TP15232E

WIND TUNNEL TRIALS TO EXAMINE ANTI-ICING FLUID FLOW-OFF CHARACTERISTICS AND TO SUPPORT THE DEVELOPMENT OF ICE PELLET ALLOWANCE TIMES, WINTERS 2009-10 TO 2012-13

Volume 2

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Prepared by:

APS Aviation Inc.

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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.

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EXECUTIVE SUMMARY

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

Background and Objective

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

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

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

During the following winter of 2006-07, the FAA provided a 25 minute allowance as a preliminary guideline; TC issued a note indicating that no changes would be made to the HOT guidelines. This allowance was based on the previous research conducted during the winter of 2005-06, primarily as a result of Falcon 20 aerodynamic research [see TC report,TP 14716E, *Falcon 20 Trials to Examine Fluid Removed from Aircraft During Takeoff with Ice Pellets* (2)]; these results were presented at the Society of Automotive Engineers (SAE) meeting in Lisbon in May 2006. To address the option of a pre-takeoff contamination check, the 20 minute targeted allowance was extended to 25 minutes; pre-takeoff contamination checks would no longer apply. This allowance was followed by a list of conditions; one restriction was that operations would be limited to ice pellets alone (no mixed conditions).

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

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

During the winter of 2007-08, additional endurance time testing and aerodynamic research was conducted to support and further expand the ice pellet allowance times [see TC report,TP 14871E, *Research for Further Development of Ice Pellet Allowance Times: Aircraft Trials to Examine Anti-Icing Fluid Flow-Off Characteristics Winter 2007-08,* (4)]). Full-scale testing with the NRC Falcon 20 and T-33 aircraft was conducted in mixed conditions with ice pellets and in non-precipitation conditions. Testing was primarily geared towards simulating low rotation speed aircraft. No changes to the allowance times were made as a result of this work as aerodynamic data was not available.

During the winter of 2008-09, testing was conducted in the PIWT using a National Aeronautics and Space Administration (NASA) LS-0417 airfoil to validate and potentially expand the allowance times. As a result of this testing, a reduction to the light ice pellets mixed with moderate snow allowance time was issued for outside air temperature (OAT) above -5ºC: the allowance time was reduced from 25 minutes to 10 minutes. The testing conducted also allowed the expansion of the table to include a new 25 minute allowance time for light ice pellets mixed with moderate rain for above -5ºC conditions, as well as a new 15 minute allowance time for light ice pellets mixed with light snow for -5ºC to -10ºC conditions. A newly updated version of the Type IV allowance time table was developed and adopted for the 2009-10 version of the HOT Guidelines. It was recommended that additional testing be conducted in the PIWT during the winter of 2009-10 using a supercritical airfoil to validate the allowance time for use with newer generation aircraft.

A series of tests were designed and carried out during the winter of 2009-10 to validate the current guidance material in ice pellet and mixed conditions for newer generation aircraft with supercritical wing designs. Testing was conducted with and without contamination. Research was conducted to validate and develop allowance times for the following application:

- Type IV Fluid - High Speed Ramp (Allowance times currently exist).

Conclusions and Observations

Type IV High Speed Allowance Times

In comparison to previous tests on other airfoils, fluid flow-off issues with the supercritical wing were observed with propylene glycol (PG) fluids at the lower temperatures. More specifically, lift losses greater than 8 percent on the 2D model were recorded during light ice pellets and moderate ice pellet conditions below -10ºC; visual observations supported the lift loss data collected. As a result, rather than restrict the allowance times to ethylene glycol (EG) fluids only, the PG data collected was re-analysed simulating higher rotation speeds. The analysis indicated that the allowance times would be acceptable for rotation speeds of 115 knots or greater (compared to 100 knots or greater). It was recommended that a footnote restricting the use of PG fluids to aircraft with rotation greater than 115 knots during light ice pellets and moderate ice pellet conditions below -10ºC be included in the allowance time table for the winter of 2010-11.

In addition, fluid failure issues with the supercritical wing were observed with PG fluids during moderate ice pellets above -5ºC. The relatively flat surface of the wing had less fluid flow-off and resulted in an earlier fluid failure for PG fluids. Data collected indicated that an allowance time of 15 minutes would be more appropriate. It was recommended that a footnote reducing the allowance time to 15-minutes for PG fluids during moderate ice pellet conditions above -5ºC be included in the allowance time table for the winter of 2010-11.

In general, it was found that the tests conducted in all other conditions generated acceptable lift losses based on the current evaluation criteria: i.e. lift loss less than 5 percent was considered “good”, between 5 and 8 percent was considered “ok” (acceptable), whereas tests with lift losses above 8 percent were considered “bad” and required further review. Typically, the EG fluid performed better, especially in the colder temperatures, and generated lower lift losses compared to the PG fluids.

In general, higher lift losses were observed with the supercritical wing compared to previous wings tested. Although initially 5 percent was used as the initial cut-off for evaluating each test, this was expanded to 8 percent based on the data collected; 8 percent lift loss correlated well with the visual observations recorded. Additional analysis paired with wind tunnel and full-scale aircraft testing is recommended to develop a correlation between the lift losses observed in the wind tunnel and those seen on an operational aircraft with newer generation supercritical wings.

Comparison of Fluid Certification BLDT Results Versus NRC Wind Tunnel Lift Loss Results

The preliminary 2D results from this analysis indicate that 5 percent lift loss may not be appropriate as the lift loss cut-off. When correlating to the fluid certification results, a higher lift loss cut-off may be more appropriate based on the Launch, ABC-S Plus and EG106 data. It is recommended that future testing be done to simulate fluid certification results in the NRC wind tunnel at specific temperatures to substantiate the correlation observed in this preliminary analysis.

Flap Retracted (UP) Versus Flap Extended (DOWN)

In general, the results indicated that a heavily contaminated flap could have adverse effects on aerodynamic performance. On average, the test results showed an average 1.4 percent improvement in lift loss (with a maximum of 3.4 percent) when the flap was up (retracted) during the contamination period. It can be assumed that the flap will fail faster compared to the main wing section by a factor less than 60 percent (likely closer to 50 percent of the main wing section protection time); however, data comparing equal levels of contamination on the main wing section and on the flap is required to provide a proper estimate.

Recommendations

New Type IV High Speed Allowance Time Table

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

Future Work

Type IV High Speed Allowance Times

Historical winter weather data has indicated that a significant portion of "light ice pellets mixed with light snow" precipitation occurs below -10°C and "light ice pellets mixed with moderate snow" precipitation occurs below -5 to -10°C where no allowance times currently exist. It is recommended that future research target these conditions in order to allow greater flexibility to operators in conditions of mixed ice pellets and light or moderate snow.

Additional testing is also recommended in light and moderate ice pellets close to the lower end of the -10 to -25ºC range (where data is limited) and in moderate ice pellets above -5ºC to validate the changes made to the allowance time table for the winter of 2010-11. Testing should also include different fluids to further validate the current allowance times.

Additional Testing and Analysis to Further Investigate Supercritical Wing Lift Losses

Additional analysis paired with wind tunnel and full-scale aircraft testing is recommended to develop a correlation between the lift losses observed in the wind tunnel and those seen on an operational aircraft with newer generation supercritical wings. Full-scale aircraft testing with the NRC Falcon 20 or FAA Technical Centre Global Express could be used to validate the wind tunnel test results. Additional wind tunnel testing is also recommended to investigate the increase in fluid flow-off as a result of higher rotation speeds (100 vs. 115 knots) and to validate the analysis methodology used to extrapolate the lift coefficient data. Comparative testing should also be conducted in the wind tunnel to obtain directly comparable data to the fluid certification boundary layer displacement thickness (BLDT) results. This data could provide insight for developing a correlation between the lift losses observed in the wind tunnel and the fluid certification test.

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SOMMAIRE

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

Contexte et objectif

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

Le 22 décembre 2004, les aéronefs de United Parcel Service (UPS) à Louisville ont été interdits de vol pendant plusieurs heures en raison de conditions prolongées de granules de glace. Étant donné la configuration des aéronefs cargos, l'équipage ne pouvait effectuer les inspections de contamination avant le décollage. L'entreprise FedEx a connu des problèmes semblables à Memphis. Après cet incident, la FAA a publié, en octobre 2005, deux avis de restriction de décollage dans des conditions de granules de glace.

En raison de cet incident coûteux, UPS s'est efforcée d'obtenir des données expérimentales afin de définir des lignes directrices et de permettre le maintien des activités dans des conditions de granules de glace. Durant l'hiver 2004-2005, des essais aérodynamiques et de durée d'efficacité ont été menés dans des conditions simulées de granules de glace. APS a également mené quelques essais préliminaires sur plaque plane [voir le rapport de Transports Canada (TC), TP 14718E, *Preliminary Endurance Time Testing in Simulated Ice Pellet Conditions* (1)]. À la lumière des données préliminaires, une marge de tolérance de 20 minutes a été proposée pour les conditions de granules de glace légers ; toutefois, aucun changement n'a été apporté aux lignes directrices sur les durées d'efficacité.

Au cours de l'hiver 2006-2007, la FAA a établi une marge de tolérance de 25 minutes à titre de ligne directrice préliminaire ; TC a publié une note selon laquelle

aucun changement ne serait apporté aux lignes directrices sur les durées d'efficacité. Cette marge s'appuyait sur des études antérieures menées à l'hiver 2005-2006, principalement à la suite de l'essai aérodynamique sur le Falcon 20 [voir le rapport de TC, TP 14716E, *Falcon 20 Trials to Examine Fluid Removed from Aircraft During Take off with Ice Pellets* (2)] ; 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 visée de 20 minutes a été prolongée à 25 minutes ; par conséquent, les vérifications 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 manœuvres dans des conditions de granules de glace seulement (et non dans des conditions mixtes).

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

Au cours de l'hiver 2007-2008, TC et la FAA ont donné des lignes directrices sur les marges de tolérance pour les opérations dans des conditions mixtes avec granules de glace. Ces marges de tolérance étaient fondées sur la recherche menée au cours de l'hiver 2006-2007 [voir le rapport de TC, TP 14779E, *Development of Allowance Times for Aircraft Deicing Operations During Conditions with Ice Pellets* (3)]. Les marges de tolérance recommandées étaient fondées sur les essais aérodynamiques menés dans la soufflerie de givrage à propulsion 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. Les 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 précises.

Au cours de l'hiver 2007-2008, des essais additionnels de durées d'efficacité et de la recherche aérodynamique ont été menés pour confirmer et compléter les marges de tolérance dans les granules de glace [voir le rapport de TC, TP 14871E, *Research for Further Development of Ice Pellet Allowance Times: Aircraft Trials to Examine Anti-Icing Fluid Flow-off Characteristics Winter 2007-08* (4)]. Des essais pleine grandeur sur les aéronefs Falcon 20 et T-33 du CNRC ont été menés dans des conditions mixtes avec granules de glace et en absence de précipitation. Les essais visaient principalement la simulation d'aéronefs à basse vitesse de rotation. En l'absence de données aérodynamiques, aucun changement aux marges de tolérance n'a été apporté à la suite de ces travaux.

Au cours de l'hiver 2008-2009, des essais ont été réalisés dans la soufflerie de givrage à propulsion à l'aide d'un profil d'aile LS-0417 de la National Aeronautics and Space Administration (NASA) afin de valider et, possiblement, d'élargir les marges de tolérance. À la suite de ces essais, la marge de tolérance pour les conditions de granules de glace légers avec neige modérée a été réduite pour les températures ambiantes supérieures à -5 °C, passant de 25 minutes à 10 minutes. Les essais ont aussi permis de développer le tableau pour y inclure une nouvelle marge de tolérance de 25 minutes pour les conditions de granules de glace légers avec pluie modérée à des températures supérieures à -5 °C, de même qu'une nouvelle marge de tolérance de 15 minutes pour les conditions de granules de glace légers avec neige légère à des températures de -5 °C à -10 °C. Une nouvelle version actualisée du tableau des marges de tolérance pour les liquides de type IV a été élaborée et adoptée pour la version 2009-2010 des lignes directrices sur les durées d'efficacité. Il a été recommandé de réaliser d'autres essais dans la soufflerie de givrage à propulsion au cours de l'hiver 2009-2010 sur une surface portante supercritique afin de valider la marge de tolérance à utiliser avec les aéronefs de nouvelle génération.

Une série d'essais ont été conçus et réalisés au cours de l'hiver 2009-2010 afin de valider les lignes directrices actuelles dans des conditions mixtes et de granules de glace pour les nouvelles générations d'aéronefs équipés d'ailes supercritiques. Les essais ont été effectués avec et sans contamination. Ils avaient pour but de valider et de développer des marges de tolérance pour les applications suivantes :

- Liquide de type IV – accélération à haute vitesse (des marges de tolérance sont actuellement disponibles).

Conclusions and observations

Marges de tolérance pour les liquides de type IV à haute vitesse

Comparativement aux essais antérieurs réalisés sur d'autres surfaces portantes, des problèmes de ruissellement ont été observés sur l'aile supercritique lors des essais sur les liquides à base de propylène glycol à basse température. Plus précisément, des pertes de portance de plus de 8 pour cent ont été enregistrées sur le modèle bidimensionnel dans des conditions de granules de glace légers et modérés à des températures inférieures à -10 °C ; des observations visuelles ont étayé les données recueillies sur la perte de portance. Par conséquent, plutôt que de restreindre les marges de tolérance des liquides à base d'éthylène glycol seulement, les données sur les liquides à base de propylène glycol ont été analysées de nouveau en simulant des vitesses de rotation plus élevées. L'analyse démontre que les marges de tolérance seraient acceptables à des vitesses de rotation de 115 nœuds ou plus (plutôt qu'à des vitesses de 100 nœuds ou plus). Il a été recommandé d'inclure au tableau des marges de tolérance de l'hiver 2010-2011 une note de bas de page limitant l'utilisation de liquides à base de propylène glycol aux aéronefs dont les vitesses de rotation sont supérieures à 115 nœuds dans des conditions de granules de glace légers ou modérés à des températures au-dessous de -10 °C.

En outre, des pertes d'efficacité ont été observées sur l'aile supercritique avec les liquides à base de propylène glycol dans des conditions de granules de glace modérés à des températures supérieures à -5 °C. La surface relativement plane de l'aile entravait le ruissellement des liquides à base de propylène glycol, ce qui se soldait par une perte d'efficacité précoce. Les données ont démontré qu'une marge de tolérance de 15 minutes serait plus appropriée. Il a été recommandé d'inclure au tableau des marges de tolérance de l'hiver 2010-2011 une note de bas de page réduisant la marge de tolérance des liquides à base de propylène glycol à 15 minutes dans des conditions de granules de glace modérés à des températures supérieures à -5 °C.

En général, il a été constaté que les essais réalisés dans toute autre condition généraient des pertes de portance acceptables selon les critères d'évaluation actuels, c'est-à-dire qu'une perte de moins de 5 pour cent était considérée comme correcte et une perte de 5 pour cent à 8 pour cent était considérée comme acceptable ; les essais entraînant une perte de portance de plus de 8 pour cent étaient considérés comme « mauvais » et nécessitaient un examen plus poussé. Le liquide à base d'éthylène glycol générait habituellement de meilleurs résultats, surtout à basse température, et entraînait une perte de portance moindre que le liquide à base de propylène glycol.

En général, les pertes de portance observées sur l'aile supercritique étaient plus importantes que celles observées sur les ailes testées auparavant. Au départ, le seuil initial pour évaluer chaque essai était fixé à 5 pour cent ; il a toutefois été augmenté à 8 pour cent à la lumière des données recueillies. Une perte de portance de 8 pour cent concordait bien avec les observations visuelles enregistrées. D'autres analyses combinées avec des essais en soufflerie et sur des aéronefs pleine grandeur devraient être réalisées afin d'établir une corrélation entre les pertes de portance observées dans la soufflerie et celles constatées sur un aéronef en mouvement équipé d'ailes supercritiques de nouvelle génération.

Comparaison des résultats des essais sur l'épaisseur de déplacement de la couche limite pour la certification des liquides et des résultats sur la perte de portance dans la soufflerie du CNRC

Les résultats bidimensionnels préliminaires tirés de cette analyse indiquent qu'une perte de portance de 5 pour cent pourrait ne pas être un seuil approprié. Lorsqu'une corrélation est établie avec les résultats des essais de certification des liquides, il semble qu'un seuil plus élevé conviendrait davantage selon les données sur les liquides Launch, ABC-S Plus et EG106. D'autres essais devraient être réalisés afin de simuler les résultats des essais de certification des liquides dans la soufflerie du CNRC à des températures précises afin d'étayer la corrélation observée dans cette analyse préliminaire.

Volet rentré (relevé) ou déployé (abaissé)

En général, les résultats ont démontré qu'un volet très contaminé pourrait nuire à la performance aérodynamique. Les résultats des essais ont indiqué une amélioration moyenne du taux de perte de portance de 1,4 pour cent (avec un maximum de 3,4 pour cent) lorsque le volet était relevé (rentré) durant la période de contamination. Il est possible de supposer que le volet connaîtra une défaillance plus rapidement que la section principale de l'aile par un facteur inférieur à 60 pour cent (probablement plus près de 50 pour cent par rapport au temps de protection de la section principale de l'aile). Il est toutefois nécessaire de recueillir des données comparant des niveaux égaux de contamination sur la principale section de l'aile et sur le volet afin de fournir une estimation adéquate.

Recommandations

Nouveau tableau des marges de tolérance pour les liquides de type IV à haute vitesse

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

Travaux à venir

Marges de tolérance pour les liquides de type IV à haute vitesse

Les données météorologiques hivernales historiques ont démontré qu'une partie importante des précipitations sous forme de « granules de glace légers avec neige légère » se produisent à des températures inférieures à -10 °C, tandis que les précipitations sous forme de « granules de glace légers avec neige modérée » se produisent à des températures entre -5 et -10 °C, une plage où aucune marge de tolérance n'est établie. Les futures recherches devraient porter sur ces conditions afin de donner une plus grande flexibilité aux exploitants dans des conditions de granules de glace avec neige légère ou modérée.

Des essais supplémentaires sont aussi recommandés dans des conditions de granules de glace légers et modérés à des températures se rapprochant du seuil inférieur de la plage allant de -10 à -25 °C (où les données sont limitées), de même que dans des conditions de granules de glace modérés à des températures supérieures à -5 °C afin de valider les changements apportés au tableau des marges de tolérance pour l'hiver 2010-2011. Les essais devraient également inclure différents liquides afin de valider les marges de tolérance actuelles.

Essais et analyses supplémentaires afin d'étudier davantage la diminution de portance sur les ailes supercritiques

D'autres analyses combinées avec des essais en soufflerie et sur des aéronefs pleine grandeur devraient être réalisées afin d'établir une corrélation entre les pertes de portance observées dans la soufflerie et celles constatées sur un aéronef en mouvement équipé d'ailes supercritiques de nouvelle génération. Des essais en grandeur réelle sur l'aéronef Falcon 20 du CNRC ou Global Express du centre technique de la FAA pourraient être menés afin de valider les résultats obtenus en soufflerie. D'autres essais devraient aussi être menés en soufflerie afin d'étudier l'augmentation du ruissellement du liquide à des vitesses de rotation plus élevées (100 nœuds par rapport à 115 nœuds) et de valider la méthode d'analyse utilisée pour extrapoler les données sur les coefficients de portance. Des essais comparatifs devraient également être réalisés dans la soufflerie afin d'obtenir des données pouvant être directement comparées aux résultats des essais d'épaisseur de déplacement de la couche limite (EDCL) pour la certification des liquides. Ces données pourraient orienter l'établissement d'une corrélation entre les pertes de portance observées dans la soufflerie et les essais de certification des liquides.

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GLOSSARY

APS	APS Aviation Inc.
BLDT	Boundary Layer Displacement Thickness
CFD	Computational Fluid Dynamics
EG	Ethylene Glycol
FAA	Federal Aviation Administration
HOT	Holdover Time
MSC	Meteorological Service of Canada
NASA	National Aeronautics and Space Administration
NRC	National Research Council Canada
NRCIAR	National Research Council Canada Institute for Aerospace Research
OAT	Outside Air Temperature
PG	Propylene Glycol
PIWT	3 m x 6 m Open-Circuit Propulsion Icing Wind Tunnel
RTD	Resistance Temperature Detector
SAE	Society of Automotive Engineers
TC	Transport Canada
TDC	Transportation Development Centre
UPS	United Parcel Service

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1. INTRODUCTION

Under winter precipitation conditions, aircraft are cleaned with a freezing point depressant fluid and protected against further accumulation by an additional application of such a fluid, possibly thickened to extend the protection time. Aircraft ground deicing had, until recently, never been researched and there is still 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 de/anti-icing fluid flow-off during simulated aircraft takeoff, APS conducted a series of full-scale tests in the NRC 3 m x 6 m Open-Circuit Propulsion Icing Wind Tunnel (PIWT) using a supercritical wing model to determine the flow-off characteristics of anti-icing fluid with and without mixed precipitation conditions with ice pellets.

NOTE: The documentation of this project has been divided into five separate volumes: one summary report, and four detailed reports on each of the respective testing years' activities. The volumes are as follows:

Volume 1:	*Summary Report*
Volume 2:	*2009-10 Testing Report*
Volume 3:	*2010-11 Testing Report*
Volume 4:	*2011-12 Testing Report*
Volume 5:	*2012-13 Testing Report*

This report is Volume 2 of 5.

1.1 Background

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

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

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

During the following winter of 2006-07, the FAA provided a 25-minute allowance as a preliminary guideline; TC issued a note indicating that no changes would be made to the HOT Guidelines. This allowance was based on the previous research conducted during the winter of 2005-06, primarily as a result of the Falcon 20 aerodynamic research [see TC report,TP 14716E, *Falcon 20 Trials to Examine Fluid Removed from Aircraft During Takeoff with Ice Pellets* (2)]; these results were presented at the Society of Automotive Engineers (SAE) meeting in Lisbon in May 2006. To address the option of a pre-takeoff contamination check, the 20-minute targeted allowance was extended to 25 minutes; pre-takeoff contamination checks would no longer apply. This allowance was followed by a list of conditions; one restriction was that operations would be limited to ice pellets alone (no mixed conditions).

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

During the winter of 2007-08, both 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 [see TC report,TP 14779E, *Development of Allowance Times for Aircraft Deicing Operations During Conditions with Ice Pellets* (3)]. The recommended allowance times were based on aerodynamic research conducted using the PIWT and the NRC Falcon 20 aircraft; these results were presented at the SAE meeting in San Diego in May 2007. These allowance time guidelines were followed by a list of restrictions based on the results obtained through the research conducted and on 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 [see TC report,TP 14871E, *Research for Further Development of Ice Pellet Allowance Times: Aircraft Trials to Examine Anti-Icing Fluid Flow-Off Characteristics Winter 2007-08,* (4)]. Full-scale testing with the NRC Falcon 20 and T-33 aircraft was conducted in mixed conditions with ice pellets and in non-precipitation conditions. Testing was primarily geared towards simulating low rotation speed aircraft. No changes to the allowance times were made as a result of this work, as aerodynamic data was not available.

During the winter of 2008-09, testing was conducted in the PIWT using a National Aeronautics and Space Administration (NASA) LS-0417 to validate and potentially expand the allowance times [see TC report, TP 14935E, *Research for Further Development of Ice Pellet Allowance Times: Wind Tunnel Trials to Examine Anti-Icing Fluid Flow-Off Characteristics Winter 2008-09* (5)]. As a result of this testing, a reduction to the light ice pellets mixed with moderate snow allowance time was issued for outside air temperature (OAT) above -5ºC: the allowance time was reduced from 25 minutes to 10 minutes. The testing conducted also allowed the expansion of the table to include a new 25-minute allowance time for light ice pellets mixed with moderate rain for above -5ºC conditions, as well as a new 15-minute allowance time for light ice pellets mixed with light snow for -5ºC to -10ºC conditions. A newly updated version of the Type IV allowance time table was developed and adopted for the 2009-10 version of the HOT Guidelines. It was recommended that additional testing be conducted in the PIWT during the winter of 2009-10 using a supercritical airfoil to validate the allowance times for use with newer generation aircraft.

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

1.2 Program Objectives

A test program was developed for the winter of 2009-10 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 2009-10 to validate the current guidance material in ice pellet and mixed conditions for newer generation aircraft with supercritical wing designs. Testing was conducted with and without contamination. Research was conducted to validate and develop allowance times for the following application:

- Type IV Fluid - High-Speed Ramp (Allowance times currently exist).

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

Table 1.1: Timeline of Developed Allowance Time Guidance Material

Winter Testing	Research Conducted	FAA Allowance Time	TC Allowance Time	Report TP #	Related Winter HOT Guidelines
2004-05	UPS Research APS PMG Research	October 2005 Notices 8000.309 and 8000.313 (no takeoff in IP)	No Changes to Guidelines	Data available through UPS & TP 14718	2005-06
2005-06	APS Falcon 20	20 minutes targeted, 25 minutes reccomended *(to include 5 min PTCC)*	Note include indicating no changes to guidelines	TP 14716E	2006-07
2006-07	APS Wind Tunnel & Falcon 20	Allowance Time Table 1st Version	Allowance Time Table 1st Version (October 2007)	TP 14779E	2007-08
2007-08	APS Falcon 20	Allowance Time Table 1st Version	Allowance Time Table 1st Version	TP 14871E	2008-09
2008-09	APS Wind Tunnel	Allowance Time Table 2nd Version	Allowance Time Table 2nd Version	TP 14935E	2009-10
2009-10	APS Wind Tunnel	Allowance Time Table 3rd Version	Allowance Time Table 3rd Version	TP 15232E (Vol 2)	2010-11

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* (6);
- TP 13479E, *Contaminated Aircraft Takeoff Tests for the 1998-99 Winter* (7);
- TP 13666E, *Contaminated Aircraft Simulated Takeoff Tests for the 1999-2000 Winter: Preparation and Procedures* (8);
- 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* (9); 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* (10).

Research was conducted during the winter of 2005-06 using the Falcon 20 aircraft to determine the maximum amount of ice pellet contamination that will flow-off an anti-iced aircraft at takeoff. This research is documented in detail in a report written by APS for TC [see TP 14716E (2)].

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

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

- TP 14778E, *Flow of Contaminated Fluid from Aircraft Wings: Feasibility Report* (11).

During the winter of 2007-08, the NRC PIWT was not available for testing during the winter months. The Falcon 20 aircraft was used to conduct simulated low rotation speed tests in mixed conditions with ice pellets. Two tests were also conducted with the NRC T-33 aircraft to validate the low rotation speed results obtained with the Falcon 20. This research is documented in detail in a report written by APS for TC [see TP 14871E (4)].

1.4 Previous NRC Wind Tunnel Full-Scale Testing

Previous trials to examine aerodynamic performance effects of de/anti-icing fluids that had been contaminated by varying quantities of freezing precipitation were conducted over three winter seasons at the NRC PIWT. The airfoil tested was a full-scale 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 (NRCIAR) for TC, TP 13426E, *Air-Flap Performance with De-Anti-Icing Fluids and Freezing Precipitation* (12).

During the winter of 2006-07, extensive testing was conducted in simulated mixed ice pellet conditions in the NRC PIWT using a NACA 23012 wing section. Testing was primarily geared towards expansion of the 25-minute allowance time for ice pellets. Testing included mixed ice pellet conditions as well as preliminary testing in heavy snow conditions. This research is documented in detail in a report written by APS for TC, see TP 14779E (3). The details of the methodology used for this testing are documented in a report written by APS for TC, see TP 14778E (11).

During the winter of 2008-09, aerodynamic research was conducted in the NRC PIWT using a NASA LS(1)-0417 section to investigate fluid flow-off of contaminated fluid following simulated ice pellet and mixed conditions to substantiate and further develop the current ice pellet allowance times. High-speed and low-speed ramp testing were conducted using Type IV fluid, as well as limited testing with Type II and III fluids. This research is documented in detail in a report written by APS for TC, see TP 14935E (5).

1.5 Overview of 2009-10 Testing

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

In addition, some preliminary work was conducted as a lower priority to address current industry concerns. This work has been documented in the TC report, TP 15057E, *Exploratory Wind Tunnel Aerodynamic Research Examination of Contaminated Anti-Icing Fluid Flow-Off Characteristics Winter 2009-10* (13).

Table 1.2 demonstrates the groupings for the global set of tests conducted at the wind tunnel during the winter of 2009-10. Only tests pertaining to ice pellet allowance times (groups 1 to 3) are described in this report. Table 1.3 demonstrates in greater detail the groupings for the secondary R&D objective tests (groups 4 and 5 from Table 1.2).

Table 1.2: Summary of 2009-10 Wind Tunnel Tests by Objective

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

Table 1.3: Summary of 2009-10 Secondary R&D Objectives

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

1.6 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 data collected during the full-scale testing conducted;

c) Section 4 describes the analysis methodology used to evaluate the wind tunnel tests conducted;

d) Section 5 includes details of additional data analysis that was conducted while developing the ice pellet allowance times for the winter of 2010-11;

e) Section 6 describes the data, results, and observations for testing conducted in Light Ice Pellet conditions;

f) Section 7 describes the data, results, and observations for testing conducted in Moderate Ice Pellet conditions;

g) Section 8 describes the data, results, and observations for testing conducted in Light Ice Pellets Mixed with Light Freezing Rain;

h) Section 9 describes the data, results, and observations for testing conducted in Light Ice Pellets Mixed with Moderate Rain;

i) Section 10 describes the data, results, and observations for testing conducted in Light Ice Pellets Mixed with Light Snow;

j) Section 11 describes the data, results, and observations for testing conducted in Light Ice Pellets Mixed with Moderate Snow;

k) Section 12 describes the data, results, and observations for the comparative testing conducted with flap up and flap down;

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

m) Section 14 lists the recommendations for future testing.

2. METHODOLOGY

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

2.1 Wind Tunnel Test Site

The 2009-10 PIWT tests were performed at the NRC Aerospace Facilities, Building M-46, at the NRC Montreal Road campus, located in Ottawa, Canada. Figure 2.1 provides a schematic of the NRC Montreal Road campus showing the location of the NRC PIWT. Photo 2.1 shows an outside view of the wind tunnel test facility. Photo 2.2 shows an inside view of the wind tunnel test section. The open-circuit layout, with a fan at entry, permits contaminants associated with the test articles (such as heat or de/anti-icing fluid) to discharge directly, without recirculating or contacting the fan. The fan is normally driven electrically, but high-speed operation can be accommodated by a gas turbine drive system. Due to the requirements of both high-speed and low-speed operations during the testing, the gas turbine was selected to allow for greater flexibility, as it can perform both low- and high-speed operations, whereas the electric drive is limited to low-speed operations.

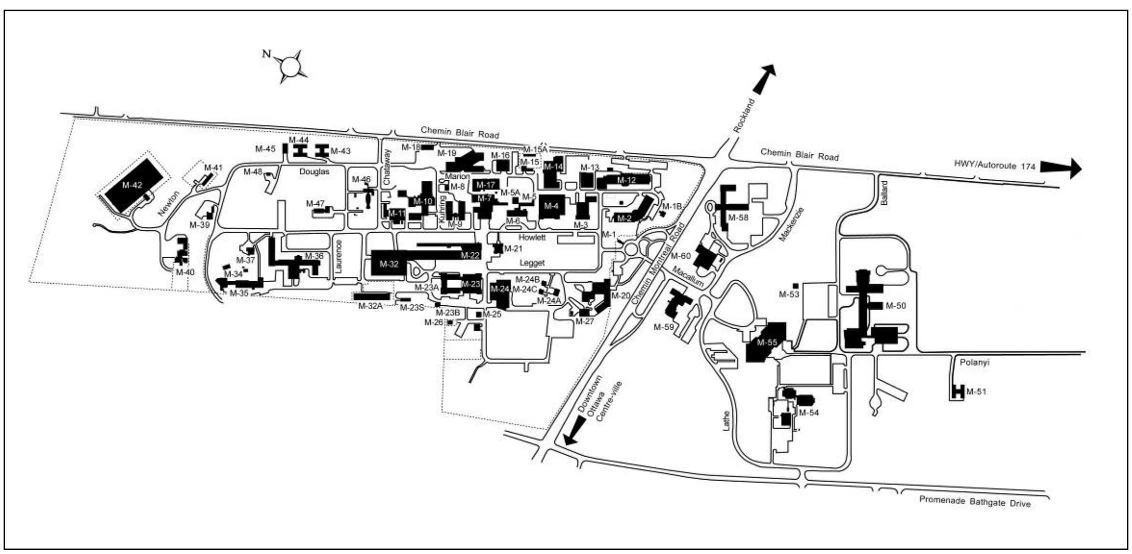

Figure 2.1: Schematic of NRC Montreal Road Campus

2.2 Test Schedule

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

Table 2.1: Calendar of Tests

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

2.3 Wind Tunnel Procedure

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

The procedure for each test was as follows:

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

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

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

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

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

2.4 Test Sequence

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

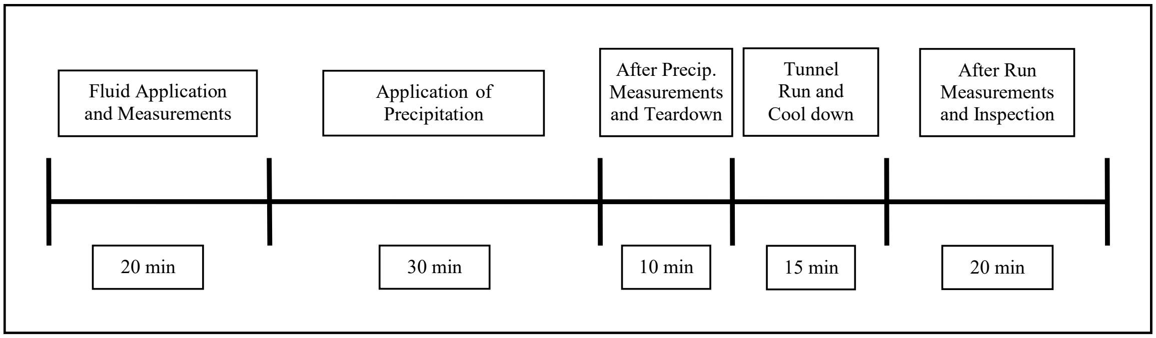

Figure 2.2: Typical Wind Tunnel Test Timeline

2.5 Wind Tunnel

The experiments were performed in the NRC PIWT. This facility is an open-circuit wind tunnel with a fan at the entry, drawing air from and exhausting to the outdoors; this design is ideal for de/anti-icing tests as it prevents contaminants from recirculating within the tunnel. This design also permits sub-freezing air to be drawn in during the Ottawa winter, thereby providing test section temperatures appropriate to these experiments. The test section is 3 m (10 ft.) wide by 6 m (20 ft.) high by 12 m (40 ft.) long, with a maximum wind speed of 78 knots when using the electrical turbine drive and with a maximum wind speed of 100 knots when using the gas turbine drive. Scaffolding was constructed to allow access to the wing section, which facilitated the application of fluids and the subsequent inspection and cleaning of the airfoil.

2.5.1 Generic Supercritical Wing Section

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

2.5.2 Generic "Supercritical" Wing Design Characteristics

A cross sectional view of the supercritical wing section used for testing has been included in Figure 2.3; the dimensions indicated are in metres. Some of the pertinent dimensions of the wing section are:

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

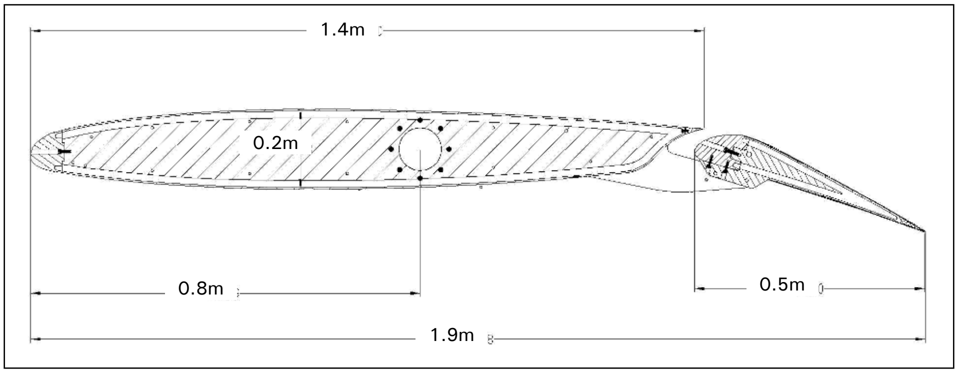

Figure 2.3: Generic "Supercritical" Wing Section

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

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

End plates were installed on the wing section to eliminate the "wall effects" from the wind tunnel walls and to provide a better aerodynamic flow-off above the test area. Figure 2.4 demonstrates the end plates installed on the supercritical wing section (note: the wing section is depicted without the top wing skin).

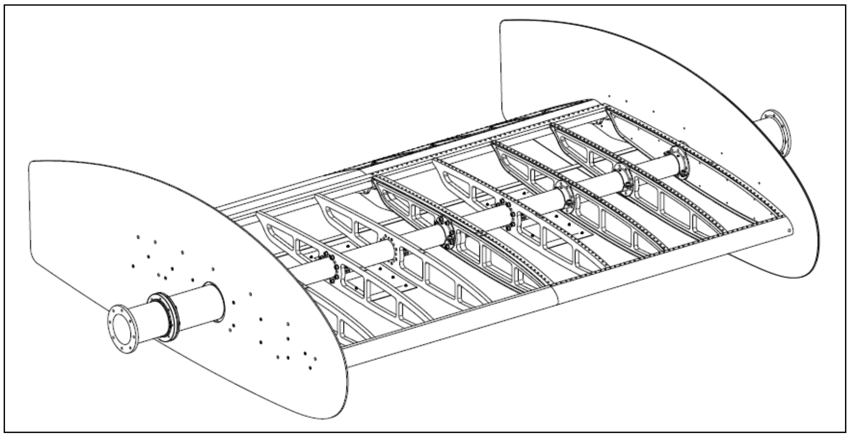

Figure 2.4: End Plates Installed on Supercritical Wing Section

2.5.3 Wind Tunnel Measurement Capabilities

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

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

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

Figure 2.5 demonstrates the general location of the RTDs. These RTDs were primarily used to monitor the skin temperature in real-time through the NRC data display system and were recorded by APS personnel as described in Subsection 2.15.3.

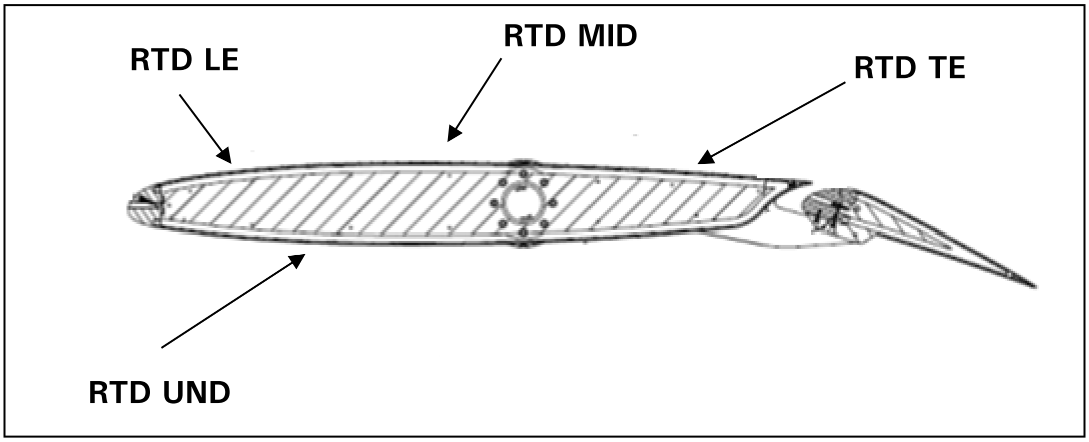

Figure 2.5: Location of RTDs Installed Inside Supercritical Wing

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

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

2.5.4 Test Area Grid

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

2.6 Equipment

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

2.7 Simulated Precipitation

2.7.1 Ice Pellets

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

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

2.7.2 Snow

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

The snow was manufactured inside a refrigerated truck. Cubes of ice were crushed and passed through calibrated sieves to obtain the required snow size range. 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.

