5S8 Fluid Brix Data

RUN 5S8: ABC-S, fluid only, OAT -18ºC				
Wing Position	FLUID BRIX (º)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37.5	N/A	N/A	38
B8	37.5	N/A	N/A	37.5

Table 8.22: Test #6P8 Fluid Brix Data

RUN 6P8: EG 106, fluid only, OAT -16°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	33.5	N/A	N/A	35.5
B8	33.75	N/A	N/A	34.25

Table 8.23: Test #6S8 Fluid Brix Data

RUN 6S8: ULTRA+, fluid only, OAT -16°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	42.00	N/A	N/A	42.00
B8	42.00	N/A	N/A	43.75

Table 8.24: Test #8P8 Fluid Brix Data

RUN 8P8: ABC-S+, fluid only, OAT -17°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37.25	N/A	N/A	39
B8	37.5	N/A	N/A	37.5

Table 8.25: Test #8S8 Fluid Brix Data

RUN 8S8: ABC-S, fluid only, OAT -17°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37.5	N/A	N/A	38.5
B8	37.25	N/A	N/A	37.5

8.3 Photos

High-speed digital photographs of each test were taken; photos were taken of the leading edge, the trailing edge, or both. For each test, photo summaries have been compiled comprising four stages:

- Start of test;
- 17 seconds after start of test;
- Time of rotation; and
- End of test.

Photos 8.1 to 8.32 show the photo summaries for Tests #4P8, #4S8, #5P8, #5S8, #6P8, #6S8, #8P8, and #8S8. During the tests where photos were not taken, a note has been included indicating “No Photo Documentation Available.” A compilation of selected high-speed photos taken during Test #8P8 are included Appendix G. A complete set of photos will be provided to the TDC.

8.4 Results

8.4.1 ABC-S vs. ABC-S Plus

A comparison of the residual fluid thickness at the end of the Falcon 20 test runs has been compiled and is demonstrated in Table 8.26. The residual fluid thickness measured with the new ABC-S Plus fluid was compared to the residual fluid thickness measured with the older ABC-S fluid. The shaded cells indicate measurements where the fluid thickness measured using the new ABC-S Plus fluid was greater in comparison to the results using the older ABC-S fluid.

High-speed and low-speed comparative testing with the ABC-S and ABC-S Plus (triozole-free) fluids demonstrated similar fluid flow-off characteristics. During the two comparative test runs, the new ABC-S Plus generated slightly greater residual thickness on the trailing edge section of the wing post test run; however, the discrepancies were minor. In general, both fluids behaved similarly aerodynamically.

Table 8.26: Comparison of Falcon 20 Residual Fluid Thicknesses – ABC-S Plus vs. ABC-S

Wing Position	Fluid Thickness After Takeoff Run (mm)					
	Run #4P8	Run #4S8	Run #5P8	Run #5S8	Run #8P8	Run #8S8
	New Fluid	*Old Fluid*	*New Fluid*	*Old Fluid*	*New Fluid*	*Old Fluid*
2	0.2	0.2	0.3	0.3	0.2	0.2
5	0.3	0.3	0.5	0.5	0.2	0.2
7	1	0.6	1.8	1.8	0.4	0.3
8	0.5	0.4	2.2	1.8	0.6	0.5

8.4.2 EG 106 vs. Ultra+

A comparison of the residual fluid thickness at the end of the Falcon 20 test runs has been compiled and is demonstrated in Table 8.27. The residual fluid thickness measured with the new EG 106 fluid was compared to the residual fluid thickness measured with the older Ultra+ fluid. The shaded cells indicate measurements where the fluid thickness measured using the old Ultra+ fluid was greater in comparison to the results using the newer EG 106 fluid.

Low-speed comparative testing with the Ultra+ and EG 106 (triozole-free) fluids demonstrated better flow-off characteristics for the new EG 106 fluid. During the comparative test run, the new EG 106 fluid demonstrated reduced residual fluid thicknesses on the trailing edge of the wing section post test run; residual fluid was reduced by approximately half. It should be noted that the new EG 106 has a lowest operational use temperature (LOUT) of -29ºC, lower than the Ultra+ LOUT of -24ºC. The same fluid characteristics that provided the EG 106 fluid with a lower LOUT may have also aided in the fluid flow-off properties at warmer temperatures.

Visually, residual EG106 fluid on the trailing edge of the wing post-run was more apparent. However, thickness measurements indicated the opposite; residual fluid was greater for ULTRA+. Visual observations seemed to be influenced by the bright dye in the new EG106.

Table 8.27: Comparison of Falcon 20 Residual Fluid Thicknesses – EG106 vs. Ultra+

Wing Position	Fluid Thickness After Takeoff Run (mm)	
	Run #6P8	Run #6S8
	New Fluid	*Old Fluid*
2	0.3	0.3
5	0.4	0.4
7	0.8	1.8
8	1.1	1.8

8.4.3 Conclusions and Recommendations for Future Work

The aerodynamic performance of the new fluids meets or exceeds the performance of the older generation fluids. As the older generation fluids are slowly being removed from operations, it will become more difficult to obtain those fluid samples for future testing. It is therefore recommended that future aerodynamic testing be conducted primarily using the new generation fluids.