2.7.3 Freezing Rain/Rain

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

2.8 Simulated Precipitation Related Equipment

2.8.1 Ice Pellet and Snow Dispenser

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

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

These tests were conducted using 121 collection pans, each measuring 15 cm x 15 cm, over an area 3.4 m x 3.4 m. Pre-measured amounts of IP/Snow were dispersed over this area, and the amount collected by each pan was recorded. A distribution footprint of the dispenser was attained, and efficiency for the dispenser was computed.

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

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

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

2.8.2 Freezing Rain Sprayer

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

2.9 Definition of Precipitation Rates

When simulating precipitation rates for full-scale and plate testing, the rate limits defined for standard HOT testing were referenced. Figure 2.6 demonstrates the HOT testing rate precipitation breakdown.

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

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

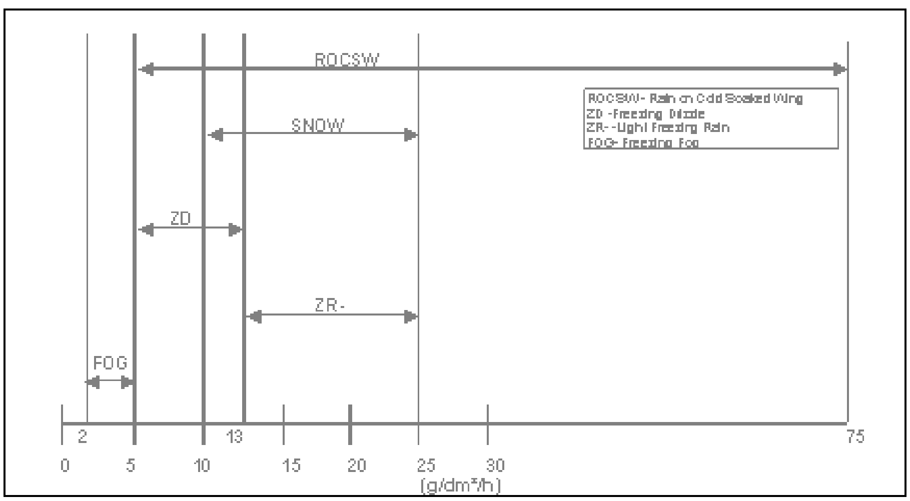

Figure 2.6: Precipitation Rate Breakdown

2.10 Video and Photo Equipment

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

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

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

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

2.11 Additional Photos Taken During Precipitation Phase

Early in the testing, the cameras were fitted with an intervalometer to limit the number of frames taken during the high-speed run and to reduce the storage size of the photos. The same intervalometer was used for taking pictures during the precipitation phase. The cameras were set to trigger every minute and, during shorter tests, at shorter intervals as required. These photos proved to be useful for demonstrating the progression of contamination, as well as for reviewing and comparing tests. This protocol should be continued for future testing.

2.12 Type II/III/IV Fluid Application Equipment

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

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

2.13 Waste Fluid Collection

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

2.14 Personnel

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

2.15 Measurement of Test Parameters

2.15.1 Measurement Locations

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

a) Before fluid application;

b) After fluid application;

c) After application of contamination; and

d) After the simulated takeoff test.

The locations designated for measurement, identified in Figure 2.7, were the following:

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

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

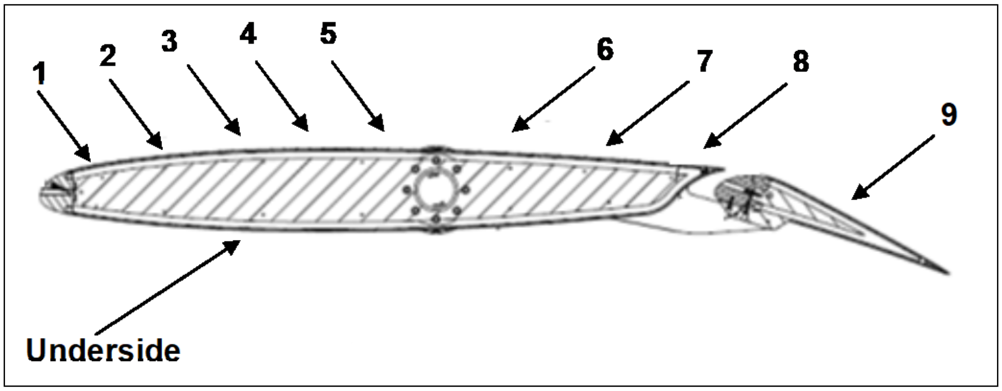

Figure 2.7: Measurement Locations Along Chord of Supercritical Wing Section

2.15.2 Fluid Thickness

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

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

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

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

- Underside: Approximately 40 cm up from the leading edge stagnation point.

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

2.15.3 Wing Skin Temperature

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

a) Before fluid application;

b) After fluid application;

c) After application of contamination; and

d) After the simulated takeoff test.

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

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

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

It should be noted that early on in the testing, the hand-held measurements were compared to the NRC-monitored data from the RTDs located inside the wing (see Subsection 2.5.3). The average of the temperatures recorded by the pairs of RTDs denoted by RTD LE, RTD MID, and RTD UND were comparable to the manual measurements taken by APS using a hand-held temperature probe on positions 2, 5, and Underside, respectively. Therefore, early on, the manual measurements were replaced by the data logged by the NRC (APS recorded an instantaneous average value from the NRC data at the required intervals for analysis purposes). The average instantaneous temperatures indicated by the three pairs of RTDs (located to the left and right of the centreline) were recorded for each of the three locations where APS typically measured skin temperature.

2.15.4 Fluid Brix

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

a) After fluid application;

b) After application of contamination; and

c) After the simulated takeoff test.

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

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

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

2.16 Data Forms

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

a) General Form;

b) Wing Temperature, Fluid Thickness and Fluid Brix Form;

c) Ice Pellet and Snow Dispensing Forms;

d) Sprayer Calibration Form;

e) Visual Evaluation Rating Form

f) Condition of Wing and Plate Form;

g) Fluid Receipt Form; and

h) Log of Fluid Sample Bottles.

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

2.17 General Methodology

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

2.17.1 Refractometer

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

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

Figure 2.8 illustrates the fluid freezing points for the Dow EG106 fluid.

2.17.2 Temperature Sensor

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

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

Conc. (% Vol)	BRIX (20°C)	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					

Table 2.3: Dilution Chart for Clariant MPIII 2031 ECO

DILUTION (v/v) Safewing : Water	**BRIX (°)** MISCO 10431 VP	**FREEZING POINT (°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

Table 2.4: Dilution Chart for Octagon Octaflo Type I

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

Table 2.5: Dilution Chart for Clariant MPIV Launch

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

Table 2.6: Brix to Refractive Index Conversion Chart

MISCO Model 10431VP • Hand-Held Refractometer
0-50 Brix Scale - Automatically Temperature Compensated

Brix % to Refractive Index @ 20°C

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

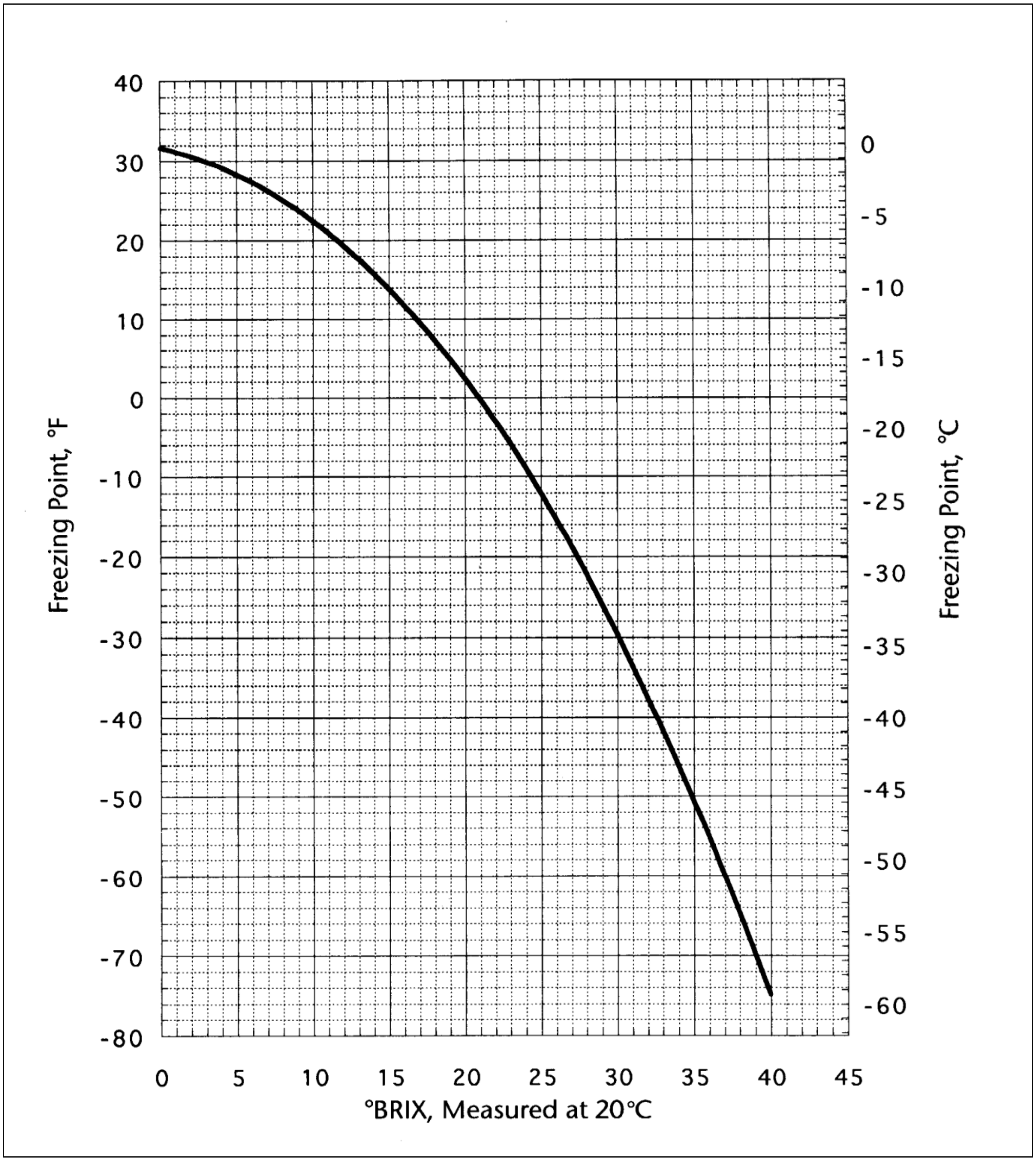

Figure 2.8: Freezing Point vs. Brix of Aqueous Solutions of Dow EG106

2.17.3 Thickness Gauges

Wet film thickness gauges, shown in Figure 2.9 and Photo 2.13, were used to measure fluid film thickness. These gauges were selected because they provide an adequate range of thicknesses (0.1 mm to 10.2 mm) for Type I/II/III/IV fluids. The rectangular gauge shown in Figure 2.9 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 2.7) was used to convert the recorded thickness values into the corrected thickness values.

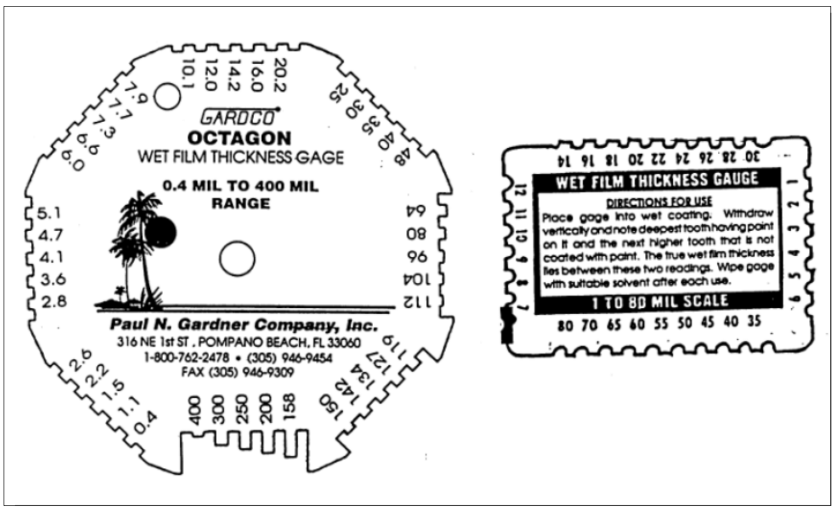

Figure 2.9: Thickness Gauges

2.17.4 Viscometer

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

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

Table 2.7: Film Thickness Conversion Table

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

* Reading of last wetted tooth.

2.17.5 Fluids

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

Table 2.8: Test Fluids

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

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

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Photo 2.1: Outside View of NRC Wind Tunnel Facility

Photo 2.2: Inside View of NRC Wind Tunnel Test Section

Photo 2.3: Supercritical Wing Section Used for Testing

Photo 2.4: Grid Markings on Supercritical Wing Section

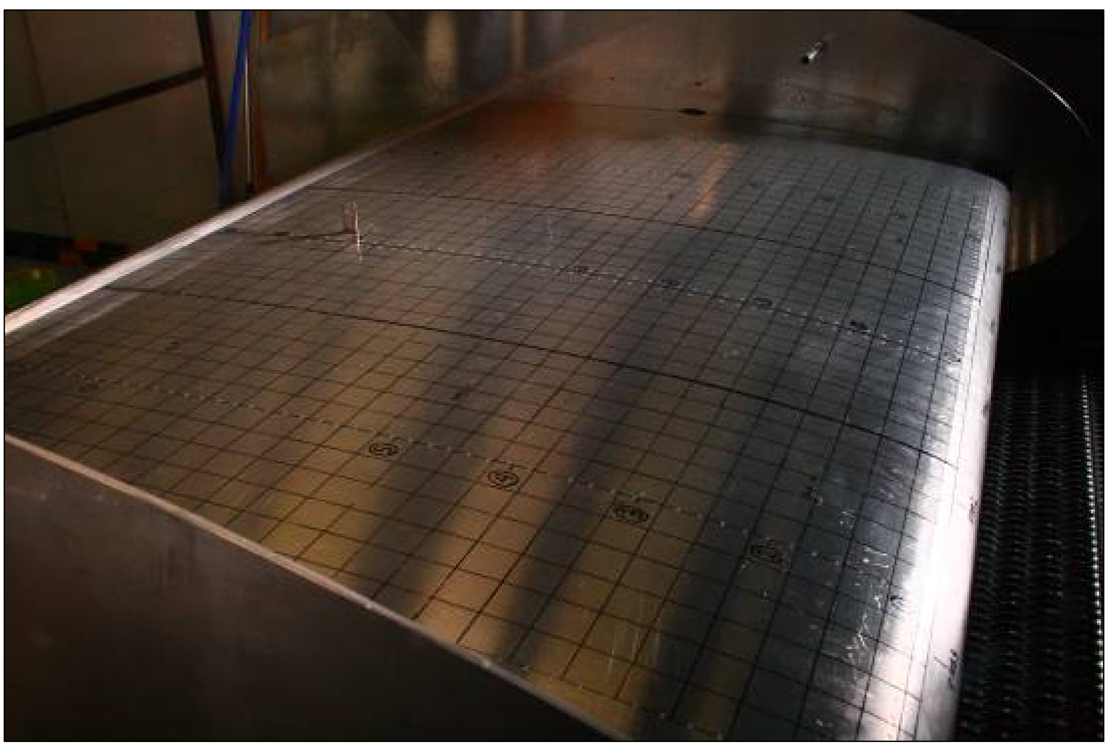

Photo 2.5: Refrigerated Truck Used for Manufacturing Ice Pellets

Photo 2.6: Calibrated Sieves Used to Obtain Desired Size Distribution

Photo 2.7: Ice Pellet Dispensers Operated by APS Personnel

Photo 2.8: Ceiling-Mounted Freezing Rain Sprayer

Photo 2.9: Wind Tunnel Setup for Flashes

Photo 2.10: Wind Tunnel Setup for Digital Cameras

Photo 2.11: Fluid Pour Containers

Photo 2.12: 2009-10 Research Team

Photo 2.13: Wet Film Thickness Gauges

Photo 2.14: Hand-Held Temperature Probe

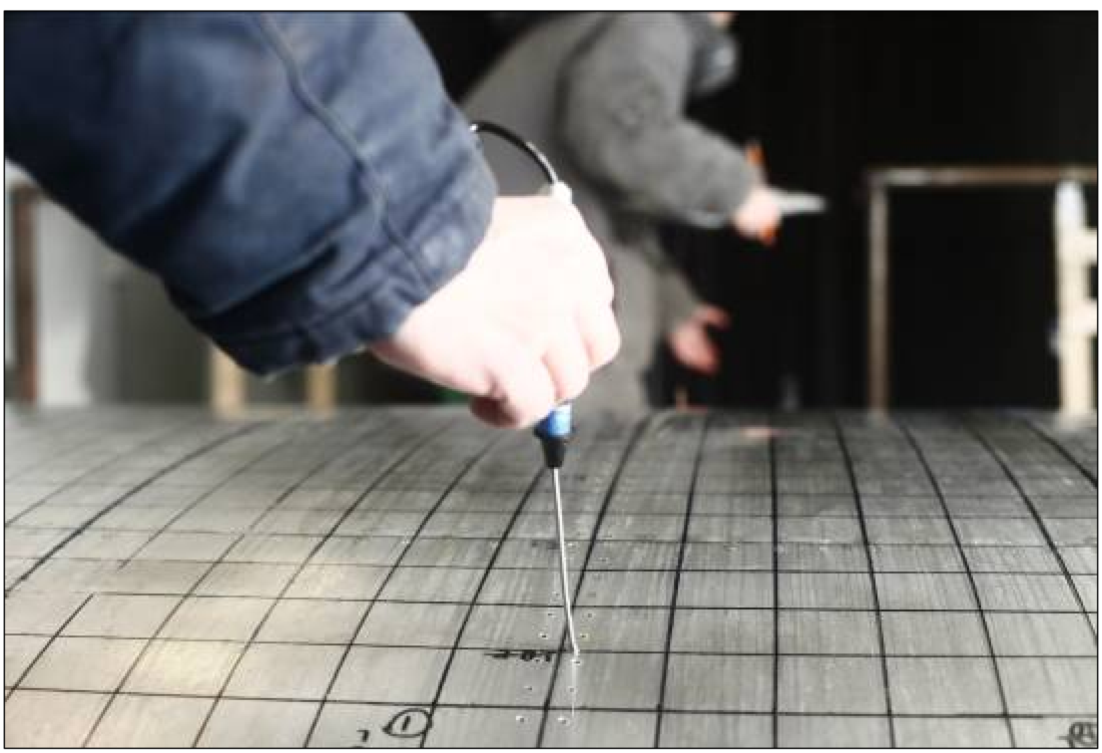

Photo 2.15: Hand-Held Brixometer (Misco 10431VP)

Photo 2.16: Brookfield Digital Viscometer Model DV-1+

Photo 2.17: Stony Brook PDVdi-120 Falling Ball Viscometer

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3. FULL-SCALE DATA COLLECTED

3.1 Test Log

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

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

Tunnel Temp. Before Test (ºC): Static tunnel air temperature recorded just before the start of the simulated takeoff test, measured in degrees Celsius.
Note: This parameter was used as the actual test temperature for analysis.

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

Precipitation Rate (Type: [g/dm²/h]): Simulated freezing precipitation rate (or combination of different precipitation rates). "N/A" indicates that no precipitation was applied.

Exposure Time: Simulated precipitation period, recorded in minutes.

The visual contamination ratings are described below. Visual contamination ratings were typically reported as the average of the three observer ratings and rounded to the nearest decimal. The visual contamination ratings system is further described in Subsection 4.1.

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

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

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

1 - Contamination not very visible, fluid still clean.
2 - Contamination is visible, but lots of fluid still present.

3 - Contamination visible, spots of bridging contamination.
4 - Contamination visible, lots of dry bridging present.
5 - Contamination visible, adherence of contamination.

Visual Contamination Rating After Takeoff (LE, TE, Flap): Visual contamination rating determined at the end of the test:

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

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

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

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

% Lift Loss: Percentage lift loss calculated based on the comparison of the 8º rotation lift coefficient during the test run versus the dry wing average lift coefficient (calculated to be 1.7213).

Table 3.1: Wind Tunnel Test Log

Run #	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip. End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipiation Rate (g/dm²/h)	Exposure Time (min)	Visual Contamination Rating Before Takeoff (LE, TE, Flap)	Visual Contamination Rating at Rotation (LE, TE, Flap)	Visual Contamination Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	CL at 6° During Rotation	CL at 8°	CL at 4° Following End of Rotation	% Lift Loss (8° CL vs. Dry CL AVG =1.7213)
0	IP Validation	IP- / ZR-	ABC-S Plus	8	20	7-Jan-10	11:26	11:37	-6.9	-6.1	-6	IP:25, ZR:25	25	2, 2, 4	1, 1, 3.7	1, 1, 1	0.665	1.423	1.609	1.247	6.52
1	Baseline	Fluid Only	ABC-S Plus	8	20	7-Jan-10	N/A	13:42	-6.6	-5.7	-4.6		-	1, 1, 1	1, 1, 1	1, 1, 1	0.695	1.463	1.635	1.266766	5.01
2	Baseline	Dry Wing	No Fluid	8	20	7-Jan-10	N/A	0.6	-6.5	-4.9	N/A		-	-, -, -	-, -, -	-, -, -	0.75	1.536992	1.698	1.303	1.35
3	Baseline	Dry Wing	No Fluid	14	20	11-Jan-10	N/A	N/A	-7.1	N/A	N/A		-	-, -, -	-, -, -	-, -, -	0.748	1.52	1.732	1.293	-0.62
4	Baseline	Fluid Only	ABC-S Plus	14	20	11-Jan-10	N/A	9:59	-6.4	-6.6	-5.4		-	1, 1, 1	1, 1, 1	1, 1, 1	0.653	1.456	1.652	1.278	4.03
5	IP Validation	IP- / SN-	ABC-S Plus	14	20	11-Jan-10	11:10	11:23	-5.5	-4.8	-6.7	IP:25, SN:10	25	2, 2, 3	1, 1.5, 1.8	1, 1, 1	0.665	1.448	1.658	1.290583	3.68
8	Baseline	Fluid Only	ABC-S Plus	13	20	12-Jan-10	N/A	18:09	-11.8	-8.8	-7.9		-	1, 1, 1	1, 1, 1	1, 1, 1	0.683	1.461	1.668	1.271	3.10
9	IP Validation	IP-	ABC-S Plus	8	20	13-Jan-10	10:21	10:31	-11.1	-7	-8.5	IP:25	50	2, 2, 3	1, 1.8, 1.8	1, 1, 1	0.677	1.462	1.641	1.27	4.67
10	IP Validation	IP Mod	ABC-S Plus	8	20	13-Jan-10	11:36	11:42	-10.6	-7.4	-10.5	IP:75	25	2, 3, 4	1, 2, 2	1, 1, 1	0.632	1.438	1.616	1.271	6.12
11	IP Expansion	IP- / SN-	ABC-S Plus	8	20	13-Jan-10	13:40	13:57	-10.2	-5.9	-8.1	IP:25, SN:10	40	3, 2.3, 4	1, 1.8, 2.5	1, 1, 1	0.684	1.459	1.646	1.274	4.37
10A	IP Validation	IP Mod	ABC-S Plus	8	20	13-Jan-10	15:18	15:26	-10	-5.6	-10.1	IP:75	25	2, 2.8, 2.7	1, 1.8, 2	1, 1, 1	0.736	1.525	1.709	1.288	0.71
12	Baseline	Fluid Only	ABC-S Plus	13	20	13-Jan-10	N/A	16:46	-10.4	-5.9	-5.8		-	1, 1, 1	1, 1, 1	1, 1, 1	0.656	1.454	1.66	1.263	3.56
10B	IP Validation	IP Mod	ABC-S Plus	8	20	13-Jan-10	17:55	18:03	-10.7	-6.2	-11.1	IP:75	25	2.2, 3, 3	1, 2, 2	1, 1, 1.2	0.609	1.405	1.587	1.268	7.80
13	IP Expansion	IP- / SN	ABC-S Plus	8	20	14-Jan-10	7:05	7:14	-9.3	-4.6	-7.9	IP:25, SN:25	20	3, 2, 3.5	1, 1.8, 2.7	1, 1, 1	0.629	1.422	1.617	1.267	6.06
14	IP Expansion	IP- / SN	ABC-S Plus	8	20	14-Jan-10	8:10	8:18	-9.3	-4.4	-8.1	IP:25, SN:25	15	2.2, 2, 2.83	2.8, 1.5, 1.5	1, 1, 1	0.641	1.414	1.626	1.271	5.54
15	IP Validation	IP- / SN	ABC-S Plus	8	20	14-Jan-10	9:19	9:28	-9	-4.3	-5.8	IP:25, SN:25	10	1.8, 2, 2.7	1, 1.3, 1.7	1, 1, 1	0.643	1.433	1.633	1.269	5.13
16	IP Validation	IP- / SN	ABC-S Plus	8	20	14-Jan-10	10:15	10:23	-8.7	-4.2	-4.7	IP:25, SN:25	5	1.4, 1.7, 1.8	1, 1, 1.3	1, 1, 1	0.628	1.414	1.622	1.26	5.77

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

Run #	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip. End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipiation Rate (g/dm²/h)	Exposure Time (min)	Visual Contamination Rating Before Takeoff (LE, TE, Flap)	Visual Contamination Rating at Rotation (LE, TE, Flap)	Visual Contamination Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	CL at 6° During Rotation	CL at 8°	CL at 4° Following End of Rotation	% Lift Loss (8° CL vs. Dry CL AVG =1.7213)
17	Baseline	Fluid Only	ABC-S Plus	8	20	14-Jan-10	N/A	11:11	-8.4	-3.9	-4.4		-	1, 1, 1	1, 1, 1	1, 1, 1	0.653	1.448	1.636	1.262	4.96
18	Baseline	Fluid Only	ABC-S Plus	12	20	14-Jan-10	N/A	12:32	-2	-2.5	-3.5		-	1, 1, 1	1, 1, 1	1, 1, 1	0.659	Data Loss	Data Loss	Data Loss	-
18A	Baseline	Fluid Only	ABC-S Plus	8	20	14-Jan-10	N/A	14:46	-5.7	-1.8	-2.9		-	1, 1, 1	1, 1, 1	1, 1, 1	0.721	1.501	1.692	1.31	1.70
19	Baseline	Fluid Only	ABC-S Plus	8	20	14-Jan-10	N/A	15:13	-5.7	-2.1	N/A		-	1, 1, 1	1, 1, 1	1, 1, 1	0.745	1.536	1.741	1.324	-1.14
20	IP Expansion	IP / R Mod	ABC-S Plus	8	20	20-Jan-10	1:27	1:35	0.3	2.9	1.1	IP:25	40	1 (3.7), 1 (4), 1	1, 1, 1	Did Not Rotate, Did Not Rotate, Did Not Rotate	0.713	Data Loss	Data Loss	Data Loss	-
21	IP Validation	IP Mod	EG106	8	20	20-Jan-10	21:00	21:05	-5.9	-3.6	-10.1	IP:75	25	2, 2.2, 4	1, 1, 1.2	1, 1, 1	0.723	1.515	1.712	1.298	0.54
22	IP Validation	IP-	EG106	8	20	20-Jan-10	22:27	22:32	-6.8	-4.1	-8.5	IP:25	50	1.8, 2, 4	1, 1, 1	1, 1, 1	0.722	1.495	1.707	1.293	0.83
23	IP Expansion	IP- / SN-	EG106	8	20	20-Jan-10	0:11	0:16	-6	-3.2	-9	IP:25, SN:10	40	2.3, 2.2, 4	1, 1.2, 1.5	1, 1, 1	0.717	1.491	1.702	1.294	1.12
24	IP Expansion	IP- / SN	EG106	8	20	21-Jan-10	1:24	1:30	-6.1	-3.7	N/A	IP:25, SN:25	20	2.5, 1.8, 4	1, 1.2, 1	1, 1, 1	0.719	1.517	1.699	1.294	1.30
25	Baseline	Fluid Only	EG106	8	20	21-Jan-10	N/A	2:05	-5.9	-4	-3.4		-	1, 1, 1	1, 1, 1	1, 1, 1	0.715	1.516	1.687	1.284	1.99
26	IP Validation	IP- / ZR-	EG106	8	20	21-Jan-10	3:22	3:28	-5.8	-1.9	-6.2	IP:25, ZR:25	25	2.2, 1.7, 4.7	1, 1, 4	1, 1, 3.5	0.657	1.441	1.639	1.283	4.78
26A	IP Validation	IP- / ZR-	EG106	8	0	21-Jan-10	4:40	4:53	-5.9	-3.3	-6.2	IP:25, ZR:25	25	1.8, 2, 1.9	1, 1, 1	1, 1, 1	0.721	1.499	1.697	1.291	1.41
27	Baseline	Fluid Only	ABC-S Plus	6	20	21-Jan-10	N/A	5:37	-6.2	-3.5	-3.7		-	1, 1, 1	1, 1, 1	1, 1, 1	0.655	1.423	-	1.254	-
28	IP Validation	IP-	Launch	8	20	21-Jan-10	21:34	21:39	-7.1	-4.2	-3.6	IP:25	50	2, 2, 3.7	1, 1.7, 2	1, 1, 1	0.659	1.449	1.648	1.275	4.26
29	Baseline	Fluid Only	Launch	8	20	21-Jan-10	N/A	22:25	-8.5	-4.8	-3.9		-	1, 1, 1	1, 1, 1	1, 1, 1	0.643	1.448	1.636	1.291	4.96
30	Baseline	Fluid Only	Launch	6	20	21-Jan-10	N/A	22:56	-8.8	-6.8	-5.2		-	1, 1, 1	1, 1, 1	1, 1, 1	0.64	1.409	-	1.252	-
28A	IP Validation	IP-	Launch	8	0	21-Jan-10	0:24	0:35	-9.1	-5.5	-7.4	IP:25	50	2, 2, 2.7	1, 1.5, 2	1, 1, 1	0.664	1.467	1.655	1.268	3.85

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

Run #	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip. End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipiation Rate (g/dm²/h)	Exposure Time (min)	Visual Contamination Rating Before Takeoff (LE, TE, Flap)	Visual Contamination Rating at Rotation (LE, TE, Flap)	Visual Contamination Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	CL at 6° During Rotation	CL at 8°	CL at 4° Following End of Rotation	% Lift Loss (8° CL vs. Dry CL AVG =1.7213)
44	IP Expansion	IP / R Mod	EG106	8	20	23-Jan-10	21:28	21:35	-8	-0.8	-1.2	IP:25, R:75	40	5, 4.5, 5	5, 5, 5	5, 5, 5	0.37	1.079	1.231	0.869	28.48
46	Baseline	Dry Wing	No Fluid	15	20	23-Jan-10	N/A	23:13	-8.6	-3.5	N/A		-	-, -, -	-, -, -	-, -, -	0.718	1.496	1.713	1.276	0.48
47	IP Validation	IP Mod	Launch	8	20	24-Jan-10	0:51	0:57	-8.7	-4.9	-10.1	IP:75	25	3.7, 3.8, 4	1, 1.7, 2.5	1, 1, 1	0.593	1.383	1.58	1.24	8.21
48	IP Validation	IP Mod	Launch	8	20	24-Jan-10	2:32	2:40	-8.7	-2.7	-8.5	IP:75	15	2, 2.8, 4	1, 1.7, 1.8	1, 1, 1	0.644	1.429	1.609	1.243	6.52
49	IP Validation	IP Mod	Launch	8	0	24-Jan-10	3:33	3:50	-8.5	-3.1	-8.8	IP:75	15	2.7, 2.8, 3	1, 1.5, 1.8	1, 1, 1	0.644	1.414	1.606	1.24	6.70
53	Baseline	Snow	Dry - Cold Wing	8	20	27-Jan-10	N/A	4:25	-2.7	-1.9	-0.3	SN:50	Approx. 7	1, 1, 1	1, 1, 1	1, 1, 1	0.648	1.441	1.654	1.275	3.91
54	Baseline	Fluid Only	Launch	8	20	27-Jan-10	N/A	4:57	-3.6	-2.2	-0.8		-	1, 1, 1	1, 1, 1	1, 1, 1	0.69	1.462	1.66	1.282	3.56
55	Baseline	Fluid Only	EG106	8	20	27-Jan-10	N/A	5:34	-4.2	-2.6	-0.9		-	1, 1, 1	1, 1, 1	1, 1, 1	0.704	1.498	1.689	1.282	1.88
56	IP Validation	IP / R Mod	EG106	8	20	27-Jan-10	7:11	7:18	-5.7	-1.1	-4.3	IP:25, R:75	25	1.8, 2, 4.7	1, 1, 5	1, 1, 5	0.701	1.478	1.666	1.259	3.21
56A	IP Expansion	IP / R Mod	EG106	8	0	27-Jan-10	8:22	0.357639	-6.2	-1.4	-2.4	IP:25, R:75	25	1.8, 2.2, 3	1, 1, 4.3	1, 1, 4.3	0.702	1.473	1.663	1.255	3.39
57	IP Expansion	IP- / SN-	Launch	8	20	27-Jan-10	22:28	22:34	-5.5	-3.6	-5.4	IP:25, SN:10	40	2.7, 2.6, 4	1, 1.7, 2.8	1, 1, 1.3	0.625	1.432	1.64	1.262	4.72
57A	IP Expansion	IP- / SN-	Launch	8	0	27-Jan-10	23:48	0:04	-5.4	-4.2	-5.7	IP:25, SM:10	40	2.6, 2.6, 3	1, 1.3, 1.7	1, 1, 1	0.654	1.488	1.671	1.292	2.92
58	IP Expansion	IP- / SN	Launch	8	0	28-Jan-10	1:04	1:14	-5.1	-3.1	-6.8	IP:25, SN:25	20	2.8, 2.6, 3	1, 1.5, 2	1, 1, 1	0.638	1.439	1.638	1.284	4.84
59	IP Validation	IP- / ZR-	Launch	8	0	28-Jan-10	3:52	4:03	-4.7	-3.3	-4.6	IP:25, ZR:25	25	2, 2, 2.2	1, 1.3, 1.5	1, 1, 1	0.667	1.449	1.651	1.271	4.08
60	Baseline	Fluid Only	Launch	8	20	28-Jan-10	N/A	5:04	-4.9	-2.8	-1.9		-	1, 1, 1	1, 1, 1	1, 1, 1	0.665	1.465	1.642	1.273	4.61
63	IP Validation	IP- / ZR-	ABC-S Plus	8	20	28-Jan-10	21:53	22:00	-14.2	-12.3	-10.8	IP:25, ZR:25	10	2.3, 2.3, 3.2	1.2, 2, 2.3	1, 1.2, 1.2	0.584	1.363	1.589	1.263	7.69
64	Baseline	Fluid Only	ABC-S Plus	8	20	28-Jan-10	N/A	22:45	-15	-13.4	-11.3		-	1, 1, 1	1, 1, 1	1, 1, 1	0.629	1.425	1.634	1.275	5.07

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

Run #	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip. End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipiation Rate (g/dm²/h)	Exposure Time (min)	Visual Contamination Rating Before Takeoff (LE, TE, Flap)	Visual Contamination Rating at Rotation (LE, TE, Flap)	Visual Contamination Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	CL at 6° During Rotation	CL at 8°	CL at 4° Following End of Rotation	% Lift Loss (8° CL vs. Dry CL AVG =1.7213)
65	IP Validation	IP-	ABC-S Plus	8	20	29-Jan-10	0:40	0:45	-16.9	-13.7	-13.9	IP:25	30	2.8, 2.8, 4	1.2, 2, 2.2	1, 1.7, 1.7	0.535	1.353	1.563	1.189	9.20
66	IP Validation	IP-	ABC-S Plus	8	20	29-Jan-10	2:29	2:34	-18.3	-13.6	-14.2	IP:25	20	2.2, 2, 3.2	1.2, 2, 2.5	1, 1.3, 1.7	0.557	1.349	1.573	1.253	8.62
67	IP Validation	IP-	EG106	8	20	29-Jan-10	3:58	4:03	-19.3	-12.6	-15	IP:25	30	2.2, 2.2, 3.2	1, 1.5, 1.8	1, 1, 1.2	0.683	1.463	1.683	1.292	2.23
68	IP Validation	IP-	Launch	8	20	29-Jan-10	5:12	5:16	-20.3	-16.6	-16.4	IP:25	30	3, 2.5, 3.7	1.3, 2, 2.2	1, 1.8, 2	0.55	1.331	1.556	1.222	9.60
69	IP Validation	IP-	Launch	8	20	29-Jan-10	6:05	6:09	-20.6	-17.8	-16.6	IP:25	15	2.8, 2.5, 3.5	1.3, 2, 2.7	1, 1, 1.8	0.546	1.331	1.556	1.235	9.60
70	Baseline	Fluid Only	Launch	8	20	29-Jan-10	N/A	6:43	-20.9	-17.9	-15.8		-	1, 1, 1	1, 1, 1	1, 1, 1	0.627	1.396	1.625	1.272	5.59
71	IP Validation	IP Mod	EG106	8	20	29-Jan-10	21:32	21:39	-21.4	-17.7	-17.2	IP:75	10	2.3, 2.3, 2.8	1, 1.3, 1.8	1, 1, 1.2	0.667	1.475	1.671	1.293	2.92
72	IP Validation	IP Mod	ABC-S Plus	8	20	29-Jan-10	22:17	22:22	-21.8	-18	-17.6	IP:75	10	2.8, 2.5, 3.8	1.2, 2, 2.8	1, 1.25, 1.7	0.554	1.338	1.561	1.226	9.31
73	IP Validation	IP Mod	ABC-S Plus	8	20	29-Jan-10	23:05	23:05	-21.9	-18.2	-17.4	IP:75	5	2.2, 2.2, 3.4	1.2, 2, 2.5	Did Not Rotate	0.688	1.45	1.635	1.284	5.01
74	IP Validation	IP Mod	Launch	8	20	29-Jan-10	23:54	0:00	-22.2	-18.5	-17.4	IP:75	5	2.7, 2.3, 3.2	1.5, 2, 2.8	1, 1.5, 1.9	0.556	1.359	1.544	1.218	10.30
75	Baseline	Fluid Only	EG106	8	20	30-Jan-10	N/A	0:40	-22.3	-18.1	-16.9		-	1, 1, 1	1, 1, 1	1, 1, 1	0.655	1.424	1.651	1.274	4.08
76	Baseline	Fluid Only	ABC-S Plus	8	20	30-Jan-10	N/A	1:13	-22.6	-17.9	-17.3		-	1, 1, 1	1, 1, 1	1, 1, 1	0.643	1.41	1.62	1.258	5.89
77	IP Expansion	IP- / SN-	ABC-S Plus	8	20	30-Jan-10	2:08	2:13	-22.4	-14.1	-16.1	IP:25, SN:10	10	2.8, 2.7, 3.7	1.7, 2, 2.8	1, 1.67, 1.5	0.554	1.338	1.551	1.227	9.89
78	IP Expansion	IP- / SN-	ABC-S Plus	8	20	30-Jan-10	2:50	2:56	-22.5	-16	-14.9	IP:25, SN:10	5	2.3, 2.2, 3	1.4, 2, 2.7	1, 1.2, 1.5	0.59	1.381	1.573	1.238	8.62
79	IP Expansion	IP- / SN-	EG106	8	20	30-Jan-10	3:40	3:45	-22.7	-14.8	-15.7	IP:25, SN:10	10	2.2, 2, 2.5	1, 1.5, 2	1, 1, 1	0.668	1.463	1.66	1.274	3.56
80	IP Validation	IP-	EG106	8	20	30-Jan-10	4:55	5:00	-22.9	-17	-18.5	IP:25	30	2.5, 2.2, 3	1, 1.25, 1.7	1, 1, 1	0.677	1.463	1.67	1.285	2.98
81	IP Expansion	IP- / SN	EG106	8	20	30-Jan-10	5:37	5:43	-22.9	-17.3	-17.1	IP:25, SN:25	5	1.8, 2, 2.3	1, 1.5, 2	1, 1, 1	0.666	1.445	1.656	1.284	3.79

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

Run #	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip. End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipiation Rate (g/dm²/h)	Exposure Time (min)	Visual Contamination Rating Before Takeoff (LE, TE, Flap)	Visual Contamination Rating at Rotation (LE, TE, Flap)	Visual Contamination Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	CL at 6° During Rotation	CL at 8°	CL at 4° Following End of Rotation	% Lift Loss (8° CL vs. Dry CL AVG =1.7213)
82	IP Expansion	IP- / SN	ABC-S Plus	8	20	30-Jan-10	6:27	6:33	-22.9	-15.8	-16	IP:25, SN:25	5	2.5, 2.2, 3.2	1.5, 1.5, 1.8	1.1, 1.7, 1.8	0.568	1.354	1.563	1.228	9.20
94	IP Validation	IP- / SN-	ABC-S Plus	8	20	2-Feb-10	3:54	3:58	-12.9	-6.3	-9.7	IP:25, SN:10	15	2.5, 2, 2.8	1, 1.8, 2	1, 1, 1	0.62	1.42	1.626	1.282	5.54
95	IP Validation	IP Mod	ABC-S Plus	8	20	2-Feb-10	4:28	4:32	-12.9	-8.1	-10.4	IP:75	10	2.2, 2, 2.8	1, 1.7, 2	1, 1, 1	0.579	1.401	1.602	1.281	6.93
96	IP Validation	IP-	ABC-S Plus	8	20	2-Feb-10	5:20	5:23	-13.4	-7.6	-10.7	IP:25	30	2.3, 2, 3	1, 2, 2	1, 1, 1	0.61	1.4	1.608	1.281	6.58
97	IP Expansion	IP- / SN	ABC-S Plus	8	20	2-Feb-10	5:55	6:00	-13.9	-8.3	-10.1	IP:25, SN:25	10	2.9, 2.3, 3	1.3, 1.8, 2.5	1, 1, 1.2	0.59	1.402	1.59	1.469	7.63
98	IP Validation	IP- / ZR-	EG106	8	20	2-Feb-10	6:36	6:41	-14.1	-6.7	-8.4	IP:25, ZR:25	10	2, 2, 2.5	1, 1, 1.3	1, 1, 1	0.705	1.501	1.691	1.299	1.76
100	Baseline	Fluid Only	EG106	8	20	3-Feb-10	N/A	2:37	-11.9	-6.3	-8.2		-	1, 1, 1	1, 1, 1	1, 1, 1	0.698	1.5	1.682	1.296	2.28
101	Baseline	Fluid Only	Launch	8	20	3-Feb-10	N/A	3:01	-11.9	-7.6	-8.4		-	1, 1, 1	1, 1, 1	1, 1, 1	0.629	1.447	1.636	1.274	4.96

4. ANALYSIS METHODOLOGY

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

4.1 Visual Contamination Ratings

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

Visual Contamination Ratings (1 to 5):

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

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

The visual contamination ratings were evaluated based on pre-determined criteria; less than or equal to 3 on the leading and trailing edge, less than or equal to 4 on the flap at the start of the test, and equal to 1 on the leading edge at the time of rotation were considered acceptable. Ratings higher than these indicated potential fluid contamination or fluid flow-off issues; these results were supported by the lift coefficient data collected.