Photo 8.1: Test #4P8 – Start of Test

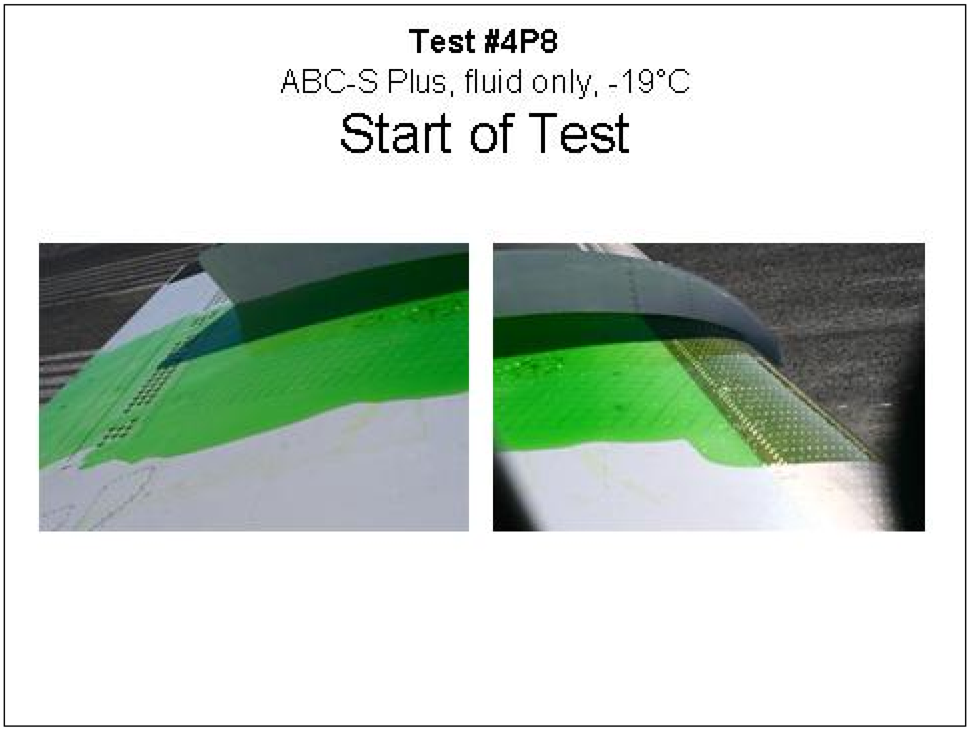


Photo 8.2: Test #4P8 – 17 Seconds

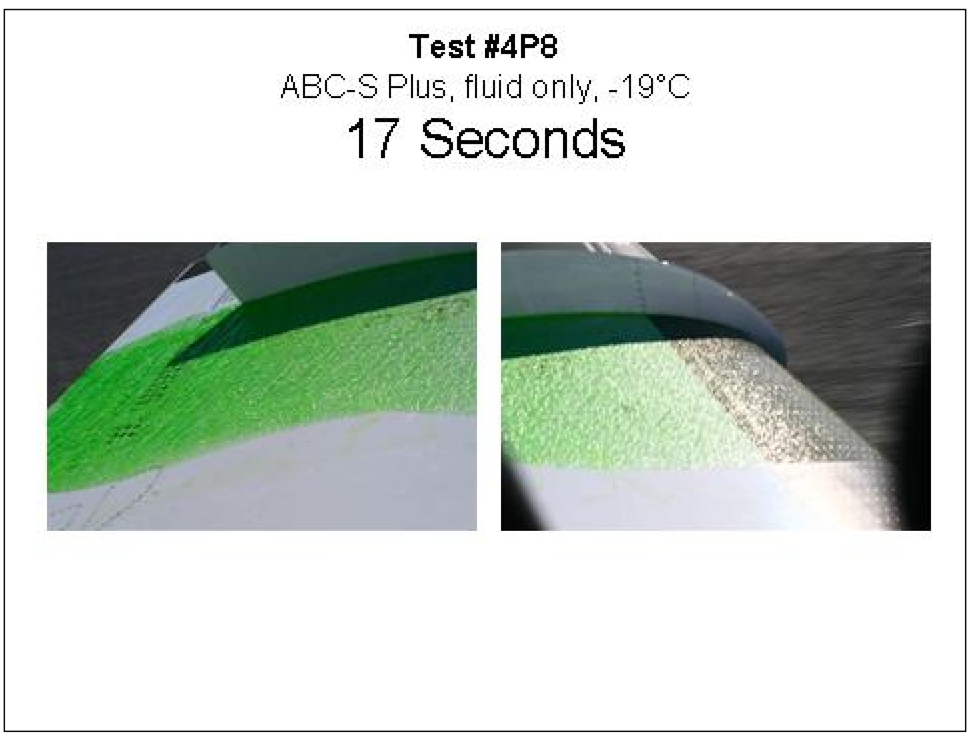


Photo 8.3: Test #4P8 – Rotation

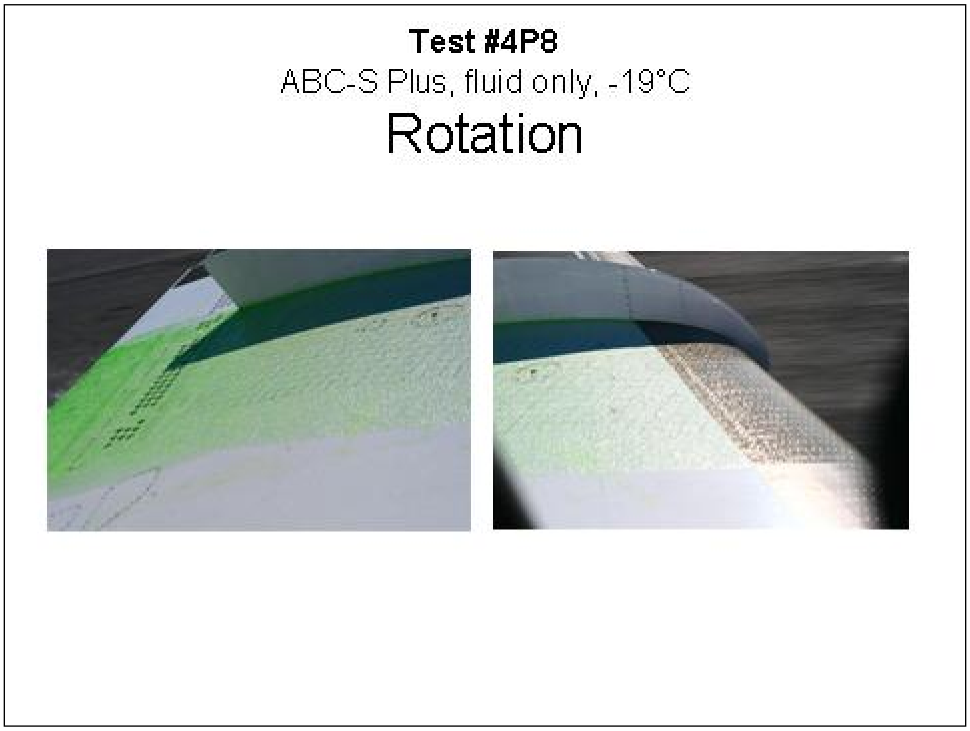


Photo 8.4: Test #4P8 – End of Test

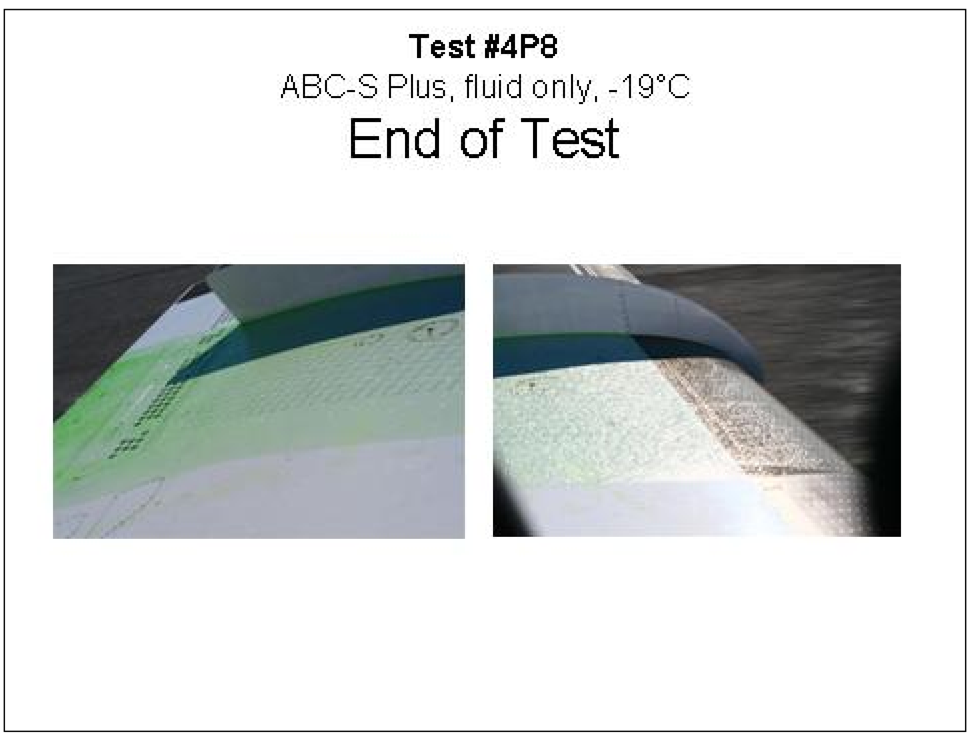


Photo 8.5: Test #4S8 – Start of Test

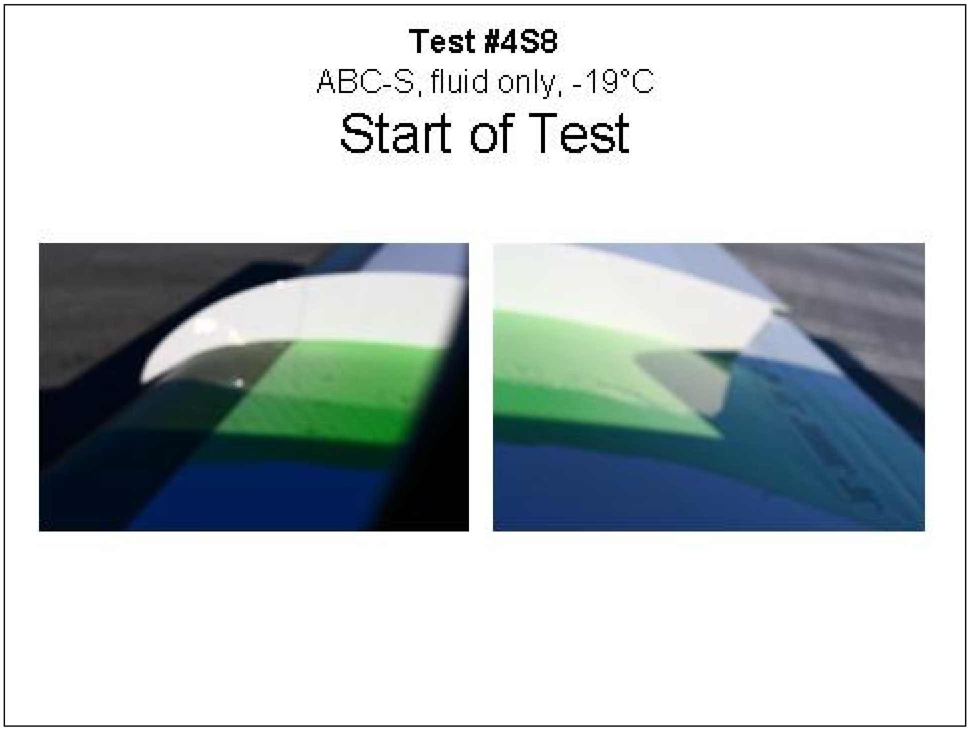


Photo 8.6: Test #4S8 – 17 Seconds

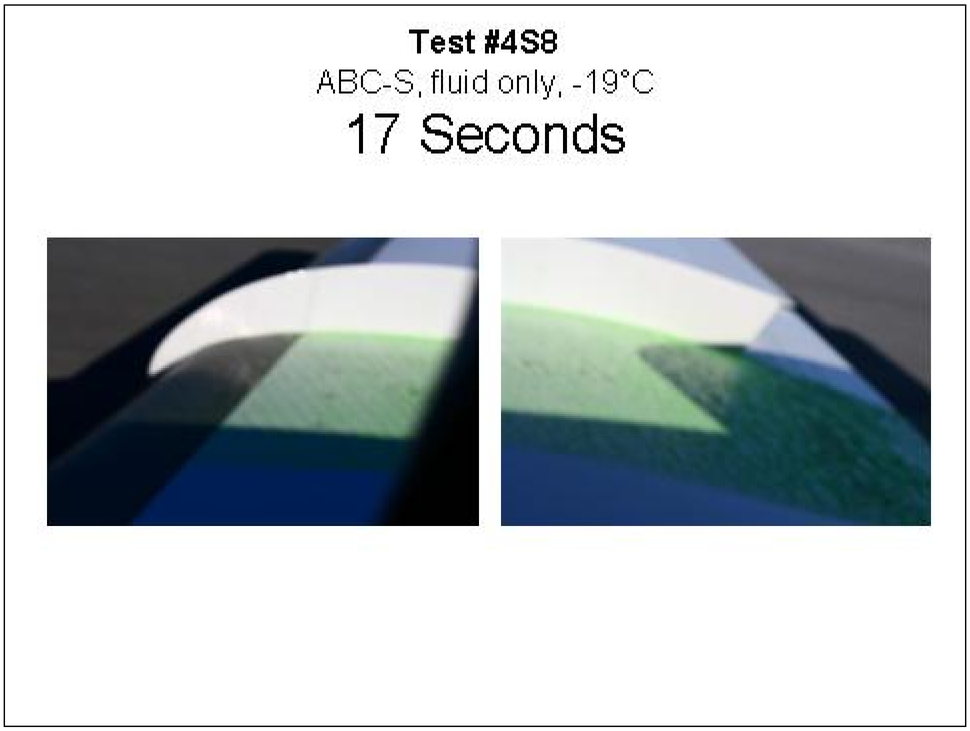


Photo 8.7: Test #4S8 – Rotation

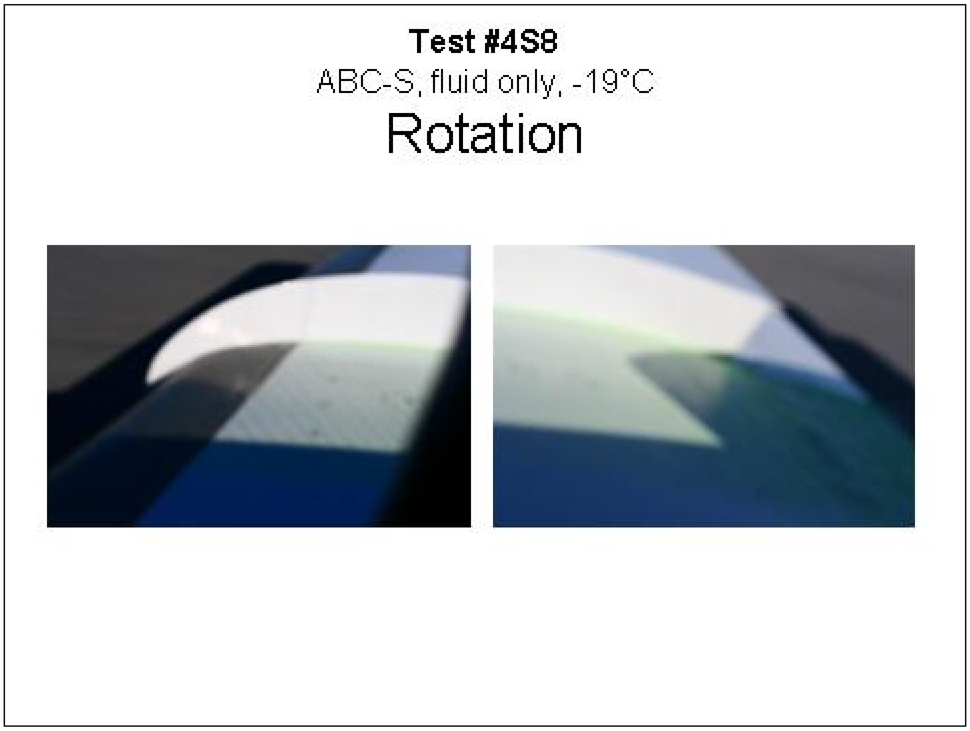


Photo 8.8: Test #4S8 – End of Test

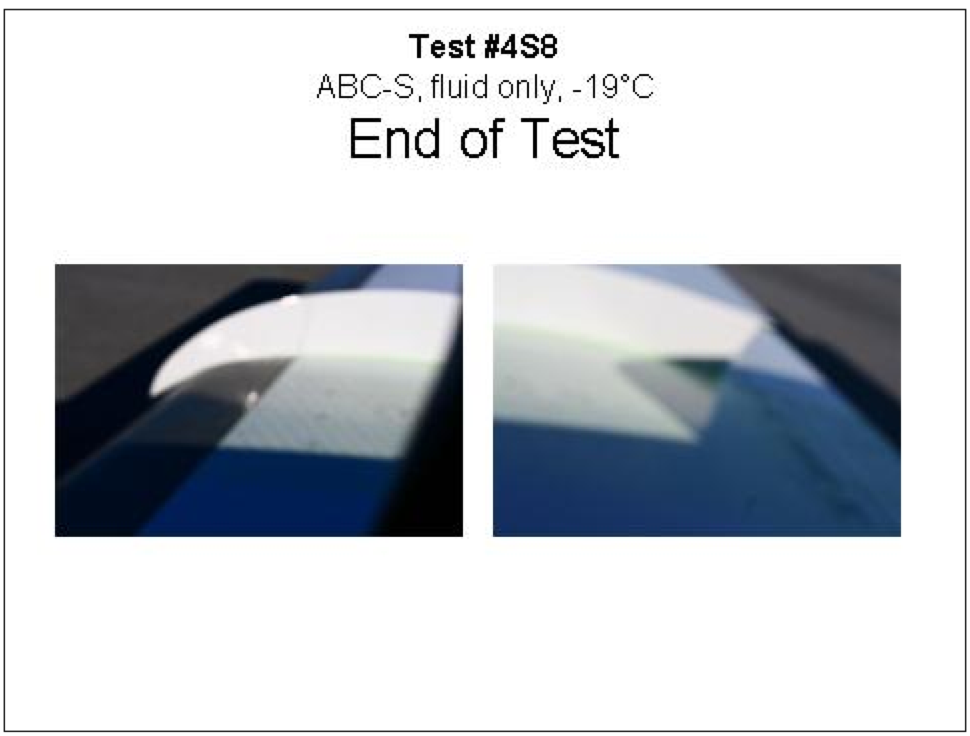


Photo 8.9: Test #5P8 – Start of Test

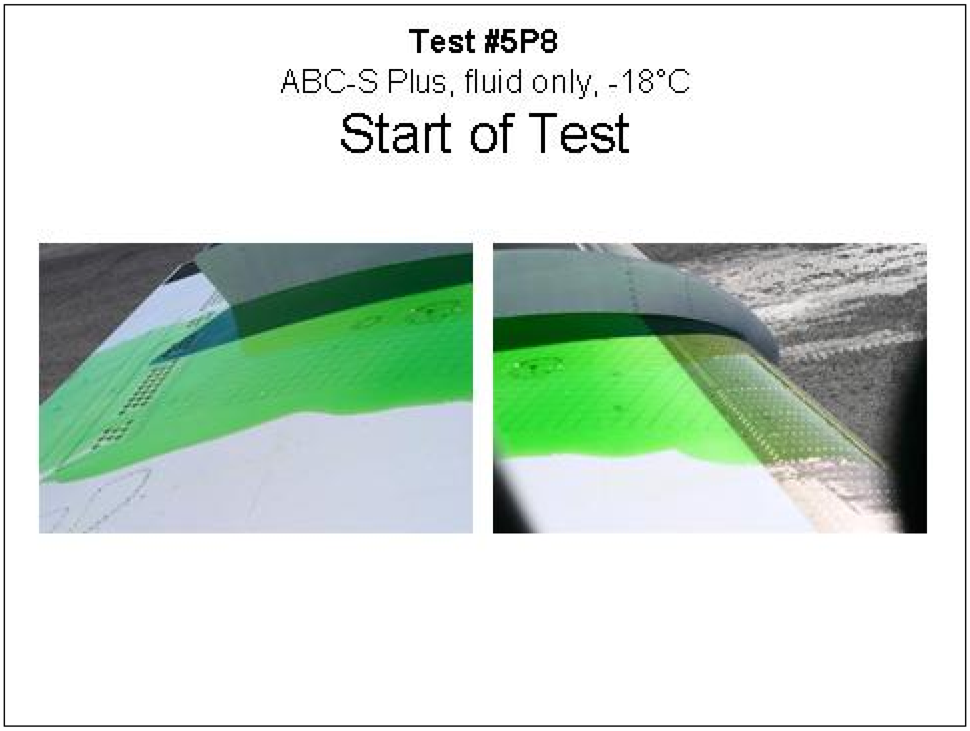


Photo 8.10: Test #5P8 – 17 Seconds

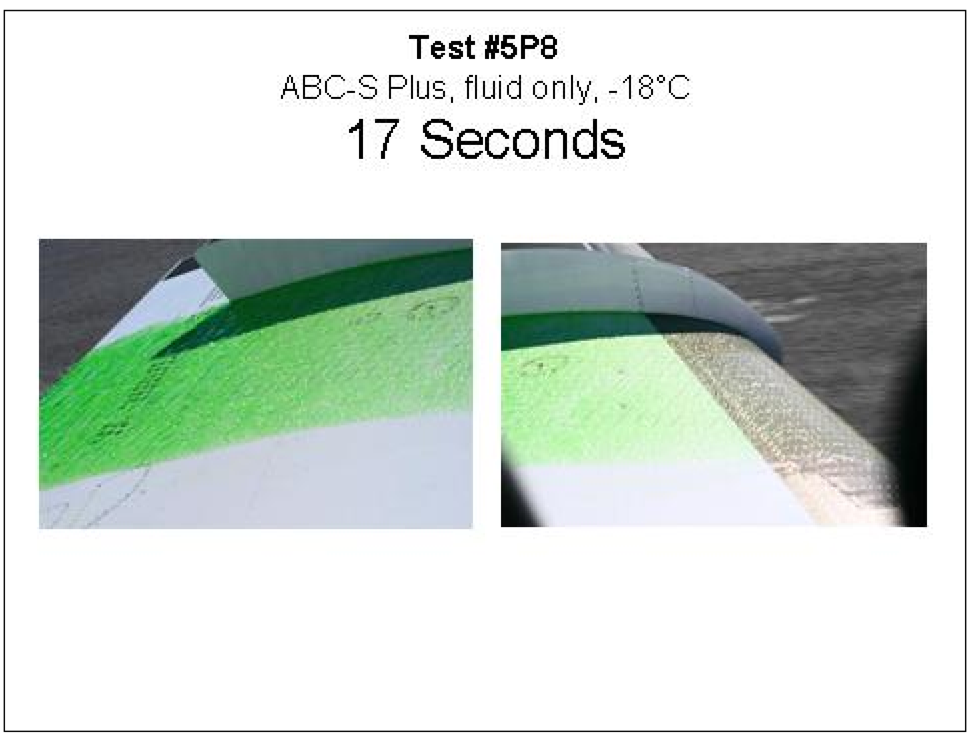


Photo 8.11: Test #5P8 – Rotation

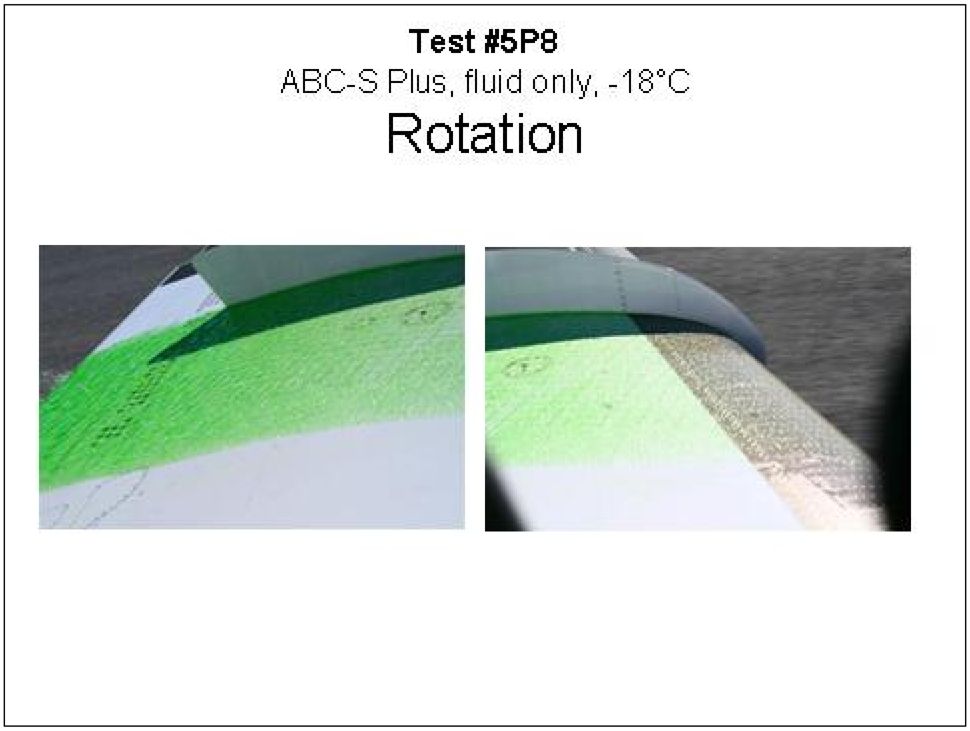


Photo 8.12: Test #5P8 – End of Test

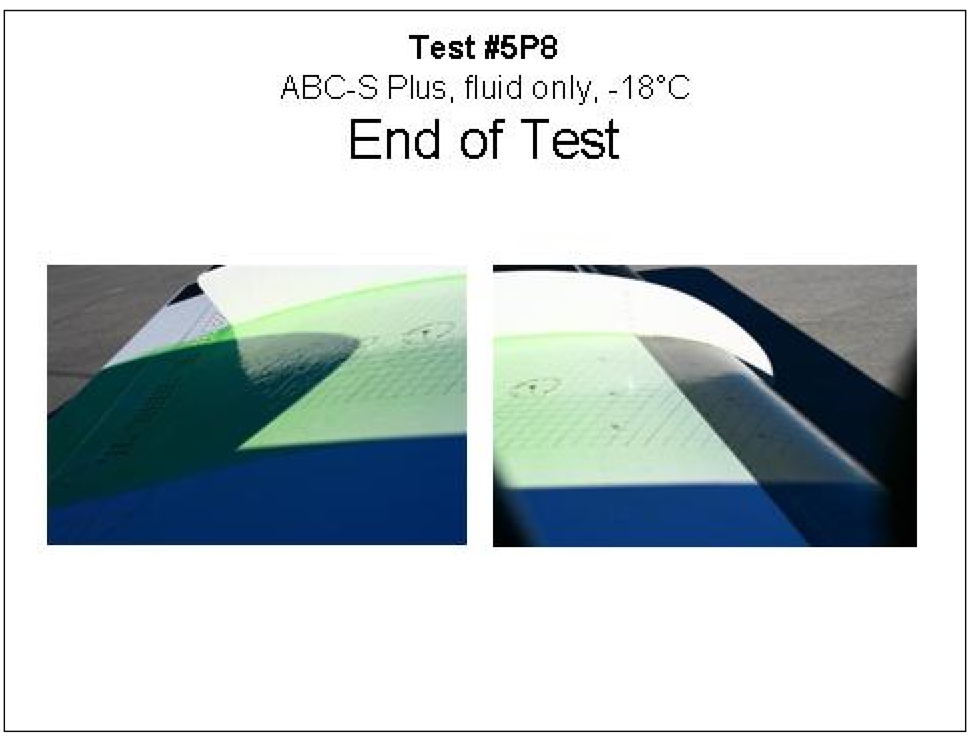


Photo 8.13: Test #5S8 – Start of Test

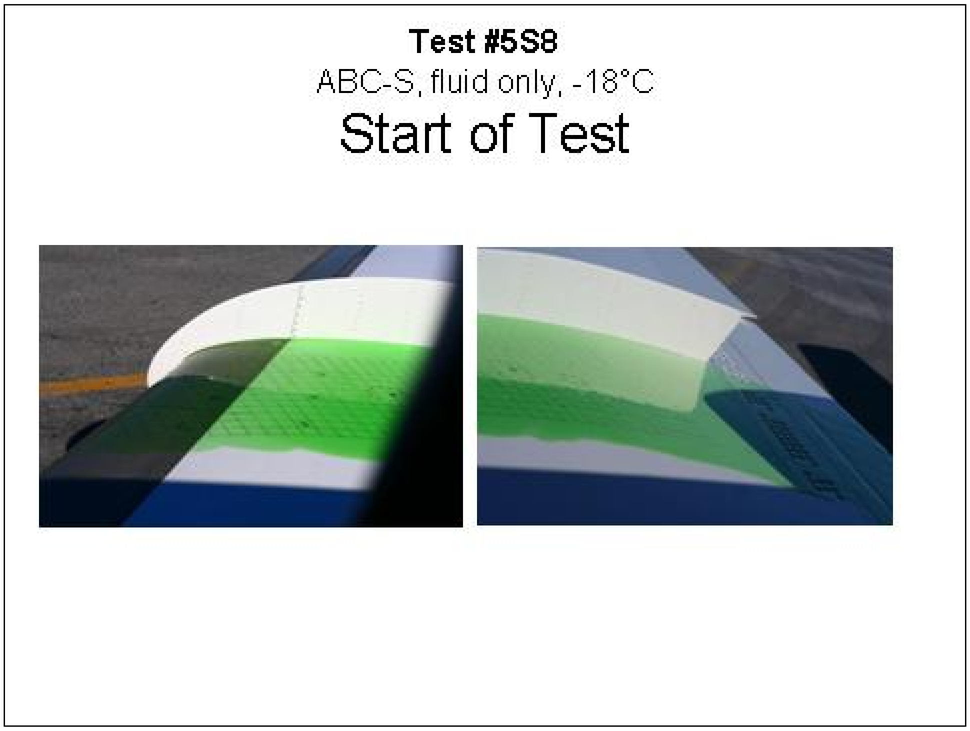


Photo 8.14: Test #5S8 – 17 Seconds

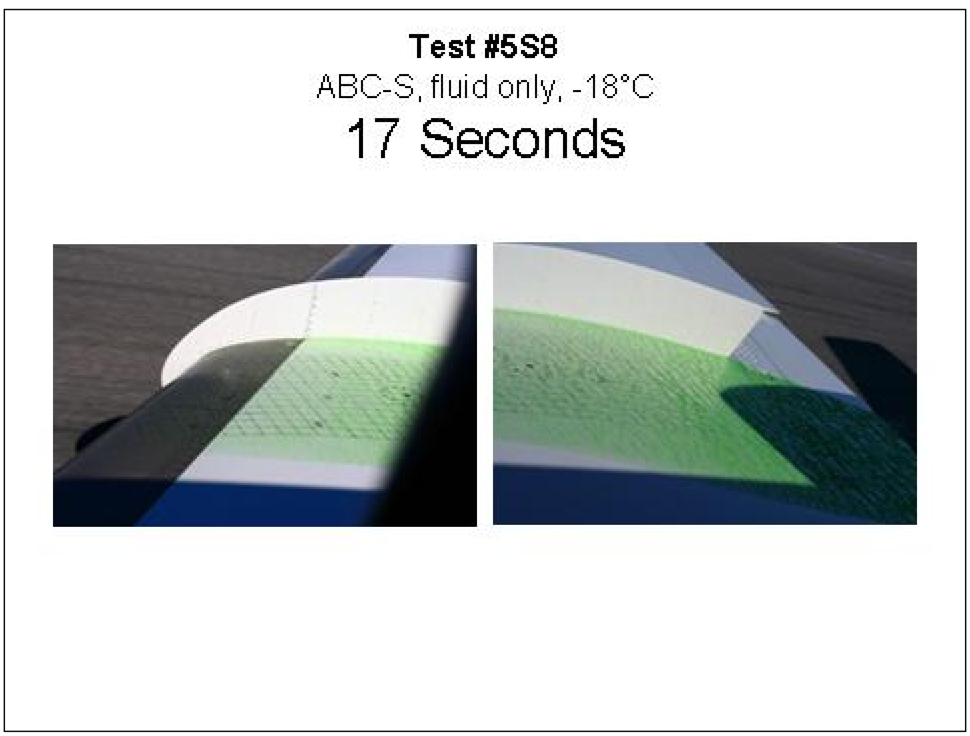


Photo 8.15: Test #5S8 – Rotation

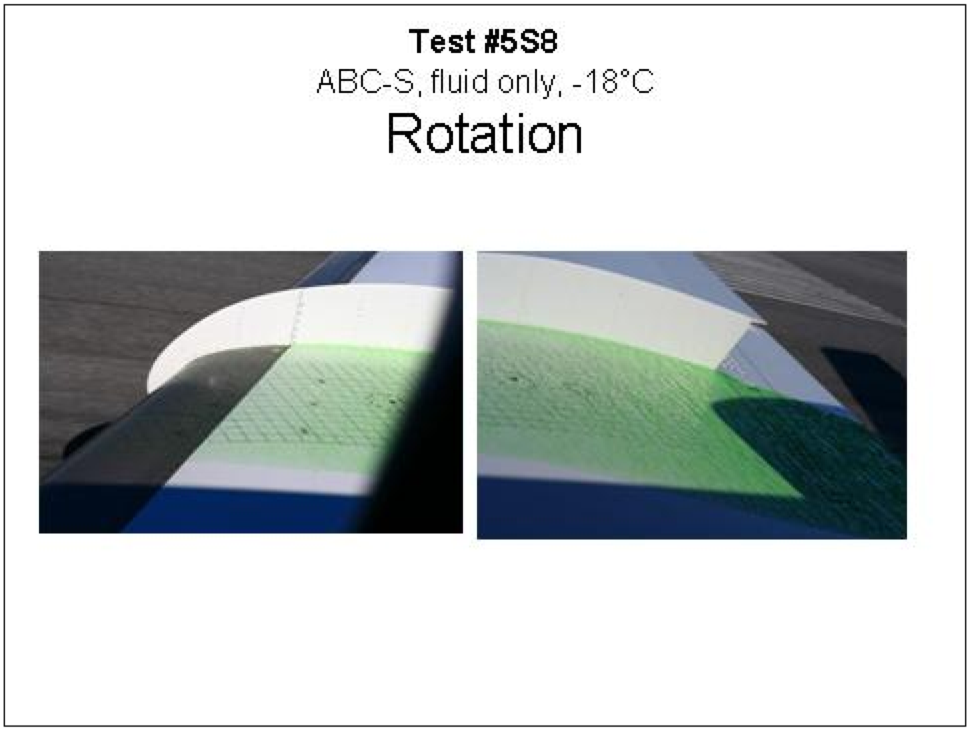


Photo 8.16: Test #5S8 – End of Test

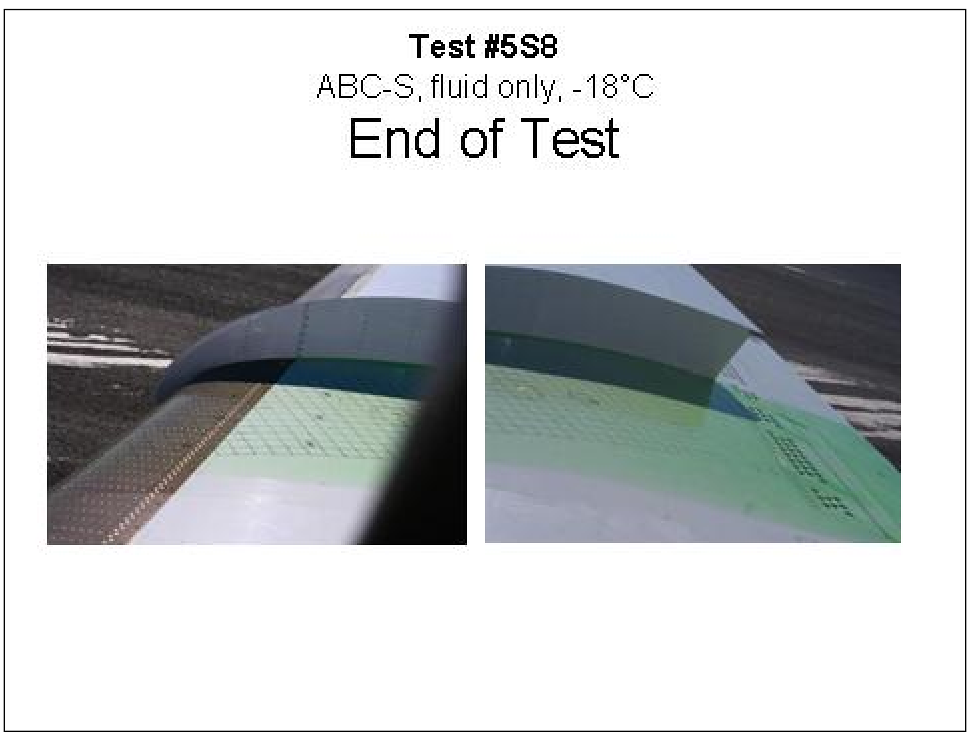


Photo 8.17: Test #6P8 – Start of Test

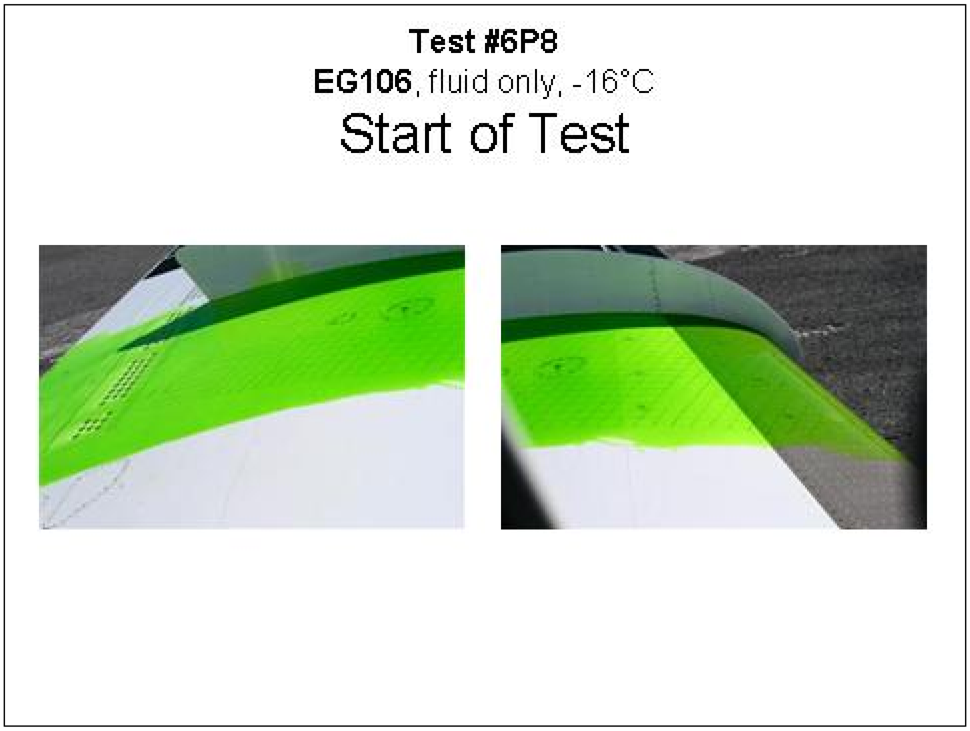


Photo 8.18: Test #6P8 – 17 Seconds

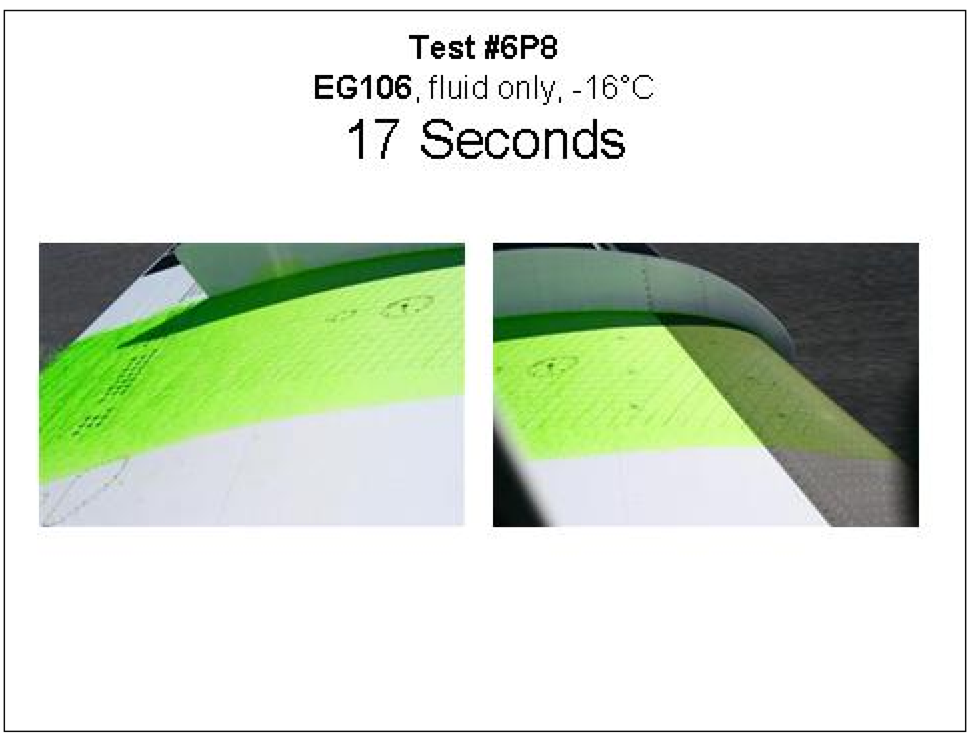


Photo 8.19: Test #6P8 – Rotation

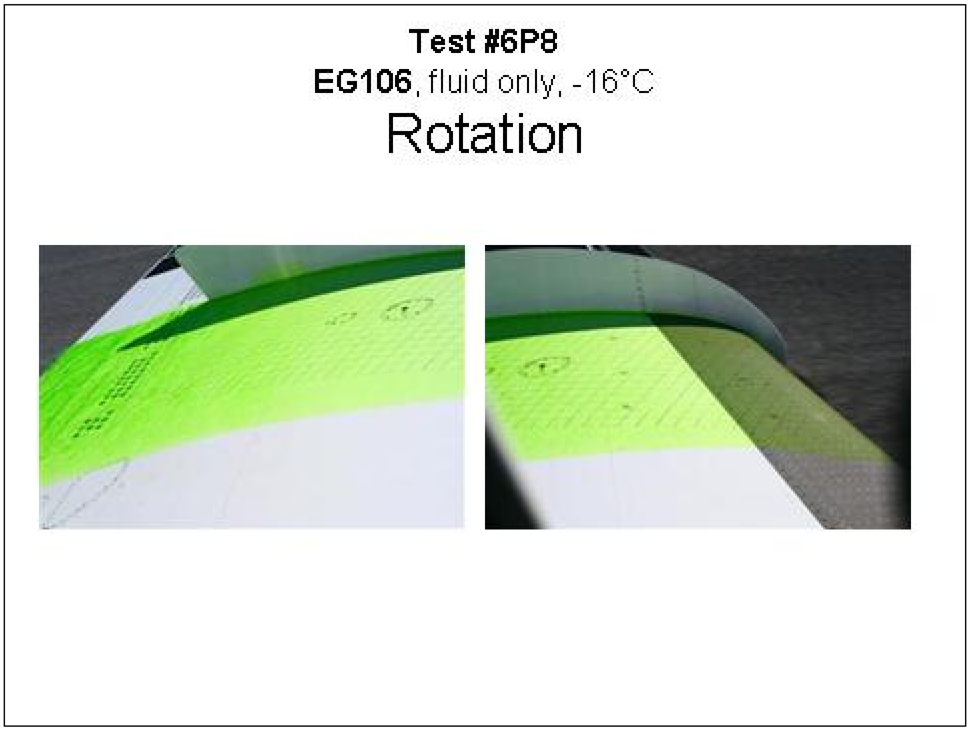


Photo 8.20: Test #6P8 – End of Test

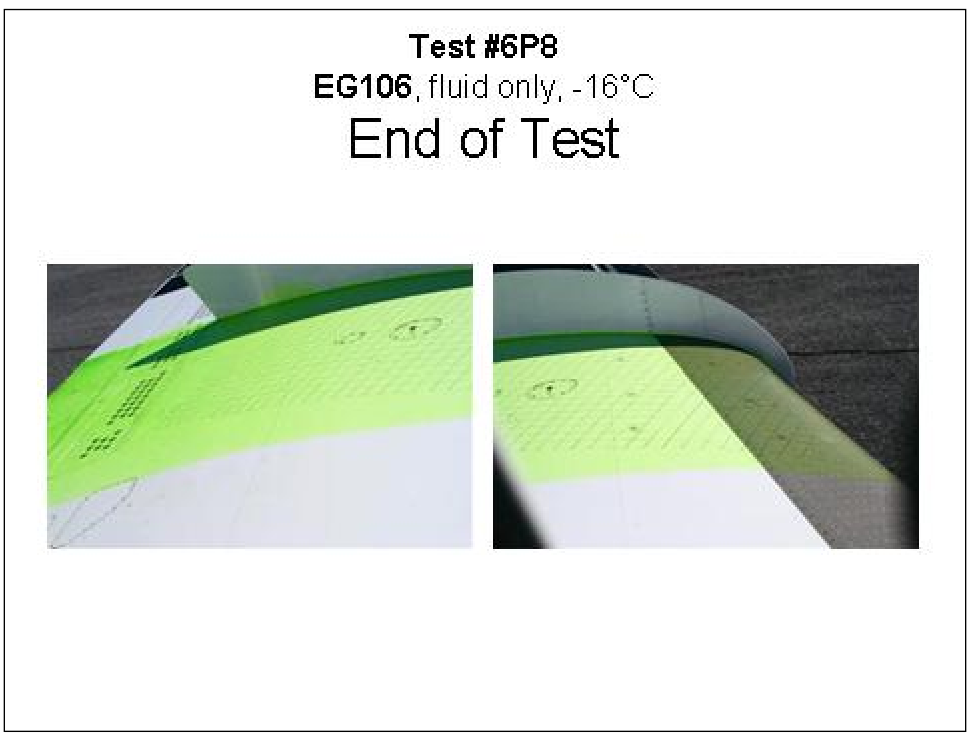


Photo 8.21: Test #6S8 – Start of Test

Photo 8.22: Test #6S8 – 17 Seconds

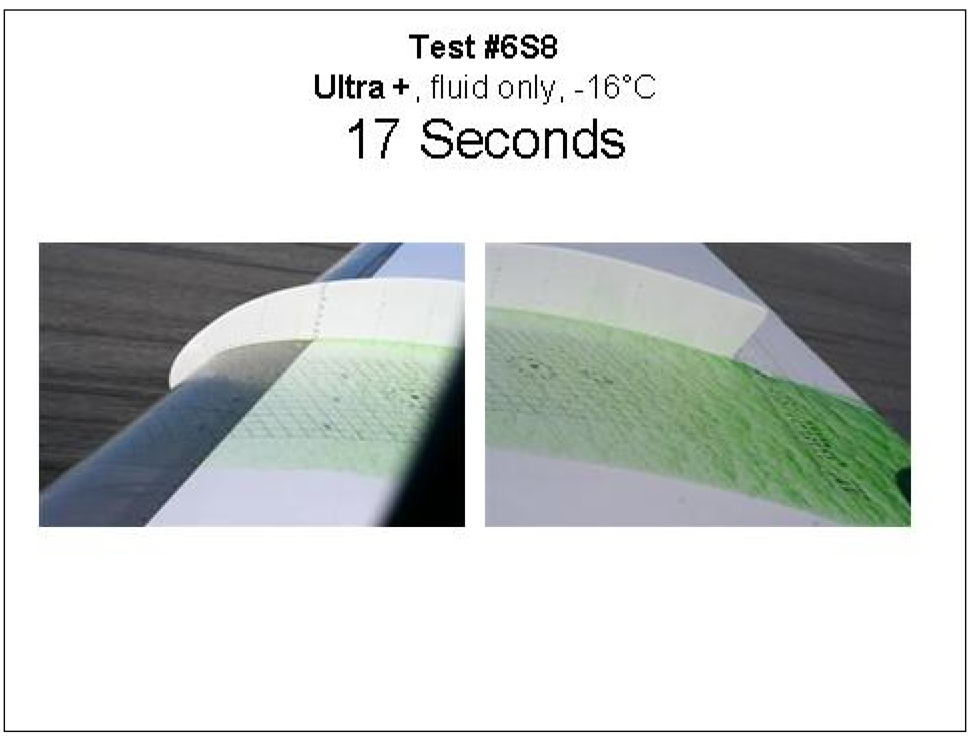


Photo 8.23: Test #6S8 – Rotation

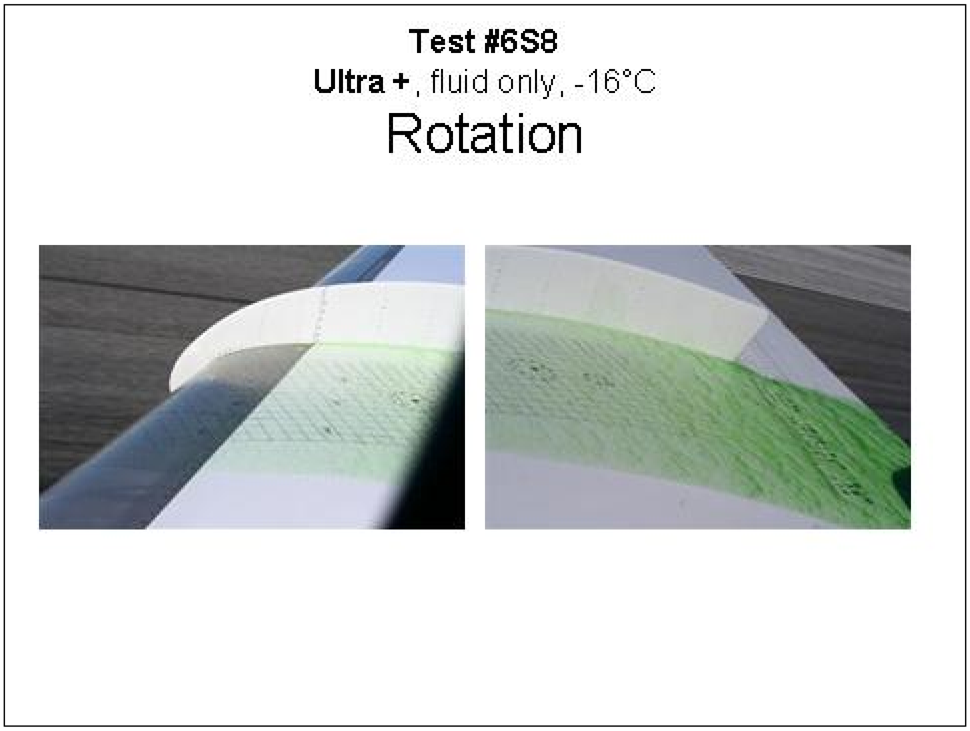


Photo 8.24: Test #6S8 – End of Test

Photo 8.25: Test #8P8 – Start of Test

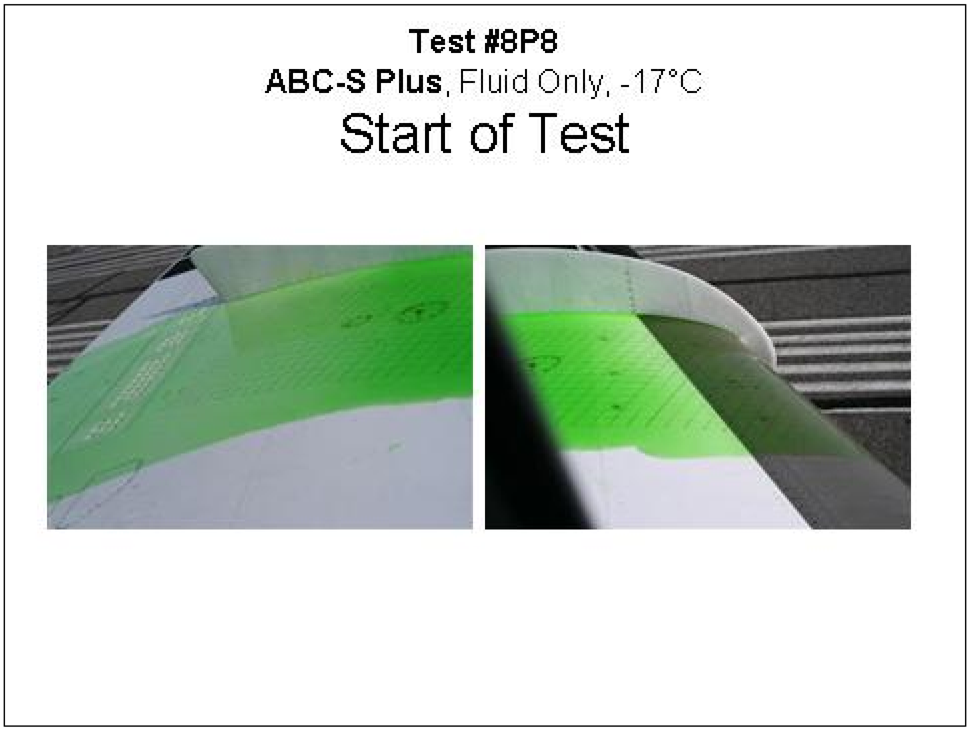


Photo 8.26: Test #8P8 – 17 Seconds

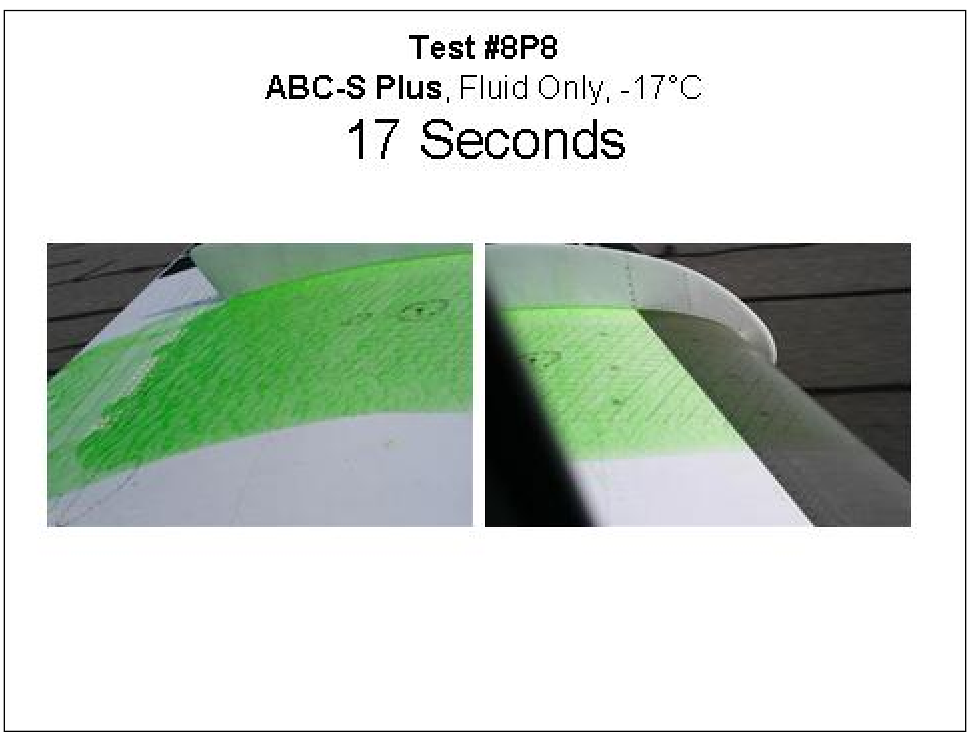


Photo 8.27: Test #8P8 – Rotation

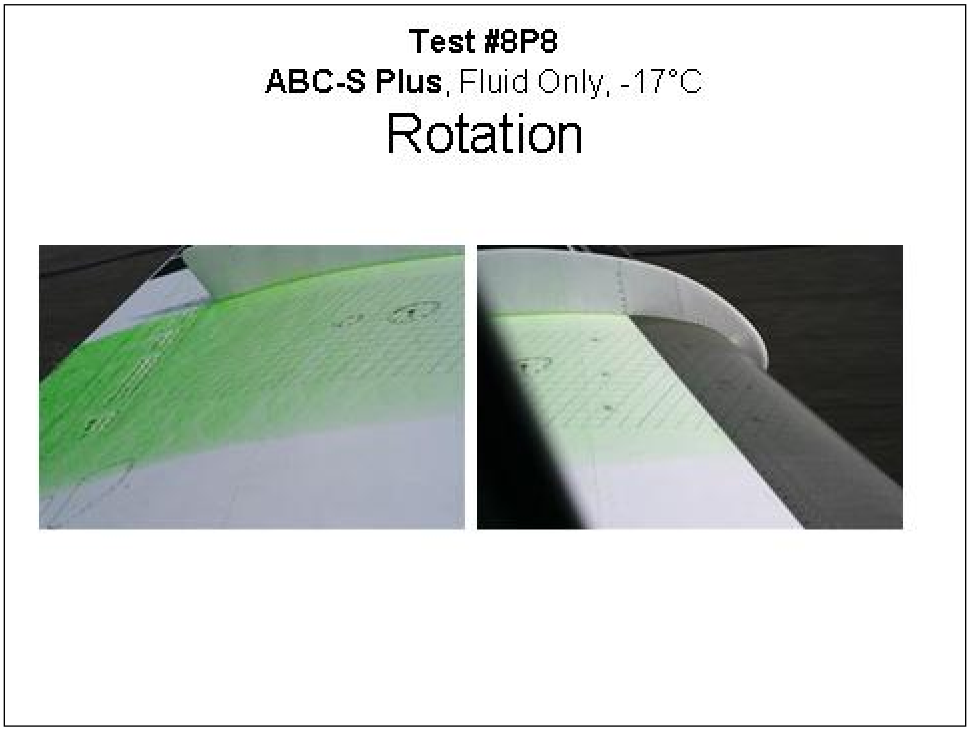


Photo 8.28: Test #8P8 – End of Test

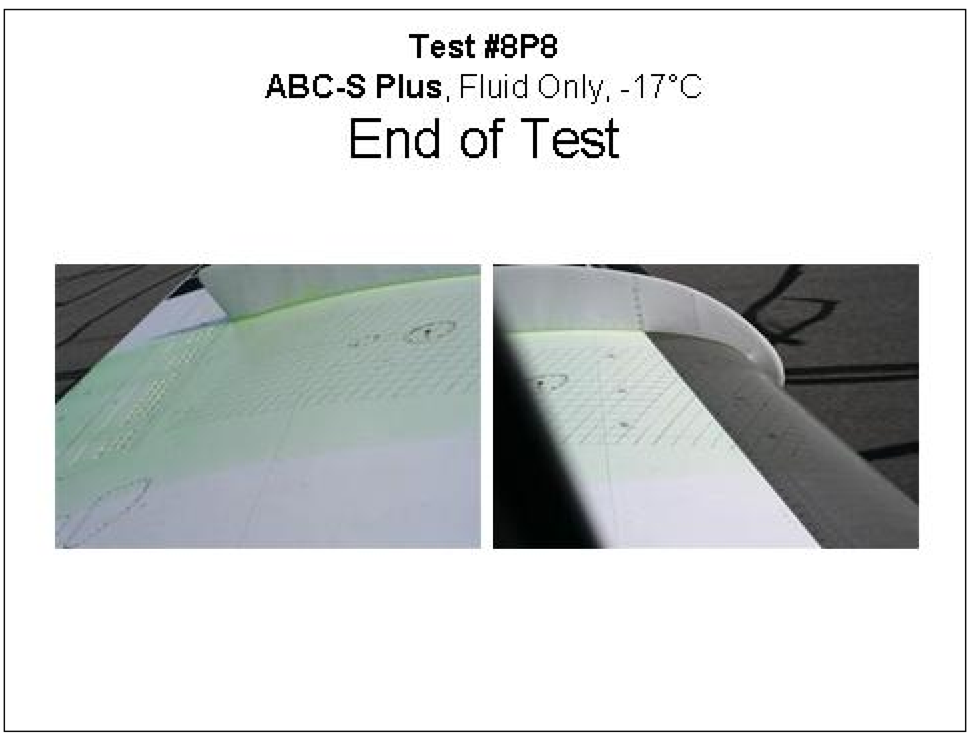


Photo 8.29: Test #8S8 – Start of Test

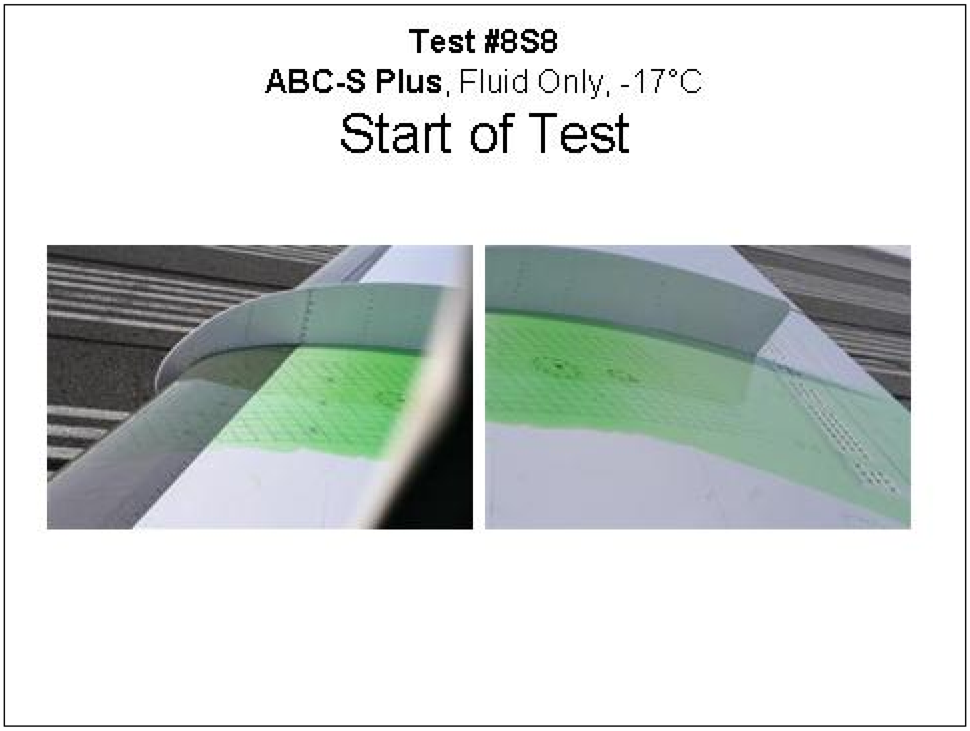


Photo 8.30: Test #8S8 – 17 Seconds

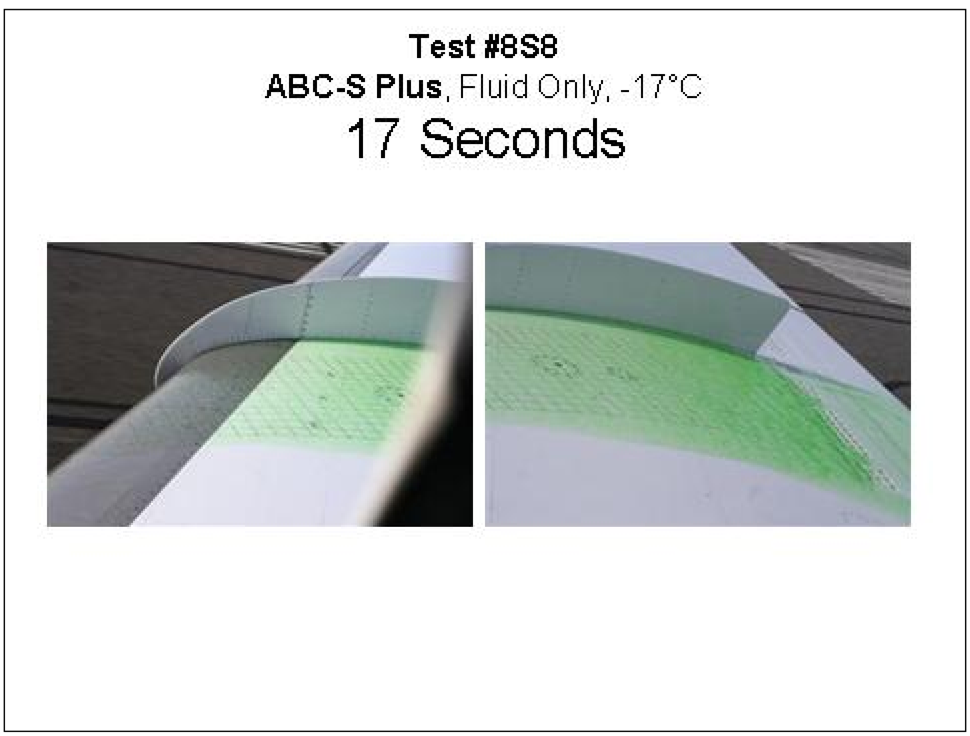


Photo 8.31: Test #8S8 – Rotation

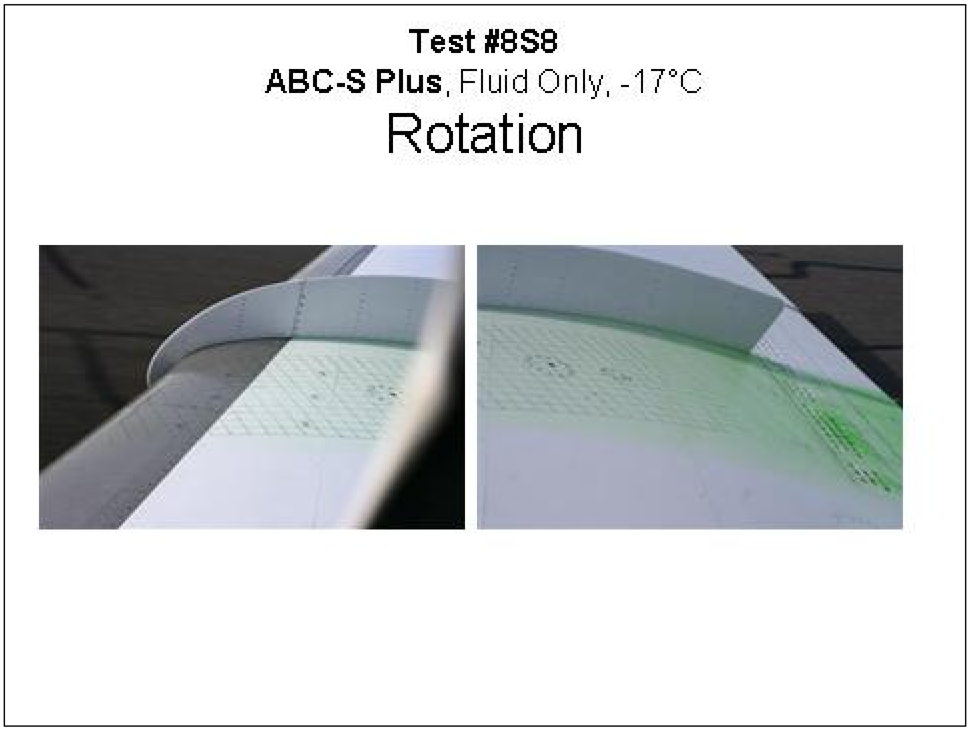
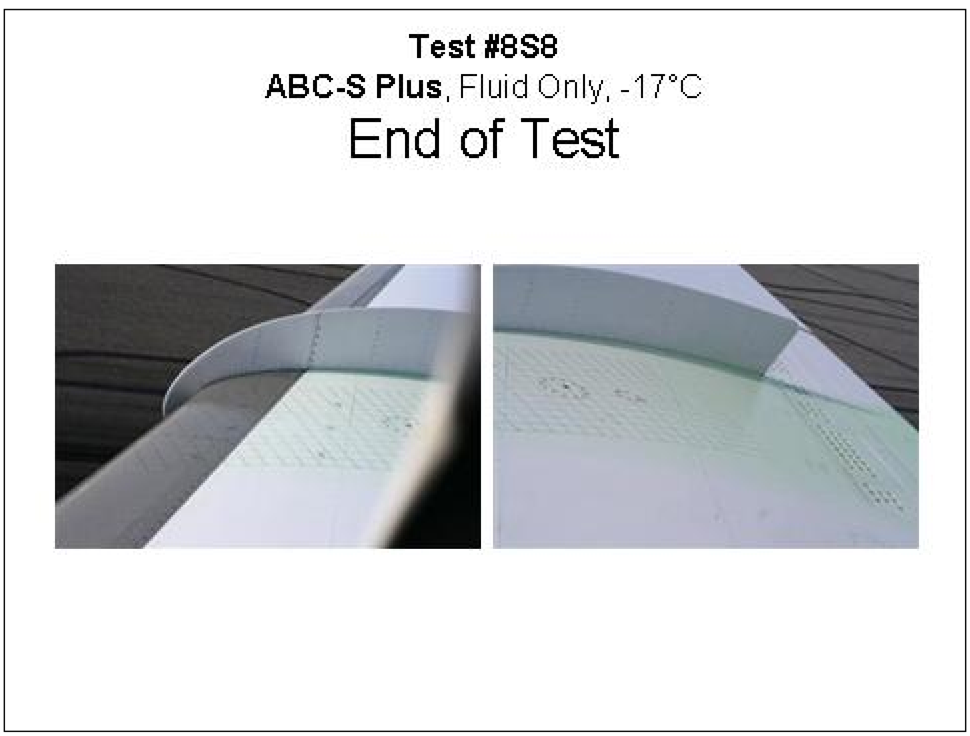


Photo 8.32: Test #8S8 – End of Test



9. EFFECT OF ROTATION

The testing conducted during the winter of 2007-08 was geared towards investigating the possibility of expanding the current ice pellet allowance times for low rotation speed aircraft. Although the NRC T-33 low-speed rotation aircraft was available for testing, the aircraft could only hold two crew members and provided little flexibility for photography. It was therefore decided to simulate the majority of the low-speed takeoff runs using the Falcon 20 aircraft, a high-speed rotation aircraft. Although the pilots were able to simulate the acceleration profile of a low-speed aircraft, aircraft rotation with the Falcon 20 at low speeds (80 knots) was not possible. Due to the extensive low-speed testing conducted with the Falcon 20 aircraft during the winter of 2007-08, the effects of aircraft rotation on fluid flow-off needed to be investigated to validate the takeoff profile simulated with the Falcon 20 aircraft and to provide a link to previous high-speed data, which includes aircraft rotation.

This section provides an overview of each test conducted as part of the test program to evaluate the effect of aircraft rotation on the flow-off behaviour of anti-icing fluid. Testing was conducted in non-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 baseline tests conducted using the Falcon 20 aircraft and T-33 aircraft is shown in Table 9.1. The table provides relevant information for each of the tests, as well as final values used for the data analysis. Each row contains data specific to one test. A more detailed test log of all conditions tested using the Falcon 20 and T-33 aircraft is provided in Subsection 4.1. The following is a brief description of the column headings for Table 9.1:

Run #: Exclusive number identifying each run.

Aircraft: Aircraft used for the test.

Date: Date when the test was conducted.

Fluid: Aircraft deicing fluid specified by product name.

Condition: Simulated precipitation condition.

IP Rate (g/dm²/h): Average simulated ice pellet precipitation rate, measured in g/dm²/h.

SN Rate (g/dm²/h): Average simulated snow precipitation rate, measured in g/dm²/h.

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

OAT at Start of Test (°C): The outside air temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.

Avg. Wing Temp.: Average wing skin temperature.

After Fluid Appl. (°C): Wing temperature following fluid application, measured in degrees Celsius.

Takeoff Profile: Description of the takeoff acceleration and velocity of the aircraft during the test run.

Comments: General comments regarding the objective of the test.

Table 9.1: Summary of 2007-08 Effect of Rotation Testing with Falcon 20 and T-33 Aircraft

Run No.	Aircraft	Date	Fluid	Condition	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Precip. Time (min.)	OAT at Start of Test (°C)	AVG Wing Temp. After Fluid Appl. (°C)	Takeoff Profile	Comments
3P	Falcon 20	28-Feb-07	ABC-S	Baseline	N/A	N/A	N/A	-8	-10.5	~120 knots in 25 sec	Rotation
4S	Falcon 20	28-Feb-07	ABC-S	Baseline	N/A	N/A	N/A	-10	-6	~120 knots in 25 sec	Rotation
4S8	Falcon 20	28-Feb-08	ABC-S	Baseline	N/A	N/A	N/A	-19	-11.1	104 knots in 31 sec	No Rotation
17P8	T-33	07-Mar-08	EG106	Baseline	N/A	N/A	N/A	0	8.5	92 knots in 29 sec	Rotation
17S8	T-33	07-Mar-08	ABC-S Plus	Baseline	N/A	N/A	N/A	0	7	92 knots in 29 sec	Rotation
18P8	T-33	07-Mar-08	EG106	Baseline	N/A	N/A	N/A	1	6.7	85 knots in 20 sec	No Rotation
18S8	T-33	07-Mar-08	ABC-S Plus	Baseline	N/A	N/A	N/A	1	6.5	85 knots in 20 sec	No Rotation

9.2 Data Collected

9.2.1 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the Falcon 20 and T-33 tests are described in Subsection 2.1.11.1. Fluid thickness measurements were recorded at the following intervals:

- Falcon 20 and T-33 Tests:
  - Approximately 5 minutes after fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

Tables 9.2 to 9.8 show the fluid thickness measurements collected during the tests.

Table 9.2: Test #3P (2006-07) Fluid Thickness Data

TEST 3P: ABC-S, fluid only, OAT -8°C				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	1.1	N/A	N/A	0.1
2	1.7	N/A	N/A	0.2
5	3.5	N/A	N/A	0.2
7	2.2	N/A	N/A	0.2
8	1.6	N/A	N/A	0.2

Table 9.3: Test #4S (2006-07) Fluid Thickness Data

TEST 4S: ABC-S, fluid only, OAT 10°C				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	0.5	N/A	N/A	0.0
2	1.7	N/A	N/A	0.0
5	3.3	N/A	N/A	0.2
7	1.5	N/A	N/A	0.3
8	0.7	N/A	N/A	0.2

Table 9.4: Test #4S8 Fluid Thickness Data

RUN 4S8: ABC-S, fluid only, OAT -19°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	N/A	N/A	0.2
5	3.3	N/A	N/A	0.3
7	1.8	N/A	N/A	0.6
8	1.8	N/A	N/A	0.4

Table 9.5: Test #17P8 (Inboard and Outboard) Fluid Thickness Data

RUN 17P8 Inboard: EG 106, fluid only, OAT 0°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.2
5	2.5	N/A	N/A	0.2
5A	2.2	N/A	N/A	0.2
6A	2.2	N/A	N/A	0.3
7	2.2	N/A	N/A	0.3
8	2.2	N/A	N/A	0.6

RUN 17P8 Outboard: EG 106, fluid only, OAT 0°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.2
5	2.2	N/A	N/A	0.2
5A	2.2	N/A	N/A	0.2
6A	2.2	N/A	N/A	0.2
7	1.8	N/A	N/A	0.4
8	1.8	N/A	N/A	0.5

Table 9.6: Test #17S8 (Inboard and Outboard) Fluid Thickness Data

RUN 17S8 Inboard: ABC-S+, fluid only, OAT 0ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	N/A	N/A	0.2
5	2.9	N/A	N/A	0.3
5A	4.5	N/A	N/A	0.3
6A	1.8	N/A	N/A	0.3
7	0.7	N/A	N/A	0.5
8	1.4	N/A	N/A	0.5

RUN 17S8 Outboard: ABC-S+, fluid only, OAT 0ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	N/A	N/A	0.2
5	3.3	N/A	N/A	0.3
5A	4.5	N/A	N/A	0.3
6A	1.8	N/A	N/A	0.2
7	1.4	N/A	N/A	0.6
8	1.4	N/A	N/A	0.5

Table 9.7: Test #18P8 (Inboard and Outboard) Fluid Thickness Data

RUN 18P8 Inboard: EG 106, fluid only, OAT +1ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.2
5	3.3	N/A	N/A	0.3
5A	3.1	N/A	N/A	0.3
6A	2.7	N/A	N/A	0.3
7	2.2	N/A	N/A	0.4
8	2.2	N/A	N/A	0.4

RUN 18P8 Outboard: EG 106, fluid only, OAT +1ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.2
5	2.9	N/A	N/A	0.3
5A	2.7	N/A	N/A	0.2
6A	2.5	N/A	N/A	0.3
7	2.2	N/A	N/A	0.4
8	2.2	N/A	N/A	0.4

Table 9.8: Test #18S8 (Inboard and Outboard) Fluid Thickness Data

RUN 18S8 Inboard: ABC-S+, fluid only, OAT +1°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	N/A	N/A	0.3
5	3.1	N/A	N/A	0.2
5A	5.7	N/A	N/A	0.2
6A	2.2	N/A	N/A	0.3
7	1.8	N/A	N/A	0.5
8	1.8	N/A	N/A	0.5

RUN 18S8 Outboard: ABC-S+, fluid only, OAT +1°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	N/A	N/A	0.2
5	3.1	N/A	N/A	0.3
5A	4.5	N/A	N/A	0.2
6A	1.8	N/A	N/A	0.3
7	1.8	N/A	N/A	0.6
8	1.8	N/A	N/A	0.5

9.2.2 Skin Temperature Data

Skin temperature 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 Subsection 2.1.11.3. Skin temperature measurements were recorded at the following intervals:

- Falcon 20 and T-33 Tests:
  - Before fluid application;
  - After fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

The wing temperature measurements recorded during each test are shown in Tables 9.9 to 9.15.

Table 9.9: Test #3P (2006-07) Wing Skin Temperature Data

TEST 3P: ABC-S, fluid only, OAT -8°C				
Wing Position	WING TEMPERATURE (°C)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
T1	-9.6	N/A	N/A	-9.8
T2	-9.5	N/A	N/A	-9.8
T3	-8.6	N/A	N/A	-10.1
T4	-9.0	N/A	N/A	-10.3
T5	-7.8	N/A	N/A	-9.6
T6	-7.8	N/A	N/A	-9.2
T7	-9.0	N/A	N/A	-8.7
T8	-9.1	N/A	N/A	-9.2

Table 9.10: Test #4S (2006-07) Wing Skin Temperature Data

TEST 4S: ABC-S, fluid only, OAT -10°C				
Wing Position	WING TEMPERATURE (°C)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
T1	-8.3	N/A	N/A	5.5
T2	-8.3	N/A	N/A	4.8
T3	-7.3	N/A	N/A	1.8
T4	-7.0	N/A	N/A	0.5
T5	-6.6	N/A	N/A	-4.0
T6	-6.1	N/A	N/A	-3.8
T7	-3.3	N/A	N/A	-5.9
T8	-3.2	N/A	N/A	-5.7

Table 9.11: Test #4S8 Wing Skin Temperature Data

RUN 4S8: ABC-S, fluid only, OAT -19°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-16.1	-14.6	N/A	N/A	-13.9
T2	-15.9	-15.1	N/A	N/A	-13.9
T3	-11.1	-9.6	N/A	N/A	-9.5
T4	-12.0	-9.6	N/A	N/A	-9.1
T5	-11.2	-8.5	N/A	N/A	-9.3
T6	-11.4	-8.0	N/A	N/A	-8.9
T7	-14.3	-9.9	N/A	N/A	-10.1
T8	-14.9	-13.7	N/A	N/A	-9.8

Table 9.12: Test #17P8 (Inboard and Outboard) Wing Skin Temperature Data

RUN 17P8 Inboard: EG 106, fluid only, OAT 0°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	N/A	N/A	N/A	N/A
T2	8.2	7.2	N/A	N/A	6.3
T3	N/A	N/A	N/A	N/A	N/A
T5	8.6	7.1	N/A	N/A	6.0
T5A	8.9	8.1	N/A	N/A	6.6
T6A	11.0	9.0	N/A	N/A	7.6
T7	11.5	9.3	N/A	N/A	7.7
T8	12.4	9.5	N/A	N/A	7.4

RUN 17P8 Outboard: EG 106, fluid only, OAT 0°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	N/A	N/A	N/A	N/A
T2	7.5	7.2	N/A	N/A	6.3
T3	N/A	N/A	N/A	N/A	N/A
T5	8.8	7.2	N/A	N/A	6.2
T5A	9.9	7.8	N/A	N/A	6.8
T6	11.5	9.5	N/A	N/A	8.2
T7	12.3	9.6	N/A	N/A	7.9
T8	12.3	9.6	N/A	N/A	7.9

Table 9.13: Test #17S8 (Inboard and Outboard) Wing Skin Temperature Data

RUN 17S8 Inboard: ABC-S+, fluid only, OAT 0°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	N/A	N/A	N/A	N/A
T2	7.7	5.8	N/A	N/A	5.6
T3	N/A	N/A	N/A	N/A	N/A
T4	8.1	6.5	N/A	N/A	5.5
T5	11.2	7.0	N/A	N/A	6.1
T6	11.5	7.5	N/A	N/A	7.0
T7	11.7	7.4	N/A	N/A	6.8
T8	12.9	7.6	N/A	N/A	7.2

RUN 17S8 Outboard: ABC-S+, fluid only, OAT 0°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	N/A	N/A	N/A	N/A
T2	7.8	6.2	N/A	N/A	5.7
T3	N/A	N/A	N/A	N/A	N/A
T5	9.5	6.3	N/A	N/A	5.7
T5A	10.7	6.4	N/A	N/A	6.0
T6	12.6	7.8	N/A	N/A	7.3
T7	13.0	7.4	N/A	N/A	7.0
T8	15.4	7.8	N/A	N/A	8.4

Table 9.14: Test #18P8 (Inboard and Outboard) Wing Skin Temperature Data

RUN 18P8 Inboard: EG 106, fluid only, OAT +1°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	N/A	N/A	N/A	N/A
T2	6.3	6.3	N/A	N/A	10.4
T3	N/A	N/A	N/A	N/A	N/A
T5	6.0	6.2	N/A	N/A	8.9
T5A	6.6	6.7	N/A	N/A	9.5
T6A	7.6	6.8	N/A	N/A	9.3
T7	7.7	6.7	N/A	N/A	9.4
T8	7.4	7.0	N/A	N/A	9.3

RUN 18P8 Outboard: EG 106, fluid only, OAT +1°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	N/A	N/A	N/A	N/A
T2	6.3	6.5	N/A	N/A	9.6
T3	N/A	N/A	N/A	N/A	N/A
T5	6.2	6.6	N/A	N/A	9.0
T5A	6.8	6.5	N/A	N/A	9.6
T6	8.2	7.0	N/A	N/A	9.6
T7	7.9	6.8	N/A	N/A	9.6
T8	7.9	6.8	N/A	N/A	9.5

Table 9.15: Test #18S8 (Inboard and Outboard) Wing Skin Temperature Data

RUN 18S8 Inboard: ABC-S+, fluid only, OAT +1ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	N/A	N/A	N/A	N/A
T2	5.6	6.1	N/A	N/A	9.1
T3	N/A	N/A	N/A	N/A	N/A
T4	5.5	6.0	N/A	N/A	7.9
T5	6.1	5.9	N/A	N/A	8.3
T6	7.0	6.8	N/A	N/A	9.3
T7	6.8	6.4	N/A	N/A	8.9
T8	7.2	6.7	N/A	N/A	9.2

RUN 18S8 Outboard: ABC-S+, fluid only, OAT +1ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	N/A	N/A	N/A	N/A
T2	7.8	6.2	N/A	N/A	5.7
T3	N/A	N/A	N/A	N/A	N/A
T5	9.5	6.3	N/A	N/A	5.7
T5A	10.7	6.4	N/A	N/A	6.0
T6	12.6	7.8	N/A	N/A	7.3
T7	13.0	7.4	N/A	N/A	7.0
T8	15.4	7.8	N/A	N/A	8.4

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

Subsection 2.1.11.2. Fluid Brix measurements were recorded at the following intervals:

- Falcon 20 and T-33 Tests:
  - After fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

Tables 9.16 to 9.22 show the fluid Brix measurements collected during the tests.

Table 9.16: Test #3P (2006-07) Fluid Brix Data

TEST 3P: ABC-S, fluid only, OAT -8ºC				
Wing Position	Fluid Brix (º)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
2	37.00	N/A	N/A	38.50
5	37.00	N/A	N/A	34.00

Table 9.17: Test #4S (2006-07) Fluid Brix Data

TEST 4S: ABC-S, fluid only, OAT -10ºC				
Wing Position	Fluid Brix (º)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
2	37.00	N/A	N/A	N/A
5	37.00	N/A	N/A	N/A

Table 9.18: Test #4S8 Fluid Brix Data

RUN 4S8: ABC-S, fluid only, OAT -19ºC				
Wing Position	FLUID BRIX (º)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37.5	N/A	N/A	39
B8	37.5	N/A	N/A	37.5

Table 9.19: Test #17P8 (Inboard and Outboard) Fluid Brix Data

RUN 17P8 Inboard: EG 106, fluid only, OAT 0°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	N/A	N/A	N/A	34.5
B8	N/A	N/A	N/A	34.5

RUN 17P8 Outboard: EG 106, fluid only, OAT 0°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	N/A	N/A	N/A	N/A
B8	N/A	N/A	N/A	N/A

Table 9.20: Test #17S8 (Inboard and Outboard) Fluid Brix Data

RUN 17S8 Inboard: ABC-S+, fluid only, OAT 0°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	N/A	N/A	N/A	37.25
B8	N/A	N/A	N/A	37

RUN 17S8 Outboard: ABC-S+, fluid only, OAT 0°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	N/A	N/A	N/A	N/A
B8	N/A	N/A	N/A	N/A

Table 9.21: Test #18P8 (Inboard and Outboard) Fluid Brix Data

RUN 18P8 Inboard: EG 106, fluid only, OAT +1°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	33.23	N/A	N/A	35
B8	33	N/A	N/A	33.5

RUN 18P8 Outboard: EG 106, fluid only, OAT +1°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	N/A	N/A	N/A	N/A
B8	N/A	N/A	N/A	N/A

Table 9.22: Test #18S8 (Inboard and Outboard) Fluid Brix Data

RUN 18S8 Inboard: ABC-S+, fluid only, OAT +1°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	36.5	N/A	N/A	38
B8	36.5	N/A	N/A	37.25

RUN 18S8 Outboard: ABC-S+, fluid only, OAT +1°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	N/A	N/A	N/A	N/A
B8	N/A	N/A	N/A	N/A

9.3 Photos

High-speed digital photographs of each test were taken; photos were taken of the leading edge, the trailing edge, or both. For each test, photo summaries have been compiled comprising four stages:

- Start of test;
- 17 seconds after start of test;
- Time of rotation; and
- End of test.

Photos 9.1 to 9.28 show the photo summaries for Tests #3P, #4S, #4S8, #17P8, #17S8, #18P8, and #18S8. During the tests where photos were not taken, a note has been included indicating "No Photo Documentation Available." A complete set of photos will be provided to the TDC.

9.4 General Observations

9.4.1 Falcon 20 General Observations

A comparison of the residual fluid thickness at the end of the Falcon 20 test runs has been compiled and is demonstrated in Table 9.23. The residual fluid thickness measured following the test run with rotation was compared to the residual fluid thickness measured following the test without rotation. The shaded cells indicate measurements where the fluid thickness following the test run without rotation was less in comparison to the test run with rotation.

During the high-speed test runs, the residual fluid on the trailing edge of the wing section following the no-rotation test run was double compared to the data collected from two tests conducted during the winter of 2006-07 with rotation. Fluid elimination on the trailing edge of the wing section seemed to improve with rotation. However, the discrepancy could have been due to the acceleration profile of the no-rotation run; the aircraft did not achieve the target 120 knots.

Table 9.23: Comparison of Falcon 20 Residual Fluid Thicknesses

Wing Position	Fluid Thickness after Takeoff Run (mm)		
	Run #3P	Run #4S	Run #4S8
	Rotation	*Rotation*	*No Rotation*
2	0.2	0	0.2
5	0.2	0.2	0.3
7	0.2	0.3	0.6
8	0.2	0.2	0.4

9.4.2 T-33 General Observations

A comparison table of the residual fluid thickness at the end of the T-33 test runs has been compiled and is demonstrated in Table 9.24. The residual fluid thickness measured following the test run with rotation was compared to the residual fluid thickness measured following the test without rotation. The shaded cells indicate measurements where the fluid thickness measured was greater than the respective comparison test run.

The results from the T-33 tests did not demonstrate significant differences in fluid flow-off characteristics following a rotation or no-rotation test run. The results indicated that the residual thickness was slightly higher on the leading edge following the no-rotation test run, but were generally slightly higher on the trailing edge following the test run with rotation. The discrepancies were within 0.2 mm for all of the cases. With the low-speed aircraft, the effects of rotation could not be distinguished visually.

Table 9.24: Comparison of T-33 Residual Fluid Thicknesses

Wing Position	Fluid Thickness After Takeoff Run (mm)							
	Run #17P8	Run #18P8	Run #17P8	Run #18P8	Run #17S8	Run #18P8	Run #17S8	Run #18S8
	Outboard	Outboard	Inboard	Inboard	Outboard	Outboard	Inboard	Inboard
	Rotation	*No Rotation*	*Rotation*	*No Rotation*	*Rotation*	*No Rotation*	*Rotation*	*No Rotation*
2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3
5	0.2	0.3	0.2	0.3	0.3	0.3	0.3	0.2
7	0.4	0.4	0.3	0.4	0.6	0.4	0.5	0.5
8	0.5	0.4	0.6	0.4	0.5	0.4	0.5	0.5

9.4.3 Conclusions Recommendations for Future Work

The results indicated some differences in fluid flow-off properties as a result of the aircraft rotating at the end of the aircraft acceleration profile. The results from the Falcon 20 tests and the T-33 tests were not completely in agreement; however, the general trend pointed towards greater residual fluid following the no-rotation test runs when compared to the tests with rotation. It is recommended that during future aerodynamic testing, the takeoff run profile should include aircraft rotation whenever possible, as this is more operationally representative. In addition, if time and resources are available during future aerodynamic test sessions, it is recommended that additional testing be conducted to further investigate the effects of aircraft rotation of fluid flow-off.

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Photo 9.1: Test #3P – Start of Test

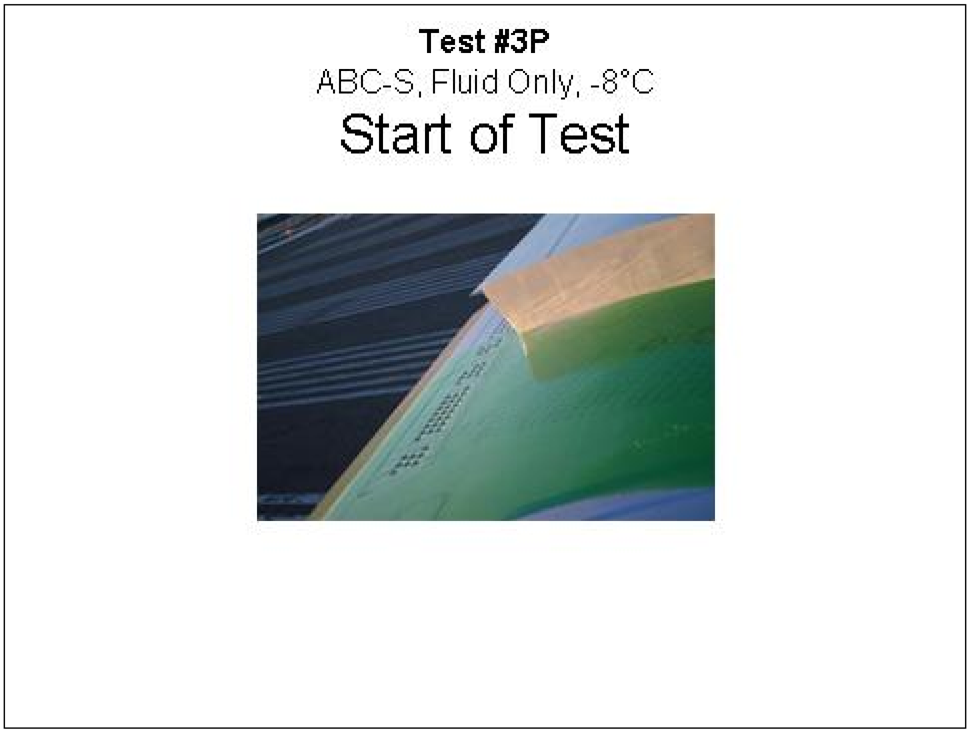


Photo 9.2: Test #3P – 17 seconds

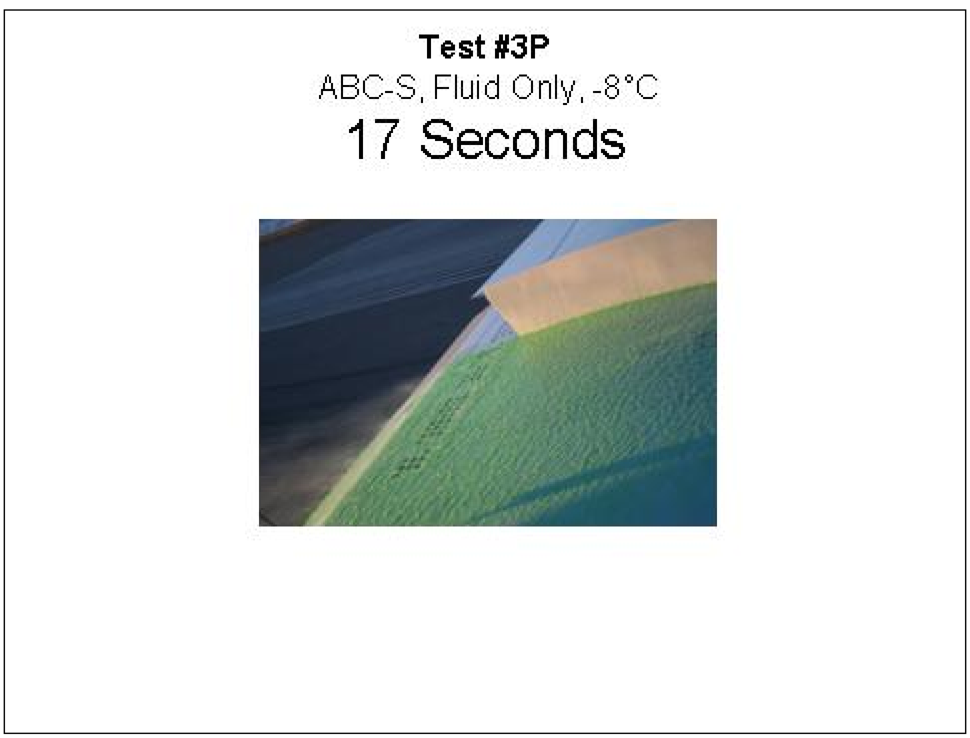


Photo 9.3: Test #3P – Rotation

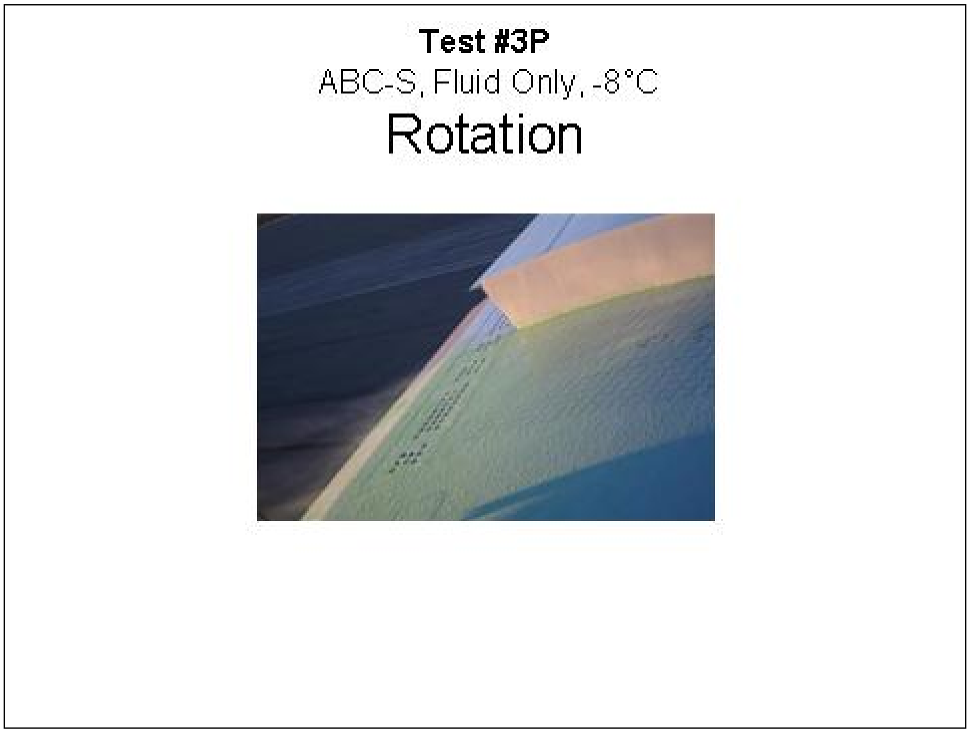


Photo 9.4: Test #3P – End of Test

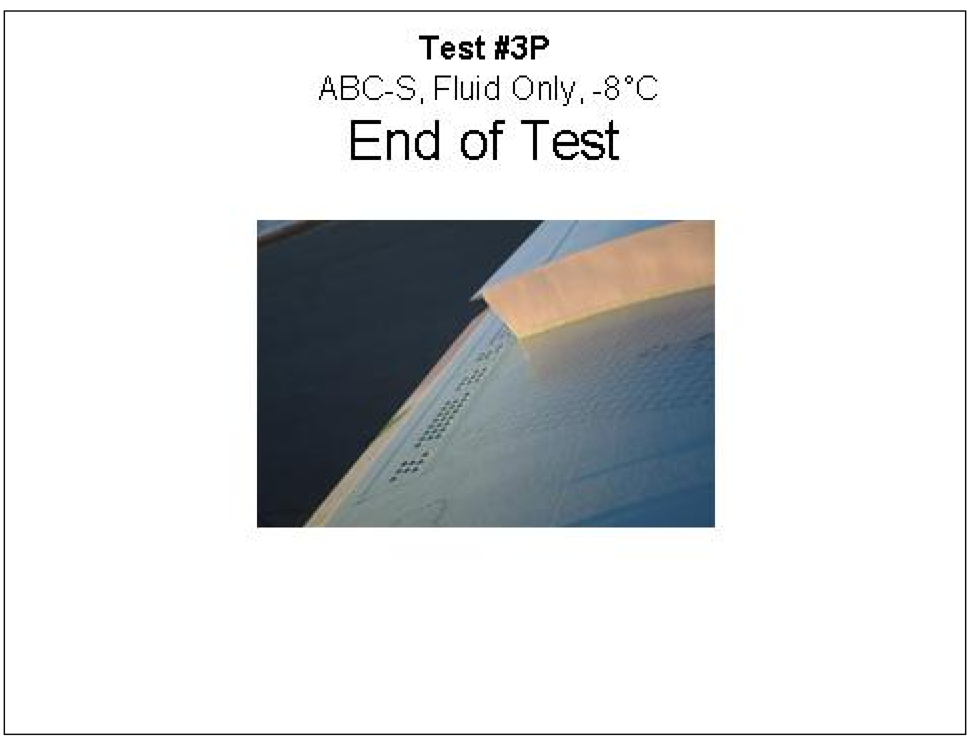


Photo 9.5: Test #4S – Start of Test

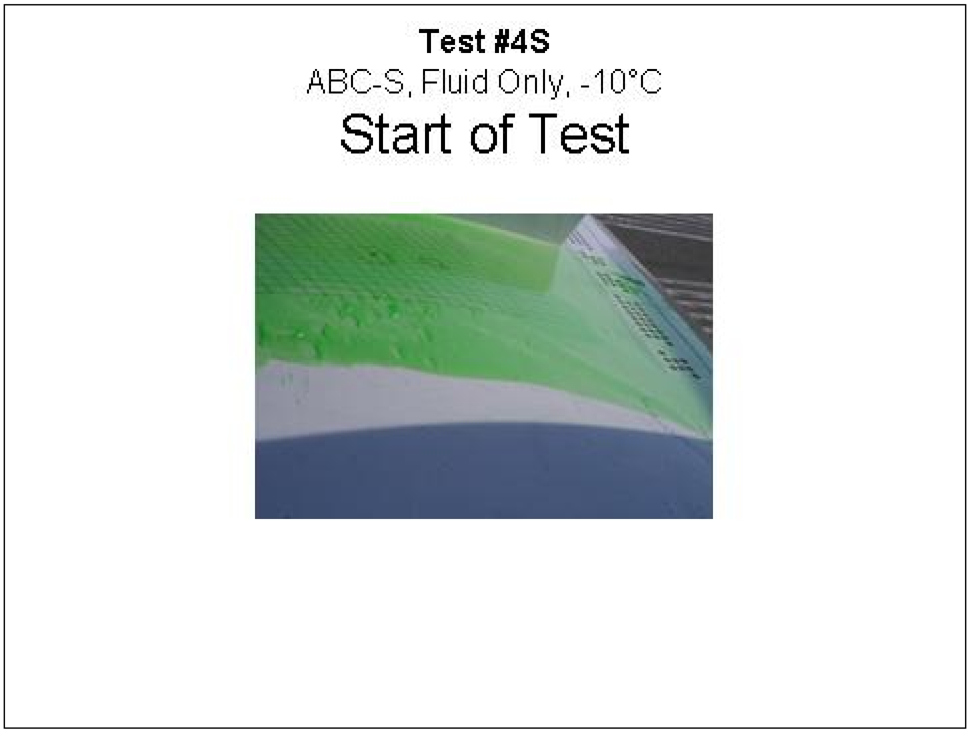


Photo 9.6: Test #4S – 17 seconds

Photo 9.7: Test #4S – Rotation

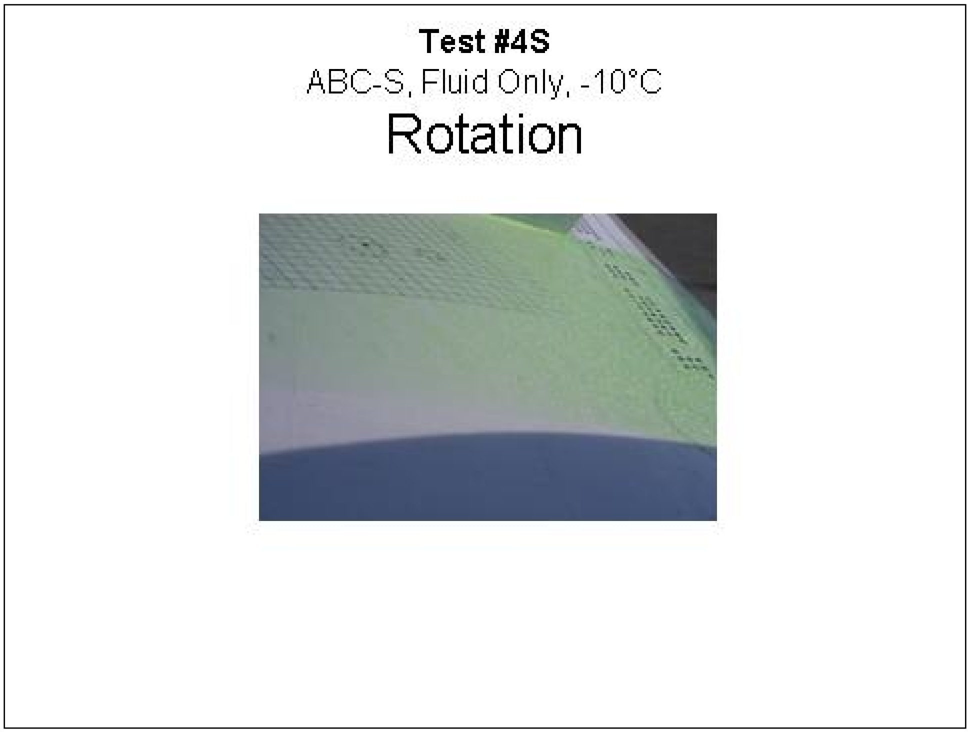


Photo 9.8: Test #4S – End of Test

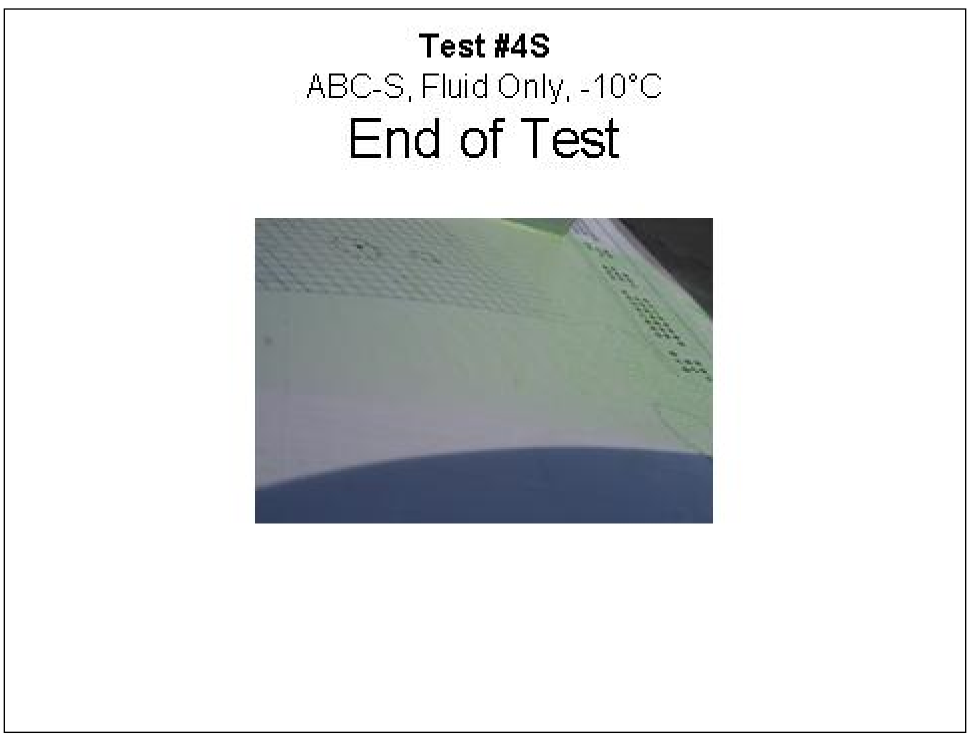


Photo 9.9: Test #4S8 – Start of Test

Photo 9.10: Test #4S8 – 17 Seconds

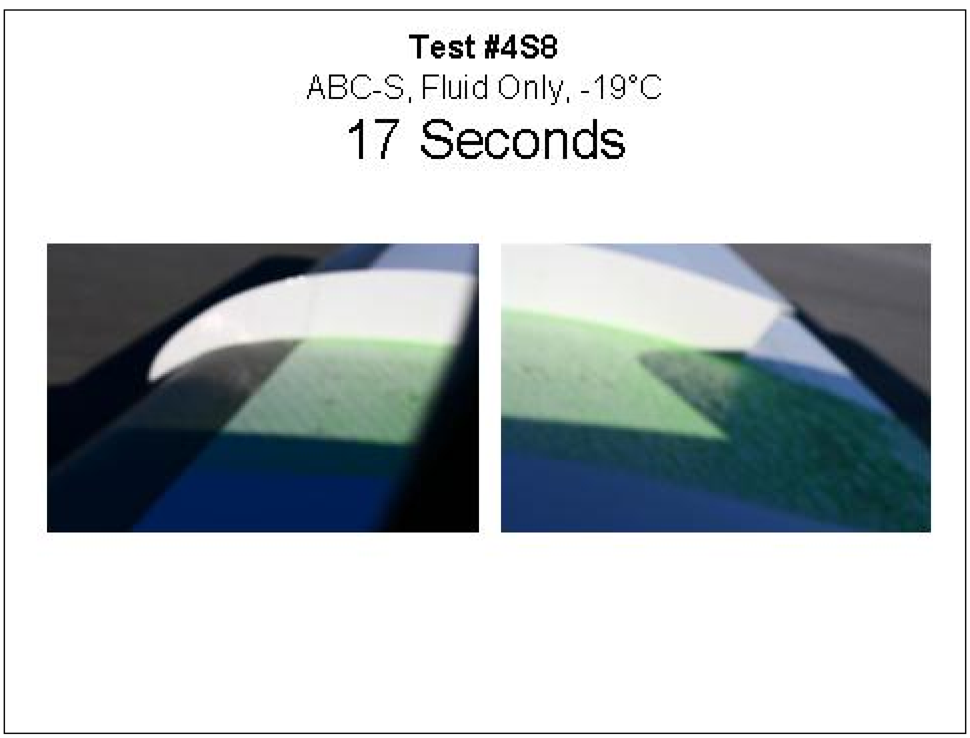


Photo 9.11: Test #4S8 – Rotation

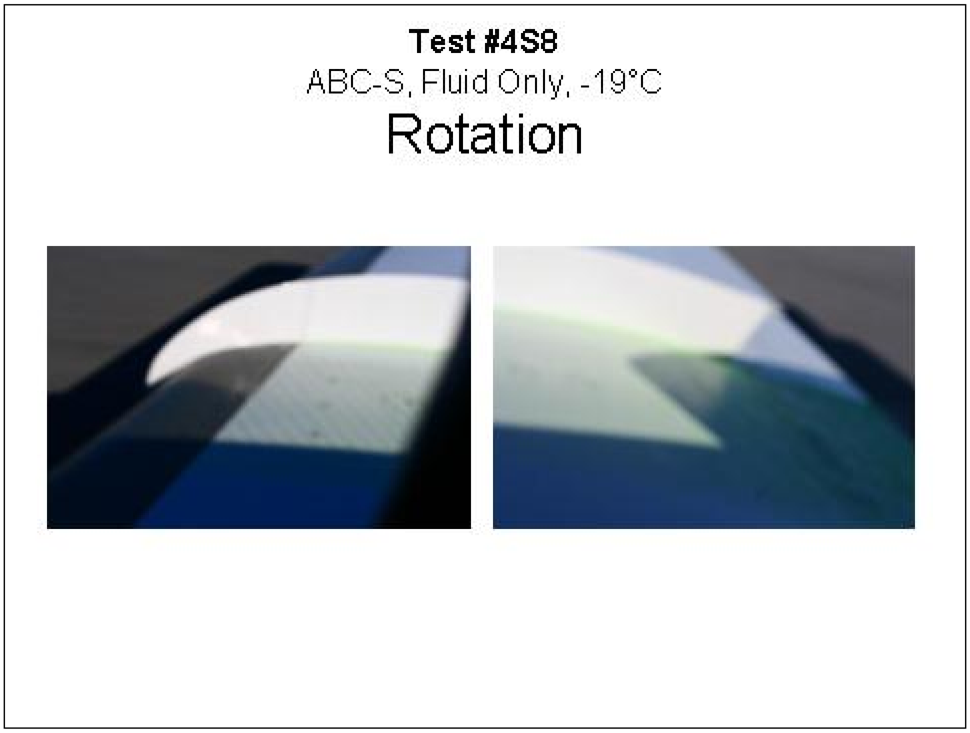


Photo 9.12: Test #4S8 – End of Test

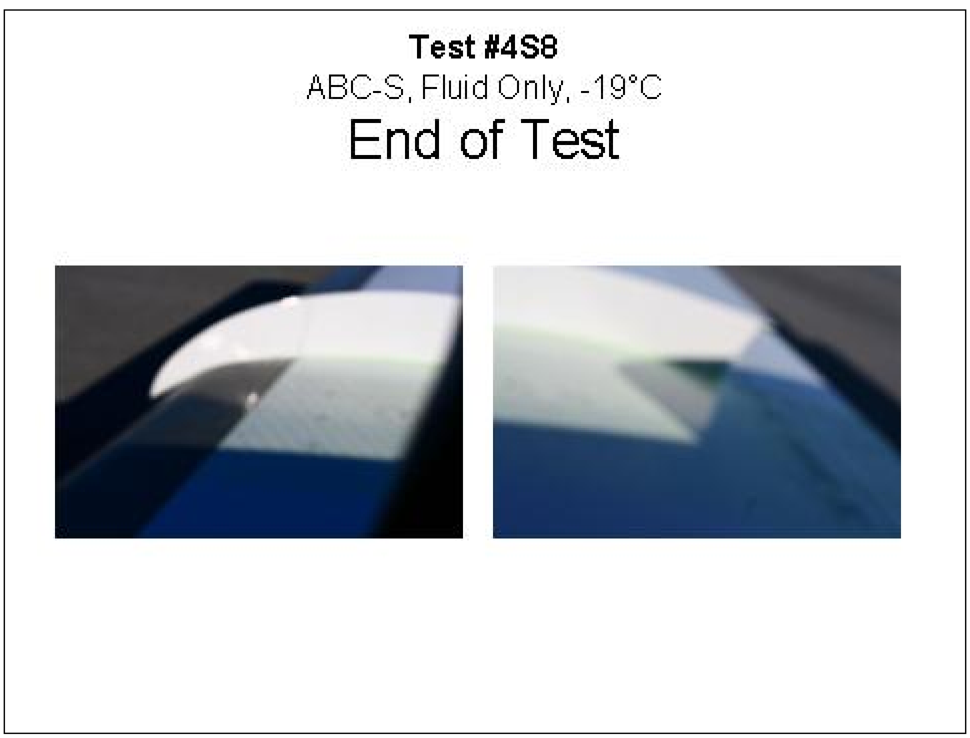


Photo 9.13: Test #17P8 – Start of Test

Photo 9.14: Test #17P8 – 17 Seconds

Photo 9.15: Test #17P8 – Rotation

Photo 9.16: Test #17P8 – End of Test

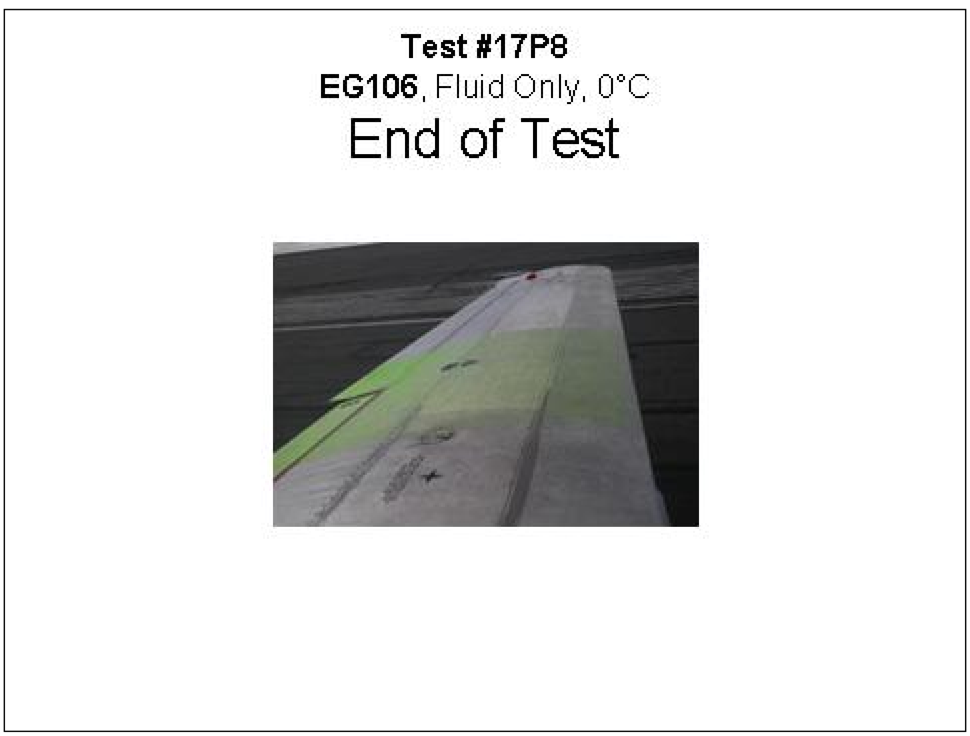


Photo 9.17: Test #17S8 – Start of Test

No Photo Documentation Available

Photo 9.18: Test #17S8 – 17 Seconds

No Photo Documentation Available

Photo 9.19: Test #17S8 – Rotation

No Photo Documentation Available

Photo 9.20: Test #17S8 – End of Test

No Photo Documentation Available

Photo 9.21: Test #18P8 – Start of Test

Photo 9.22: Test #18P8 – 17 Seconds

Photo 9.23: Test #18P8 – Rotation

Photo 9.24: Test #18P8 – End of Test

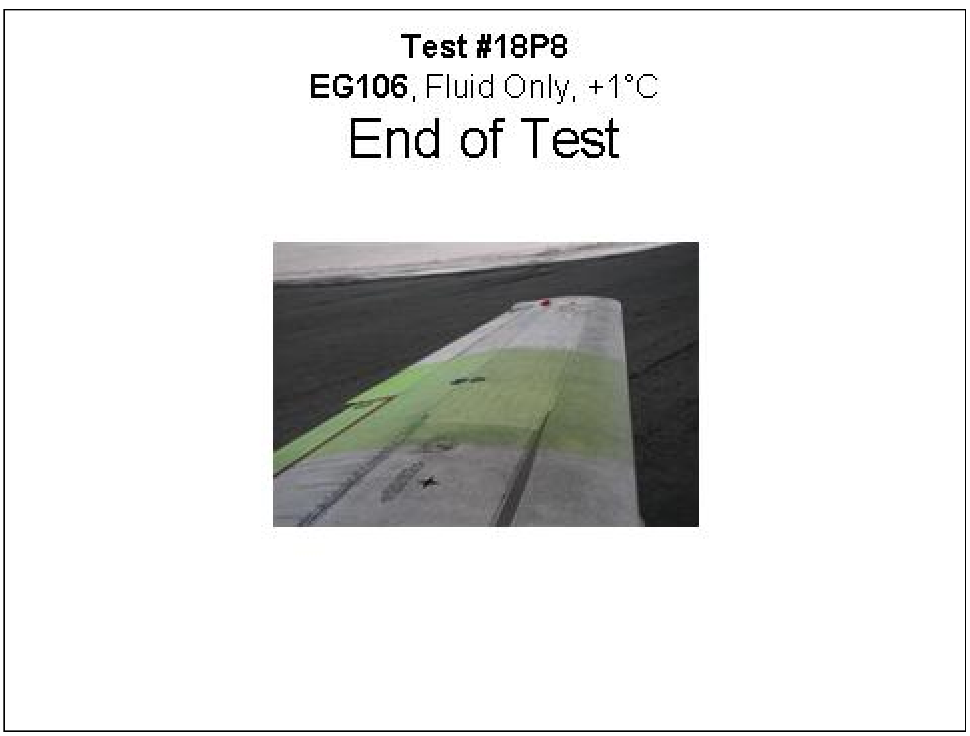


Photo 9.25: Test #18S8 – Start of Test

No Photo Documentation Available

Photo 9.26: Test #18S8 – 17 Seconds

No Photo Documentation Available

Photo 9.27: Test #18S8 – Rotation

No Photo Documentation Available

Photo 9.28: Test #18S8 – End of Test

No Photo Documentation Available

10. TYPE III FLUID

The testing conducted during the winter of 2007-08 was geared towards investigating 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 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. Testing was conducted in both precipitation and non-precipitation conditions.

This section provides an overview of each test conducted as part of the test program to evaluate the flow-off performance of Type III fluid for low rotation speed aircraft. Testing was conducted in non-precipitation conditions. The parameters for each test are detailed, and a description of the data collected during each test is provided.

10.1 Overview of Tests

A summary of the baseline tests conducted using the Falcon 20 aircraft is shown in Table 10.1. The table provides relevant information for each of the tests, as well as final values used for the data analysis. Each row contains data specific to one test. A more detailed test log of all conditions tested using the Falcon 20 aircraft is provided in Subsection 4.1. The following is a brief description of the column headings for Table 10.1:

Run #: Exclusive number identifying each run.

Date: Date when the test was conducted.

Fluid: Aircraft deicing fluid specified by product name.

Condition: Simulated precipitation condition.

IP Rate (g/dm²/h): Average simulated ice pellet precipitation rate, measured in g/dm²/h.

SN Rate (g/dm²/h): Average simulated snow precipitation rate, measured in g/dm²/h.

Precip. Time (min.):	Total time of exposure to simulated precipitation.
OAT at Start of Test (ºC):	The outside air temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.
Avg. Wing Temp.:	Average wing skin temperature.
After Fluid Appl. (ºC):	Wing temperature following fluid application, measured in degrees Celsius.
Takeoff Profile:	Description of the takeoff acceleration and velocity of the aircraft during the test run.
Comments:	General comments regarding the objective of the test.

Table 10.1: Summary of 2007-08 Type III Testing with Falcon 20 Aircraft

Run No.	Date	Fluid	Condition	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Precip. Time (min.)	OAT at Start of Test (°C)	AVG Wing Temp. After Fluid Appl. (°C)	Takeoff Profile	Comments
2P8	27-Feb-08	2031	IP	26	N/A	10	-13	-4.3	74 knots in 19 sec	No Rotation, Retracted Flaps
2S8	27-Feb-08	2031	Baseline	N/A	N/A	N/A	-13	-7.5	74 knots in 19 sec	No Rotation, Retracted Flaps
16P8	6-Mar-08	2031	IP/SN	25	25	20	1	5.1	75 knots in 17 sec	No Rotation, Extended Flaps

10.2 Data Collected

10.2.1 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the Falcon 20 tests are described in Subsection 2.1.11.1. Fluid thickness measurements were recorded at the following intervals:

- Falcon 20 Tests:
  - Approximately 5 minutes after fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

Tables 10.2 to 10.4 show the fluid thickness measurements collected during the tests.

Table 10.2: Test #2P8 Fluid Thickness Data

RUN 2P8: 2031, IP, OAT -13°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	0.6	0.8	0.6	0.2
5	1.7	1.8	1.6	0.3
7	0.8	1.1	0.6	0.5
8	0.7	1.2	0.5	0.4

Table 10.3: Test #2S8 Fluid Thickness Data

RUN 2S8: 2031, fluid only, OAT -13°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	0.8	N/A	N/A	0.2
5	1.7	N/A	N/A	0.3
7	0.7	N/A	N/A	0.5
8	0.8	N/A	N/A	0.4

Table 10.4: Test #16P8 Fluid Thickness Data

Run 16P8: 2031, IP/SN, OAT+1°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	0.5	0.4	0.3	0.1
5	1	1	0.5	0.2
7	0.4	4.5 (slush)	4.5 (slush)	0.1
8	0.5	4.5 (slush)	0.3	0.1

10.2.2 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the Falcon 20 tests are described in Subsection 2.1.11.3. Skin temperature measurements were recorded at the following intervals:

- Falcon 20 Tests:
  - Before fluid application;
  - After fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

The wing temperature measurements recorded during each test are shown in Tables 10.5 to 10.7.

Table 10.5: Test #2P8 Wing Skin Temperature Data

RUN 2P8: 2031, IP, OAT -13ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-9.8	-8.9	-9.5	-0.5	-7.9
T2	-10.4	-9.1	-10.6	-2.2	-8.4
T3	-7.6	-6.6	-7.9	-1.4	-5.9
T4	-7.9	-6.8	-9.5	-1.7	-6.3
T5	-9.5	-7.3	-8.0	-5.1	-8.2
T6	-9.8	-8	-9.0	-6.3	-8.8
T7	-9.5	6	-8.3	-6.4	-7.4
T8	-9.2	6.4	-8.7	-6.8	-6.8

Table 10.6: Test #2S8 Wing Skin Temperature Data

RUN 2S8: 2031, fluid only, OAT -13ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-9.8	-8.6	N/A	N/A	-8.0
T2	-9.5	-8.9	N/A	N/A	-8.0
T3	-7.9	-6.7	N/A	N/A	-5.7
T4	-7.9	-6.7	N/A	N/A	-5.2
T5	-9.8	-7.7	N/A	N/A	-7.7
T6	-10.1	-7.4	N/A	N/A	-7.6
T7	-10.2	-7.1	N/A	N/A	-5.4
T8	-9.6	-6.8	N/A	N/A	-5.0

Table 10.7: Test #16P8 Wing Skin Temperature Data

Run 16P8: 2031, IP/SN, OAT+1ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	7.6	4.1	6.1	4.7
T2	N/A	6.7	0.1	4.2	4.2
T3	N/A	6.5	2.7	5.9	4.4
T4	N/A	6.3	-1.1	5.0	3.9
T5	N/A	2.7	0.2	3.6	2.2
T6	N/A	2.2	-1.6	2.4	1.8
T7	N/A	4.4	-1.0	1.5	2.9
T8	N/A	4.0	-0.5	0.7	2.5

10.2.3 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the Falcon 20 tests are described in Subsection 2.1.11.2. Fluid Brix measurements were recorded at the following intervals:

- Falcon 20 Tests:
  - After fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

Tables 10.8 to 10.10 show the fluid Brix measurements collected during the tests.

Table 10.8: Test #2P8 Fluid Brix Data

RUN 2P8: 2031, IP, OAT -13°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37.25	28	28	29.5
B8	37	30	25.5	27.5

Table 10.9: Test #2S8 Fluid Brix Data

RUN 2S8: 2031, fluid only, OAT -13°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37.25	N/A	N/A	38.5
B8	36.5	N/A	N/A	37

Table 10.10: Test #16P8 Fluid Brix Data

Run 16P8: 2031, IP/SN, OAT+1°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	36.25	9.25	16	23.5
B8	36.25	3	3	12

10.3 Photos

High-speed digital photographs of each test were taken; photos were taken of the leading edge, the trailing edge, or both. For each test, photo summaries have been compiled comprising four stages:

- Start of test;
- 17 seconds after start of test;
- Time of rotation; and
- End of test.

Photos 10.1 to 10.12 show the photo summaries for Tests #2P8, #2S8, and #16P8. A compilation of selected high-speed photos taken during Test 2S8 are included in Appendix G. A complete set of photos will be provided to the TDC.

10.4 General Observations

A comparison of the residual fluid thickness at the end of the Falcon 20 test runs has been compiled and is demonstrated in Table 10.11. The residual fluid thickness measured following the test run with ice pellet contamination was compared to the residual fluid thickness measured following the test without contamination.

Table 10.11: Comparison of Falcon 20 Residual Type III Fluid Thickness

Wing Position	Fluid Thickness After Takeoff Run (mm)		
	Run #2S8	Run #2P8	Run #16P8
	Retr. Flaps	*Retr. Flaps*	*Ext. Flaps*
	No Contamination	*Ice Pellet Contamination*	*Ice Pellet and Snow Contamination*
2	0.2	0.2	0.1
5	0.3	0.3	0.2
7	0.5	0.5	0.1
8	0.4	0.4	0.1

Low-speed Type III fluid testing with retracted flaps demonstrated significant amounts of residual fluid post-run. When compared to Type IV fluid flow-off, the Type III fluid performed better during low-speed retracted flap tests; however, it still produced greater residual fluid compared to the high-speed Type IV testing with extended flaps (residual fluid during 2006-07 Type IV high-speed tests was on average 0.2 mm on the trailing edge wing).

During the contaminated wing tests, the Type III fluid did an excellent job of eliminating the contamination by the time of rotation; contamination was removed with little effort. The residual fluid on the contaminated wing tests was equal to or less than the fluid only wing tests. It should be noted that in the case of Run #16P8, the flaps were extended, which reduced residual fluid thickness, and the air temperature and wing skin temperature were above freezing, allowing for better fluid flow-off.

10.4.1 Conclusions and Recommendations for Future Work

The preliminary 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. During the contaminated wing tests, the Type III fluid did an excellent job of eliminating the contamination by the time of rotation. It is recommended that future aerodynamic research in the NRC wind tunnel should further investigate the aerodynamic effects of residual Type III fluid during low-speed takeoff and the potential for using Type III fluid during ice pellet conditions; allowance times would have to be reduced to account for shorter Type III protection times as compared to Type IV fluids.

Photo 10.1: Test #2P8 – Start of Test

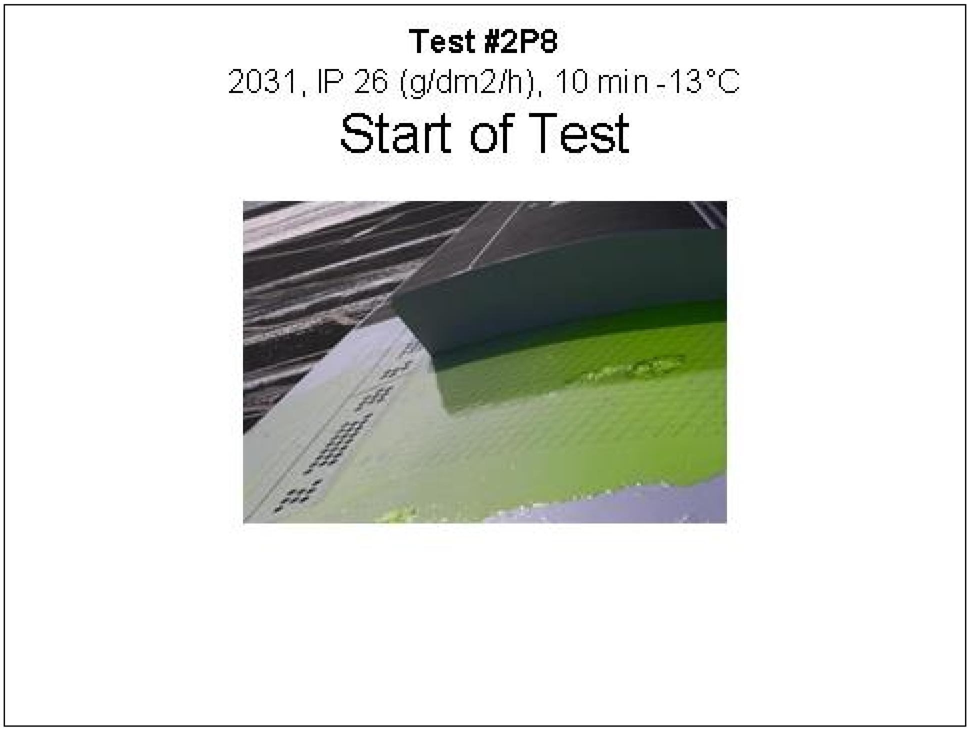


Photo 10.2: Test #2P8 – 17 Seconds

Photo 10.3: Test #2P8 – Rotation

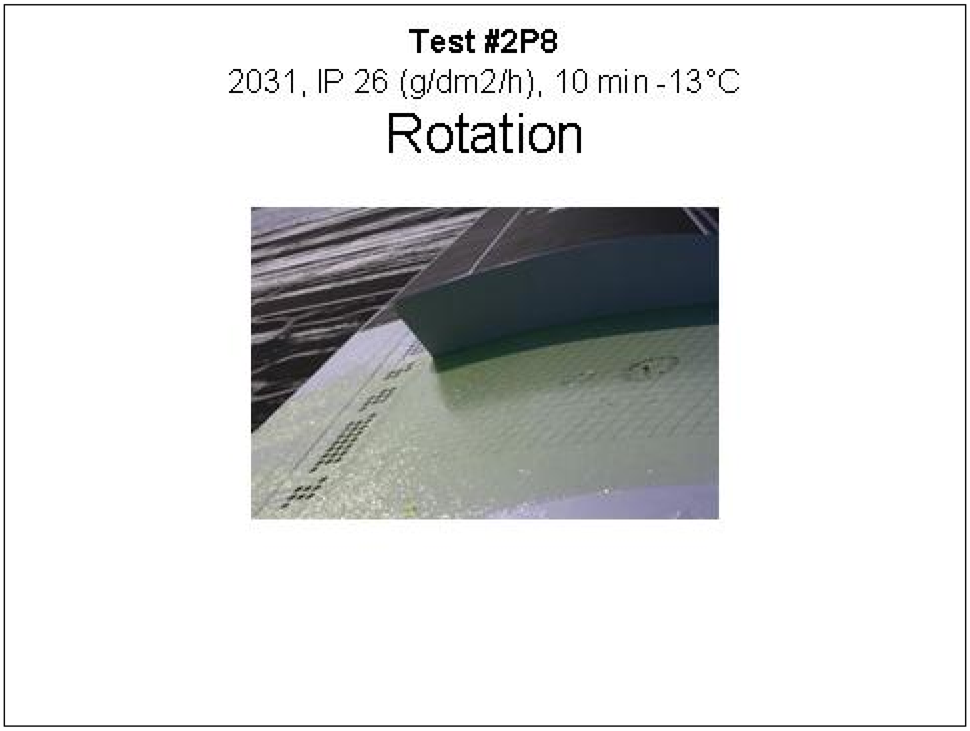


Photo 10.4: Test #2P8 – End of Test

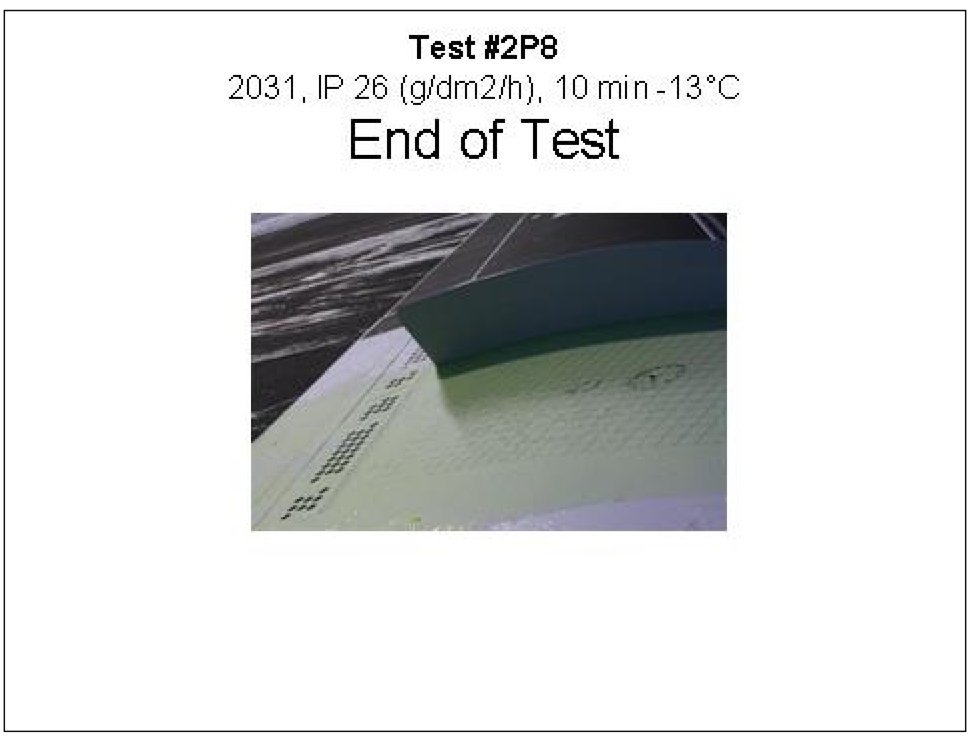


Photo 10.5: Test #2S8 – Start of Test

Photo 10.6: Test #2S8 – 17 Seconds

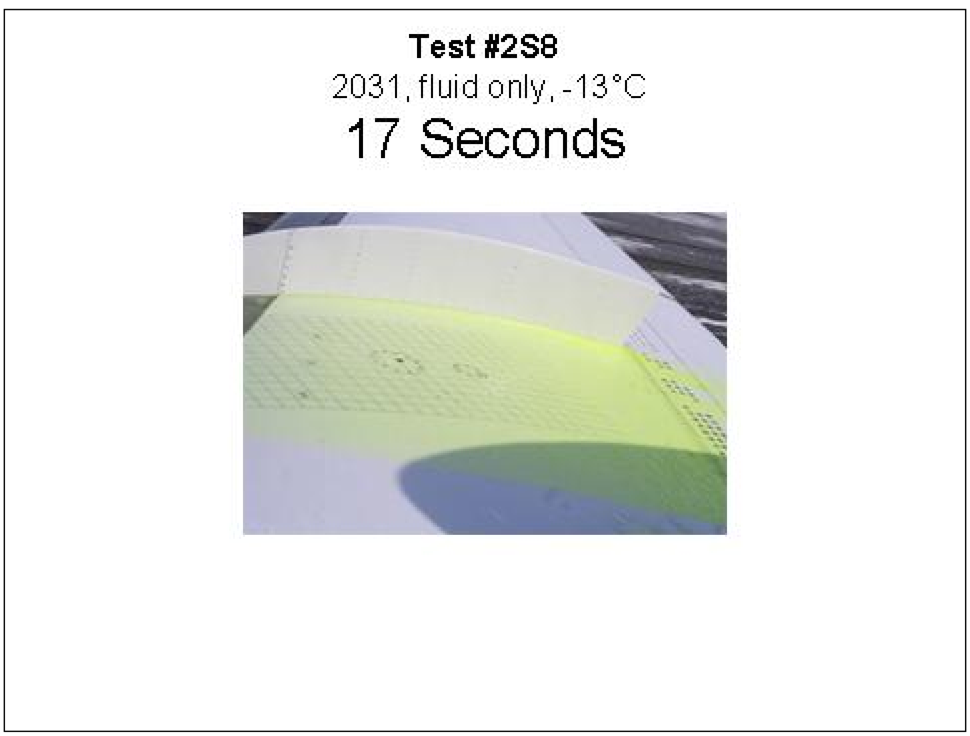


Photo 10.7: Test #2S8 – Rotation

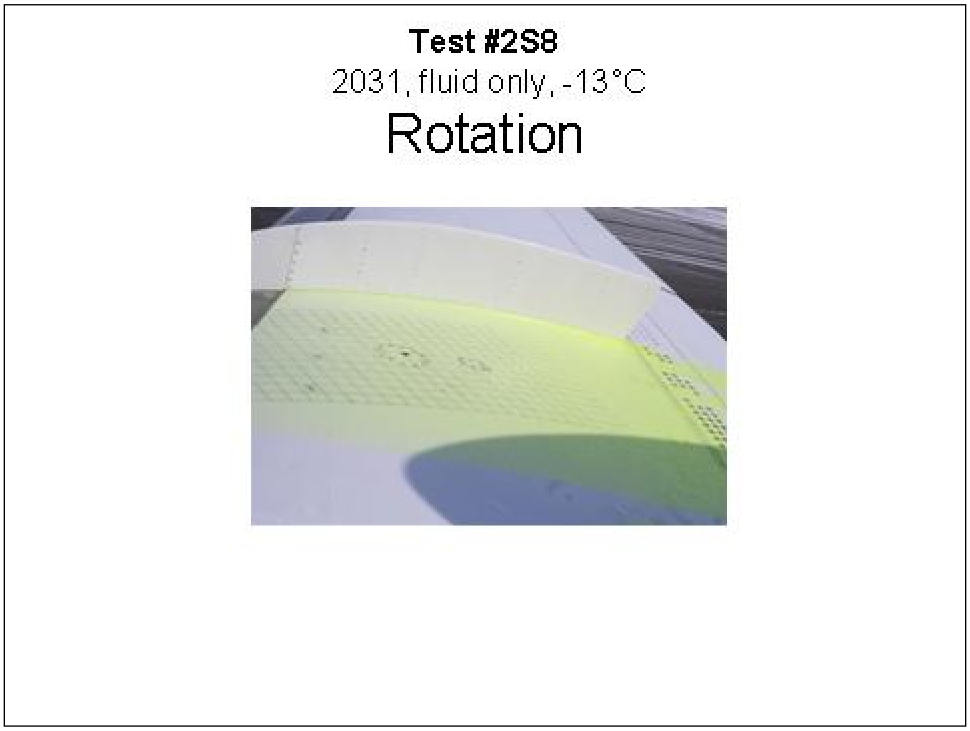


Photo 10.8: Test #2S8 – End of Test

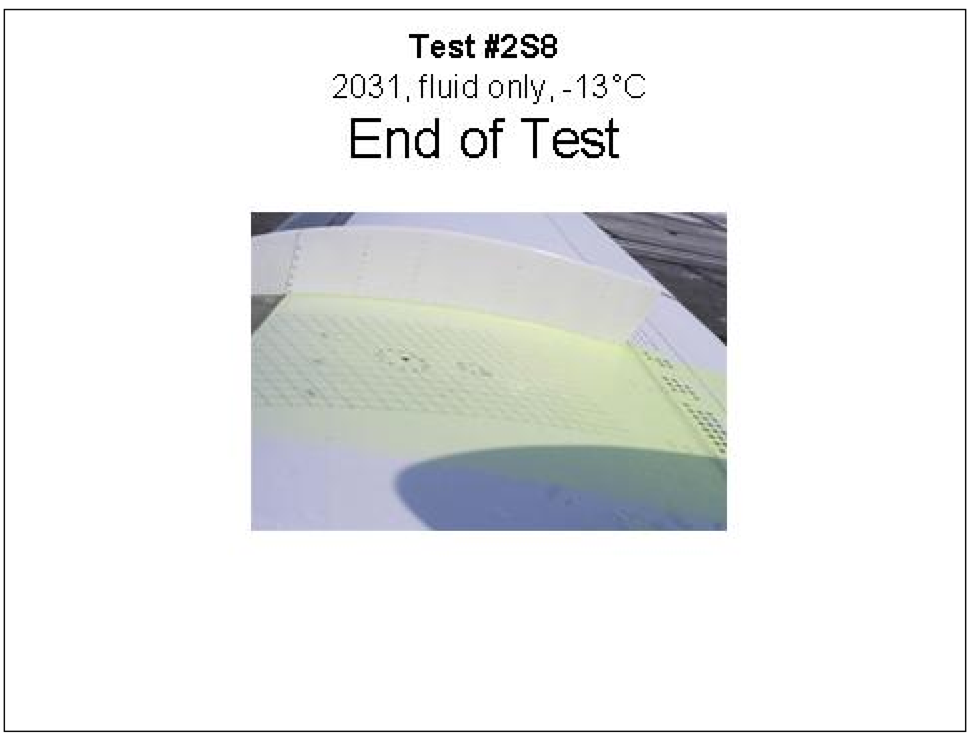


Photo 10.9: Test #16P8 – Start of Test

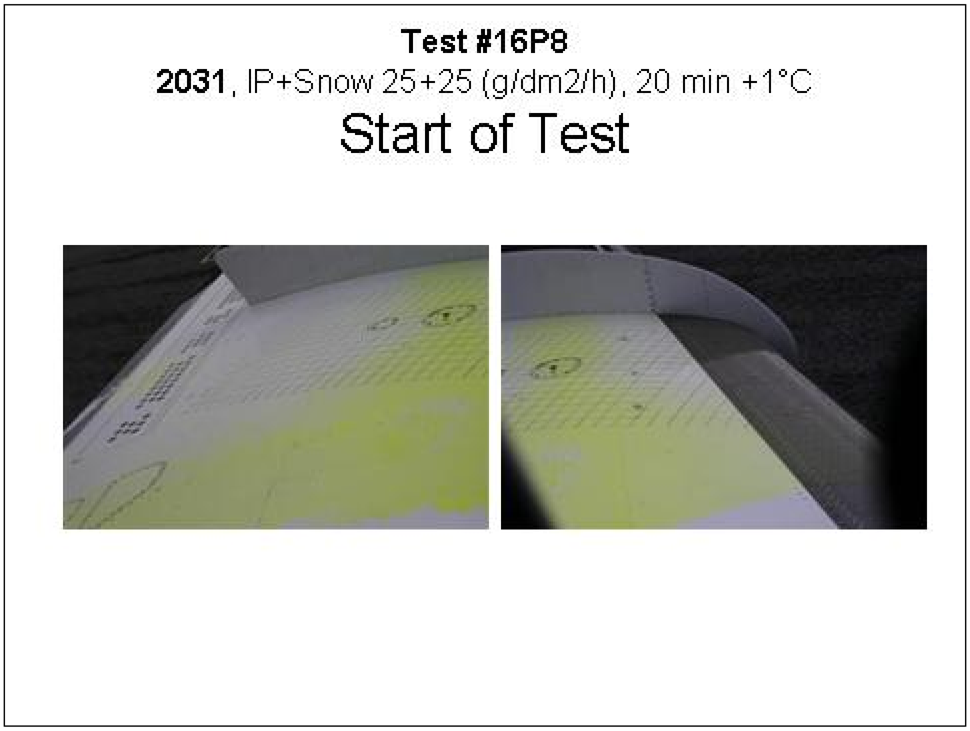


Photo 10.10: Test #16P8 – 17 Seconds

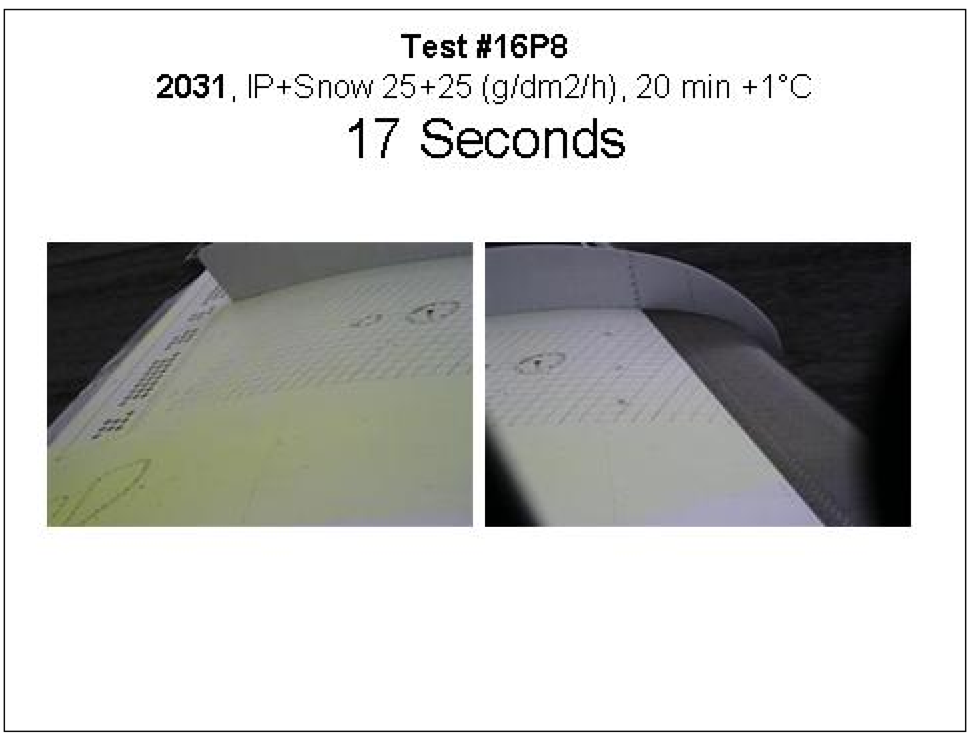


Photo 10.11: Test #16P8 – Rotation

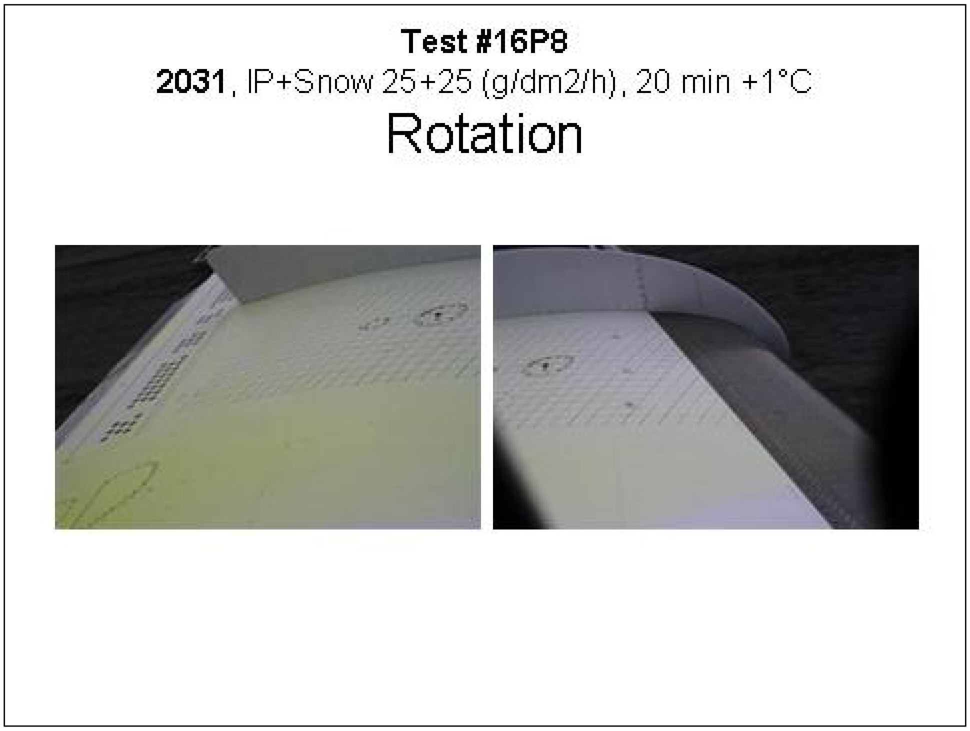
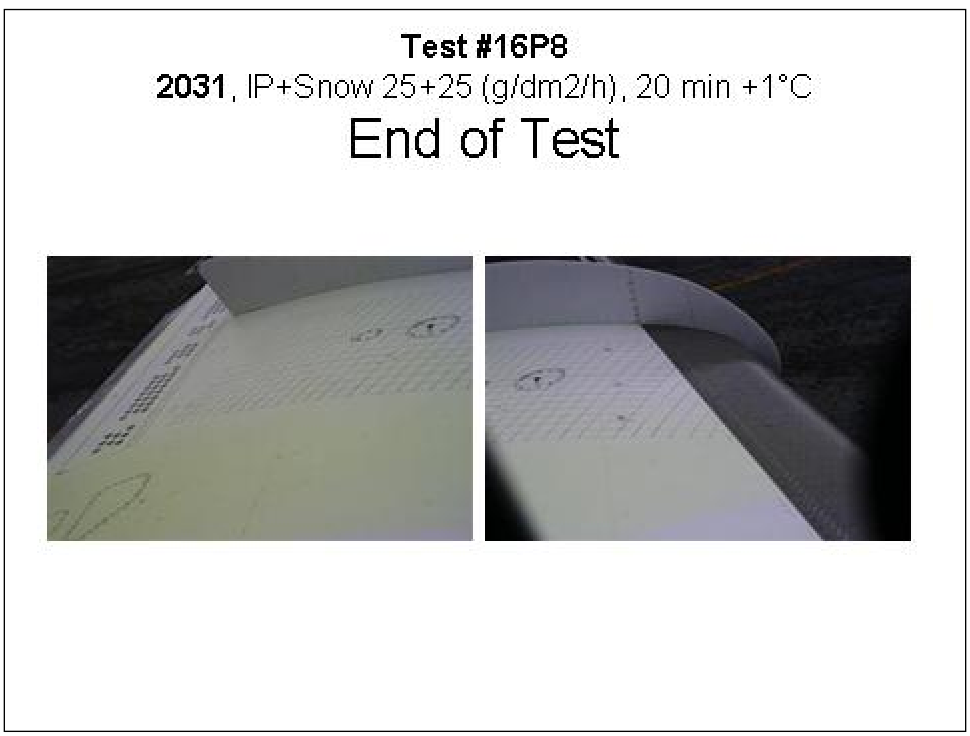


Photo 10.12: Test #16P8 – End of Test



11. ICE PELLETS MIXED WITH SNOW CONDITIONS

During the winter of 2006-07, aerodynamic data was collected using both the NRC wind tunnel and the NRC Falcon 20 aircraft. The purpose of that testing was to expand the current ice pellets only allowance time to include mixed precipitation conditions including mixed ice pellets and snow. Due to a lack of cold weather data (below -5°C) in simulated mixed ice pellets and snow conditions, allowance times for that condition were only issued for above -5°C. It was recommended that additional testing in simulated mixed ice pellets and snow conditions be conducted to potentially expand the allowance time to below -5°C and below -10°C in accordance with the allowance time table format for the various mixed conditions with ice pellets.

This section provides an overview of each test conducted as part of the test program to evaluate the effect of ice pellets mixed with snow conditions on the flow-off behaviour of anti-icing fluid. Testing was conducted in mixed ice pellets and snow precipitation conditions. The parameters for each test are detailed, and a description of the data collected during each test is provided.

11.1 Overview of Tests

A summary of the baseline tests conducted using the Falcon 20 aircraft is shown in Table 11.1. The table provides relevant information for each of the tests, as well as final values used for the data analysis. Each row contains data specific to one test. A more detailed test log of all conditions tested using the Falcon 20 aircraft is provided in Subsection 4.1. The following is a brief description of the column headings for Table 11.1:

Run #:	Exclusive number identifying each run.
Date:	Date when the test was conducted.
Fluid:	Aircraft deicing fluid specified by product name.
Condition:	Simulated precipitation condition.
IP Rate (g/dm²/h):	Average simulated ice pellet precipitation rate, measured in g/dm²/h.
SN Rate (g/dm²/h):	Average simulated snow precipitation rate, measured in g/dm²/h.
Precip. Time (min.):	Total time of exposure to simulated precipitation.
OAT at Start of Test (°C):	The outside air temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.

Avg. Wing Temp.: Average wing skin temperature.

After Fluid Appl. (ºC): Wing temperature following fluid application, measured in degrees Celsius.

Takeoff Profile: Description of the takeoff acceleration and velocity of the aircraft during the test run.

Comments: General comments regarding the objective of the test.

Table 11.1: Summary of 2007-08 Mixed Ice Pellet and Snow Testing with Falcon 20 Aircraft

Run No.	Date	Fluid	Condition	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Precip. Time (min.)	OAT at Start of Test (°C)	AVG Wing Temp. After Fluid Appl. (°C)	Takeoff Profile	Comments
9P8	29-Feb-08	ABC-S Plus	IP/SN	25	25	20	-15	-9.7	117 knots in 29 sec	Rotation, Retracted Flaps
9S8	29-Feb-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-15	-3.6	117 knots in 29 sec	Rotation, Retracted Flaps
14P8	6-Mar-08	ABC-S Plus	IP/SN	25	25	20	-9	-4.7	117 knots in 30 sec	Rotation, Extended Flaps
14S8	6-Mar-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-9	-5.1	117 knots in 30 sec	Rotation, Extended Flaps
15P8	6-Mar-08	ABC-S Plus	IP/SN	25	25	20	-4	-0.5	77 knots in 19 sec	No Rotation, Extended Flaps
15S8	6-Mar-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-4	-1.4	77 knots in 19 sec	No Rotation, Extended Flaps
16P8	6-Mar-08	2031	IP/SN	25	25	20	1	5.1	75 knots in 17 sec	No Rotation, Extended Flaps
16AP8	6-Mar-08	2031	Baseline	N/A	N/A	N/A	1	13.7	75 knots in 17 sec	No Rotation, Extended Flaps

11.2 Data Collected

11.2.1 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the Falcon 20 tests are described in Subsection 2.1.11.1. Fluid thickness measurements were recorded at the following intervals:

- Falcon 20 Tests:
  - Approximately 5 minutes after fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

Tables 11.2 to 11.9 show the fluid thickness measurements collected during the tests.

Table 11.2: Test #9P8 Fluid Thickness Data

RUN 9P8: ABC-S+, IP/SN, OAT -15°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	2.7	2.5	0.2
5	3.1	4.5	4.5	0.2
7	1.4	2.7	2.7	0.5 - 1.1
8	1.4	2.9	2.7	1.6

Table 11.3: Test #9S8 Fluid Thickness Data

RUN 9S8: ABC-S+, fluid only, OAT -15°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	N/A	N/A	0.2
5	3.5	N/A	N/A	0.2
7	1.8	N/A	N/A	0.5
8	2.5	N/A	N/A	0.8

Table 11.4: Test #14P8 Fluid Thickness Data

RUN 14P8: ABC-S+, IP/SN, OAT -9ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	3.3	2.2	0.2
5	0.4	4.5	4.5	0.3
7	2.5	3.9	3.7	0.6
8	2.7	3.9	3.9	0.4

Table 11.5: Test #14S8 Fluid Thickness Data

RUN 14S8: ABC-S+, fluid only, OAT -9ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.2
5	4.5	N/A	N/A	0.2
7	2.5	N/A	N/A	0.3
8	2.5	N/A	N/A	0.3

Table 11.6: Test #15P8 Fluid Thickness Data

RUN 15P8: ABC-S+, IP/SN, OAT -4ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	2.5	2.5	0.3
5	4.5	5.7	4.5	0.3
7	3.1	3.3	2.9	0.6
8	2.9	3.5	2.9	0.7

Table 11.7: Test #15S8 Fluid Thickness Data

RUN 15S8: ABC-S+, fluid only, OAT -4°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.5
5	4.5	N/A	N/A	0.4
7	2.7	N/A	N/A	0.7
8	2.9	N/A	N/A	0.7

Table 11.8: Test #16P8 Fluid Thickness Data

Run 16P8: 2031, IP/SN, OAT+1°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	0.5	0.4	0.3	0.1
5	1	1	0.5	0.2
7	0.4	4.5 (slush)	4.5 (slush)	0.1
8	0.5	4.5 (slush)	0.3	0.1

Table 11.9: Test #16AP8 Fluid Thickness Data

RUN 16AP8: 2031, fluid only, OAT +1°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	0.3	N/A	N/A	0.1
5	0.3	N/A	N/A	0.1
5A	0.4	N/A	N/A	0.1
6A	0.6	N/A	N/A	0.1
7	0.6	N/A	N/A	0.1
8	0.4	N/A	N/A	0.1

11.2.2 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the Falcon 20 tests are described in Subsection 2.1.11.3. Skin temperature measurements were recorded at the following intervals:

- Falcon 20 Tests:
  - Before fluid application;
  - After fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

The wing temperature measurements recorded during each test are shown in Tables 11.10 to 11.17.

Table 11.10: Test #9P8 Wing Skin Temperature Data

RUN 9P8: ABC-S+, IP/SN, OAT -15ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-11.1	-10.3	-9.1	-4.0	-7.0
T2	-10.8	-10.0	-11.2	-6.1	-7.9
T3	-12.0	-7.1	-6.7	-3.7	-5.3
T4	-9.3	-5.9	-8.7	-5.6	-5.6
T5	-13.3	-8.3	-7.5	-6.1	-7.9
T6	-13.0	-8.1	-8.8	-8.8	-9.2
T7	-13.6	-14.1	-15.4	-9.3	-8.0
T8	-13.5	-13.9	-15.1	-9.5	-8.0

Table 11.11: Test #9S8 Wing Skin Temperature Data

RUN 9S8: ABC-S+, fluid only, OAT -15°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-5.2	-0.2	N/A	N/A	-4.2
T2	-5.2	-0.8	N/A	N/A	-4.2
T3	-6.1	-1.9	N/A	N/A	-3.9
T4	-6.2	-1.7	N/A	N/A	-3.0
T5	-12.4	-7.5	N/A	N/A	-7.4
T6	-11.5	-5.9	N/A	N/A	-6.7
T7	-10.4	-6.5	N/A	N/A	-5.1
T8	-9.2	-4.4	N/A	N/A	-4.4

Table 11.12: Test #14P8 Wing Skin Temperature Data

RUN 14P8: ABC-S+, IP/SN, OAT -9°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-7.7	-3.9	-8.3	-5.4	-4.0
T2	-7.9	-4.1	-10.6	-6.2	-4.4
T3	-8.1	-4.4	-8.8	-5.5	-3.4
T4	-8.2	-4.7	-10.5	-6.6	-3.2
T5	-9.3	-5.7	-9.0	-6.6	-5.4
T6	-9.5	-6.4	-8.8	-71.0	-5.8
T7	-8.4	-4.2	-10.8	-7.6	-4.4
T8	-8.6	-4.4	-9.6	-7.0	-4.5

Table 11.13: Test #14S8 Wing Skin Temperature Data

RUN 14S8: ABC-S+, fluid only, OAT -9°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-8.2	-4.2	N/A	N/A	-2.2
T2	-7.9	-3.9	N/A	N/A	-2.0
T3	-8.2	-4.8	N/A	N/A	-1.4
T4	-8.2	-4.8	N/A	N/A	-1.3
T5	-8.9	-6.0	N/A	N/A	-3.6
T6	-9.1	-6.1	N/A	N/A	-3.8
T7	-8.8	-5.5	N/A	N/A	-3.3
T8	-8.7	-5.8	N/A	N/A	-3.6

Table 11.14: Test #15P8 Wing Skin Temperature Data

RUN 15P8: ABC-S+, IP/SN, OAT -4°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	-0.3	0.4	1.6	2.0
T2	N/A	-0.7	-4.9	-0.4	1.1
T3	N/A	0.5	1.4	2.8	2.6
T4	N/A	0.2	-5.1	-0.1	2.0
T5	N/A	-1.2	-2.1	0.9	-0.3
T6	N/A	-2.0	-5.1	-2.4	-1.6
T7	N/A	-0.2	-5.8	-1.2	2.6
T8	N/A	-0.6	-6.2	-1.4	1.9

Table 11.15: Test #15S8 Wing Skin Temperature Data

RUN 15S8: ABC-S+, fluid only, OAT -4°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	-0.9	N/A	N/A	3.2
T2	N/A	-0.8	N/A	N/A	3.6
T3	N/A	-0.9	N/A	N/A	4.0
T4	N/A	-0.7	N/A	N/A	3.5
T5	N/A	-2.4	N/A	N/A	1.2
T6	N/A	-2.0	N/A	N/A	1.4
T7	N/A	-2.0	N/A	N/A	2.0
T8	N/A	-1.4	N/A	N/A	2.6

Table 11.16: Test #16P8 Wing Skin Temperature Data

Run 16P8: 2031, IP/SN, OAT+1°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	7.6	4.1	6.1	4.7
T2	N/A	6.7	0.1	4.2	4.2
T3	N/A	6.5	2.7	5.9	4.4
T4	N/A	6.3	-1.1	5.0	3.9
T5	N/A	2.7	0.2	3.6	2.2
T6	N/A	2.2	-1.6	2.4	1.8
T7	N/A	4.4	-1.0	1.5	2.9
T8	N/A	4.0	-0.5	0.7	2.5

Table 11.17: Test #16AP8 Wing Skin Temperature Data

RUN 16AP8: 2031, fluid only, OAT +1°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	11.9	N/A	N/A	7.6
T2	N/A	12.3	N/A	N/A	7.1
T3	N/A	14.2	N/A	N/A	9.2
T4	N/A	14.8	N/A	N/A	8.2
T5	N/A	14.9	N/A	N/A	10.6
T6	N/A	16.0	N/A	N/A	10.2
T7	N/A	12.5	N/A	N/A	8.3
T8	N/A	12.6	N/A	N/A	8.3

11.2.3 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the Falcon 20 tests are described in Subsection 2.1.11.2. Fluid Brix measurements were recorded at the following intervals:

- Falcon 20 Tests:
    - After fluid application;
    - After the application of contamination (on the test wing, not the fluid only wing);
    - Before the takeoff test; and
    - After the takeoff test (end of test).

Tables 11.18 to 11.25 show the fluid Brix measurements collected during the tests.

Table 11.18: Test #9P8 Fluid Brix Data

RUN 9P8: ABC-S+, IP/SN, OAT -15°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37.5	26	18	30
B8	37.5	29	27	30

Table 11.19: Test #9S8 Fluid Brix Data

RUN 9S8: ABC-S+, fluid only, OAT -15°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37.25	N/A	N/A	40
B8	37.5	N/A	N/A	37.5

Table 11.20: Test #14P8 Fluid Brix Data

RUN 14P8: ABC-S+, IP/SN, OAT -9°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37	18	23	24.5
B8	37	21	17	25.5

Table 11.21: Test #14S8 Fluid Brix Data

RUN 14S8: ABC-S+, fluid only, OAT -9°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37	N/A	N/A	37.5
B8	37	N/A	N/A	37

Table 11.22: Test #15P8 Fluid Brix Data

RUN 15P8: ABC-S+, IP/SN, OAT -4°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37	18.5	18	33
B8	37	16	16	31

Table 11.23: Test #15S8 Fluid Brix Data

RUN 15S8: ABC-S+, fluid only, OAT -4°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37	N/A	N/A	37.5
B8	37	N/A	N/A	37.25

Table 11.24: Test #16P8 Fluid Brix Data

Run 16P8: 2031, IP/SN, OAT +1°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	36.25	9.25	16	23.5
B8	36.25	3	3	12

Table 11.25: Test #16AP8 Fluid Brix Data

RUN 16AP8: 2031, fluid only, OAT +1°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	N/A	N/A	N/A	N/A
B8	N/A	N/A	N/A	N/A

11.3 Photos

High-speed digital photographs of each test were taken; photos were taken of the leading edge, the trailing edge, or both. For each test, photo summaries have been compiled comprising four stages:

- Start of test;
- 17 seconds after start of test;
- Time of rotation; and
- End of test.

Photos 11.1 to 11.32 show the photo summaries for Tests #9P8, #9S8, #14P8, #14S8, #15P8, #15S8, #16P8, and #16AP8. During the tests where photos were not taken, a note has been included indicating "No Photo Documentation Available." A complete set of photos will be provided to the TDC.

11.4 General Observations

A comparison of the residual fluid thickness at the end of the Falcon 20 test runs has been compiled and is demonstrated in Table 11.26. The residual fluid thickness measured following the mixed ice pellet and snow test was compared to the residual fluid thickness measured following the baseline fluid only test. The shaded cells indicate measurements where the fluid thickness was greater than the respective comparison test run.

The high-speed testing results at colder temperatures (below -5°C) with Type IV fluid demonstrated greater residual fluid thickness on the trailing edge section of the wing during the contaminated test run compared to the fluid only test runs (Run #9P/S8 and #14P/S8). The low-speed testing conducted at warmer temperatures with Type III and IV fluids demonstrated similar residual fluid on both the contaminated and uncontaminated wing section; discrepancies were within 0.1 mm. The results obtained were in accordance with previous aerodynamic data collected during the winter of 2006-07, which indicated potential fluid flow-off problems at colder temperatures with mixed ice pellet and snow conditions. Although the leading edge is generally cleared by the time of rotation, the finer snow particles combined with the colder OAT may impede fluid flow-off on the trailing edge of the wing in mixed ice pellet and snow conditions.

Table 11.26: Comparison of Falcon 20 Residual Fluid Thicknesses

Wing Position	Fluid Thickness After Takeoff Run (mm)							
	Run #9P8	Run #9S8	Run #14P8	Run #14S8	Run #15P8	Run #15S8	Run #16P8	Run #16AP8
	Type IV PG	*Type IV PG*	*Type IV PG*	*Type IV PG*	*Type IV PG*	*Type IV PG*	*Type III PG*	*Type III PG*
	IP/SN	*No Contamination*	*IP/SN*	*No Contamination*	*IP/SN*	*No Contamination*	*IP/SN*	*No Contamination*
2	0.2	0.2	0.2	0.2	0.3	0.5	0.1	0.1
5	0.2	0.2	0.3	0.2	0.3	0.4	0.2	0.1
7	0.5 - 1.1	0.5	0.6	0.3	0.6	0.7	0.1	0.1
8	1.6	0.8	0.4	0.3	0.7	0.7	0.1	0.1

11.4.1 Conclusions and Recommendations for Future Work

Further wind tunnel work is required to investigate the aerodynamic penalties associated with the trailing edge contamination observed in mixed ice pellet and snow conditions. Testing should also investigate snow only conditions to isolate the source of the fluid flow-off problem in order to help determine if it is potentially related to the type of precipitation. Testing should be primarily conducted at colder temperatures below -5°C.