4.2 Lift Coefficient Data

The NRC collected various parameters during each of the wind tunnel test runs. The data was collected at a rate of 250 samples per second. Parameters such as lift force, normal force, drag force, wind speed, and pitch angle were collected and used to calculate the lift, normal, and drag coefficients. For the purpose of the tests conducted, the lift coefficient was primarily used as the evaluation criteria when analysing the fluid flow-off performance during the tests. Typically, the lift coefficient varied from 0.6 and 1.7 depending on the wing angle of attack, which ranged from -2° to 8°. The calculated lift coefficient at the 6 and 8 degree rotation angles was typically evaluated against the dry wing average data. Lift losses below 5 percent compared to the dry wing were considered acceptable, and lift losses between 5 percent to 8 percent were considered marginal; additional work is being done to correlate these lift losses to the aerodynamic fluid certification results. The lift coefficient data collected as part of the ice pellet allowance time research has been included in Appendix D.

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

4.2.1 Sequence of When Test Parameters Were Recorded

Figure 4.1 demonstrates the lift coefficient data collected during an example test run. The x-axis shows the time in seconds as of the start of the test; rotation begins at approximately 28 seconds, the wing rotates to a maximum angle of 8 degrees in approximately 3.7 seconds, and then it is rotated back to 4 degrees over a period of approximately 16 seconds. The y-axis indicates the calculated lift coefficient. The visual observations of the condition of the wing were recorded at the start of the test (time = 0), just before the start of rotation (time = 28 sec.), at the end of the rotation (time = 32 sec.), and at the end of the test (time = 60 sec.). The lift coefficient data used to calculate lift losses compared to the baseline test (typically the dry wing case) was measured at the 8° angle of rotation.

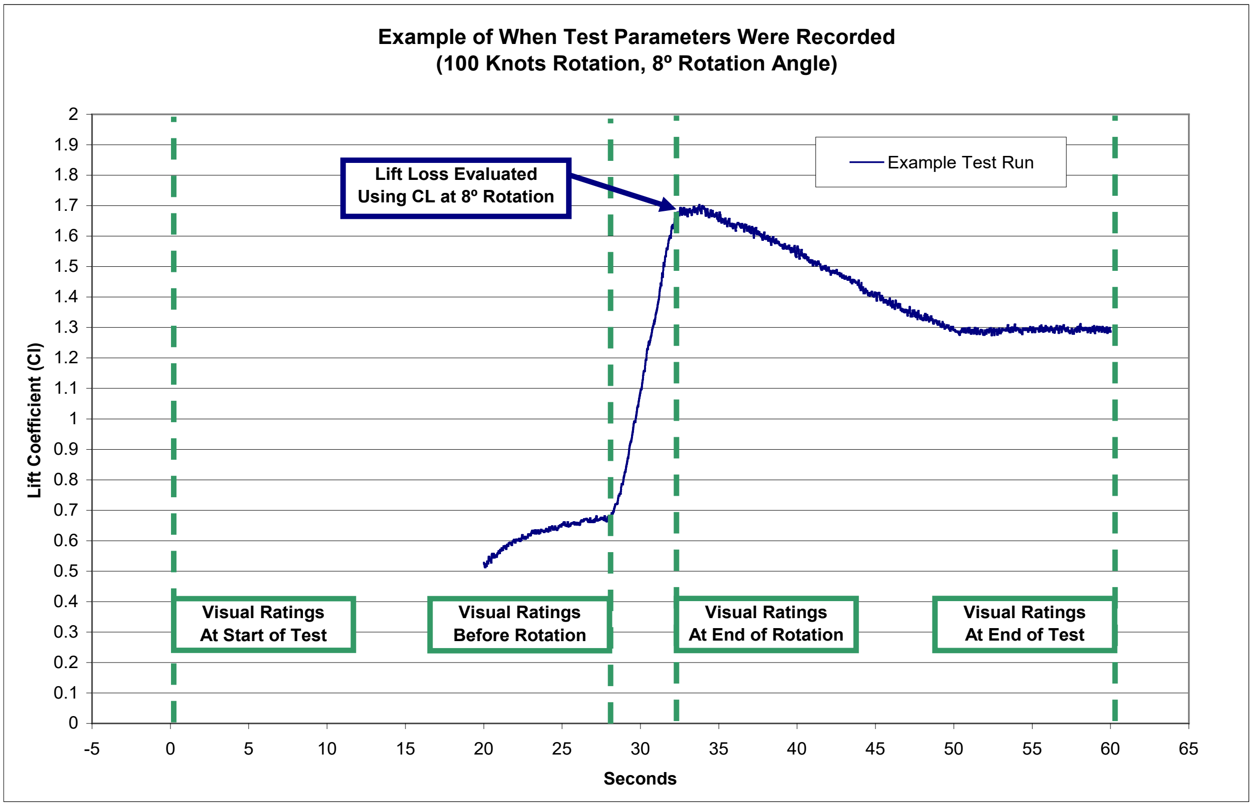

Figure 4.1: Example of When Test Parameters Were Recorded

4.3 Analysis Summary Worksheets

Due to the large amount of data to be processed for each of the tests conducted, analysis worksheets were developed and completed for each of the tests to provide a summary regarding the status of each test. Figure 4.2 demonstrates a typical worksheet.

Each worksheet comprised eleven rows: the first three rows indicated the basic test information, such as test objective, fluid, and test number. The next four rows evaluated test parameters, such as the tunnel temperature before the start of the test, rate of precipitation, and exposure time of precipitation, and provided a link to the associated fluid only case. The following three rows then evaluated the primary evaluation data collected during the test, which included visual contamination ratings at the start of the test and time of rotation, calculated lift coefficient at 6 and 8 degree rotation, and the calculated lift loss at 8 degree rotation. Lastly, an overall status summarizing the test was provided in the final row.

Objective	IP VALIDATION	
Fluid	EG106 (EG)	
Test # / Test Plan #	RUN 80 (P28)	
OAT	TARGET: -25°C ACTUAL: -17°C OK	
Rate	IP=25 GOOD	
Exposure Time	30 MINS GOOD	
Associated Fluid Only Case	RUN 75 (E24): 4.08%	
Visual Contamination	START: 2.5/2.2/3 ROT: 1/1.25/1.7 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.480 8°: 1.670 GOOD	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } 5% ***** 8° Cl should be >=1.64 } 5% ***** 6° Cl should be >=1.40 } 8% ***** 8° Cl should be >=1.59 } 8%
Lift Loss At 8°	2.98% GOOD	
OVERALL STATUS (good, bad, or review)	GOOD	

NOTE: For the purpose of the worksheets, OAT refers to the Tunnel Temperature Before the start of the test.
This applies for all analysis worksheets included in Appendix E.

Figure 4.2: Typical Worksheet Used for Analysis

The evaluation grades included "very good," "good," "good/review," "fair," and "bad," and they were determined based on whether the criteria satisfied the test objective requirements or not. In the case of the tunnel temperature before the start of the test, Rate, and Exposure Time, these parameters were compared against the target parameters determined from the test plan (i.e., a colder temperature than the target would constitute a more conservative test and was therefore "good," whereas a warmer temperature would be "fair" or "bad"). The visual contamination ratings were evaluated based on pre-determined criteria; less than or equal to 3 on the leading and trailing edge and less than or equal to 4 on the flap at the start of the test were considered "good" or "very good," and equal to 1 on the leading edge at the time of rotation was also considered "good" or "very good." The calculated lift coefficient at the 6 and 8 degree rotation angles was evaluated against the corresponding 5 percent lift loss cut-off (as described in Subsection 5.8). The overall status provided a summary of the test and indicated whether or not the test objective was met with successful results.

A complete set of the analysis summary sheets for the ice pellet allowance time objectives has been included in Appendix E and separated according to test objectives.

4.4 Comparison of Test Methodologies

4.4.1 Methodology Used for 2006-07 vs. 2008-09

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

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

4.4.2 Methodology Used for 2009-10 vs. 2008-09

During the 2009-10 testing, the lift data collected by the NRC was provided to APS at the end of each test run, and as in 2008-09, testing was monitored in real-time. Due to some software upgrades, preliminary analysis was done following each test run during the winter of 2009-10, which provided guidance when modifying the test plan on site. The analysis methodology and criteria used to evaluate each test during the winter of 2009-10 were essentially the same as those used during the winter of 2008-09.

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5. ADDITIONAL ANALYSIS OF TEST PARAMETERS AND TESTING METHODOLOGIES USED

This section describes the additional analysis performed in order to support and substantiate the analysis methodologies used to evaluate the tests conducted (as described in Section 4).

5.1 Tunnel Measurement Repeatability

The testing methodology in the wind tunnel was based on comparative test runs; therefore, it was necessary to evaluate the repeatability of the tests to validate the comparative test methodology. A comparison of similar test runs conducted in the wind tunnel with contaminated and uncontaminated fluid was performed. The lift coefficient data collected by the NRC was superimposed to identify any potential differences in the results obtained. Figure 5.1 demonstrates a comparison of two light ice pellet allowance time tests conducted in comparable conditions. The x-axis shows the time in seconds as of the start of the test; rotation begins at approximately 33 seconds, the wing rotates to a maximum angle of 8 degrees in approximately 3 seconds, and then it is rotated back to 4 degrees over a period of approximately 16 seconds. The y-axis indicates the calculated lift coefficient. Similar graphs were compiled for uncontaminated fluid only cases. Figures 5.2 and 5.3 demonstrate the comparison of the data collected for Type IV propylene glycol (PG) (two test runs) and Type IV ethylene glycol (EG) fluids (three test runs), respectively.

In all three figures (Figures 5.1 to 5.3), the data demonstrate that there was very little difference in the results obtained during the individual comparative tests. Each set of tests demonstrates a similar aerodynamic improvement as the fluid sheds prior to rotation, and an almost identical lift coefficient profile following the time of rotation. During sets of tests with varying air conditions (i.e., OAT, humidity), differences were observed and are primarily due to the differences in fluid dynamics and the resulting effects on aerodynamic performance. In general, the uncontaminated and the contaminated fluid test runs demonstrated a good repeatability, which adds confidence to the results obtained during the testing.

In addition, a dry wing test run was conducted at the start of each test day to ensure that the recorded baseline dry wing data had not changed; the integrity of the measurement capabilities was monitored by the NRC. Figure 5.4 demonstrates the CL data collected during five dry wing runs conducted with similar test parameters (i.e., rotation speed and max rotation angle). As is demonstrated, all five lift profiles are superimposed with little variation, indicating minimal scatter in the data collected.

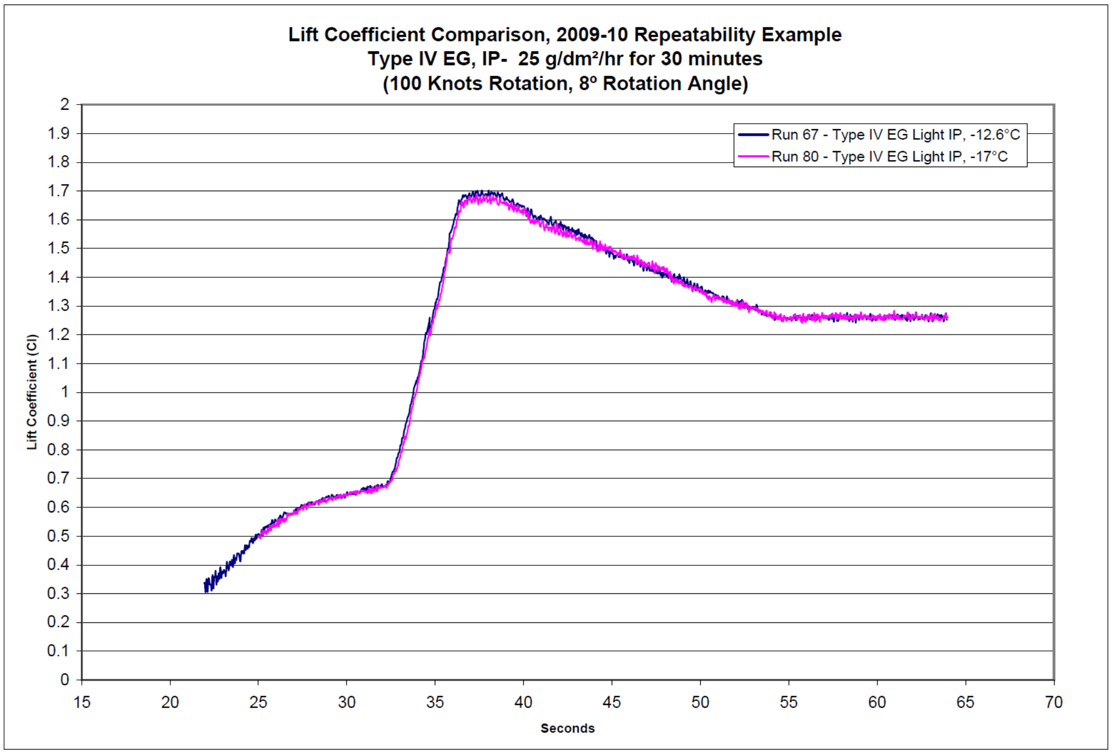


Figure 5.1: Lift Coefficient Repeatability Example for IP-

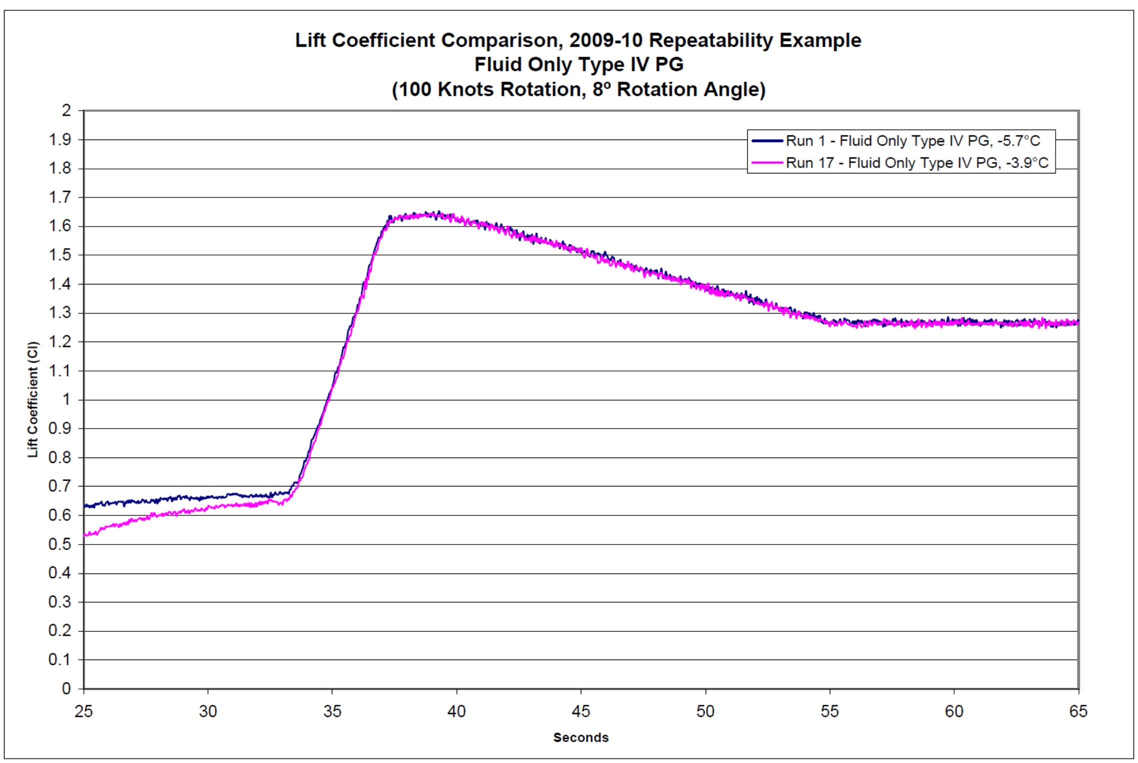


Figure 5.2: Lift Coefficient Repeatability Example for Type IV PG Fluid Only

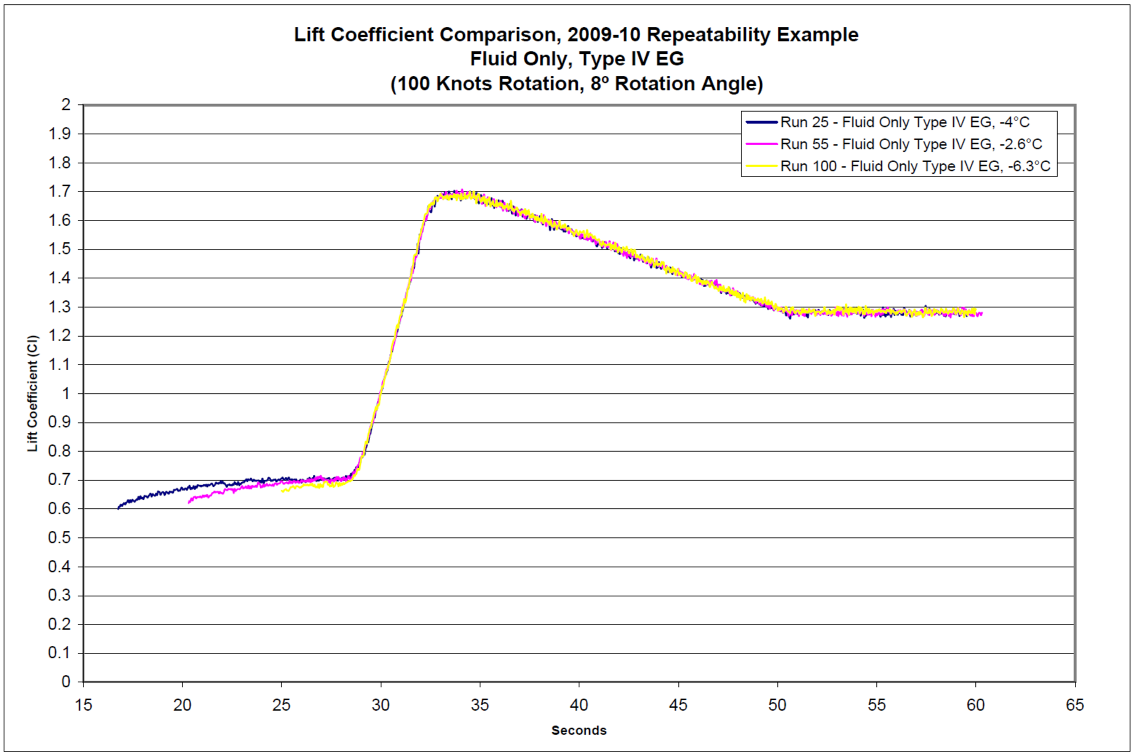


Figure 5.3: Lift Coefficient Repeatability Example for Type IV EG Fluid Only

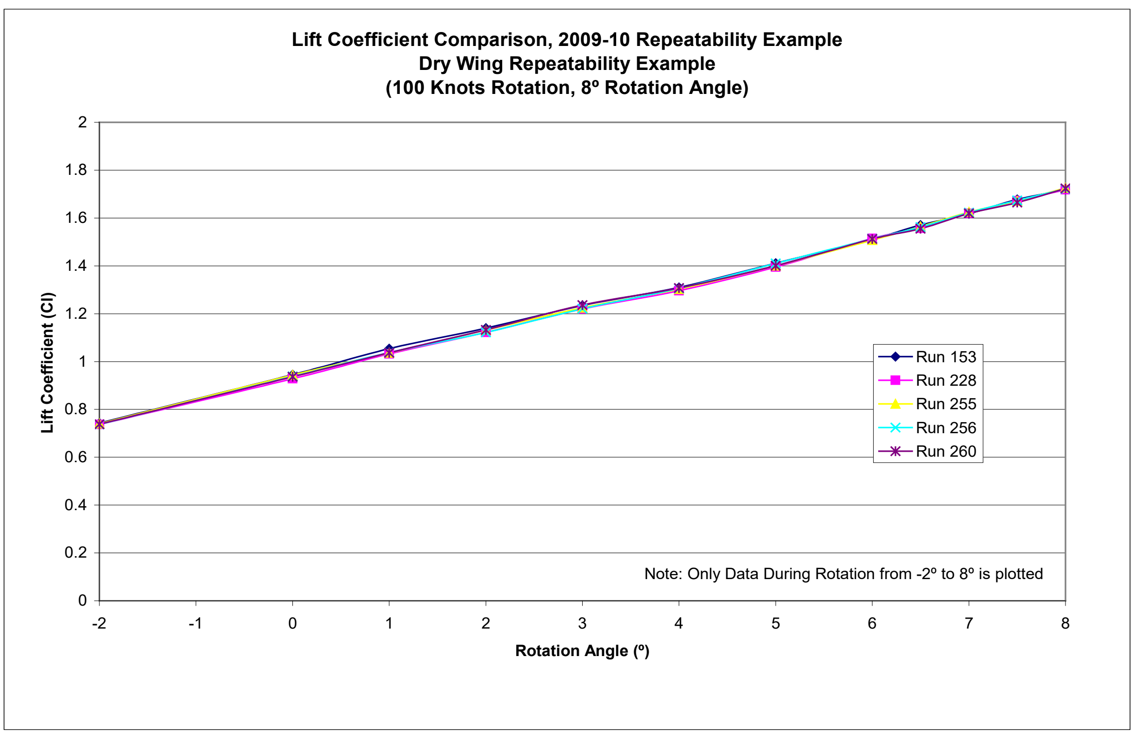


Figure 5.4: Dry Wing Lift Coefficient Repeatability Example

5.2 Comparison of Experimental vs. Simulated Lift Profile

Prior to the start of testing, the NRC conducted extensive testing to calibrate the wind tunnel. One task was to compare the actual experimental lift profile curve to the theoretical curve developed analytically by the airframe manufacturer through simulation. Figure 5.5 demonstrates the comparison of the lift coefficient curves obtained by the NRC calibration and by the simulation analysis. The results indicated that the wing performance in the wind tunnel was as expected, and the slope of the curve closely matched the simulation results. Based on the opinions of the aerodynamicists at the NRC and the airframe manufacturer, the discrepancies in the simulated versus actual results are associated with 2D versus 3D effects. It was determined that these differences would not affect the testing results, as the allowance time testing was comparative and based on the delta differences when comparing dry wing versus fluid only versus fluid and contamination lift performances and not based on the absolute value of the lift coefficient.

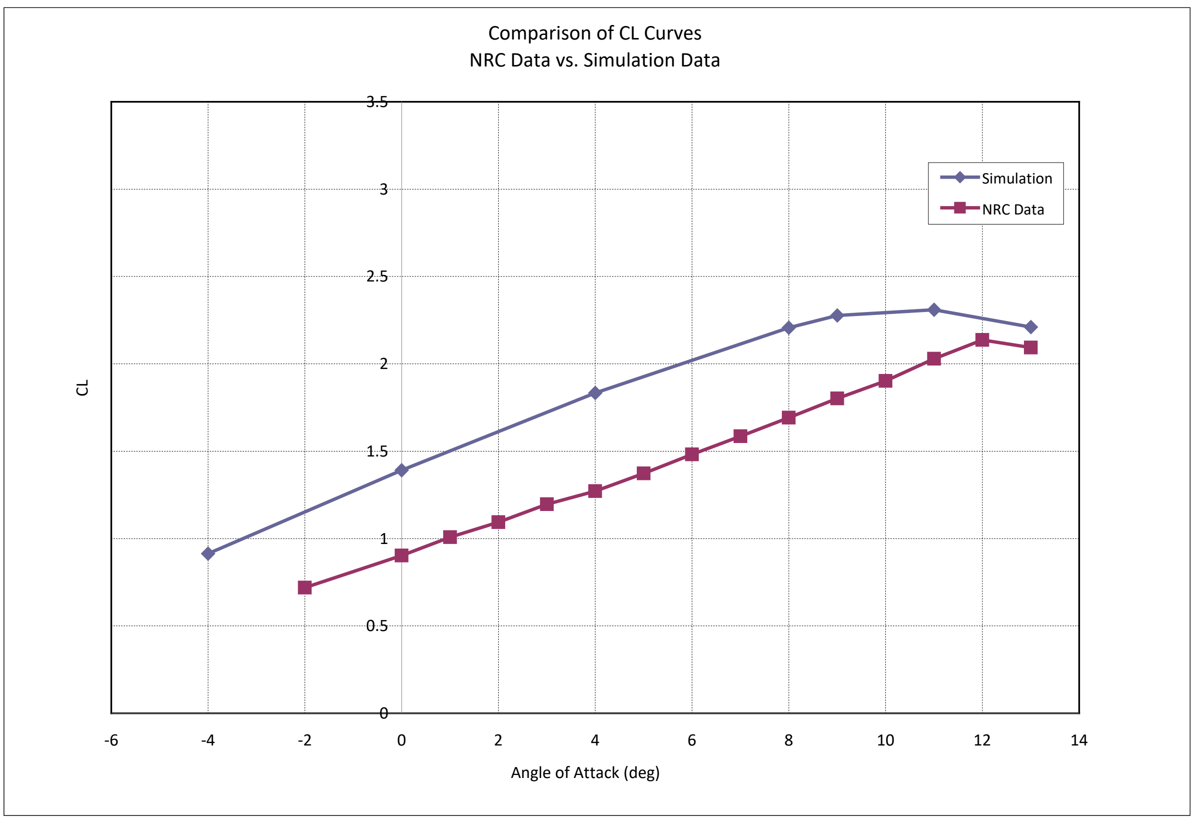


Figure 5.5: Comparison of Experimental vs. Simulated CL Data

5.3 Regression Analysis of Lift Coefficient Data vs. Visual Contamination Ratings

The following analysis was performed to identify any potential link between the lift coefficient data collected and the visual contamination ratings recorded by the observers. The objective was to determine if a regression equation could be developed and used to estimate lift loss of a typical wind tunnel run using only visual contamination ratings taken during the test.

5.3.1 Methodology

A multi-variable linear regression was performed using the 2009-10 wind tunnel data collected specific to EG106, Launch, and ABC-S+. The data included baseline fluid only cases and fluid and precipitation cases (IP allowance time tests) conducted during high-speed 8° takeoff profiles and included flap up and flap down tests. Some data was eliminated due to irrelevance, primarily R&D type tests that were not representative.

For each case studied, the visual ratings at the start of the test and at the time of rotation, along with the wing area temperature, were regressed against the lift loss calculated based on the CL data collected. The following are the details of the parameters studied:

Y-Output:

- Lift Loss (%) as calculated from the dry wing

X-Input:

- Visual Rating at Start of the Test
    - Leading Edge (LE Start)
    - Trailing Edge (TE Start)
    - Flap (FL Start)
- Visual Rating at the Time of Rotation
    - Leading Edge (LE ROT)
    - Trailing Edge (TE ROT)
    - Flap (FL ROT)
- Tunnel Air Temperature at Start of Tunnel (TAT)

Parameters were sequentially eliminated based on the p-value calculated; parameters with a calculated p-value greater than 0.05 were eliminated, and the regression analysis was re-calculated. Two regression outputs were of particular interest:

- When all remaining parameters had a p-value of less than 0.05; and
- The last remaining parameter of strongest significance to the regression calcualtion.

Two additional studies were performed. The first analysis was with EG106, which included only the visual rating at the start of test and the wing area temperature, the purpose of which was to identify the potential to predict lift loss based on the visual condition of the wing prior to takeoff. The second was conducted with both Launch and ABC-S+ data to identify any potential relationship among PG fluids.

Note: This regression analysis was conducted prior to the final review of the data collected. Following the end of testing, the NRC re-issued the lift loss data, which had been adjusted slightly for various experimental parameters. Although the adjusted data was not used for this analysis, the general trends and conclusions are still valid; the modifications made to the data were generally consistent among all tests.

5.3.2 General Observations

The following sections describe the observations from the analysis conducted. A summary table of these results isincluded in Table 5.1.

5.3.2.1 EG106

The EG106 analysis identified the TE Start, LE ROT, FL ROT, and TAT as the significant parameters in the regression analysis. The R-square value calculated was 0.99, which indicates a strong relationship between visual observations recorded and the lift loss calculated. When all other parameters were eliminated, the LE ROT observation remained the parameter of the strongest significance. The R-square value for this single parameter analysis case was still very good, with a value of 0.96.

The results indicated that the visual observations at the time of rotation, particularly the LE ROT, were of particular importance in the assessment of lift loss.

Table 5.1: Summary of Regression Coefficients - Analysis Results

Observation	EG106	Launch	ABC-S+	EG106 (Start and TAT)	Launch and ABC-S+
	Multi Variable Analysis Best Fit				
LE Start				7.05	
TE Start	-1.13	2.16	3.31		1.65
FL Start		-3.73	-2.22	-2.04	-1.61
LE ROT	6.80		1.22		1.46
TE ROT		11.48			1.6
FL ROT	0.85		2.42		1.92
TAT	-0.13		-0.17		-0.17
Intercept	-4.52	-5.36	-1.13	-4.72	-1.44
R-Square	0.99	0.82	0.83	0.63	0.8
	Single Variable Analysis Best Fit				
LE Start				4.83	
TE Start					
FL Start					
LE ROT	6.51				
TE ROT		4.39			
FL ROT			2.05		2.15
TAT					
Intercept	-3.88	-0.31	3.10	-6.32	2.65
R-Square	0.96	0.51	0.48	0.53	0.46
Note: Coefficients denote the variables of most significance to the regression analysis.					
Lift Loss = Intercept + 7 Variables * Coefficients					

5.3.2.2 EG106 – Using Only Visual Observations at Start and TAT

The EG106 analysis using only visual observations at start and TAT identified the LE Start and FL Start as the significant parameters in the regression analysis. The R-square value calculated was 0.63, which is significantly less when compared to the previous analysis using observations at the start and at the time of rotation. When all other parameters were eliminated, the LE Start observation remained the parameter of the strongest significance. The R-square value for this single parameter analysis case was still low at 0.53.

The results indicated that using only the visual observations at the start of the test does not provide a reliable means of determining the lift losses at the time of rotation.

5.3.2.3 Launch

The Launch analysis identified the TE Start, FL Start, and TE ROT as the significant parameters in the regression analysis. The R-square value calculated was 0.82, which indicates a good relationship between visual observations recorded and the lift loss calculated. When all other parameters were eliminated, the TE ROT observation remained the parameter of the strongest significance. The R-square value for this single parameter analysis case was low, with a value of 0.51.

Similar to EG106, the results indicated that observations at the time of rotation were of particular importance in deriving a regressions correlation. As compared to EG106, the TE ROT visual observation was of most importance as compared to the LE ROT.

5.3.2.4 ABC-S+

The ABC-S+ analysis identified the TE Start, FL Start, LE ROT, FL ROT, and TAT as the significant parameters in the regression analysis. The R-square value calculated was 0.83, which indicates a good relationship between visual observations recorded and the lift loss calculated. When all other parameters were eliminated, the FL ROT observation remained the parameter of the strongest significance. The R-square value for this single parameter analysis case was low, with a value of 0.48.

Similar to EG106 and Launch, the results indicated that visual observations at the time of rotation were of particular importance in deriving a regressions correlation. Compared to EG106 and Launch, the FL ROT visual observation was of most importance compared to the LE ROT and TE ROT, respectively.

5.3.2.5 Launch and ABC-S+

An analysis was conducted by grouping both Launch and ABC-S+ to identify if any conclusions could be drawn for PG fluids in general. The Launch/ABC-S+ analysis identified the TE Start, FL Start, LE ROT, TE ROT, FL ROT, and TAT as the significant parameters in the regression analysis. The R-square value calculated was 0.80, which indicates a good relationship between visual observations recorded and the lift loss calculated. When all other parameters were eliminated, the FL ROT observation remained the parameter of the strongest significance. The R-square value for this single parameter analysis case was low, with a value of 0.46.

Results of this analysis were similar to the ABC-S+ alone analysis. This is likely a result of the greater number of tests conducted with ABC-S+ versus Launch, therefore, the analysis was weighted more towards ABC-S+.

5.3.3 Conclusion

The analysis identified a good correlation between the visual observations recorded during the tests and the lift losses calculated based on the lift coefficient data collected; this is particularity true for visual observations taken at the start of rotation. EG106 generated the best fit correlation, even with a single variable regression. The PG fluids, however, demonstrated more scatter in the results, likely due to the fluid flow-off issues observed at the colder temperatures. Visual observations should continue to be recorded for future wind tunnel testing, as they have proven to be of value as an analysis tool.

5.4 Regression Analysis of Lift Loss vs. Leading Edge Visual Rating at Rotation

Similar to the previous section, a more in-depth and thorough analysis was performed to identify any potential link between the lift coefficient data collected and the visual contamination ratings recorded by the observers: more specifically, the visual rating of the leading edge at the time of rotation. The objective was to determine if a regression equation could be developed and used to estimate lift loss of a typical wind tunnel run using only the leading edge visual contamination rating at the time of rotation.

5.4.1 Methodology

A multi-variable linear regression was performed using the 2009-10 wind tunnel data collected specific to EG106, Launch, and ABC-S+, as well as for all fluids grouped together. For each case studied, the leading edge visual ratings at the time of rotation along with the wing area temperature were regressed against the lift loss calculated based on the CL data collected. The following are the details of the parameters studied:

Y-Output:

- Lift Loss (%) as calculated from the dry wing

X-Input:

- Leading Edge Visual Rating at the Time of Rotation (LE ROT)

- Tunnel Air Temperature at Start of Tunnel (TAT)

The regression analysis was conducted using both the X-Inputs (LE ROT and TAT) as well as using only the Leading Edge Visual Rating at the time of Rotation.

5.4.2 General Observations

The following sections describe the observations from the analysis conducted. Figures 5.6 to 5.9 demonstrate the details of the regression analysis performed. A summary table of the R-squared values obtained from each of the analyses is included in Table 5.2.

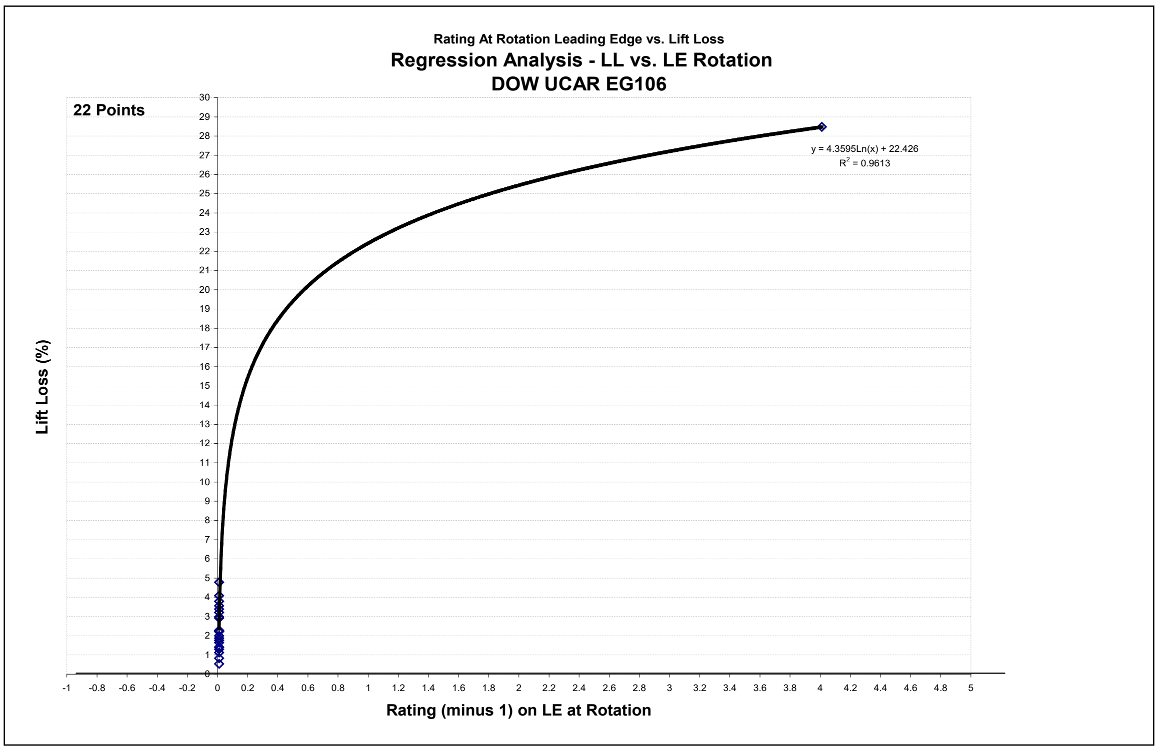


Figure 5.6: Dow UCAR EG106 - Regression Analysis of LL vs. LE ROT

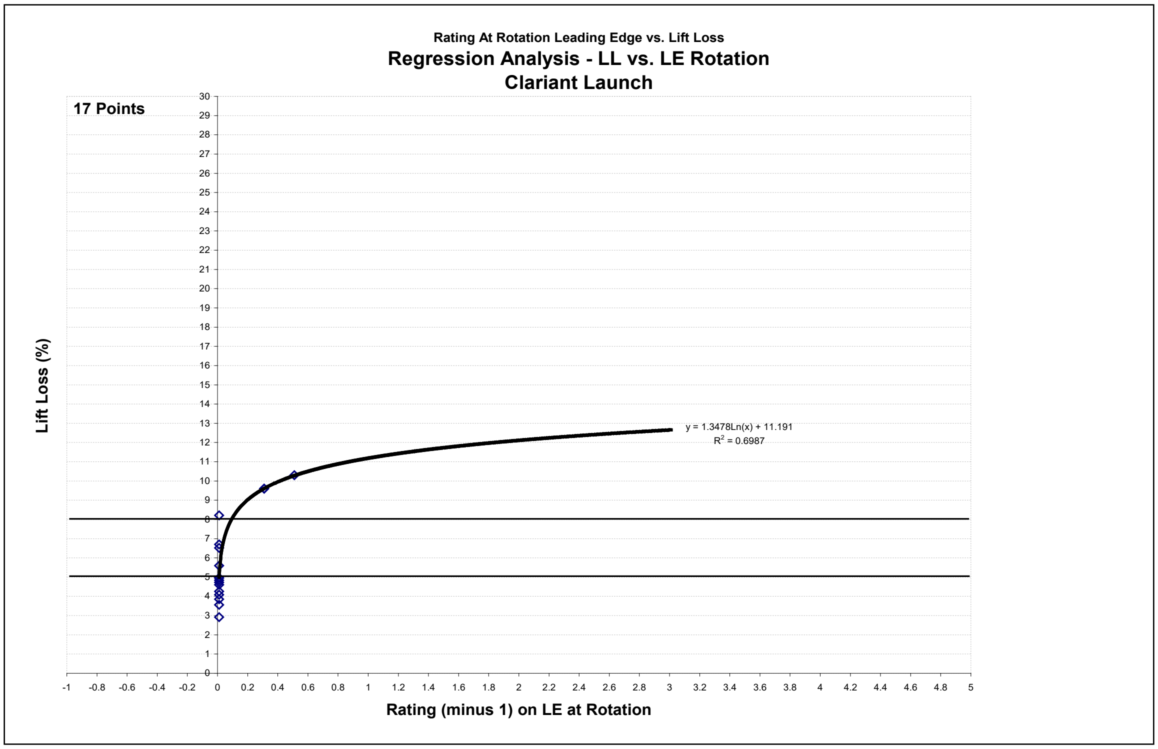


Figure 5.7: Clariant Launch - Regression Analysis of LL vs. LE ROT

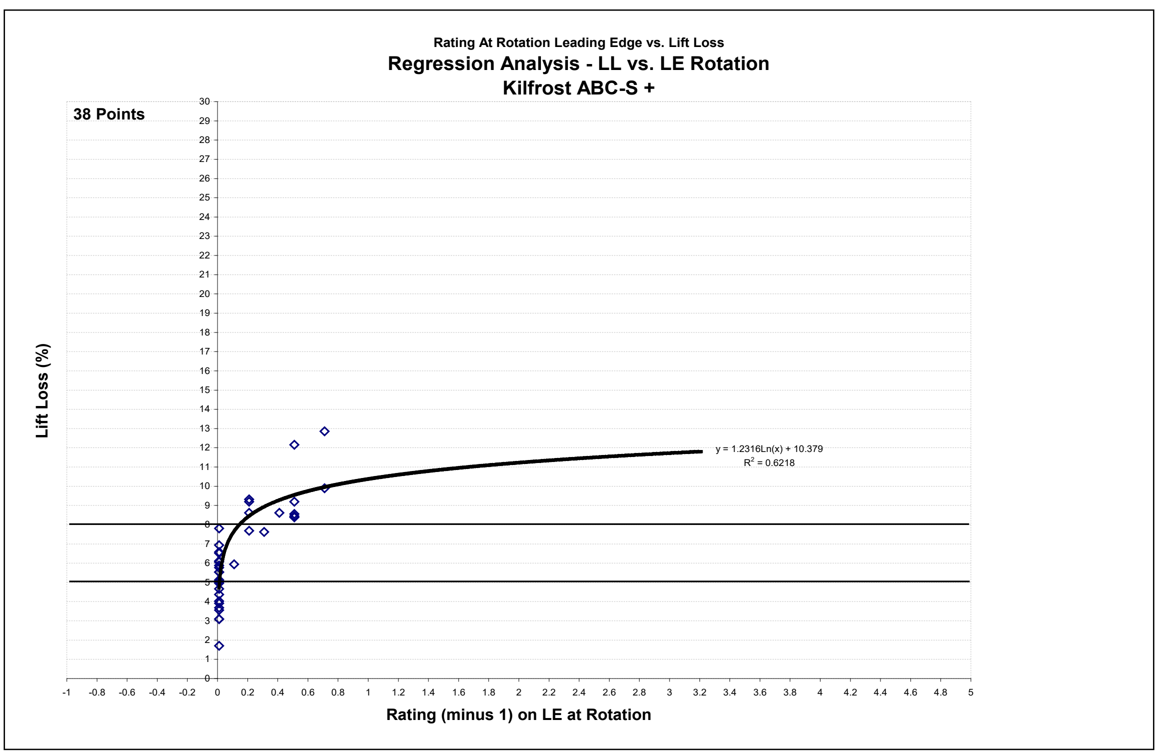


Figure 5.8: Kilfrost ABC-S＋ - Regression Analysis of LL vs. LE ROT

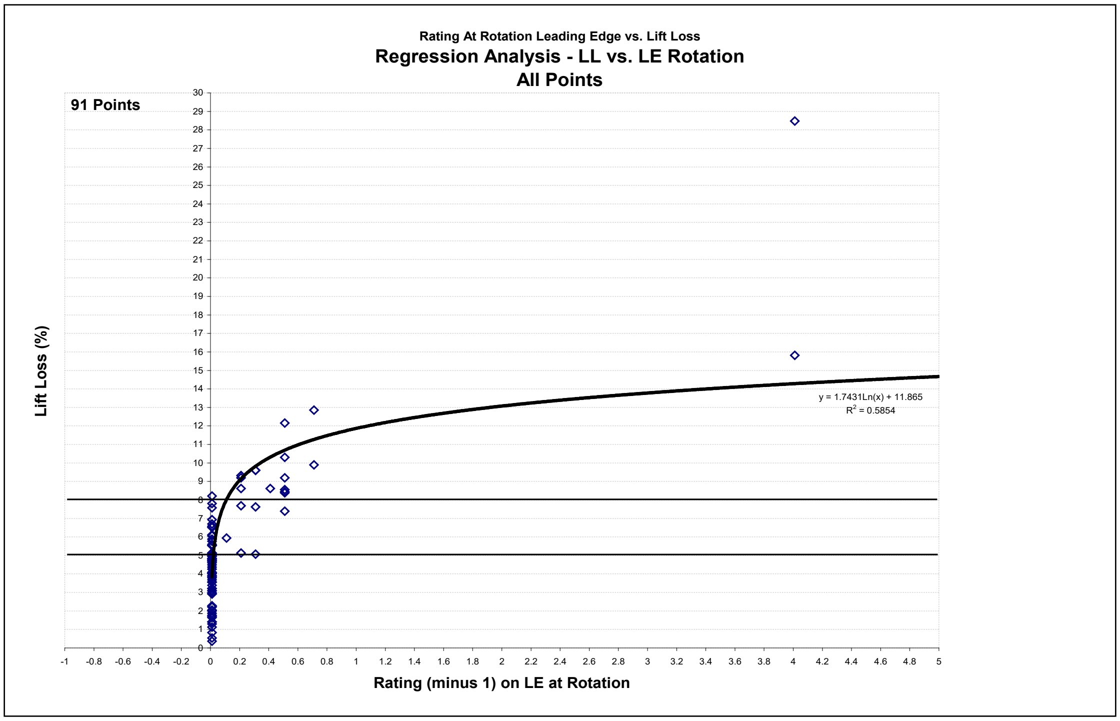


Figure 5.9: All Data Points - Regression Analysis of LL vs. LE ROT

Table 5.2: Summary of R-Squared Values from Regression Analysis

R-Squared Values *(LE ROT vs. LL Regression)*			
EG106	**Launch**	**ABC-S+**	**All Data**
0.96	0.70	0.62	0.59

The results of the analysis indicated that there was a reasonable relationship for each of the fluids when separated. The relationship improves for Launch and ABC-S+ when temperature is included in the regression as an additional variable.

5.4.3 Detailed Analysis of Data Points Selected for Regression

To better understand the variance in the results obtained, the data points were separated into seven groupings (groups A to G) based on the general trends derived from the lift loss (LL) and the rating on the leading edge (LE) at the time of rotation (Figure 5.10). These groupings were further analysed, and conclusions were made based on the results. The more detailed groupings are shown in Figures 5.11 to 5.17, and the conclusions made are indicated in each of the respective graphs.

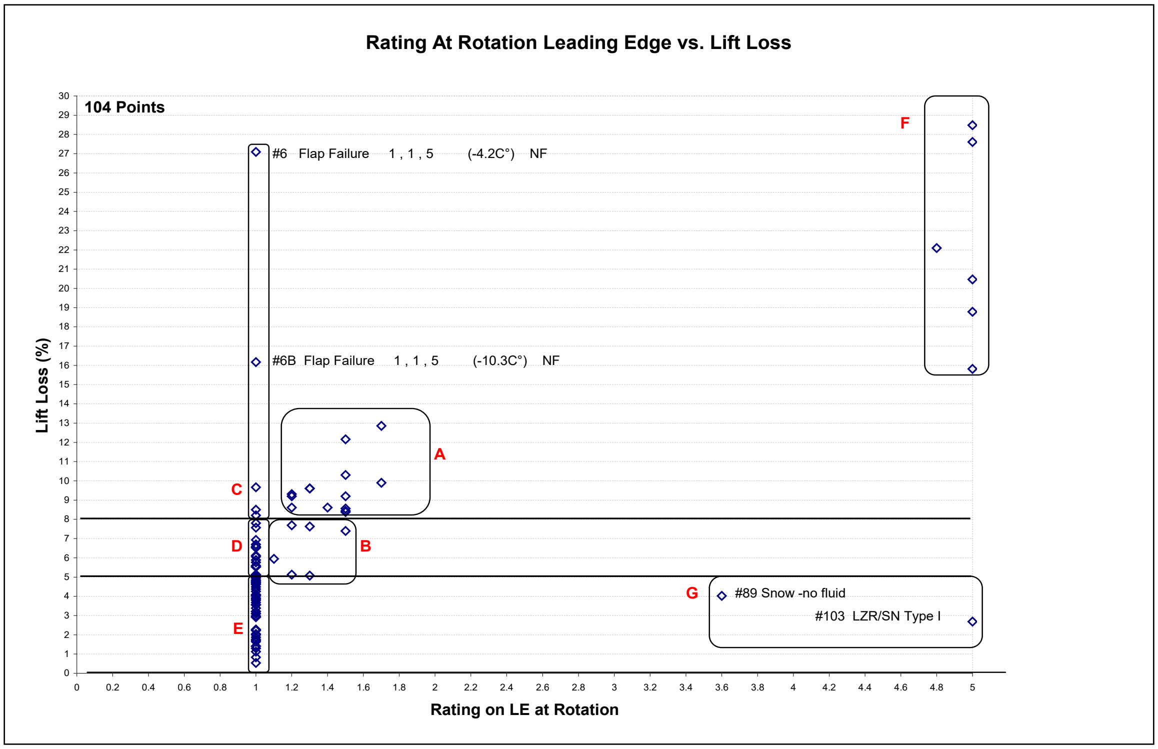


Figure 5.10: All Data – Grouping of Results Based on General Trend

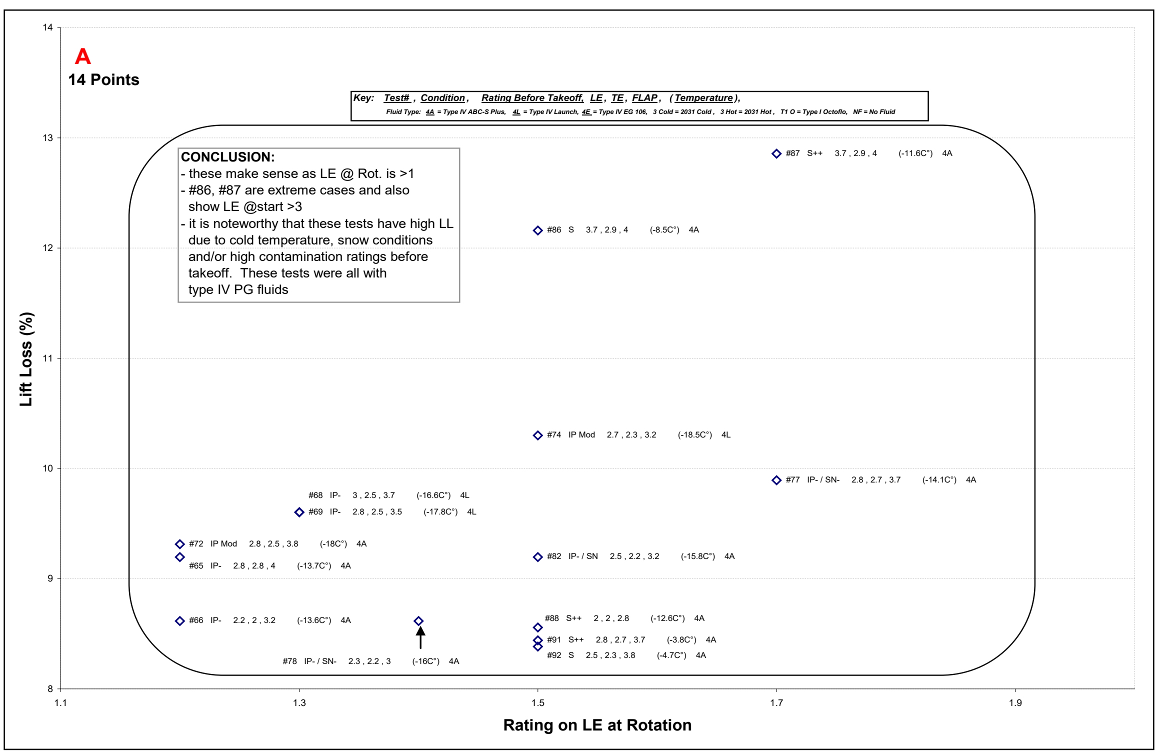


Figure 5.11: Group A – LL >8%; LE Rating >1

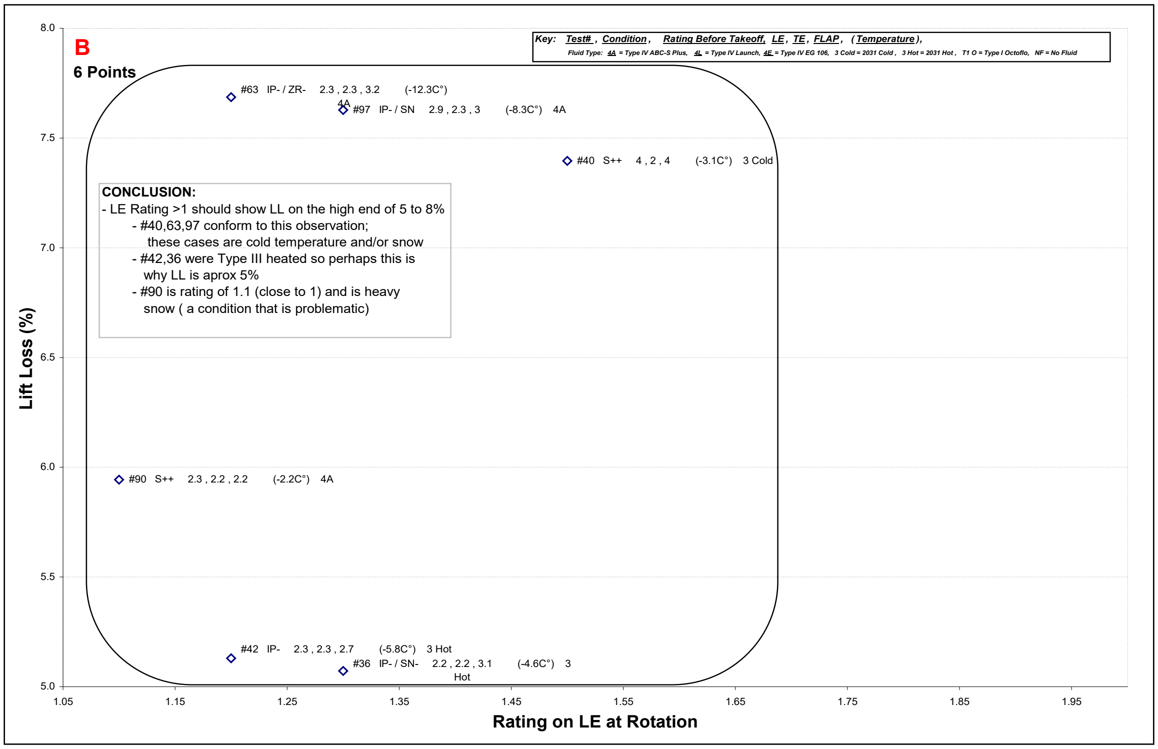


Figure 5.12: Group B – LL Between 5% and 8%; LE Rating >1

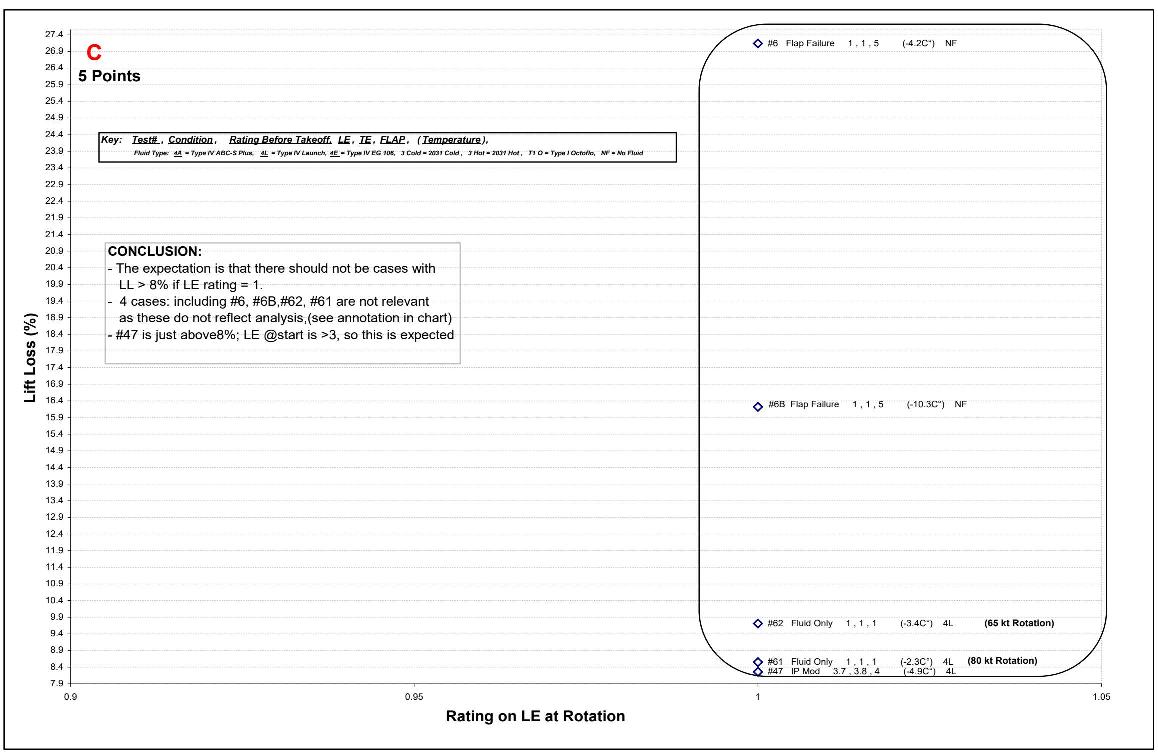


Figure 5.13: Group C – LL >8%; LE Rating =1

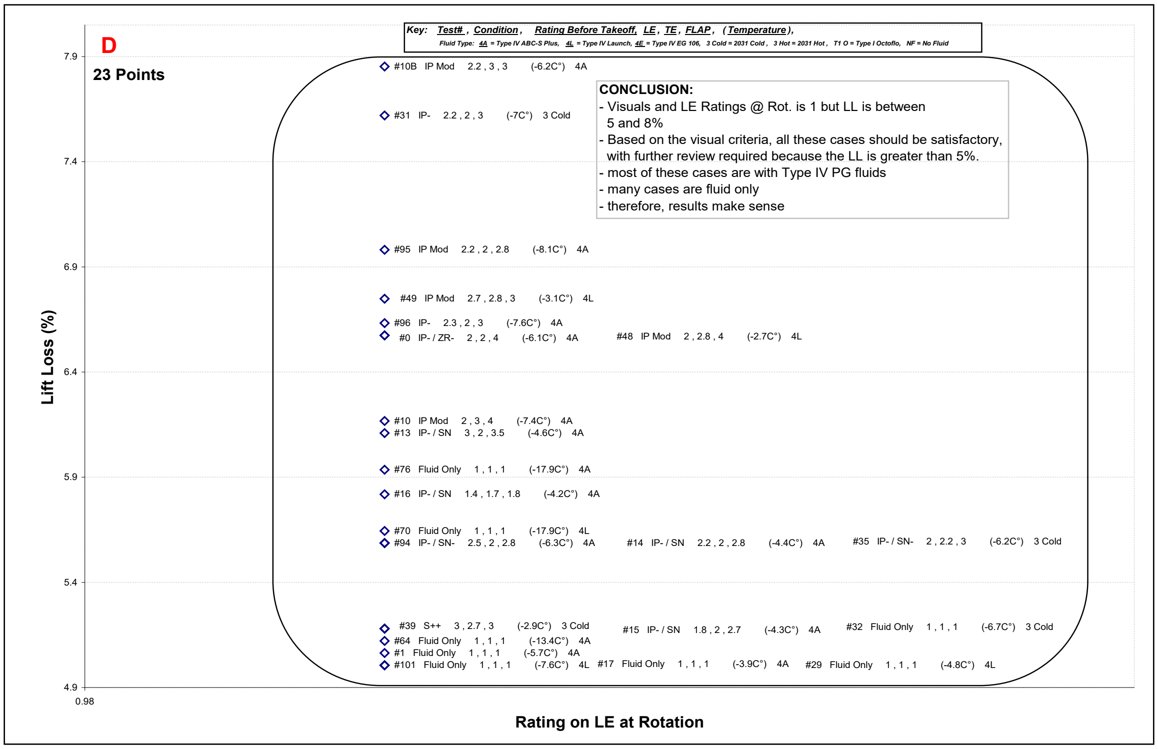


Figure 5.14: Group D – LL Between 5% and 8%; LE Rating = 1

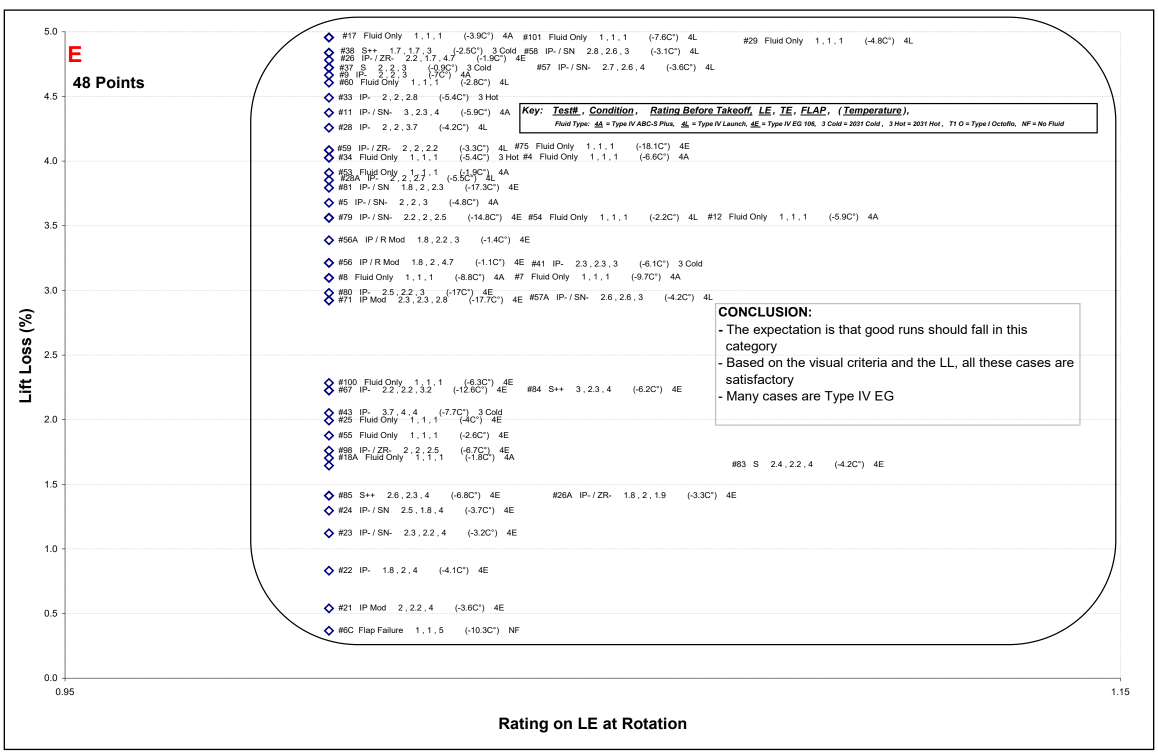


Figure 5.15: Group E – LL <5%; LE Rating = 1

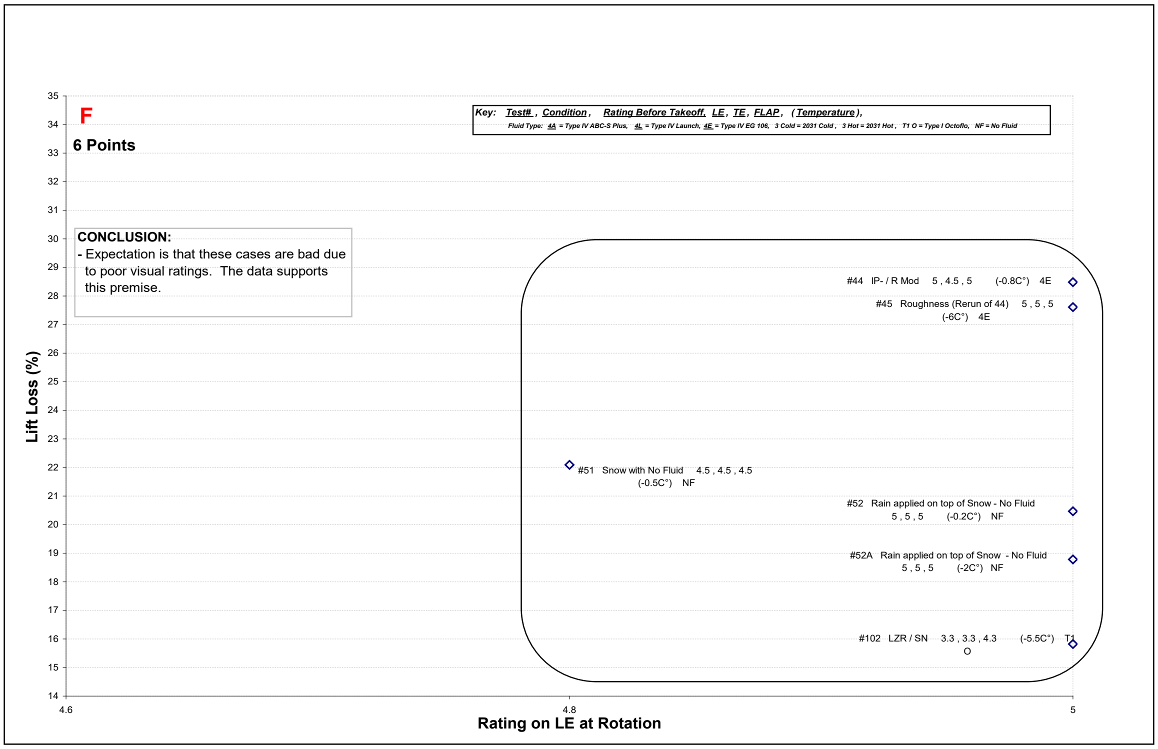


Figure 5.16: Group F – LL >15%; LE Rating >4.5

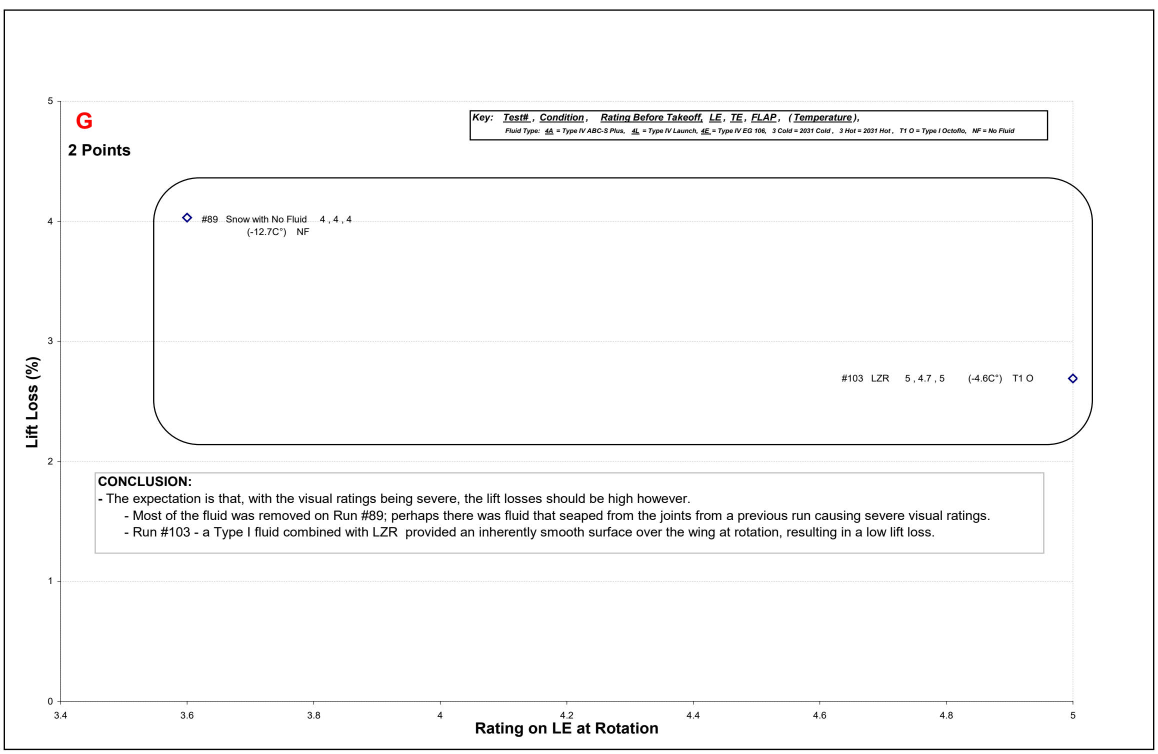


Figure 5.17: Group G – LL <5%; LE Rating >3

5.5 Effect of Wing Surface Slope on Fluid Failure Mechanism

The geometry of the supercritical wing used during the 2009-10 testing created a relatively flat and level top wing surface aft of the leading edge. The anti-icing fluid sitting on the top of the wing did not readily flow-off due to the shallow angles of the top surface. The result was that often contamination would begin to “bridge” earlier on the top surface of the wing; the fluid and contamination would not easily flow-off the wing. In comparison, a wing with more prominent top curvature, such as the wings used during the 2006-07 and 2008-09 testing (NACA 23012 and NASA LS(1)-0417, respectively) will have more fluid flow-off during exposure to precipitation and will more readily shed some contamination.

Figure 5.18 demonstrates a comparison of the wing models used for the ice pellet allowance time testing. The average slopes of the top surface of each wing model used was calculated based on the highest point on the top of the wing surface and the leading edge stagnation point and trailing edge tip. It is apparent that the supercritical wing model has a much shallower leading and trailing edge, which explains the behaviour of the fluid “sitting” on the top surface on the wing and not easily flowing off.

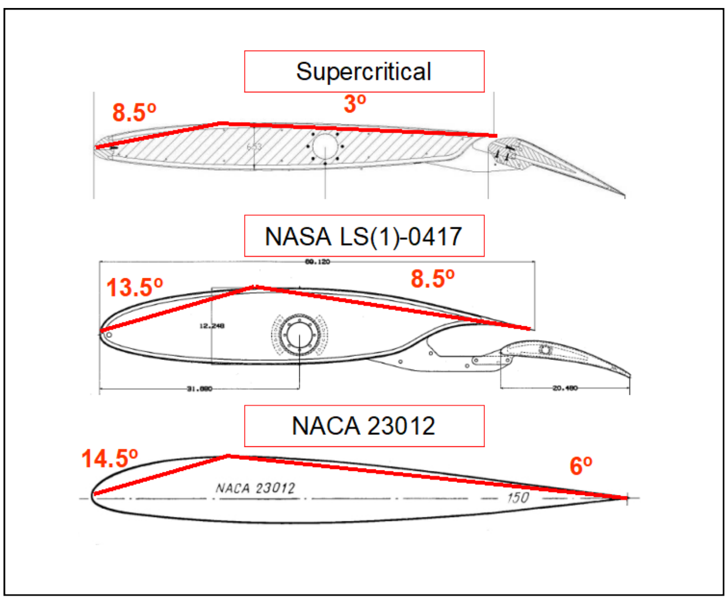


Figure 5.18: Comparison of Wing Models Used for Ice Pellet Allowance Time Testing

5.6 Analysis of Associated Test Temperature Used for Development of Allowance Times

When testing in the wind tunnel, temperature fluctuations during a test run are inevitable. The presence of personnel, test equipment, lighting, and the opening and closing of the tunnel doors cause the wind tunnel test section to warm up by several degrees. This is especially true during calm wind conditions; typically, during higher wind conditions, the wind blows through the wind tunnel and continually cools the test section. This phenomenon causes some complications when choosing the appropriate air temperature to associate with the test during analysis.

During the winter of 2006-07, the 10-minute average of the air temperature (measured using a probe attached to the tunnel wall well above the wing) prior to the start of the takeoff run was used as the associated test temperature; the average was taken to compensate for large temperature fluctuations. Over the years, procedural improvements and personnel training have drastically decreased the time required for setup and teardown for each test, minimizing the tunnel warming phenomenon experienced. In addition, a new probe was installed onto the wing end plates in 2008-09 located directly above the wing section. When analyzing the 2008-09 data, the instantaneous temperature reading just prior to the start of the test was deemed appropriate and was used for the analysis. The same methodology was used for the winter of 2009-10; therefore, an analysis was conducted to verify any potential differences in using the instantaneous temperature versus using the 10-minute average temperature, both of which were recorded using the probe located above the wing. Table 5.3 shows the 2009-10 results for a representative selection of tests. Table 5.4 compares the differences in instantaneous versus 10-minute average air temperature for the 2006-07 versus 2009-10 testing.

The results from Table 5.3 indicated that during the 2009-10 testing, the differences in the two recorded temperatures were minimal; therefore, using the instantaneous temperature was appropriate and facilitated real-time analysis. The results from Table 5.4 demonstrate that during the 2006-07 testing, there was a larger difference between the instantaneous and 10-minute average air temperatures during the test due to the factors mentioned during the 2006-07 analysis; however, this was no longer necessary following the procedural improvements and relocation of the temperature probe. The conclusion of this analysis indicates that the instantaneous air temperature prior to the start of the takeoff run is both representative and appropriate for use in the data analysis.

Table 5.3: Comparison of Instantaneous vs. 10-Minute Average Air Temperature During Wind Tunnel Tests

Test #	Instantaneous Temp. Before Start of Test Run °C (WT 2009-10)*	Temp. 10 min AVG Before Start of Test Run °C (WT 2009-10)**	Temperature Difference °C
0	-6.1	-6.3	-0.2
10	-7.4	-7.3	0.1
10B	-6.2	-6.3	-0.1
15	-4.3	-4.3	0
47	-4.9	-4.6	0.3
56	-1.1	-0.6	0.5
56A	-1.4	-0.1	1.3
57	-3.6	-3.7	-0.1
63	-12.3	-11.9	0.4
65	-13.7	-13.1	0.6
68	-16.6	-16.4	0.2
72	-18.0	-18.3	-0.3
94	-6.3	-6.6	-0.3
95	-8.1	-8.6	-0.5
96	-7.6	-7.8	-0.2

AVG	0.1
STD DEV	0.46

*NRC Wing Area RTD Temperature Before Start of Test Run

**NRC Wing Area RTD Temperature 10 Minutes Before Start of Test Run

Table 5.4: Comparison of 2006-07 vs. 2009-10 Difference Between Instantaneous and 10-Minute Average Air Temperature During Wind Tunnel Tests

Test #	Temp. Difference Between Instantaneous & Temp. During Last 10 Min. of Precip. (WT 2006-07)
4	1
5	5
6	0
6A	-0.5
SP1	0.5
SP2	-2
SP3	-1
SS7	0.5
7	0
8	-1
9	1
SP4	-1.0
10	3
11	-1
12	3
AVG	0.5
STD DEV	1.9

Test #	Temp. Difference Between Instantaneous & Temp. 10 Min. Before Start of Test Run (WT 2009-10)
0	-0.2
10	0.1
10B	-0.1
15	0
47	0.3
56	0.5
56A	1.3
57	-0.1
63	0.4
65	0.6
68	0.2
72	-0.3
94	-0.3
95	-0.5
96	-0.2
AVG	**0.1**
STD DEV	**0.5**

5.7 Analysis of NRC vs. APS Recorded Wing Skin Temperature

During the winters of 2006-07 and 2008-09, APS manually recorded skin temperature measurements using a hand-held probe at select locations on the wing along one chord length (typically in the middle). When constructing the supercritical wing model for the winter of 2009-10, APS requested that temperature sensors be installed on the underside of the wing skin. The location of the sensors is shown in Subsection 2.5.3. It was recommended that if the NRC-recorded skin temperature was similar to the measurements taken by APS, the procedure would be changed to eliminate the hand-held measurement and only use the NRC-collected data.

Early in the testing, a preliminary analysis was conducted comparing the hand-held measurements to the NRC-monitored data from the sensors located inside the wing. The data provided from both sources were comparable; therefore, the manual measurements were replaced by the data recorded by the NRC (APS recorded instantaneous data at the required intervals). The average of the two RTDs (located to the left and right of the centreline) was used for each of the four locations where temperature was typically measured.

An analysis was conducted on wing skin temperature data collected by APS and NRC personnel. Seven test runs were selected to compare the differences in temperature measurements. Temperature measurements at three locations, location 2, 5, and Underside (see Subsection 2.14), were compared. The results are presented in Table 5.5. The analysis showed that the NRC temperature data is on average 0.6°C colder than the data collected by APS personnel. It was determined that the NRC wing skin temperature data was appropriate and should be used for future testing during data collection.

5.8 Analysis of Wind Tunnel Ramp-Up Time

The NRC PIWT is an open-circuit wind tunnel with a fan located at the tunnel entry. The fan is driven by a gas turbine, which allows the test section to reach wind speeds of 100 knots. The gas turbine drive is manually operated by NRC personnel and, as a result, acceleration profile and resulting ramp-up time can vary based on operator familiarity and human variances.

To investigate the variability in ramp-up time, the tests conducted as part of the ice pellet allowance time testing were analysed. A total of 66 tests were included, and the time to ramp-up from 40 knots to time of rotation (close to 100 knots) was calculated. The 40 knots was chosen as the lower cut-off speed to reduce variability in the results, as typically the initial ramp-up is slower; these lower speeds do not significantly affect the fluid (very little shear).