Photo 11.1: Test #9P8 – Start of Test

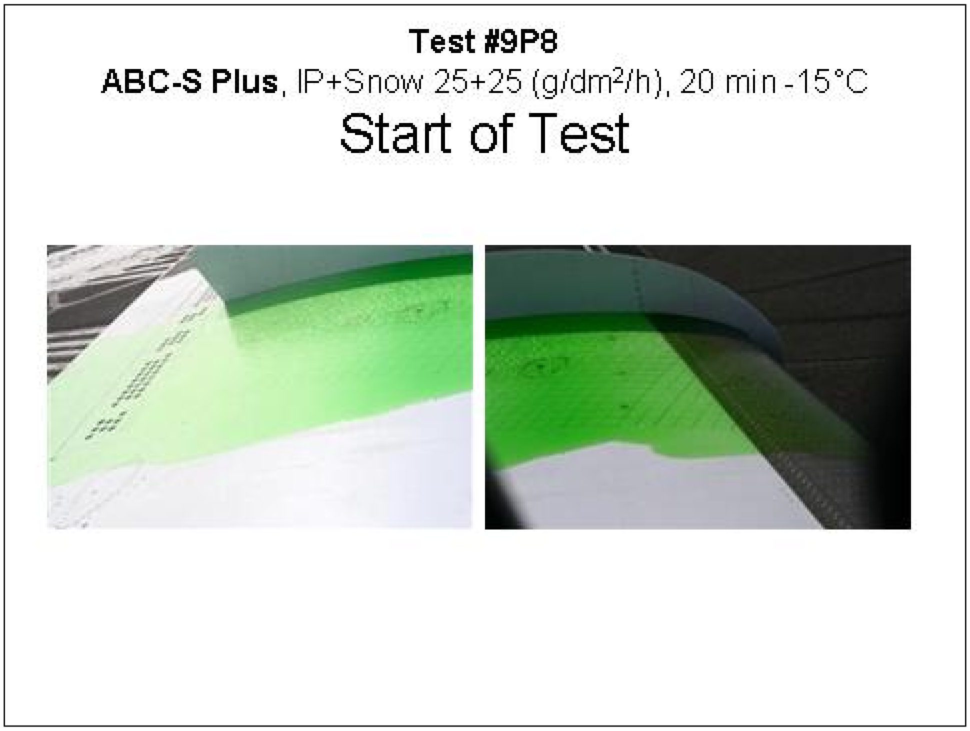


Photo 11.2: Test #9P8 – 17 Seconds

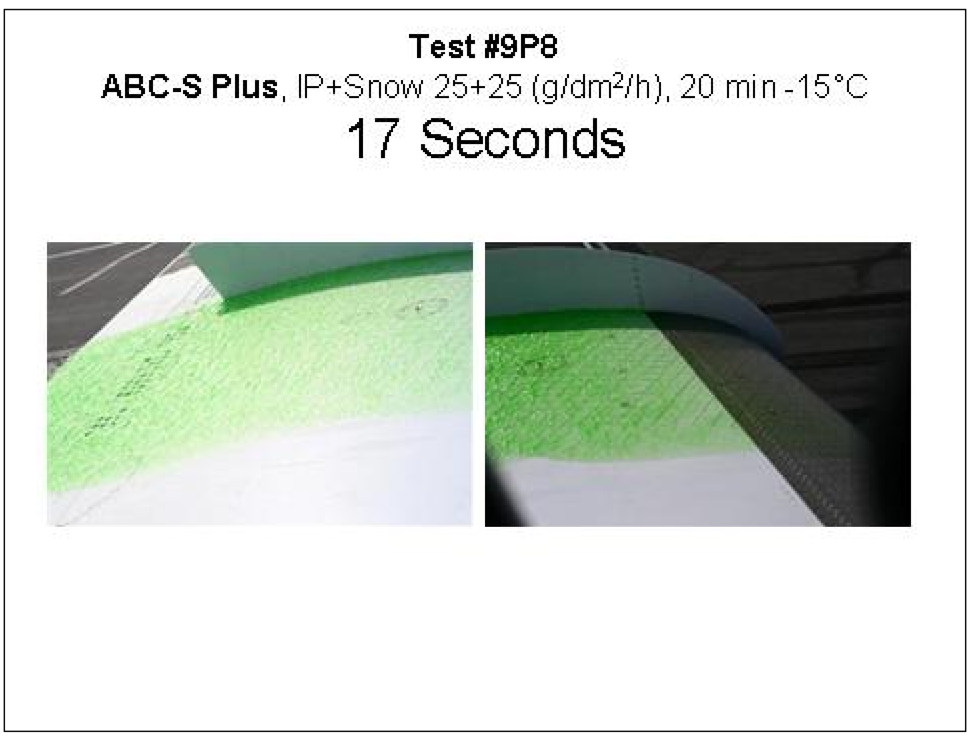


Photo 11.3: Test #9P8 – Rotation

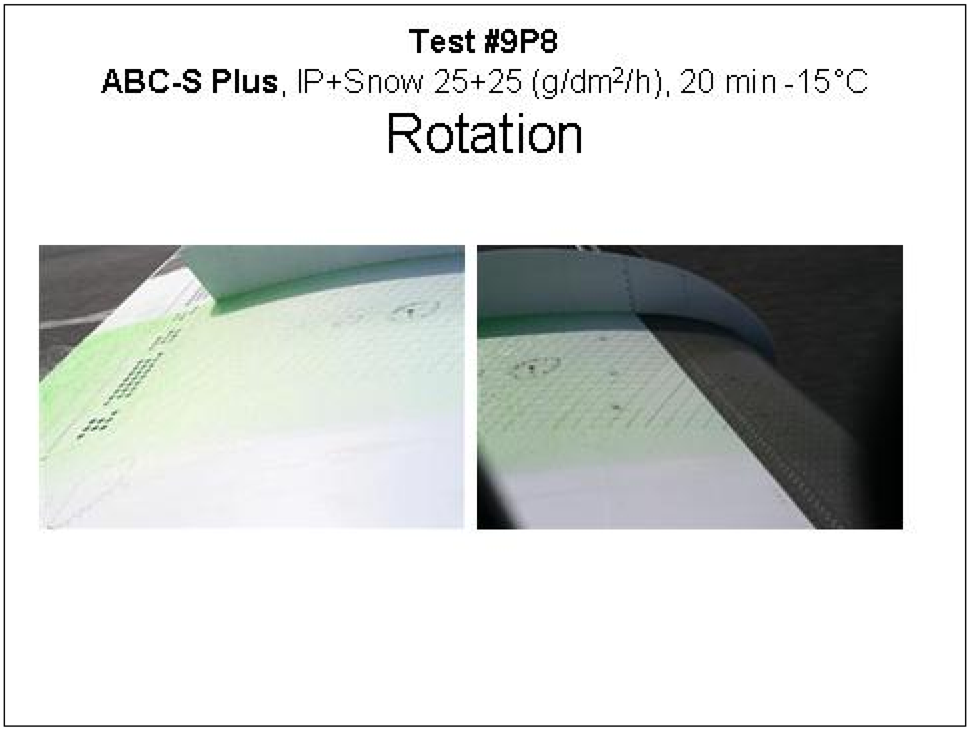


Photo 11.4: Test #9P8 – End of Test

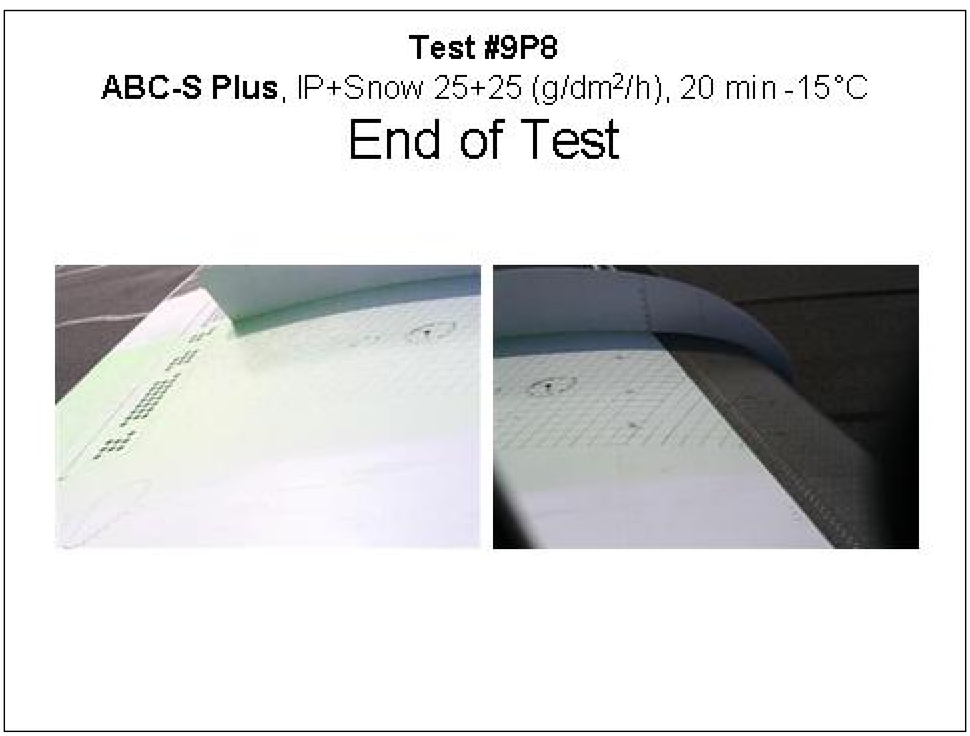


Photo 11.5: Test #9S8 – Start of Test

Photo 11.6: Test #9S8 – 17 Seconds

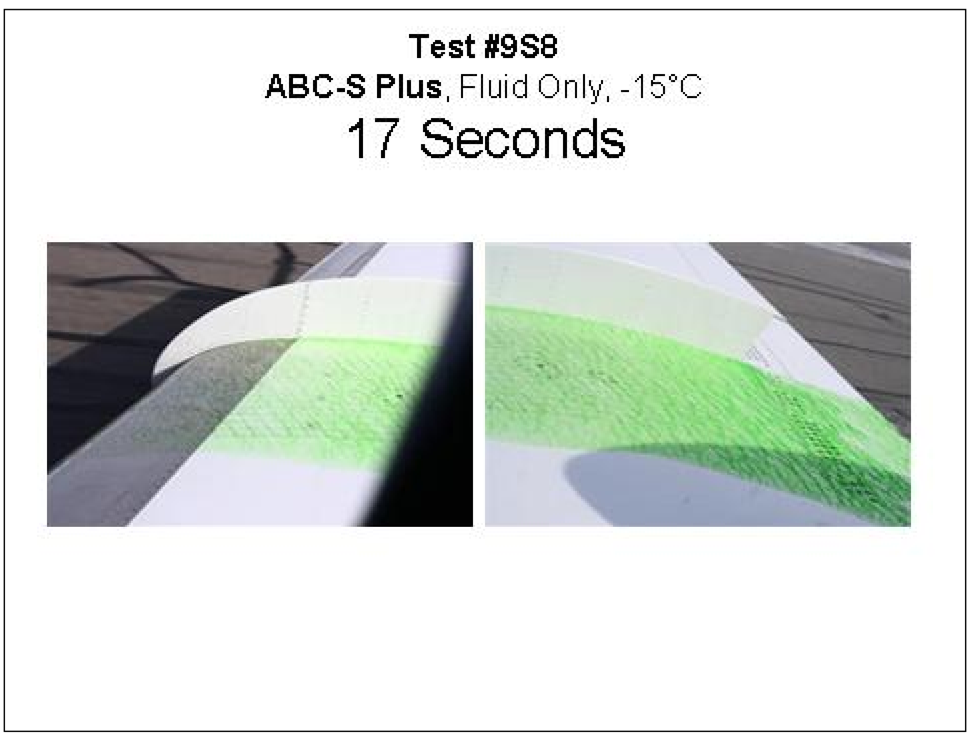


Photo 11.7: Test #9S8 – Rotation

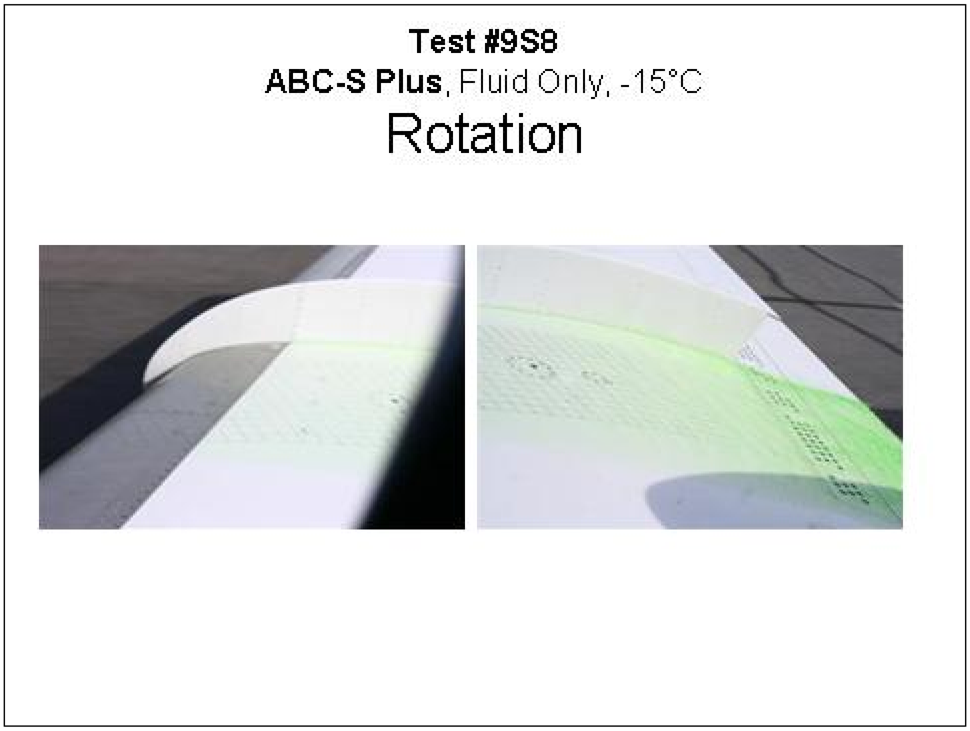


Photo 11.8: Test #9S8 – End of Test

Photo 11.9: Test #14P8 – Start of Test

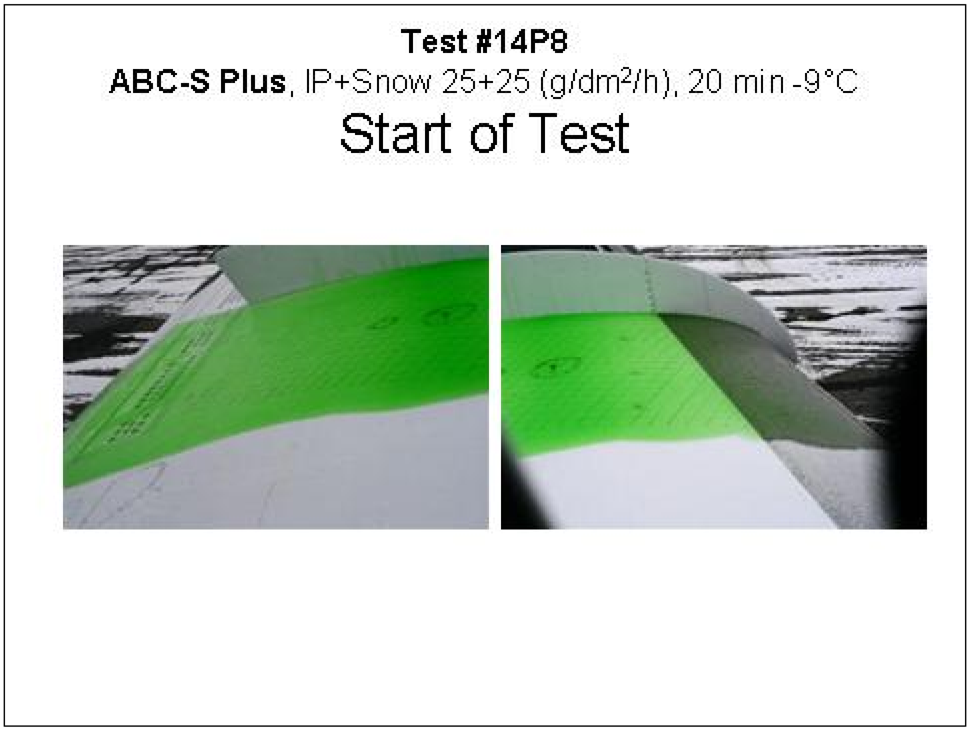


Photo 11.10: Test #14P8 – 17 Seconds

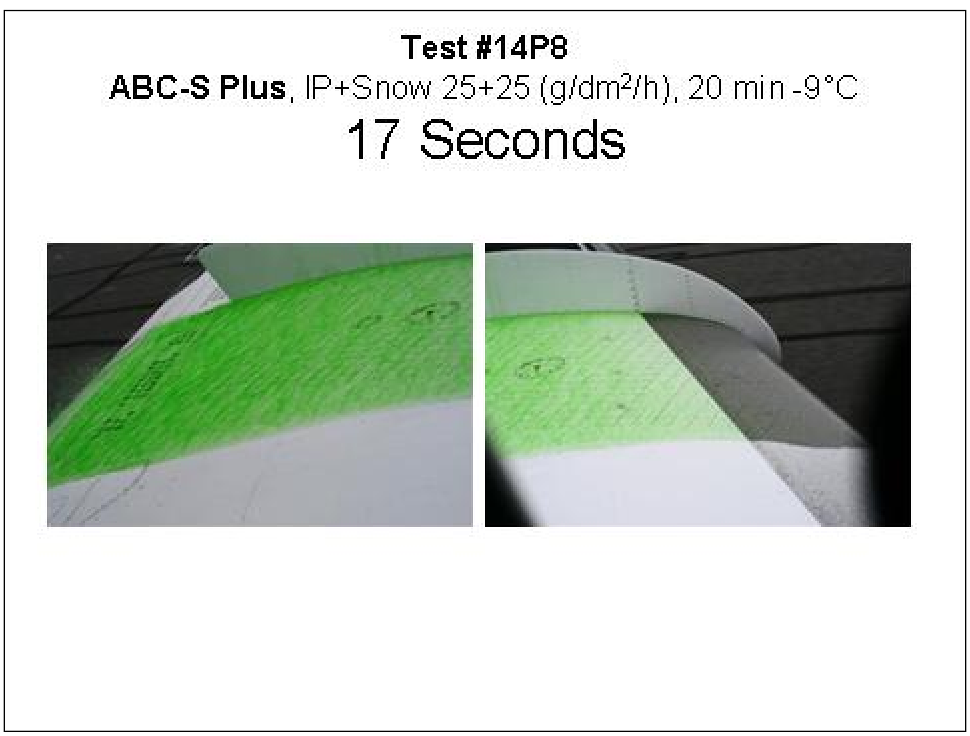


Photo 11.11: Test #14P8 – Rotation

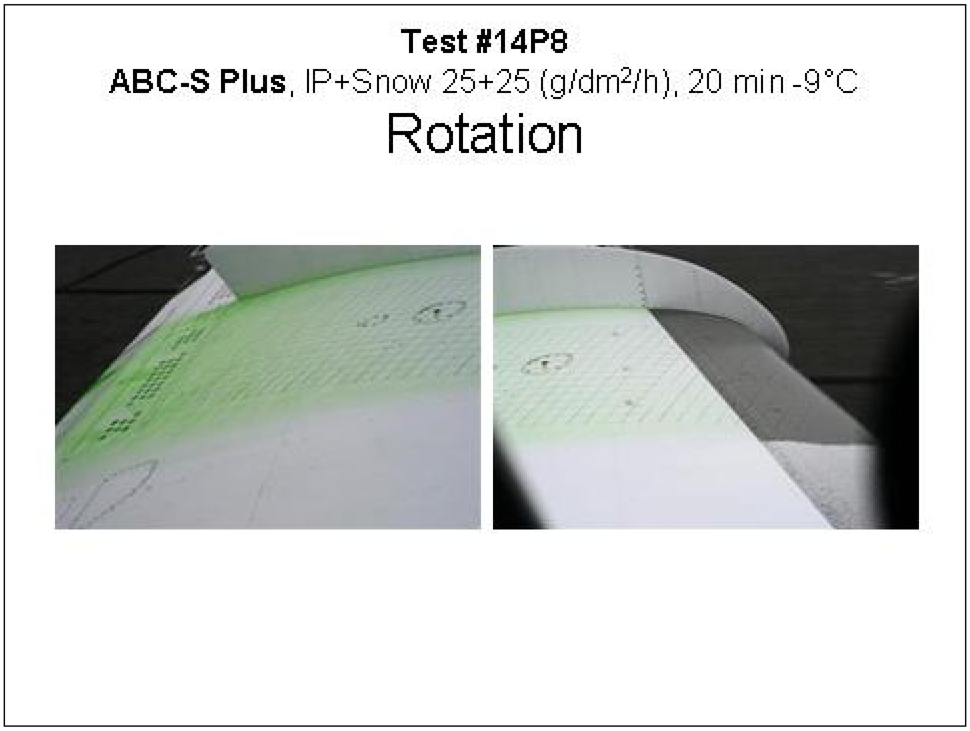


Photo 11.12: Test #14P8 – End of Test

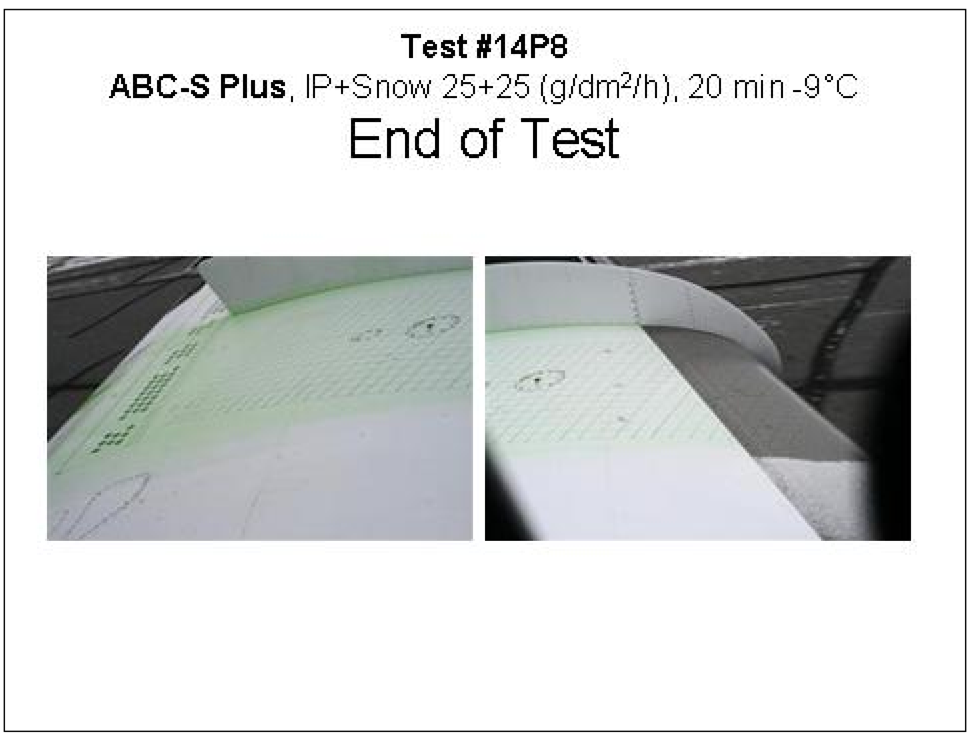


Photo 11.13: Test #14S8 – Start of Test

Photo 11.14: Test #14S8 – 17 Seconds

Photo 11.15: Test #14S8 – Rotation

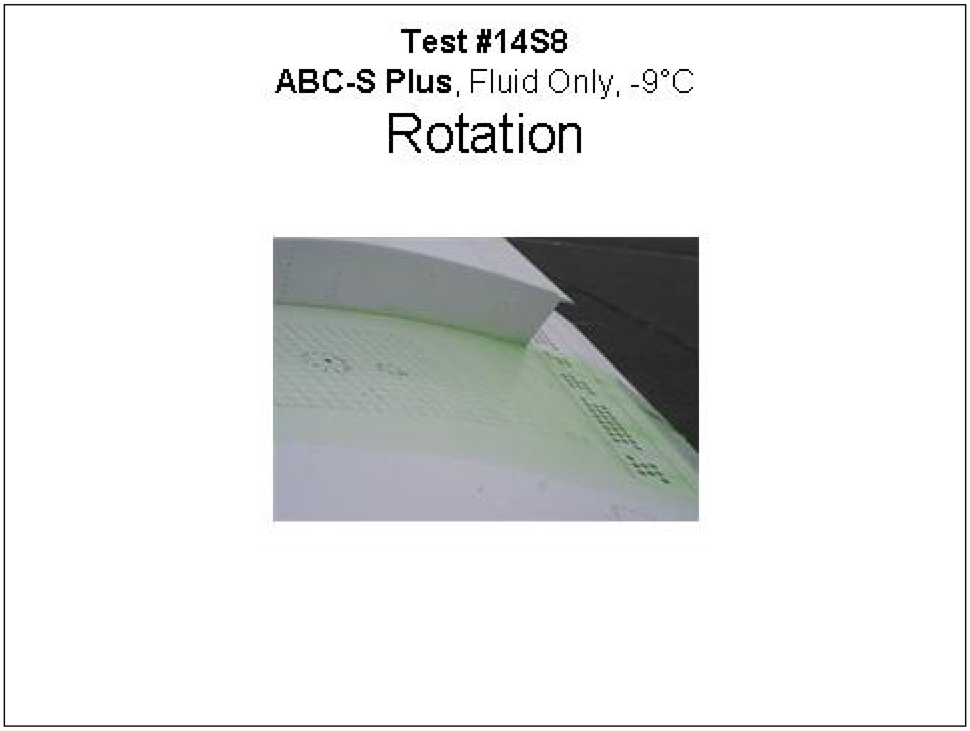


Photo 11.16: Test #14S8 – End of Test

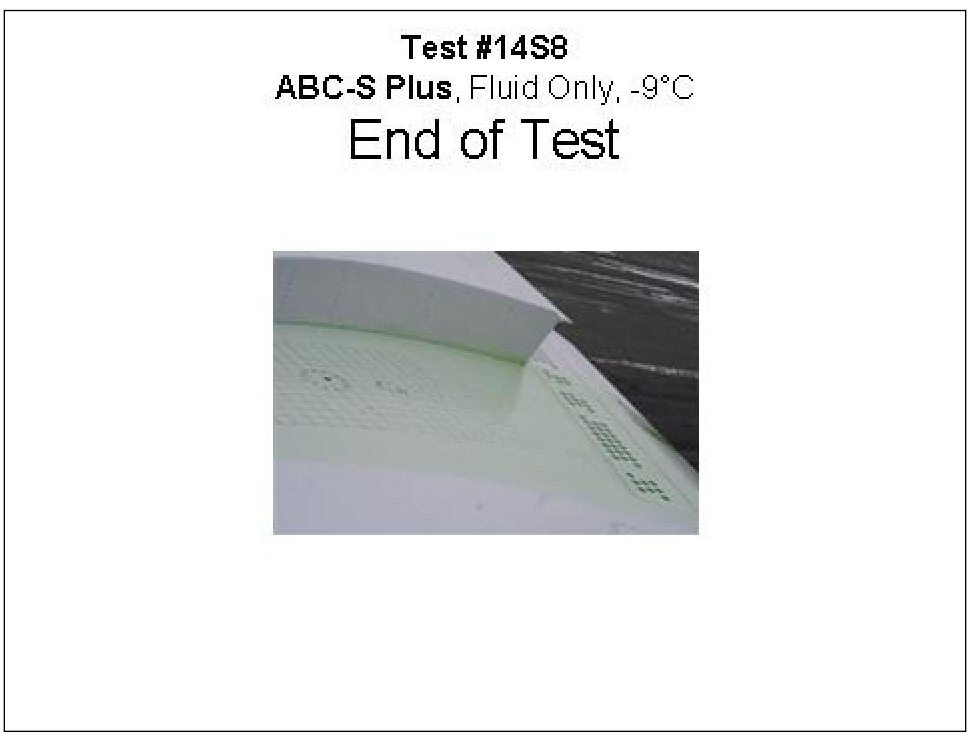


Photo 11.17: Test #15P8 – Start of Test

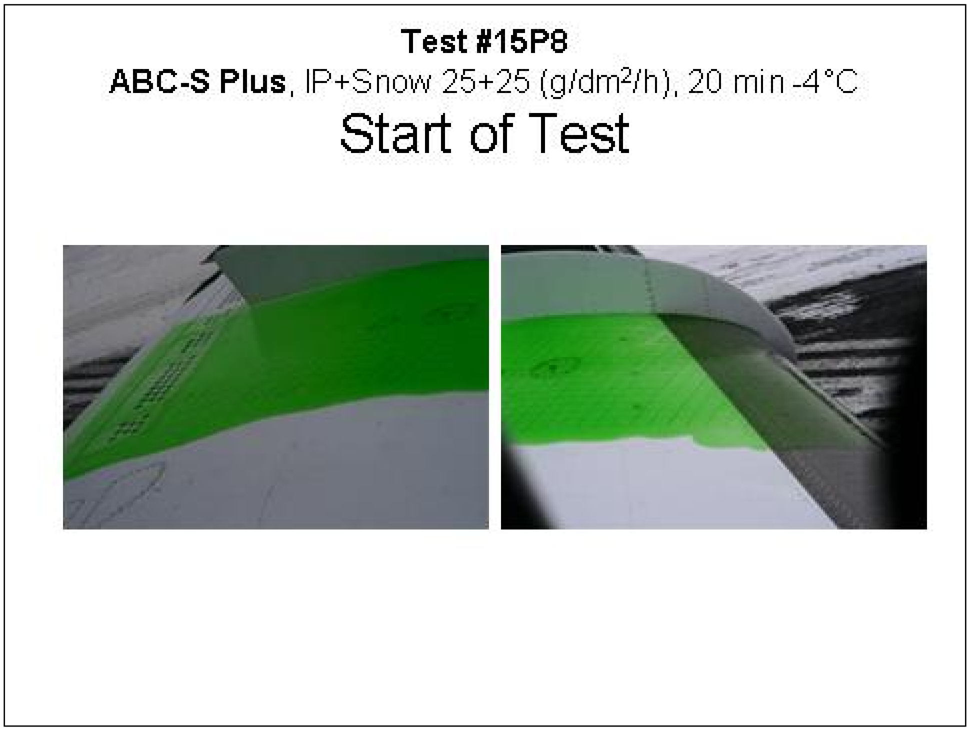


Photo 11.18: Test #15P8 – 17 Seconds

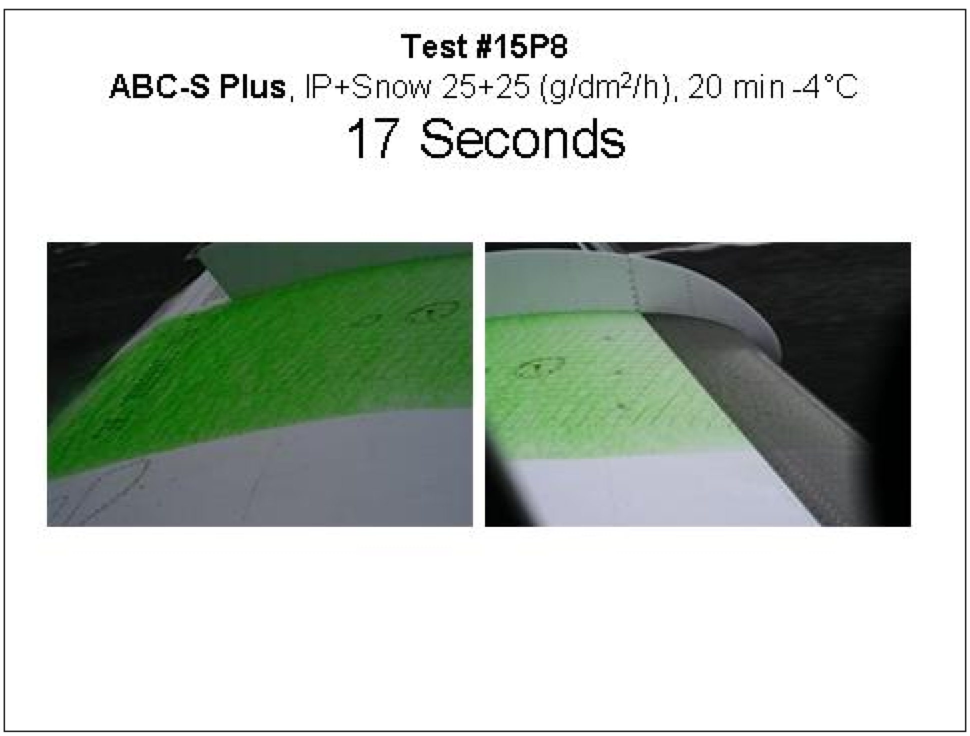


Photo 11.19: Test #15P8 – Rotation

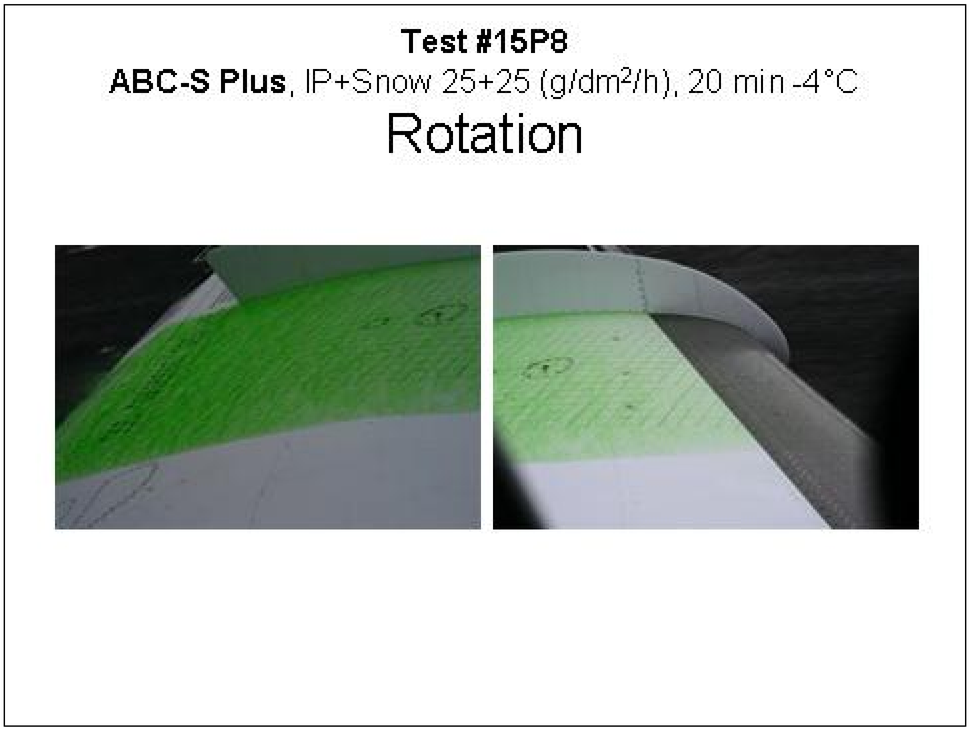


Photo 11.20: Test #15P8 – End of Test

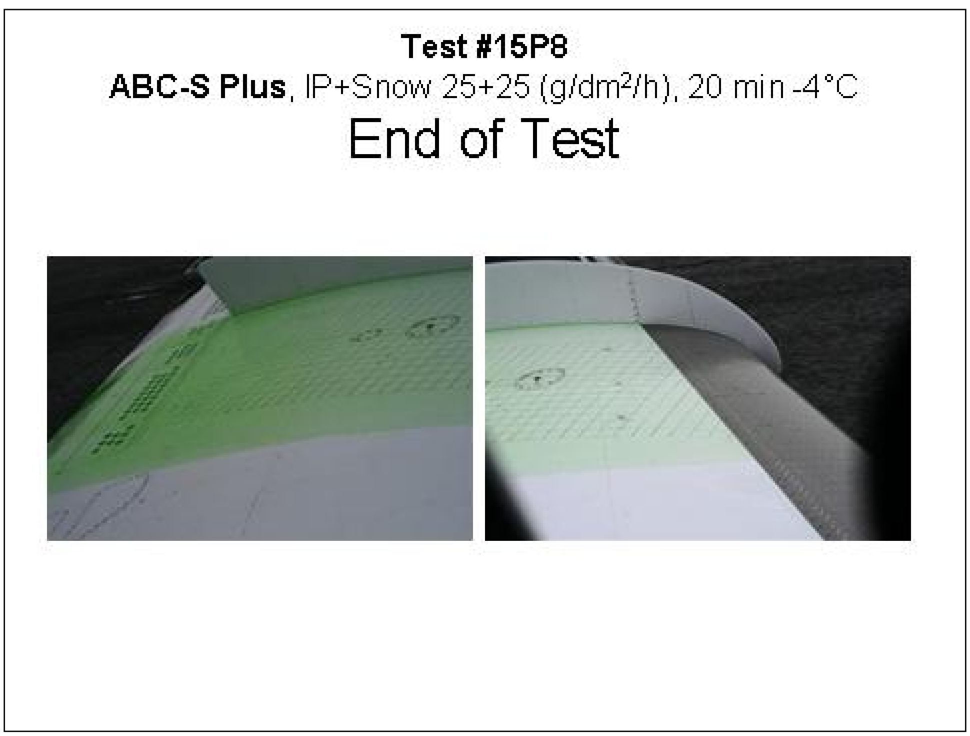


Photo 11.21: Test #15S8 – Start of Test

Photo 11.22: Test #15S8 – 17 Seconds

Photo 11.23: Test #15S8 – Rotation

Photo 11.24: Test #15S8 – End of Test

Photo 11.25: Test #16P8 – Start of Test

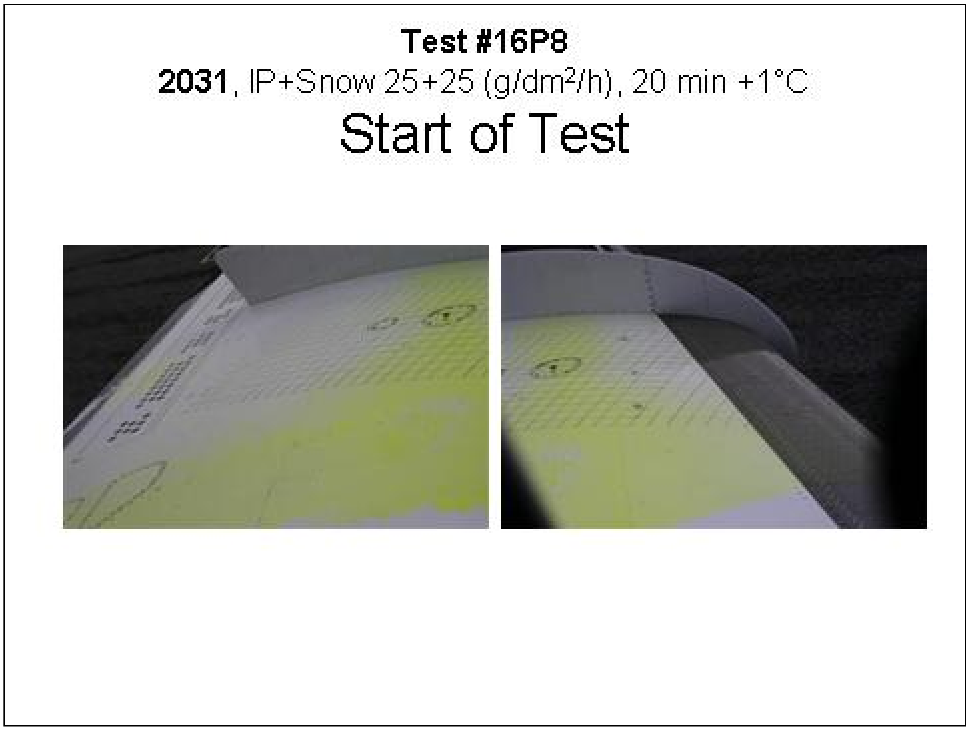


Photo 11.26: Test #16P8 – 17 Seconds

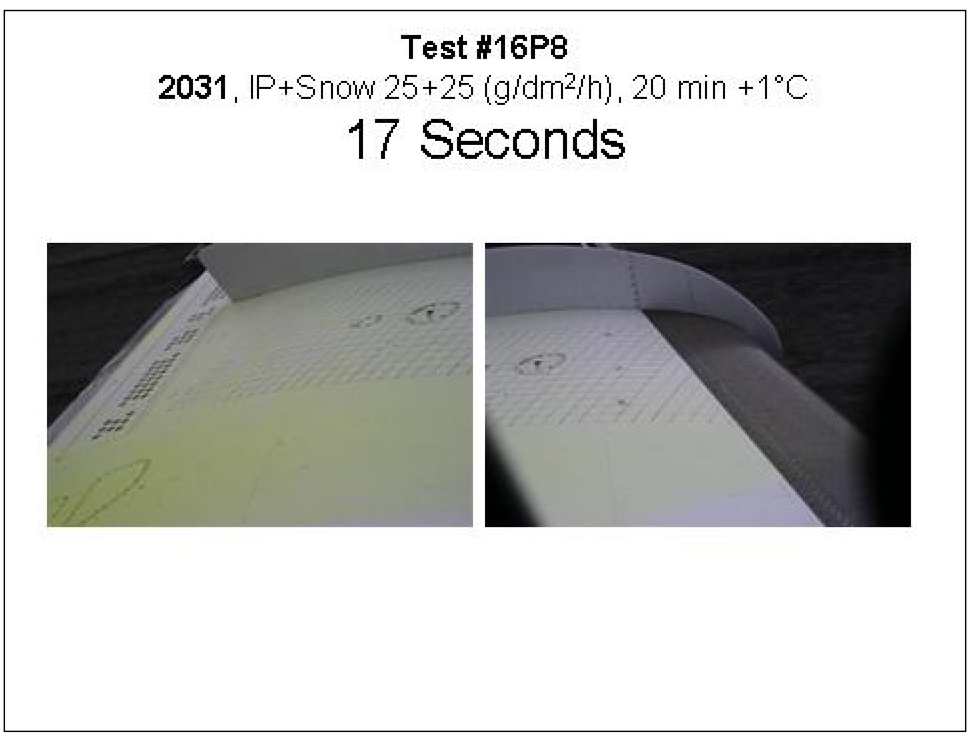


Photo 11.27: Test #16P8 – Rotation

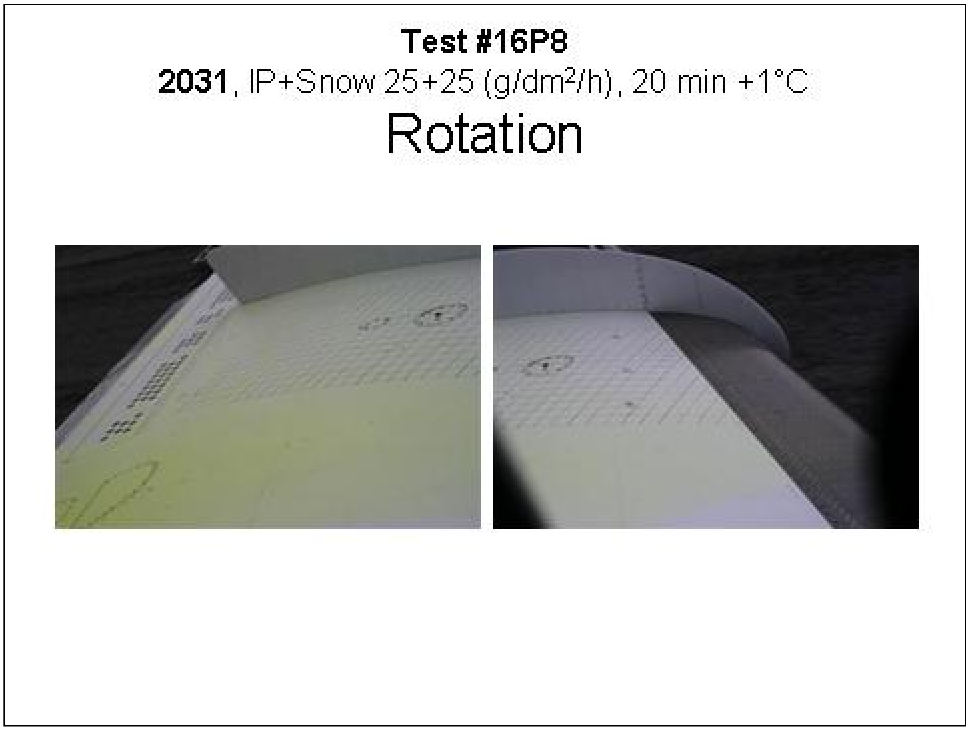


Photo 11.28: Test #16P8 – End of Test

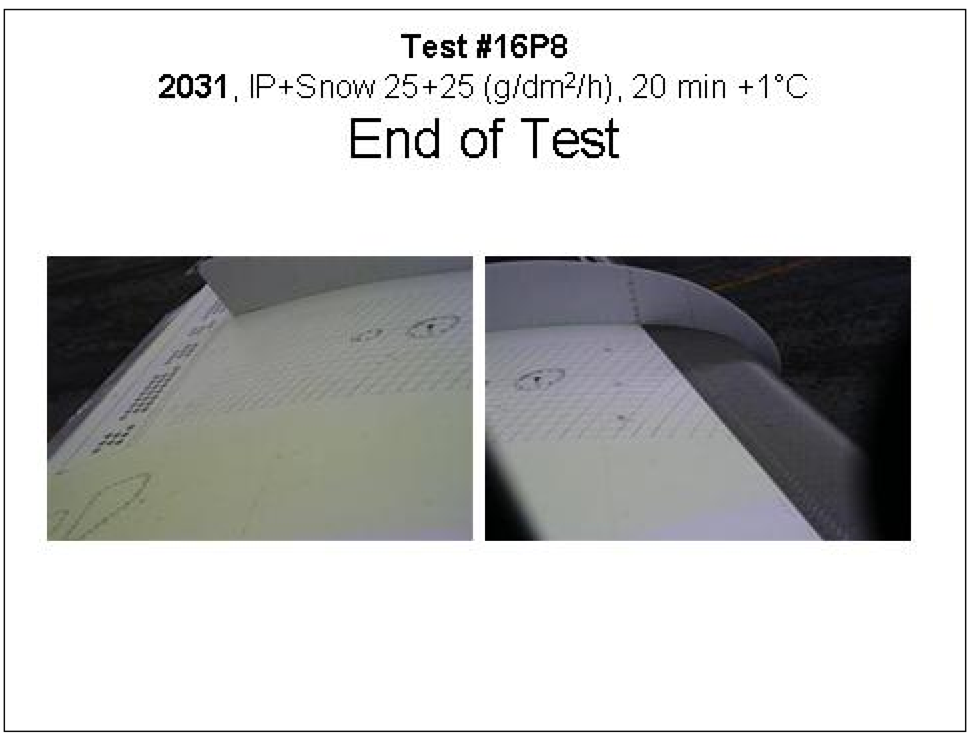


Photo 11.29: Test #16AP8 – Start of Test

No Photo Documentation Available

Photo 11.30: Test #16AP8 – 17 Seconds

No Photo Documentation Available

Photo 11.31: Test #16AP8 – Rotation

No Photo Documentation Available

Photo 11.32: Test #16AP8 – End of Test

No Photo Documentation Available

12. HIGH SPEED VS. LOW SPEED

The testing conducted during the winter of 2007-08 was geared towards investigating the possibility of expanding the current ice pellet allowance times for 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 fluid manufacturers for use on low rotation speed aircraft. Some airframe manufacturers have approved the use of Type IV on their low rotation speed turboprop aircraft; however, they have imposed speed penalties to compensate for the poor fluid flow-off at low speeds. 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 non-precipitation conditions. In addition, a mid-speed test (acceleration to 100 knots in approximately 21 seconds) was also conducted after having witnessed poor fluid flow-off at low rotation speeds during the 2007-08 testing.

This section provides an overview of each test conducted as part of the test program to evaluate the effect of aircraft rotation speed on the flow-off behaviour of anti-icing fluid. Testing was conducted in ice pellet conditions, mixed ice pellet and snow conditions, and no precipitation conditions. The parameters for each test are detailed, and a description of the data collected during each test is provided.

12.1 Overview of Tests

A summary of the baseline tests conducted using the Falcon 20 aircraft is shown in Table 12.1. The table provides relevant information for each of the tests, as well as final values used for the data analysis. Each row contains data specific to one test. A more detailed test log of all conditions tested using the Falcon 20 aircraft is provided in Subsection 4.1. The following is a brief description of the column headings for Table 12.1:

Run #: Exclusive number identifying each run.

Date: Date when the test was conducted.

Fluid: Aircraft deicing fluid specified by product name.

Condition: Simulated precipitation condition.

IP Rate (g/dm²/h):	Average simulated ice pellet precipitation rate, measured in g/dm²/h.
SN Rate (g/dm²/h):	Average simulated snow precipitation rate, measured in g/dm²/h.
Precip. Time (min.):	Total time of exposure to simulated precipitation.
OAT at Start of Test (°C):	The outside air temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.
Avg. Wing Temp.:	Average wing skin temperature.
After Fluid Appl. (°C):	Wing temperature following fluid application, measured in degrees Celsius.
Takeoff Profile:	Description of the takeoff acceleration and velocity of the aircraft during the test run.
Comments:	General comments regarding the objective of the test.

Table 12.1: Summary of 2007-08 High Speed vs. Low Speed Testing with Falcon 20 Aircraft

Run No.	Date	Fluid	Condition	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Precip. Time (min.)	OAT at Start of Test (°C)	AVG Wing Temp. After Fluid Appl. (°C)	Takeoff Profile	Comments
3P	28-Feb-07	ABC-S	Baseline	N/A	N/A	N/A	-8	-10.5	~120 knots in 25 sec	High Speed, Extended Flaps, Rotation
4S	28-Feb-07	ABC-S	Baseline	N/A	N/A	N/A	-10	-6	~120 knots in 25 sec	High Speed, Extended Flaps, Rotation
5S	1-Mar-07	Ultra+	Baseline	N/A	N/A	N/A	-11	-14	~120 knots in 25 sec	High Speed, Extended Flaps, Rotation
6S	1-Mar-07	Ultra+	Baseline	N/A	N/A	N/A	-11	-3	~120 knots in 25 sec	High Speed, Extended Flaps, Rotation
1P8	26-Feb-08	ABC-S Plus	IP	77	7.5*	25	-1	3.2	78 knots in 21 sec	Low Speed, Retracted Flaps, No Rotation
1S8	26-Feb-08	ABC-S Plus	Baseline	N/A	N/A (7.5*)	N/A	-1	2.6	78 knots in 21 sec	Low Speed, Retracted Flaps, No Rotation
3P8	27-Feb-08	EG106	IP	75	N/A	10	-11	-2.6	75 knots in 18 sec	Low Speed, Retracted Flaps, No Rotation
3S8	27-Feb-08	EG106	Baseline	N/A	N/A	N/A	-11	-3.1	75 knots in 18 sec	Low Speed, Retracted Flaps, No Rotation
7P8	28-Feb-08	ABC-S Plus	IP	75	N/A	10	-15	-2.2	74 knots in 19 sec	Low Speed, Retracted Flaps, No Rotation
7S8	28-Feb-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-15	-7.5	74 knots in 19 sec	Low Speed, Retracted Flaps, No Rotation
10P8	29-Feb-08	EG106	Baseline	N/A	N/A	N/A	-13	-5	90 knots in 22 sec	Mid Speed, Retracted Flaps, No Rotation
10S8	29-Feb-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-13	-3.4	90 knots in 22 sec	Mid Speed, Retracted Flaps, No Rotation
12P8	4-Mar-08	ABC-S Plus	IP	75	N/A	25	-3	3.4	72 knots in 22 sec	Low Speed, Extended Flaps, No Rotation
12S8	4-Mar-08	ABC-S Plus	Baseline	N/A	N/A	N/A	-3	2.7	72 knots in 22 sec	Low Speed, Extended Flaps, No Rotation
13P8	4-Mar-08	EG106	IP	75	N/A	25	-5	3.4	71 knots in 19 sec	Low Speed, Extended Flaps, No Rotation
13S8	4-Mar-08	EG106	Baseline	N/A	N/A	N/A	-5	2.7	71 knots in 19 sec	Low Speed, Extended Flaps, No Rotation

* Natural snow during test.

12.2 Data Collected

12.2.1 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the wind tunnel tests and Falcon 20 tests are described in Subsection 2.1.11.1. Fluid thickness measurements were recorded at the following intervals:

- Falcon 20 Tests:

- Approximately 5 minutes after fluid application;
- After the application of contamination (on the test wing, not the fluid only wing);
- Before the takeoff test; and
- After the takeoff test (end of test).

Tables 12.2 to 12.17 show the fluid thickness measurements collected during the tests.

Table 12.2: Test #3P Fluid Thickness Data

TEST 3P: ABC-S, fluid only, OAT -8°C				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	1.1	N/A	N/A	0.1
2	1.7	N/A	N/A	0.2
5	3.5	N/A	N/A	0.2
7	2.2	N/A	N/A	0.2
8	1.6	N/A	N/A	0.2

Table 12.3: Test #4S Fluid Thickness Data

TEST 4S: ABC-S, fluid only, OAT -10°C				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	0.5	N/A	N/A	0.0
2	1.7	N/A	N/A	0.0
5	3.3	N/A	N/A	0.2
7	1.5	N/A	N/A	0.3
8	0.7	N/A	N/A	0.2

Table 12.4: Test #5S Fluid Thickness Data

TEST 5S: Ultra+, fluid only, OAT -11°C				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	1.1	N/A	N/A	0.1
2	2.2	N/A	N/A	0.2
5	4.5	N/A	N/A	0.2
7	2.2	N/A	N/A	0.2
8	2.2	N/A	N/A	0.2

Table 12.5: Test #6S Fluid Thickness Data

TEST 6S: Ultra+, fluid only, OAT -11°C				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	1.1	N/A	N/A	0.0
2	2.2	N/A	N/A	0.1
5	3.7	N/A	N/A	0.2
7	2.5	N/A	N/A	0.2
8	1.2	N/A	N/A	0.2

Table 12.6: Test #1P8 Fluid Thickness Data

RUN 1P8: ABC-S+, IP/SN, OAT -1°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.5	1.8	0.6	0.1
5	4.5	5.7	3.9	0.5
7	2.9	3.5	0.5	1
8	3.1	3.7	0.3	1

Table 12.7: Test #1S8 Fluid Thickness Data

RUN 1S8: ABC-S+, fluid only (natural snow during test), OAT -1°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	-	-	0.6
5	4.5	-	-	0.5
7	3.1	-	-	1.2
8	3.1	-	-	1.3

Table 12.8: Test #3P8 Fluid Thickness Data

RUN 3P8: EG 106, IP, OAT -11°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	1.4	1.1	0.2
5	3.5	3.5	2.9	0.3
7	2.2	2.2	1.2	0.6
8	2.2	1.1	0.5	0.6

Table 12.9: Test #3S8 Fluid Thickness Data

RUN 3S8: EG 106, fluid only, OAT -11°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.5	N/A	N/A	0.3
5	3.9	N/A	N/A	0.3
7	1.8	N/A	N/A	0.6
8	2.2	N/A	N/A	0.7

Table 12.10: Test #7P8 Fluid Thickness Data

RUN 7P8: ABC-S+, IP, OAT -15°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.4	2.2	2.2	0.4
5	4.5	4.5	3.9	0.7
7	2.2	2.9	3.1	2.9
8	2.2	3.3	2.7	2.9

Table 12.11: Test #7S8 Fluid Thickness Data

RUN 7S8: ABC-S+, fluid only, OAT -15ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.3
5	4.5	N/A	N/A	0.4
7	1.8	N/A	N/A	1.4
8	1.8	N/A	N/A	1.4

Table 12.12: Test #10P8 Fluid Thickness Data

RUN 10P8: EG 106, fluid only, OAT -13ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.3
5	3.1	N/A	N/A	0.3
7	2.5	N/A	N/A	0.7
8	3.1	N/A	N/A	0.5

Table 12.13: Test #10S8 Fluid Thickness Data

RUN 10S8: ABC-S+, fluid only, OAT -13ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.3
5	4.5	N/A	N/A	0.3
7	2.9	N/A	N/A	0.7
8	3.1	N/A	N/A	1.1

Table 12.14: Test #12P8 Fluid Thickness Data

RUN 12P8: ABC-S+, IP, OAT -3ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	1.8	1.1	2.2	0.3
5	4.5	4.5	3.9	0.3
7	1.8	1.7	0.5	0.6
8	2.2	1.8	0.5	0.3

Table 12.15: Test #12S8 Fluid Thickness Data

RUN 12S8: ABC-S+, fluid only, OAT -3ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	1.8	N/A	0.3
5	4.5	3.9	N/A	0.3
7	2.5	2.5	N/A	0.4
8	2.2	2.5	N/A	0.5

Table 12.16: Test #13P8 Fluid Thickness Data

RUN 13P8: EG 106, IP, OAT -5ºC				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	0.4	0.2	0
5	2.9	2.9	2.2	0.3
7	1.8	0.6	0.1	0.5
8	1.8	0.6	0.3	0.2

Table 12.17: Test #13S8 Fluid Thickness Data

RUN 13S8: EG 106, fluid only, OAT -5°C				
FLUID THICKNESS (mm)				
Wing Position	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
2	2.2	N/A	N/A	0.2
5	3.1	N/A	N/A	0.3
7	2.2	N/A	N/A	0.4
8	2.2	N/A	N/A	0.3

12.2.2 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the Falcon 20 tests are described in Subsection 2.1.11.3. Skin temperature measurements were recorded at the following intervals:

- Falcon 20 Tests:
  - Before fluid application;
  - After fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

The wing temperature measurements recorded during each test are shown in Tables 12.18 to 12.33.

Table 12.18: Test #3P Wing Skin Temperature Data

TEST 3P: ABC-S, fluid only, OAT -8°C				
Wing Position	Skin Temperature (°C)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
T1	-9.6	N/A	N/A	-9.8
T2	-9.5	N/A	N/A	-9.8
T3	-8.6	N/A	N/A	-10.1
T4	-9.0	N/A	N/A	-10.3
T5	-7.8	N/A	N/A	-9.6
T6	-7.8	N/A	N/A	-9.2
T7	-9.0	N/A	N/A	-8.7
T8	-9.1	N/A	N/A	-9.2

Table 12.19: Test #4S Wing Skin Temperature Data

TEST 4S: ABC-S, fluid only, OAT -10°C				
Wing Position	Skin Temperature (°C)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
T1	-8.3	N/A	N/A	5.5
T2	-8.3	N/A	N/A	4.8
T3	-7.3	N/A	N/A	1.8
T4	-7.0	N/A	N/A	0.5
T5	-6.6	N/A	N/A	-4.0
T6	-6.1	N/A	N/A	-3.8
T7	-3.3	N/A	N/A	-5.9
T8	-3.2	N/A	N/A	-5.7

Table 12.20: Test #5S Wing Skin Temperature Data

TEST 5S: Ultra+, fluid only, OAT -11°C				
Wing Position	Skin Temperature (°C)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
T1	-12.0	N/A	N/A	-8.7
T2	-12.1	N/A	N/A	-8.5
T3	-11.7	N/A	N/A	-11.0
T4	-11.6	N/A	N/A	-11.2
T5	-10.2	N/A	N/A	-12.5
T6	-10.1	N/A	N/A	-12.8
T7	-12.7	N/A	N/A	-12.7
T8	-12.8	N/A	N/A	-12.7

Table 12.21: Test #6S Wing Skin Temperature Data

TEST 6S: Ultra+, fluid only				
Wing Position	Skin Temperature (°C)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
T1	-3.6	N/A	N/A	1.9
T2	-3.7	N/A	N/A	0.7
T3	-6.4	N/A	N/A	0.9
T4	-6.1	N/A	N/A	-0.1
T5	-6.6	N/A	N/A	-4.9
T6	-6.4	N/A	N/A	-3.8
T7	-7.9	N/A	N/A	-6.4
T8	-7.1	N/A	N/A	-6.0

Table 12.22: Test #1P8 Wing Skin Temperature Data

RUN 1P8: ABC-S+, IP/SN, OAT -1°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	1.3	3.4	-2.4	3.4	3.0
T2	0.9	3.3	-4.8	1.9	2.6
T3	1.8	3.7	-3.7	2.9	3.8
T4	2.0	3.7	-5.5	2.7	3.8
T5	0.4	3.4	-3.9	1.8	2.8
T6	0.6	3.2	-4.0	1.1	2.4
T7	0.3	2.6	-6.4	0.8	2.4
T8	0.4	2.6	-6.3	0.9	2.5

Table 12.23: Test #1S8 Wing Skin Temperature Data

RUN 1S8: ABC-S+, fluid only, OAT -1°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	2.3	3.6	N/A	N/A	3.2
T2	2.2	3.4	N/A	N/A	2.9
T3	2.7	3.2	N/A	N/A	5.0
T4	2.7	3.0	N/A	N/A	5.3
T5	1.0	2.0	N/A	N/A	2.9
T6	1.0	1.8	N/A	N/A	3.2
T7	0.3	1.9	N/A	N/A	3.5
T8	0.3	2.1	N/A	N/A	4.2

Table 12.24: Test #3P8 Wing Skin Temperature Data

RUN 3P8: EG 106, IP, OAT -11ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-4.4	-5.0	-9.8	-2.1	-2.4
T2	-5.5	-4.5	-10.8	-3.2	-3.2
T3	-2.7	-2.4	-8.2	-1.7	1.6
T4	-3	-1.7	-9.3	-1.7	-2.4
T5	-3.8	-3.2	-6.0	-2.9	-5.1
T6	-4.7	-3.0	-7.0	-4.1	-6.3
T7	-2.7	-0.4	-7.3	-5.5	-3.5
T8	-3.4	-0.7	-7.5	-5.3	-3.6

Table 12.25: Test #3S8 Wing Skin Temperature Data

RUN 3S8: EG 106, fluid only, OAT -11ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-7.2	-5.9	N/A	N/A	-6.8
T2	-7.0	-6.5	N/A	N/A	-6.8
T3	-4.2	-3.1	N/A	N/A	-4.6
T4	-4.5	-3.0	N/A	N/A	-4.6
T5	-5.5	-2.9	N/A	N/A	-5.5
T6	-5.5	-2.2	N/A	N/A	-5.8
T7	-4.2	-1.1	N/A	N/A	-5.2
T8	-3.3	-0.3	N/A	N/A	-8.2

Table 12.26: Test #7P8 Wing Skin Temperature Data

RUN 7P8: ABC-S+, IP, OAT -15°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-5.1	-2.1	-5.9	-6.5	-2.5
T2	-5.4	-2.7	-6.7	-8.3	-4.6
T3	-2.9	1.0	-4.7	-2.4	-1.2
T4	-4.5	-1.1	-6.7	-4.4	-1.4
T5	-5.5	-2.9	-5.1	-3.8	-4.7
T6	-7.6	-6.7	-7.9	-6.2	-7.0
T7	-7.4	-1.1	-9.5	-10.0	-6.9
T8	-6.6	-2.2	-8.5	-9.0	-6.4

Table 12.27: Test #7S8 Wing Skin Temperature Data

RUN 7S8: ABC-S+, fluid only, OAT -15°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	-9.9	-8.8	N/A	N/A	-8.1
T2	-10.8	-8.8	N/A	N/A	-8.8
T3	-5.5	-3.7	N/A	N/A	-4.0
T4	-6.2	-4.2	N/A	N/A	-4.6
T5	-6.9	-4.6	N/A	N/A	-5.1
T6	-7.3	-4.6	N/A	N/A	-5.3
T7	-13.3	-11.6	N/A	N/A	-11.8
T8	-14.0	-13.5	N/A	N/A	-12.5

Table 12.28: Test #10P8 Wing Skin Temperature Data

RUN 10P8: EG 106, fluid only, OAT -13ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	-5.8	N/A	N/A	-6.1
T2	N/A	-5.8	N/A	N/A	-6.5
T3	N/A	-3.9	N/A	N/A	-3.8
T4	N/A	-3.7	N/A	N/A	-4.1
T5	N/A	-4.8	N/A	N/A	-5.8
T6	N/A	-5.7	N/A	N/A	-6.3
T7	N/A	-6.2	N/A	N/A	-6.6
T8	N/A	-3.8	N/A	N/A	-4.4

Table 12.29: Test #10S8 Wing Skin Temperature Data

RUN 10S8: ABC-S+, fluid only, OAT -13ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	-3.4	N/A	N/A	-5.5
T2	N/A	-2.8	N/A	N/A	-5.7
T3	N/A	-2.0	N/A	N/A	-5.7
T4	N/A	-1.1	N/A	N/A	-2.4
T5	N/A	-4.9	N/A	N/A	-5.0
T6	N/A	-4.2	N/A	N/A	-4.4
T7	N/A	-4.7	N/A	N/A	-2.2
T8	N/A	-4.1	N/A	N/A	-3.0

Table 12.30: Test #12P8 Wing Skin Temperature Data

RUN 12P8: ABC-S+, IP, OAT -3°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	2.1	1.6	-0.2	6.2	0.6
T2	2.0	1.8	-3.1	3.7	0.4
T3	2.9	4.2	1.6	9.0	2.8
T4	3.2	4.4	-2.9	11.2	2.6
T5	3.0	4.8	-0.1	7.5	2.8
T6	3.2	4.8	-1.9	6.0	2.8
T7	1.2	2.8	-5.1	1.0	0.2
T8	1.0	2.4	-5.5	1.2	0.7

Table 12.31: Test #12S8 Wing Skin Temperature Data

RUN 12S8: ABC-S+, fluid only, OAT -3°C					
WING TEMPERATURE (°C)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	0.9	1.2	N/A	N/A	0.5
T2	1.2	1.0	N/A	N/A	-0.5
T3	2.5	4.2	N/A	N/A	2.7
T4	3.2	4.3	N/A	N/A	3.4
T5	3.5	4.4	N/A	N/A	2.2
T6	2.5	4.2	N/A	N/A	1.9
T7	0.2	1.1	N/A	N/A	0.3
T8	-0.1	1.0	N/A	N/A	0.4

Table 12.32: Test #13P8 Wing Skin Temperature Data

RUN 13P8: EG 106, IP, OAT -5ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	2.5	-0.7	3.4	3.5
T2	N/A	1.6	-3.0	2.0	3.4
T3	N/A	4.7	1.4	4.5	4.7
T4	N/A	4.1	-3.0	3.4	5.4
T5	N/A	4.1	-1.4	3.2	1.8
T6	N/A	3.7	-4.2	2.0	1.5
T7	N/A	3.4	-4.2	-2.2	0.6
T8	N/A	2.9	-4.2	-1.0	0.4

Table 12.33: Test #13S8 Wing Skin Temperature Data

RUN 13S8: EG 106, fluid only, OAT -5ºC					
WING TEMPERATURE (ºC)					
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
T1	N/A	0.2	N/A	N/A	-0.6
T2	N/A	0.5	N/A	N/A	0.1
T3	N/A	3.7	N/A	N/A	3.3
T4	N/A	3.7	N/A	N/A	2.5
T5	N/A	3.9	N/A	N/A	2.0
T6	N/A	4.1	N/A	N/A	1.9
T7	N/A	2.3	N/A	N/A	1.6
T8	N/A	2.9	N/A	N/A	-0.8

12.2.3 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the Falcon 20 tests are described in Subsection 2.1.11.2. Fluid Brix measurements were recorded at the following intervals:

- Falcon 20 Tests:
  - After fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

Tables 12.34 to 12.49 show the fluid Brix measurements collected during the tests.

Table 12.34: Test #3P Fluid Brix Data

TEST 3P: ABC-S, fluid only, OAT -8°C				
Wing Position	Fluid Brix (°)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
2	37.00	N/A	N/A	38.50
5	37.00	N/A	N/A	34.00

Table 12.35: Test #4S Fluid Brix Data

TEST 4S: ABC-S, fluid only, OAT -10°C				
Wing Position	Fluid Brix (°)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
2	37.00	N/A	N/A	N/A
5	37.00	N/A	N/A	N/A

Table 12.36: Test #5S Fluid Brix Data

TEST 5S: Ultra+, fluid only, OAT -11°C				
Wing Position	Fluid Brix (°)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
2	41.50	N/A	N/A	41.00
5	41.50	N/A	N/A	41.00

Table 12.37: Test #6S Fluid Brix Data

TEST 6S: Ultra+, fluid only, OAT -11°C				
Wing Position	Fluid Brix (°)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
2	41.00	N/A	N/A	49.00
5	41.00	N/A	N/A	43.00

Table 12.38: Test #1P8 Fluid Brix Data

RUN 1P8: ABC-S+, IP/SN, OAT -1°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	35	15	14	7.25
B8	34.5	16	10	23

Table 12.39: Test #1S8 Fluid Brix Data

RUN 1S8: ABC-S+, fluid only, OAT -1°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	36	N/A	N/A	26.5
B8	35	N/A	N/A	32

Table 12.40: Test #3P8 Fluid Brix Data

RUN 3P8: EG 106, IP, OAT -11°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	34.25	27	26.25	30.5
B8	33.5	23	26	29.5

Table 12.41: Test #3S8 Fluid Brix Data

RUN 3S8: EG 106, fluid only, OAT -11°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	34	N/A	N/A	36.5
B8	34	N/A	N/A	35

Table 12.42: Test #7P8 Fluid Brix Data

RUN 7P8: ABC-S+, IP, OAT -15°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37.25	27	19	26.5
B8	37.5	22	22	28

Table 12.43: Test #7S8 Fluid Brix Data

RUN 7S8: ABC-S+, fluid only, OAT -15°C				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37.5	N/A	N/A	38
B8	37.5	N/A	N/A	38

Table 12.44: Test #10P8 Fluid Brix Data

RUN 10P8: EG 106, fluid only, OAT -13ºC				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	33.25	N/A	N/A	36.25
B8	33.5	N/A	N/A	34

Table 12.45: Test #10S8 Fluid Brix Data

RUN 10S8: ABC-S+, fluid only, OAT -13ºC				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37.25	N/A	N/A	39.25
B8	37.25	N/A	N/A	38

Table 12.46: Test #12P8 Fluid Brix Data

RUN 12P8: ABC-S+, IP, OAT -3ºC				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37	26	21	28
B8	37	17.5	13.25	22

Table 12.47: Test #12S8 Fluid Brix Data

RUN 12S8: ABC-S+, fluid only, OAT -3ºC				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	37	N/A	N/A	40
B8	37	N/A	N/A	38

Table 12.48: Test #13P8 Fluid Brix Data

RUN 13P8: EG 106, IP, OAT -5ºC				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	33.5	12.5	21	39
B8	33	12	12	26

Table 12.49: Test #13S8 Fluid Brix Data

RUN 13S8: EG 106, fluid only, OAT -5ºC				
Wing Position	FLUID BRIX (°)			
	After Fluid Application	After Precip. Application	Before Takeoff Run	After Takeoff Run
B2	33	N/A	N/A	40
B8	33.5	N/A	N/A	35.5

12.3 Photos

High-speed digital photographs of each test were taken; photos were taken of the leading edge, the trailing edge, or both. For each test, photo summaries have been compiled comprising four stages:

- Start of test;
- 17 seconds after start of test;
- Time of rotation; and
- End of test.

Photos 12.1 to 12.64 show the photo summaries for Tests #3P, #4S, #5S, #6S, #1P8, #1S8, #3P8, #3S8, #7P8, #7S8, #10P8, #10S8, #12P8, #12S8, #13P8, and #13S8. During the tests where photos were not taken, a note has been included indicating “No Photo Documentation Available.” A compilation of selected high-speed photos taken during Test #7S8 are included in Appendix G. A complete set of photos will be provided to the TDC.

12.4 General Observations

A comparison of the residual fluid thickness at the end of the Falcon 20 high-speed test runs conducted during the winter of 2006-07 has been compiled and is demonstrated in Table 12.50. Comparison tables of the residual fluid thickness at the end of the Falcon 20 mid-speed and low-speed test runs conducted during the winter of 2007-08 have been compiled and are demonstrated in Tables 12.51 to 12.53. The shaded cells indicate measurements where the fluid thickness measured was greater than the respective comparison test run.

The results from the low-speed comparative testing in ice pellet conditions (and mixed ice pellets with natural snow) indicated that fluid flow-off is comparable for both contaminated and non-contaminated fluid at warmer temperatures (Runs #1P/S8, 3P/S8, 12P/S8, and 13P/S8); discrepancies were generally minimal. It should be noted that the natural snow conditions during Run #1S8 may have accounted for the increased fluid thickness on both the leading and trailing edge. At the colder temperatures (Run #7P/S8), the contaminated test run demonstrated significantly more residual fluid post-run compared to the fluid only test: up to twice as much residual fluid.

Table 12.50: Comparison of Falcon 20 Residual Fluid Thickness – 2006-07 High Speed Tests

Wing Position	Fluid Thickness After Takeoff Run (mm)			
	Run #3P	Run #4S	Run #5S	Run #6S
	Ext. Flaps	*Ext. Flaps*	*Ext. Flaps*	*Ext. Flaps*
	ABC-S	*ABC-S*	*Ultra+*	*Ultra+*
	No Contamination	*No Contamination*	*No Contamination*	*No Contamination*
2	0.2	0	0.2	0.1
5	0.2	0.2	0.2	0.2
7	0.2	0.3	0.2	0.2
8	0.2	0.2	0.2	0.2

Table 12.51: Comparison of Falcon 20 Residual Fluid Thickness – 2007-08 Mid Speed Tests

Wing Position	Fluid Thickness After Takeoff Run (mm)		
	Run #10P8		Run #10S8
	Retr. Flaps		*Retr. Flaps*
	EG 106		*ABC-S Plus*
	No Contamination		*No Contamination*
2	0.3		0.3
5	0.3		0.3
7	0.7		0.7
8	0.5		1.1

Table 12.52: Comparison of Falcon 20 Residual Fluid Thickness – 2007-08 Low Speed Tests With Retracted Flaps

Wing Position	Fluid Thickness After Takeoff Run (mm)							
	Run #1P8	Run #1S8		Run #3P8	Run #3S8		Run #7P8	Run #7S8
	Retr. Flaps	*Retr. Flaps*		*Retr. Flaps*	*Retr. Flaps*		*Retr. Flaps*	*Retr. Flaps*
	ABC-S Plus	*ABC-S Plus*		*EG 106*	*EG 106*		*ABC-S Plus*	*ABC-S Plus*
	Ice Pellet Contamination *	*No Contamination* *		*Ice Pellet Contamination*	*No Contamination*		*Ice Pellet Contamination*	*No Contamination*
2	0.1	0.6		0.2	0.3		0.4	0.3
5	0.5	0.5		0.3	0.3		0.7	0.4
7	1	1.2		0.6	0.6		2.9	1.4
8	1	1.3		0.6	0.7		2.9	1.4

* Natural Snow During Test

Table 12.53: Comparison of Falcon 20 Residual Fluid Thickness – 2007-08 Low Speed Tests With Extended Flaps

Wing Position	Fluid Thickness After Takeoff Run (mm)			
	Run #12P8	Run #12S8	Run #13P8	Run #13S8
	Ext. Flaps	*Ext. Flaps*	*Ext. Flaps*	*Ext. Flaps*
	ABC-S Plus	*ABC-S Plus*	*EG 106*	*EG 106*
	Ice Pellet Contamination	*No Contamination*	*Ice Pellet Contamination*	*No Contamination*
2	0.3	0.3	0	0.2
5	0.3	0.3	0.3	0.3
7	0.6	0.4	0.5	0.4
8	0.3	0.5	0.2	0.3

When comparing the residual fluid of the low-speed runs to the high-speed runs of the previous year, the residual fluid post-run was significantly greater during the low-speed runs with retracted flaps: up to 7 times greater. The same was true for the mid-speed tests, where the residual fluid was in some cases more than 5 times greater compared to the previous year's high-speed tests. However, during the low-speed tests with extended flaps, the residual fluid was generally reduced to 2-3 times greater compared to the previous year's high-speed tests. The effect of the extended flaps significantly improved fluid flow-off, as described in Section 5.

Fluid elimination problems with Type IV fluids at lower rotation speeds appear to be a fluid issue rather than a contamination issue. Even fluid only tests were demonstrating significant amounts of residual fluid post-run at low rotation speeds. Extended flaps significantly helped fluid elimination prior to rotation; however, residual trailing edge fluid was still greater during the low-speed runs by a factor of two or more when compared to the previous year's high-speed test runs. The general trend indicated that as the speed was increased, fluid elimination was improved.

12.4.1 Conclusions and Recommendations for Future Work

The aerodynamic effects of this residual fluid for low-speed aircraft needs to be further investigated in the NRC wind tunnel. Aerodynamic lift data is required to determine potential lift losses associated with residual fluid, both contaminated and uncontaminated, at the time of rotation. Previous high-speed wind tunnel testing demonstrated acceptable lift losses for fluid contaminated with ice pellets at colder temperatures, where residual fluid is greatest. It is recommended that low rotation speed testing in ice pellet conditions be conducted at colder temperatures (below 10°C) to investigate potential lift losses associated with anti-icing fluid flow-off.

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Photo 12.1: Test #3P – Start of Test

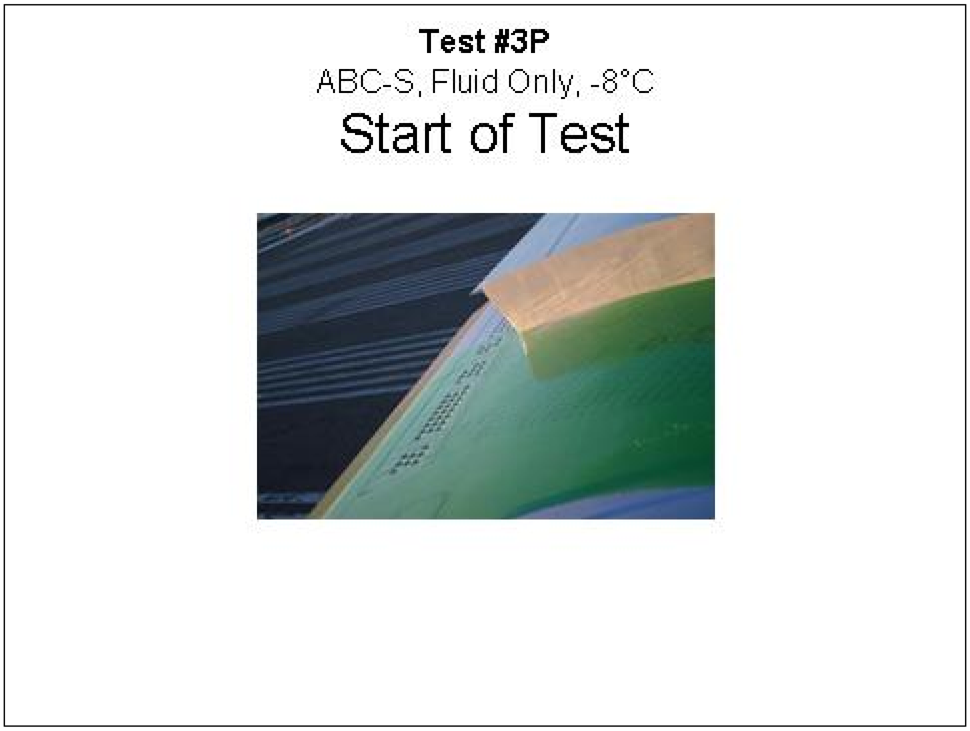


Photo 12.2: Test #3P – 17 seconds

Photo 12.3: Test #3P – Rotation

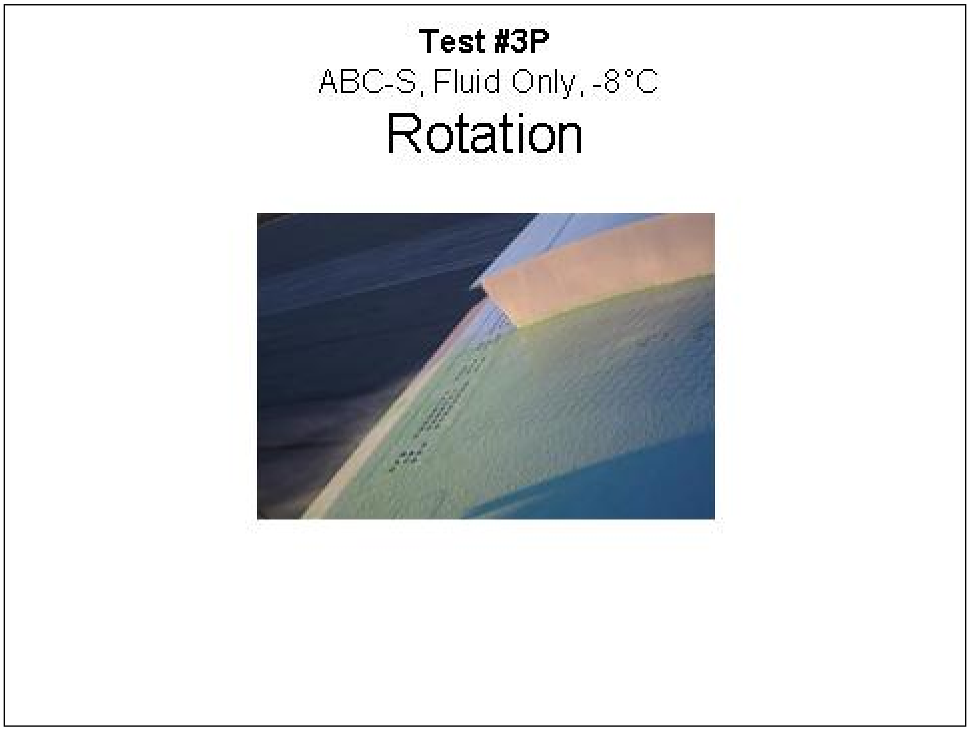


Photo 12.4: Test #3P – End of Test

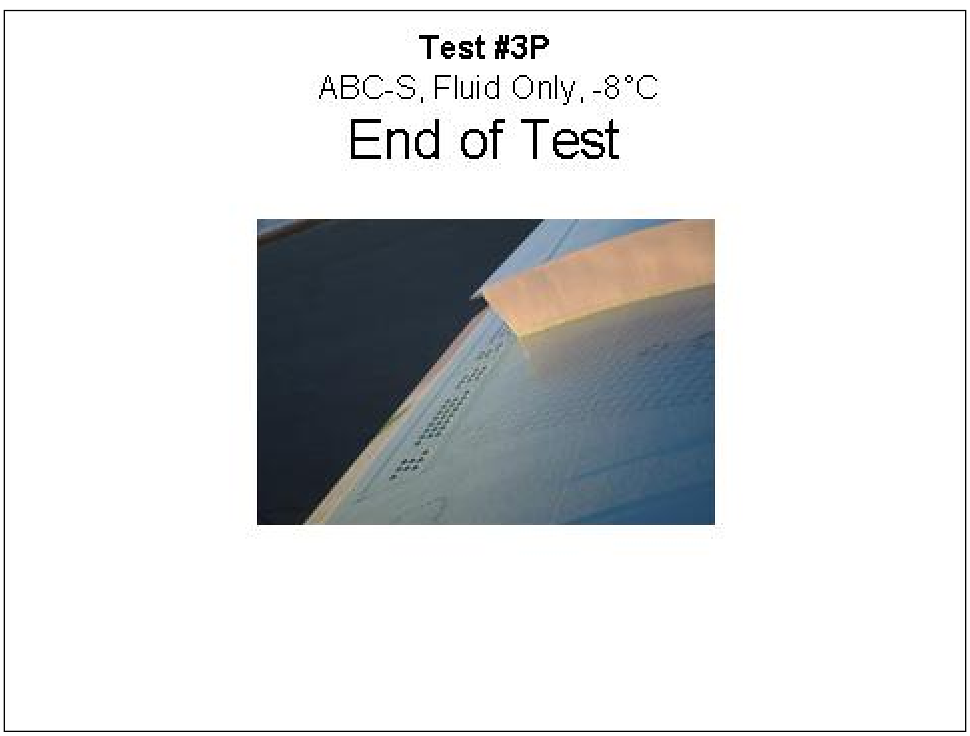


Photo 12.5: Test #4S – Start of Test

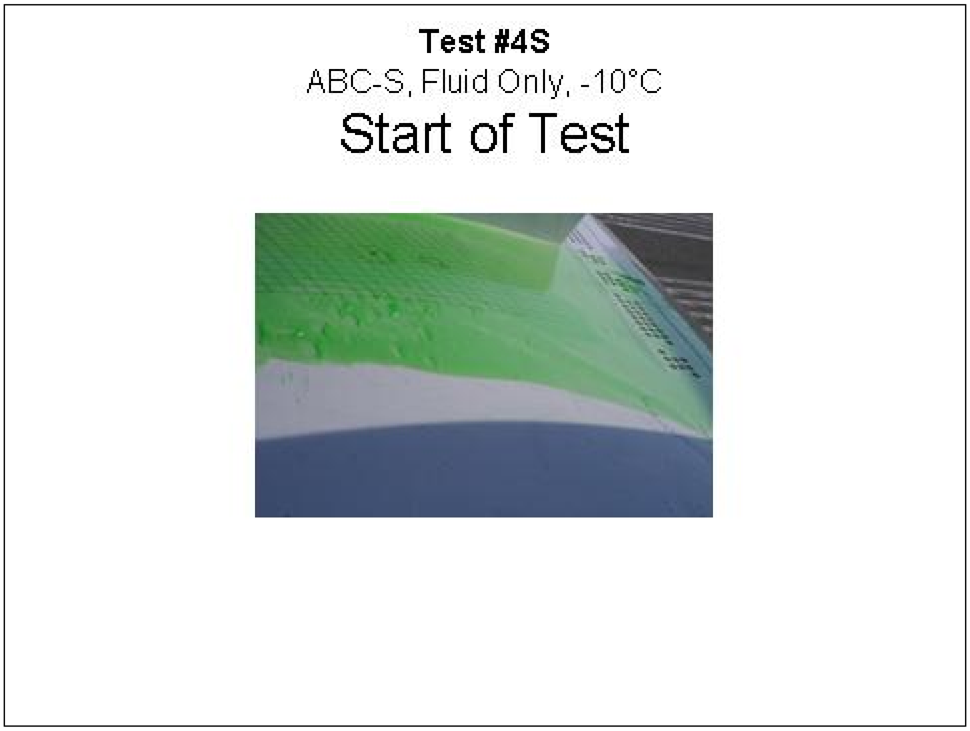


Photo 12.6: Test #4S – 17 seconds

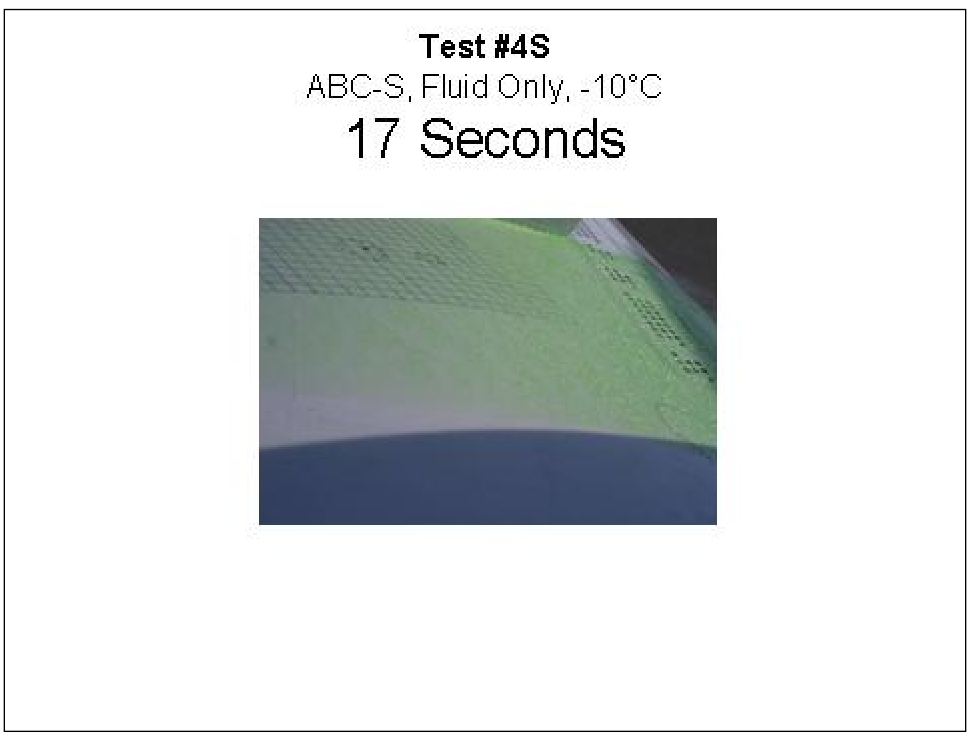


Photo 12.7: Test #4S – Rotation

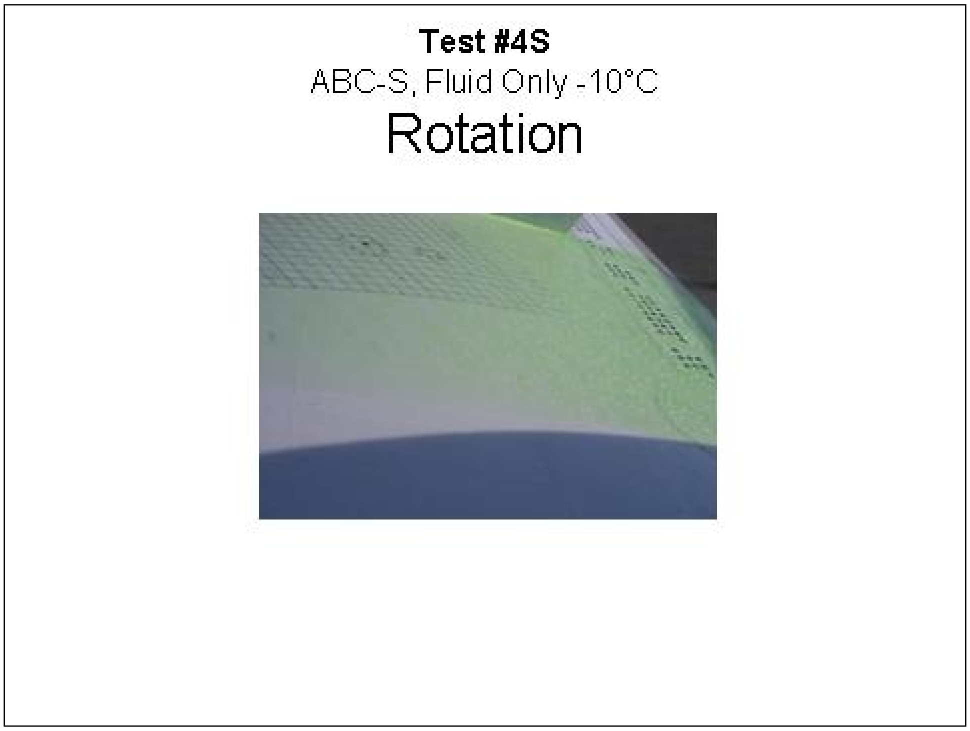


Photo 12.8: Test #4S – End of Test

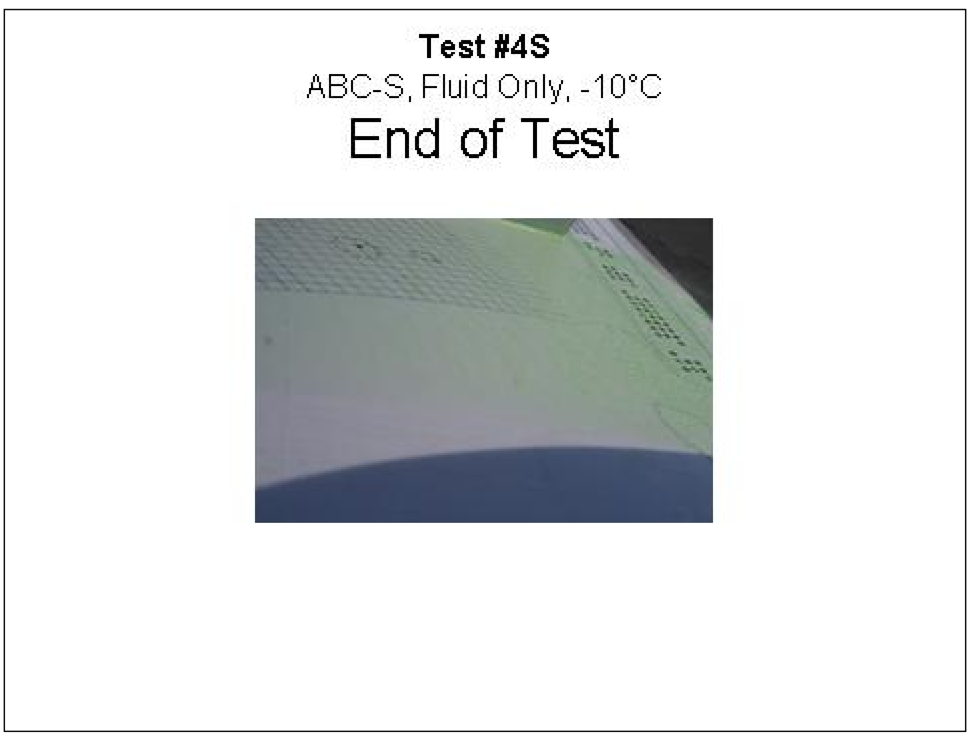


Photo 12.9: Test #5S – Start of Test

Photo 12.10: Test #5S – 17 seconds

Photo 12.11: Test #5S – Rotation

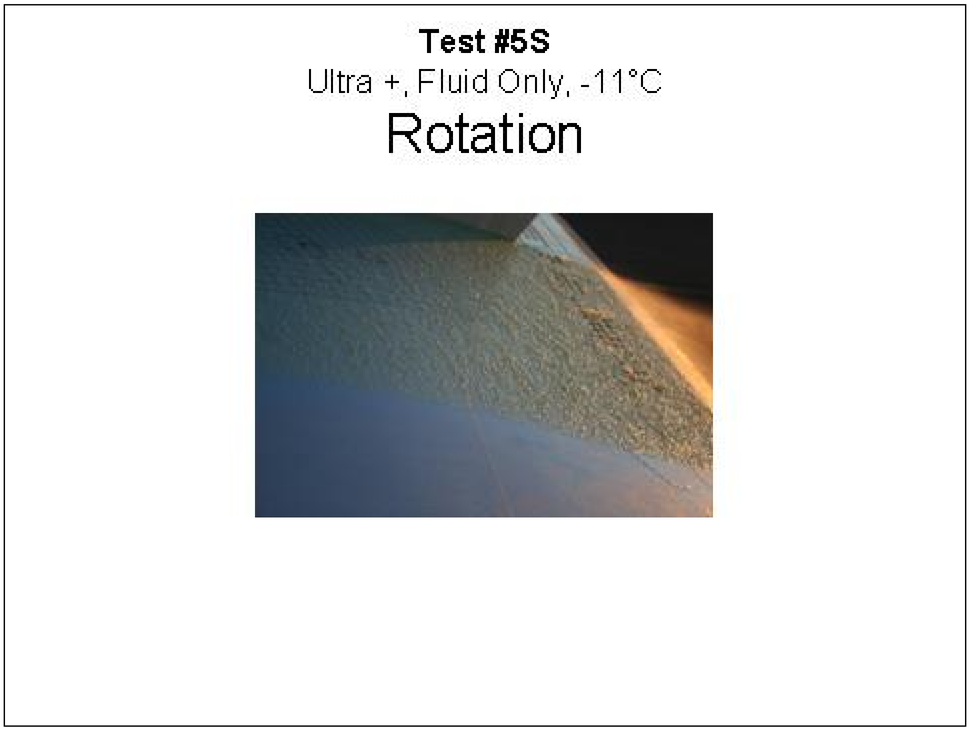


Photo 12.12: Test #5S – End of Test

Photo 12.13: Test #6S – Start of Test

Photo 12.14: Test #6S – 17 seconds

Photo 12.15: Test #6S – Rotation

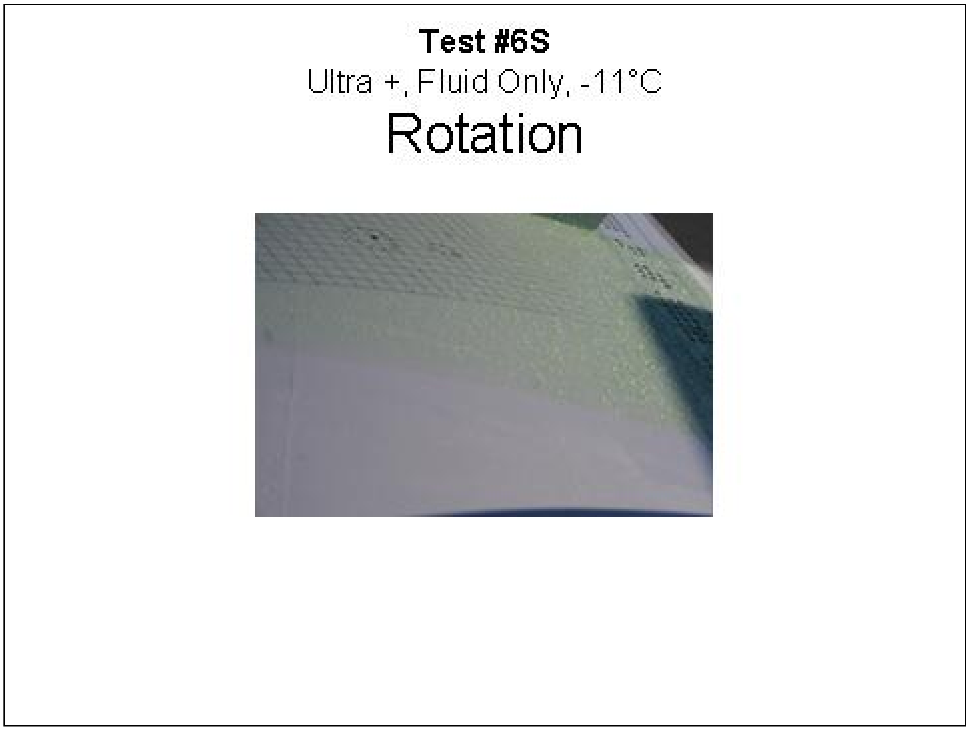


Photo 12.16: Test #6S – End of Test

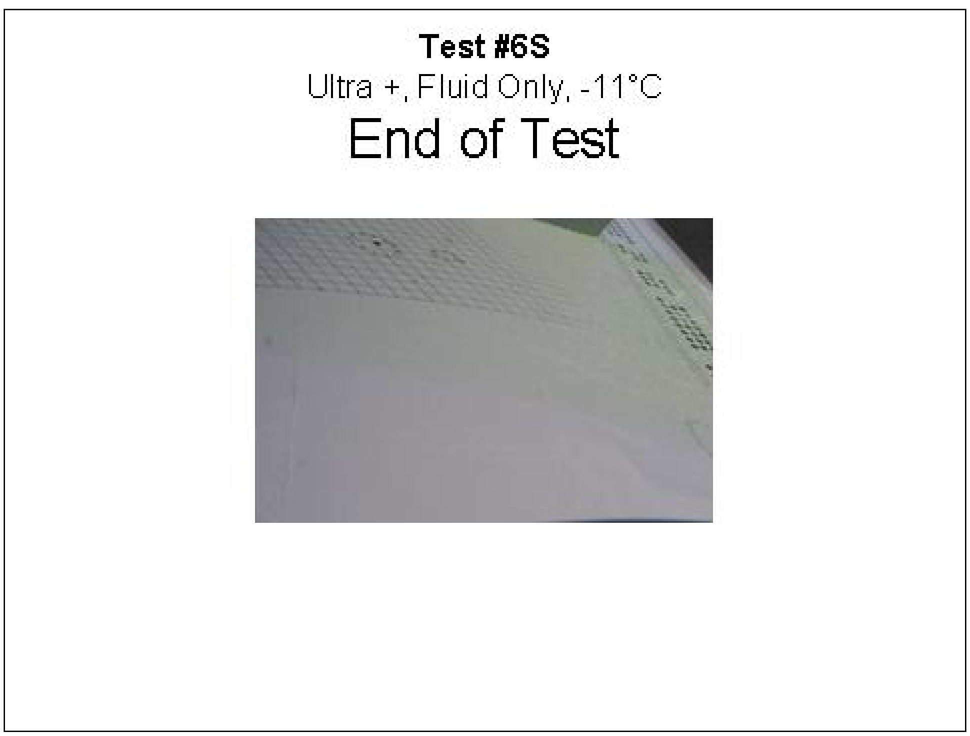


Photo 12.17: Test #1P8 – Start of Test

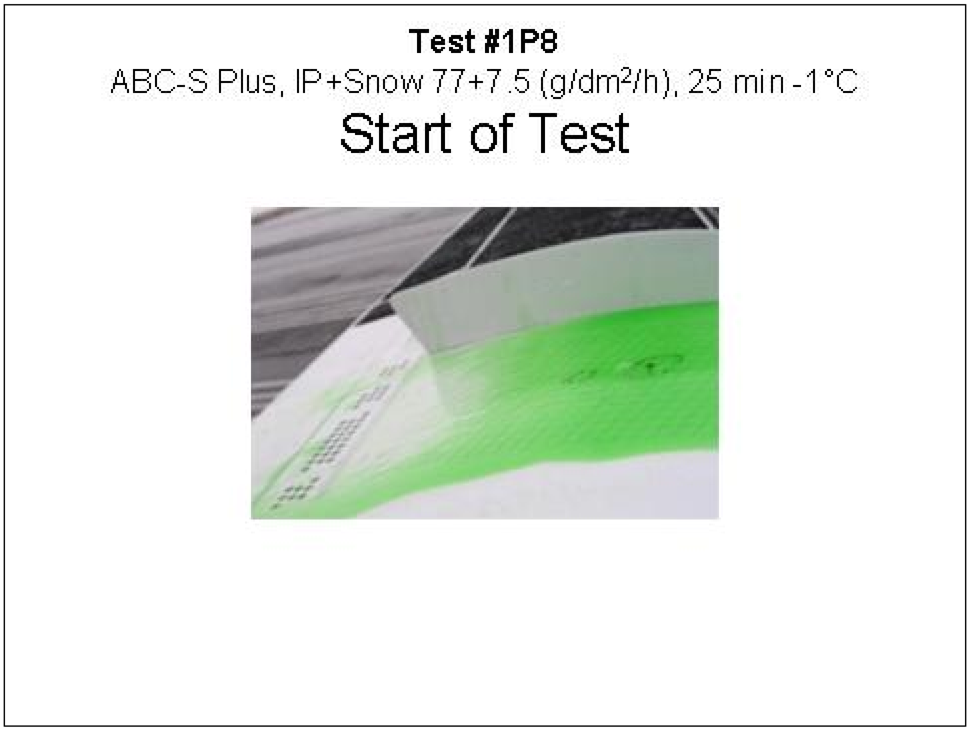


Photo 12.18: Test #1P8 – 17 Seconds

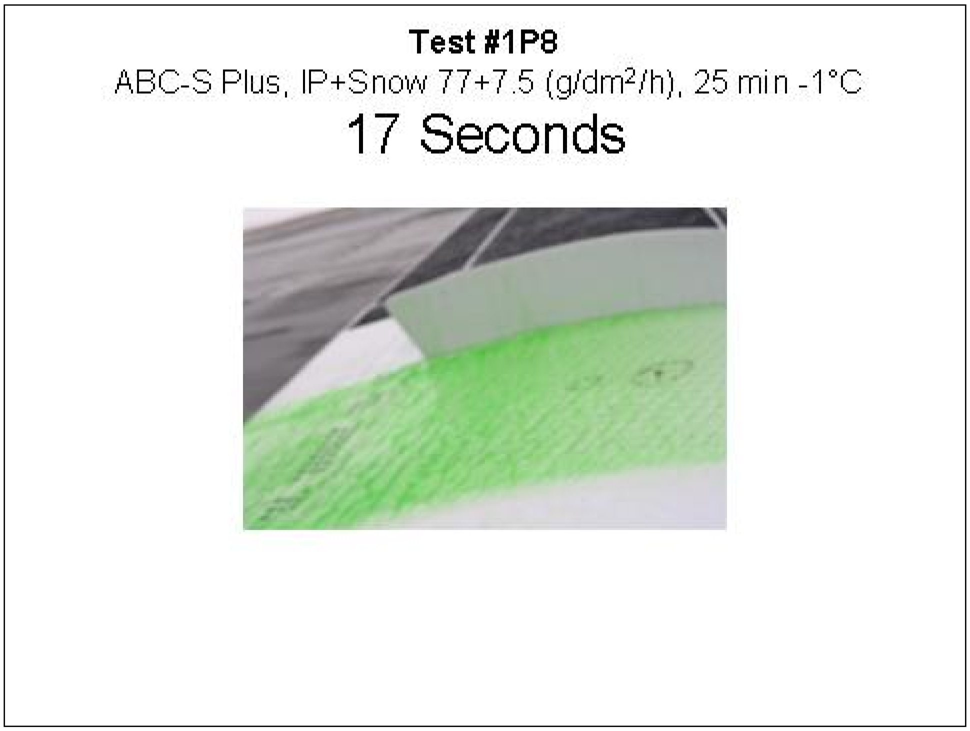


Photo 12.19: Test #1P8 – Rotation

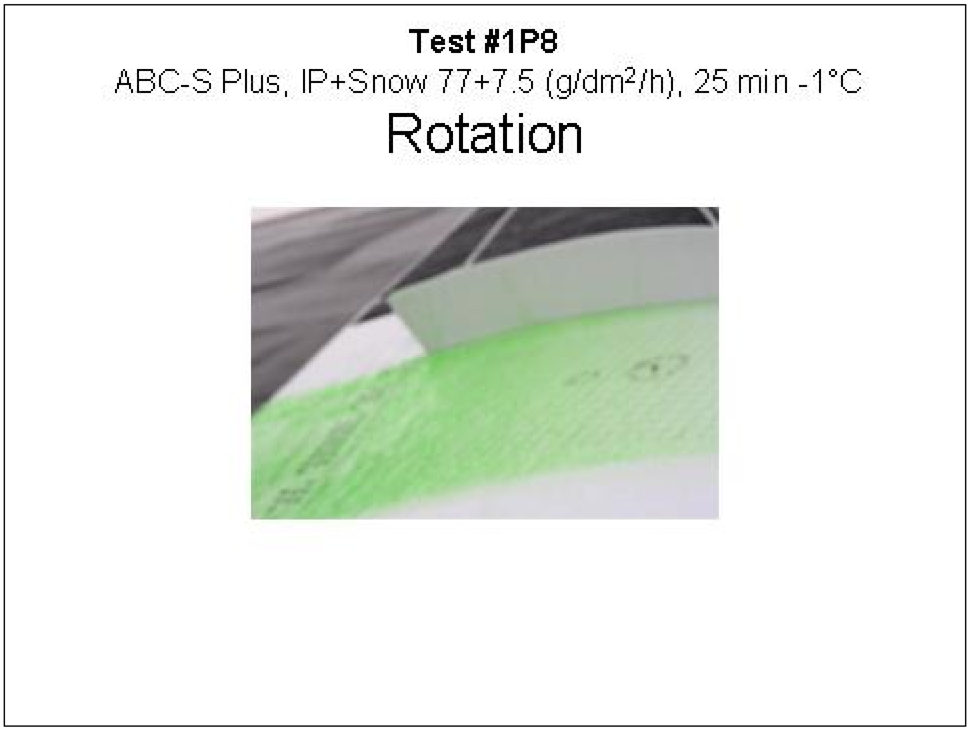


Photo 12.20: Test #1P8 – End of Test

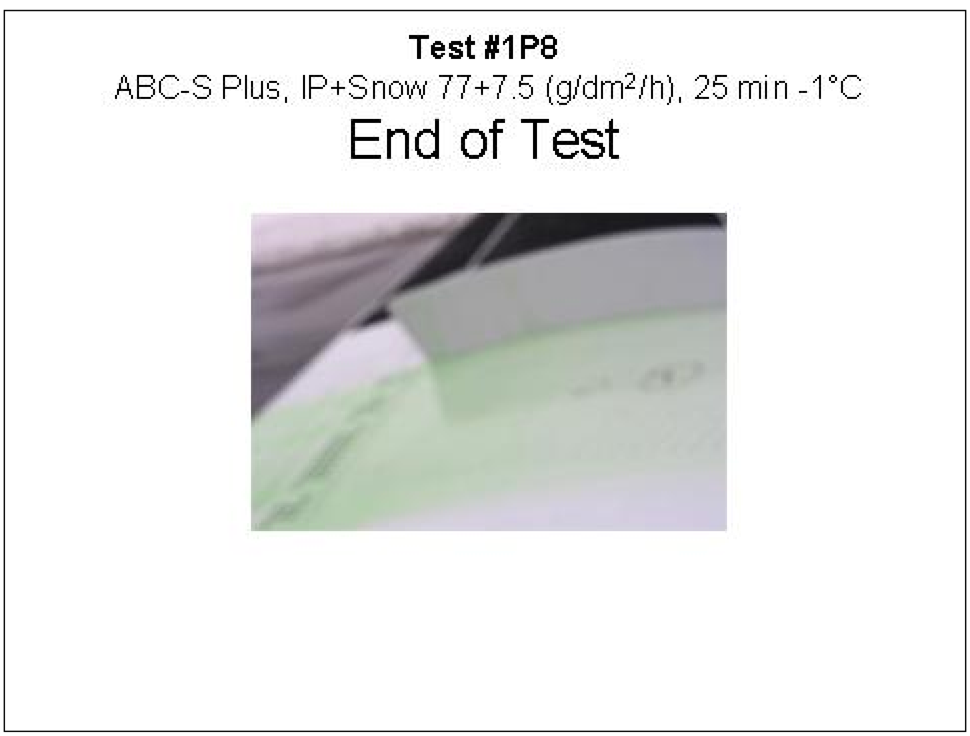


Photo 12.21: Test #1S8 – Start of Test

Photo 12.22: Test #1S8 – 17 Seconds

Photo 12.23: Test #1S8 – Rotation

Photo 12.24: Test #1S8 – End of Test

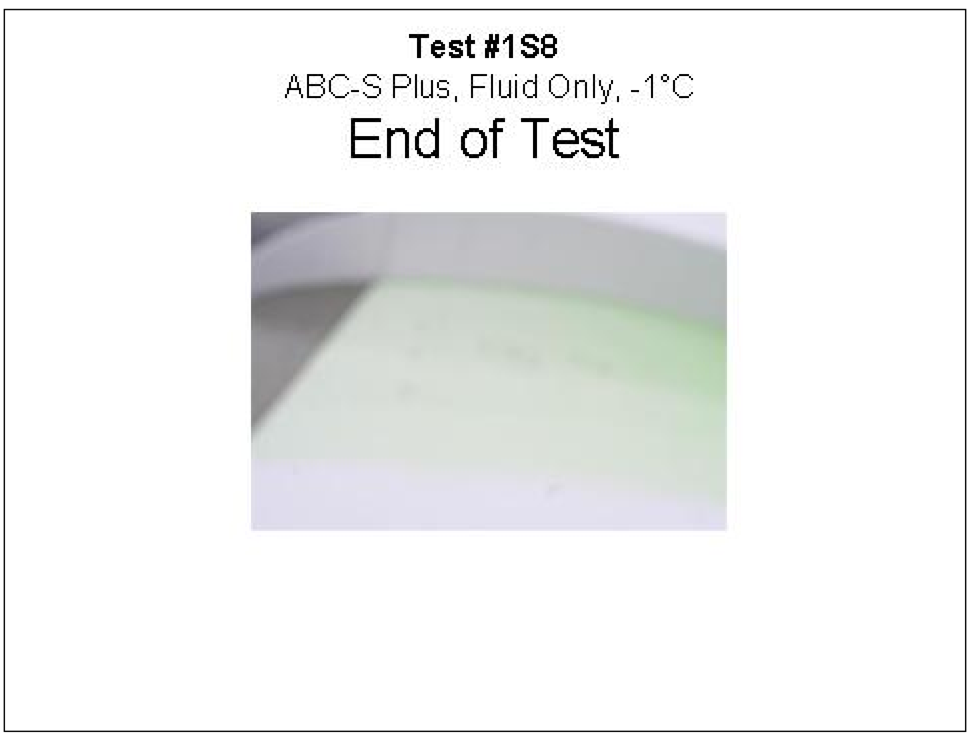


Photo 12.25: Test #3P8 – Start of Test

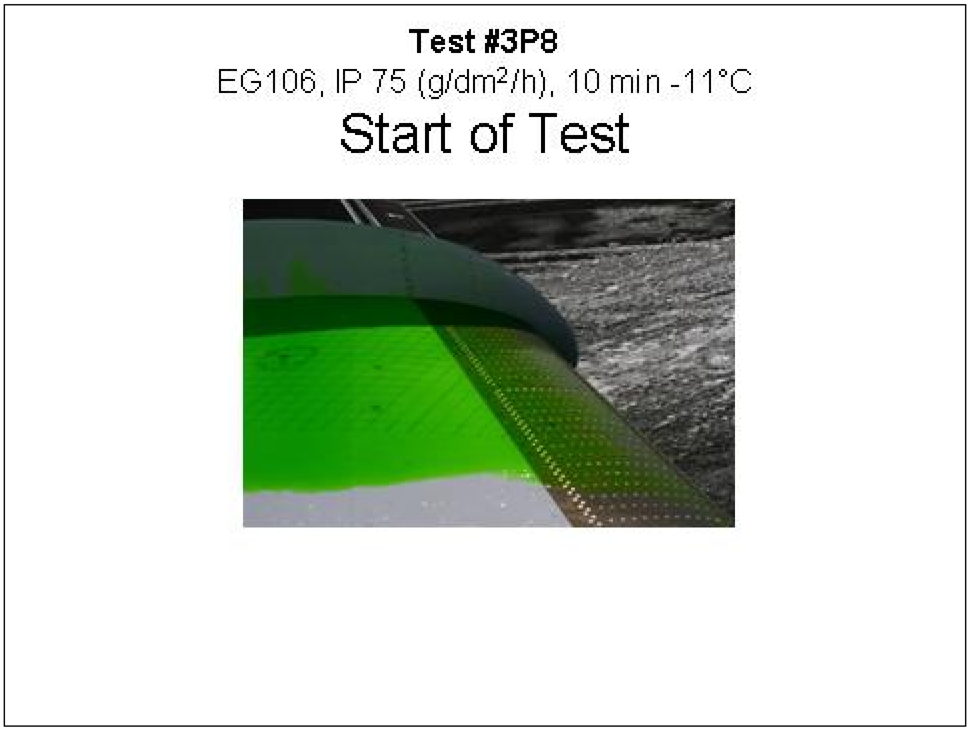


Photo 12.26: Test #3P8 – 17 Seconds

No Photo Documentation Available

Photo 12.27: Test #3P8 – Rotation

No Photo Documentation Available

Photo 12.28: Test #3P8 – End of Test

No Photo Documentation Available

Photo 12.29: Test #3S8 – Start of Test

Photo 12.30: Test #3S8 – 17 Seconds

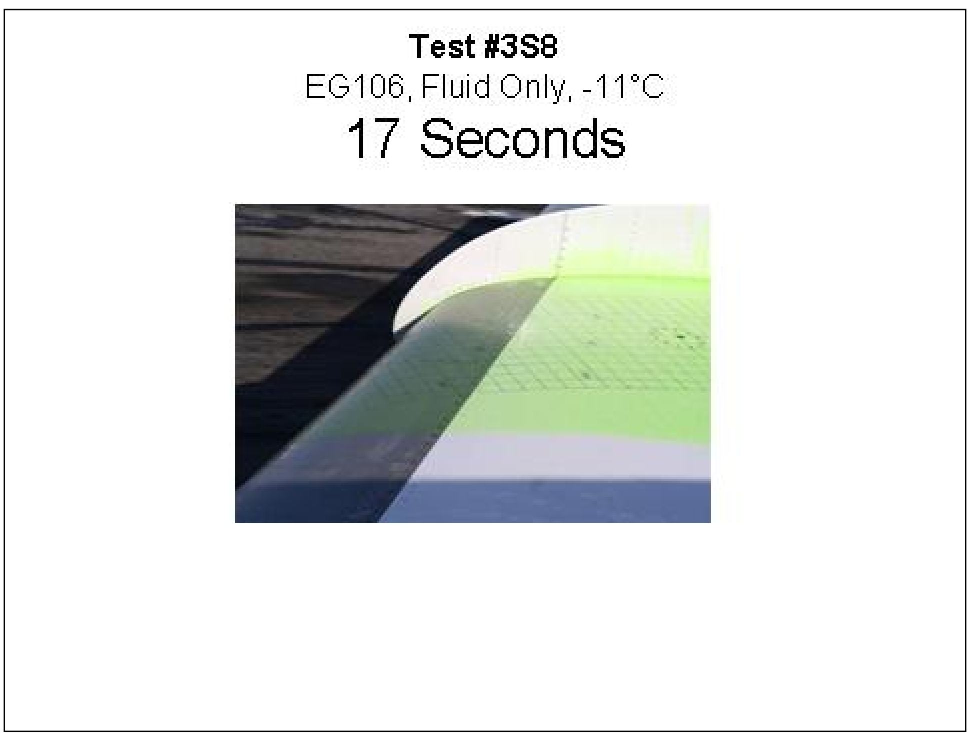


Photo 12.31: Test #3S8 – Rotation

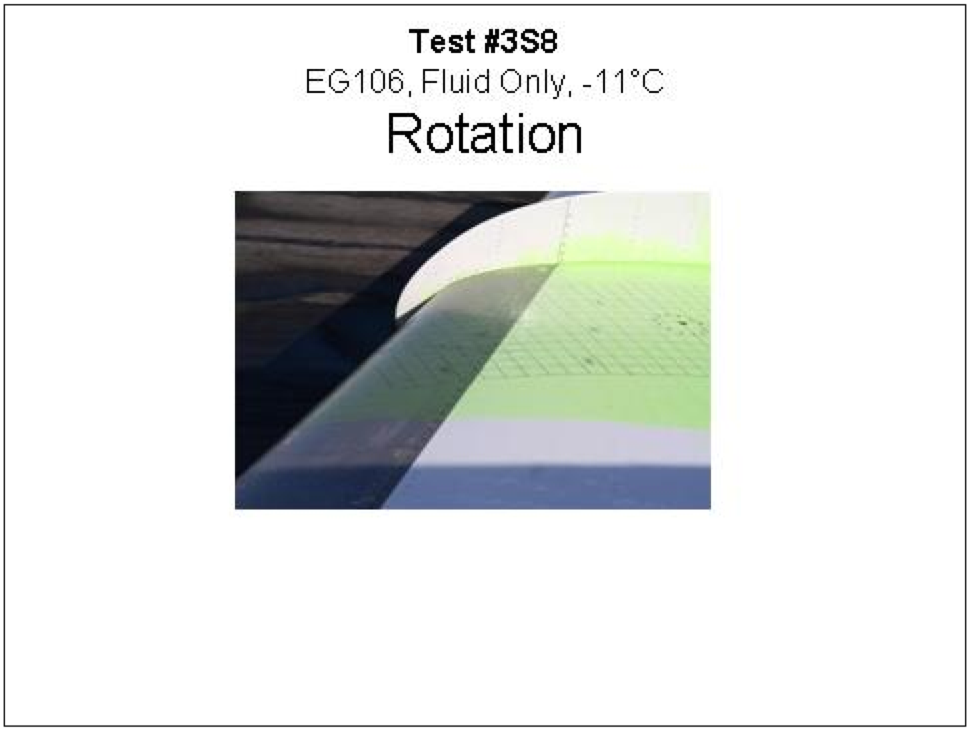


Photo 12.32: Test #3S8 – End of Test

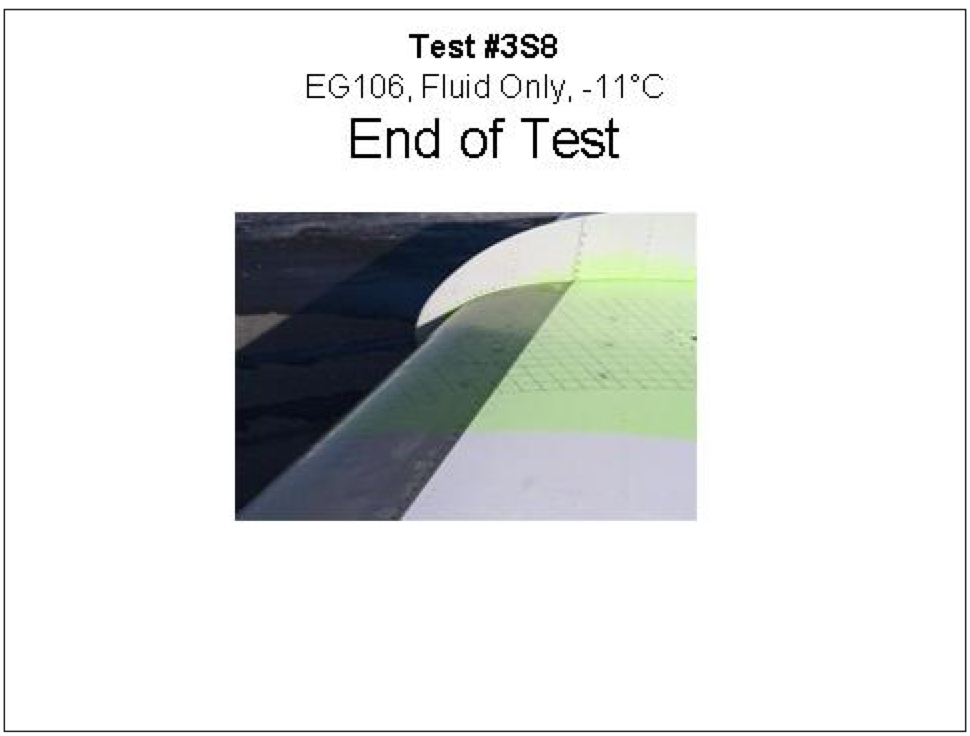


Photo 12.33: Test #7P8 – Start of Test

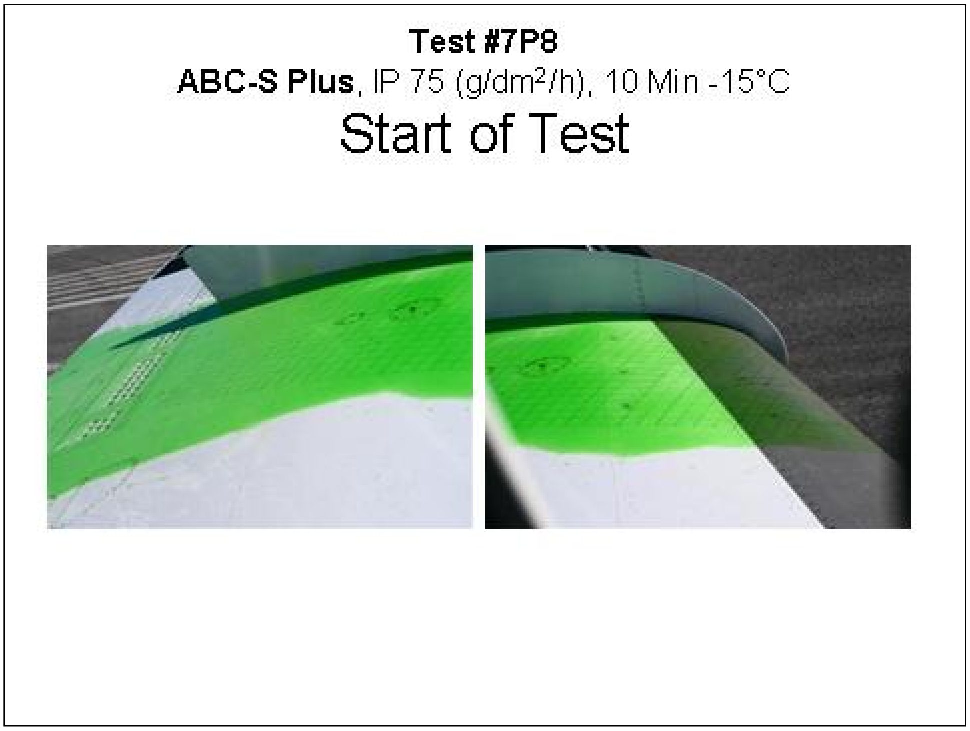


Photo 12.34: Test #7P8 – 17 Seconds

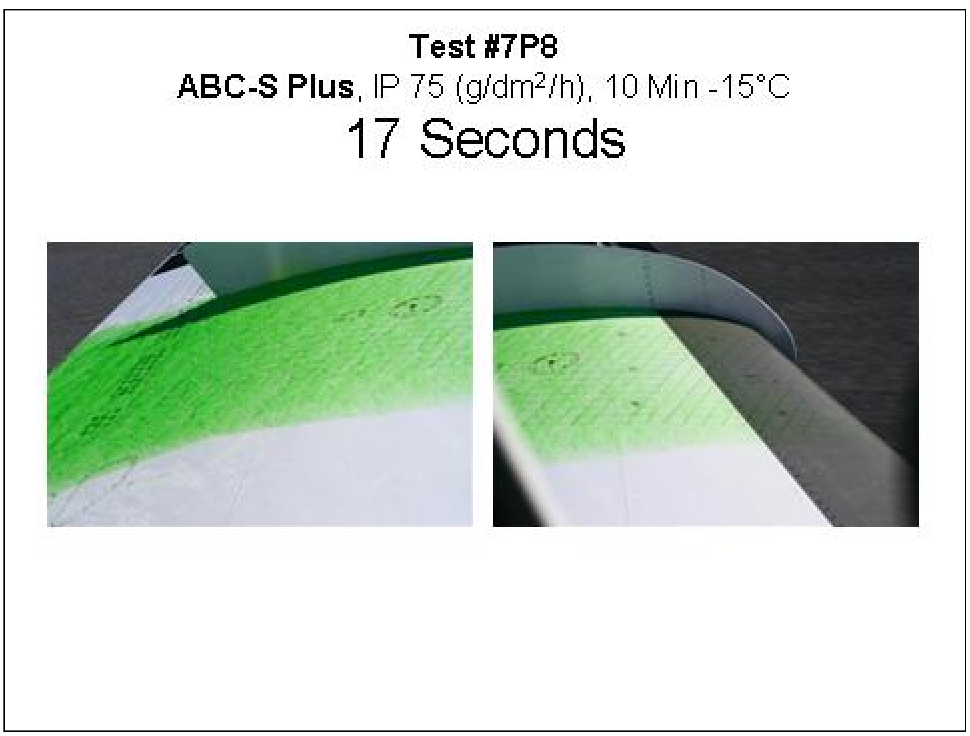


Photo 12.35: Test #7P8 – Rotation

Test #7P8

ABC-S Plus, IP 75 (g/dm²/h), 10 Min -15°C

Rotation

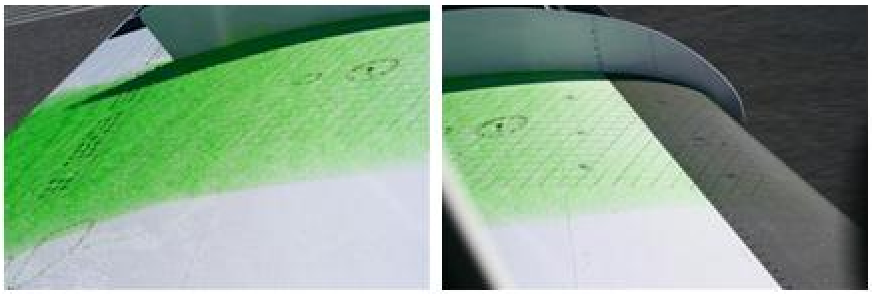


Photo 12.36: Test #7P8 – End of Test

Test #7P8

ABC-S Plus, IP 75 (g/dm²/h), 10 Min -15°C

End of Test

Photo 12.37: Test #7S8 – Start of Test

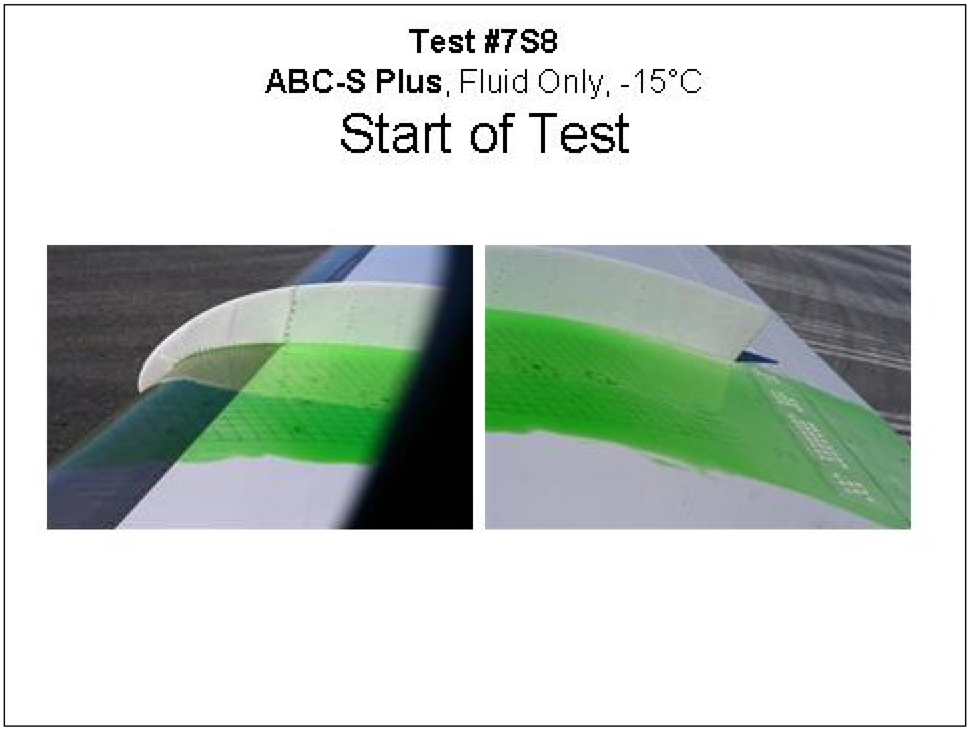


Photo 12.38: Test #7S8 – 17 Seconds

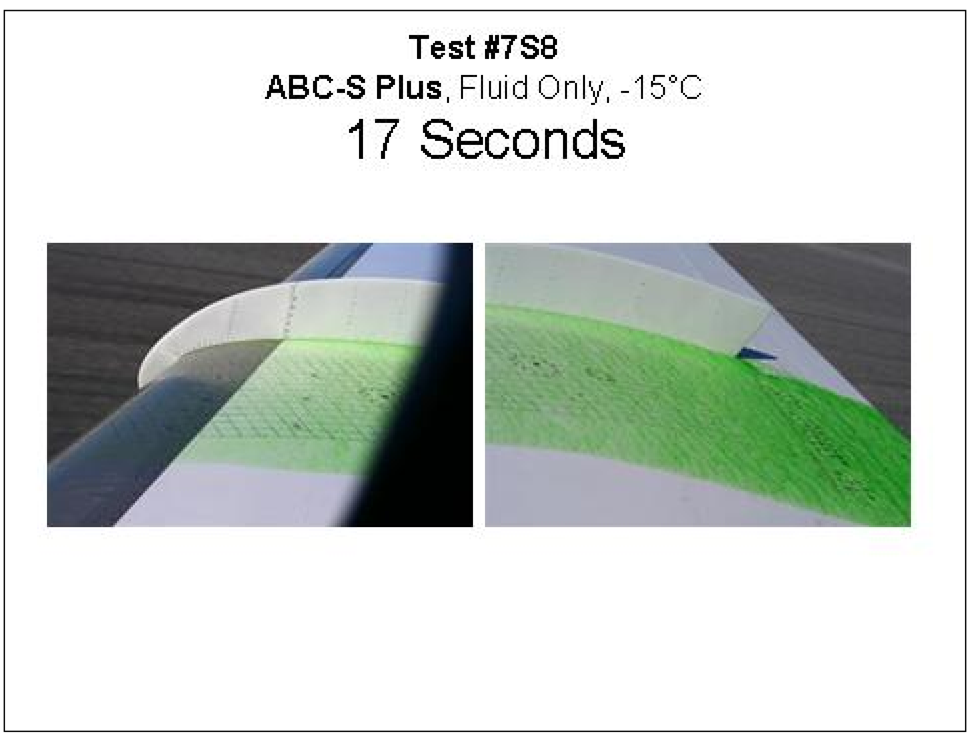


Photo 12.39: Test #7S8 – Rotation

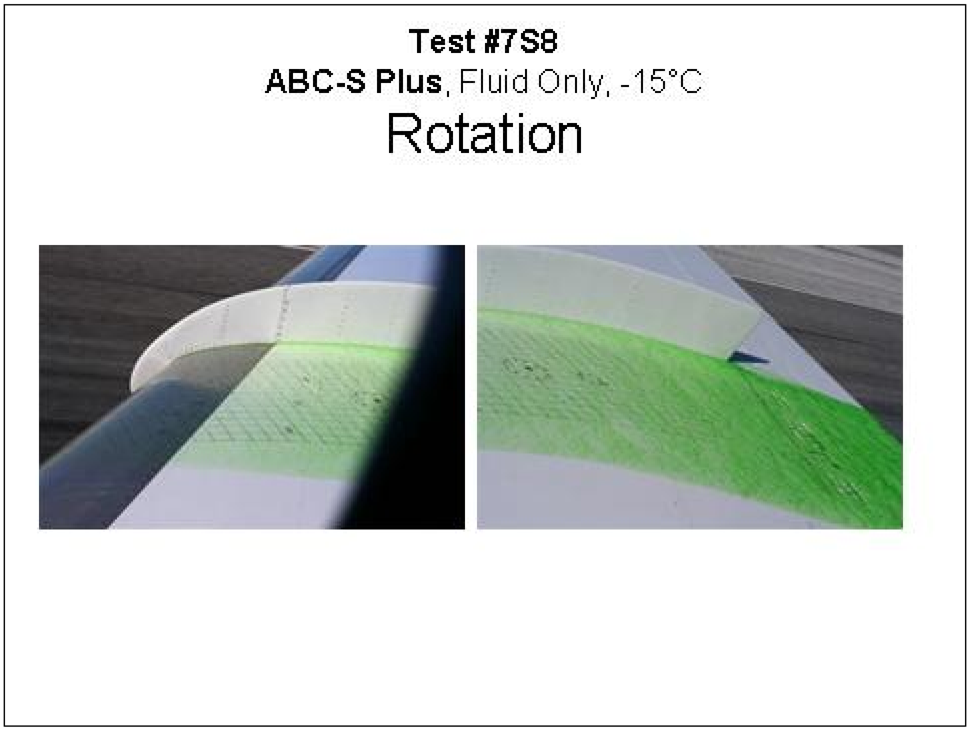


Photo 12.40: Test #7S8 – End of Test

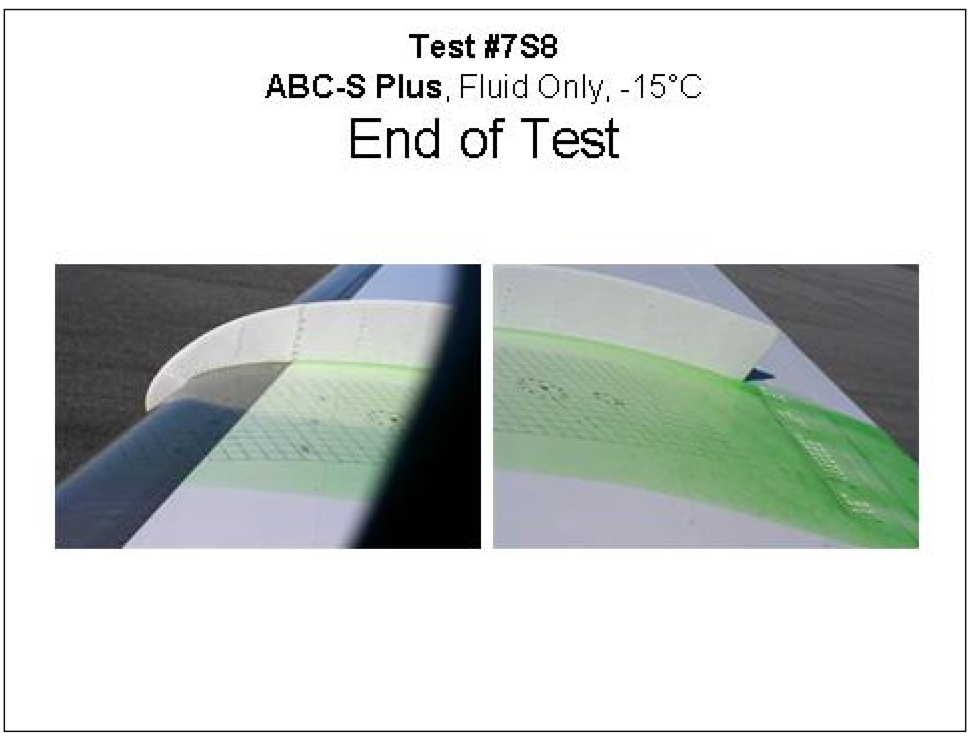


Photo 12.41: Test #10P8 – Start of Test

Photo 12.42: Test #10P8 – 17 Seconds

Photo 12.43: Test #10P8 – Rotation

Photo 12.44: Test #10P8 – End of Test

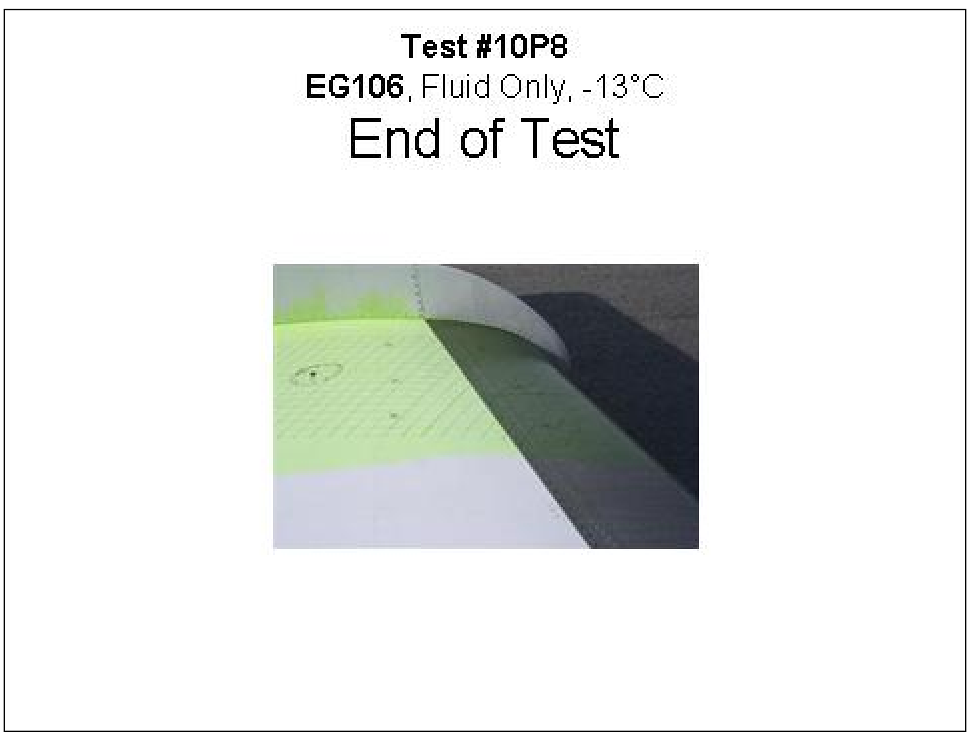


Photo 12.45: Test #10S8 – Start of Test

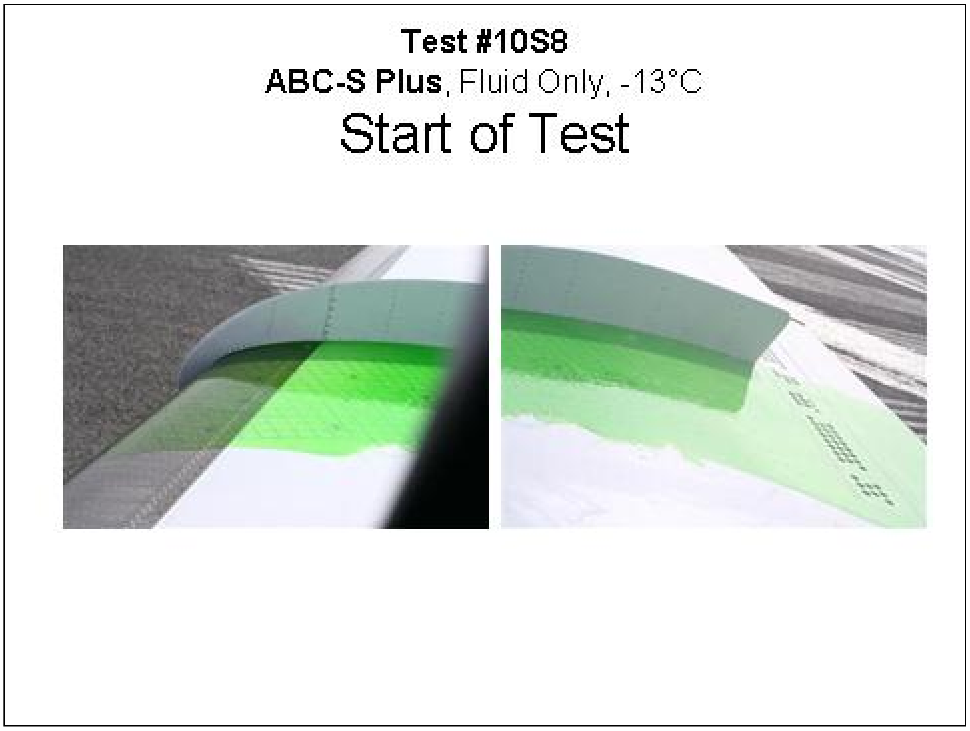


Photo 12.46: Test #10S8 – 17 Seconds

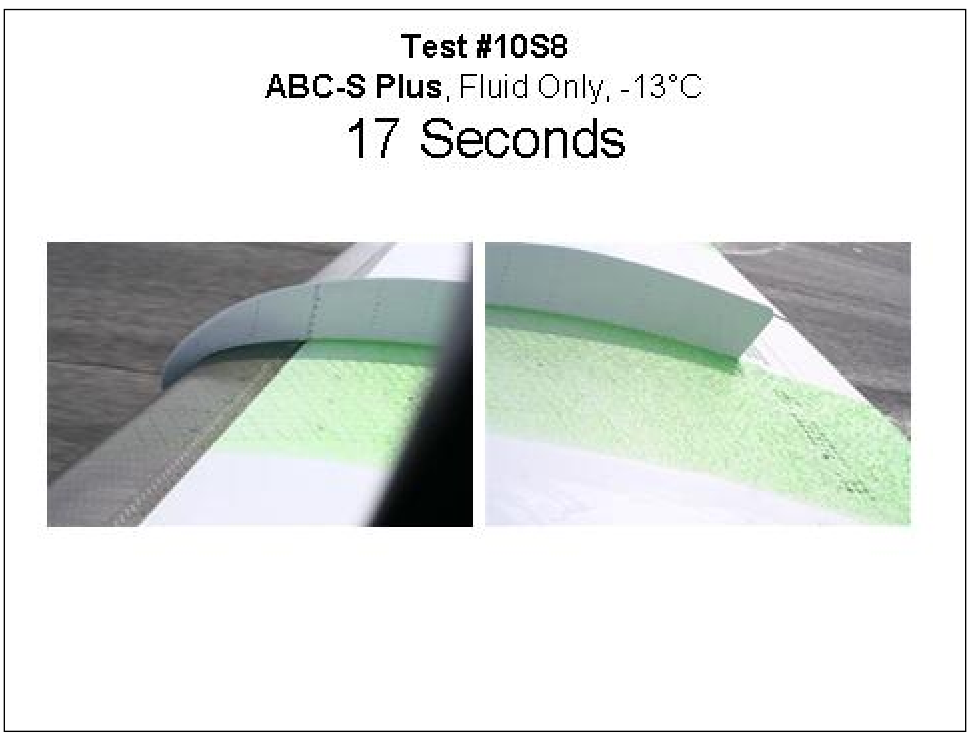


Photo 12.47: Test #10S8 – Rotation

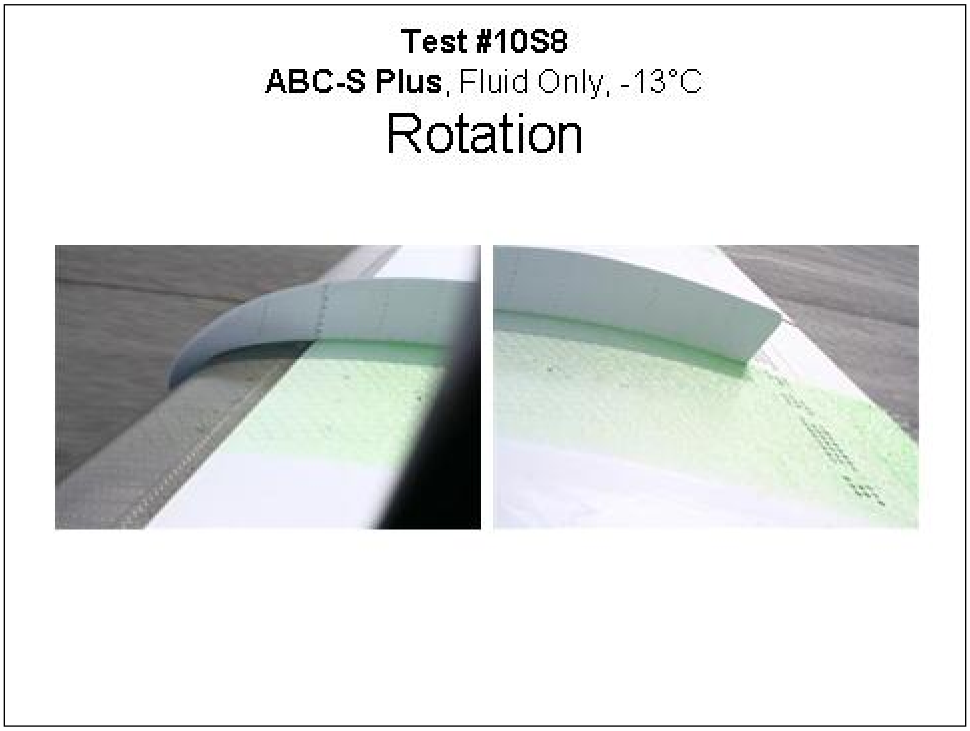


Photo 12.48: Test #10S8 – End of Test

Photo 12.49: Test #12P8 – Start of Test

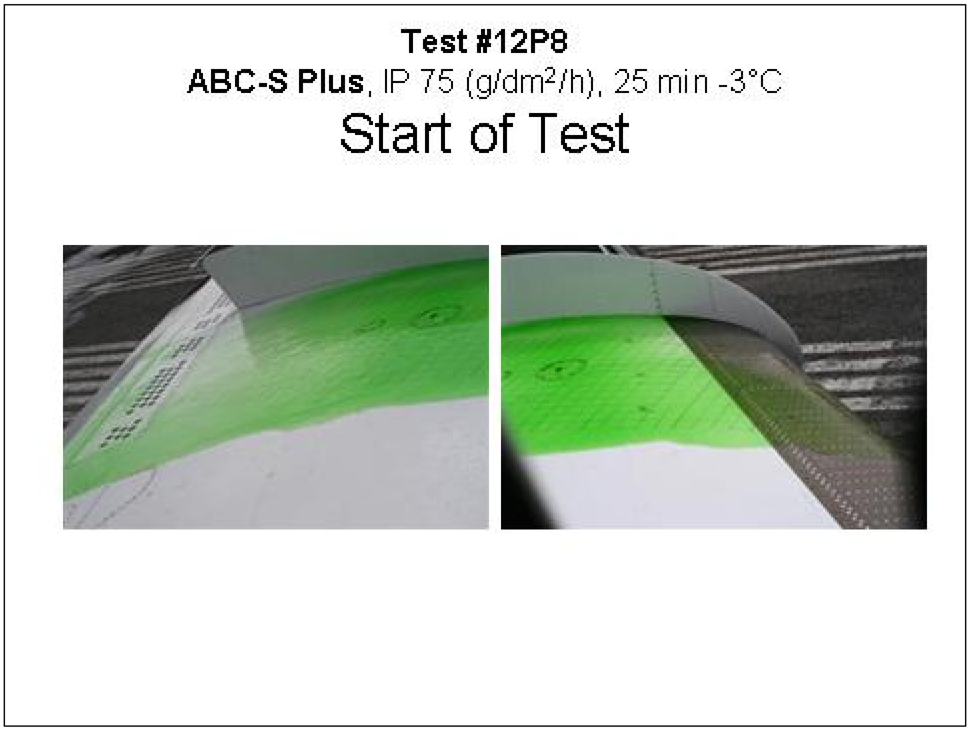


Photo 12.50: Test #12P8 – 17 Seconds

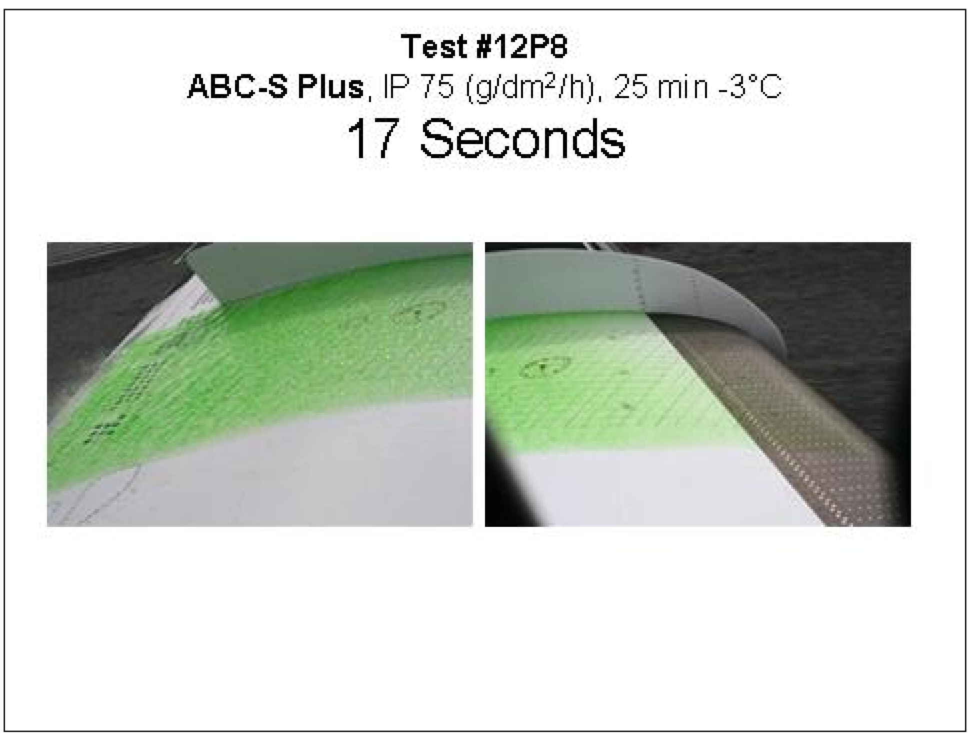


Photo 12.51: Test #12P8 – Rotation

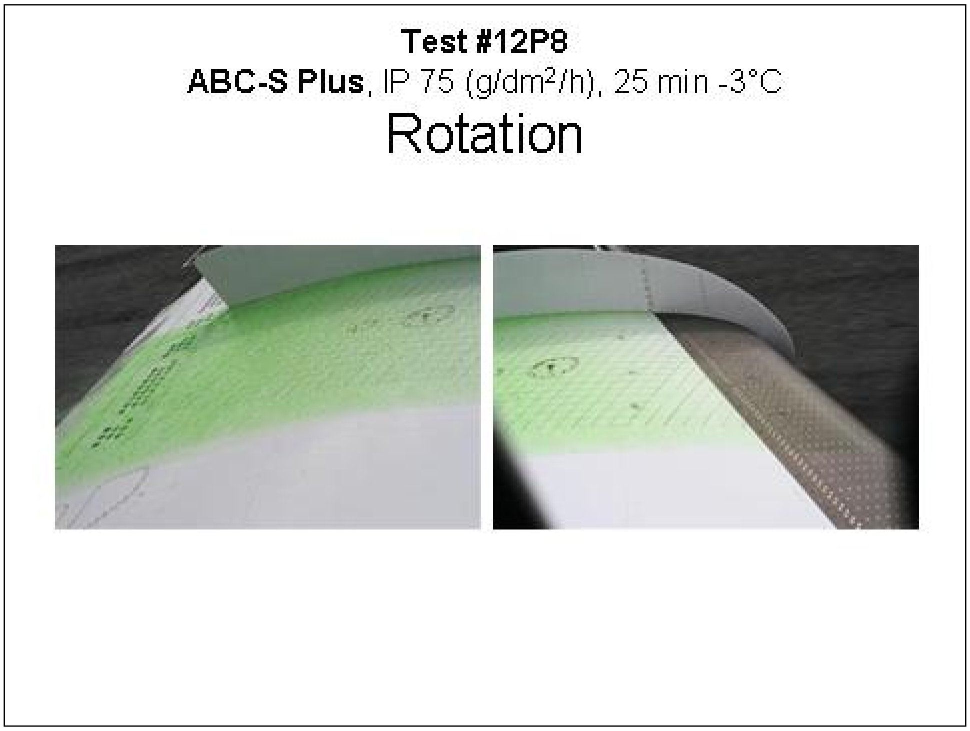


Photo 12.52: Test #12P8 – End of Test

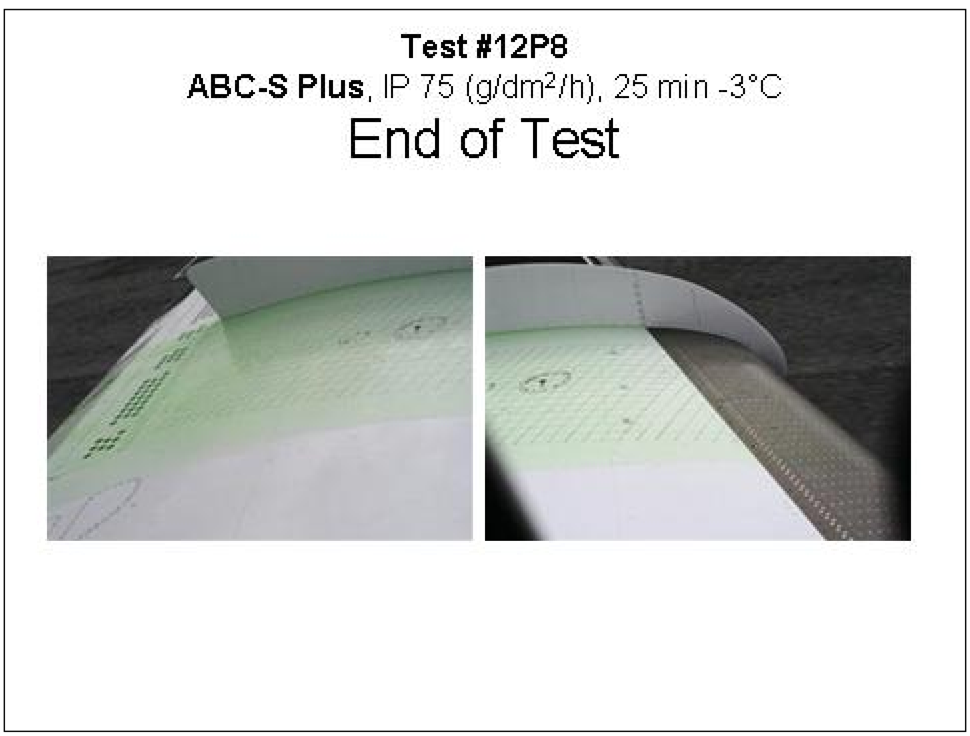


Photo 12.53: Test #12S8 – Start of Test

Photo 12.54: Test #12S8 – 17 Seconds

Photo 12.55: Test #12S8 – Rotation

Photo 12.56: Test #12S8 – End of Test

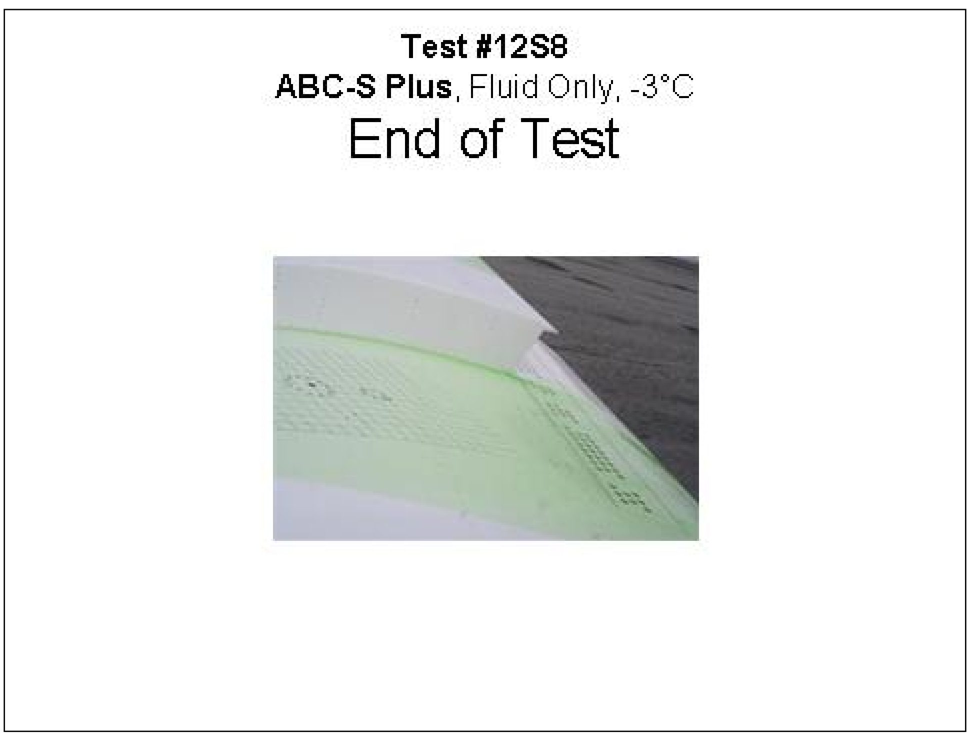


Photo 12.57: Test #13P8 – Start of Test

Test #13P8
EG106, IP 75 (g/dm²/h), 25 min -5°C
Start of Test

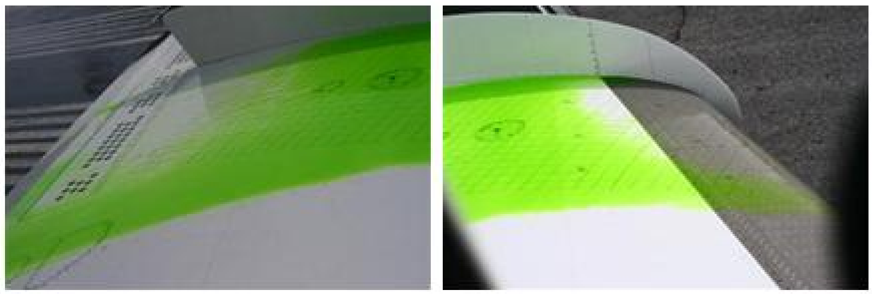


Photo 12.58: Test #13P8 – 17 Seconds

Test #13P8
EG106, IP 75 (g/dm²/h), 25 min -5°C
17 Seconds

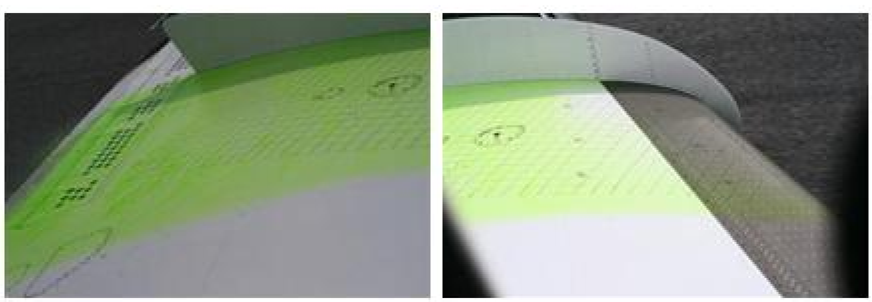


Photo 12.59: Test #13P8 – Rotation

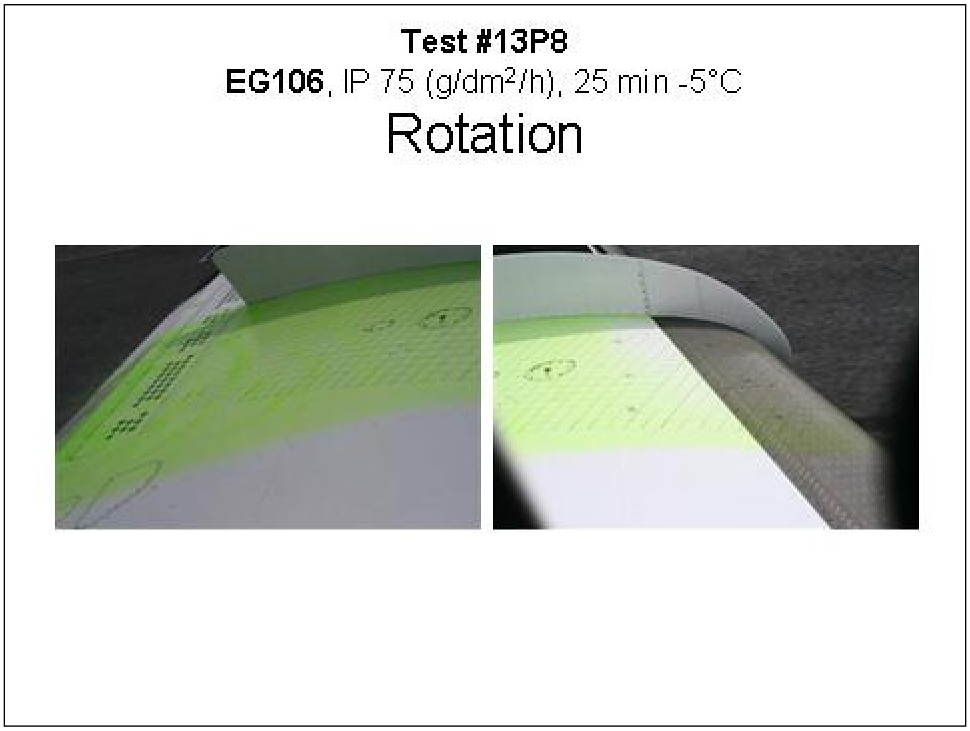


Photo 12.60: Test #13P8 – End of Test

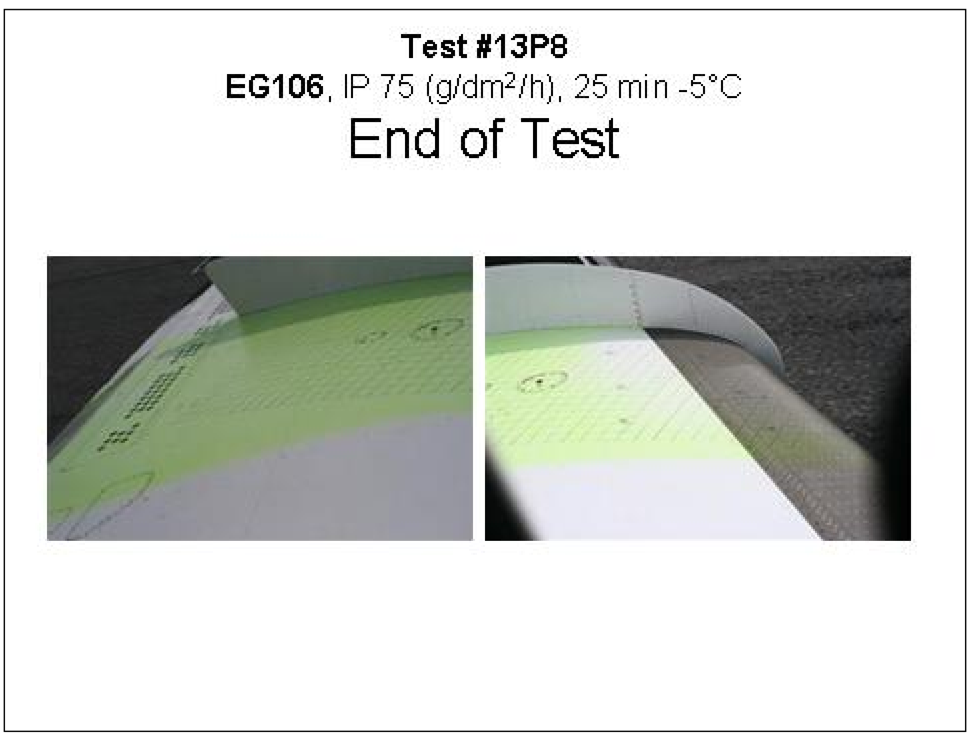
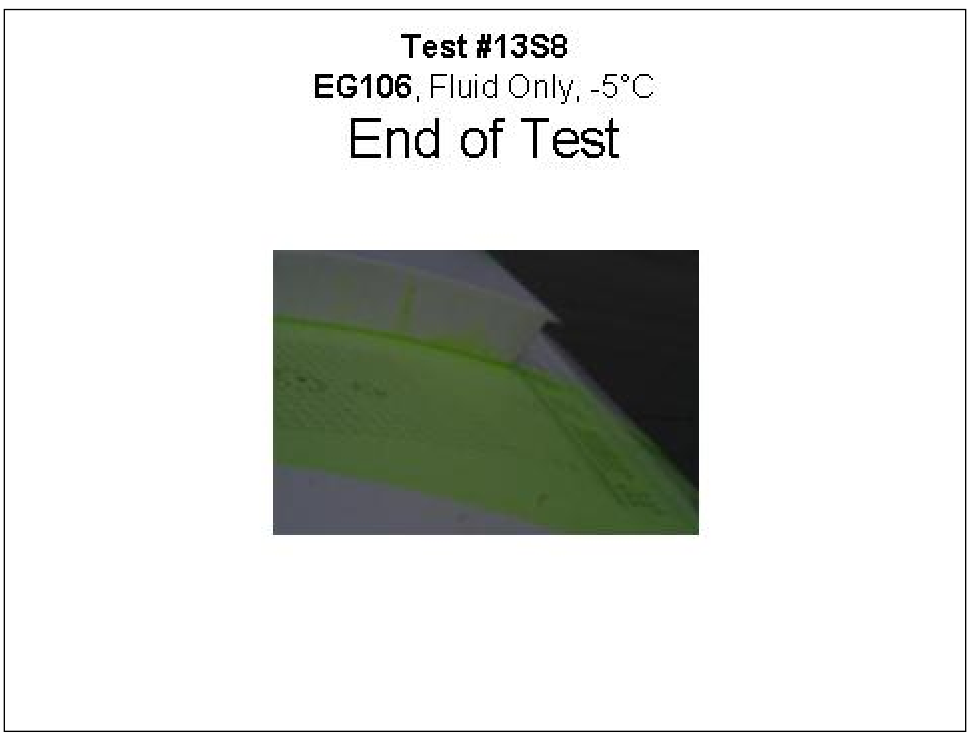


Photo 12.61: Test #13S8 – Start of Test

Photo 12.62: Test #13S8 – 17 Seconds

Photo 12.63: Test #13S8 – Rotation

Photo 12.64: Test #13S8 – End of Test



13. SUMMARY OF OBSERVATIONS

13.1 Effect of Flaps

The Falcon 20 results indicated that the residual thickness was up to three times greater on the trailing edge during the retracted flap tests compared to the extended flap tests. Residual fluid thickness on the leading edge was generally comparable. The T-33 results indicated that the residual thickness was generally comparable in both cases. The discrepancy in the T-33 results versus the Falcon 20 results may have been due to proximity of the T-33 test areas with each other. Visually, fluid elimination seemed to improve with flaps extended in both cases. It is normal for aircraft to be configured with extended flaps prior to takeoff; therefore, to be operationally representative, future testing should be conducted using extended flaps on the wing test surfaces.

13.2 Effect of Slats

No comparable outboard slats extended versus slats retracted tests were performed. Rather, during each Falcon 20 test run, the outboard slatted section of the wing was compared to the inboard flapped (but non-slatted) section of the wing. The results indicated that the residual thickness was generally equal on the trailing edge during the outboard extended slat tests compared to the inboard fixed leading edge tests. Visually, fluid elimination seemed to be hampered by the extended slats when compared to the inboard fixed wing extended flap section. Considering the shorter length of the chord at the slatted section, smaller residual trailing edge thicknesses post-run were expected; however, they were equal in comparison to the longer flapped section. The results did not demonstrate significant differences in results due to leading edge slats; therefore, future testing with fixed leading edge wing sections seems acceptable.

13.3 Effect of Chord Length

Testing conducted simulated three different chord lengths: the 2.9 m (9.5 ft.) chord was inboard of the fence and was configured with retracted flaps, the 2.4 m (8 ft.) chord was just outboard of the fence and was a fixed wing section, and the 1.7 m (5.5 ft.) chord was located across the ailerons and was configured with retracted slats. The results indicated that the residual thickness was greater (almost double in some cases) on the longer 2.9 m (9.5 ft.) chord test section when compared to the shorter 1.7 m (5 ft.) chord test section. When comparing the results of the 2.9 m (9.5 ft.) versus the 2.4 m (8 ft.) chord test sections, residual fluid on the trailing edge was comparable and within 0.1 mm. The results demonstrated better fluid flow-off for shorter chord length test sections. These results should be considered when conducting future low-speed aerodynamic testing. Although the shear forces may not be as great during low-speed takeoff, the shorter chord lengths on low-speed aircraft can facilitate anti-icing fluid flow-off.

13.4 New Generation vs. Old Generation Fluid

High-speed and low-speed comparative testing with the ABC-S Plus (triozole-free) and ABC-S fluids demonstrated similar fluid flow-off characteristics. During the three comparative test runs, the new ABC-S Plus generated slightly greater residual thickness on the trailing edge section of the wing post test run; however, the discrepancies were minor and generally within 0.1 mm. Visually, both fluids behaved similarly aerodynamically.

Low-speed comparative testing with the Ultra+ and EG 106 (triozole-free) fluids demonstrated better flow-off characteristics for the new EG 106 fluid. During the comparative test run, the new EG 106 fluid demonstrated reduced residual fluid thicknesses on the trailing edge of the wing section post test run; residual fluid was reduced by approximately half. It should be noted that the new EG 106 has an LOUT of -29ºC, lower than the Ultra+ LOUT of -24ºC. The same fluid characteristics that provided the EG 106 fluid with a lower LOUT may have also aided in the fluid flow-off properties at warmer temperatures.

The aerodynamic performance of the new fluids meets or exceeds the performance of the older generation fluids. As the older generation fluids are slowly being removed from operations, it will become more difficult to obtain those fluid samples for future testing. It is therefore recommended that future aerodynamic testing be conducted primarily using the new generation fluids.

13.5 Effect of Rotation

During the Falcon 20 high-speed test runs, the residual fluid on the trailing edge of the wing section following the no-rotation test run was double compared to the data collected from two tests conducted during the winter of 2006-07 with rotation. Fluid elimination on the trailing edge of the wing section seemed to improve with rotation. However, the discrepancy could have been due to the acceleration profile of the no-rotation run; the aircraft did not achieve the target 120 knots.

The results from the T-33 tests did not demonstrate significant differences in fluid flow-off characteristics following a rotation or no-rotation test run. The results indicated that the residual thickness was slightly higher on the leading edge following the no-rotation test run, but were generally slightly higher on the trailing edge following the test run with rotation. The discrepancies were within 0.2 mm for all of the cases. With the low-speed aircraft, the effects of rotation could not be distinguished visually.

The results indicated some differences in fluid flow-off properties as a result of the aircraft rotating at the end of the aircraft acceleration profile. The results from the Falcon 20 tests and the T-33 tests were not completely in agreement; however, the general trend pointed towards greater residual fluid following the no-rotation test runs. It is recommended that during future aerodynamic testing, the takeoff run profile should include aircraft rotation whenever possible, as this is operationally more representative. In addition, if time and resources are available during future aerodynamic test sessions, it is recommended that additional testing be conducted to further investigate the effects of aircraft rotation of fluid flow-off.

13.6 Type III Fluid

Low-speed Type III fluid testing with retracted flaps demonstrated significant amounts of residual fluid post-run. When compared to Type IV fluid flow-off, the Type III fluid performed better during low-speed retracted flap tests; however, it still produced greater residual fluid compared to the high-speed Type IV testing with extended flaps (residual fluid during 2006-07 Type IV high-speed tests was on average 0.2 mm on the trailing edge wing). During the contaminated wing tests, the Type III fluid did an excellent job of eliminating the contamination by the time of rotation; contamination was removed with little effort. The residual fluid on the contaminated wing tests was equal to or less than the fluid only wing tests.

The preliminary 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. During the contaminated wing tests, the Type III fluid did an excellent job of eliminating the contamination by the time of rotation. It is recommended that future aerodynamic research in the NRC wind tunnel should further investigate the aerodynamic effects of residual Type III fluid during low-speed takeoff and the potential for using Type III fluid during ice pellet conditions. Allowance times would have to be reduced to account for shorter Type III protection times compared to Type IV fluids.

13.7 Ice Pellets Mixed with Snow

The high-speed testing results at colder temperatures (below -5°C) with Type IV fluid demonstrated greater residual fluid thickness on the trailing edge section of the wing during the contaminated test run compared to the fluid only test run. The low-speed testing conducted at warmer temperatures with Type III and IV fluid demonstrated similar residual fluid on both the contaminated and uncontaminated wing section. The results obtained were in accordance with previous aerodynamic data collected during the winter of 2006-07, which indicated potential fluid flow-off problems at colder temperatures with mixed ice pellet and snow conditions. Although the leading edge is generally cleared by the time of rotation, the finer snow particles combined with the colder OAT may impede fluid flow-off on the trailing edge of the wing in mixed ice pellet and snow conditions.

Further wind tunnel work is required to investigate the aerodynamic penalties associated with the trailing edge contamination observed in mixed ice pellet and snow conditions. Testing should also investigate snow only conditions to isolate the source of the fluid flow-off problem in order to help determine if it is potentially related to type of precipitation. Testing should be primarily conducted at colder temperatures below -5°C.

13.8 High Speed vs. Low Speed

The results from the low-speed comparative testing in ice pellet conditions (and mixed ice pellets with natural snow) indicated that fluid flow-off is comparable for both contaminated and non-contaminated fluid at warmer temperatures. At the colder temperatures, the contaminated test run demonstrated significantly more residual fluid post-run compared to the fluid only test: up to twice as much residual fluid.

When comparing the residual fluid of the low-speed runs to the high-speed runs of the previous year, the residual fluid post-run was significantly greater during the low-speed runs with retracted flaps: up to 7 times greater. The same was true for the mid-speed test, where the residual fluid was in some cases more than 5 times greater compared to the previous year’s high-speed tests. However, during the low-speed tests with extended flaps, the residual fluid was generally reduced to 2-3 times greater compared to the previous year’s high-speed tests; the effect of the extended flaps significantly improved fluid flow-off, as described in Section 5.

Fluid elimination problems with Type IV fluids at lower rotation speeds appear to be a fluid issue rather than a contamination issue. Even fluid only tests were demonstrating significant amounts of residual fluid post-run at low rotation speeds. Extended flaps significantly helped fluid elimination prior to rotation; however, residual trailing edge fluid was still greater during the low-speed runs by a factor of two or more when compared to the previous year’s high-speed test runs. The general trend indicated that as the speed was increased, fluid elimination was improved.

The aerodynamic effects of this residual fluid for low-speed aircraft needs to be further investigated in the NRC wind tunnel. Aerodynamic lift data is required to determine potential lift losses associated with residual fluid, both contaminated and uncontaminated, at the time of rotation. Previous high-speed wind tunnel testing demonstrated acceptable lift losses for fluid contaminated with ice pellets at colder temperatures, where residual fluid is greatest. It is recommended that low rotation speed testing in ice pellet conditions be conducted at colder temperatures (below -10°C) to investigate potential lift losses associated with anti-icing fluid flow-off.

13.9 Changes to Ice Pellet Allowance Times

No changes were made to the Ice Pellet Allowance Time Guidelines for the winter of 2008-09. Although a significant amount of data was collected with the Falcon 20 and T-33 aircraft during the winter of 2007-08, further testing in the wind tunnel is required in order to obtain appropriate lift and drag data to determine the effects of the residual fluid present on the wing at the time of rotation and before any changes can be made to the allowance times. It is anticipated that the wind tunnel testing will be conducted during the winter of 2008-09.

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14. FUTURE WORK

The following future work is recommended for the winter of 2008-09.

14.1 Low Rotation Speed

The current allowance times were generated based on data collected with rotation speeds of greater than 100 knots. In order to allow for greater latitude to aircraft operators, it is recommended that aerodynamic research be conducted in the wind tunnel during the winter of 2008-09 to support the low-speed work conducted with the Falcon 20 to simulate aircraft takeoff with lower rotation speeds (i.e., 80 knots for operators with low rotation speed aircraft).

14.2 Additional Testing in Mixed Ice Pellets and Snow Conditions

Testing should be conducted in the wind tunnel during the winter of 2008-09 in mixed snow and ice pellet conditions to support the results from the Falcon 20 testing and to potentially provide guidance material for below -5°C conditions.

14.3 Refine Current Ice Pellet Allowance Times

It is recommended that additional testing be conducted in the NRC wind tunnel during the winter of 2008-09 to expand the recommended allowance time issued during the winter of 2007-08. Testing should be geared towards different fluid types and formulations, air temperatures, and precipitation types.

14.4 Additional Research Activities

It is recommended that aerodynamic research be conducted in the wind tunnel during the winter of 2008-09 to investigate current issues that have been brought forth by various members of the industry. This preliminary research should focus on the following.

14.4.1 Improper Fluid Application

Testing should be conducted with fluid application at reduced thickness as well as with degraded fluid; this testing will investigate the effects of poor fluid application methods and poor fluid quality control on the use of the current allowance times.

14.4.2 Snow Pellets

Snow pellets are a transitional precipitation condition; however, guidance material does not currently exist. It is recommended that testing be conducted to investigate the aerodynamic effects of snow pellet contamination of anti-icing fluid flow-off to determine if snow HOTSs are applicable for snow pellets.

14.4.3 Type I Testing on Composite Wing

Recent research conducted by APS has indicated that fluid endurance times may be reduced when Type I fluid is applied to aircraft surfaces made of composite material. Wind tunnel testing should be conducted to investigate the aerodynamic impacts of the reduced endurance times on Type I fluid flow-off.

14.4.4 Reduced Anti-Icing Holdover Times in Frost Conditions

Recent research conducted by APS has indicated that radiational cooling during active frost conditions may reduce anti-icing HOTs when operating close to the lower end of the outside air temperature range; details of this research is documented in an interim report, which was provided to TC and the FAA, and a final report is expected to be published once the research is completed in a future winter. Wind tunnel testing should be conducted to investigate the aerodynamic impacts of the reduced endurance times on Type II and Type IV fluids.

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2. Dawson, P., Hanna, M., *Contaminated Aircraft Takeoff Tests for the 1998-99 Winter*, APS Aviation Inc., Transportation Development Centre, Montreal, October 1999, TP 13479E, 157.

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4. Campbell, R., Chaput, M., *Aircraft Takeoff Test Program for Winter 2001-02: Testing to Evaluate the Aerodynamic Penalties of Clean or Partially Expended De/Anti-Icing Fluid,* APS Aviation Inc., Transportation Development Centre, Montreal, November 2002, TP 13995E, 92.

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APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT –
AIRCRAFT & ANTI-ICING FLUID
WINTER TESTING 2007-08

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT –
AIRCRAFT & ANTI-ICING FLUID
WINTER TESTING 2007-08

7.3 Aircraft Performance Research

7.3.3 Full Scale Aircraft Testing to Support Wind Tunnel Results

a) Develop a test plan jointly with the NRC staff who operate the aircraft. Consideration will be given to using both slatted and non-slatted wing aircraft i.e. Bombardier Challenger Aircraft. Consideration will also be given to using aircraft with leading edge devices, as well as aircraft with a supercritical airfoil.

b) Plan and co-ordinate the application of SAE Type IV fluid (ethylene and propylene-based) at Ottawa or Mirabel airport over a period of three days.

c) Plan and co-ordinate the application of controlled amounts of ice pellets, snow and/or freezing rain contamination on the applied fluids.

d) Document the appearance of fluids on the wing and adherence of fluid to the wing prior to departure of the aircraft for the test flight.

e) Spot deicing: Evaluate how partial wing deicing (spot deicing) affects the aerodynamic properties of the aircraft. Low viscosity fluids (such as Type I or Type III) should be used. The fluids will be sprayed only on a designated section of the aircraft.

f) Collect the following data during the tests:

   i) Type and amount of fluid applied;

   ii) Type and rate of contamination applied;

   iii) Extent of fluid contamination prior to the takeoff run;

   iv) Document the appearance of fluid on the wings during the takeoff run and climb of the aircraft by analyzing the video records; and

   v) Measurements of thickness, concentration, viscosity, and adherence of clean and contaminated fluid prior to departure for the flight test.

g) Co-ordinate the ground aspects of test activities and initiate tests in conjunction with NRC staff based on forecast weather and aircraft availability; and

h) Document collected data from the ground aspect of testing for inclusion in the analysis and report.

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APPENDIX B

GLYCOL MITIGATION PLAN

GLYCOL MITIGATION PLAN

APS AVIATION INC.

FALCON 20 TRIALS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS OTTAWA, ONTARIO (YOW) FEBRUARY 25 – MARCH 7, 2008

1. CORPORATE PROFILE

APS Aviation Inc. (APS), member of the ADGA Group of companies, is a worldwide leader in aircraft de-icing research and development. Since 1990, APS has been contracted by the Transportation Development Centre (TDC) of Transport Canada to further advance aircraft pre-flight de/anti-icing technology.

2. BACKGROUND

At the request of the TDC of Transport Canada, APS has undertaken a research program to examine the potential aerodynamic penalties resulting from the presence of clean and diluted anti-icing fluid on aircraft wings.

Previous trials to examine the aerodynamic elimination of failed Type IV fluid from aircraft wings during takeoff were conducted on behalf of Transport Canada during the 1997-98 and 1998-99 and winter seasons at Mirabel Airport. Those trials, based on simulated takeoff runs using a National Research Council Falcon 20 aircraft, provided an improved understanding of the subject matter and demonstrated that the selected test approach was a viable one.

During the winter of 2001-02 and 2002-03, flight tests were performed at Ottawa International Airport (YOW). Tests were performed with one ethylene glycol-based Type IV fluid, Dow Ultra+, in neat and diluted form. Fluid was applied at the central de-icing pad at YOW by GlobeGround personnel.

The effects of (simulated) ice pellets and ice pellets mixed with freezing rain and/or snow on the wing of Falcon 20 aircraft during takeoff were studied in 2005-2007. Since the precipitation embedded in the fluid was not adhering according to previous tests, it is not known whether this contamination in the fluid would come off during aircraft rotation. The tests performed at YOW during the last two years allowed the FAA to issue allowance times for aircraft departing in ice pellets and ice pellets/freezing rain/snow mixed precipitation conditions.

The primary objective of the February-March 2008 tests at YOW will be to investigate the effects of mixed conditions with ice pellets for aircraft with low rotation speeds.

This document describes the glycol mitigation plan for the planned tests as follows:

- The fluid application procedures;
- The locations designated for fluid application;
- The anticipated fluid quantities to be sprayed; and
- The fluid recovery plan.

3. FLUID APPLICATION PROCEDURES

In February-March 2008, tests will be conducted at YOW with ethylene and propylene glycol-based Type IV fluids. In addition, a limited number of tests with an SAE certified propylene glycol-based Type III fluid may be attempted.

APS personnel are highly experienced in aircraft deicing matters, and attempts will be made to limit the quantities of fluid applied to the aircraft. The fluids will be applied to a 2.7 square-meter section of the aircraft wings by pouring, thus limiting the amount of fluid that falls on the ground after application.

In previous tests conducted at YOW in 2006 ethylene and propylene fluids were applied over the same 2.7 square-meter section. In total, 60 liters of ethylene fluid and 180 liters of propylene fluid were used for the entire test session. All deicing fluid that fell to the ground within the application area was properly recovered.

The fluid application will be performed by APS personnel at the NRC pad.

All Type IV fluids will be applied unheated to the wings of the Falcon 20. No Type I fluid will be applied prior to the Type IV.

4. LOCATIONS DESIGNATED FOR FLUID APPLICATION

The fluid application will be performed by APS personnel at the NRC pad.

Fluid applications at the NRC pad will be conducted in close proximity to the NRC hangar. Two separate areas will be assigned, one for ethylene applications, the other for propylene applications. NRC personnel will determine the precise locations prior to testing. The aircraft will not be positioned near the stormwater catch basins located on the southern edge of the NRC apron.

5. ANTICIPATED FLUID QUANTITIES TO BE SPRAYED

Twelve tests are anticipated for February-March 2007 at YOW. Of this total, four will be performed with Dow EG 106 (ethylene) six will be performed with Kilfrost ABC-S (propylene), and two will be performed with Clariant Safewing MP III 2031 Eco (propylene).

Based on preliminary testing, the estimated maximum amount of fluid required for the conduct of these tests will be 480 liters (160 of ethylene glycol and 320 of propylene glycol base). Of this quantity, roughly 20% falls to the ground immediately following application.