Table 5.5: Wing Skin Temperature Comparison – NRC vs. APS

	Run #	Wing Position	APS Temp (°C)	NRC Temp (°C)	Delta NRC-APS (-ve = NRC Colder)
Before Fluid Application	1	2	-4.5	-5.4	-0.9
		5	-5	-5.6	-0.6
		U	-5.1	-5.1	0
	4	2	-5.8	-7	-1.2
		5	-5	-6.5	-1.5
		U	-5.8	-6.8	-1
	5	2	-4.2	-4.9	-0.7
		5	-3.6	-4.4	-0.8
		U	-5	-5	0
	9	2	-4	-4.5	-0.5
		5	-3.6	-4.3	-0.7
		U	-4.4	-4.8	-0.4
	10	2	-5.3	-5.2	0.1
		5	-4.9	-6.1	-1.2
		U	-6.8	-7.1	-0.3
	11	2	-4.6	-5.3	-0.7
		5	-3.2	-4.8	-1.6
		U	-5.5	-6	-0.5
	10A	2	-6.2	-7	-0.8
		5	-6.5	-6.6	-0.1
		U	-7.8	-7.8	0
After Fluid Application	1	2	-4.5	-5.5	-1
		5	-4.9	-5.1	-0.2
		U	-4.5	-5.1	-0.6
	4	2	-5.2	-5.9	-0.7
		5	-5.2	-6.5	-1.3
		U	-5.8	-6.8	-1
	5	2	-4.2	-5.3	-1.1
		5	-4.4	-6	-1.6
		U	-4.6	-5.5	-0.9
	9	2	-5	-5.9	-0.9
		5	-6.4	-7.3	-0.9
		U	-4.9	-5.2	-0.3
	10	2	-6.9	-6.9	0
		5	-7.4	-7.4	0
		U	-7.1	-7.3	-0.2
	11	2	-4.8	-5.8	-1
		5	-5.3	-5.2	0.1
		U	-5.5	-5.8	-0.3
	10A	2	-5	-5.2	-0.2
		5	-5.2	-4.7	0.5
		U	-5.5	-5.7	-0.2
Afte Precip Application	5	2	-7.8	-9	-1.2
		5	-7	-8.8	-1.8
		U	-5.2	-4.8	0.4
	9	2	-9.4	-9.7	-0.3
		5	-8.3	-10.4	-2.1
		U	-7.9	-7.7	0.2
	10	2	-11.7	-12.5	-0.8
		5	-10	-13.2	-3.2
		U	-9.7	-8.6	1.1
	11	2	-8.7	-9.1	-0.4
		5	-8	-10.3	-2.3
		U	-7.7	-7.2	0.5
	10A	2	-11	-13.2	-2.2
		5	-10	-12.2	-2.2
		U	-9.2	-7.9	1.3
After Takeoff Run	1	2	-3.6	-3.6	0
		5	-3.2	-3.7	-0.5
		U	-4.3	-4.4	-0.1
	4	2	-4.2	-4.9	-0.7
		5	-3.6	-4.4	-0.8
		U	-5	-5	0
	5	2	-3	-3.1	-0.1
		5	-2.9	-3.6	-0.7
		U	-4	-4.2	-0.2
	9	2	-6.2	-6.9	-0.7
		5	-5.5	-6	-0.5
		U	-7.5	-8.1	-0.6
	11	2	-6.2	-7	-0.8
		5	-6.5	-6.6	-0.1
		U	-7.3	-7.8	-0.5
	10A	2	-5.8	-5	0.8
		5	-4.7	-5.9	-1.2
		U	-6.7	-7	-0.3
				AVERAGE	-0.6
				STDEV	0.8

Table 5.6 shows the data used for the analysis as well as the calculated averages and standard deviation. The results indicated that on average the ramp-up time from 40 knots to rotation was 19 ± 5 seconds. The data indicated that the longer ramp-up times typically occurred during the first test runs #0-12 (likely due to operator learning curve), and Run #44 appeared to be an anomaly. The average calculated while omitting these tests was 18 ± 3 seconds; this calculated average is more representative of the testing conducted.

A frequency distribution chart of the data was developed and is shown in Figure 5.19. The chart supports the results previously calculated and shows that 53 percent of the test runs had ramp-up times below 18 seconds. These results should be taken into consideration, especially when analysing tests with fluid and contamination, because abnormally short or long ramp-up times can affect aerodynamic performance due to the resulting fluid shearing effect.

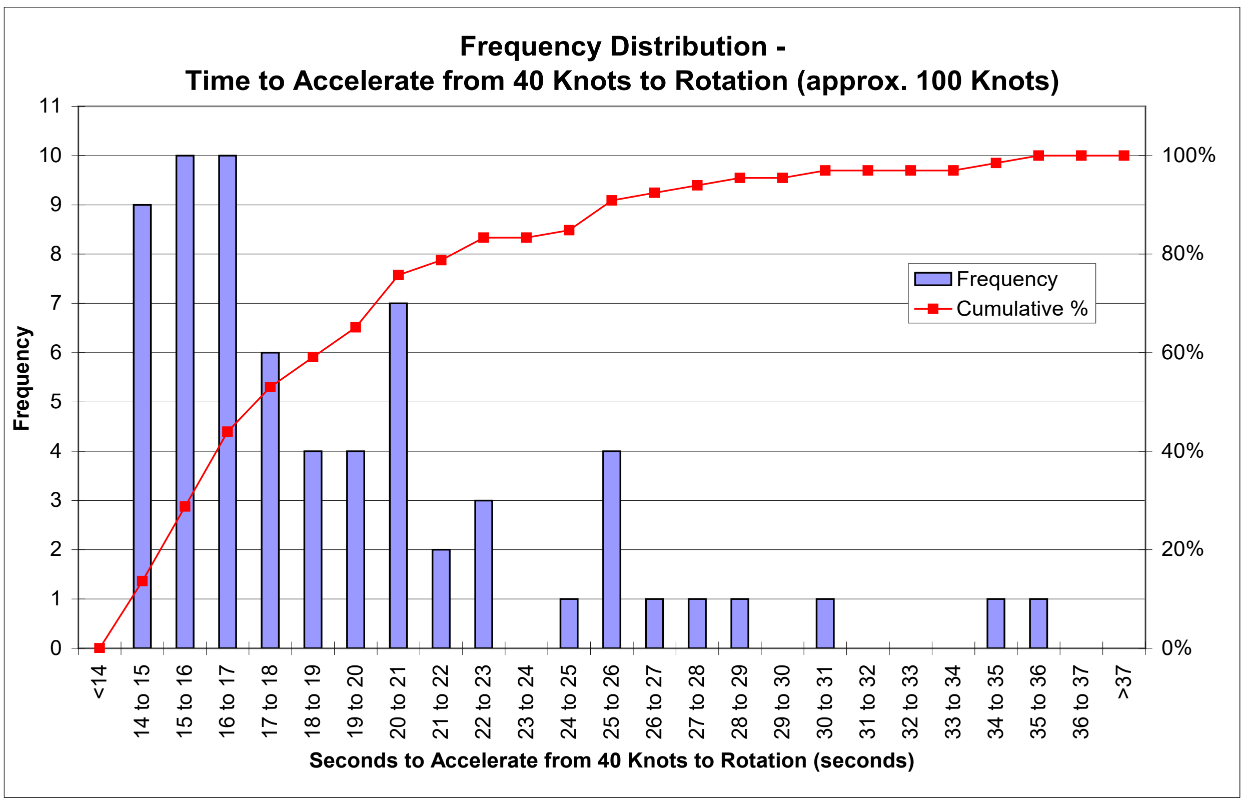


Figure 5.19: Frequency Distribution of Wind Tunnel Ramp-Up Time

Table 5.6: Analysis of Wind Tunnel Ramp-Up Time

Run #	Date	Condition	Temp. (°C)	8° Lift Loss (%)	Max Speed at Approx. Rotation (kts)	Time from 40 kts to Rotation (sec)
0	7-Jan-10	IP- / ZR-	-6.1	6.5	98	31
1		Fluid Only	-5.7	5.0	98	26
2		Dry Wing	-4.9	1.4	99	25
3	11-Jan-10	Dry Wing	N/A	-0.6	98	28
4		Fluid Only	-6.6	4.0	102	19
5		IP- / SN-	-4.8	3.7	101	21
7	12-Jan-10	Fluid Only	-9.7	3.1	101	34
9	13-Jan-10	IP-	-7	4.7	100	26
10		IP Mod	-7.4	6.1	102	27
10B		IP Mod	-6.2	7.8	102	17
11		IP- / SN-	-5.9	4.4	98	28
12		Fluid Only	-5.9	2.4	102	18
13	14-Jan-10	IP- / SN	-4.6	6.1	102	20
14		IP- / SN	-4.4	5.5	101	22
15		IP- / SN	-4.3	5.1	102	20
16		IP- / SN	-4.2	5.8	101	18
17		Fluid Only	-3.9	5.0	101	18
18A		Fluid Only	-1.8	1.7	101	21
21	20-Jan-10	IP Mod	-3.6	0.5	102	20
22		IP-	-4.1	0.8	101	20
23		IP- / SN-	-3.2	1.1	101	21
24	21-Jan-10	IP- / SN	-3.7	1.3	102	20
25		Fluid Only	-4	2.0	101	21
26		IP- / ZR-	-1.9	4.8	101	20
26A		IP- / ZR-	-3.3	1.4	101	22
28		IP-	-4.2	4.3	100	19
28A		IP-	-5.5	3.9	101	17
29		Fluid Only	-5	5.0	101	17
44	23-Jan-10	IP/ R Mod	-1	28.5	100	36
47	24-Jan-10	IP Mod	-4.9	8.2	101	23
48		IP Mod	-2.7	6.5	98	25
49		IP Mod	-3.1	6.7	101	25
53	27-Jan-10	Fluid Only	-1.9	3.9	101	17
54		Fluid Only	-2	3.6	101	22
55		Fluid Only	-3	1.9	101	17
56		IP / R Mod	-1.1	3.2	102	17
57		IP- / SN-	-3.6	4.7	101	19
57A		IP- / SN-	-4.2	2.9	101	20
58	28-Jan-10	IP- / SN	-3.1	4.8	102	17
59		IP- / ZR-	-3.3	4.1	102	17
60		Fluid Only	-3	4.6	101	20
63		IP- / ZR-	-12.3	7.7	102	16
64		Fluid Only	-13	5.1	101	16
65	29-Jan-10	IP-	-13.7	9.2	102	16
66		IP-	-13.6	8.6	102	16
67		IP-	-12.6	2.2	101	16
68		IP-	-16.6	9.6	102	16
69		IP-	-17.8	9.6	102	16
70		Fluid Only	-18	5.6	102	15
71		IP Mod	-17.7	2.9	101	14
72		IP Mod	-18	9.3	103	15
74		IP Mod	-18.5	10.3	102	14
75	30-Jan-10	Fluid Only	-18	4.1	102	15
76		Fluid Only	-18	5.9	102	16
77		IP- / SN-	-14.1	9.9	102	15
78		IP- / SN-	-16	8.6	102	15
79		IP- / SN-	-14.8	3.6	102	16
80		IP-	-17	3.0	101	16
81		IP- / SN	-17.3	3.8	101	14
82		IP- / SN	-15.8	9.2	102	15
94	2-Feb-10	IP- / SN-	-6.3	5.5	101	16
95		IP Mod	-8.1	6.9	102	16
96		IP-	-7.6	6.6	101	16
97		IP- / SN	-8.3	7.6	101	16
98		IP- / ZR-	-6.7	1.8	102	15
100	3-Feb-10	Fluid Only	-6	2.3	101	15

AVG	**101**	**19**
STD DEV	**1.0**	**5**

AVG (Excluding Tests 0-12 & 44)	**101**	**18**
STD DEV (Excluding Tests 0-12 & 44)	**0.7**	**3**

5.9 6º vs. 8º Rotation Lift Coefficient Analysis

The simulated wing rotation profile was developed based on discussions with an airframe manufacturer and previous testing. It was concluded that the wing model used for testing would typically experience a -2º angle during acceleration and typically rotate to 6º. The stall angle of this wing section was approximately 10-11º. It was concluded that using 8º as the maximum rotation angle (approximate midpoint between typical angle and stall angle) would provide a more conservative testing scenario; previous testing had indicated that lift losses during comparative testing were increasingly apparent as the rotation angle approached the stall angle.

During the testing, larger lift losses (greater than 5 percent) were observed with the supercritical wing compared to the previous testing conducted in 2006-07 and 2008 09. These larger lift losses were typically experienced with the PG based fluids.

An analysis of the testing conducted with ice pellets as well as fluid only tests was conducted to investigate the impact of using an 8º CL limit for analysis versus a 6º CL limit, which may be less conservative. Table 5.7 shows all the tests conducted with ice pellets, along with the lift losses calculated using the 8º and 6º CL. Table 5.8 shows the same set of tests; however, only the test runs with lift losses greater than 5 percent (calculated using the 8º CL) were included. Table 5.9 shows the fluid only tests conducted along with the lift losses calculated using the 8º and 6º CL limits.

The results indicated that there would be no significant difference in the end result of the analysis when using the 6º CL rather than the 8º CL to calculate the lift loss. The average lift loss for all ice pellet tests (Table 5.7) indicated comparable lift losses using both the 6º and 8º CL. When this data was re-analysed using only tests with greater than 5 percent lift losses (Table 5.8), the results actually indicated that the 6º lift loss analysis was slightly worse by an average 0.6 percent compared to the 8º lift loss analysis. In the fluid only cases (Table 5.9), the average lift loss would be 0.5 percent better using the 6º CL versus the 8º CL; however, again, the differences were not significant.

These results indicate that, in general, using the 6º or 8º rotation CL data to calculate lift loss would on average generate comparable results. It was therefore recommended that the analysis continue to be conducted using the 8º CL limit to calculate the lift losses, as the results have indicated that using either the 6º or 8º CL would not significantly change the conclusions from the testing.

Table 5.7: Comparison of Lift Losses Using 6º and 8º CL for Ice Pellet Tests

Ice Pellet Cases Only (8° Rotation)			
Condition	**Test Run**	**8° Lift Loss (%)**	**6° Lift Loss (%)**
IP- / ZR-	0	6.5	5.9
IP-	9	4.7	3.3
IP Mod	10	6.1	4.9
IP- / SN-	11	4.4	3.5
IP Mod	10A	0.7	-0.9
IP Mod	10B	7.8	7.1
IP- / SN	13	6.1	5.9
IP- / SN	14	5.5	6.5
IP- / SN	15	5.1	5.2
IP- / SN	16	5.8	6.5
IP Mod	21	0.5	-0.2
IP-	22	0.8	1.1
IP- / SN-	23	1.1	1.4
IP- / SN	24	1.3	-0.3
IP- / ZR-	26	4.8	4.7
IP- / ZR-	26A	1.4	0.9
IP-	28	4.3	4.2
IP-	26A	3.9	3.0
IP / R Mod	44	28.5	28.6
IP Mod	47	8.2	8.5
IP Mod	48	6.5	5.5
IP Mod	49	6.7	6.5
IP / R Mod	56	3.2	2.2
IP / R Mod	56A	3.4	2.6
IP- / SN-	57	4.7	5.3
IP- / SN-	57A	2.9	1.6
IP- / SN	58	4.8	4.8
IP- / ZR-	59	4.1	4.2
IP- / ZR-	63	7.7	9.8
IP-	65	9.2	10.5
IP-	66	8.6	10.8
IP-	67	2.2	3.2
IP-	68	9.6	12.0
IP-	69	9.6	12.0
IP Mod	71	2.9	2.4
IP Mod	72	9.3	11.5
IP Mod	73	5.0	4.1
IP Mod	74	10.3	10.1
IP- / SN-	77	9.9	11.5
IP- / SN-	78	8.6	8.7
IP- / SN-	79	3.6	3.2
IP-	80	3.0	3.2
IP- / SN	81	3.8	4.4
IP- / SN	82	9.2	10.4
IP- / SN-	94	5.5	6.1
IP Mod	95	6.9	7.3
IP-	95	6.6	7.4
IP- / SN	97	7.6	7.3
IP- / ZR-	98	1.8	0.7
AVERAGE		**5.8**	**5.9**

Table 5.8: Comparison of Greater than 5% Lift Losses Using 6º and 8º CL for Ice Pellet Tests

Ice Pellet Cases >5% Lift Loss (8° Rotation)			
Condition	**Test Run**	**8° Lift Loss (%)**	**6° Lift Loss (%)**
IP- / ZR-	0	6.5	5.9
IP Mod	10	6.1	4.9
IP Mod	10B	7.8	7.1
IP- / SN	13	6.1	5.9
IP- / SN	14	5.5	6.5
IP- / SN	15	5.1	5.2
IP- / SN	16	5.8	6.5
IP / R Mod	44	28.5	28.6
IP Mod	47	8.2	8.5
IP Mod	48	6.5	5.5
IP Mod	49	6.7	6.5
IP- / ZR-	63	7.7	9.8
IP-	65	9.2	10.5
IP-	66	8.6	10.8
IP-	68	9.6	12.0
IP-	69	9.6	12.0
IP Mod	72	9.3	11.5
IP Mod	73	5.0	4.1
IP Mod	74	10.3	10.1
IP- / SN-	77	9.9	11.5
IP- / SN-	78	8.6	8.7
IP- / SN	82	9.2	10.4
IP- / SN-	94	5.5	6.1
IP Mod	95	6.9	7.3
IP-	95	6.6	7.4
IP- / SN	97	7.6	7.3
	AVERAGE	**8.3**	**8.9**

Table 5.9: Comparison of Lift Losses Using 6º and 8º CL for Fluid-Only Tests

Fluid Only Cases (8° Rotation)			
Condition	**Test Run**	**8° Lift Loss (%)**	**6° Lift Loss (%)**
Fluid Only	1	5.0	3.2
Fluid Only	17	5.0	4.2
Fluid Only	18A	1.7	0.7
Fluid Only	25	2.0	-0.3
Fluid Only	29	5.0	4.2
Fluid Only	32	5.1	3.6
Fluid Only	34	4.0	3.0
Fluid Only	53	3.9	4.7
Fluid Only	54	3.6	3.3
Fluid Only	55	1.9	0.9
Fluid Only	60	4.6	3.1
Fluid Only	64	5.1	5.7
Fluid Only	70	5.6	7.6
Fluid Only	75	4.1	5.8
Fluid Only	76	5.9	6.7
Fluid Only	100	2.3	0.8
Fluid Only	101	5.0	4.3
	AVERAGE	**4.1**	**3.6**

5.10 Comparison of Fluid Certification BLDT Results vs. NRC Wind Tunnel Lift Loss Results

During the 2009-10 wind tunnel testing, larger lift losses were observed compared to the previous testing conducted in 2006-07 and 2008-09; this was especially true for Type IV PG fluids. During the 2009-10 testing, 5 percent lift loss was generally used as the cut-off for the acceptable lift loss for a test; the 5 percent lift loss is linked to the historical development of the fluid certification boundary layer displacement thickness (BLDT) requirements.

During the testing, some fluid only cases were generating lift losses greater than 5 percent. It was recommended that the data from the fluid only cases tested in the NRC wind tunnel be compared to the fluid certification BLDT results; the intent was to develop a correlation between the two tests. The assumption used was that the point at which the fluid fails during the BLDT test is the limit of acceptable lift loss. By superimposing the NRC lift data for fluid only cases, a correlation could be made between the temperature when a fluid fails the BLDT and the lift loss recorded by the NRC when conducting fluid only tests in similar conditions.

Figures 5.20, 5.21, and 5.22 show the fluid certification BLDT and NRC lift loss results for Launch, EG106, and ABC-S+ neat fluids; no contamination was used during these tests. The x-axis indicates the test temperature in degrees Celsius, and the y-axis indicates the BLDT results in millimeters and the lift loss of the fluids tested in the NRC wind tunnel in percentage compared to the baseline dry wing. In each case, a linear regression of the data was calculated to facilitate the analysis. On each of the graphs, the BLDT limit has been plotted for reference. In Figures 5.20 and 5.21, the dotted lines demonstrate the correlation between the BLDT failure point and the NRC observed lift loss.

In the case of the Launch fluid, the fluid certification data regression line exceeds the BLDT limit at approximately -27ºC. At this temperature, the NRC data regression line indicates approximately 6.6 percent lift loss.

In the case of the EG106 fluid, the fluid certification data regression line exceeds the BLDT limit at approximately -32ºC. At this temperature, the NRC data regression line indicates approximately 6.1 percent lift loss.

In the case of the ABC-S+ fluid, a correlation could not be calculated, as the fluid certification data was well below the BLDT limit; the regression line only crosses the BLDT limit at approximately -66ºC.

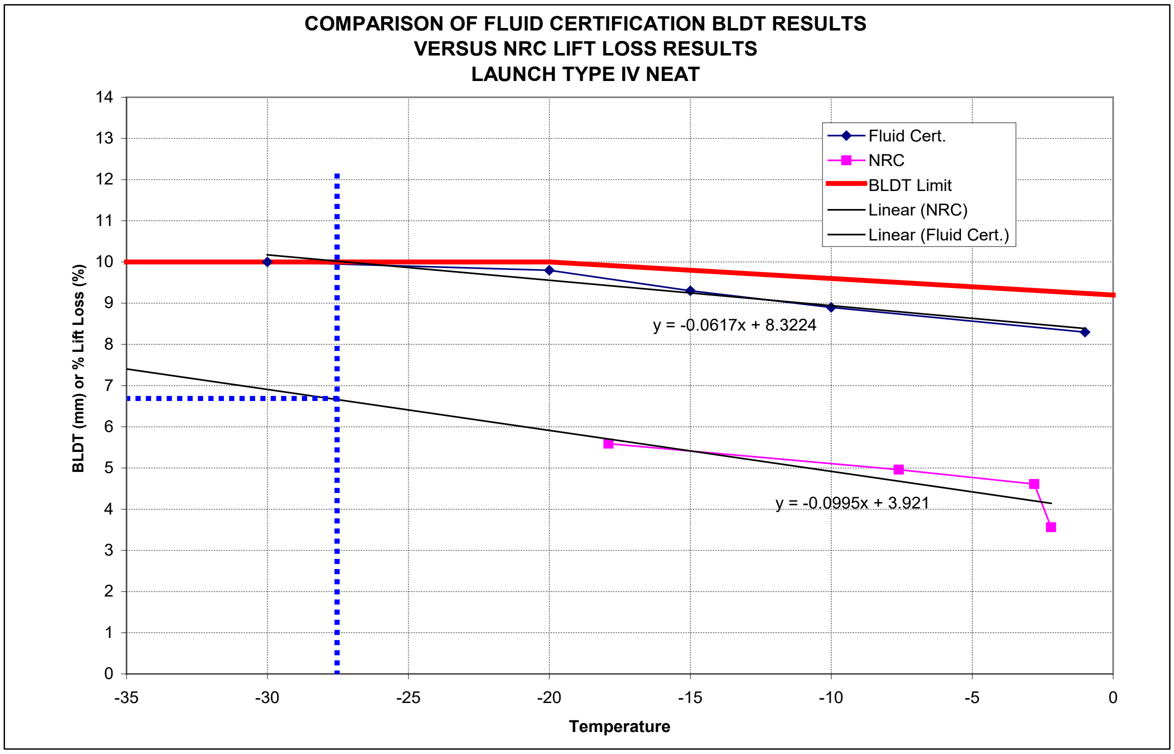


Figure 5.20: Comparison of Fluid Certification and NRC Results for Launch Fluid

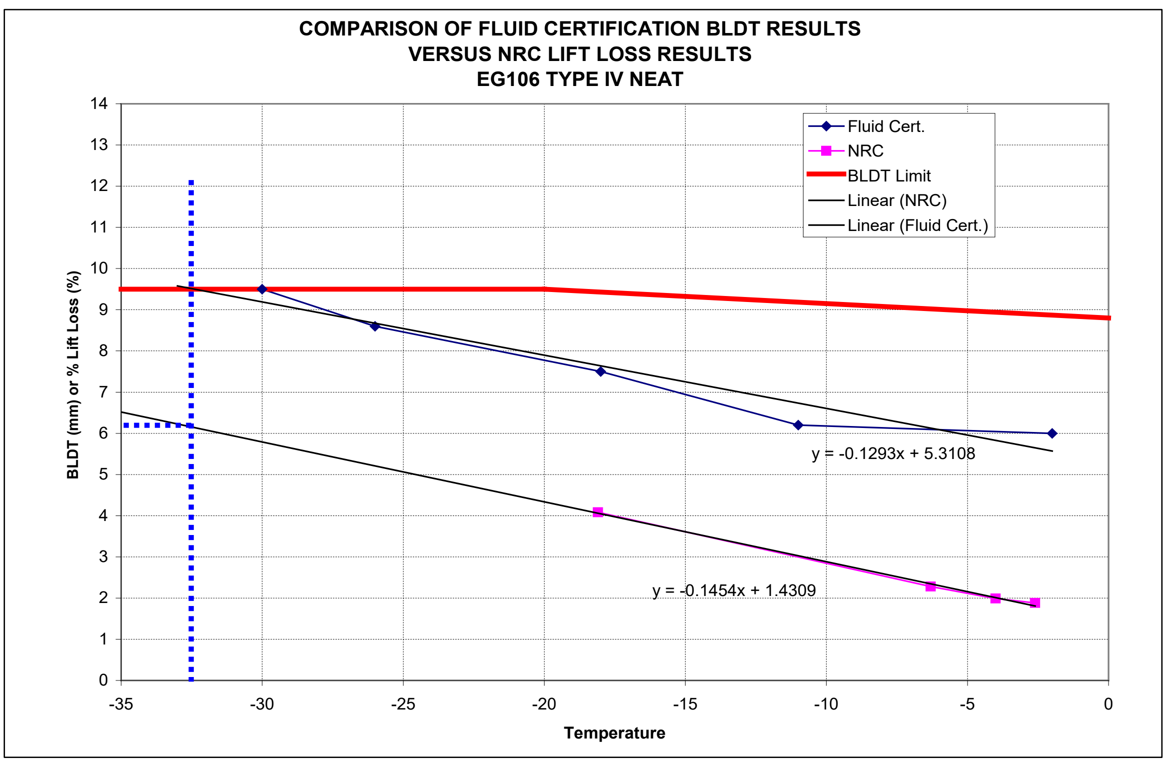


Figure 5.21: Comparison of Fluid Certification and NRC Results for EG106 Fluid

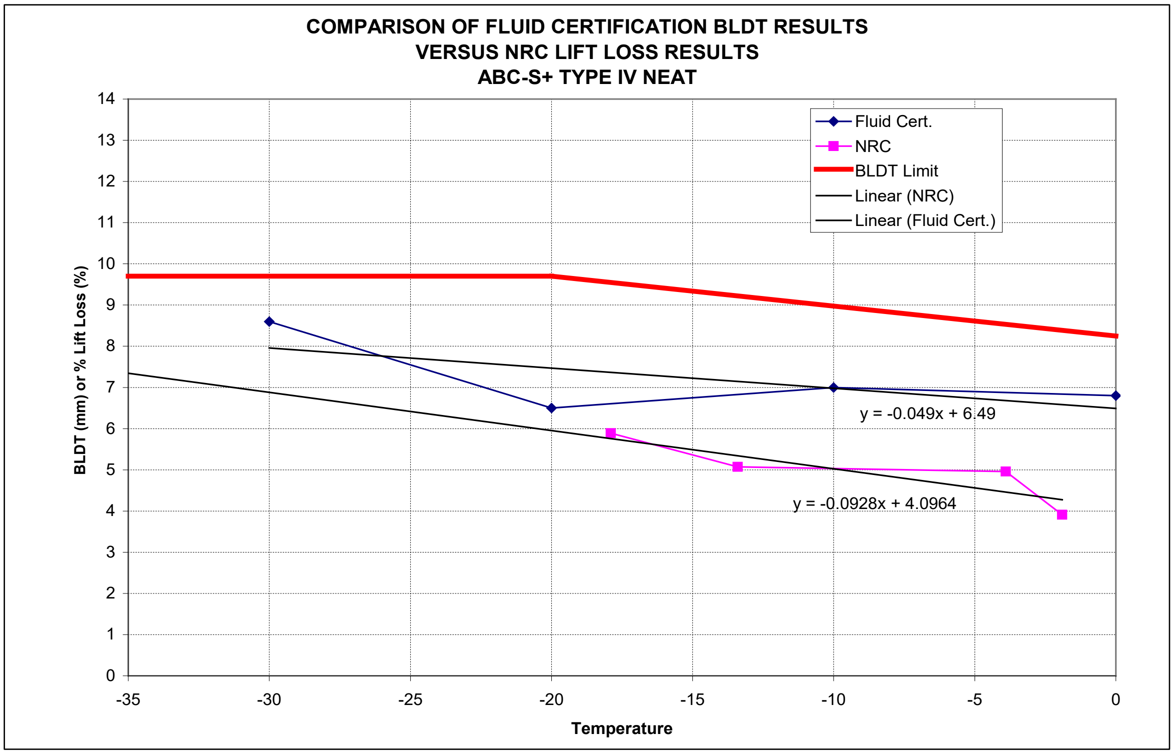


Figure 5.22: Comparison of Fluid Certification and NRC Results for ABC-S+ Fluid

The results from this analysis indicate that 5 percent lift loss may not be appropriate as the lift loss cut-off. When correlating to the fluid certification results, the 7 percent lift loss cut-off may be more appropriate based on the Launch and EG106 data. It is recommended that future testing be done to simulate fluid certification results in the NRC wind tunnel at specific temperatures to substantiate the correlation observed in this preliminary analysis.

5.10.1 Detailed Correlation of Lift Loss and BLDT

Fluid BLDT results may vary based on fluid viscosity. As a result, a more detailed analysis was conducted comparing the NRC lift loss data to the fluid certification data of several different fluid batches of high, low, and mid viscosity. Assumptions were made based on the data available, and a preliminary conclusion was drawn as to the correlation between the BLDT limit and the highest allowable NRC lift loss. Figures 5.23 to 5.25 demonstrate the data used and the conclusions made from the analysis for each specific fluid tested. The results are still preliminary, as additional work is anticipated to be conducted during the winter of 2010-11 to further refine this correlation.

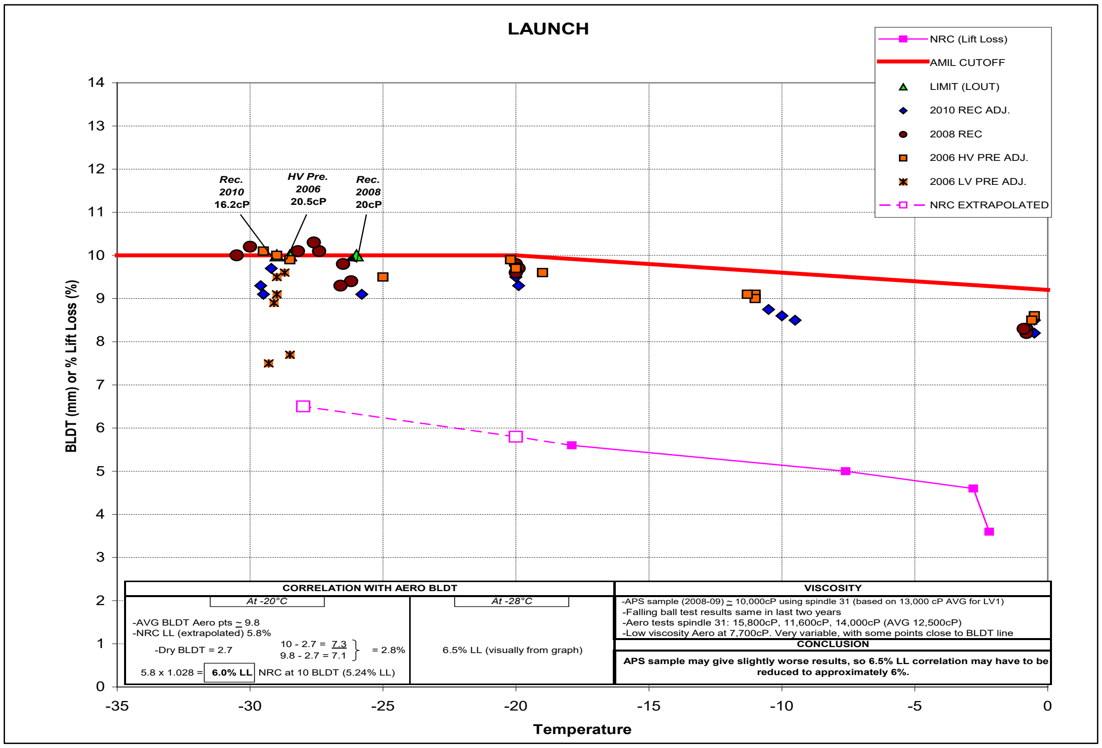


Figure 5.23: Detailed Comparison of Fluid Certification and NRC Results for Launch Fluid

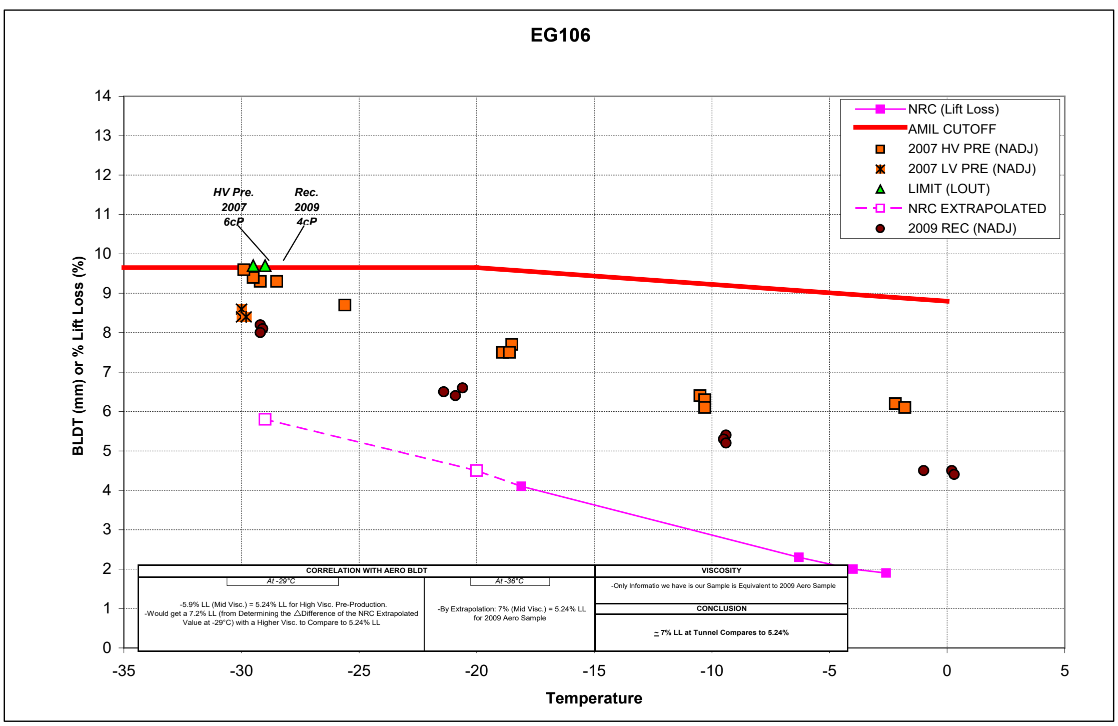


Figure 5.24: Detailed Comparison of Fluid Certification and NRC Results for EG106 Fluid

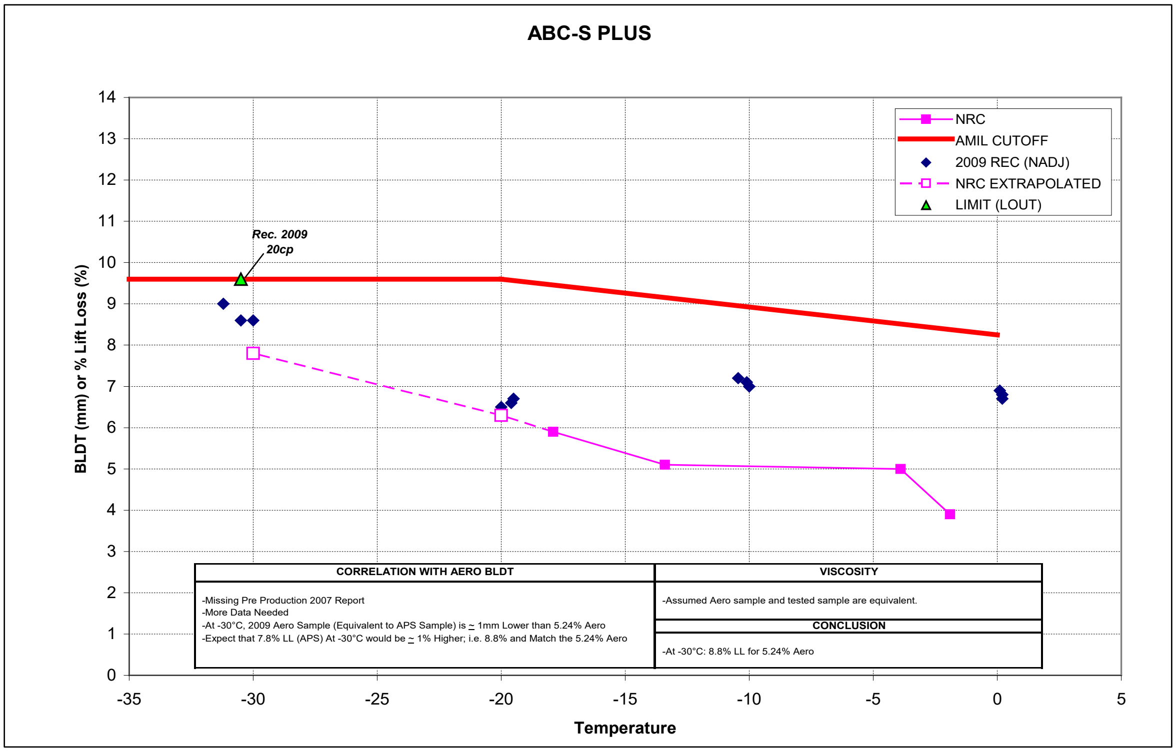


Figure 5.25: Detailed Comparison of Fluid Certification and NRC Results for ABC-S+ Fluid

5.11 Extrapolation of Test Results for 110-120 Knots Rotation Speeds

Due to the limitations of the NRC PIWT, testing could only be conducted with a maximum speed of approximately 100 knots. Typically, jet aircraft rotate at slightly higher speeds nearing 115 to 120 knots or greater. Aerodynamic testing with lower rotation speeds is conservative; however, during the winter of 2009-10, larger than expected lift losses were experienced in several test conditions (as will be described in detail in Sections 6 to 11). These results indicated necessary reductions to the allowance times; therefore, it was recommended that the data be further analysed to investigate whether the results would be appropriate with higher rotation speeds.

5.11.1 Methodology

The objective of this analysis was to determine the increase in CL (and reduction in lift loss) as a result of higher rotation speeds. For each test, time required to accelerate from 60 to 70 knots and 70 to 80 knots was calculated and an average was taken; this was the more linear portion of the acceleration profile and was chosen as being more conservative (resulting in a shorter time for fluid to flow-off) compared to the greater than 80 knots profile, where the acceleration begins to taper off. Based on this data, the average time needed to ramp an extra 10 knots was found to be approximately 2 seconds; this time would be used to simulate the time to ramp an extra 10 knots (for example, from 100 to 110 or 110 to 120 knots). It was then recommended that the calculations be performed for 110, 115, and 120 knots; therefore, the additional time required to ramp-up was assumed to be the following: $\Delta t1 = 2sec$ (100 to 110 knots), $\Delta t2 = 1sec$ (110 to 115 knots), and $\Delta t3 = 1sec$ (115 to 120 knots).

For each test, the CL profile during ramp-up (90 to 100 knots prior to rotation) was regressed and extrapolated to 110, 115, and 120 knots based on Δt1, Δt2, and Δt3. It should be noted that the last 0.1 seconds of data before rotation was omitted due to the dynamic variability in the results, and adjustments were made if the rotation occurred at less than or greater than 100 knots. The delta increase in CL for Δt1, Δt2, and Δt3 was used to calculate new lift losses at the simulated 110, 115, and 120 knots. Figure 5.26 shows the formula used to calculate the simulated lift losses at 110, 115, and 120 knots; this formula is also used in the example shown in Figure 5.28. Figure 5.27 demonstrates one example of the linear extrapolation methodology to simulate a 110 knot rotation speed.