6. FLUID RECOVERY PLAN

The method of application, pouring, minimizes the fluid that is applied to the wing section and the fluid falling on the ground immediately after application. APS personnel will collect the excess fluid immediately after application using fluid collection containers, tarps and a powerful vacuum.

The waste solutions will be recovered and stored separately to prevent cross-contamination of the products. APS will incur the costs of these fluid recovery services.

7. ADDITIONAL REPORTS

Upon request, a report will be provided by APS to the airport authority following the conduct of tests at YOW to provide the quantities of fluid used in testing.

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APPENDIX C

PROCEDURE:
FALCON 20 TRIALS TO EXAMINE FLUID REMOVED FROM LOW ROTATION AIRCRAFT DURING TAKEOFF IN SIMULATED CONDITIONS WITH ICE PELLETS, SNOW AND/OR FREEZING RAIN

CM2103.001 (07-08)

PROCEDURE
FALCON 20 TRIALS TO EXAMINE FLUID REMOVED FROM LOW ROTATION AIRCRAFT DURING TAKEOFF IN SIMULATED CONDITIONS WITH ICE PELLETS, SNOW AND/OR FREEZING RAIN

Winter 2007-08

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Marco Ruggi

Reviewed by: John D'Avirro

APS Aviation Inc.

February 22, 2008
Final Version 2.0

FALCON 20 TRIALS TO EXAMINE FLUID REMOVED FROM LOW ROTATION AIRCRAFT DURING TAKEOFF WITH ICE PELLETS, SNOW AND/OR FREEZING RAIN

Winter 2007-08

1 BACKGROUND

1.1 2005-06 Falcon 20 Research

Previous trials to examine the elimination of failed SAE Type IV fluid from aircraft wings during takeoff were conducted during the 1997-98 and 1998-99 winter seasons. Those trials, based on simulated takeoff runs using a National Research Council (NRC) Falcon 20 aircraft, showed that the test approach was a viable one. The test program conducted during winter 2005-06 addressed the effects of deicing fluid contaminated with ice pellets that the airflow at takeoff fails to remove.

In March 2006, a series of simulated takeoff runs were performed with the National Research Council Falcon 20 research aircraft at the Ottawa Airport. Eight runs were performed with simulated ice pellet precipitation rates ranging from 25 g/dm^2/h to 167 g/dm^2/h and two Type IV de/anti-icing fluids, DOW UCAR Ultra+ and Kilfrost ABC-S. One run was completed with Type I EG deicing fluid.

The fluid present on the wings was almost completely eliminated during the takeoff. In general, a small film of fluid remained on certain wing surfaces, most notably on the trailing edge of the aircraft. The leading edge was cleared of any contamination during the takeoff run, even at very high precipitation rates. Some contamination was observed on the trailing edge at very high precipitation rates (136 g/dm^2/h). The Type I EG run showed that a small amount of ice was adhered to the wing surface at the end of the takeoff run.

1.2 2006-07 Wind tunnel Research

A NACA 23012 wing section was treated with anti-icing fluid using a one-step operation. Simulated precipitation was then applied over the anti-iced test section until specified levels of contamination were achieved. The wind tunnel was then operated through a simulated takeoff test. The behaviour of the fluid during the simulated takeoff was documented with high-speed digital still cameras and video cameras. In addition, drag and lift data collected by the NRC was used to generate lift coefficient curves for each of the tests conducted. The lift data collected during contaminated fluid tests were compared to the data collected during the baseline fluid only and dry wing tests.

The lift coefficient data collected in the wind tunnel indicated that the application of anti-icing fluid caused a lift loss when compared to the baseline dry wing aerodynamic properties. In general the application of the specified and limited amounts of contamination to the anti-icing fluid did not generate significant additional lift losses; the lift data collected during fluid and contamination tests and fluid only tests was comparable.

1.3 2006-07 Falcon 20 Research

At the start of each test, a designated test area of the Falcon 20 wing was treated with anti-icing fluid using a one-step operation. Simulated precipitation was then applied over the anti-iced test section until specified levels of contamination were achieved. The Falcon 20 aircraft was then operated through a simulated takeoff test. The behaviour of the fluid during the simulated takeoff was documented with high-speed digital still cameras and video cameras.

The Falcon 20 tests were primarily conducted as a verification of the results obtained in the wind tunnel using the NACA 23012 test wing section; lift data was not collected. Testing conducted with the Falcon 20 aircraft confirmed the results obtained in the wind tunnel and demonstrated that the wind tunnel test methodology provided a representative substitute for full-scale aircraft tests.

1.4 Regulatory Recommendation

Ice pellet allowance times for operations during mixed conditions with ice pellets were generated based on the results obtained in the Wind Tunnel and with the Falcon 20 aircraft. Restrictions for the allowance times were issued based on residual contamination observed on the airfoil, lift characteristics, and limitations of the data collected regarding rotation speeds, test temperatures and other pertinent parameters. The ice pellet allowance times were issued within the Transport Canada HOT Guidelines and the Federal Aviation Administration Approved Deicing Program updated for the winter of 2007-08.

1.5 Proposed 2007-08 Test Program

Further testing was recommended as a result of the observations made during the 2006-07 tests. It was recommended that additional testing be conducted at the NRC wind tunnel and with the NRC Falcon 20 aircraft to refine and possibly expand the current ice pellet allowance times. Testing would investigate parameters such as the effects of lower rotation speeds, different fluid types, improper or degraded fluid application, and flaps and leading edge devices on the fluid flow-off properties.

Initial plans proposed an extensive series of tests in the wind tunnel followed by a limited number of tests with the Falcon 20 to confirm the results obtained. The focus on the wind tunnel work was due to the ease of operation and controllability of meteorological conditions when conducting tests inside the NRC wind tunnel.

Due to scheduling conflicts, the NRC wind tunnel was not available for the desired time period in the 2007-08 winter season. As a result, an abbreviated test matrix has been proposed which will be conducted using the Falcon 20 aircraft. Testing with the wind tunnel has been postponed until the 2008-09 winter season.

2 OBJECTIVES

To expand the current ice pellet allowance times through a series a series of simulated takeoff runs performed with the NRC Falcon 20 research aircraft.

To satisfy this objective, testing will investigating the following parameters:

- Effects of lower rotation speeds;
- Use of Type III fluid during mixed conditions with ice pellets;
- Mixed ice pellet and snow conditions in below -5°C conditions; and
- Effect of flaps on fluid flow off.

In addition, preliminary testing in heavy snow conditions may be performed.

3 TEST REQUIREMENTS

APS will co-ordinate the planned test activities and prepare a final report as well as present results at industry deicing meetings.

APS will provide support to these tests for instrumentation, fluid application, and artificial precipitation application. A high-quality digital videotape record and still pictures of fluid on aircraft wings during the simulated takeoff run are required.

Desired weather conditions are dry, with subfreezing outside air temperatures. Tests will be limited to a maximum of 10 kts crosswind. Overcast skies are very important to avoid overheating the aircraft wings from exposure to the sun. Runway conditions are to be clean and dry.

The Falcon 20 tests are scheduled for February 25 – March 7, 2008.

Attachment I presents the quantities of ice pellets required to achieve a target precipitation rate. Attachments II, III, IV and V present the Snow and Ice Pellet Dispenser data sheets to be completed. Attachment VI includes the holdover time (HOT) tables for the fluids used in the tests. The ice pellet size is the same for both wind tunnel and Falcon 20 tests (1 - 3.35 mm in diameter).

Attachment VII contains a draft schedule test plan. The test plan may be subject to change during the actual test period based on results obtained.

A list of safety issues that must be considered when testing is shown in Attachment VIII.

A glycol mitigation plan was prepared for the Ottawa Airport Authority prior to requesting the approval for the conduct of tests at YOW. The mitigation plan is shown in Attachment IX.

4 EQUIPMENT AND FLUIDS

4.1 Equipment

Equipment to be employed is shown in Attachment X.

4.2 Fluids

The following fluids will available for testing:

- Kilfrost ABC-S Plus - 400 L;
- Kilfrost ABC-S – 60 L;
- Dow UCAR Ultra + - 60 L;
- Dow UCAR EG106 – 200 L; and
- Clariant Safewing MPIII 2031 ECO – 100 L.

5 PROCEDURE

The test procedures are shown in Attachment XI.

6 PERSONNEL

Five APS staff members are required for tests at the airport. Four additional persons will be required from Ottawa for making and dispersing the ice pellets. One additional person will be required from Ottawa to record images of the testing. Waste fluid clean-up and recovery will be performed by APS personnel.

Fluid and artificial precipitation application will be performed by APS personnel at the NRC hangar. NRC flight crews will operate the NRC aircraft.

Attachment XII provides task assignments.

7 DATA FORMS

The following data forms are required for the Falcon 20 tests to be conducted in February-March 2007:

- Attachment II: Ice Pellet Dispenser Data Sheet (IP Wind 10 km);
- Attachment III: Ice Pellet Dispenser Data Sheet (IP No Wind , 5 km);
- Attachment IV: Snow Dispenser Data Sheet (Snow Wind 10 km);
- Attachment V: Snow Dispenser Data Sheet (Snow No Wind < 5 km);
- Attachment XIII: General Form (Every Test);
- Attachment XIV: Fluid Thickness/Wing Temperature/Brix Form (Port Wing);
- Attachment XV: Fluid Thickness/Wing Temperature/Brix Form (Starboard Wing);
- Attachment XVI: Freezing Rain/Snow Quantity Form;
- Attachment XVII: Test Results Form;
- Attachment XVIII: Fluid Receipt Form;
- Attachment XIX: Time Record of Operations; and
- Attachment XX: Nominal Test Conditions.

ATTACHMENT I
Falcon 20 Ice Pellet / Snow Calibration Procedure

1. Ice Pellet/Snow Dispenser Calibration and Set-Up for Falcon 20 Testing

Calibration work was performed on the modified Ice Pellet/Snow dispensers prior to testing for 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 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.

2. Dispensing Ice Pellets/Snow for Falcon 20

Using the results from these calibration tests, a decision was rendered to use one dispenser at three different positions along each edge of the Falcon 20 wing. The following pages display the data sheets that will be used during testing at the Falcon 20. All information relating to the amount of Ice Pellets/Snow needed, effective rates and positions of dispensers are included in data sheets (Attachments II, III, IV and V).

3. Freezing Rain Sprayer Calibration for Falcon 20 Testing

Calibration work with the freezing rain sprayer was not conducted during the winter of 2007-08; freezing rain tests are a low priority. In the event that freezing rain testing is required, the sprayer settings from the 2006-07 winter testing should be used in order to obtain the desired rates. A pre-test calibration should be performed prior to applying freezing rain precipitation on the Falcon 20 wing section. The following steps should be followed:

1. Designate an area away from aircraft representative in size of the test section;

2. Place five rate pans in the four corners of the test section, as well as one in the center of the test section;
3. Begin spraying the freezing rain;
4. Sequentially measure each of the rate pans after a 5-minute or more exposure to the freezing rain;
5. Analyze the rates produced; and
6. Adjust sprayer settings based on results obtained and repeat steps 2 - 6.

ATTACHMENT II: Ice Pellet Dispenser Data Sheet (IP Wind 10 km)

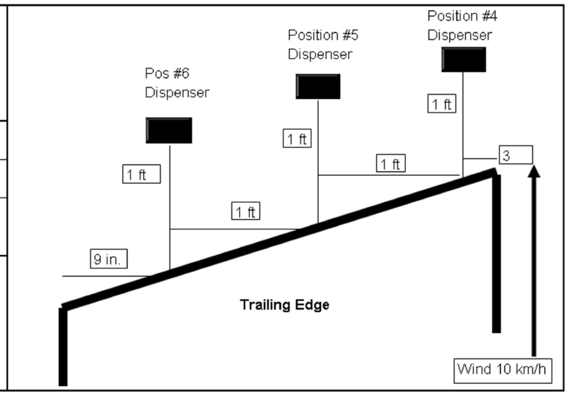
Procedure for data sheet: *This data sheet will be filled out electronically, prior to each test conducted at the Falcon 20. The quantity of Ice Pellets/Snow will be displayed and are dependent on the Target rate, Exposure Time, etc. This information will be communicated to the IP/Snow Manufactures prior to each test so that the quantity needed will be known. Following each test, this data sheet will be printed and filed.*

Precipitation Type	IP
Target Rate (g/dm2/h)	75
Exposure Time (min)	5
Wind Speed (km/h)	10

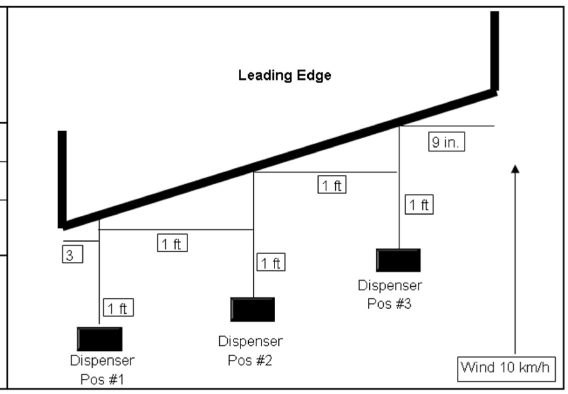
Date:	24-Feb-08
Start Time:	7:00
End Time:	7:10
Test #:	1

Total amount on Wing (g)	1732
Approximate Effective Rate on Wing (g/dm2/h)	77

Trailing Edge Efficiency of Dispenser: 57%	
Total amount needed for test on T.E. (g)	**1215**
Total amount needed per dispenser (g)	**405**
Total amount needed per dispenser per 5 minute cycle (g)	**405**



Leading Edge Efficiency of Dispenser: 79%	
Total amount needed for test on L.E. (g)	**1316**
Total amount needed per dispenser (g)	**439**
Total amount needed per dispenser per 5 minute cycle (g)	**439**



- One dispenser will be used on each edge.
- The dispensers at each position must be emptied at approximately 1-minute intervals.
- Once a dispenser is emptied, the dispenser is placed at its next position.
  (e.g. Pos #1 -> Pos #2 -> Pos #3 -> Pos #1 -> etc…) and (e.g. Pos #4 -> Pos #5 -> Pos #6 -> Pos #4 -> etc…)

ATTACHMENT III: Ice Pellet Dispenser Data Sheet (IP No Wind < 5 km)

Procedure for data sheet: *This data sheet will be filled out electronically, prior to each test conducted at the Falcon 20. The quantity of Ice Pellets/Snow will be displayed and are dependent on the Target rate, Exposure Time, etc. This information will be communicated to the IP/Snow Manufactures prior to each test so that the quantity needed will be known. Following each test, this data sheet will be printed and filed.*

Precipitation Type	IP
Target Rate (g/dm2/h)	75
Exposure Time (min)	5
Wind Speed (km/h)	0 or <5

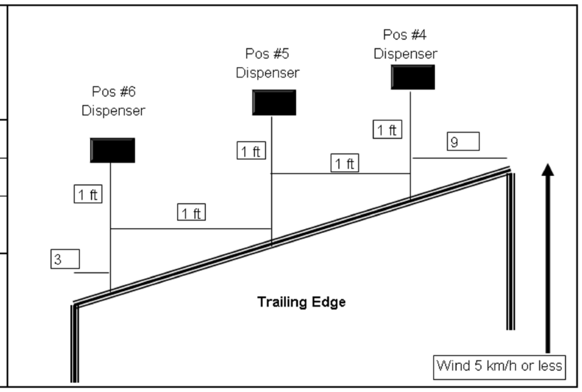
Date:	24-Feb-08
Start Time:	7:00
End Time:	7:10
Test #:	1

Total amount on Wing (g)	1858
Approximate Effective Rate on Wing (g/dm2/h)	83

Trailing Edge

Efficiency of Dispenser: 72%

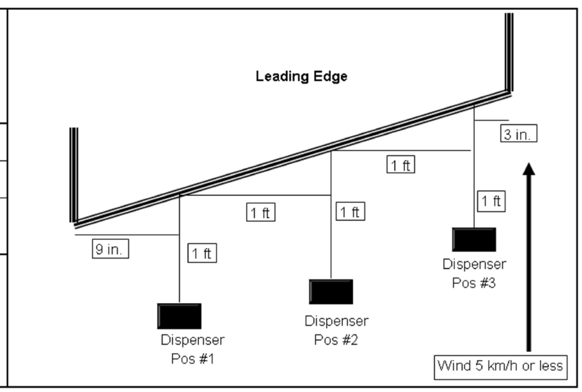
Total amount needed for test on T.E. (g)	**1290**
Total amount needed per dispenser (g)	**430**
Total amount needed per dispenser per 5 minute cycle (g)	**430**



Leading Edge

Efficiency of Dispenser: 72%

Total amount needed for test on L.E. (g)	**1290**
Total amount needed per dispenser (g)	**430**
Total amount needed per dispenser per 5 minute cycle (g)	**430**



- One dispenser will be used on each edge.
- The dispensers at each position must be emptied at approximately 1-minute intervals.
- Once a dispenser is emptied, the dispenser is placed at its next position.
  (e.g. Pos #1 -> Pos #2 -> Pos #3 -> Pos #1 -> etc…) and (e.g. Pos #4 -> Pos #5 -> Pos #6 -> Pos #4 -> etc…)

ATTACHMENT IV: Snow Dispenser Data Sheet (Snow Wind 10 km)

Procedure for data sheet: *This data sheet will be filled out electronically, prior to each test conducted at the Falcon 20. The quantity of Ice Pellets/Snow will be displayed and are dependent on the Target rate, Exposure Time, etc. This information will be communicated to the IP/Snow Manufactures prior to each test so that the quantity needed will be known. Following each test, this data sheet will be printed and filed.*

Precipitation Type	Snow
Target Rate (g/dm2/h)	25
Exposure Time (min)	5
Wind Speed (km/h)	10

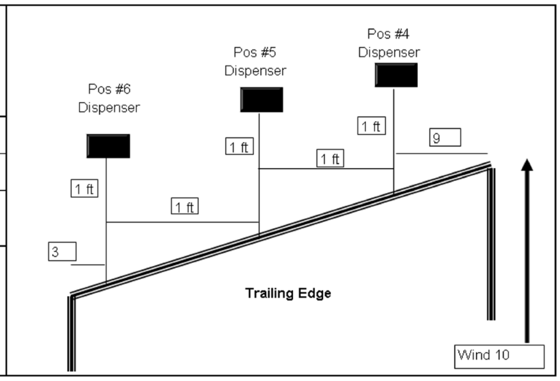
Date:	24-Feb-08
Start Time:	7:00
End Time:	7:10
Test #:	1

Total amount on Wing (g)	588
Approximate Effective Rate on Wing (g/dm2/h)	26

Trailing Edge

Efficiency of Dispenser: 37%

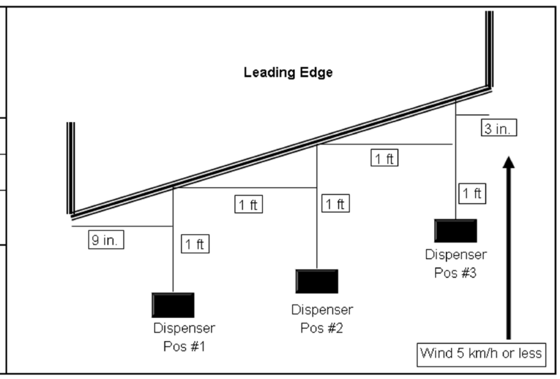
Total amount needed for test on T.E. (g)	**635**
Total amount needed per dispenser (g)	**212**
Total amount needed per dispenser per 5 minute cycle (g)	**212**



Leading Edge

Efficiency of Dispenser: 70%

Total amount needed for test on L.E. (g)	**505**
Total amount needed per dispenser (g)	**168**
Total amount needed per dispenser per 5 minute cycle (g)	**168**



- One dispenser will be used on each edge.
- The dispensers at each position must be emptied at approximately 1-minute intervals.
- Once a dispenser is emptied, the dispenser is placed at its next position.
  (e.g. Pos #1 -> Pos #2 -> Pos #3 -> Pos #1 -> etc…) and (e.g. Pos #4 -> Pos #5 -> Pos #6 -> Pos #4 -> etc…)

ATTACHMENT V: Snow Dispenser Data Sheet (Snow No Wind < 5 km)

Procedure for data sheet: *This data sheet will be filled out electronically, prior to each test conducted at the Falcon 20. The quantity of Ice Pellets/Snow will be displayed and are dependent on the Target rate, Exposure Time, etc. This information will be communicated to the IP/Snow Manufactures prior to each test so that the quantity needed will be known. Following each test, this data sheet will be printed and filed.*

Precipitation Type	Snow
Target Rate (g/dm2/h)	25
Exposure Time (min)	5
Wind Speed (km/h)	0 or <5

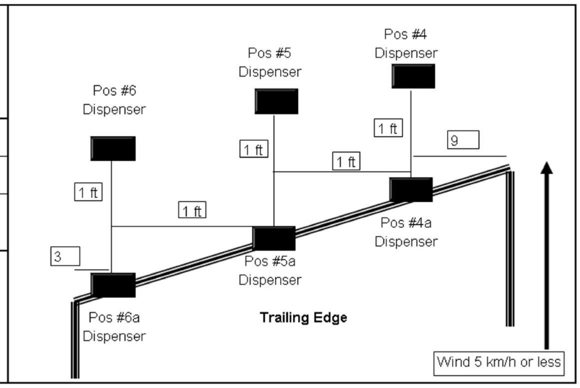
Date:	24-Feb-08
Start Time:	7:00
End Time:	7:10
Test #:	1

Total amount on Wing (g)	559
Approximate Effective Rate on Wing (g/dm2/h)	25

Trailing Edge

Efficiency of Dispenser: 86%

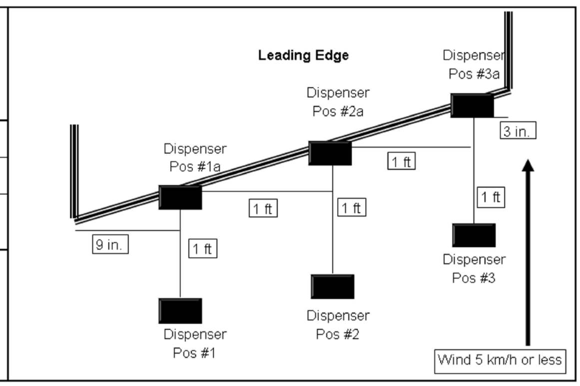
Total amount needed for test on T.E. (g)	**325**
Total amount needed per dispenser (g)	**108**
Total amount needed per dispenser per 5 minute cycle (g)	**108**



Leading Edge

Efficiency of Dispenser: 86%

Total amount needed for test on L.E. (g)	**325**
Total amount needed per dispenser (g)	**108**
Total amount needed per dispenser per 5 minute cycle (g)	**108**



- One dispenser will be used on each edge.
- The dispensers at each position must be emptied at approximately 1-minute intervals.
- Once a dispenser is emptied, the dispenser is placed at its next position.
- ***For SNOW (No/Low Wind), the dispensers will need to be brought in closer to the wing to improve distribution. Therefore alternate position have been designed. The sequence should go as follows: (e.g. Pos #1 -> Pos #2a -> Pos #3 -> Pos #1a -> Pos #2 -> Pos #3a -> Pos #1 -> etc…)***

ATTACHMENT VI

DOW CHEMICAL TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2005-2006[1]
UCAR™ ADF/AAF ULTRA+

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	1:35 – 3:35	0:35 – 1:15	0:45 – 1:35	0:25 – 0:40	0:10 – 1:20	CAUTION: No holdover time guidelines exist
		75/25							
		50/50							
below -3 to -14	below 27 to 7	100/0	12:00	1:25 – 3:00	0:25 – 0:55	0:45 – 1:25[3]	0:30 – 0:45[3]		
		75/25							
below -14 to -25	below 7 to -13	100/0	12:00[5]	0:40 – 2:10[5]	0:20 – 0:45[5]				
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.[5] 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. These holdover times only apply to outside air temperatures to -24°C (-11°F).

CAUTIONS

- **The only acceptable decision criteria time is the shortest time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

ATTACHMENT VI (cont.)

DOW CHEMICAL TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2007-2008[1]
UCAR™ ENDURANCE EG106

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

<table>
<tr><th colspan="2">Outside Air Temperature</th><th rowspan="2">Type IV Fluid Concentration Neat Fluid/Water (Volume %/Volume %)</th><th colspan="7">Approximate Holdover Times Under Various Weather Conditions (hours:minutes)</th></tr>
<tr><th>Degrees Celsius</th><th>Degrees Fahrenheit</th><th>Active Frost</th><th>Freezing Fog</th><th>Snow or Snow Grains</th><th>Freezing Drizzle[4]</th><th>Light Freezing Rain</th><th>Rain on Cold Soaked Wing</th><th>Other[2]</th></tr>
<tr><td rowspan="3">-3 and above</td><td rowspan="3">27 and above</td><td>100/0</td><td>12:00</td><td>2:05 – 3:10</td><td>0:40 – 1:20</td><td>1:10 – 2:00</td><td>0:50 – 1:15</td><td>0:20 – 2:00</td><td rowspan="6">CAUTION:
No holdover time guidelines exist</td></tr>
<tr><td>75/25</td><td></td><td></td><td></td><td></td><td></td><td rowspan="5"></td></tr>
<tr><td>50/50</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">below -3 to -14</td><td rowspan="2">below 27 to 7</td><td>100/0</td><td>12:00</td><td>1:50 – 3:20</td><td>0:30 – 1:05</td><td>0:55 – 1:50[3]</td><td>0:45 – 1:10[3]</td></tr>
<tr><td>75/25</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>below -14 to -25</td><td>below 7 to -13</td><td>100/0</td><td>12:00</td><td>0:30 – 1:05</td><td>0:15 – 0:30</td><td></td><td></td></tr>
<tr><td>below -25</td><td>below -13</td><td>100/0</td><td colspan="7">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.</td></tr>
</table>

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.

CAUTIONS

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

ATTACHMENT VI (cont.)

KILFROST TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2005-2006[1]
ABC-S

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	2:35 – 4:00	1:00 – 1:40	1:20 – 1:50	1:00 – 1:25	0:20 – 1:15	
		75/25	5:00	1:05 – 1:45	0:30 – 0:55	0:45 – 1:10	0:35 – 0:50	0:10 – 0:50	
		50/50	3:00	0:20 – 0:35	0:05 – 0:15	0:15 – 0:20	0:05 – 0:10	CAUTION: No holdover time guidelines exist	
below -3 to -14	below 27 to 7	100/0	12:00	0:45 – 2:05	0:45 – 1:20	0:20 – 1:00[3]	0:10 – 0:30[3]		
		75/25	5:00	0:25 – 1:00	0:25 – 0:50	0:20 – 1:10[3]	0:10 – 0:35[3]		
below -14 to -25	below 7 to -13	100/0	12:00	0:20 – 0:40	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.

CAUTIONS
- **The only acceptable decision criteria time is the shortest time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

ATTACHMENT VI (cont.)

KILFROST TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2007-2008[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	
		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	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	0:55 – 3:30	1:00 – 1:45	0:25 – 1:35[3]	0:20 – 0:30[3]		
		75/25	5:00	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	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.

CAUTIONS

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

ATTACHMENT VI (cont.)

SAE TYPE III FLUID HOLDOVER GUIDELINES FOR WINTER 2007-2008

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

Outside Air Temperature[3]		Approximate Holdover Times Under Various Weather Conditions (minutes)									
					Snow or Snow Grains						
Degrees Celsius	Degrees Fahrenheit	Type III Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Active Frost	Freezing Fog	Very Light	Light	Moderate	Freezing Drizzle[1]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[2]
-3 and above	27 and above	100/0	120	20 – 40	35	20 – 35	10 – 20	10 – 20	8 – 10	6 – 20	CAUTION: No holdover time guidelines exist
		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		
below -3 to -10	below 27 to 14	100/00	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.**

FALCON 20 TRIALS TO EXAMINE FLUID REMOVED FROM LOW ROTATION AIRCRAFT DURING TAKEOFF

ATTACHMENT VII
2007-08 Falcon 20 Test Plan

TEST NO	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
Objective	80 kts IP Expansion	80 kts IP Expansion	80 kts IP Expansion	EG 106 vs. Ultra+	EG 106 vs. Ultra+	ABC-S vs. ABC-S Plus	ABC-S vs. ABC-S Plus	**Flap Up** vs Flap Down	Allowance Time Expansion	Allowance Time Expansion	Allowance Time Expansion	**Rotation** vs No Rotation	Rotation vs **No Rotation**
Priority	1	1	2	1	2	2	1	3	3	2	3	2	2
Aircraft	Falcon 20	Falcon 20	Falcon 20	Falcon 20	Falcon 20	Falcon 20	Falcon 20	Falcon 20	Falcon 20	Falcon 20	Falcon 20	T-33	T-33
Take-off Profile	80knts in 17 sec	80knts in 17 sec	80knts in 17 sec	120knts in 25 sec	80knts in 17 sec	120knts in 25 sec	80knts in 17 sec	120knts in 25 sec	120knts in 25 sec	120knts in 25 sec	80knts in 17 sec	80knts in 17 sec	80knts in 17 sec
OAT	Below 0ºC	Below 0ºC	Below 0ºC	Below 0ºC	Below 0ºC	Below 0ºC	Below 0ºC	Below 0ºC	Below -5ºC	Below -5ºC	Below -5ºC	Below 0ºC	Below 0ºC
PORT WING:													
Fluid	EG 106	ABC-S Plus	Type III	EG 106	EG 106	ABC-S Plus	ABC-S Plus	TBD	EG 106	ABC-S Plus	ABC-S Plus	TBD	TBD
Precipitation Type	IP Moderate	IP Moderate	IP Moderate	N/A	N/A	N/A	N/A	N/A	SN/IP	SN/IP	SN/IP	N/A	N/A
Effective Precip Rate (g/dm²/h)	75	75	75	N/A	N/A	N/A	N/A	N/A	25 + 25	25 + 25	25 + 25	N/A	N/A
Exposure Time (min)	25 or 10 based on OAT	25 or 10 based on OAT	TBD based on HOT	N/A	N/A	N/A	N/A	N/A	> 10	> 10	> 10	N/A	N/A
STARBOARD WING:													
Fluid	EG 106	ABC-S Plus	Type III	Ultra+	Ultra+	ABC-S	ABC-S	TBD	EG 106	ABC-S Plus	ABC-S Plus	TBD	TBD
Precipitation Type	N/A (Baseline)	N/A (Baseline)	N/A (Baseline)	N/A	N/A	N/A	N/A	N/A	N/A (Baseline)	N/A (Baseline)	N/A (Baseline)	N/A	N/A
Effective Precip Rate (g/dm²/h)	N/A (Baseline)	N/A (Baseline)	N/A (Baseline)	N/A	N/A	N/A	N/A	N/A	N/A (Baseline)	N/A (Baseline)	N/A (Baseline)	N/A	N/A
Exposure Time (min)	N/A (Baseline)	N/A (Baseline)	N/A (Baseline)	N/A	N/A	N/A	N/A	N/A	N/A (Baseline)	N/A (Baseline)	N/A (Baseline)	N/A	N/A
Comments	In the case of elimination failure consider doing SN/IP tests	In the case of elimination failure consider doing SN/IP tests	In the case of elimination failure consider doing SN/IP tests	Comparative test to verify any differences	Comparative test to verify any differences	Comparative test to verify any differences	Comparative test to verify any differences	Run test with flap up and compare residual fluid to baseline flap down tests.	To provide guidance material for below -5ºC in IP/SN conditions	To provide guidance material for below -5ºC in IP/SN conditions	To provide guidance material for below -5ºC in IP/SN conditions	Aircraft Rotated at 80 Knots	Aircraft **NOT** Rotated at 80 Knots

ATTACHMENT VIII
Safety Issues

- All personnel must be familiar with Material Safety Data Sheets (MSDS) for fluids;
- When in controlled airport areas, ensure correct procedures and make sure escorts are available;
- When engines are operating, no loose objects should be used around the engines;
- When engines are operating, ensure ear plugs are worn and 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;
- The test area must be cleared of snow and ice before testing;
- 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 IX

GLYCOL MITIGATION PLAN

APS AVIATION INC.

FALCON 20 TRIALS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS OTTAWA, ONTARIO (YOW) FEBRUARY 25 – MARCH 7, 2008

1. CORPORATE PROFILE

APS Aviation Inc. (APS), member of the ADGA Group of companies, is a worldwide leader in aircraft de-icing research and development. Since 1990, APS has been contracted by the Transportation Development Centre (TDC) of Transport Canada to further advance aircraft pre-flight de/anti-icing technology.

2. BACKGROUND

At the request of the TDC of Transport Canada, APS has undertaken a research program to examine the potential aerodynamic penalties resulting from the presence of clean and diluted anti-icing fluid on aircraft wings.

Previous trials to examine the aerodynamic elimination of failed Type IV fluid from aircraft wings during takeoff were conducted on behalf of Transport Canada during the 1997-98 and 1998-99 and winter seasons at Mirabel Airport. Those trials, based on simulated takeoff runs using a National Research Council Falcon 20 aircraft, provided an improved understanding of the subject matter and demonstrated that the selected test approach was a viable one.

During the winter of 2001-02 and 2002-03, flight tests were performed at Ottawa International Airport (YOW). Tests were performed with one ethylene glycol-based Type IV fluid, Dow Ultra+, in neat and diluted form. Fluid was applied at the central de-icing pad at YOW by GlobeGround personnel.

The effects of (simulated) ice pellets and ice pellets mixed with freezing rain and/or snow on the wing of Falcon 20 aircraft during takeoff were studied in 2005-2007. Since the precipitation embedded in the fluid was not adhering according to previous tests, it is not known whether this contamination in the fluid would come off during aircraft rotation. The tests performed at YOW during the last two years allowed the FAA to issue allowance times for aircraft departing in ice pellets and ice pellets/freezing rain/snow mixed precipitation conditions.

The primary objective of the February-March 2008 tests at YOW will be to investigate the effects of mixed conditions with ice pellets for aircraft with low rotation speeds.

This document describes the glycol mitigation plan for the planned tests as follows:

- The fluid application procedures;
- The locations designated for fluid application;
- The anticipated fluid quantities to be sprayed; and
- The fluid recovery plan.

3. FLUID APPLICATION PROCEDURES

In February-March 2008, tests will be conducted at YOW with ethylene and propylene glycol-based Type IV fluids. In addition, a limited number of tests with an SAE certified propylene glycol-based Type III fluid may be attempted.

APS personnel are highly experienced in aircraft deicing matters, and attempts will be made to limit the quantities of fluid applied to the aircraft. The fluids will be applied to a 2.7 square-meter section of the aircraft wings by pouring, thus limiting the amount of fluid that falls on the ground after application.

In previous tests conducted at YOW in 2006 ethylene and propylene fluids were applied over the same 2.7 square-meter section. In total, 60 liters of ethylene fluid and 180 liters of propylene fluid were used for the entire test session. All deicing fluid that fell to the ground within the application area was properly recovered.

The fluid application will be performed by APS personnel at the NRC pad.

All Type IV fluids will be applied unheated to the wings of the Falcon 20. No Type I fluid will be applied prior to the Type IV.

4. LOCATIONS DESIGNATED FOR FLUID APPLICATION

The fluid application will be performed by APS personnel at the NRC pad.

Fluid applications at the NRC pad will be conducted in close proximity to the NRC hangar. Two separate areas will be assigned, one for ethylene applications, the other for propylene applications. NRC personnel will determine the precise locations prior to testing. The aircraft will not be positioned near the stormwater catch basins located on the southern edge of the NRC apron.

5. ANTICIPATED FLUID QUANTITIES TO BE SPRAYED

Thirteen tests are anticipated for February-March 2008 at YOW. Of this total, four will be performed with Dow fluid (ethylene), five will be performed with Kilfrost fluid (propylene), one will be performed with Clariant Safewing MP III 2031 Eco (propylene) and three will be determined on site.

Based on preliminary testing, the estimated maximum amount of fluid required for the conduct of these tests will be 400 liters (160 of ethylene glycol and 240 of propylene glycol base). Of this quantity, roughly 20% falls to the ground immediately following application.

6. FLUID RECOVERY PLAN

The method of application, pouring, minimizes the fluid that is applied to the wing section and the fluid falling on the ground immediately after application. APS personnel will collect the excess fluid immediately after application using fluid collection containers, tarps and a powerful vacuum.

The waste solutions will be recovered and stored separately to prevent cross-contamination of the products. APS will incur the costs of these fluid recovery services.

7. ADDITIONAL REPORTS

Upon request, a report will be provided by APS to the airport authority following the conduct of tests at YOW to provide the quantities of fluid used in testing.

ATTACHMENT X
Test Equipment Checklist

TASK Test Equipment	*STATUS*
General Equipment	
Panel van	
Freezer for ice and ice pellets storage	
Portable radio	
Fluids (order and ship to Ottawa)	
Horse and tap for fluid barrel	
Vacuum for fluid collection	
Waste fluid containers x 5	
Funnels for dispensers	
Sample bottles for viscosity measurement / 1Lires bottles x 5	
Squeegees (big and small)	
Large tape measure	
Isopropyl	
Gloves, hearing protectors, paper towel	
Extension cords	
Yellow Lighting	
Walkie Talkies	
Wise grip for fluid container	
Camera Equipment	
Digital still cameras x 3 (with lenses, chargers, batteries, etc)	
Video camera(s) provided by NRC	
Test Equipment	
Test Procedure, data forms	
Power inverter	
Large clock	
Fluid pouring devices x 6	
Ice pellets dispensing devices x 6 / stands and adapter	
Desktop/Laptop computer with printer with paper	
Portable hard drive and memory card reader	
Aluminum Rate pans (NCAR)	
Clipboards, pencils, wing markers for sample locations and solvent	
Temperature Probe x 2 and spare batteries / immersion and surface probes	
Thickness Gauges (large and small)	
Brixometers x 3	
Adherence Probes	
Weigh scale (NCAR and HOT)	
Gas containers	
Digital watches x 4	
Ice Pellets Fabrication Equipment	
Styrofoam containers x 20	
Ice bags Blenders (x 6) Ice pellets sieves (round and square)	
Folding tables	

ATTACHMENT X (cont.)
Test Equipment Checklist

TASK **Test Equipment (cont.)**	***STATUS***
Scrapers	
Measuring cups	
Rubber mats	
Neon light	
Freezing Rain Sprayer Equipment	
Freezing Rain Sprayer pump	
NRC compressed Air Fitting	
Water container	
Water hoses	
Air hoses	
Freezing Rain Sprayer nozzles	
Needles for the nozzles	
Extension cords (heavy duty)	

ATTACHMENT XI
Test Procedures

1. PRE-TEST SETUP

- Co-ordinate with Ottawa Airport Authority;
- Arrange for security escorts and passes, if required;
- Find video/photo specialist in Ottawa to record behaviour of fluid on the aircraft during the precipitation phase, taxi and simulated takeoff run of the Falcon 20;
- Hotels and advances for APS personnel;
- Arrange for vehicles to transport fluid and ice pellets fabrication and dispersion material;
- Arrange personnel travel to Ottawa;
- Ensure proper functioning of mobile equipment;
- Ensure proper functioning of ice pellets dispersers;
- Ensure proper functioning of freezing rain sprayer;
- Ensure NRC personnel draw grid on aircraft wings;
- Prepare and arrange for transport of equipment to Ottawa;
- Co-ordinate fabrication of ice pellets;
- Ensure the quantity of ice pellets is sufficient for the test;
- Arrange for storage and transportation of ice pellets;
- Order fluids;
- Mark aircraft data collection locations; and
- Collect virgin samples of Type IV fluid for viscosity tests.

2. CONTACT LIST

- NRC Flight Research Laboratory: Matthew Bastian (613) 998-3337;
- Security escorts: Harvey Airfield: Doug Harvey (613) 794-6884; and
- Ottawa Airport Authority: Yvon Larochelle (613) 248-2000 ext. 1157.

3. CONDUCT TESTS

3.1 Prior to Fluid Application:

- Record OAT, wind speed, direction and sky condition (Attachment XIII); and
- Measure wing temperature (Attachment XIV and XV).

3.2 Fluid Application (Pour):

- Pour fluid at NRC hangar;
- Record fluid application times and quantities (Attachment XIII);
- Let the fluid settle for 5 minutes;
- Measure thickness and Brix value (Attachment XIV and XV);
- Photograph and videotape the appearance of the fluid on the wing; and
- Collect the excess fluid.

3.3 Freezing Precipitation Application:

- Prepare and place rate pan on wing;
- Start the rate collection period;
- Record start of freezing precipitation application;
- Conduct freezing rain application;
- Spread the ice pellets evenly over the test area using the handheld dispenser;
- Measure the fluid freeze points at 2 numbered locations (see Attachments XIV and XV) at 5-minute intervals;
- When the desired level of precipitation has been applied to the wings, the wing observer will call for the end of the precipitation application process;
- Remove rate pans from the wing surface;
- Clean sprayer and prepare it for next run;
- Record quantity of ice pellets dispersed (Attachment XIII);
- Record quantity of freezing rain applied (Attachments XIII and XVI);
- Measure fluid thickness on the leading edge (Attachment XIV and XV);
- Measure fluid Brix value (Attachment XIV and XV); and
- Photograph and videotape the appearance of the fluid on the wing.

3.4 Prior to Simulated Takeoff Run (at runway button):

- Record wing temperatures at the numbered locations (Attachment XIV and XV);
- Measure fluid thickness (Attachment XIV and XV);
- Measure fluid Brix value (Attachment XIV and XV);
- Record departure runway, wind speed and direction (Attachment XIII); and
- Record time of departure (Attachments XIII and XVII).

3.5 During Simulated Takeoff Run:

- Take still pictures/videotape the behavior of the fluid on the wing during the takeoff run, capturing any movement of fluid/ice pellets; and

- With a second camera, record readings from the air speed indicator (NRC to perform).

3.6 Upon Return to the De-icing Pad:

- Observe and record the status of the fluid/ice pellets (Attachment XVII).

3.7 After Each Test Session

APS personnel will collect the waste solution from the NRC apron. APS will apply EG and PG-based Type IV fluids at different locations on the NRC apron to ensure the waste solutions are properly separated.

3.8 Typical Falcon 20 Test: Anticipating Timing

Below is a description of a typical Falcon 20 test, assuming the test starts at 08:00:00.

APPROX. TIME	TASK
08:00:00	START OF THE TEST. ALL EQUIPMENT READY.
08:00:00	Record test conditions (OAT, wind, RH, sky condition, etc).
08:05:00	Prepare wings for fluid application (clean wing, etc).
08:15:00	Pour fluid over test area and let settle for 5 minutes
08:15:00	Start aircraft engines. Pilots follow standard pre-departure procedures
08:20:00	Measure fluid Brix, thickness. Photograph test area.
08:30:00	Disperse freezing precipitation over test area.
09:00:00	Measure Brix, thickness. Photograph test area.
09:20:00	Aircraft starts to taxi towards runway. Waste fluid collected and pad prepared for next test.
09:30:00	Aircraft is positioned for the simulated takeoff run. Measure Brix, thickness. Photograph test area.
09:40:00	Start of the simulated takeoff run.
09:50:00	Aircraft returns to the deicing pad.
09:50:00	Measure Brix, thickness. Photograph test area. Record test observations
10:00:00	END OF TEST

3.9 Typical Falcon 20 Test: Number of People Required

Below is a description of the major steps of a typical Falcon 20 test and the number of people required for each test.

STEP	TASKS	NO. OF PEOPLE REQUIRED
1	Complete general forms	1 (APS) GB
	Prepare fluid	2 (APS) SB/YOW 2
	Prepare IP for test	2 (IP makers) JT/YOW 1
	Prepare sprayer	2 (APS) JT/YOW 1
2	Pour fluid	4 (APS) JT/YOW 1/GB/MR
	Refill fluid pouring devices	2 (APS + IP makers) YOW 2/YOW 3
3	Take measurements (temp, thickness, brix)	2 (APS) MR/JT
	Ready IP dispensers	2 (APS + IP makers) JT/YOW 1/YOW 2/YOW 3
	Ready ZR sprayer	2 (APS) JT/SB/YOW 1/YOW 2
4	Apply IP	4 (APS + IP makers) JT/YOW 1/YOW 2/YOW 3
	Apply ZR	2 (APS) JT/YOW 1
	Assist with ZR application and take measurements	1 (APS) GB
5	Take measurements at hangar	2 (APS) GB/MR
	Clean sprayer and prepare for next test	2 (APS) JT/YOW 1
	Prepare fluid for next test	2 (APS + IP makers) SB/YOW 2
6	Take measurements at button and record test results	2 (APS) GB/MR
7	Collect and file data forms/photos	1 (APS) SB

ATTACHMENT XII
APS Staff Task Description

Overall Co-ordinator (JD)

- Co-ordinate tests with NRC, TDC;
- Advise all other agencies, including security; and
- Provide direction as required during the tests.

Co-ordinator 1 (GB)

- Ensure that all required equipment is available and functional;
- Maintain General Form for every test (Attachment XIII);
- Ensure all data are collected and recorded, and that all test records submitted;
- Measure temperature of the wing (Attachment XIV and XV) and Brix (Attachments XIV and XV);
- Pour fluid over test area;
- Note the observed wing condition after each run (Attachment XIV and XV); and
- Communicate safety concerns.

Co-ordinator 2 (MR)

- Pour fluid over test area;
- Measure thickness measurements (Attachments XIV and XV); and
- Note the observed wing condition after each run (Attachment XIV and XV);

Freezing Rain Sprayer Application (JT/SB/YOW 1)

- Ensure the proper operation of the sprayer;
- Calibrate the sprayer prior to the test session;
- Apply freezing rain as required for each test; and
- Clean the sprayer and prepare it for the next test.

Data collection (GB/MR)

- Complete the Fluid Receipt Form (Attachment XVIII) for each fluid;
- Record temperature measurements (Attachment XIV and XV);
- Record Brix and thickness measurements (Attachment XIV and XV);
- Record start and end of fluid application (Attachment XIII);
- Record start and end of freezing precipitation application (Attachment XIII);
- Record amount of ice pellets applied (Attachment XIII);

- Record quantity of freezing rain applied (Attachment XVI);
- Collect samples of fluid for viscosity tests:
  - Virgin Type IV prior to application;
  - Type IV fluid on wing applied by pouring;
  - Type IV fluid remaining on trailing edge following takeoff run; and
  - Record the specifics for each sample on the bottle in permanent marker.

Videographer/Photographer (from Ottawa)

- Ensure time stamps are operating and accurately set;
- Videotape fluid on wing "before and after" each run and during takeoff run, ensuring constant viewing angles are used, to facilitate comparisons; and
- Photograph all test set-up, outside and onboard the aircraft;
- Photograph the condition of wing with ice pellets at specified times.

Ice Pellets Makers (YOW 1/YOW 2/YOW 3/YOW 4)

- Responsible for the fabrication of ice pellets;
- One ice pellet maker will operate the blender;
- One ice pellet maker will filter the crushed ice;
- Disperse ice pellets over the test area using the handheld disperser;
- Transport ice pellets to the test site; and
- Assist with the ice pellet application.

Ice Pellets Co-ordinator (JT)

- Supervise the production of ice pellets;
- Supply the ice pellet makers with raw ice;
- Ensure that the quantity of ice pellets produced is sufficient for the test requirements;
- Disperse ice pellets over the test area using the handheld disperser;
- Ensure proper storage of ice pellets and raw ice; and
- Assist with ice pellets application

Ground Co-Ordinator (SB)

- Management of YOW 1/2/3/4 personnel;
- Co-ordinate ground activities during and post tests; and
- Correct and file data forms/photos.

Falcon 20 Observer

- One person seated inside the Falcon 20 during tests will keep a time record of operations (Attachment XIX).

ATTACHMENT XIII: General Form (Every Test)

DATE: ____________________ AIRCRAFT TYPE: Falcon 20

RUN #: __________ AIRPORT: YOV

OAT BEFORE TEST: __________ (˚C) OPERATOR: NRC

OAT AFTER TEST: __________ (˚C) FUEL LOAD: __________

VIND SPEED / DIRECTION: __________ FIN #: __________

SKY CONDITIONS __________ DIRECTION OF AIRCRAFT: degrees

EXACT PAD LOCATION OF TEST: __________

FLUID APPLIED: ____________________

FLUID BRIX: ____________________ DRAV DIRECTION OF VIND VRT AIRCRAFT

FLUID APPLICATION - PORT / STARBOARD VING			
ACTUAL START TIME:	__________	ACTUAL END TIME:	__________
FLUID TEMPERATURE	______ (˚C)	AMOUNT OF FLUID:	__________
FLUID APPLICATION METHOD:	__________		
ICE PELLETS APPLICATION - PORT / STARBOARD VING		PHOTOGRAPH SAMPLE ( )	
ACTUAL START TIME:	__________	ACTUAL END TIME:	__________
QUANTITY OF ICE PELLETS APPLIED	__________ kg	ICE PELLETS SIZE:	__________
SNOV APPLICATION - PORT / STARBOARD VING		PHOTOGRAPH SAMPLE ( )	
ACTUAL START TIME:	__________	ACTUAL END TIME:	__________
QUANTITY OF SNOV APPLIED	__________ kg	SNOV SIZE:	__________
FREEZING RAIN APPLICATION - PORT / STARBOARD VING		PHOTOGRAPH SAMPLE ( )	
ACTUAL START TIME:	__________	ACTUAL END TIME:	__________
PRECIPITATION RATE	__________		

COMMENTS: ______________________________

____

____

____

MEASUREMENTS BY: ____________________ HANDVRITTEN BY: ____________________

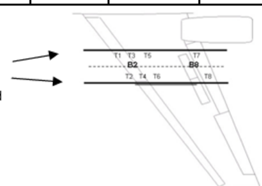
ATTACHMENT XIV: Fluid Thickness/Wing Temperature/Brix Form (Port Wing)

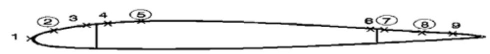
Date: ______________________ Run: __________

WING TEMPERATURE					
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	Before Takeoff Run	After Takeoff Run
T1					
T2					
T3					
T4					
T5					
T6					
T7					
T8					
Time					

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

Test area denoted by lines





Location: 1 - LE nose
2,8 - Halfway
3,4,6,7 - 1" form joint
5 - As far as can reach
9 - 6" from TE

Notes: - Measure thickness along centerline indicated in the diagram.
- Give priority to circled locations; measure other locations only if time allows.

FLUID BRIX				
Wing Position	After Fluid Application	After Precip Application	Before Takeoff Run	After Takeoff Run
B2				
B8				
Time:				

Comments: ____________________________________

OBSERVER: ______________________

ASSISTED BY: ______________________

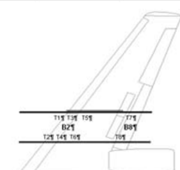
ATTACHMENT XV: Fluid Thickness/Wing Temperature/Brix Form (Starboard Wing)

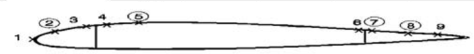
Date: ______________________ Run: __________

WING TEMPERATURE					
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	Before Takeoff Run	After Takeoff Run
T1					
T2					
T3					
T4					
T5					
T6					
T7					
T8					
Time					

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

Test area denoted by lines





Location: 1 - LE nose
2,8 - Halfway
3,4,6,7 - 1" form joint
5 - As far as can reach
9 - 6" from TE

Notes: - Measure thickness along centerline indicated in the diagram.
- Give priority to circled locations; measure other locations only if time allows.

FLUID BRIX				
Wing Position	After Fluid Application	After Precip Application	Before Takeoff Run	After Takeoff Run
B2				
B8				
Time:				

Comments: ________________________________

OBSERVER: ____________________

ASSISTED BY: ____________________

ATTACHMENT XVI: Freezing Rain/Snow Quantity Form

Date: ____________________

Run #: ____________________

Wing: ____________________

Time Before	Time After	ZR- or Snow	Container Weight (kg)		Rate g/dm2/h
			Before	After	

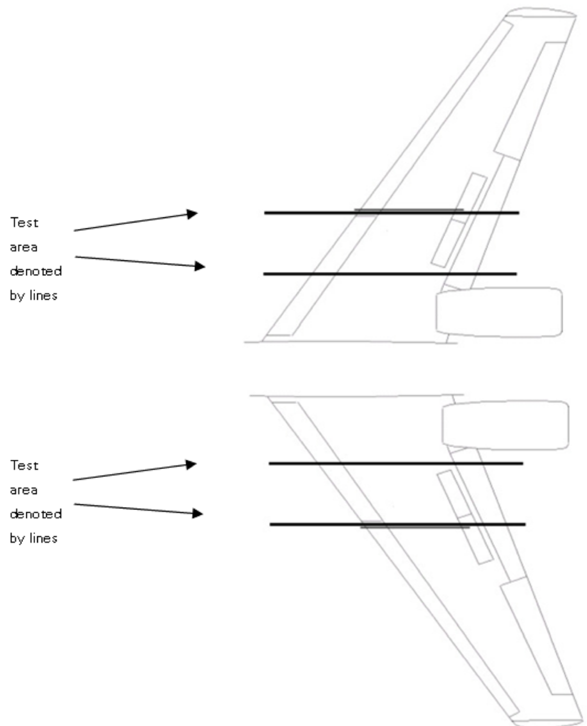
COMMENTS: ____________________

MEASUREMENTS BY: ____________________

HANDWRITTEN BY: ____________________

ATTACHMENT XVII: Test Results Form

Date: ____________________ Time: ____________________ Run Number: __________



Observations (Starboard Wing): ____________________

Observations (Port Wing): ____________________

OBSERVER: ____________________

ASSISTED BY: ____________________

ATTACHMENT XVIII: Fluid Receipt Form

RECEIVING LOCATION: **DATE OF RECEIVING:** **SAMPLE COLLECTED FROM BARREL: Y / N**

GENERAL

Fluid Name: ____________________

Manufacturer: ______________ **Fluid Type:** ____ **Batch #:** __________________

APS Code: ____________________

Certificates of Conformance acc. to SAE AMS 1424: ☐
(check the box if received)

Fluid Freeze Point Curves (FP vs. Dilution & FP vs. Refraction): ☐
(for Type I Fluids only; check the box if received)

Lowest Operational Use Temperature: ☐
(check the box if received)

WSET Done by the Certification Agency: ☐
(check the box if received)

Date of Production: ____________ **Quantity:** ___,___,___(L) **Fluid Dilution:** ________ (100/75/50 or Neat)(%)

Manufacturer stated BRIX: ____________ **APS Measured BRIX:** ____________ **MSDS Sheets Received:** ☐

Manufacturer's Authorization to Proceed with Endurance Time Testing: ☐
(check the box if received)

Authorized by: ____________________
(PRINT NAME)

on: ____________________
(DATE)

TYPE IV FLUIDS

Manufacturers stated VISCOSITY: ☐ mPa*s (cP)
(VALUE)

APS Measured VISCOSITY: Using Manufacturer's Method ☐ mPa*s (cP)
(VALUE)

Viscosity shall be determined using the same Brookfield spindle/sample size combination as used for the AMS 1428 certification (most current).

ATTACHMENT XIX: Time Record of Operations

Run Number ________________
Date ________________

OPERATION	TIME / OBSERVATION
Pilots Bboard	
Start Engines	
Systems Rready	
Fluid Application Start	
Fluid Application Completed	
Measure Ffluid and Air Temperature	
Close Door	
Ready to Roll	
Start Taxi	
Arrive Runway Hold	
Door Open	
Measure Aair Temperature	
Measure Fluid Thickness Brix and Temperature	
Start Pellet Application	
Complete Pellet Application	
Measure Fluid Thickness Brix and Temperature	
Door Closed	
Taxi to Take Off	
Start Cameras	
Start Take Off Roll	
End Acceleration	
End Take Off Roll	
Arrive at Hanger	
Engine Shut Down	
Door Open	
Measure Fluid Thickness Brix and Temperature	
Record Wing Condition	

ATTACHMENT XX: Nominal Test Conditions

TEST NO	1	2	3	4	5
Date					
Fluid					
Precipitation (PORT/STARBOARD)	/	/	/	/	/
Pellets size [mm]					
Dyed Pellets					
PORT WING:	-	-	-	-	-
Effective IP Rate [g/dm^2/h]					
Total Pellet Weigh Applied [kg]					
Effective ZR Rate [g/dm2/h]					
Quantity of water applied [kg]					
Brix after precipitation application					
PORT WING:	-	-	-	-	-
Effective IP Rate [g/dm^2/h]					
Total Pellet Weigh Applied [kg]					
Effective ZR Rate [g/dm2/h]					
Quantity of water applied [kg]					
Brix after precipitation application					
Remarks					

APPENDIX D

FALCON 20
TIME RECORD OF OPERATIONS DATA FORMS

FALCON 20
TIME RECORD OF OPERATIONS DATA FORMS

INDEX

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TIME RECORD OF OPERATIONS

Run Number 1

Date 26 FEB 2008

OPERATION	TIME / OBSERVATION
Pilots Bboard	11:58
Start Engines	12:03
Systems Rready	
Fluid Application Start	11:05
Fluid Application Completed	11:18
Measure Ffluid and Air Temperature	11:22 & 11:55
Close Door	12:02
Ready to Roll	12:17
Start Taxi	12:17
Arrive Runway Hold	12:29
Door Open	12:30
Measure Aair Temperature	12:32
Measure Fluid Thickness Brix and Temperature	12:33
Start Pellet Application	11:25
Complete Pellet Application	11:50
Measure Fluid Thickness Brix and Temperature	[illegible]
Door Closed	12:33
Taxi to Take Off	12:29
Start Cameras	
Start Take Off Roll	12:34
End Acceleration	12:34 ~17 sec acceleration run
End Take Off Roll	12:34
Arrive at Hangar	12:43
Engine Shut Down	12:43
Door Open	12:44
Measure Fluid Thickness Brix and Temperature	12:49
Record Wing Condition	12:49

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TIME RECORD OF OPERATIONS

Run Number 258 / 2P8
Date 27 FEB 08

OPERATION	TIME / OBSERVATION
Pilots Bboard	10:56
Start Engines	11:05
Systems Rready	
Fluid Application Start	10:18
Fluid Application Completed	10:27
Measure Ffluid and Air Temperature	10:31 / [illegible]
Close Door	10:58
Ready to Roll	
Start Taxi	11:12
Arrive Runway Hold	11:24
Door Open	11:24
Measure Aair Temperature	10:33 / 11:25
Measure Fluid Thickness Brix and Temperature	10:33 / 11:25
Start Pellet Application	10:35
Complete Pellet Application	10:45
Measure Fluid Thickness Brix and Temperature	10:48 / 11:25
Door Closed	10:58
Taxi to Take Off	11:29
Start Cameras	
Start Take Off Roll	11:26:55 act = 17 sec
End Acceleration	11:27:12
End Take Off Roll	11:27:15
Arrive at Hanger	11:36
Engine Shut Down	11:36
Door Open	11:37
Measure Fluid Thickness Brix and Temperature	11:39
Record Wing Condition	11:39

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TIME RECORD OF OPERATIONS

Run Number 358 1388
Date 27 FEB 08

OPERATION	TIME / OBSERVATION
Pilots Bboard	12:58
Start Engines	1:11
Systems Rready	
Fluid Application Start	not present, in meeting
Fluid Application Completed	" " " "
Measure Ffluid and Air Temperature	1:09
Close Door	1:10
Ready to Roll	1:15
Start Taxi	1:20
Arrive Runway Hold	1:31
Door Open	1:31
Measure Aair Temperature	
Measure Fluid Thickness Brix and Temperature	12:56 / 1:35
Start Pellet Application	12:57
Complete Pellet Application	1:07
Measure Fluid Thickness Brix and Temperature	1:32
Door Closed	1:33
Taxi to Take Off	1:34
Start Cameras	
Start Take Off Roll	1:35:47 1:36:04
End Acceleration	1:36:04 Δt = 17sec.
End Take Off Roll	1:36:35
Arrive at Hangerar	1:47
Engine Shut Down	1:48
Door Open	1:48
Measure Fluid Thickness Brix and Temperature	1:52
Record Wing Condition	1:52

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R#1

TIME RECORD OF OPERATIONS

Run Number 4 S/P 8
Date 28 FEB 2004

OPERATION	TIME / OBSERVATION
Pilots Bboard	9:32
Start Engines	9:43
Systems Rready	
Fluid Application Start	9:20 (P)
Fluid Application Completed	9:29 ?
Measure Ffluid and Air Temperature	9:37
Close Door	9:39
Ready to Roll	9:51
Start Taxi	9:51
Arrive Runway Hold	9:56
Door Open	N/A
Measure Aair Temperature	N/A
Measure Fluid Thickness Brix and Temperature	N/A
Start Pellet Application	N/A
Complete Pellet Application	N/A
Measure Fluid Thickness Brix and Temperature	N/A
Door Closed	N/A
Taxi to Take Off	9:56
Start Cameras	
Start Take Off Roll	9:57
End Acceleration	30 sec total acceleration
End Take Off Roll	9:57
Arrive at Hanger	10:04
Engine Shut Down	N/A
Door Open	
Measure Fluid Thickness Brix and Temperature	10:08
Record Wing Condition	10:08

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RK 2

TIME RECORD OF OPERATIONS

Run Number 5 S/P 8
Date 28 FEB 2008

OPERATION	TIME / OBSERVATION
Pilots Bboard	
Start Engines	
Systems Rready	
Fluid Application Start	≈ 10:09
Fluid Application Completed	10:19
Measure Ffluid and Air Temperature	10:27
Close Door	10:27
Ready to Roll	
Start Taxi	10:29
Arrive Runway Hold	10:34
Door Open	N/A
Measure Aair Temperature	N/A
Measure Fluid Thickness Brix and Temperature	N/A
Start Pellet Application	N/A
Complete Pellet Application	N/A
Measure Fluid Thickness Brix and Temperature	N/A
Door Closed	N/A
Taxi to Take Off	10:34
Start Cameras	
Start Take Off Roll	10:34
End Acceleration	Δ = 17.91 secs
End Take Off Roll	10:34
Arrive at Hanger	10:39
Engine Shut Down	10:39
Door Open	10:39
Measure Fluid Thickness Brix and Temperature	10:52
Record Wing Condition	10:52

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Version 3.0

P #3
- 2/28/08

TIME RECORD OF OPERATIONS

Run Number 6 SIP 8
Date 28 FEB 2008

OPERATION	TIME / OBSERVATION
Pilots Bboard	
Start Engines	
Systems Rready Measure skin temp	11:43
Fluid Application Start	11:45
Fluid Application Completed	11:51
Measure Ffluid and Air Temperature	11:58
Close Door	11:59
Ready to Roll	
Start Taxi	12:07
Arrive Runway Hold	12:12
Door Open	
Measure Aair Temperature	
Measure Fluid Thickness Brix and Temperature	
Start Pellet Application	
Complete Pellet Application	
Measure Fluid Thickness Brix and Temperature	
Door Closed	
Taxi to Take Off	12:12
Start Cameras	
Start Take Off Roll	12:13
End Acceleration	12:13 Δ = 17.71 secs
End Take Off Roll	12:13
Arrive at Hanger	12:17
Engine Shut Down	12:18
Door Open	12:19
Measure Fluid Thickness Brix and Temperature	
Record Wing Condition	

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Version 3.0

TIME RECORD OF OPERATIONS

Run Number 7 S/P 8
Date 24 FEB 2008

OPERATION	TIME / OBSERVATION
Pilots Bboard	13:15
Start Engines	13:28
Systems Rready	
Fluid Application Start	12:57
Fluid Application Completed	13:05
Measure Ffluid and Air Temperature	13:10
Close Door	13:29
Ready to Roll	
Start Taxi	13:35
Arrive Runway Hold	13:40
Door Open	13:40
Measure Aair Temperature	
Measure Fluid Thickness Brix and Temperature	13:12 hangar/ 13:
Start Pellet Application	13:15
Complete Pellet Application	13:25
Measure Fluid Thickness Brix and Temperature	13:28 hangar/ 13:42 runway
Door Closed	13:43
Taxi to Take Off	13:44
Start Cameras	
Start Take Off Roll	13:44 ΔT= 18.45 secs
End Acceleration	13:44
End Take Off Roll	13:45
Arrive at Hanger	13:49
Engine Shut Down	13:50
Door Open	13:50
Measure Fluid Thickness Brix and Temperature	13:55
Record Wing Condition	13:57

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12-29

TIME RECORD OF OPERATIONS

Run Number 8 P/S 8
Date 29 FEB 2008

OPERATION	TIME / OBSERVATION
Pilots Bboard	
Start Engines	9:23
Systems Rready	
Fluid Application Start	
Fluid Application Completed	
Measure Ffluid and Air Temperature	
Close Door	9:22
Ready to Roll	
Start Taxi	9:34
Arrive Runway Hold	9:45
Door Open	
Measure Aair Temperature	
Measure Fluid Thickness Brix and Temperature	
Start Pellet Application	
Complete Pellet Application	
Measure Fluid Thickness Brix and Temperature	
Door Closed	
Taxi to Take Off	
Start Cameras	
Start Take Off Roll	9:48
End Acceleration	AT = 29.70 9:48
End Take Off Roll	9:48
Arrive at Hanger	9:57
Engine Shut Down	9:58
Door Open	9:58
Measure Fluid Thickness Brix and Temperature	10:07
Record Wing Condition	10:07

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Version 3.0

TIME RECORD OF OPERATIONS

Run Number 9P/S 8
Date 25 FEB 2008

OPERATION	TIME / OBSERVATION
Pilots Bboard	11:10
Start Engines	11:12
Systems Rready	
Fluid Application Start	
Fluid Application Completed	
Measure Ffluid and Air Temperature	
Close Door	11:10
Ready to Roll	
Start Taxi	11:18
Arrive Runway Hold	11:29
Door Open	11:29
Measure Aair Temperature	
Measure Fluid Thickness Brix and Temperature	
Start Pellet Application	10:40
Complete Pellet Application	10:59
Measure Fluid Thickness Brix and Temperature	11:05 vision / 11:32 runway
Door Closed	11:09 vision / 11:32 runway
Taxi to Take Off	11:33
Start Cameras	
Start Take Off Roll	11:36
End Acceleration	11:36 ΔT = 29.365 secs.
End Take Off Roll	11:37
Arrive at Hanger	11:46
Engine Shut Down	11:46
Door Open	11:47
Measure Fluid Thickness Brix and Temperature	11:56
Record Wing Condition	11:59

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Version 3.0

TIME RECORD OF OPERATIONS

100kt
no rotation

Run Number 10 PIS 8
Date 29 FEB 2008

OPERATION	TIME / OBSERVATION
Pilots Bboard	12:40
Start Engines	12:43
Systems Rready	
Fluid Application Start	
Fluid Application Completed	
Measure Ffluid and Air Temperature	
Close Door	12:40
Ready to Roll	
Start Taxi	12:51
Arrive Runway Hold	12:59
Door Open	
Measure Aair Temperature	
Measure Fluid Thickness Brix and Temperature	
Start Pellet Application	
Complete Pellet Application	
Measure Fluid Thickness Brix and Temperature	
Door Closed	
Taxi to Take Off	12:59
Start Cameras	
Start Take Off Roll	13:00
End Acceleration	13:00 AT = 21.97
End Take Off Roll	13:00
Arrive at Hang~~e~~r ar	13:05
Engine Shut Down	13:06
Door Open	13:07
Measure Fluid Thickness Brix and Temperature	13:10
Record Wing Condition	13:10

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Version 3.0

TIME RECORD OF OPERATIONS

Run Number 11 P/S 8
Date 29 FEB 2008

OPERATION	TIME / OBSERVATION
Pilots Bboard	
Start Engines	
Systems Rready	
Fluid Application Start	13:31
Fluid Application Completed	
Measure Ffluid and Air Temperature	
Close Door	13:47
Ready to Roll	
Start Taxi	13:54
Arrive Runway Hold	14:03
Door Open	
Measure Aair Temperature	
Measure Fluid Thickness Brix and Temperature	
Start Pellet Application	
Complete Pellet Application	
Measure Fluid Thickness Brix and Temperature	
Door Closed	
Taxi to Take Off	14:03
Start Cameras	
Start Take Off Roll	1403
End Acceleration	1403 ≈ 17 secs
End Take Off Roll	1403
Arrive at Hanger	14:10
Engine Shut Down	14:11
Door Open	14:12
Measure Fluid Thickness Brix and Temperature	
Record Wing Condition	

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Version 3.0

TIME RECORD OF OPERATIONS

Run Number 12 P/S 8
Date 4 March 2008

skiing lamp @ 09:14

OPERATION	TIME / OBSERVATION
Pilots Bboard	
Start Engines	10:06
Systems Rready	
Fluid Application Start	9:17
Fluid Application Completed	9:27
Measure Ffluid and Air Temperature	
Close Door	10:03
Ready to Roll	
Start Taxi	10:14
Arrive Runway Hold	10:20
Door Open	10:20
Measure Aair Temperature	10:22
Measure Fluid Thickness Brix and Temperature	10:22
Start Pellet Application	not at aircraft
Complete Pellet Application	not at aircraft
Measure Fluid Thickness Brix and Temperature	
Door Closed	10:22
Taxi to Take Off	10:22
Start Cameras	
Start Take Off Roll	10:25 47 = 21.7
End Acceleration	10:25
End Take Off Roll	10:25
Arrive at Hanger	10:31
Engine Shut Down	10:32
Door Open	
Measure Fluid Thickness Brix and Temperature	
Record Wing Condition	

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Version 3.0

TIME RECORD OF OPERATIONS

Run Number 13 P/S 8
Date 4 Mar 2008

OPERATION	TIME / OBSERVATION
Pilots Bboard	
Start Engines	
Systems Rready	
Fluid Application Start	
Fluid Application Completed	
Measure Ffluid and Air Temperature	
Close Door	
Ready to Roll	
Start Taxi	
Arrive Runway Hold	
Door Open	
Measure Aair Temperature	
Measure Fluid Thickness Brix and Temperature	
Start Pellet Application	
Complete Pellet Application	
Measure Fluid Thickness Brix and Temperature	
Door Closed	
Taxi to Take Off	
Start Cameras	
Start Take Off Roll	
End Acceleration	
End Take Off Roll	
Arrive at Hanger	
Engine Shut Down	
Door Open	
Measure Fluid Thickness Brix and Temperature	
Record Wing Condition	

No timers available for form. General times See run Takeoff

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Version 3.0

9:40 9:45

TIME RECORD OF OPERATIONS

Run Number 11 PIS 2
Date 6 MAR 2008

OPERATION	TIME / OBSERVATION
Pilots Bboard	08:48
Start Engines	08:51
Systems Rready	
Fluid Application Start	7:57
Fluid Application Completed	8:07
Measure Ffluid and Air Temperature	8:17
Close Door	08:50
Ready to Roll	
Start Taxi	09:02
Arrive Runway Hold	09:13 ✓
Door Open	09:13 ✓
Measure Aair Temperature	09:16
Measure Fluid Thickness Brix and Temperature	09:16
Start Pellet Application	08:25
Complete Pellet Application	8:45
Measure Fluid Thickness Brix and Temperature	8:47 at hangar
Door Closed	09:16
Taxi to Take Off	09:13
Start Cameras	
Start Take Off Roll	09:17
End Acceleration	09:18 ΔT = 28.36s
End Take Off Roll	09:18
Arrive at Hanger	09:29
Engine Shut Down	09:29
Door Open	09:33
Measure Fluid Thickness Brix and Temperature	09:37
Record Wing Condition	

M:\Groups\CM (TC-Deicing 05-06)\Procedures\Data Forms\ Time Record of Operations
Version 3.0

TIME RECORD OF OPERATIONS

Run Number 15 P/S 8
Date 6 MAR 2008

OPERATION	TIME / OBSERVATION
Pilots Bboard	10:36
Start Engines	10:40
Systems Rready	
Fluid Application Start	Not present
Fluid Application Completed	Not present
Measure Ffluid and Air Temperature	10:33
Close Door	10:36
Ready to Roll	
Start Taxi	10:47
Arrive Runway Hold	10:54
Door Open	10:54
Measure Aair Temperature	10:56
Measure Fluid Thickness Brix and Temperature	10:33 hangar ...
Start Pellet Application	
Complete Pellet Application	10:30
Measure Fluid Thickness Brix and Temperature	10:56
Door Closed	10:56
Taxi to Take Off	10:59
Start Cameras	
Start Take Off Roll	11:00
End Acceleration	11:0?
End Take Off Roll	11:00 ΔT = 18.63 secs.
Arrive at Hanger	11:06
Engine Shut Down	11:06
Door Open	11:06
Measure Fluid Thickness Brix and Temperature	11:16
Record Wing Condition	11:16

M:\Groups\CM (TC-Deicing 05-06)\Procedures\Data Forms\ Time Record of Operations
Version 3.0

TIME RECORD OF OPERATIONS

Run Number 16 P/S 8
Date 6 MAR 8

OPERATION	TIME / OBSERVATION
Pilots Bboard	12:24
Start Engines	12:27
Systems Rready	
Fluid Application Start ?	
Fluid Application Completed ?	
Measure Ffluid and Air Temperature	12:02, 12:06 A
Close Door	12:26
Ready to Roll	
Start Taxi	12:34
Arrive Runway Hold	12:39
Door Open	12:39
Measure Aair Temperature	
Measure Fluid Thickness Brix and Temperature	
Start Pellet Application	12:02
Complete Pellet Application	12:22
Measure Fluid Thickness Brix and Temperature	12:42
Door Closed	12:42
Taxi to Take Off	12:43
Start Cameras	
Start Take Off Roll	12:44
End Acceleration	12:44 Δt ≈ 18 sec.
End Take Off Roll	12:44
Arrive at Hanger	12:52
Engine Shut Down	12:53
Door Open	12:54
Measure Fluid Thickness Brix and Temperature	12:57
Record Wing Condition	12:57

M:\Groups\CM (TC-Deicing 05-06)\Procedures\Data Forms\ Time Record of Operations
Version 3.0

APPENDIX E

FALCON 20 AND T-33 TEST RESULTS DATA FORMS

FALCON 20 AND T-33 TEST RESULTS DATA FORMS

INDEX

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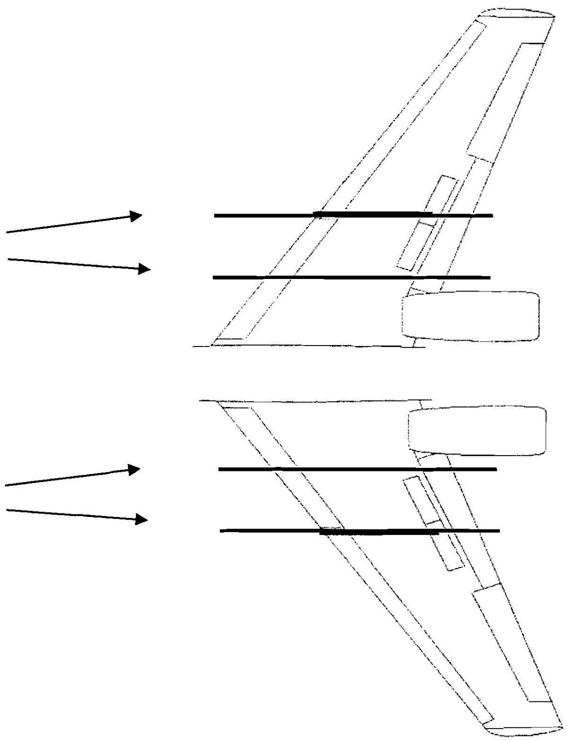
TEST RESULTS FORM

Date: 26-FEB-2008 Time: ____________ Run Number: 1

Test area denoted by lines



Test area denoted by lines

Observations (Starboard Wing):

ALOT OF FLUID LEFT ON WING

Observations (Port Wing):

FLUID CLEARED 1/3 OF WING AT 80 KNTS.

SEEMS LIKE MORE FLUID THAN 120 KNTS

OBSERVER: ____________

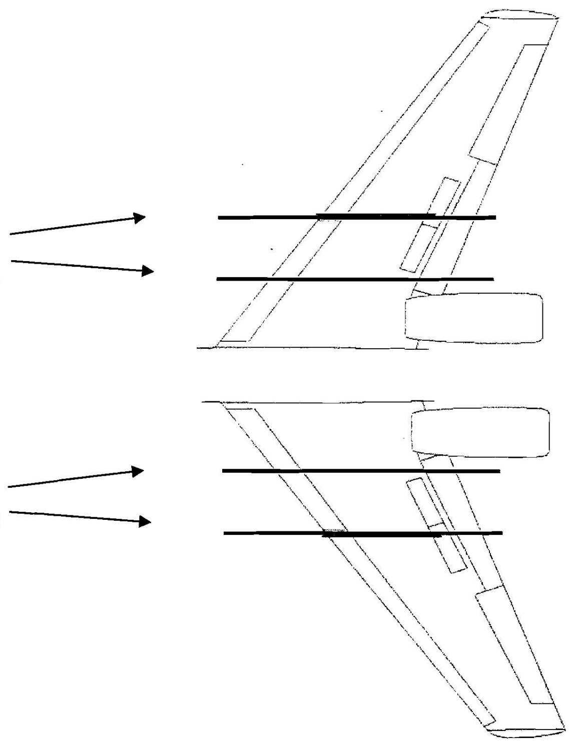
ASSISTED BY: ____________

TEST RESULTS FORM

Date: 27FEB08 Time: __________ Run Number: 258/2P8

Test area denoted by lines

Test area denoted by lines



Observations (Starboard Wing):

Observations (Port Wing):

LESS FLUID THAN TIV TEST

BOTH WINGS SIMILAR

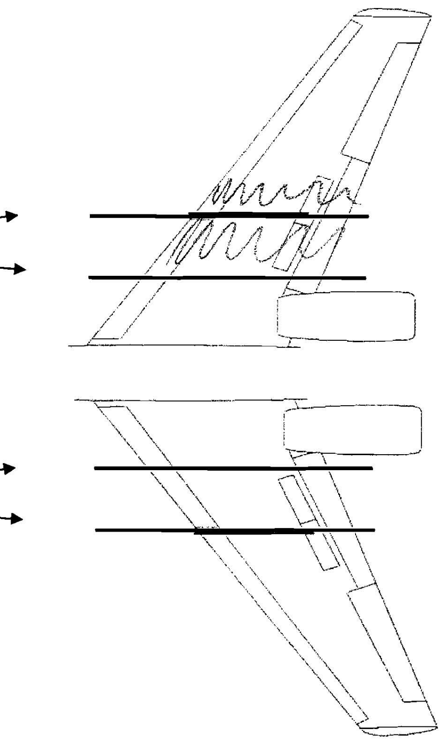
OBSERVER: MP

ASSISTED BY:

TEST RESULTS FORM

Date: 27FEB 08 Time: ________ Run Number: 338/3P8

Test area denoted by lines



Test area denoted by lines

Observations (Starboard Wing):

SHORT VS LONG CHORD

SHOWED SIMILAR RESULTS

Observations (Port Wing):

FLUIDS SEEMED TO CLEAR

OFF BETTER THAN ABC-S PLUS

THICKNESS CONFIRMED

OBSERVER: [signature]

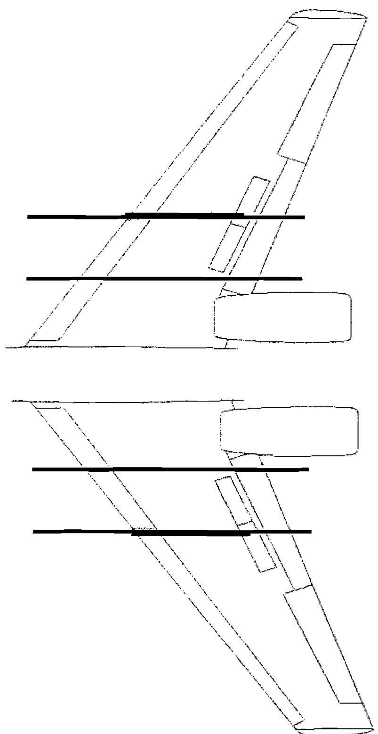
ASSISTED BY: ________

TEST RESULTS FORM

Date: 28 FEB 2000 Time: ____________ Run Number: 4 P/S 8

Test area denoted by lines

Test area denoted by lines



Observations (Starboard Wing):

HIGH SPEED

BOTH WINGS HAD SIMILAR RESIDUAL FLUID AT END OF TEST

SAME

Observations (Port Wing):

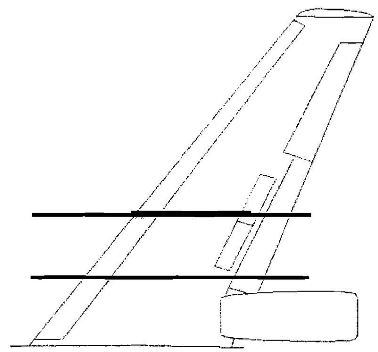
OBSERVER: ____________

ASSISTED BY: ____________

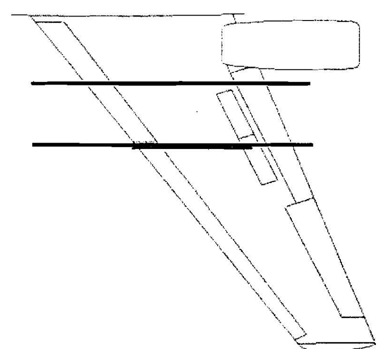
TEST RESULTS FORM

Date: 28 FEB 2008 Time: ______ Run Number: SP15 8

Test area denoted by lines



Test area denoted by lines



Observations (Starboard Wing):

LOW SPEED

MORE FLUID AT END OF TEST COMPARED TO HIGH SPEED.

BOTH WINGS COMPARABLE AT END OF TEST

Observations (Port Wing):

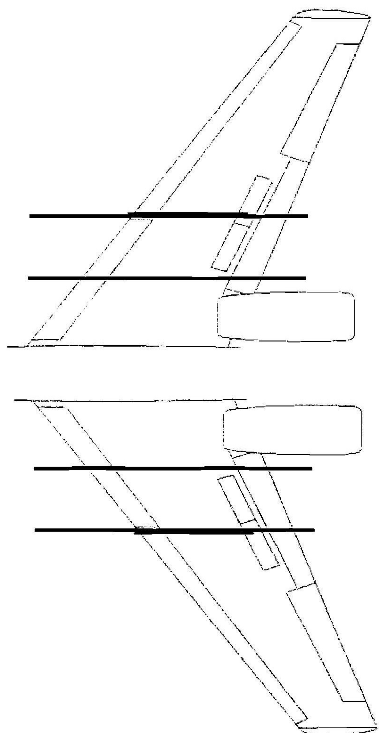
OBSERVER: ______

ASSISTED BY: ______

TEST RESULTS FORM

Date: 28 FEB 2008 Time: ______ Run Number: GP/S 8

Test area denoted by lines



Test area denoted by lines

Observations (Starboard Wing):

Observations (Port Wing):

LE HAD SIMILAR RESULTS
TE HAD LESS FLUID
WHEN COMPARED
TO STARBOARD (U+)

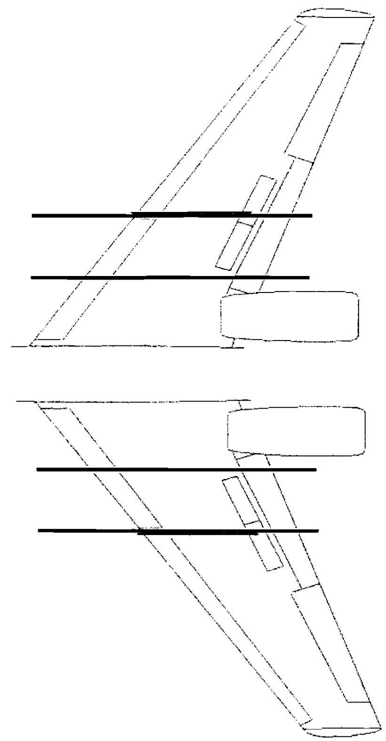
OBSERVER: [signature]

ASSISTED BY:

TEST RESULTS FORM

Date: 28 FEB 2008 Time: ____________ Run Number: 7P/S8

Test area denoted by lines



Test area denoted by lines

Observations (Starboard Wing):

Observations (Port Wing):

IP REMAINED AFT OF LE TO TE

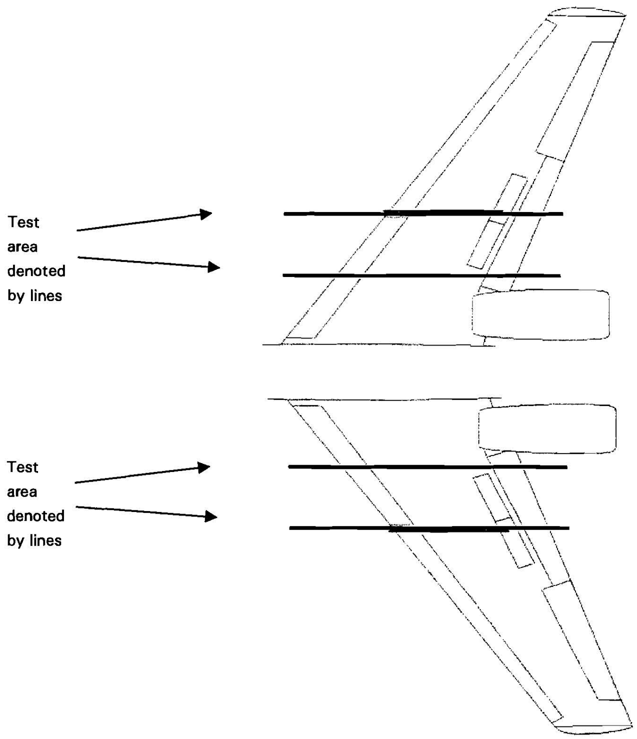
FLUID THICKNESS GREATER THAN ON STARBOARD.

OBSERVER: [signature]

ASSISTED BY:

TEST RESULTS FORM

Date: 29 FEB 2008 Time: ____________ Run Number: 8 P/S 8



Observations (Starboard Wing):

TEST RUN SLIGHTLY LONGER THAN USUAL ≈ 29 SEC.

SAME

Observations (Port Wing):

BOTH WINGS HAD COMPARABLE RESIDUAL THICKNESSES

SEEMED LESS THAN 120 [illegible] ROTATION RUN HOWEVER MAY HAVE BEEN DUE TO LOWER ACCELERATION.

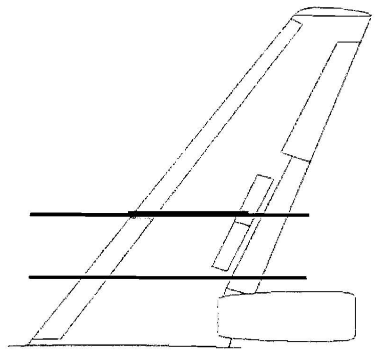
OBSERVER: ____________

ASSISTED BY: ____________

TEST RESULTS FORM

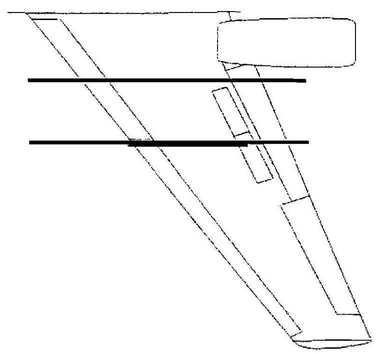
Date: 29 FEB 2008 Time: ____________ Run Number: 9 P/S 8

Test area denoted by lines



Observations (Starboard Wing):

Test area denoted by lines



Observations (Port Wing):

TRACES OF CONTAMINATION PRESENT ON TE (1/3 OF WING)

NOT ADHERED.

FLUID THICKNESS ON TE THICKER IN COMPARISON TO STARBOARD

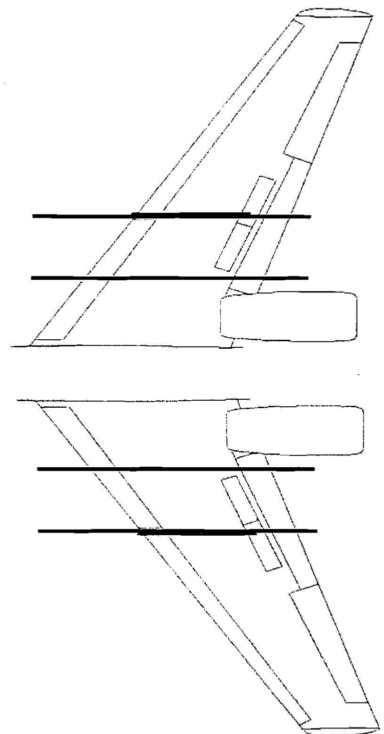
OBSERVER: ____________

ASSISTED BY: ____________

TEST RESULTS FORM

Date: 29 FEB 2008 Time: __________ Run Number: 10 P/S 8

Test area denoted by lines



Test area denoted by lines

Observations (Starboard Wing):

SAME

Observations (Port Wing):

OUTBOARD VS INBOARD WITH THRUST

EG 106 THICKER AT END OF TEST COMPARED TO ABC-S PLUS

OBSERVER: __________

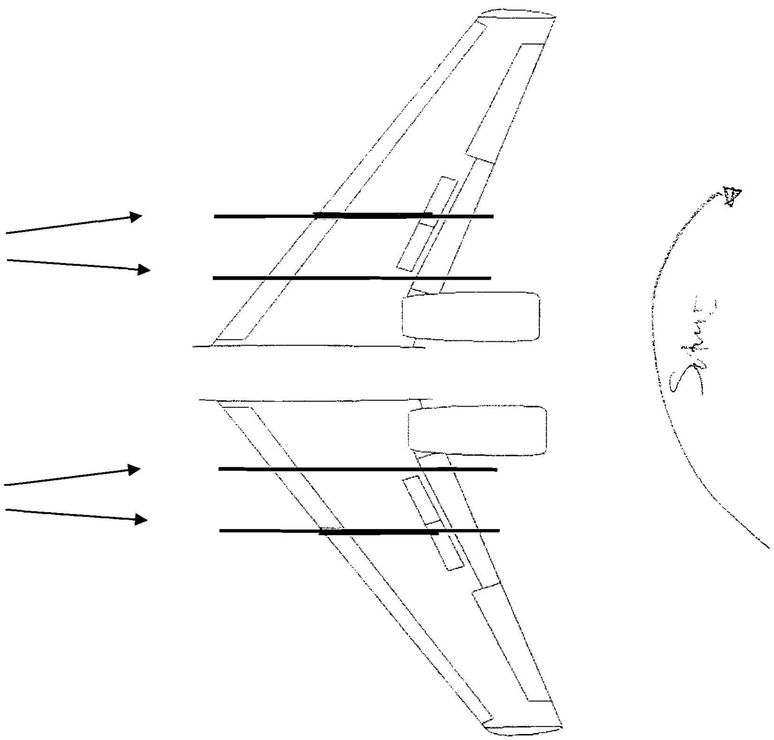
ASSISTED BY: __________

TEST RESULTS FORM

Date: 25 FEB 2008 Time: ______ Run Number: 11 PIS 8

Test area denoted by lines

Test area denoted by lines



Observations (Starboard Wing):

Observations (Port Wing):

EG106 THINNER COMPARED TO ABC-S RUN

FLAPS SEEMED TO HELP FLUID ELIMINATION.

VISUALLY APPROX 2/3 CLEAN AT ROTATION

WU - ALMOST COMPLETELY CLEAN

OBSERVER: MR

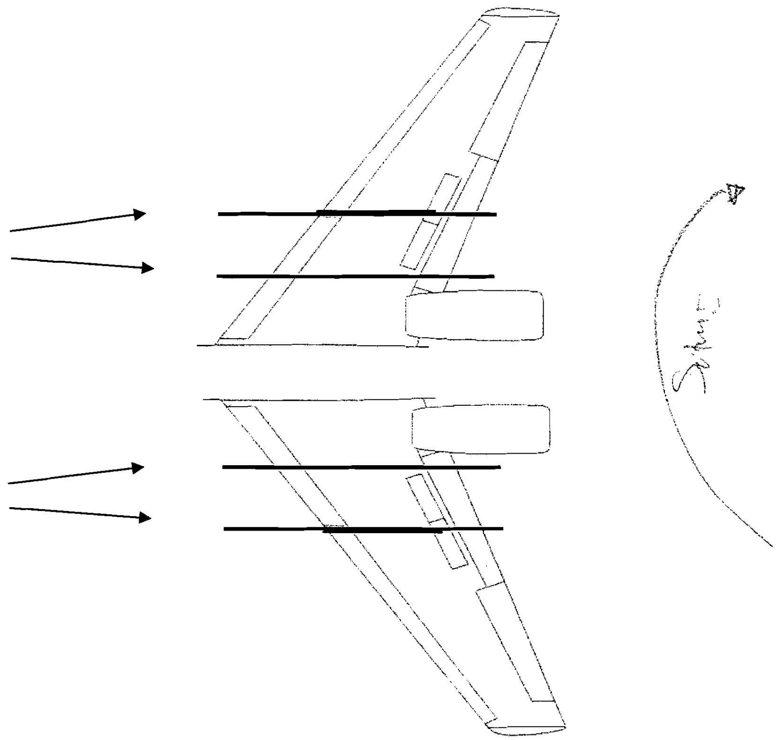
ASSISTED BY:

TEST RESULTS FORM

Date: 25 FEB 2008 Time: ____________ Run Number: 11 P/S 8

Test area denoted by lines

Test area denoted by lines



Observations (Starboard Wing):

Observations (Port Wing):

EG106 THINNER COMPARED TO ABC-S RUN

FLAPS SEEMED TO HELP FLUID ELIMINATION.