The extrapolation methodology was applied using various types of regression methods; the best fit curve was difficult to standardize due to the different behaviour patterns of fluid flow-off during ramp-up. Initially, the analysis was conducted using the following regression methods:

- Semi-Log Regression (Log Time);
- Semi-Log Regression (Log CL);
- Log-Log Regression;
- Linear Regression;
- Polynomial Regression; and
- Visual Extrapolation (estimated based on visual trend).

$$LL\%_{(110, 115,\ or\ 120\ Knots)} = \frac{CL8^{\circ}Dry - [CL8^{\circ}Cont + \Delta CL]}{CL8^{\circ}Dry}$$

Figure 5.26: Formula for Calculating Lift Loss at Simulated 110, 115, and 120 Knots Rotation Speeds

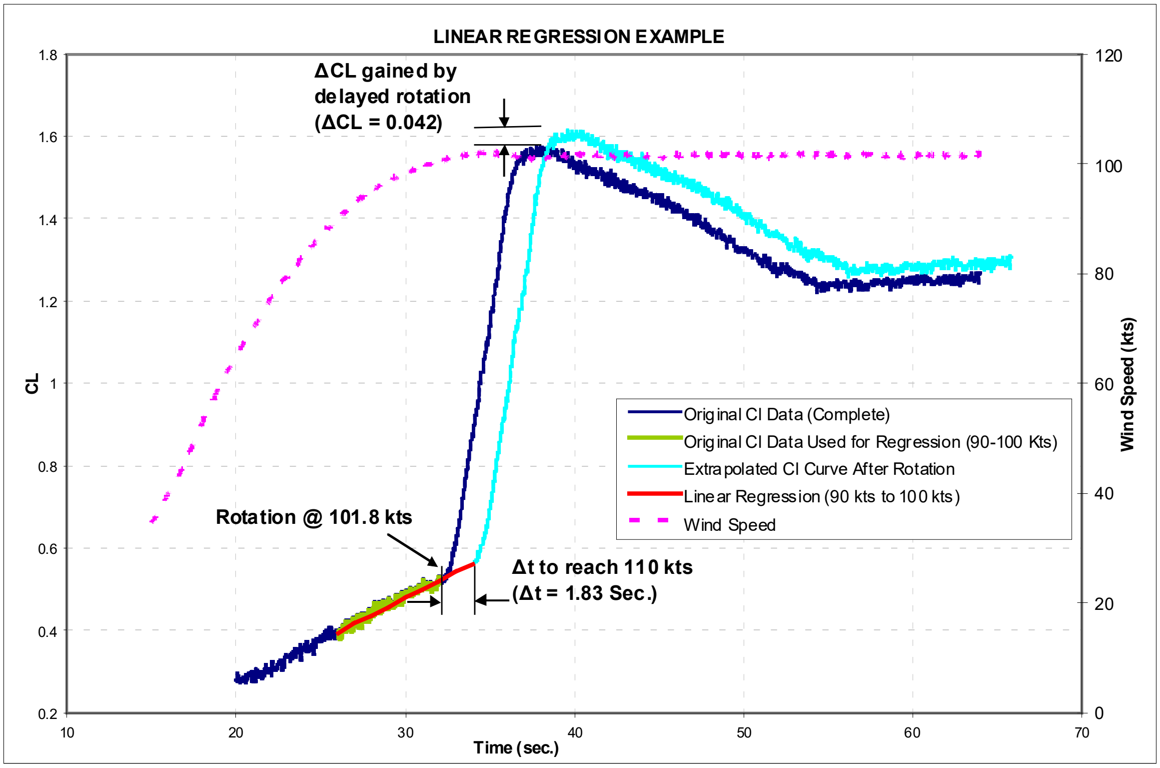


Figure 5.27: Example of Extrapolation Methodology to Simulate Rotation Speed of 110 Knots

Figure 5.28 demonstrates the details of the linear regression extrapolation analysis conducted for Run#65 based on the CL data collected from 90 to 100 knots. Figure 5.29 demonstrates the general trends of all the regression analysis conducted; the calculation method to evaluate the increase in CL was the same regardless of the regression method used. Table 5.10 summarizes the different regression methods used and provides comments regarding the appropriateness of each different method, along with a generalized visualization of the shape of the curve generated.

It was determined that the semi-log regression with log of time as the input was the most appropriate for this type of analysis, as it best described the trend indicating that the CL will improve over time but will begin to level off and will not go to infinity. Semi-log using time as the input seems the most appropriate, theoretically and mathematically, and represents the fluid flow-off physics. It was therefore recommended that the semi-log analysis be used as the basis for the analysis; however, all other regression methods would be calculated for reference purposes. The details of this analysis are included in the "Summary of Results" sections for of the affected ice pellet conditions (Sections 6 to 11).

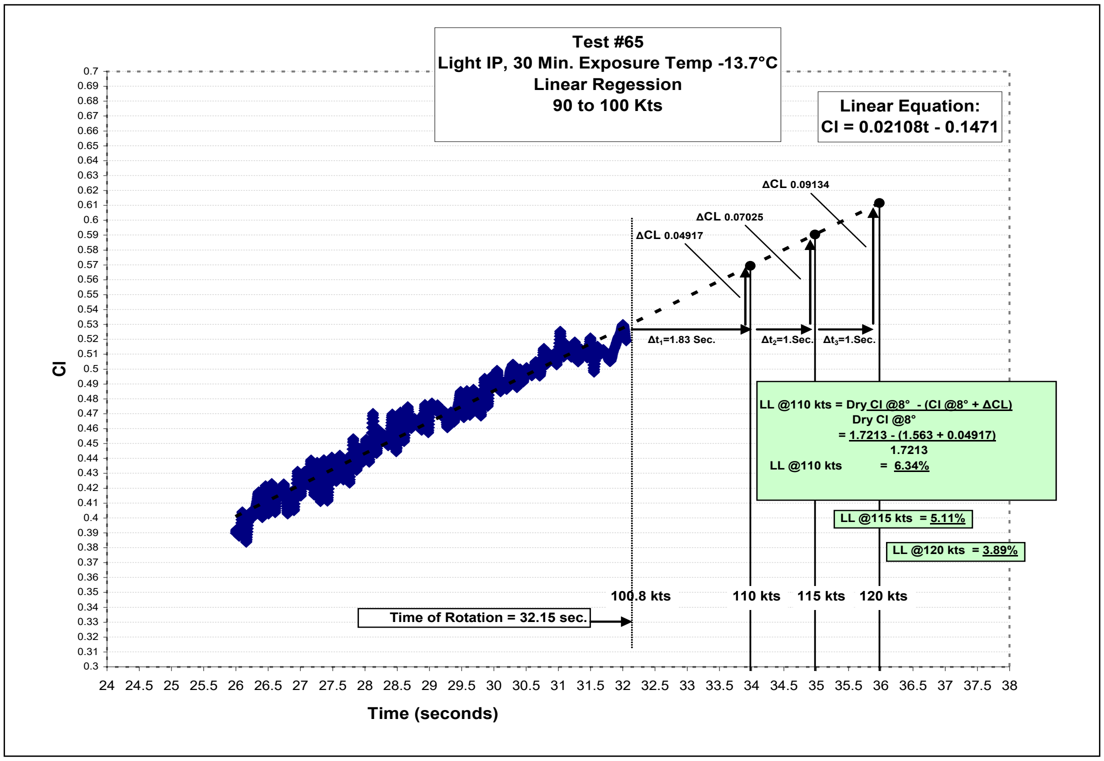


Figure 5.28: Example of Linear Regression Method Used for Extrapolation of Data to 110, 115, and 120 Knots

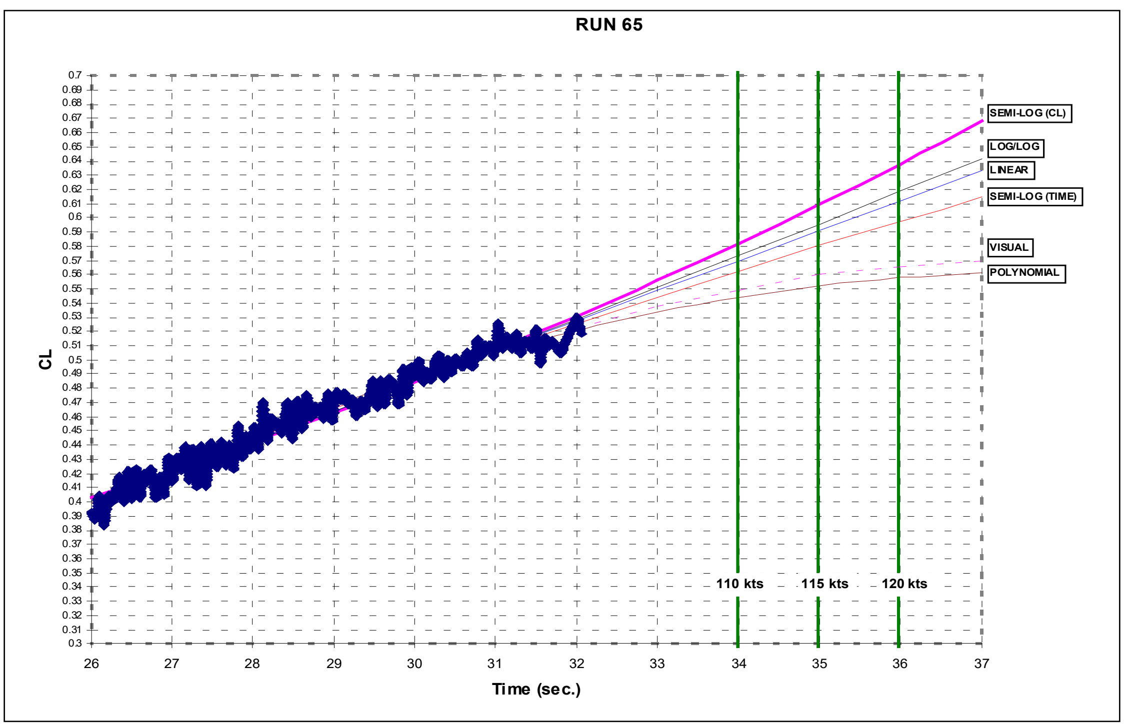
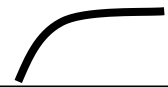
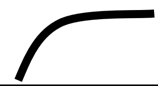
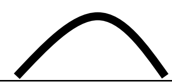
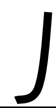


Figure 5.29: Example of Different Regression Methods Used for Extrapolation of Data to 110, 115, and 120 Knots

Table 5.10: Description of Different Regression Methods Used for Extrapolation to 110, 115, and 120 Knots

Regression Method	Comments	General Shape
Semi-Log Regression (Log Time)	Simulates expected trend (i.e., CL will level off after a certain time)	
Visual Extrapolation	Similar to above, but much more conservative	
Linear Regression	OK in some cases but not conservative (could be considered upper limit)	
Polynomial Regression	Ok in some cases but too conservative in others (not appropriate because trend could force CL to be below CL at 100 knots)	
Semi-Log Regression (Log Cl)	Does not represent data and does not represent physics of fluid flow-off	
Log-Log Regression	Dependant on previous, so does not represent data and physics of fluid flow-off	

6. LIGHT ICE PELLET ALLOWANCE TIMES

Aerodynamic testing was conducted to validate and further develop the Type IV high-speed ice pellet allowance times in the NRC wind tunnel. Previous testing in 2006-07 and 2008-09 consisted of wind tunnel tests and Falcon 20 aircraft tests to develop allowance times for mixed conditions with ice pellets. Due to the limitations of the data, some extrapolation of the results was required in order to develop a comprehensive table. It was recommended that testing be conducted at the most critical limits of the allowance times to validate the current guidance material for use with newer generation aircraft operating with supercritical wings. Additional testing was also required to provide guidance material where data was limited or non-existent. The results of this testing have been separated by test condition, and the details can be found in the following sections:

- Section 6: Light Ice Pellets;
- Section 7: Moderate Ice Pellets;
- Section 8: Light Ice Pellets and Light Freezing Rain;
- Section 9: Light Ice Pellets and Moderate Rain;
- Section 10: Light Ice Pellets and Light Snow; and
- Section 11: Light Ice Pellets and Moderate Snow.

This section provides an overview of each test conducted to substantiate and further develop the current high-speed allowance times for Type IV fluids in "Light Ice Pellet" conditions. Testing was conducted in simulated precipitation conditions. The parameters for each test are detailed, and a description of the data collected during each test is provided.

6.1 Overview of Tests

A summary of the Light Ice Pellet tests conducted in the wind tunnel is shown in Table 6.1. The table provides relevant information for each of the tests, as well as final values used for the data analysis. Each row contains data specific to one test. A more detailed test log of all conditions tested using the wind tunnel is provided in Subsection 4.1. The following is a brief description of the column headings for Table 6.1:

Test #: Exclusive number identifying each test.

Date: Date when the test was conducted.

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

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

Condition: Simulated precipitation condition.

Precipitation Rate (g/dm²/h): Simulated freezing precipitation rate (or combination of different precipitation rates). "N/A" indicates that no precipitation was applied.

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

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

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

Flap Angle (º): Positioning of the flap during the precipitation period; either 0° (retracted) or 20° (extended).

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

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

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

1 - Contamination not very visible, fluid still clean.

2 - Contamination is visible, but lots of fluid still present.
3 - Contamination visible, spots of bridging contamination.
4 - Contamination visible, lots of dry bridging present.
5 - Contamination visible, adherence of contamination.

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

% Lift Loss: % Lift Loss calculated based on the comparison of the 8º lift coefficient during the test run versus the dry wing average lift coefficient (calculated to be 1.7213).

Table 6.1: Summary of 2009-10 Light Ice Pellet Testing

Test No.	Date	Fluid	Associated Baseline Test	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Flap Angle (°)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° During Rotation	8° Lift Loss (%)
9	13-Jan-10	ABC-S Plus	1	IP-	25	50	-7	-8.5	20	2, 2, 3	1, 1.8, 1.8	1.641	4.7
22	20-Jan-10	EG106	25	IP-	25	50	-4.1	-8.5	20	1.8, 2, 4	1, 1, 1	1.707	0.8
28	21-Jan-10	Launch	29	IP-	25	50	-4.2	-3.6	20	2, 2, 3.7	1, 1.7, 2	1.648	4.3
28A	21-Jan-10	Launch	29	IP-	25	50	-5.5	-7.4	0	2, 2, 2.7	1, 1.5, 2	1.655	3.9
65	29-Jan-10	ABC-S Plus	64	IP-	25	30	-13.7	-13.9	20	2.8, 2.8, 4	1.2, 2, 2.2	1.563	9.2
66	29-Jan-10	ABC-S Plus	64	IP-	25	20	-13.6	-14.2	20	2.2, 2, 3.2	1.2, 2, 2.5	1.573	8.6
67	29-Jan-10	EG106	100	IP-	25	30	-12.6	-15	20	2.2, 2.2, 3.2	1, 1.5, 1.8	1.683	2.2
68	29-Jan-10	Launch	70	IP-	25	30	-16.6	-16.4	20	3, 2.5, 3.7	1.3, 2, 2.2	1.556	9.6
69	29-Jan-10	Launch	70	IP-	25	15	-17.8	-16.6	20	2.8, 2.5, 3.5	1.3, 2, 2.7	1.556	9.6
80	30-Jan-10	EG106	75	IP-	25	30	-17	-18.5	20	2.5, 2.2, 3	1, 1.25, 1.7	1.67	3.0
96	2-Feb-10	ABC-S Plus	64	IP-	25	30	-7.6	-10.7	20	2.3, 2, 3	1, 2, 2	1.608	6.6
1	7-Jan-10	ABC-S Plus	N/A	Fluid Only	N/A	N/A	-5.7	-4.6	20	1, 1, 1	1, 1, 1	1.635	5.01
25	21-Jan-10	EG106	N/A	Fluid Only	N/A	N/A	-4	-3.4	20	1, 1, 1	1, 1, 1	1.687	1.99
29	21-Jan-10	Launch	N/A	Fluid Only	N/A	N/A	-4.8	-5.2	20	1, 1, 1	1, 1, 1	1.636	4.96
64	28-Jan-10	ABC-S Plus	N/A	Fluid Only	N/A	N/A	-13.4	-11.3	20	1, 1, 1	1, 1, 1	1.634	5.07
70	29-Jan-10	Launch	N/A	Fluid Only	N/A	N/A	-17.9	-15.8	20	1, 1, 1	1, 1, 1	1.625	5.59
75	30-Jan-10	EG106	N/A	Fluid Only	N/A	N/A	-18.1	-16.9	20	1, 1, 1	1, 1, 1	1.651	4.08
100	3-Feb-10	EG106	N/A	Fluid Only	N/A	N/A	-6.3	-8.2	20	1, 1, 1	1, 1, 1	1.682	2.28

6.2 Data Collected

6.2.1 Fluid Thickness Data

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

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

Tables 6.2 to 6.12 show the corrected fluid thickness measurements (in millimetres) collected during the contaminated fluid tests. The associated baseline fluid only cases are also shown in Tables 6.13 to 6.19 for comparison purposes.

Table 6.2: Test #9 Fluid Thickness Data

Test 9: ABC-S Plus, IP-, Tunnel OAT -7°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.5	1.8	0.0
2	2.2	3.7	0.1
3	3.1	3.9	0.2
4	4.5	4.5	0.2
5	5.7	5.7	0.2
6	5.7	8.9	0.2
7	4.5	5.7	0.2
8	3.5	4.5	0.3
Flap	1.0	0.1	0.2

Table 6.3: Test #22 Fluid Thickness Data

Test 22: EG106, IP-, Tunnel OAT -4.1°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	2.2	1.2	0.0
2	2.5	1.7	0.0
3	2.7	2.9	0.1
4	3.3	4.5	0.1
5	4.5	5.7	1.0
6	3.1	7.0	0.1
7	3.3	7.0	0.1
8	3.1	4.5	0.1
Flap	1.0	slush	0.0

Table 6.4: Test #28 Fluid Thickness Data

Test 28: Launch, IP-, Tunnel OAT -4.2°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.3	2.2	0.0
2	1.8	3.9	0.1
3	2.2	4.5	0.1
4	2.7	4.5	0.2
5	2.9	4.5	0.3
6	3.1	5.7	0.2
7	2.7	4.5	0.2
8	2.2	4.5	0.2
Flap	0.7	slush	0.2

Table 6.5: Test #28A Fluid Thickness Data

Test 28A: Launch, IP-, Tunnel OAT -5.5°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.0	slush	0.0
2	1.6	1.8	0.0
3	1.8	3.3	0.0
4	2.2	4.5	0.1
5	2.2	4.5	0.1
6	2.2	4.5	0.2
7	1.8	4.5	0.2
8	1.5	3.7	0.2
Flap	2.2	3.5	0.1

Table 6.6: Test #65 Fluid Thickness Data

Test 65: ABC-S Plus, IP-, Tunnel OAT -13.7°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.6	1.8	0.0
2	2.2	2.5	0.1
3	2.2	2.9	0.1
4	3.1	3.7	0.2
5	3.1	3.9	0.2
6	3.3	4.5	0.2
7	3.1	3.9	0.2
8	2.7	3.5	0.2
Flap	0.8	slush	0.1

Table 6.7: Test #66 Fluid Thickness Data

Test 66: ABC-S Plus, IP-, Tunnel OAT -13.6°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.1	1.6	0.1
2	1.8	2.2	0.2
3	2.5	2.5	0.2
4	3.1	3.1	0.2
5	3.1	3.1	0.3
6	3.1	3.9	0.3
7	2.9	3.5	0.2
8	2.7	3.1	0.1
Flap	0.6	slush	0.2

Table 6.8: Test #67 Fluid Thickness Data

Test 67: EG106, IP-, Tunnel OAT -12.6°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.8	1.5	0.0
2	3.1	2.7	0.1
3	3.5	4.5	0.1
4	4.5	4.5	0.2
5	4.5	4.5	0.2
6	5.7	5.7	0.2
7	4.5	5.7	0.1
8	3.7	4.5	0.1
Flap	0.8	slush	0.1

Table 6.9: Test #68 Fluid Thickness Data

Test 68: Launch, IP-, Tunnel OAT -16.6°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.0	1.2 (slush)	0.1
2	1.3	1.6 (slush)	0.1
3	1.6	1.8 (slush)	0.2
4	1.8	2.2 (slush)	0.2
5	1.8	2.2 (slush)	0.3
6	2.2	2.9 (slush)	0.1
7	2.2	2.5 (slush)	0.1
8	1.6	2.5 (slush)	0.1
Flap	0.5	N/A	0.1

Table 6.10: Test #69 Fluid Thickness Data

Test 69: Launch, IP-, Tunnel OAT -17.8°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	0.7	1.6	0.0
2	1.6	1.6	0.2
3	1.8	1.7	0.2
4	2.2	2.2	0.2
5	2.5	2.7	0.2
6	2.5	2.5	0.3
7	2.2	2.7	0.2
8	1.7	2.7	0.3
Flap	0.8	slush	0.2

Table 6.11: Test #80 Fluid Thickness Data

Test 80: EG106, IP-. Tunnel OAT -17.0°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.8	1.8	0.0
2	2.2	2.9	0.1
3	2.5	3.3	0.1
4	3.1	4.5	0.1
5	3.9	4.5	0.1
6	4.5	4.5	0.1
7	4.5	4.5	0.2
8	3.9	3.9	0.2
Flap	1.1	slush	0.1

Table 6.12: Test #96 Fluid Thickness Data

Test 96: ABC-S Plus, IP-, Tunnel OAT -7.6°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.6	1.8	0.1
2	2.2	3.1	0.1
3	2.7	3.7	0.1
4	3.3	3.9	0.2
5	3.5	4.5	0.2
6	3.3	4.5	0.2
7	3.3	4.5	0.2
8	2.9	3.5	0.2
Flap	1.0	N/A	0.2

Table 6.13: Test #1 (Baseline) Fluid Thickness Data

Test 1: ABC-S Plus, Fluid-only, Tunnel OAT -5.7°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.8	N/A	0.0
2	2.5	N/A	0.0
3	3.3	N/A	0.1
4	4.5	N/A	0.1
5	5.7	N/A	0.1
6	5.7	N/A	0.1
7	5.7	N/A	0.1
8	4.5	N/A	0.1
Flap	1.0	N/A	0.1

Table 6.14: Test #25 (Baseline) Fluid Thickness Data

Test 25: EG106, Fluid-only, Tunnel OAT -4.0°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	2.2	N/A	0.0
2	3.1	N/A	0.1
3	3.7	N/A	0.1
4	4.5	N/A	0.2
5	4.5	N/A	0.2
6	4.5	N/A	0.1
7	4.5	N/A	0.1
8	3.5	N/A	0.1
Flap	N/A	N/A	0.1

Table 6.15: Test #29 (Baseline) Fluid Thickness Data

Test 29: Fluid-only, Launch, Tunnel OAT -4.8°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.5	N/A	0.0
2	2.2	N/A	0.1
3	2.2	N/A	0.1
4	3.1	N/A	0.1
5	3.1	N/A	0.2
6	3.1	N/A	0.1
7	2.9	N/A	0.1
8	2.2	N/A	0.2
Flap	0.8	N/A	0.2

Table 6.16: Test #64 (Baseline) Fluid Thickness Data

Test 64: ABC-S Plus, Fluid-only, Tunnel OAT -13.4°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.2	N/A	0.0
2	2.2	N/A	0.1
3	1.7	N/A	0.1
4	1.8	N/A	0.1
5	3.1	N/A	0.2
6	3.1	N/A	0.2
7	3.1	N/A	0.2
8	2.7	N/A	0.2
Flap	0.8	N/A	0.2

Table 6.17: Test #70 (Baseline) Fluid Thickness Data

Test 70: Launch, Fluid-only, Tunnel OAT -17.9°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.1	N/A	0.0
2	1.5	N/A	0.1
3	1.8	N/A	0.1
4	2.2	N/A	0.2
5	2.2	N/A	0.2
6	1.6	N/A	0.2
7	1.8	N/A	0.2
8	2.2	N/A	0.2
Flap	0.5	N/A	0.1

Table 6.18: Test #75 (Baseline) Fluid Thickness Data

Test 75: EG106, Fluid-only, Tunnel OAT -18.1°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	2.2	N/A	0.1
2	2.9	N/A	0.2
3	3.1	N/A	0.2
4	3.7	N/A	0.1
5	4.5	N/A	0.1
6	4.5	N/A	0.1
7	4.5	N/A	0.1
8	2.2	N/A	0.2
Flap	0.2	N/A	0.2

Table 6.19: Test #100 (Baseline) Fluid Thickness Data

Test 100: EG106, Fluid-only, Tunnel OAT -6.3°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.6	N/A	0.0
2	2.5	N/A	0.0
3	2.7	N/A	0.1
4	3.5	N/A	0.1
5	4.5	N/A	0.1
6	5.7	N/A	0.1
7	5.7	N/A	0.2
8	4.5	N/A	0.3
Flap	0.8	N/A	0.2

6.2.2 Skin Temperature Data

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

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

Tables 6.20 to 6.30 demonstrate the wing temperature measurements (in degrees Celsius) recorded during the contaminated fluid tests. The associated baseline fluid only cases are also shown in Tables 6.31 to 6.37 for comparison purposes.

Table 6.20: Test #9 Wing Skin Temperature Data

Test 9: ABC-S Plus, IP-, Tunnel OAT -7°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-4	-5.0	-9.4	-6.2
T5	-3.6	-6.4	-8.3	-5.5
TU	-4.4	-4.9	-7.9	-7.5

Table 6.21: Test #22 Wing Skin Temperature Data

Test 22: EG106, IP-, Tunnel OAT -4.1°C				
WING TEMPERATURE (°C)				
Wing Positio n	Before Fluid Applicatio n	After Fluid Applicatio n	After Precip. Applicatio n	After Takeof f Test
T2	-4.2	-2.8	-10.4	-4.2
T5	-3.6	-2.9	-9.1	-3.4
TU	-5.0	-4.3	-6.1	-4.5

Table 6.22: Test #28 Wing Skin Temperature Data

Test 28: Launch, IP-, Tunnel OAT -4.2°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-1.2	-1.6	-7.3	-5.0
T5	-0.4	-1.6	-7.6	-4.4
TU	-1.6	-1.6	-3.9	-5.7

Table 6.23: Test #28A Wing Skin Temperature Data

Test 28A: Launch, IP-, Tunnel OAT -5.5°C				
WING TEMPERATURE (°C)				
Wing Positio n	Before Fluid Applicatio n	After Fluid Applicatio n	After Precip. Applicatio n	After Takeof f Test
T2	-3.4	-3.3	-8.5	-7.4
T5	-2.8	-3.4	-8.3	-7.3
TU	-5.1	-4.6	-5.4	-7.8

Table 6.24: Test #65 Wing Skin Temperature Data

Test 65: ABC-S Plus, IP-, Tunnel OAT -13.7°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-11.3	-9.8	-14.5	-14.2
T5	-10.9	-9.8	-13.8	-14.0
TU	-12.0	-12.4	-13.5	-14.7

Table 6.25: Test #66 Wing Skin Temperature Data

Test 66: ABC-S Plus, IP-, Tunnel OAT -13.6°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-13.5	-11.5	-15.0	-15.8
T5	-13.2	-11.1	-13.7	-15.9
TU	-14.1	-13.8	-13.8	-16.3

Table 6.26: Test #67 Wing Skin Temperature Data

Test 67: EG106, IP-, Tunnel OAT -12.6°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-14.4	-12.7	-15.6	-16.2
T5	-14.3	-12.5	-15.0	-15.5
TU	-15.3	-14.4	-14.4	-16.6

Table 6.27: Test #68 Wing Skin Temperature Data

Test 68: Launch, IP-, Tunnel OAT -16.6°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-14.3	-13.7	-16.8	-16.3
T5	-13.9	-13.4	-16.5	-16.1
TU	-15.8	-16.1	-16.0	-17.5

Table 6.28: Test #69 Wing Skin Temperature Data

Test 69: Launch, IP-, Tunnel OAT -17.8°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-16.3	-14.2	-16.9	-16.6
T5	-16.1	-13.9	-16.3	-16.2
TU	-17.5	-16.7	-16.7	-17.7

Table 6.29: Test #80 Wing Skin Temperature Data

Test 80: EG106, IP-. Tunnel OAT -17.0°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-16.1	-17.0	-19.2	-16.5
T5	-15.5	-16.8	-18.1	-15.3
TU	-18.5	-18.1	-18.3	-18.0

Table 6.30: Test #96 Wing Skin Temperature Data

Test 96: ABC-S Plus, IP-, Tunnel OAT -7.6°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-9.2	-10.2	-11.9	-11.1
T5	-8	-10.1	-11.5	-10.8
TU	-9.6	-9.0	-8.7	-11.3

Table 6.31: Test #1 (Baseline) Wing Skin Temperature Data

Test 1: ABC-S Plus, Fluid-only, Tunnel OAT -5.7°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-4.5	-4.5	N/A	-3.6
T5	-5	-4.9	N/A	-3.2
TU	-5.1	-4.5	N/A	-4.3

Table 6.32: Test #25 (Baseline) Wing Skin Temperature Data

Test 25: EG106, Fluid-only, Tunnel OAT -4.0°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.6	-3.0	N/A	-3.4
T5	-3.0	-3.1	N/A	-3.2
TU	-4.4	-4.2	N/A	-3.9

Table 6.33: Test #29 (Baseline) Wing Skin Temperature Data

Test 29: Fluid-only, Launch, Tunnel OAT -4.8°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.0	-3.8	N/A	-6.0
T5	-2.2	-3.9	N/A	-5.4
TU	-4.5	-4.1	N/A	-6.6

Table 6.34: Test #64 (Baseline) Wing Skin Temperature Data

Test 64: ABC-S Plus, Fluid-only, Tunnel OAT -13.4°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-11.8	-10.8	N/A	-12.2
T5	-11.9	-10.8	N/A	-12.1
TU	-12.3	-12.4	N/A	-12.4

Table 6.35: Test #70 (Baseline) Wing Skin Temperature Data

Test 70: Launch, Fluid-only, Tunnel OAT -17.9°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-16.6	-15.1	N/A	-16.0
T5	-16.2	-15.1	N/A	-15.7
TU	-17.7	-17.1	N/A	-17.0

Table 6.36: Test #75 (Baseline) Wing Skin Temperature Data

Test 75: EG106, Fluid-only, Tunnel OAT -18.1°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Test
T2	-16.2	-16.5	N/A	-16.4
T5	-15.8	-16.4	N/A	-15.6
TU	-17.9	-17.7	N/A	-18.4

Table 6.37: Test #100 (Baseline) Wing Skin Temperature Data

Test 100: EG106, Fluid-only, Tunnel OAT -6.3°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T3	-7.4	-8.7	N/A	-8.7
T5	-7.5	-8.3	N/A	-8.4
TU	-7.4	-7.6	N/A	-9.1

6.2.3 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Subsection 2.15.4.

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

Tables 6.38 to 6.48 show the fluid Brix measurements (in degrees Brix) collected during the contaminated fluid tests. The associated baseline fluid only cases are also shown in Tables 6.49 to 6.55 for comparison purposes.

Table 6.38: Test #9 Fluid Brix Data

Test 9: ABC-S Plus, IP-, Tunnel OAT -7°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.50	21.75	23.50
8	36.25	25.00	27.00

Table 6.39: Test #22 Fluid Brix Data

Test 22: EG106, IP-, Tunnel OAT -4.1°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.25	15.75	25.00
8	35.00	15.00	28.25

Table 6.40: Test #28 Fluid Brix Data

Test 28: Launch, IP-, Tunnel OAT -4.2°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	35.75	15.75	23.00
8	36.50	14.75	24.00

Table 6.41: Test #28A Fluid Brix Data

Test 28A: Launch, IP-, Tunnel OAT -5.5°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.25	18.50	29.25
8	37.00	19.00	21.00

Table 6.42: Test #65 Fluid Brix Data

Test 65: ABC-S Plus, IP-, Tunnel OAT -13.7°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.50	29.50	31.50
8	36.50	29.50	30.50

Table 6.43: Test #66 Fluid Brix Data

Test 66: ABC-S Plus, IP-, Tunnel OAT -13.6°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.25	31.50	32.00
8	37.50	34.25	32.00

Table 6.44: Test #67 Fluid Brix Data

Test 67: EG106, IP-, Tunnel OAT -12.6°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.75	19.50	30.00
8	32.75	17.75	30.25

Table 6.45: Test #68 Fluid Brix Data

Test 68: Launch, IP-, Tunnel OAT -16.6°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.00	29.50	29.75
8	36.75	26.75	29.25

Table 6.46: Test #69 Fluid Brix Data

Test 69: Launch, IP-, Tunnel OAT -17.8°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.00	35.50	34.25
8	37.50	34.50	33.50

Table 6.47: Test #80 Fluid Brix Data

Test 80: EG106, IP-. Tunnel OAT -17.0°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.75	22.50	28.00
8	32.50	23.00	29.25

Table 6.48: Test #96 Fluid Brix Data

Test 96: ABC-S Plus, IP-, Tunnel OAT -7.6°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.50	23.50	30.25
8	37.00	23.50	30.00

Table 6.49: Test #1 (Baseline) Fluid Brix Data

Test 1: ABC-S Plus, Fluid-only, Tunnel OAT -5.7°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.5	N/A	39.5
8	36.5	N/A	38.25

Table 6.50: Test #25 (Baseline) Fluid Brix Data

Test 25: EG106, Fluid-only, Tunnel OAT -4.0°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.00	N/A	31.50
8	32.25	N/A	32.50

Table 6.51: Test #29 (Baseline) Fluid Brix Data

Test 29: Fluid-only, Launch, Tunnel OAT -4.8°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.75	N/A	37.50
8	37.00	N/A	36.50

Table 6.52: Test #64 (Baseline) Fluid Brix Data

Test 64: ABC-S Plus, Fluid-only, Tunnel OAT -13.4°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.75	N/A	38.50
8	37.50	N/A	38.00

Table 6.53: Test #70 (Baseline) Fluid Brix Data

Test 70: Launch, Fluid-only, Tunnel OAT -17.9°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.50	N/A	39.25
8	37.50	N/A	38.25

Table 6.54: Test #75 (Baseline) Fluid Brix Data

Test 75: EG106, Fluid-only, Tunnel OAT -18.1°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Test
2	32.25	N/A	34.00
8	32.25	N/A	34.00

Table 6.55: Test #100 (Baseline) Fluid Brix Data

Test 100: EG106, Fluid-only, Tunnel OAT -6.3°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	33.00	N/A	33.75
8	33.00	N/A	33.00

6.3 Photos

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

- Start of test;
- Before Rotation (just before the wing began to pitch);
- End of Rotation (end of the rotation cycle when the wing position is returned to 4 degrees); and
- End of test.

The photos taken during the Light Ice Pellet testing have been presented along with the fluid only (baseline) tests for comparison purposes. In each case, the fluid only photo is presented first, followed by the contaminated fluid photo. Photos 6.1 to 6.88 show the photo summaries of the tests conducted. A complete set of photos will be provided to the TDC in electronic format.

6.4 Summary of Results

6.4.1 OAT -5°C and Above

Four tests were conducted with exposure times of 50 minutes in this cell: Tests #9, #22, #28, and #28A (see Table 6.56). It is important to note that Test #28A was conducted with the flap at 0°. For a summary of the results found in this cell, see Table 6.57.

Test #22 was conducted with EG fluid at a temperature of -4.1°C, demonstrating very good results. The visual contamination ratings were all good. The lift loss at 8° was 0.83 percent, well below the 5 percent criteria. The ramp-up time from 40 knots to rotation for this test run (20 seconds) was close to the average.

Test #9 was conducted with PG fluid and demonstrated good results. This test was conducted at a temperature of -7.0°C, colder than the temperature band in this cell. The visual results were deemed good. The lift loss at 8° was 4.67 percent, below the 5 percent margin of safety criteria. An examination of the time from 40 knots to rotation showed an approximate ramp-up time of 26 seconds. This is above the 19-second average and would have likely provided a higher lift loss should it have rotated at 19 seconds.

Tests #28 and #28A were both conducted with PG fluid. Temperatures were -4.2°C and -5.5°C, respectively. Results from these two tests were very good. Test #28 had positive visual fluid elimination and lift loss results (4.26 percent). Because the visual rating on the flap for Test #28 was close to 4 at the start of the test, the test was repeated (Test #28A) with the flap set at 0° for the contamination period. Although both tests were deemed good, the aerodynamic performance and visual contamination results were better during Test #28A with the flap at 0° (3.85 percent lift loss). The ramp-up time for these two tests was near the 19-second average.

In conclusion, all four tests demonstrated positive results, indicating that the current allowance time of 50 minutes for this cell is acceptable and validated.

6.4.2 OAT Less than -5°C to -10°C

Two tests were conducted with exposure times of 30 minutes in this cell: Test #67 and Test #96. A third test, Test #9, was also used for analysis based on temperature data closer to the target cell OAT (see Table 6.56); exposure time for this run was 50 minutes.

Test #67 was conducted with EG fluid and demonstrated very good results. The temperature during this test run was -12.6°C. The lift coefficient and the visual rating results were deemed good. The 8° lift loss was 2.23 percent, well below the 5 percent safety criteria. The ramp-up time from 40 knots to rotation was 16 seconds in this run, slightly below the 19-second average. Due to the positive results that were displayed, there is a potential to further expand the current allowance time for EG fluids. Table 6.57 provides a summary of the results.

Test #96 was conducted at a temperature of -7.6°C with a PG fluid and demonstrated satisfactory results. Although these results were deemed acceptable, further review is required based on lift loss results (see Table 6.57). The lift loss at 8° was 6.58 percent, which is above the 5 percent margin of safety criteria. An analysis of the lift loss was conducted with speeds greater than 100 knots (see Table 6.58 and Figure 6.1). The semi-log of time results indicate a speed of 110 knots or more is required to achieve a lift loss below 5 percent. It took 16 seconds to reach rotation from a speed of 40 knots. This is below the average, potentially indicating an improvement in lift loss should it have had the extra 3 seconds during ramp-up.

Although Test #9 is found in the light ice pellet OAT -5°C and above cell, it was used to support Test #96 during analysis (see Table 6.57). This test was conducted at a temperature of -7.6°C with PG fluid. Though exposure times were different (Test #9 at 50 minutes), the visual results and a lift loss of 4.67 percent were deemed good, confirming the 30-minute allowance time for PG fluids. An examination of the time from 40 knots to rotation was done for this test, and results show a longer ramp-up time than a typical test run (average time 19 seconds; Test #9, 26 seconds); this may have helped improve flow-off and reduce lift losses.

In conclusion, the current allowance time of 30 minutes for this cell is satisfactory at this time based on the results obtained, but further review is required for PG fluids. For the PG fluids with the newer generation flat wing sections, a rotation speed of 110 knots is required to reduce the measured lift loss to less than 5 percent; this would also be equivalent to the 5 percent lift loss measured with the baseline PG fluid only case.

6.4.3 OAT Less than -10°C

Four tests were conducted in this cell with an exposure time of 30 minutes: Tests #65, #67, #68, and #80 (see Table 6.56). Two other tests, #66 and #69, were also used for analysis, but exposure times were below the allowance time of 30 minutes (Test #66 at 20 minutes and Test #69 at 15 minutes). Table 6.57 contains more details on the results of these two tests.

Test #80 was conducted using EG fluid and demonstrated very good results. The temperature during this test was -17.0°C. The 8° lift loss (2.98 percent) and visual contamination ratings show positive results, confirming the 30-minute allowance time for EG fluids. Test #67 with EG fluid at -12.6°C, which was used for the analysis in the light ice pellet cell with OAT less than -5°C to -10°C, also had positive results.

Test #65, conducted at a temperature of -13.7°C with PG fluid, demonstrated poor results. The visual result on the LE at the time of rotation was 1.2, and the 8° lift loss was 9.20 percent; both results did not satisfy their required criteria, resulting in the need for further review (see Table 6.57). An examination into the ramp-up time for this test shows a time of 16 seconds to reach rotation from a speed of 40 knots. The lift loss and visual ratings could have potentially improved should this run had an extra 3 seconds during ramp-up. When the lift loss analysis of speeds greater than 100 knots was conducted, the semi-log of time results indicate that a speed of approximately 105 knots is required to bring the lift loss to less than 8 percent. A speed of just under 120 knots is required to bring the lift loss to the 5 percent safety margin (see Table 6.58 and Figure 6.2).

Test #66 was conducted using the same PG fluid as Test #65 but with an exposure time of 20 minutes. After close examination of the test parameters and results for Test #66, it is seen that findings were similar to Test #65; there were only slight differences in the visuals at the start of the test run. It could be inferred from this test that the 10-minute difference in exposure of contamination did not have a significant effect on the results (see Table 6.58 and Figure 6.3).

Test #68 was conducted with PG fluid and also demonstrated poor results, requiring further review. The temperature during this test was -16.6°C. Lift loss and visuals at rotation had unfavourable results (see Table 6.57). The lift loss at 8° for this test was 9.60 percent. As in Test #65, Test #68 had a ramp-up time of 16 seconds. This would provide a possibility of an improvement in the results should an extra 3 seconds have been used during the ramp-up time. When the lift loss analysis of speeds greater than 100 knots was conducted, the semi-log of time results indicate a speed of just under 115 knots is required to bring the lift loss to less than 8 percent. Using the methodology described to extrapolate beyond 100 knots, a speed of 140 knots would be required to bring the lift loss below 5 percent (see Table 6.58 and Figure 6.4). This estimate is provided for reference purposes, however it is not recommended to extrapolate to this extent.

Test #69 was conducted using the same PG fluid as Test #68 but with an exposure time of 15 minutes. After close examination of the test parameters and results for Test #69, it is seen that the findings were essentially the same as Test #68. It could be inferred from this test that the 15-minute difference in exposure to contamination did not have a significant effect on the results (see Table 6.57).

In conclusion, the current allowance time of 30 minutes is acceptable for EG fluids. With PG fluids, a speed of 115 knots or more is required to drive lift losses below 8 percent for the flatter and newer generation airfoils. At this time, the current allowance time of 30 minutes for PG fluids is acceptable with speeds of 115 kts or more, but further research and testing is required.

Table 6.56: Light Ice Pellets Allowance Time Tests Winter 2009-10

	OAT -5°C and Above	**OAT Less than -5°C to -10°C**	**OAT Less than -10°C**
Light Ice Pellets	50 minutes **Test # 9, 22, 28, 28A**	30 minutes **Test # 67, 96, (9)**	30 minutes **Test # 65, 68, 80, (67)**

Table 6.57: Summary of Light Ice Pellets Allowance Time Test Results

	OAT -5°C and Above	OAT Less than -5°C to -10°C	OAT Less than -10°C
Light Ice Pellets	**50 minutes** Run 9 (Exposure Time 50 min), -7.0°C ABC-S Plus Visual At Start: GOOD (2, 2, 3) Visuals At Rotation: GOOD (1, 1.8, 1.8) LL At 100 kts: GOOD (4.67%) **GOOD At 100 kts** Run 22 (Exposure Time 50 min), -4.1°C EG106 Visual At Start: GOOD (1.8, 2, 4) Visuals At Rotation: GOOD (1, 1, 1) LL At 100 kts: GOOD (0.83%) **GOOD At 100 kts** Run 28 (Exposure Time 50 min), -4.2°C LAUNCH Visual At Start: GOOD (2, 2, 3.7) Visuals At Rotation: GOOD (1, 1.7, 2) LL At 100 kts: GOOD (4.26%) **GOOD At 100 kts** Run 28A (Exposure Time 50 min), -5.5°C *Flap At 0°* LAUNCH Visual At Start: GOOD (2, 2, 2.7) Visuals At Rotation: GOOD (1, 1.5, 2) LL At 100 kts: GOOD (3.85%) **GOOD At 100 kts** ▪ **50 min GOOD for EG Fluid** ▪ **50 min GOOD for PG Fluid** **CONCLUSION: ALLOWANCE TIME OF 50 MIN GOOD**	**30 minutes** Run 67 (Exposure Time 30 min), -12.6°C EG106 Visual At Start: GOOD (2.2, 2.2, 3.2) Visuals At Rotation: GOOD (1, 1.5, 1.8) LL At 100 kts: GOOD (2.23%) **GOOD At 100 kts** Run 96 (Exposure Time 30 min), -7.6°C ABC-S Plus Visual At Start: GOOD (2.3, 2, 3) Visuals At Rotation: GOOD (1, 2, 2) LL At 100 kts: OK (6.58%) LL At 110 kts: GOOD (4.88%) LL At 115 kts: GOOD (4.00%) LL At 120 kts: GOOD (3.15%) **GOOD >100 kts** ▪ **30 min GOOD for EG Fluid; Could be Higher** ▪ **30 min OK for PG Fluid; Further Review Required** **CONCLUSION: ALLOWANCE TIME OF 30 MIN OK, FURTHER REVIEW REQUIRED**	**30 minutes** Run 65 (Exposure Time 30 min), -13.7°C ABC-S Plus Visual At Start: GOOD (2.8, 2.8, 4) Visuals At Rotation: BAD (1.2, 2, 2.2) LL At 100 kts: BAD (9.20%) LL At 105 kts: OK (7.81 %) LL At 115 kts: OK (5.71%) LL At 120 kts: GOOD (4.71%) **GOOD At 120 kts** Run 68 (Exposure Time 30 min), -16.6°C LAUNCH Visual At Start: GOOD (3, 2.5, 3.7) Visuals At Rotation: BAD (1.3, 2, 2.2) LL At 100 kts: BAD (9.60%) LL At 115 kts: OK (7.64%) LL At 140 kts: GOOD (4.68%) **OK >115 kts** Run 80 (Exposure Time 30 min), -17.0°C EG106 Visual At Start: GOOD (2.5, 2.2, 3) Visuals At Rotation: GOOD (1, 1.25, 1.7) LL At 100 kts: GOOD (2.98%) **GOOD At 100 kts** Run 66 (Exposure Time 20 min), -13.6°C ABC-S Plus Visual At Start: GOOD (2.2, 2, 3.2) Visuals At Rotation: BAD (1.2, 2, 2.5) LL At 100 kts: BAD (8.62%) LL At 110 kts: OK (6.71%) LL At 115 kts: OK (5.86%) LL At 120 kts: OK (5.03%) **OK >105 kts** Run 69 (Exposure Time 15 min), -17.8°C LAUNCH Visual At Start: GOOD (2.8, 2.5, 3.5) Visuals At Rotation: BAD (1.3, 2, 2.7) LL At 100 kts: BAD (9.60%) LL At 110 kts: OK (7.59%) LL At 115 kts: OK (6.76%) LL At 130 kts: GOOD (4.41%) **OK > 110 kts** ▪ **Higher Rotation Speeds of 115 or More are Needed to Drive LL Below 8%** ▪ **30 min GOOD for EG Fluid** ▪ **30 min OK for PG Fluid and Supercritical Wings for Speeds >115 kts** **CONCLUSION: ALLOWANCE TIME OF 30 MIN OK FOR >115 KTS**

Table 6.58: Details of Increased Rotation Speed Analysis

Condition	Test #	Speed (Kts)	Lift Loss at 8 Degrees (%)	Visual (%)	Linear (%)	Semi-Log (Time) (%)	Polynomial (2nd Order) (%)
Light Ice Pellets (OAT Less than -5°C to -10°C)	**96**	100	6.58				
		110		5.55	4.52	4.88	6.21
		115		5.00	3.47	4.00	6.01
		120		4.36	2.43	3.15	5.95
Light Ice Pellets (OAT Less than -10°C)	**65**	100	9.20				
		105		-	7.56	7.81	8.43
		115		6.88	5.11	5.71	7.35
		120		6.59	3.89	4.71	7.02
	66	100	8.62				
		110		7.24	6.41	6.71	7.65
		115		6.54	5.41	5.86	7.30
		120		6.19	4.41	5.03	7.07
	68	100	9.60				
		110		8.47	8.05	8.28	9.20
		115		7.89	7.30	7.64	9.03
		140		-	3.52	4.68	9.87
	69	100	9.60				
		110		7.52	7.25	7.59	8.11
		115		7.17	6.26	6.76	7.56
		130		-	3.30	4.41	6.38

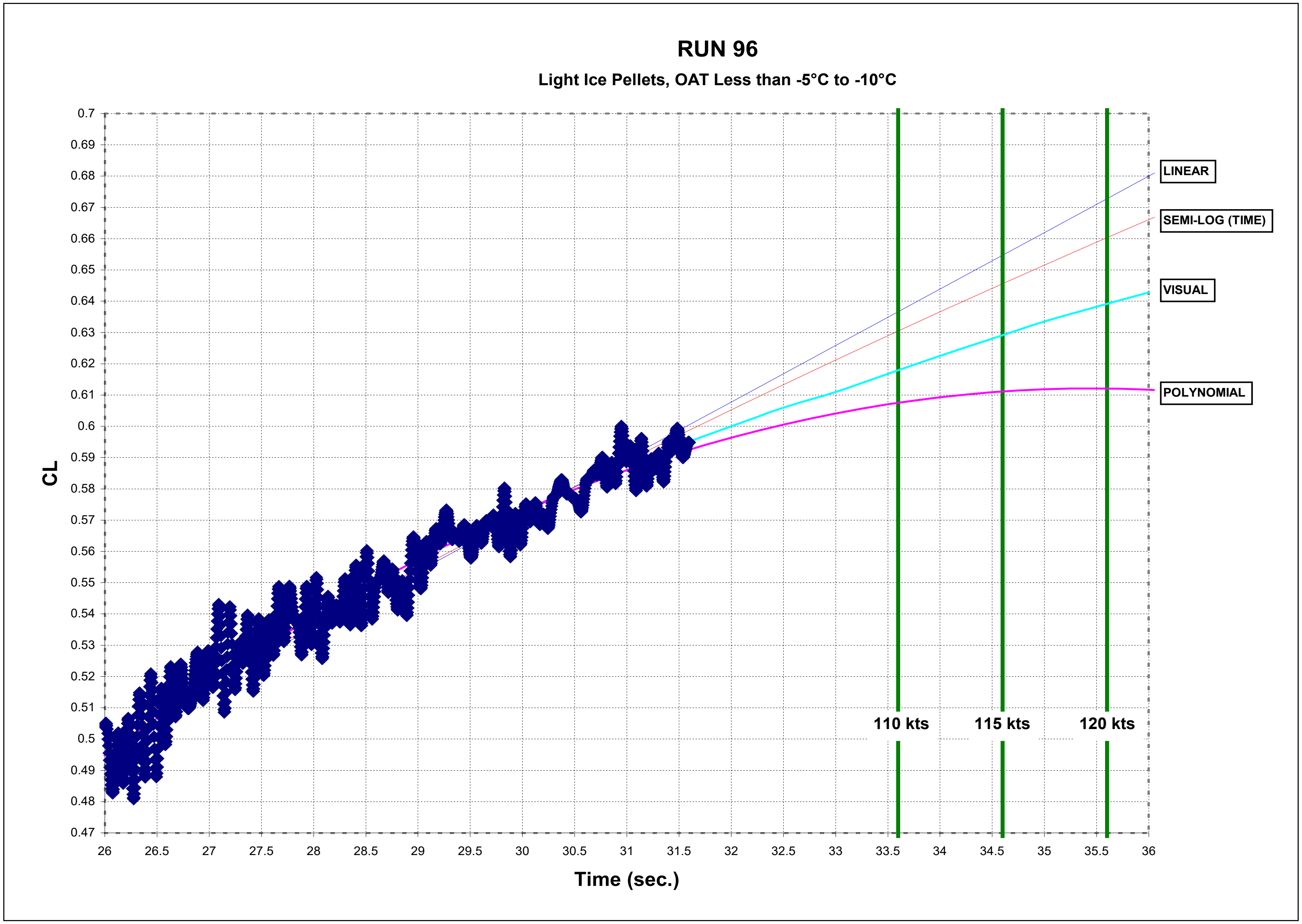


Figure 6.1: Increased Rotation Speed Extrapolation Results – Test #96

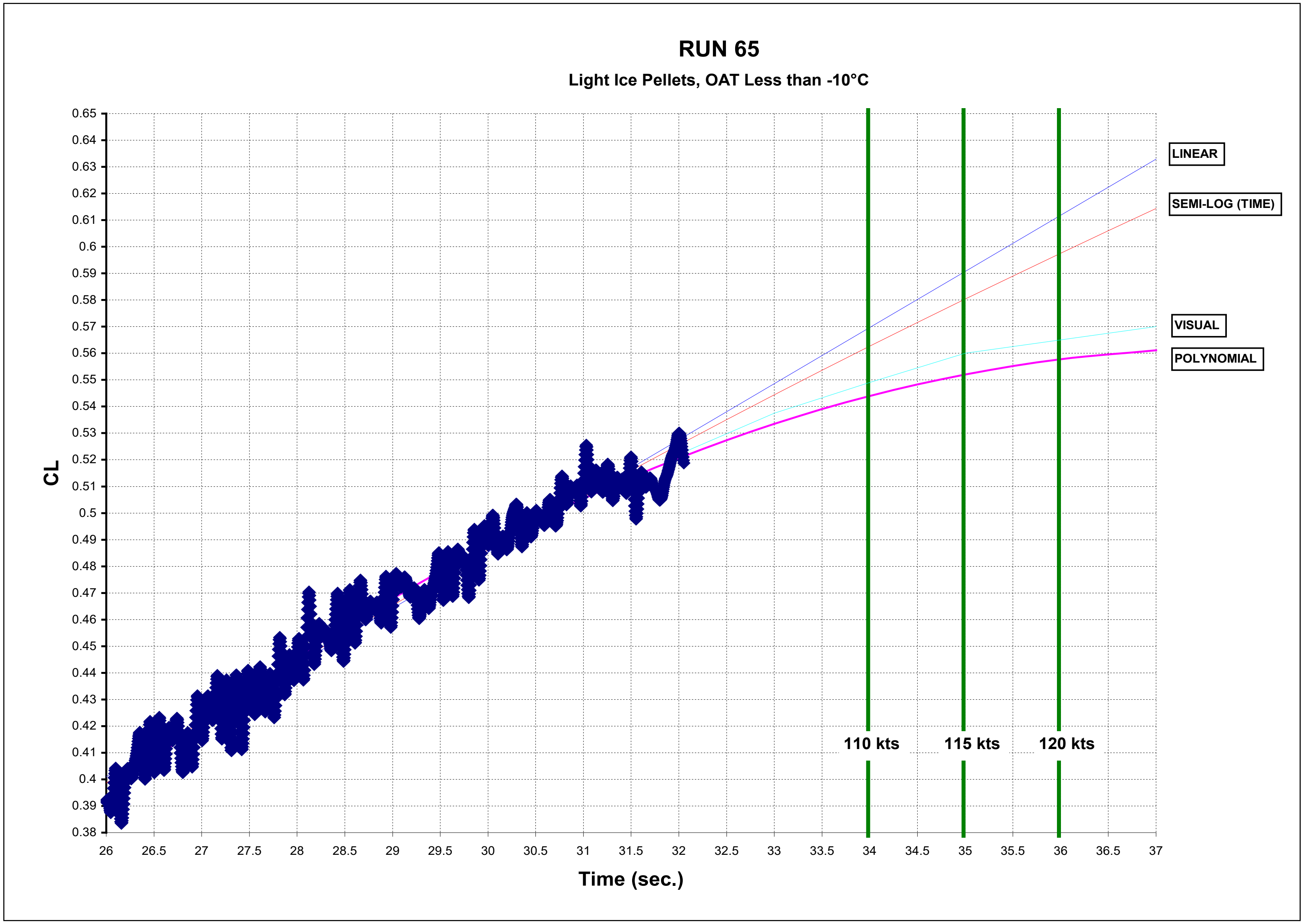


Figure 6.2: Increased Rotation Speed Extrapolation Results – Test #65

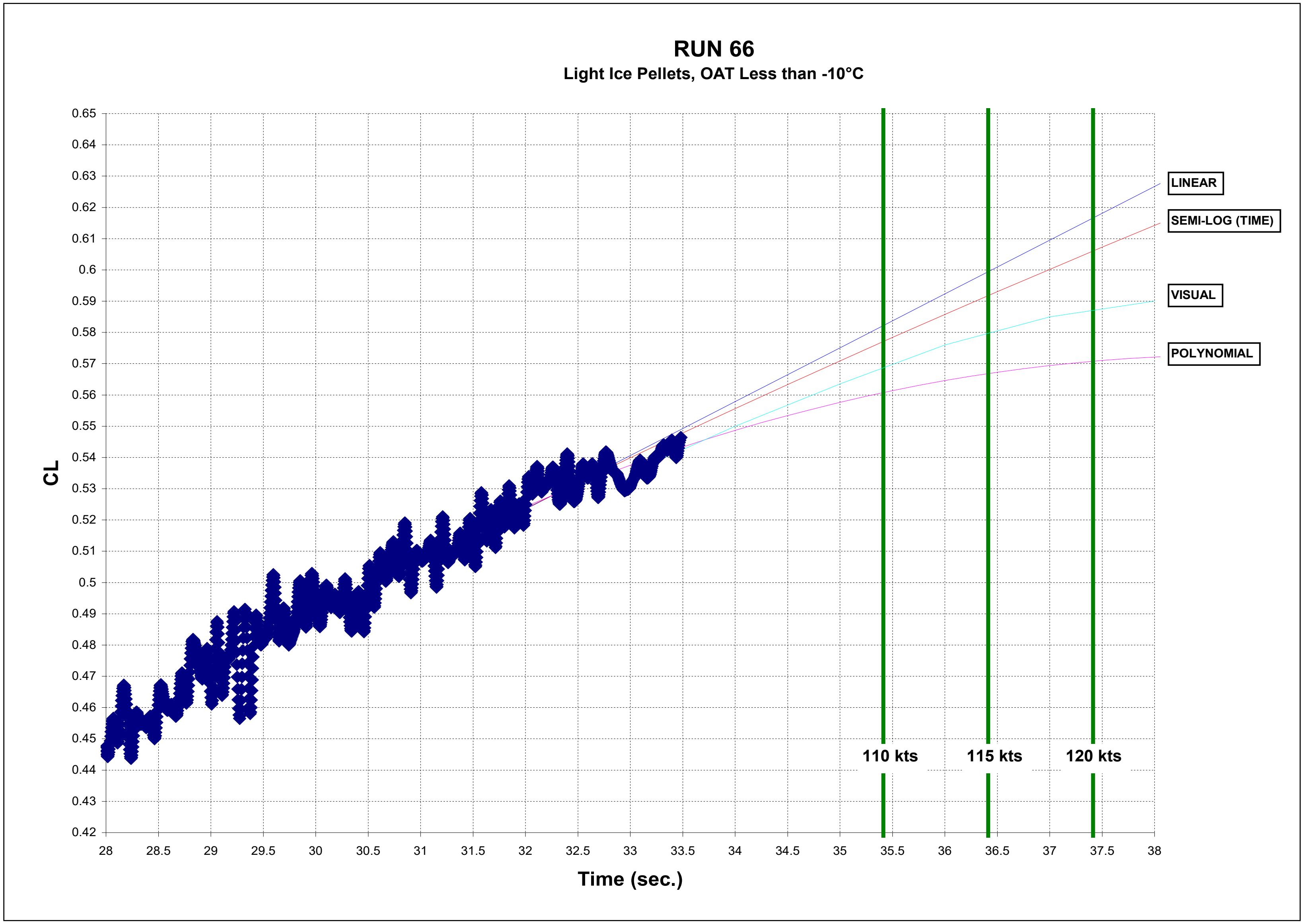


Figure 6.3: Increased Rotation Speed Extrapolation Results – Test #66

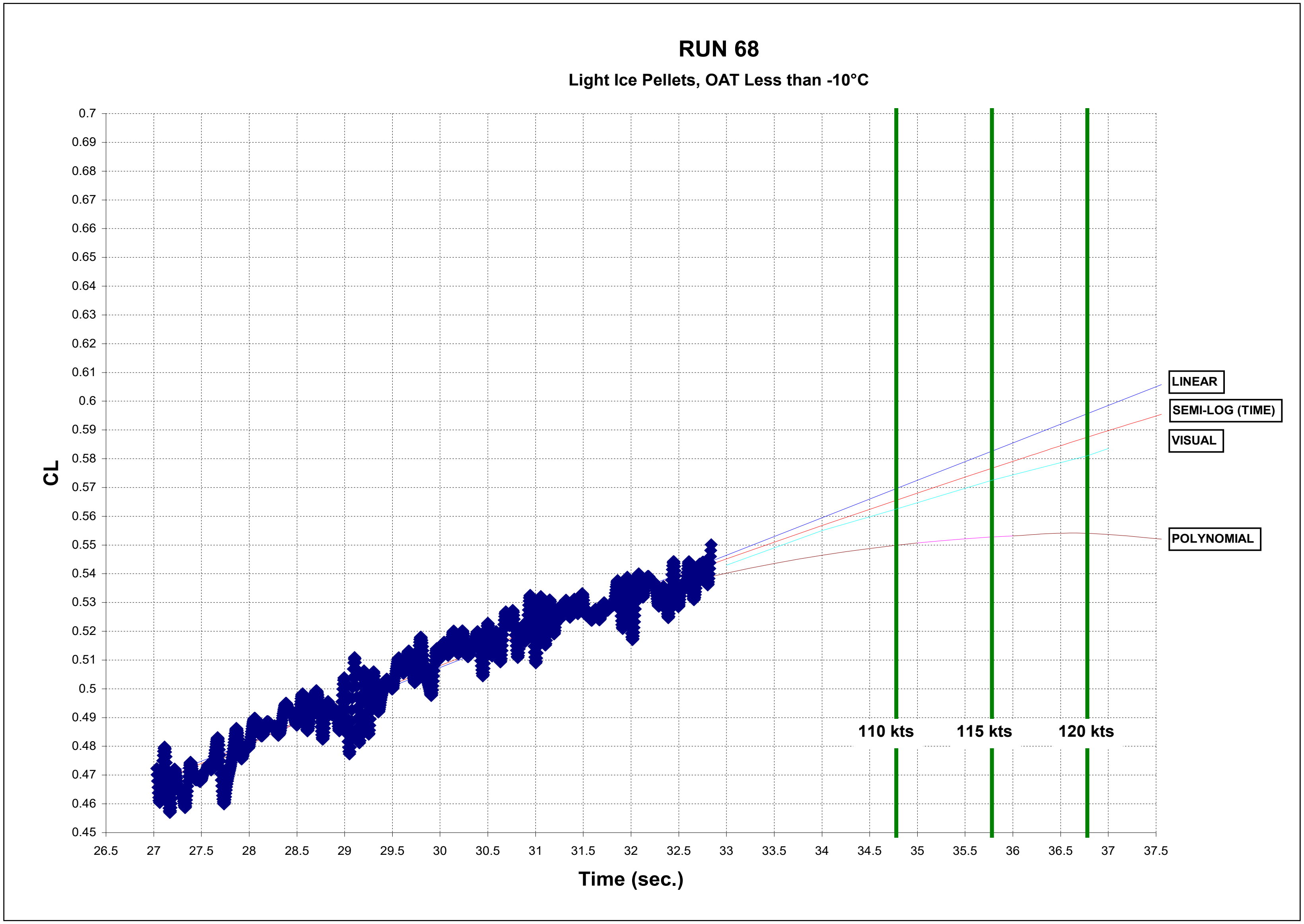
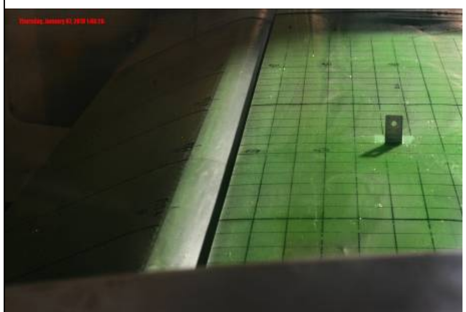


Figure 6.4: Increased Rotation Speed Extrapolation Results – Test #68

Photo 6.1: Test #1 – Start of Test

Test #1
ABC-S Plus, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test



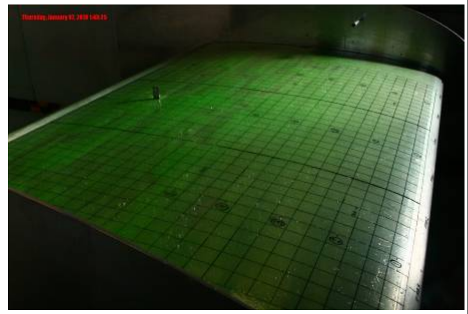
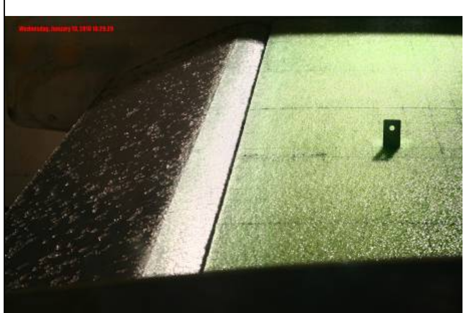


Photo 6.2: Test #1 – Before Rotation

Test #9
ABC-S Plus, IP- 25 g/dm²/h, 50 min
-7°C, 8° Rotation
Visual Contamination Rating (2,2,3)
Start of Test



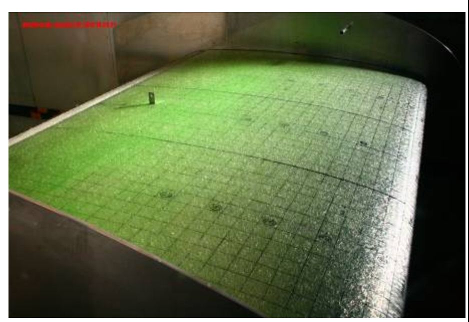
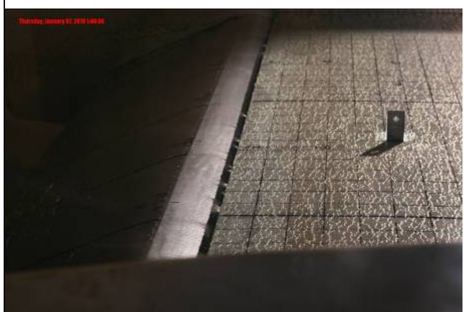


Photo 6.3: Test #1 – End of Rotation

Test #1
ABC-S Plus, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)

Before Rotation



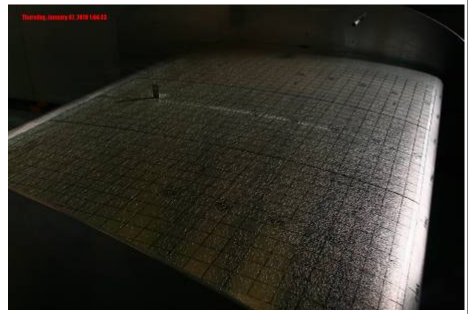
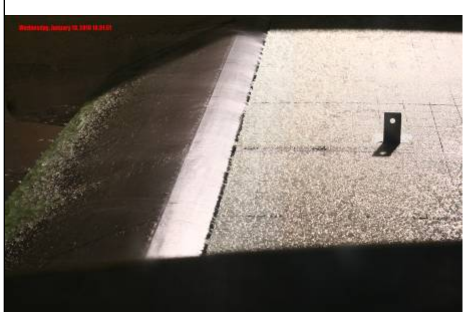


Photo 6.4: Test #1 – End of Test

Test #9
ABC-S Plus, IP- 25 g/dm²/h, 50 min
-7°C, 8° Rotation
Visual Contamination Rating (1,1.8,1.8)

Before Rotation



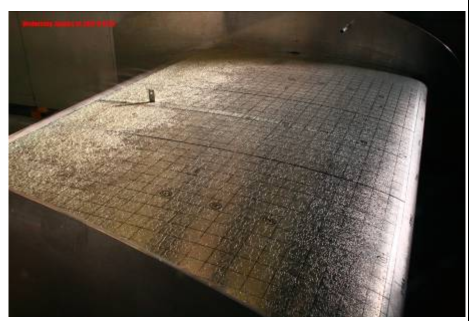


Photo 6.5: Test #9 – Start of Test

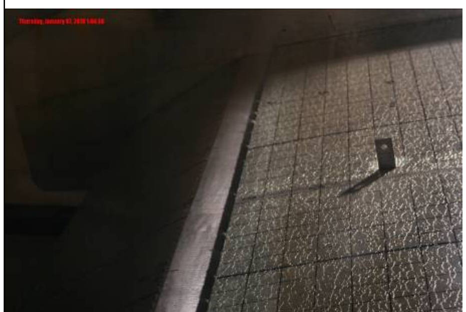
Test #1

ABC-S Plus, Fluid Only

-6°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.01%

End of Rotation



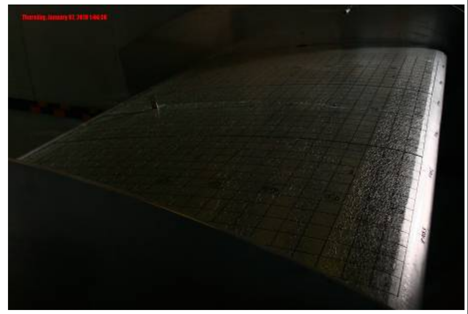


Photo 6.6: Test #9 – Before Rotation

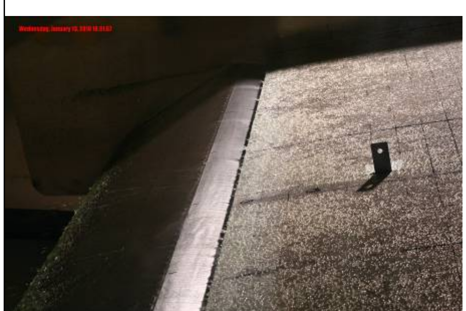
Test #9

ABC-S Plus, IP- 25 g/dm²/h, 50 min

-7°C, 8° Rotation

Visual Contamination Rating (1,1.8,1.8), 8° Lift Loss = 4.67%

End of Rotation



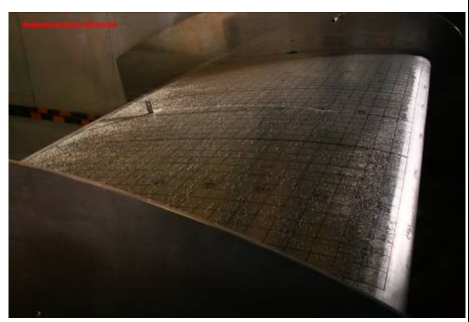


Photo 6.7: Test #9 – End of Rotation

Test #1
ABC-S Plus, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

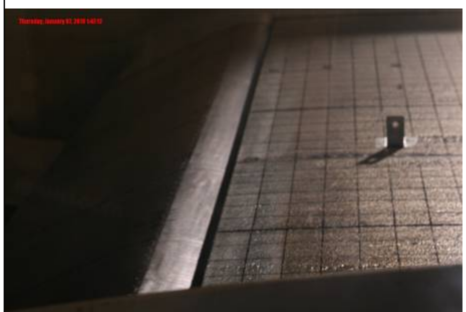


Photo 6.8: Test #9 – End of Test

Test #9
ABC-S Plus, IP- 25 g/dm²/h, 50 min
-7°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

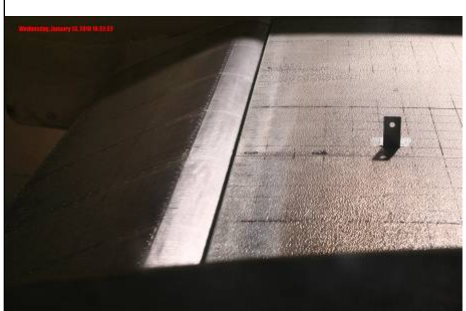
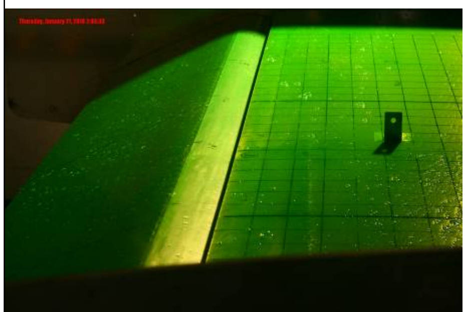


Photo 6.9: Test #25 – Start of Test

Test #25
EG106, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test



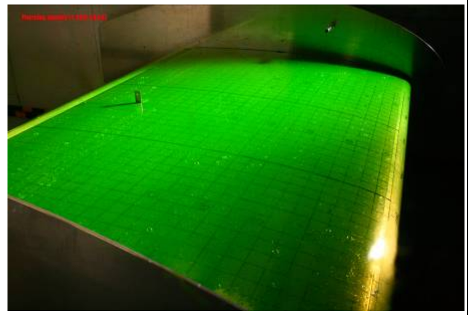
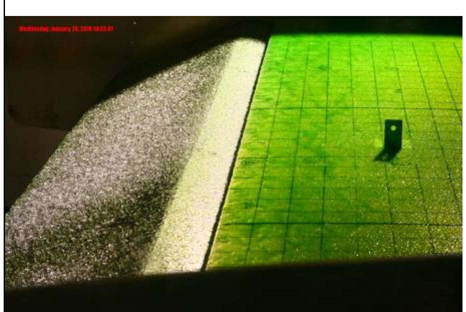


Photo 6.10: Test #25 – Before Rotation

Test #22
EG106, IP- 25 g/dm²/h, 50 min
-4°C, 8° Rotation
Visual Contamination Rating (1.8,2,4)
Start of Test



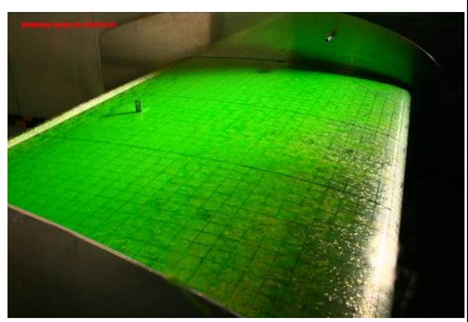


Photo 6.11: Test #25 – End of Rotation

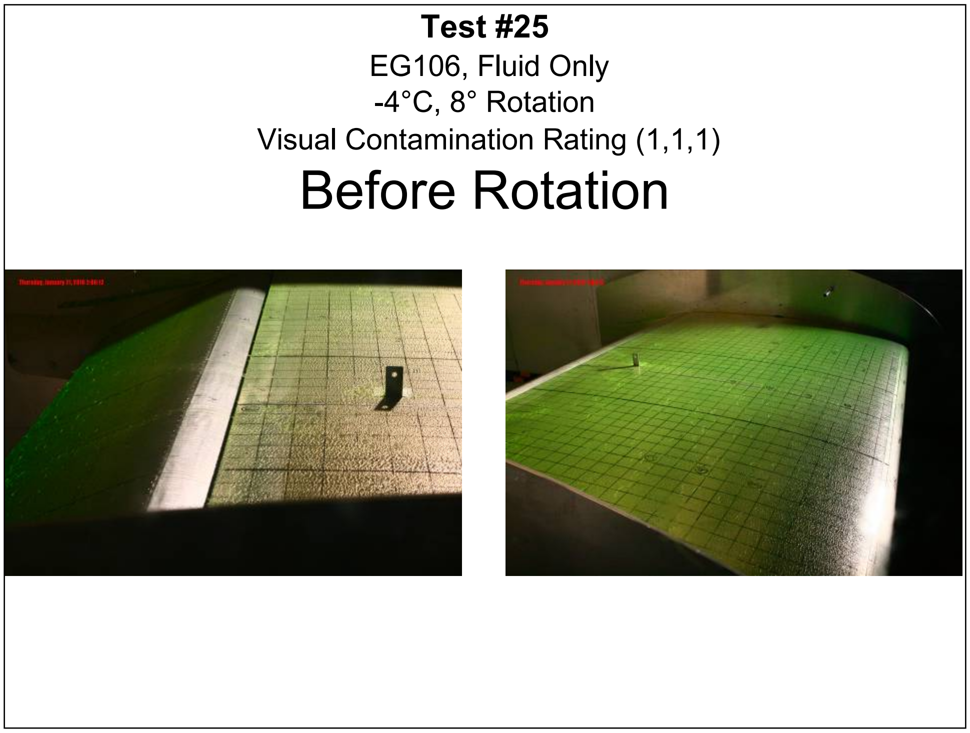


Photo 6.12: Test #25 – End of Test

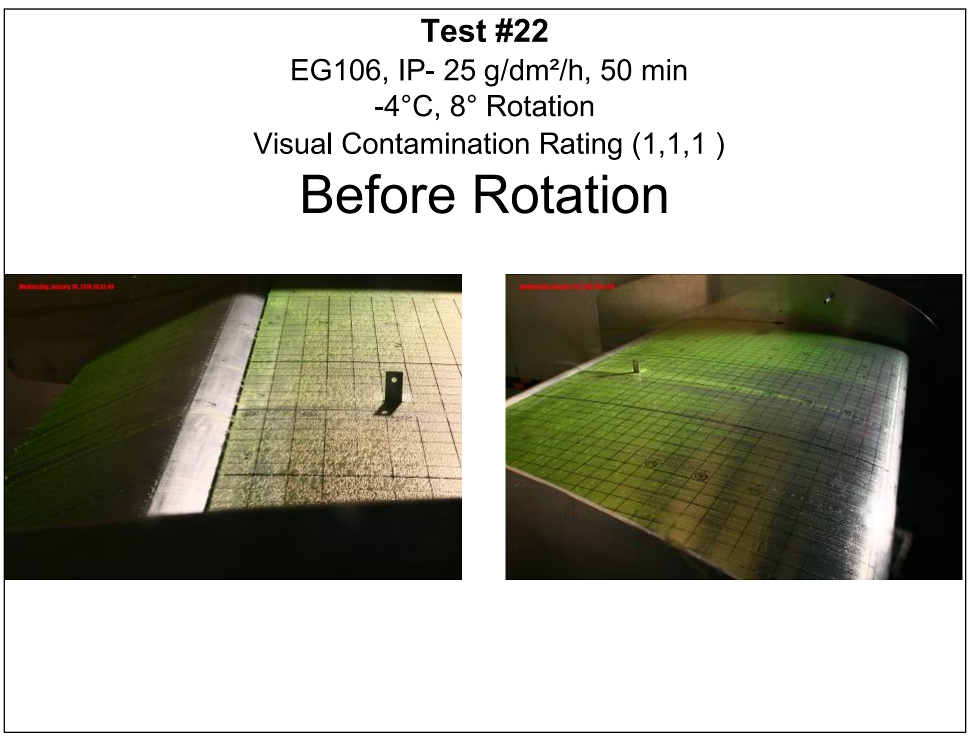


Photo 6.13: Test #22 – Start of Test

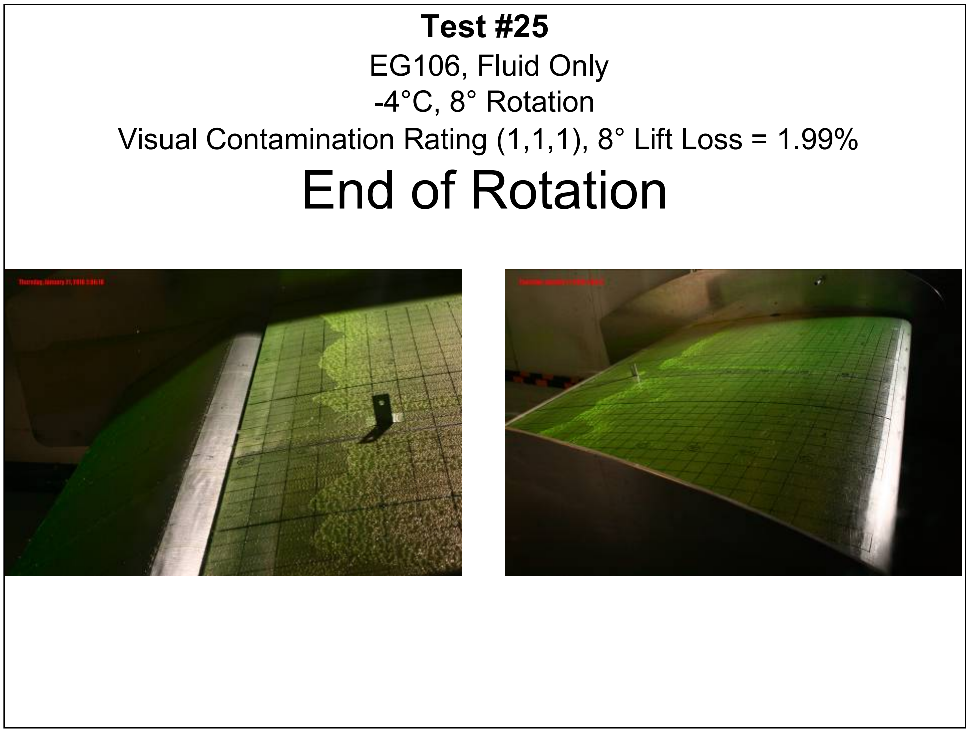


Photo 6.14: Test #22 – Before Rotation

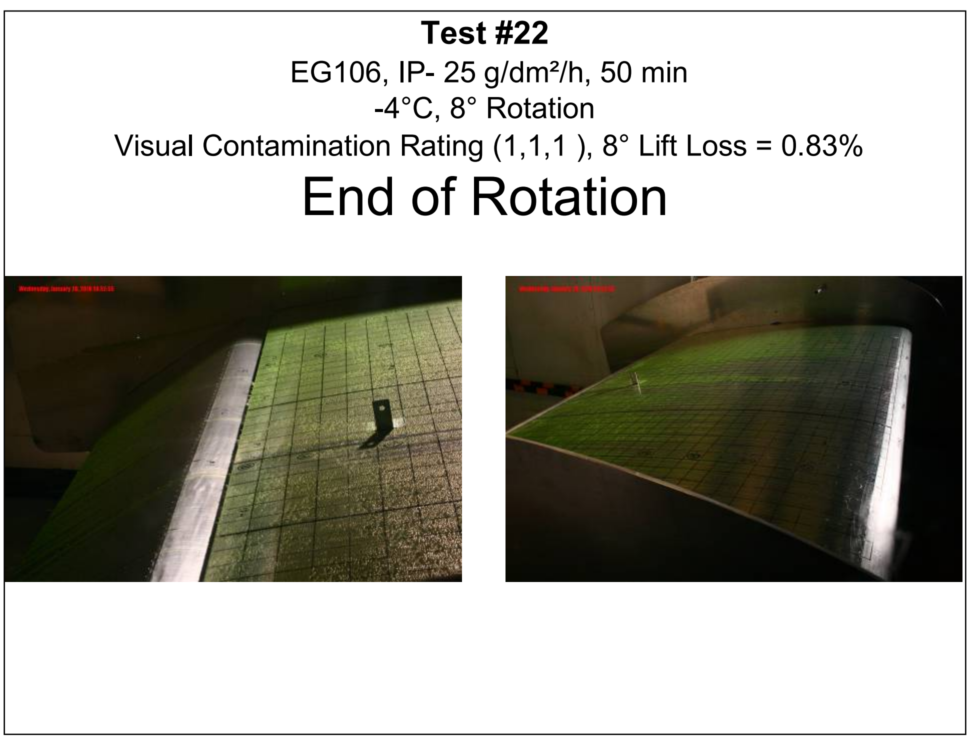
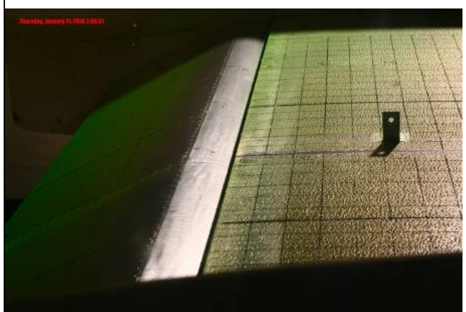