VISUALLY APPROX 2/3 CLEAN AT ROTATION

WU - ALMOST COMPLETELY CLEAN

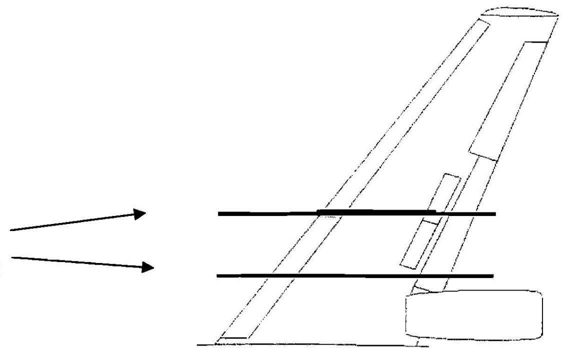
OBSERVER: MR

ASSISTED BY:

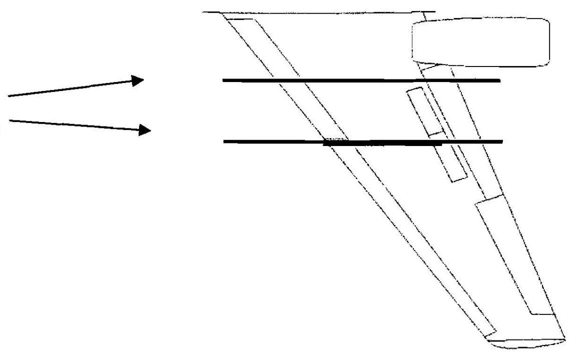
TEST RESULTS FORM

Date: 4 Mar 2008 Time: ______ Run Number: 12P158

Test area denoted by lines



Test area denoted by lines



Observations (Starboard Wing):

Observations (Port Wing):

FLUID CAME OFF TEST SECTION >2/3 @ V_R

SLATS SEEMED TO IMPOSE SHADOW OF FLUID OUTBOARD ON 5.5 ft SECTION

RUN WAS LONG ≈21 SEC NOT 17 SEC

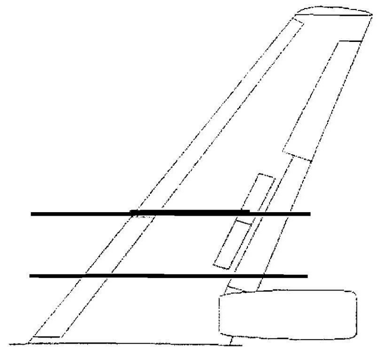
OBSERVER: [signature]

ASSISTED BY:

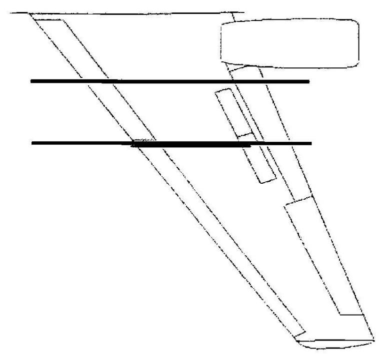
TEST RESULTS FORM

Date: 4 Mar 2008 Time: ______ Run Number: 13 P/S 8

Test area denoted by lines



Test area denoted by lines



Observations (Starboard Wing):

Observations (Port Wing):

CLEARED > 2/3 of WING AT VR

TREATED SECTION SHEARED ≤ 1/2 OF WING AT 1/R

NO CONTAMINATION LEFT AT END.

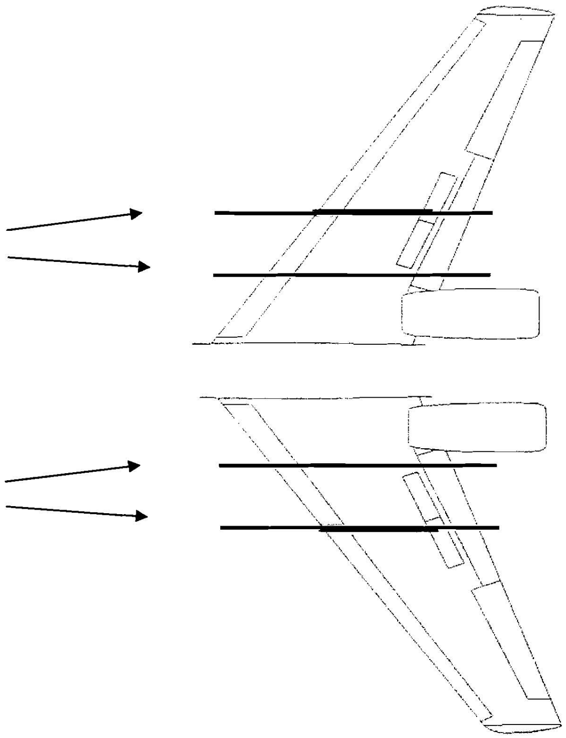
OBSERVER: ______

ASSISTED BY: ______

TEST RESULTS FORM

Date: 6 Mar 2008 Time: ____________ Run Number: 14 P/S8

Test area denoted by lines



Test area denoted by lines

Observations (Starboard Wing):

THERMAL CREATED ON 5.5" SEEMING IS COMPARED TO NORMAL EXPERIENCE ON TE

Observations (Port Wing):

SOME CONTAMINATION ON TE MR ON STARBOARD (COULD NOT SEE)

VR ≈ 30 SEC

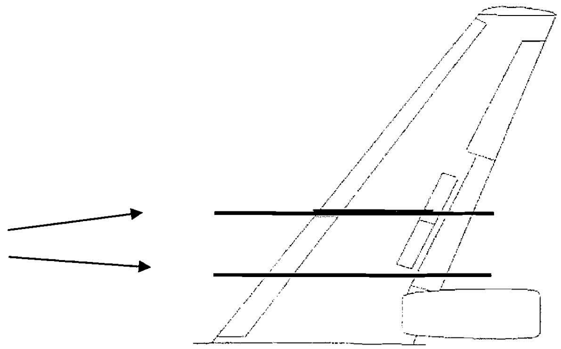
OBSERVER:

ASSISTED BY:

TEST RESULTS FORM

Date: 6 Mar 2008 Time: ________ Run Number: 15 PIS 8

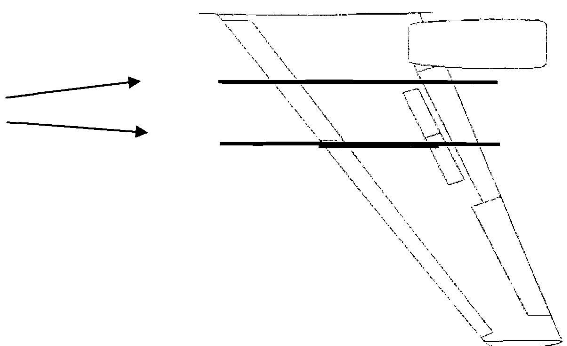
Test area denoted by lines



Observations (Starboard Wing):

THICKNESS OUTBOARD GREATER THAN INBOARD.

Test area denoted by lines



Observations (Port Wing):

FLUID COMPLETELY ELIMINATED. SOME MINIMAL CONTAMINATION LEFT ON TE. TEMP >0°C SO MOSTLY MELTED.

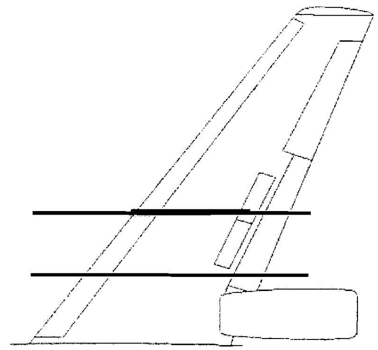
OBSERVER:

ASSISTED BY:

TEST RESULTS FORM

Date: 6 Mar 2008 Time: ______ Run Number: 16 P158

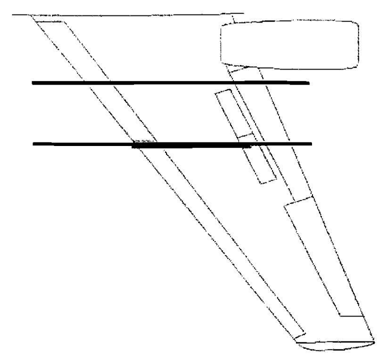
Test area denoted by lines



Observations (Starboard Wing):

SIMILAR RESULTS
FOR OUT VS IN BOARD

Test area denoted by lines



Observations (Port Wing):

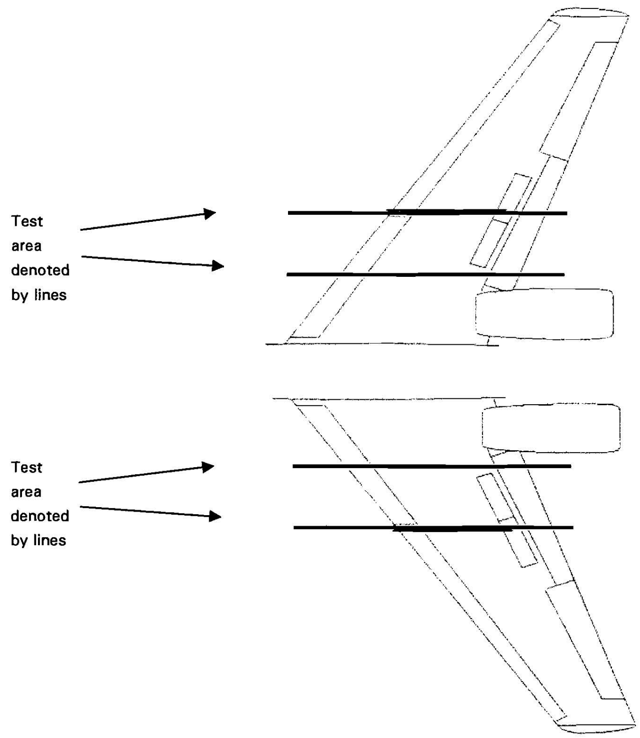
OUTBOARD NOT - NO MOVEMENT AT VR
INBOARD CLEANED AT VR
ICE CONTAMINATION REMOVED AT VR

OBSERVER:

ASSISTED BY:

TEST RESULTS FORM

Date: ______________ Time: ______________ Run Number: 17P158



Observations (Starboard Wing):

FLUIDS THICKNESS SIMILAR ON BOTH WINGS.

Observations (Port Wing):

EG 106 SEEMS TO HAVE MORE RIPPLES IN RESIDUAL FLUID. LIKELY ILLUSION DUE TO [illegible].

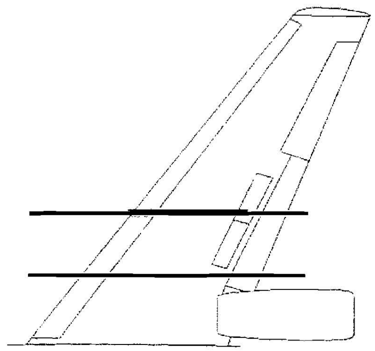
OBSERVER:

ASSISTED BY:

TEST RESULTS FORM

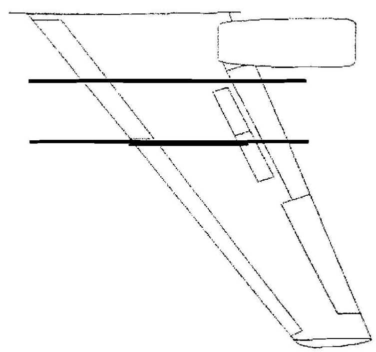
Date: ____________ **Time:** ____________ **Run Number:** 18 PIS 8

Test area denoted by lines



Observations (Starboard Wing):

Test area denoted by lines



Observations (Port Wing):
EG 106 CLEARED BEFORE ABC-4 (MB)
THICKNESS THINNER ON TE PORT vs TE STARBOARD
FLAX SEEMED TO HAVE HELPED
FLOW OFF (1/3 SECTION) (VISUAL)

OBSERVER: ____________

ASSISTED BY: ____________

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APPENDIX F

TEST REPORT:
ADHESION OF TYPE II & III DE/ANTI-ICING FLUIDS ON ALUMINUM SURFACES DURING MIXED ICE PELLETS AND FREEZING RAIN PRECIPITATION CONDITIONS

CM 2103.001

TEST REPORT:
ADHESION OF TYPE II & III DE/ANTI-ICING FLUIDS ON ALUMINUM SURFACES DURING MIXED ICE PELLETS AND FREEZING RAIN PRECIPITATION CONDITIONS

Winter 2008

Prepared for

Transportation Development Centre
Transport Canada

And

The Federal Aviation Administration
William J. Hughes Technical Center

Prepared by: Marco Ruggi

Reviewed by: John D'Avirro

January 5, 2009
Final Version 1.0

TEST REPORT: ADHESION OF TYPE II & III DE/ANTI-ICING FLUIDS ON ALUMINUM SURFACES DURING MIXED ICE PELLETS AND FREEZING RAIN PRECIPITATION CONDITIONS

January 5, 2009

1. BACKGROUND

Prior to the winter of 2006, 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, 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, the FAA provided a 25-minute allowance as a preliminary guideline; 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 ice pellets alone (no mixed conditions).

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

During the winter of 2007, 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. The recommended allowance time were based on aerodynamic research conducted using the NRC Open Circuit Wind Tunnel and the NRC Falcon 20 aircraft; these results were presented at the Society of Automotive Engineers (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. One of the restrictions indicates that the allowance times are only applicable to Type IV anti-icing fluids applied in neat formulation.

During the winter of 2007-08, endurance time testing was conducted to investigate if the current ice pellet allowance times could be expanded to include Type II and Type III anti-icing fluids.

2. OBJECTIVE

The objective of this project was to investigate the level of ice pellet and freezing rain contamination required to cause fluid adherence to the test surface. Baseline testing was conducted in freezing rain conditions only. Testing was primarily conducted to investigate if the current allowance times for Type IV fluids could be expanded to include Type II and Type III fluids.

3. 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".*

Endurance time testing was conducted in April 2008 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 two test plates (test plate positions 1 and 2).

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 approximated 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.

3.1 Test Parameters Measured and Documented

1L of fluid at OAT was poured onto the test plate. Fluid dilution, fluid thickness, surface temperature, fluid failure, and adhesion were documented throughout the test. Photos of the test plate were taken every 5 minutes for the duration of the test. As this work was preliminary, rate of precipitation was not measured during the test. Previous work was done at the APS P.E.T Airport test site to calibrate the ice pellet dispensers. In addition, testing followed the standard HOT testing, therefore, there was no need to reconfirm light freezing rain precipitation rates.

4. TEST PLAN AND TEST LOG

To investigate the level of ice pellet and freezing rain contamination required to cause fluid adherence to the test surface, testing with Type II/III fluid was conducted in simulated mixed icing conditions. In conjunction with every mixed precipitation test, a baseline endurance time test was conducted in freezing rain conditions alone; this allowed for a direct correlation of the baseline test data to the HOT Guidelines endurance time data. Table 4.1 describes the test conditions:

Table 4.1: Test Condition Parameters

Condtion	ZR- Rate (g/dm²/h)	IP Rate (g/dm²/h)	OAT (ºC)
ZR- and IP-	25	25	-5
ZR- (Baseline Test)	25	N/A	-5
ZR- and IP-	25	25	-10
ZR- (Baseline Test)	25	N/A	-10

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 4.2 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.

Table 4.2: Test Log

Test #	Fluid Type	Fluid Brand	Plate Loc.	Date	Start Time	Fail Time	Total Time (min)	Test Temp. [°C]	Precip (type, rate)	Approx. Combined Precip Rate [g/dm²/h]	Time of Adh to 1" Line (min)	Avg. Time of Adh to 1" Line (min)	Adh at End of Test	Final Brix (°)
IP1	II	Kilfrost 2143 (3500)	1	07-Apr-08	18:58	19:14	16.0	-5	ZR, 25 / IP, 25	50	25	30	Adh to 6" Line @ 40 min.	7 @ 40 min.
IP1A	II	Kilfrost 2143 (3500)	2	07-Apr-08	18:58	19:14	16.0	-5	ZR, 25 / IP, 25	50	34		Adh to 6" Line @ 40 min.	8 @ 40 min.
IP2	III	Clariant Type III	1	07-Apr-08	19:44	19:54	10.0	-5	ZR, 25 / IP, 25	50	10	10	Full Plate Adh @ 20 min.	10 @ 13 min.
IP2A	III	Clariant Type III	2	07-Apr-08	19:44	19:54	10.0	-5	ZR, 25 / IP, 25	50	10		Full Plate Adh @ 20 min.	8.5 @ 13 min.
IP1-1	II	Kilfrost 2143 (3500)	5	07-Apr-08	17:13	17:52	No Fail	-5	ZR, 25	25	39	39	N/A	15 @ 39 min.
IP1-1A	II	Kilfrost 2143 (3500)	6	07-Apr-08	17:13	17:52	No Fail	-5	ZR, 25	25	39		N/A	17 @ 39 min.
IP2-1	III	Clariant Type III	5	07-Apr-08	19:45:15	19:57:30	12.3	-5	ZR, 25	25	9	9	Adh to 12" Line @ 19 min.	12 @ 12 min.
IP2-1A	III	Clariant Type III	6	07-Apr-08	19:45:15	19:57:30	12.3	-5	ZR, 25	25	9		Adh to 12" Line @ 19 min.	11 @ 12 min.
IP3	II	Kilfrost 2143 (3500)	1	07-Apr-08	20:43	20:55	12.0	-10	ZR, 25 / IP, 25	50	20	20	N/A	19 @ 20 min.
IP3A	II	Kilfrost 2143 (3500)	2	07-Apr-08	20:43	20:55	12.0	-10	ZR, 25 / IP, 25	50	20		N/A	20 @ 20 min.
IP4	III	Clariant Type III	1	07-Apr-08	21:06	21:12:30	6.5	-10	ZR, 25 / IP, 25	50	7	7	Adh <6" Line @ 14 min.	19.25 @ 5 min.
IP4A	III	Clariant Type III	2	07-Apr-08	21:06	21:12:30	6.5	-10	ZR, 25 / IP, 25	50	7		Adh <6" Line @ 14 min.	19.25 @ 5 min.
IP3-1	II	Kilfrost 2143 (3500)	11	07-Apr-08	14:11:18	14:25	13.7	-10	ZR, 25	25	24	24	Adh <3" Line @ 47 min.	16 @ 25 min.
IP3-1A	II	Kilfrost 2143 (3500)	12	07-Apr-08	14:11:34	14:25	13.4	-10	ZR, 25	25	23		Adh <3" Line @ 47 min.	17 @ 24 min.
IP4-1	III	Clariant Type III	8	07-Apr-08	14:03:48	14:16:30	12.7	-10	ZR, 25	25	9	11	Adh <6" Line @ 17 min.	9 @ 17 min.
IP4-1A	III	Clariant Type III	10	07-Apr-08	15:05:30	15:17:30	12.0	-10	ZR, 25	25	13		Adh <6" Line @ 20 min.	9 @ 20 min.

Notes:
All Fluids applied Neat and at Ambient Temperature.
Ice Pellet Diameter ranged from 1-3.75 mm.

5. GENERAL OBSERVATIONS

Table 5.1 summarizes the time of adherence to the 2.5 cm (1 inch) line for all respective mixed and baseline tests conducted. The following sections describe the observations and conclusions respective to each test condition.

5.1 Type II Mixed Precipitation Tests

Testing conducted with the Type II fluid in mixed light ice pellets and light freezing rain demonstrated that the presence of ice pellets during the -5°C test accelerated the time to first adherence as compared to the -10°C test during which the time to first adherence was comparable within 4 minutes to the baseline light freezing rain test. This may be due to the lower viscosity of the fluid at warmer temperature which is more conducive to melting and dissolving frozen precipitate.

Based on the results at -5°C, the current mixed light freezing rain and light ice pellets 25 minute allowance time for Type IV fluids at -5°C would not be appropriate for Type II fluids. Estimated failure occurred at 16 minutes however first adherence occurred at 25 minutes.

Based on the results at -10°C, the current mixed light freezing rain and light ice pellets 10 minute allowance time for Type IV fluids at -10°C seems appropriate for the Type II fluid that was tested. Estimated failure occurred at 12 min and adherence at 20 min, both exceeding the 10 minute allowance time for the condition.

5.2 Type III Mixed Precipitation Tests

Testing conducted with the Type III fluid demonstrated differences in the visual fluid failure call when comparing mixed conditions versus the baseline light freezing rain only test; mixed condition tests failed quicker. However, the time of first adherence was comparable (within 4 minutes) for both mixed and baseline tests. Due to the thin fluid layer of Type III fluid, ice pellets likely protrude further out of the fluid (as compared to t thickened Type II or Type IV fluid) causing early visual failure, however the ice pellets likely do not significantly add to the occurrence of adherence.

Based on the results at -5°C, the current mixed light freezing rain and light ice pellets 25 minute allowance time for Type IV fluids at -5°C does not seem appropriate for Type III fluids. Estimated failure and adherence occurred at 10 min.

Based on the results at -10°C, the current mixed light freezing rain and light ice pellets 10 minute allowance time for Type IV fluids at -10°C is not appropriate for Type III fluids. Estimated failure and adherence occurred at 7 min.

Table 5.1: Summary of Time of Adherence to 2.5 cm Line

Test #	OAT (°C)	Fluid Type	Mixed Precip 2.5 cm (1") Adherence Time (min)	Baseline 2.5 cm (1") Adherence Time (min)	% Ratio (Mixed / Baseline) (%)	Time Difference (Mixed / Baseline) (min)
ZR- and IP- / ZR-						
IP1/IP1A vs. IP1-1/IP1-1A	-5	II	30	44	68%	-14.0
IP2/IP2A vs. IP2-1/IP2-1A	-5	III	10	9	111%	1.0
IP3/IP3A vs. IP3-1/IP3-1A	-10	II	20	24	83%	-4.0
IP4/IP4A vs. IP4-1/IP4-1A	-10	III	7	11	64%	-4.0
				Average	82%	

6. FUTURE WORK - AERODYNAMIC VALIDATION OF RESULTS

Aerodynamic validation of the results is required before allowance time recommendations for Type II and Type III fluids can be issued. Aerodynamic research is required to quantify the lift loss caused by adhered ice pellet contamination. Testing should be conducted in the NRC wind tunnel during the winter of 2008-09.

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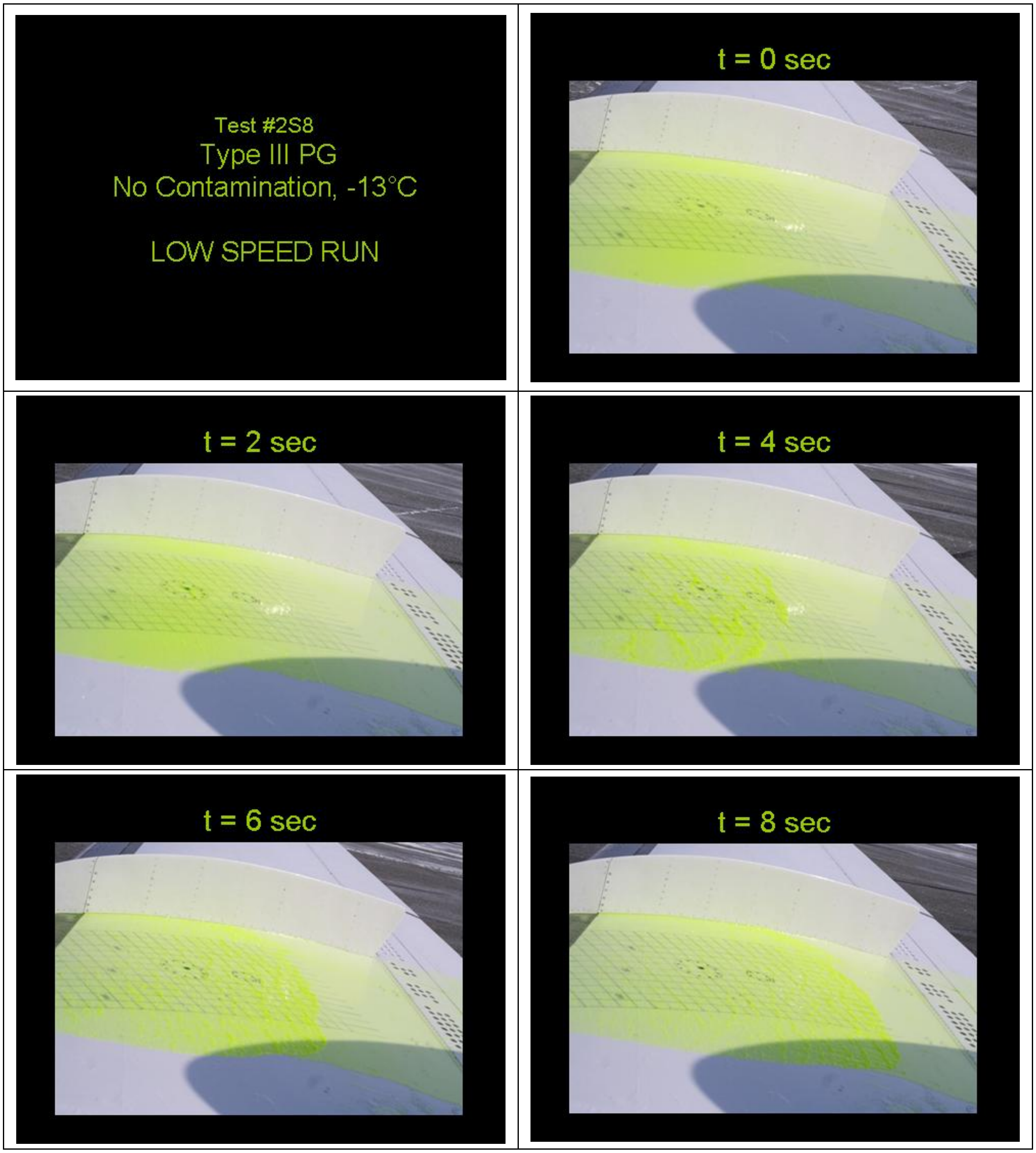
APPENDIX G

PHOTO DOCUMENTATION OF TESTS 2S8, 7S8 AND 8P8 OF FALCON 20 TESTS

PHOTO DOCUMENTATION OF TEST 2S8


Test #2S8
Type III PG
No Contamination, -13°C
LOW SPEED RUN
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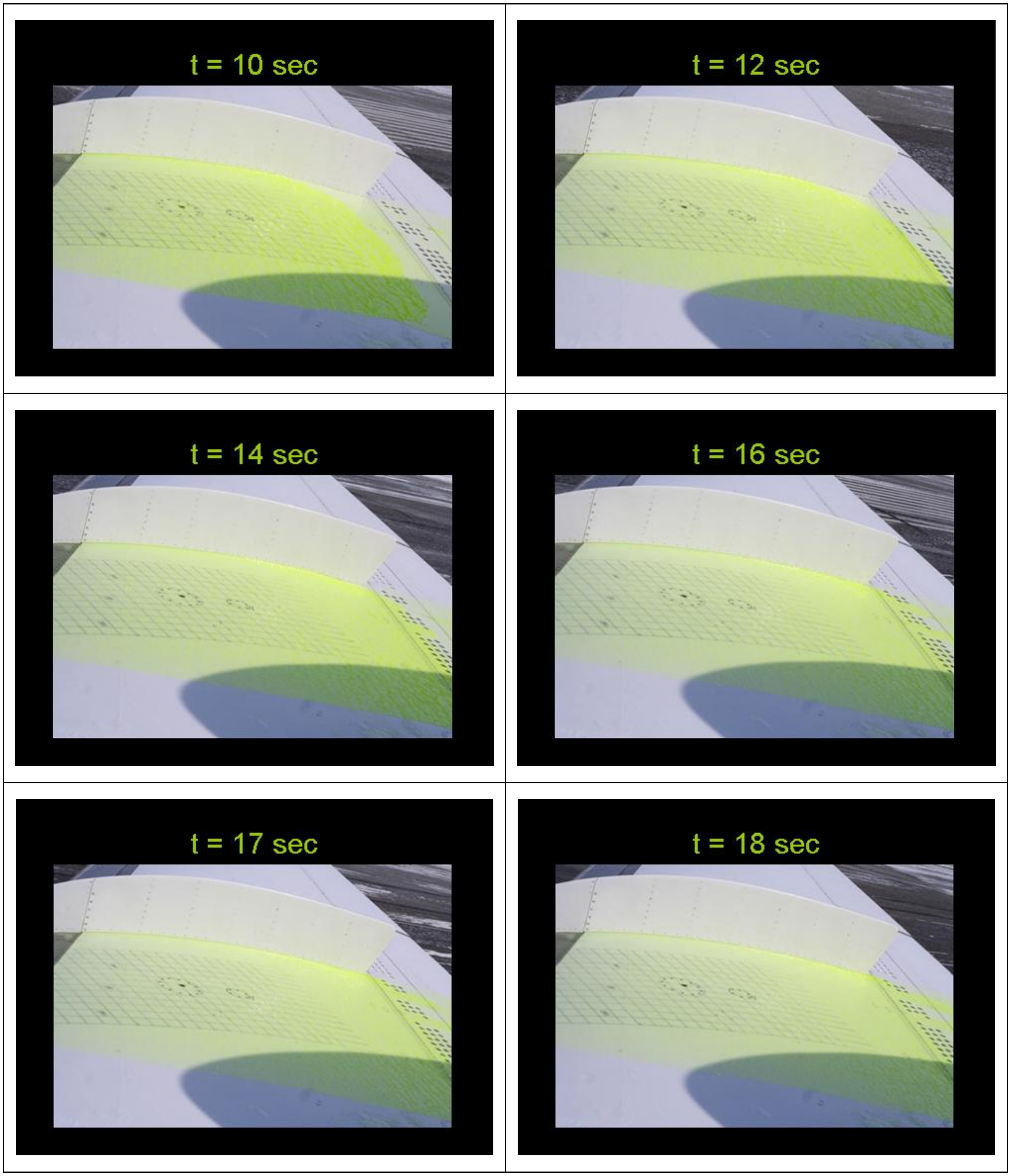
t = 4 sec
t = 6 sec
t = 8 sec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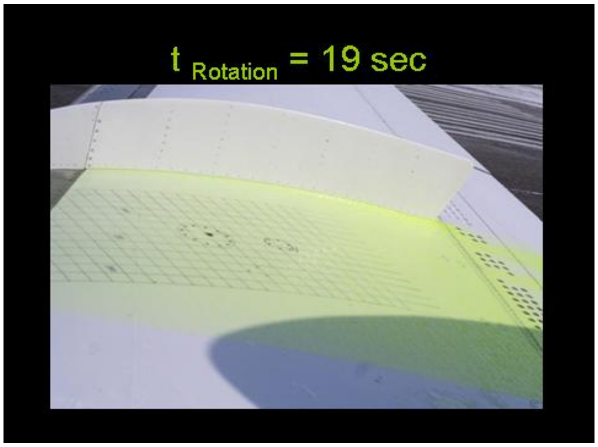	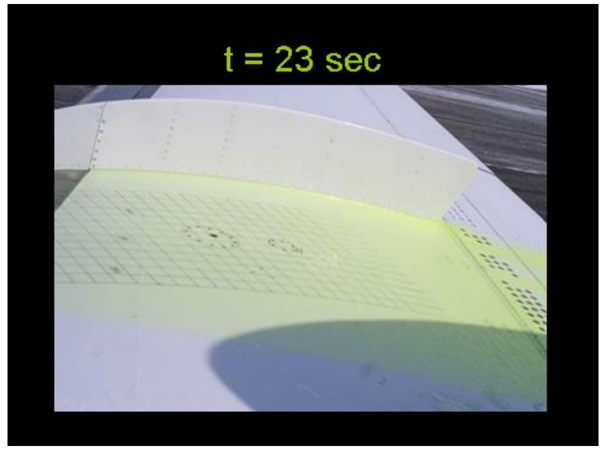
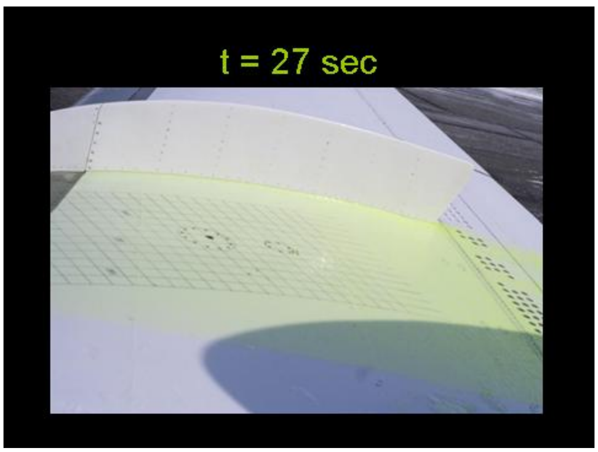	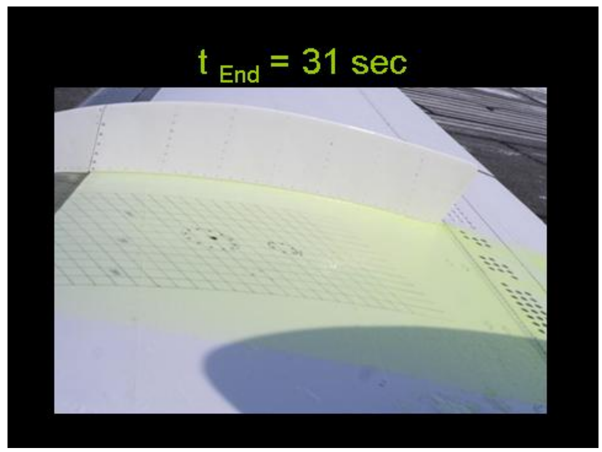
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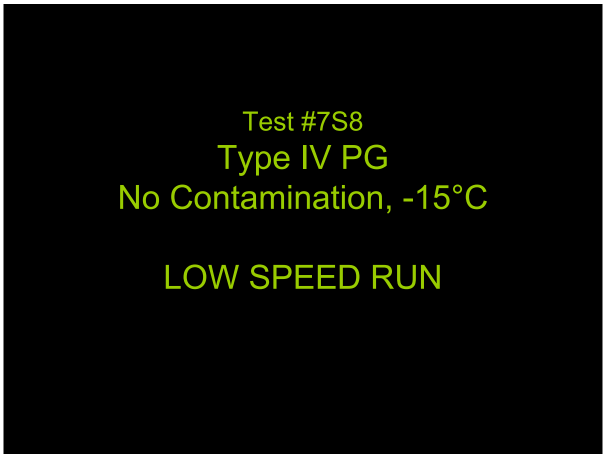
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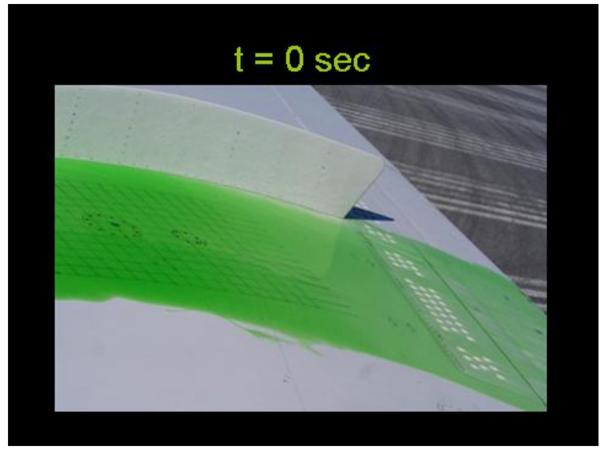
Type IV PG
No Contamination, -15°C
LOW SPEED RUN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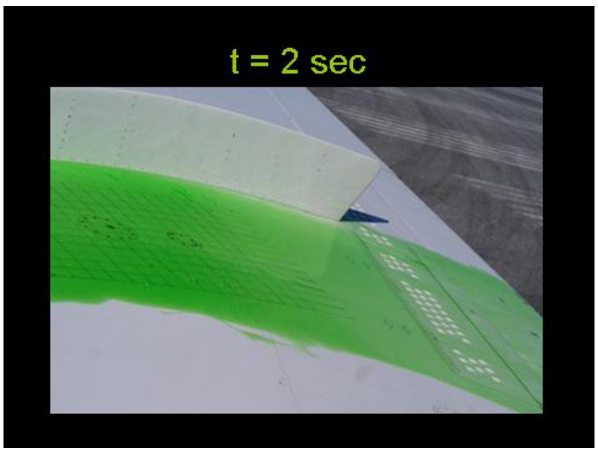
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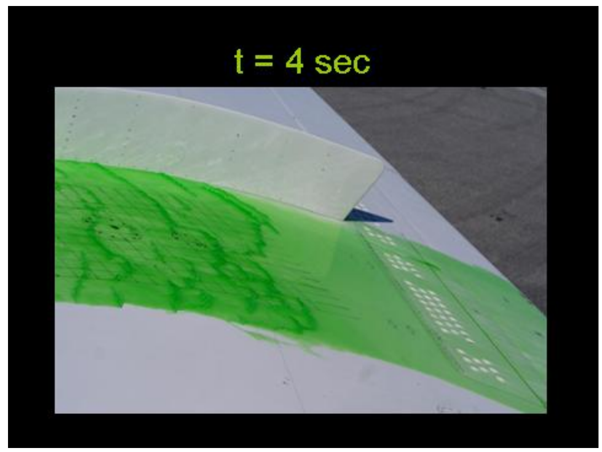
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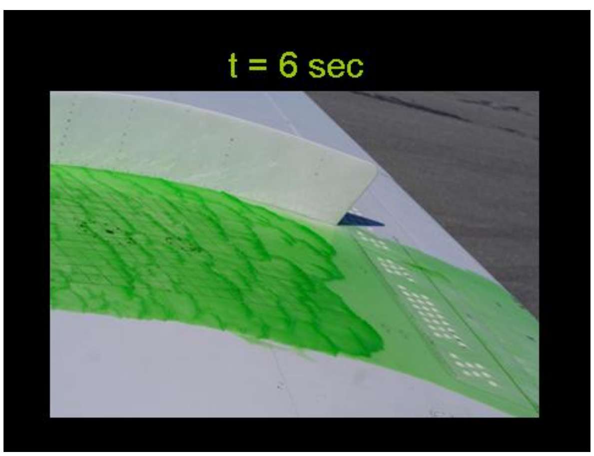
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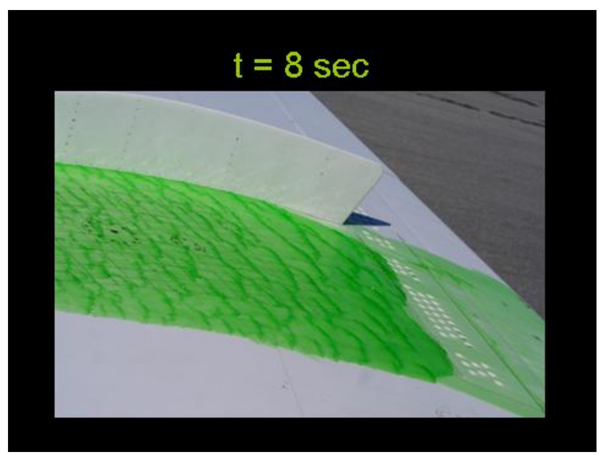
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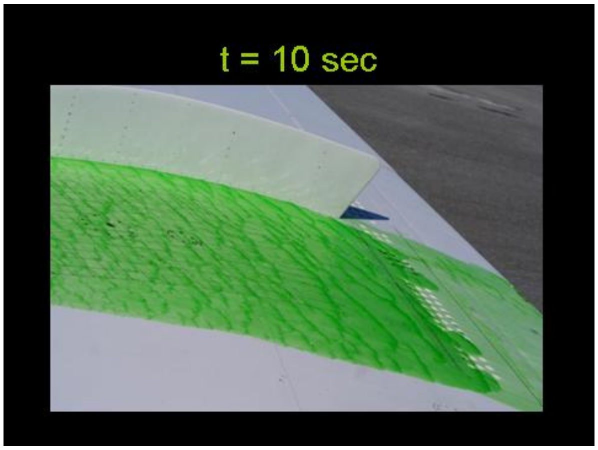
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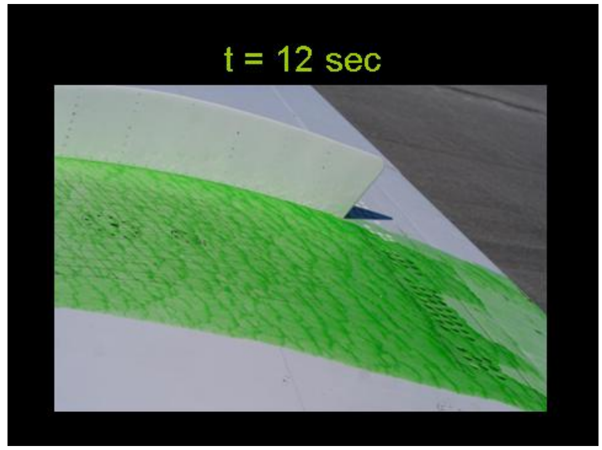
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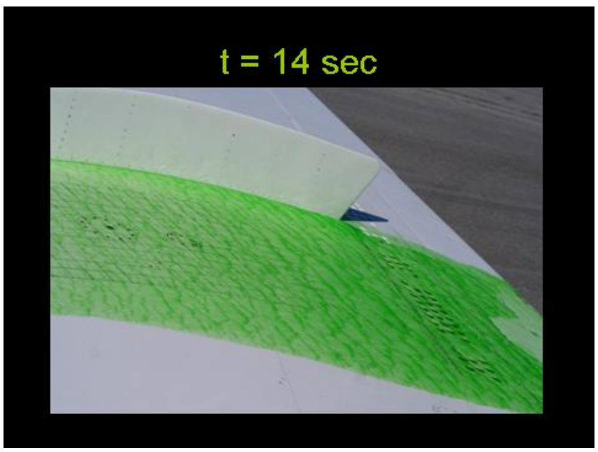
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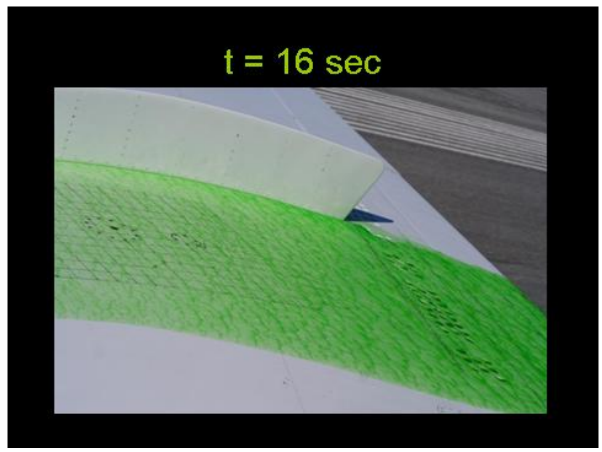
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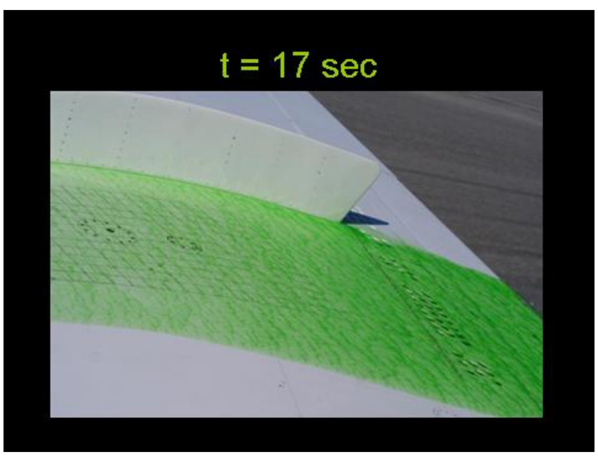
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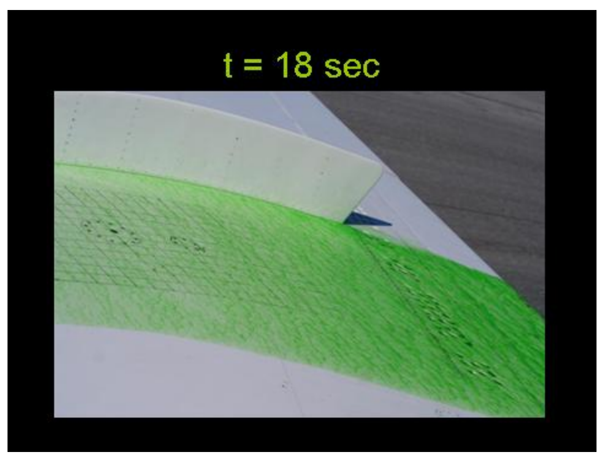
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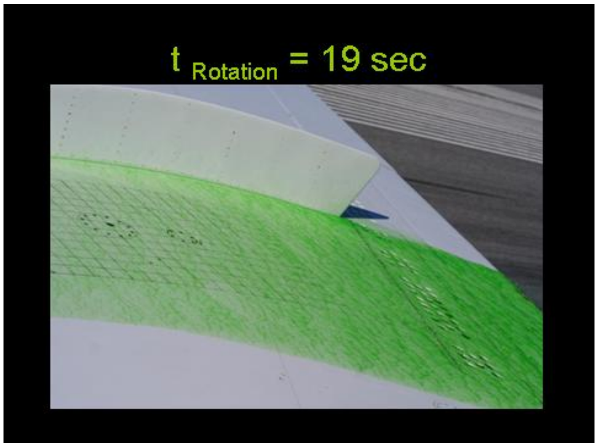	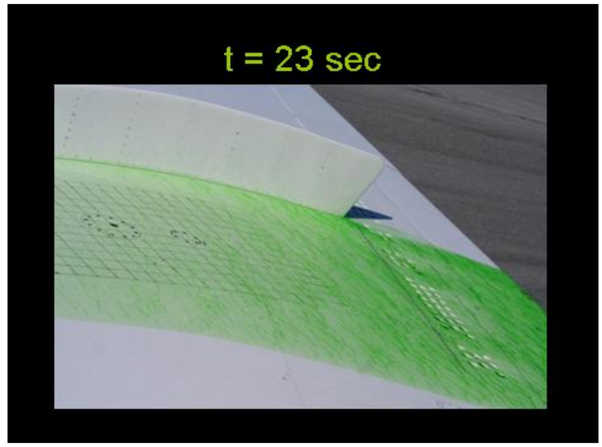
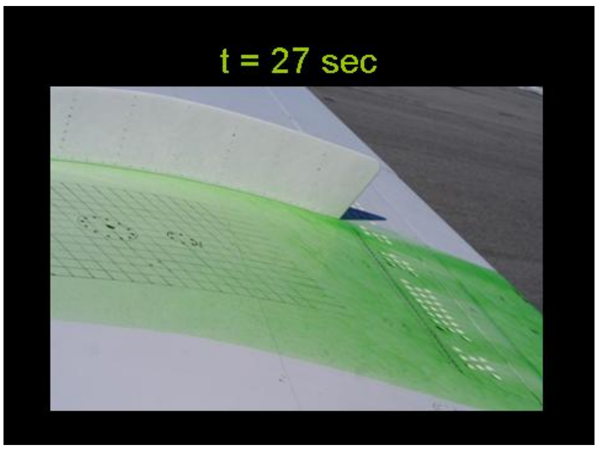	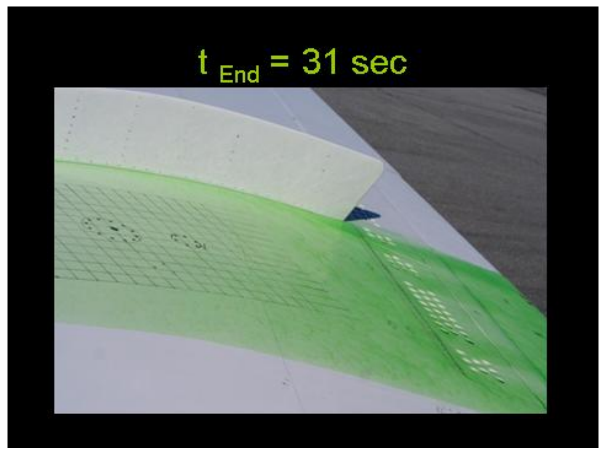
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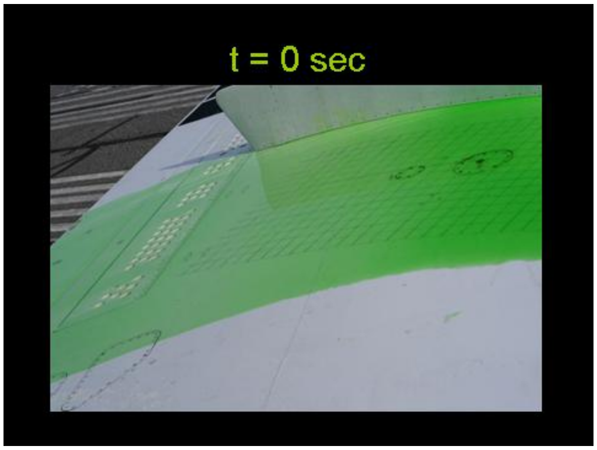
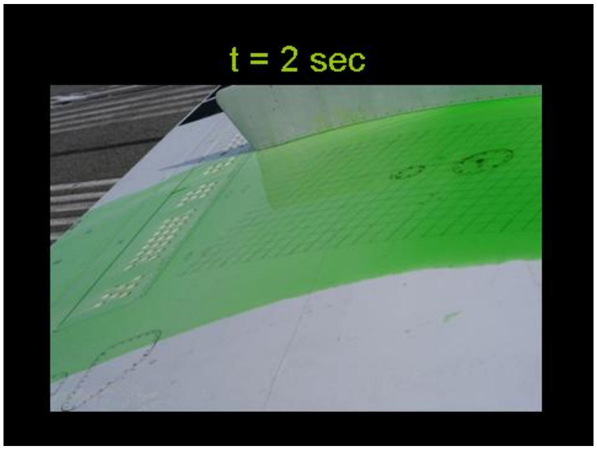
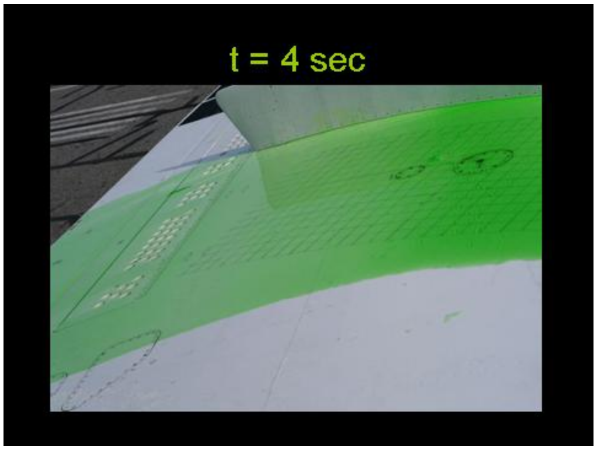
PHOTO DOCUMENTATION OF TEST 8P8

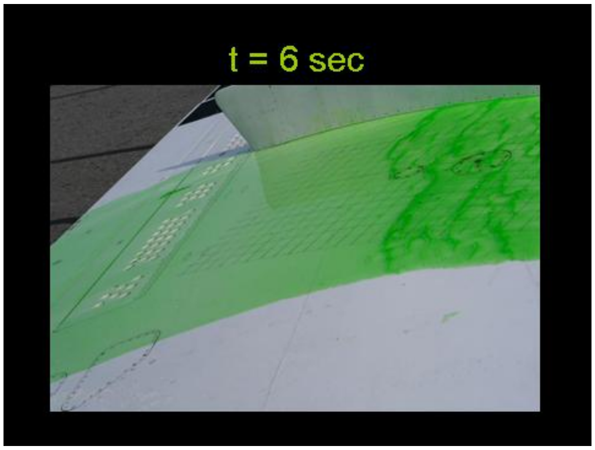
Test #8P8
Type IV PG Neat
No Contamination, -17°C

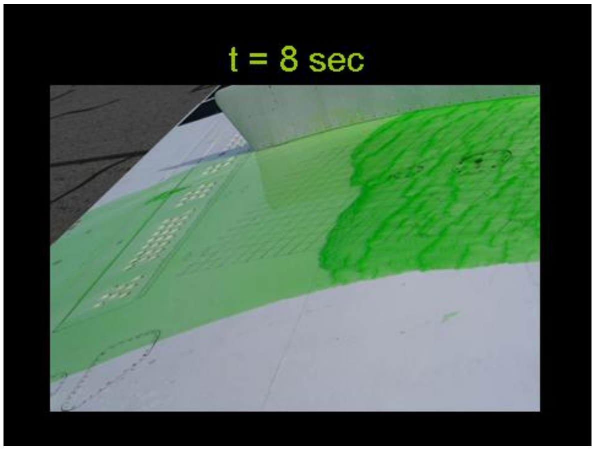
HIGH SPEED RUN

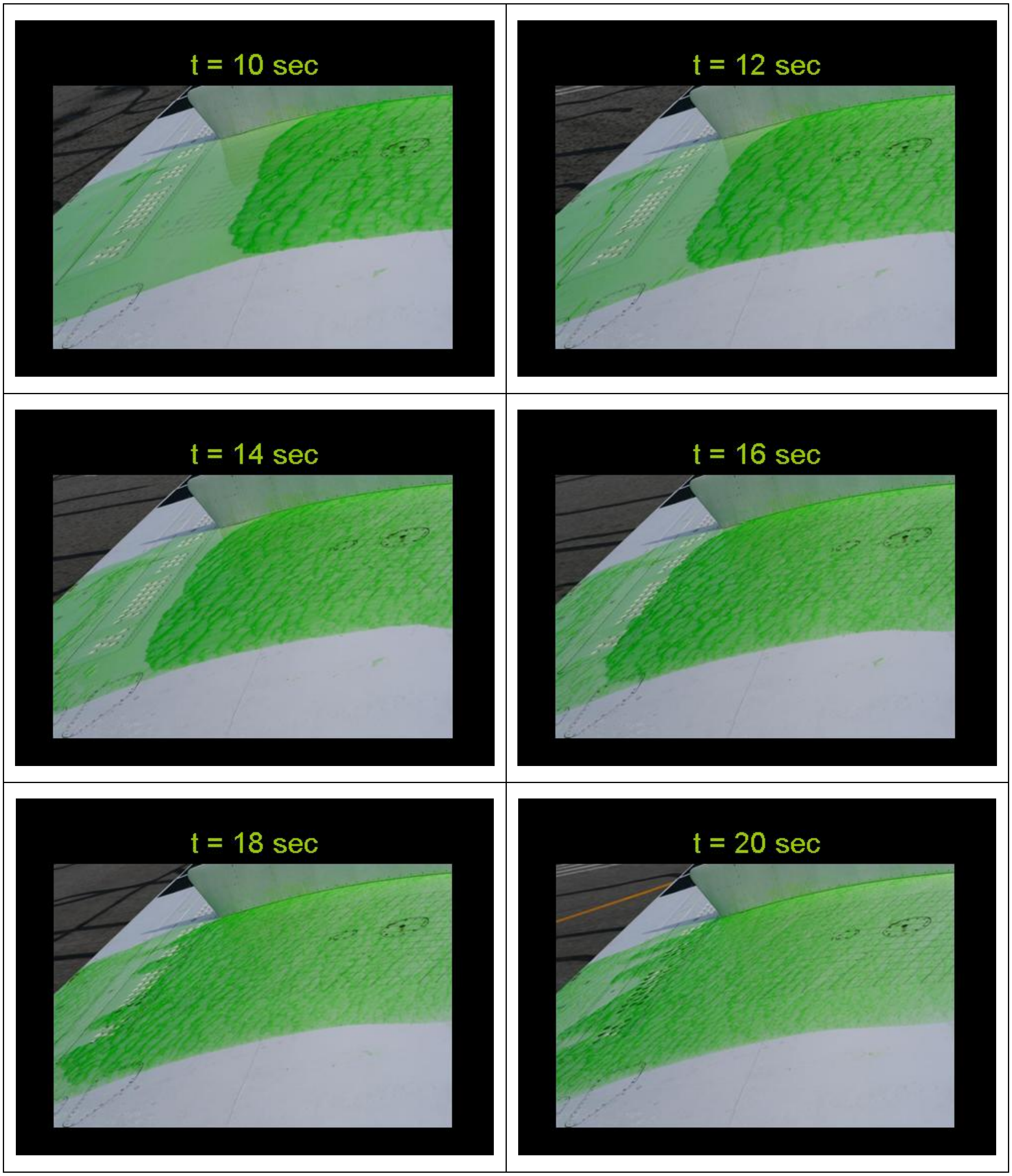








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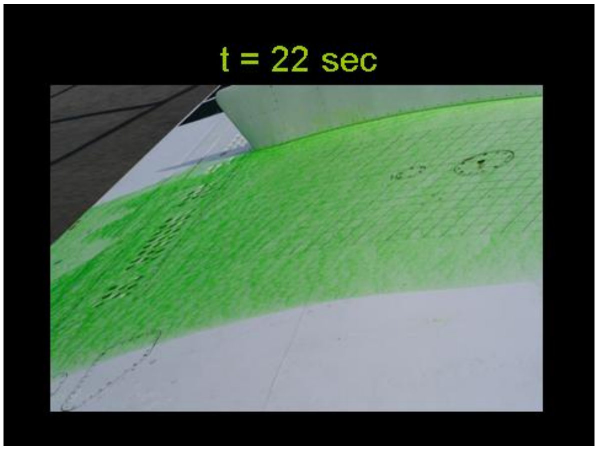
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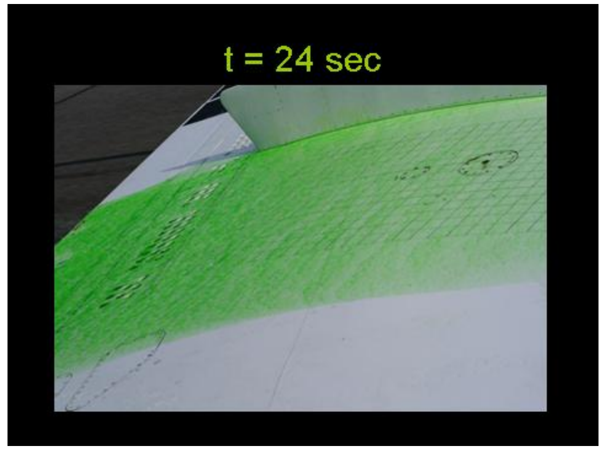
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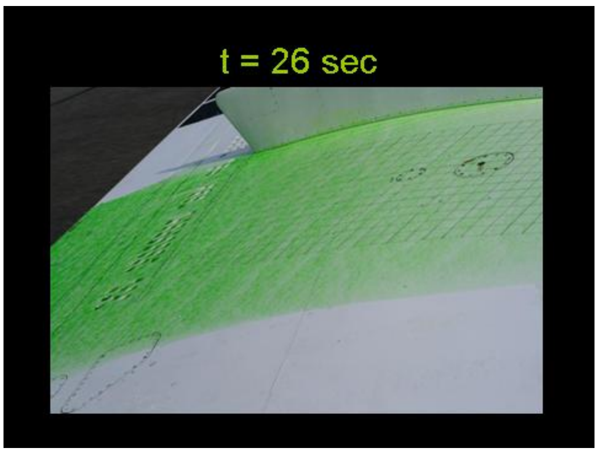
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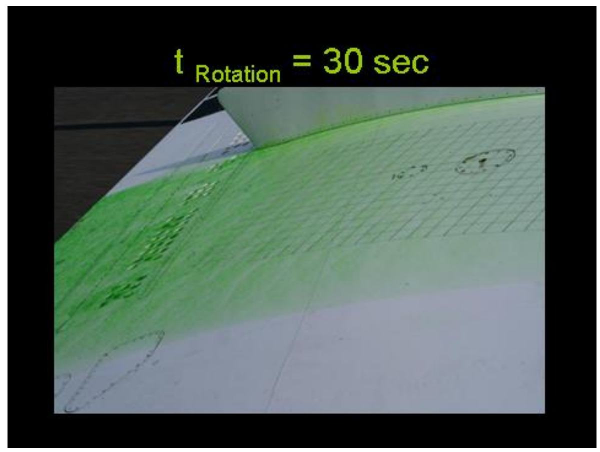
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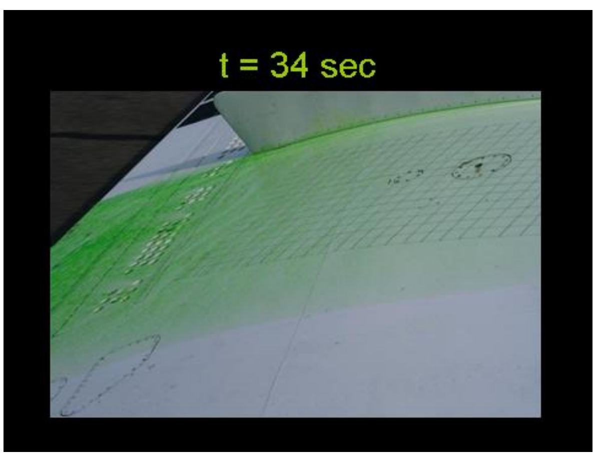
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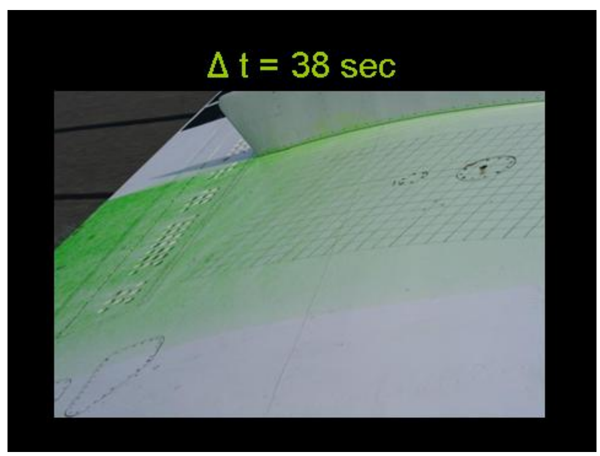
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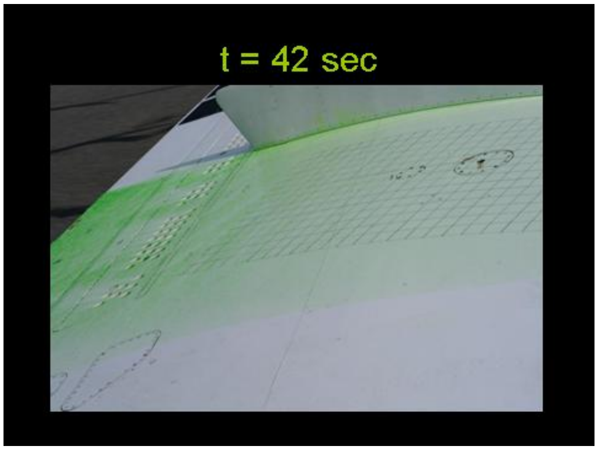

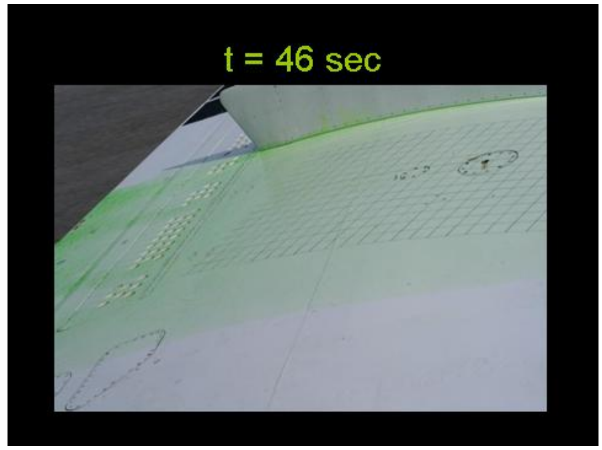

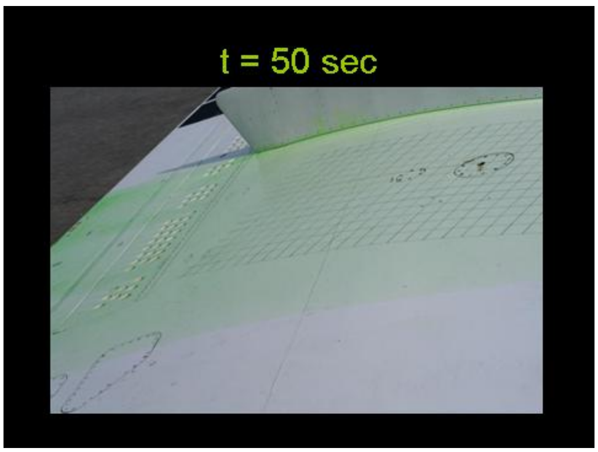

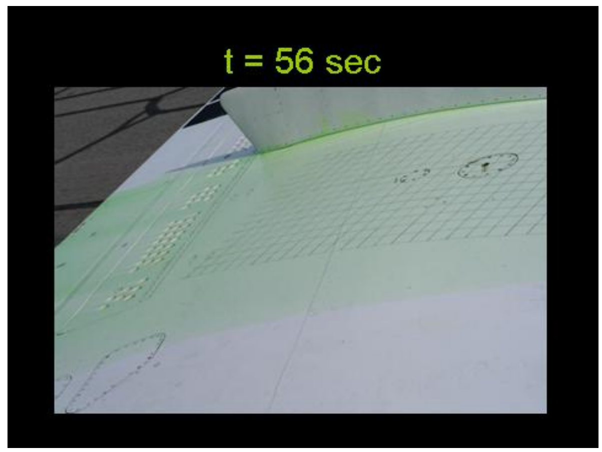

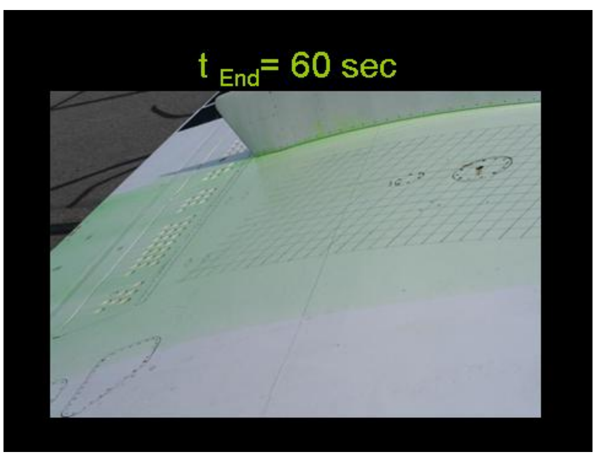

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