Photo 6.15: Test #22 – End of Rotation

Test #25
EG106, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test



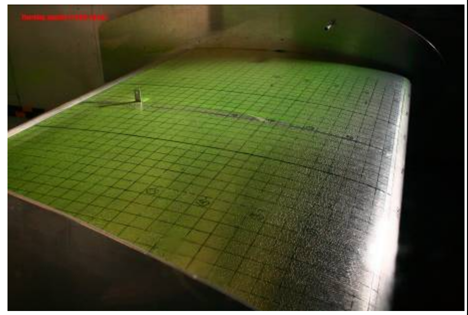
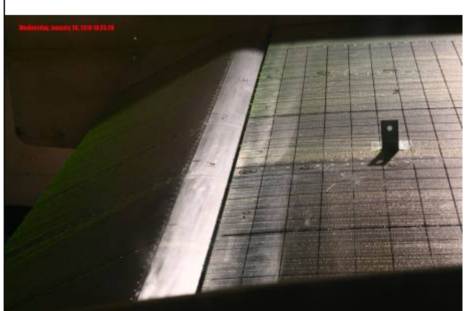


Photo 6.16: Test #22 – End of Test

Test #22
EG106, IP- 25 g/dm²/h, 50 min
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test



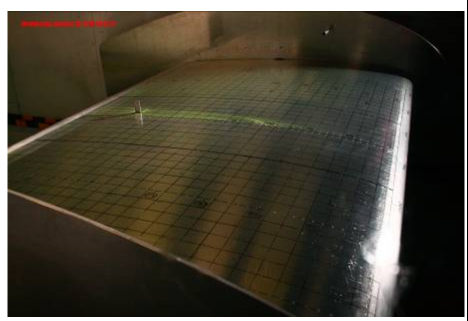


Photo 6.17: Test #29 – Start of Test

Test #29
Launch, Fluid Only
-5°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

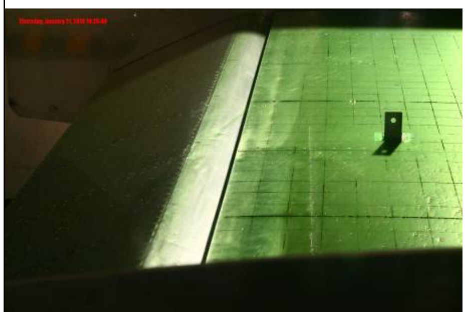
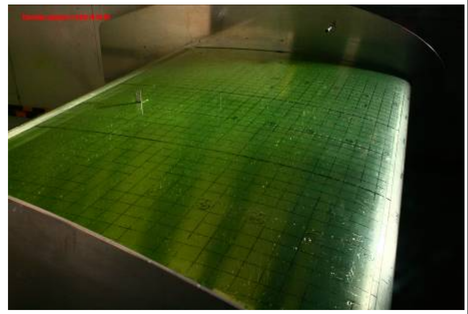



Photo 6.18: Test #29 – Before Rotation

Test #28
Launch, IP- 25 g/dm²/h, 50 min
-4°C, 8° Rotation
Visual Contamination Rating (2,2,3.7)
Start of Test

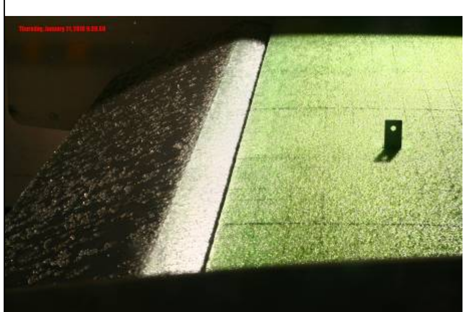
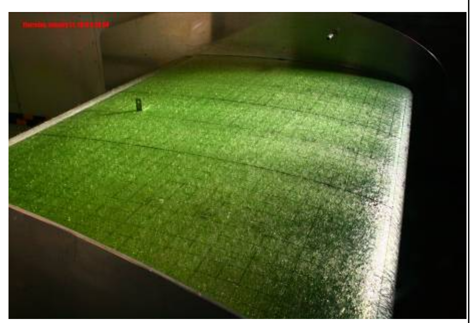



Photo 6.19: Test #29 – End of Rotation

Test #29
Launch, Fluid Only
-5°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

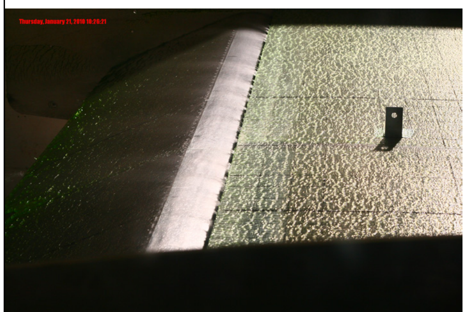
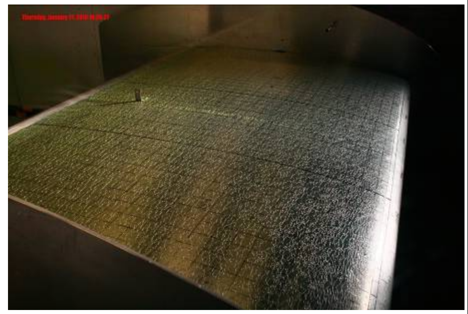



Photo 6.20: Test #29 – End of Test

Test #28
Launch, IP- 25 g/dm²/h, 50 min
-4°C, 8° Rotation
Visual Contamination Rating (1,1.7,2)
Before Rotation

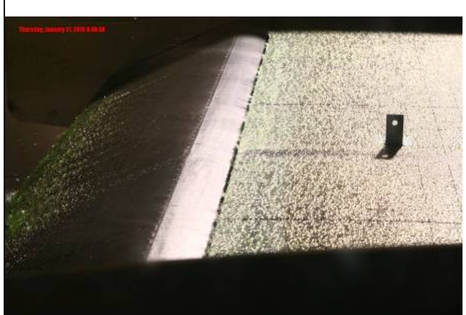



Photo 6.21: Test #28 – Start of Test

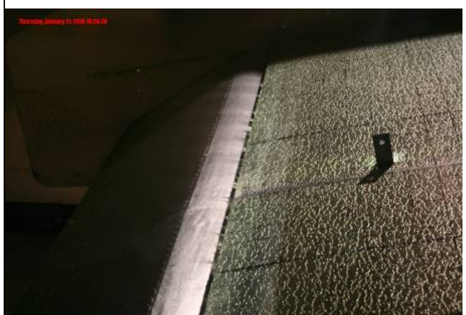
Test #29

Launch, Fluid Only

-5°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 4.96%

End of Rotation



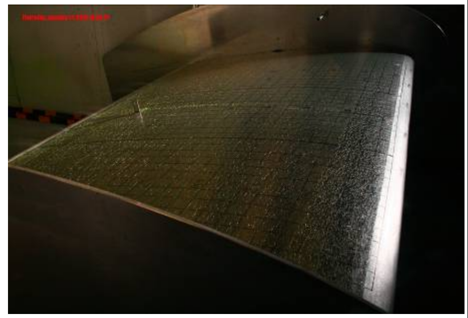


Photo 6.22: Test #28 – Before Rotation

Test #28

Launch, IP- 25 g/dm²/h, 50 min

-4°C, 8° Rotation

Visual Contamination Rating (1,1.7,2), 8° Lift Loss = 4.26%

End of Rotation

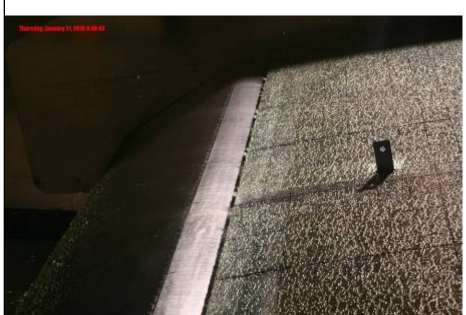


Photo 6.23: Test #28 – End of Rotation

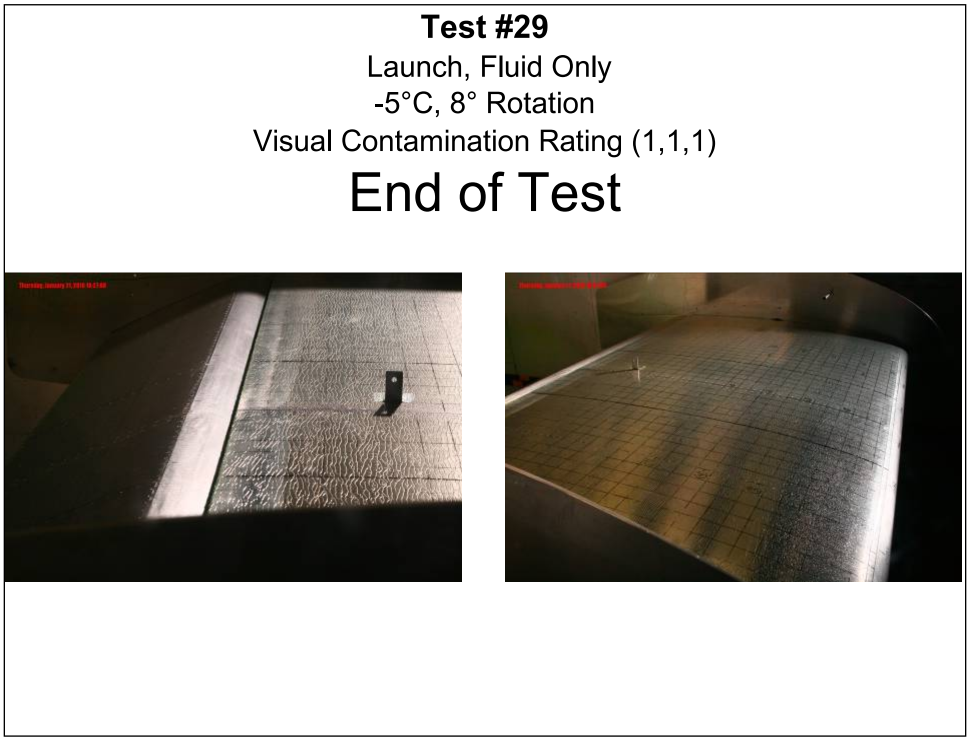


Photo 6.24: Test #28 – End of Test

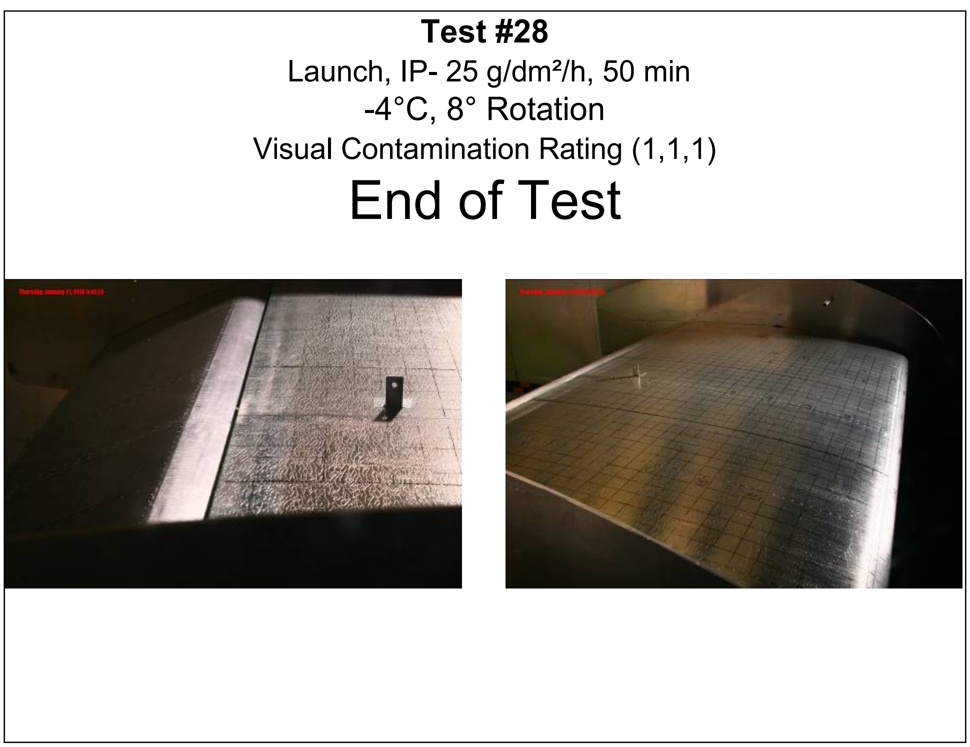


Photo 6.25: Test #29 – Start of Test

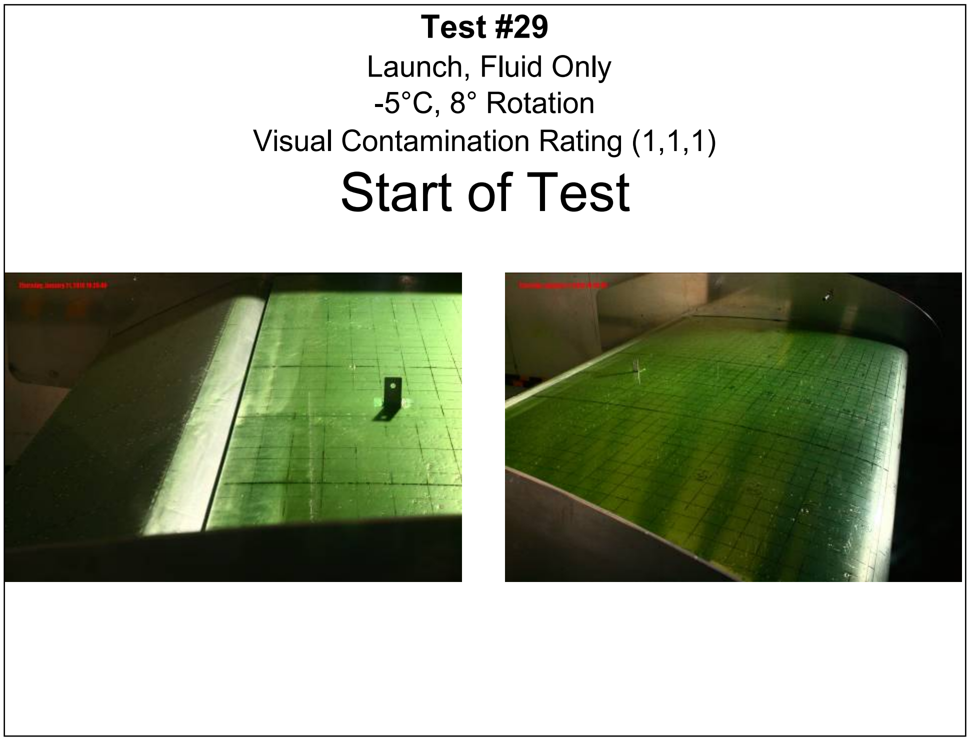


Photo 6.26: Test #29 – Before Rotation

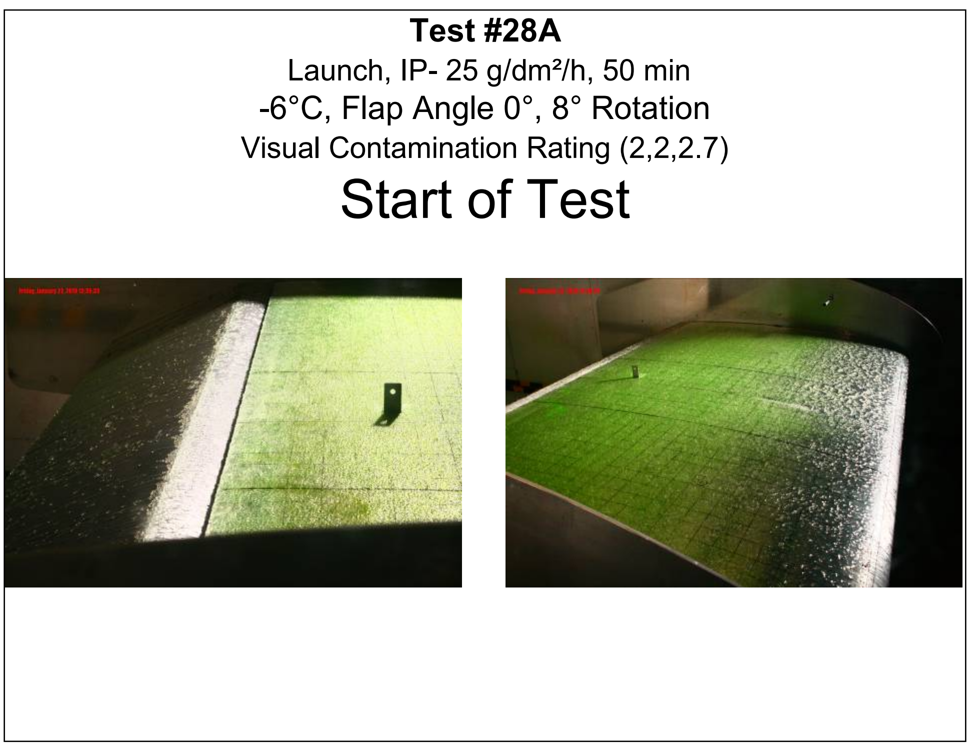


Photo 6.27: Test #29 – End of Rotation

Test #29
Launch, Fluid Only
-5°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

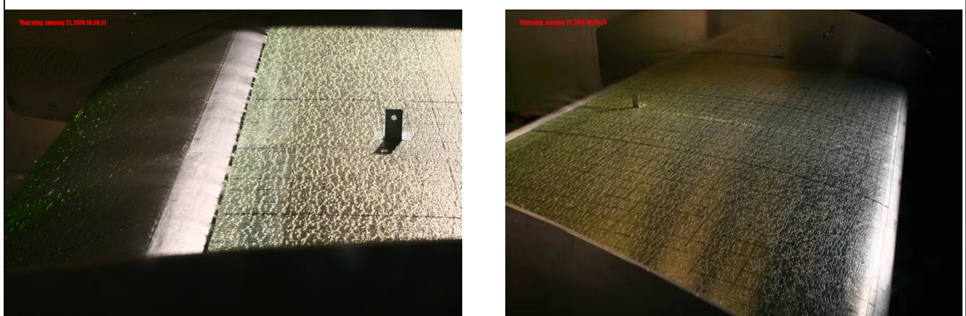


Photo 6.28: Test #29 – End of Test

Test #28A
Launch, IP- 25 g/dm²/h, 50 min
-6°C, Flap Angle 0°, 8° Rotation
Visual Contamination Rating (1,1.5,2)
Before Rotation

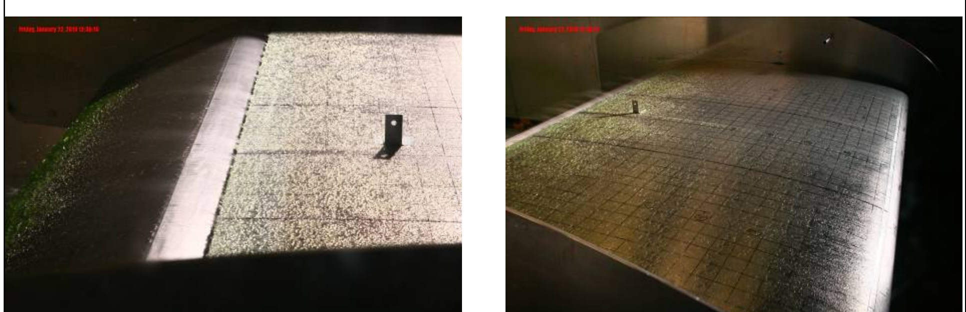


Photo 6.29: Test #28A – Start of Test

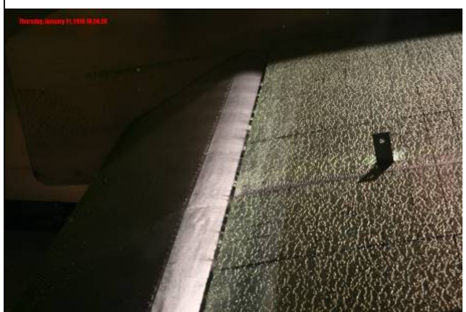
Test #29

Launch, Fluid Only

-5°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 4.96%

End of Rotation



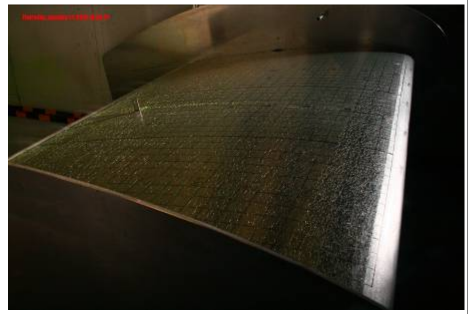


Photo 6.30: Test #28A – Before Rotation

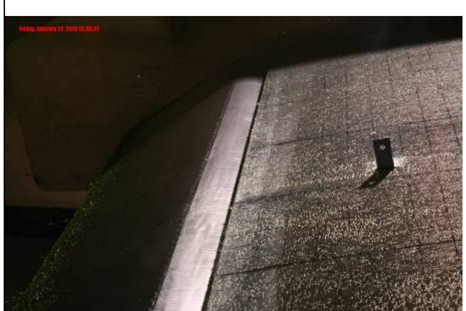
Test #28A

Launch, IP- 25 g/dm²/h, 50 min

-6°C, Flap Angle 0°, 8° Rotation

Visual Contamination Rating (1,1.5,2), 8° Lift Loss = 3.85%

End of Rotation



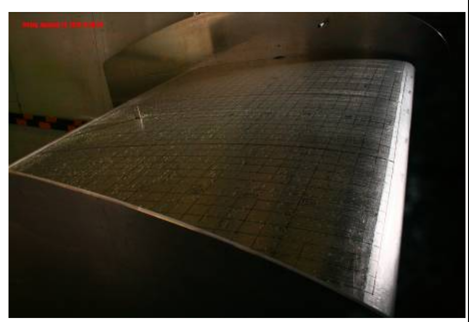


Photo 6.31: Test #28A – End of Rotation

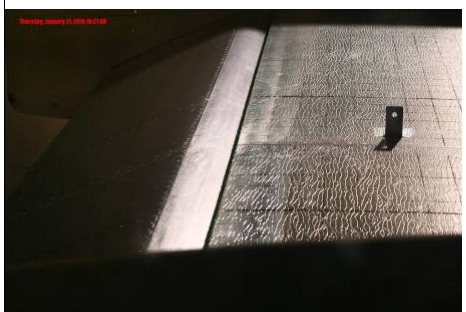
Test #29

Launch, Fluid Only

-5°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test



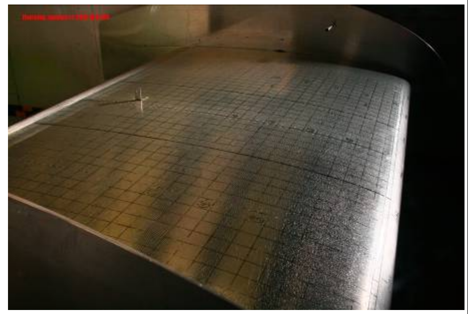


Photo 6.32: Test #28A – End of Test

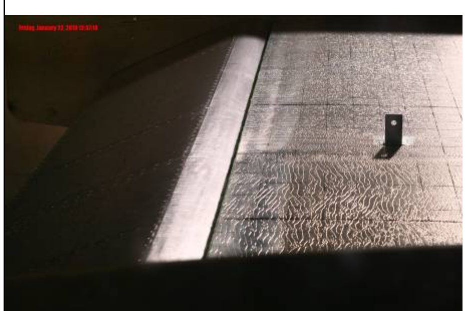
Test #28A

Launch, IP- 25 g/dm²/h, 50 min

-6°C, Flap Angle 0°, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test



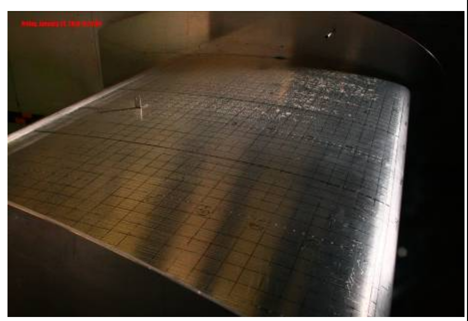


Photo 6.33: Test #64 – Start of Test

Test #64
ABC-S Plus, Fluid Only
-13°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

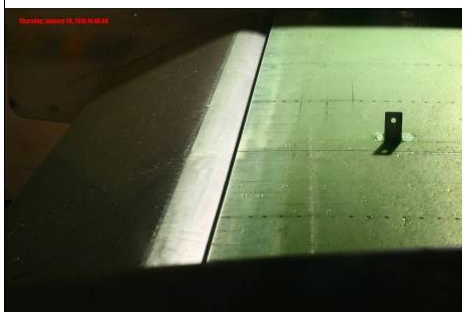
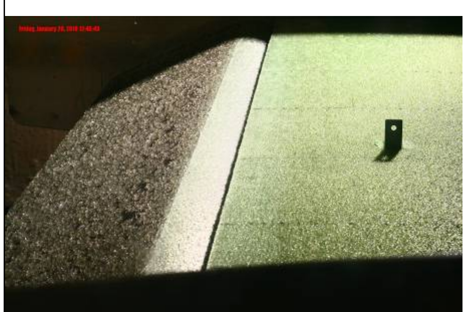


Photo 6.34: Test #64 – Before Rotation

Test #65
ABC-S Plus, IP- 25 g/dm²/h, 30 min
-14°C, 8° Rotation
Visual Contamination Rating (2.8,2.8,4)
Start of Test



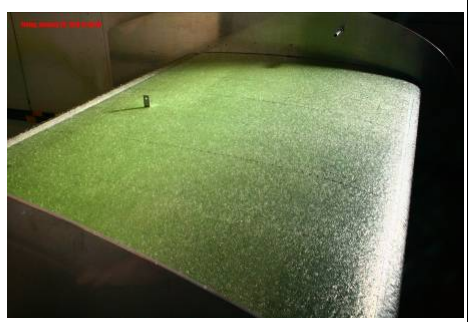


Photo 6.35: Test #64 – End of Rotation

Test #64
ABC-S Plus, Fluid Only
-13°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

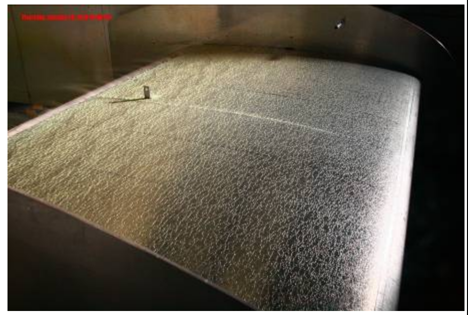


Photo 6.36: Test #64 – End of Test

Test #65
ABC-S Plus, IP- 25 g/dm²/h, 30 min
-14°C, 8° Rotation
Visual Contamination Rating (1.2,2,2.2)
Before Rotation

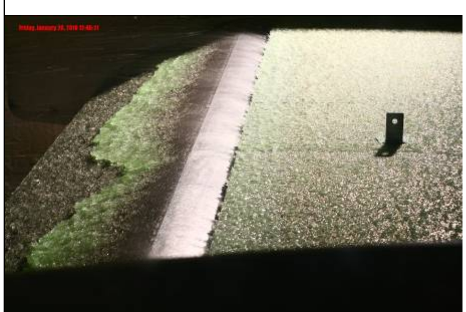


Photo 6.37: Test #65 – Start of Test

Test #64

ABC-S Plus, Fluid Only

-13°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.07%

End of Rotation

Photo 6.38: Test #65 – Before Rotation

Test #65

ABC-S Plus, IP- 25 g/dm²/h, 30 min

-14°C, 8° Rotation

Visual Contamination Rating (1.2,2,2.2), 8° Lift Loss = 9.20%

End of Rotation

Photo 6.39: Test #65 – End of Rotation

Test #64
ABC-S Plus, Fluid Only
-13°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

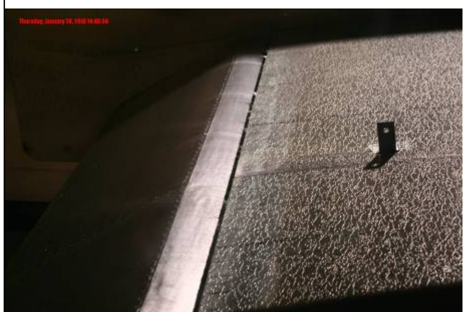



Photo 6.40: Test #65 – End of Test

Test #65
ABC-S Plus, IP- 25 g/dm²/h, 30 min
-14°C, 8° Rotation
Visual Contamination Rating (1,1.7,1.7)
End of Test

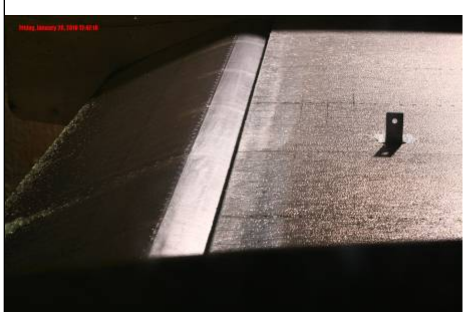
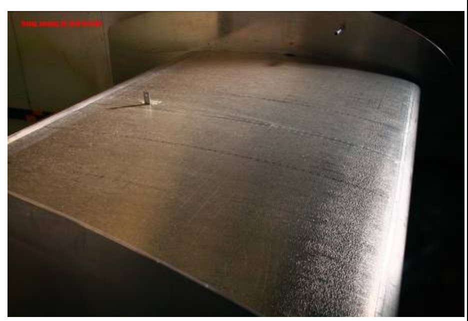



Photo 6.41: Test #64 – Start of Test

Test #64

ABC-S Plus, Fluid Only

-13°C, 8° Rotation

Visual Contamination Rating (1,1,1)

Start of Test

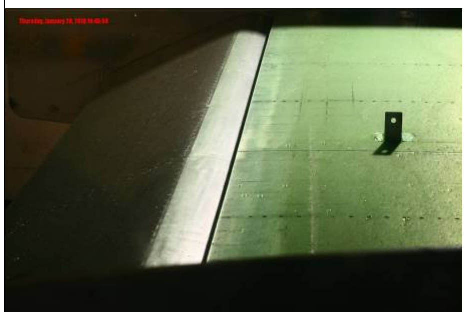


Photo 6.42: Test #64 – Before Rotation

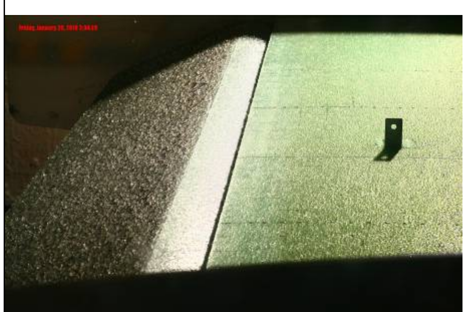
Test #66

ABC-S Plus, IP- 25 g/dm²/h, 20 min

-14°C, 8° Rotation

Visual Contamination Rating (2.2,2,3.2)

Start of Test



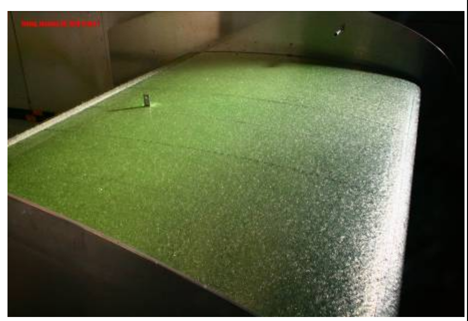


Photo 6.43: Test #64 – End of Rotation

Test #64
ABC-S Plus, Fluid Only
-13°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

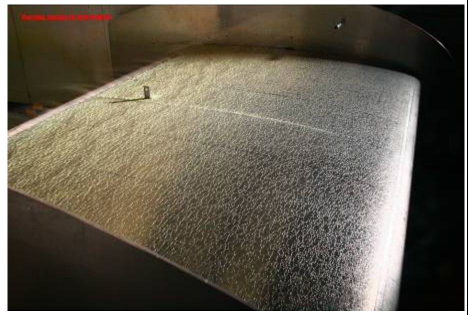



Photo 6.44: Test #64 – End of Test

Test #66
ABC-S Plus, IP- 25 g/dm²/h, 20 min
-14°C, 8° Rotation
Visual Contamination Rating (1.2,2,2.5)
Before Rotation

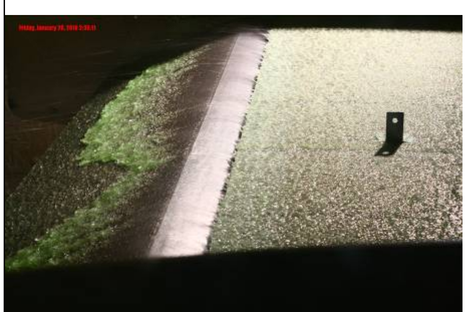



Photo 6.45: Test #66 – Start of Test

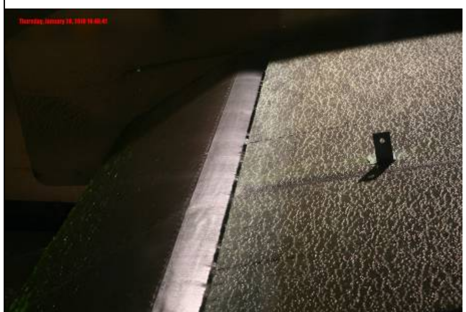
Test #64

ABC-S Plus, Fluid Only

-13°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.07%

End of Rotation



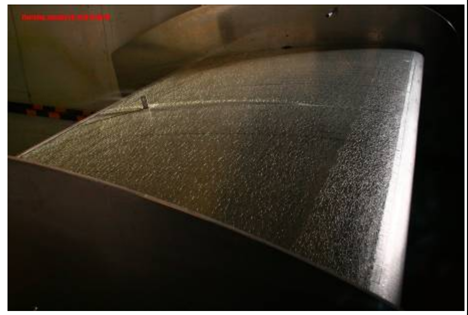


Photo 6.46: Test #66 – Before Rotation

Test #66

ABC-S Plus, IP- 25 g/dm²/h, 20 min

-14°C, 8° Rotation

Visual Contamination Rating (1.2,2,2.5), 8° Lift Loss = 8.62%

End of Rotation

Photo 6.47: Test #66 – End of Rotation

Test #64

ABC-S Plus, Fluid Only

-13°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test

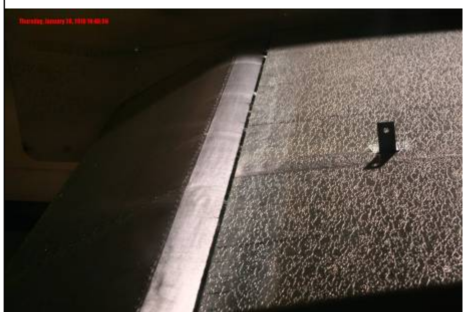


Photo 6.48: Test #66 – End of Test

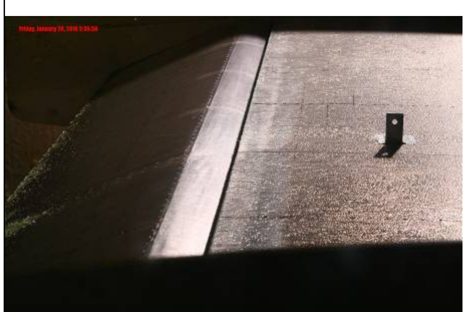
Test #66

ABC-S Plus, IP- 25 g/dm²/h, 20 min

-14°C, 8° Rotation

Visual Contamination Rating (1,1.3,1.7)

End of Test



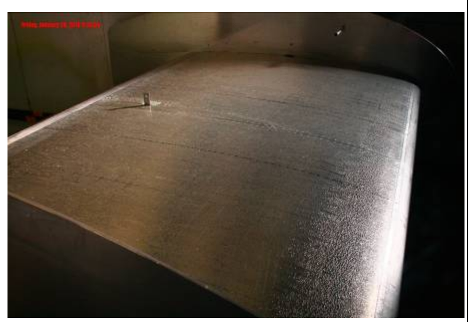
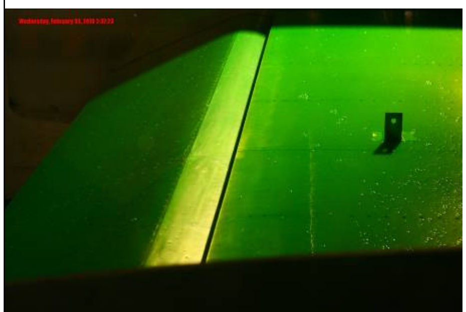


Photo 6.49: Test #100 – Start of Test

Test #100
EG106, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)

Start of Test



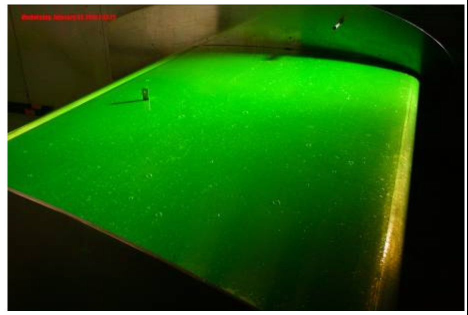
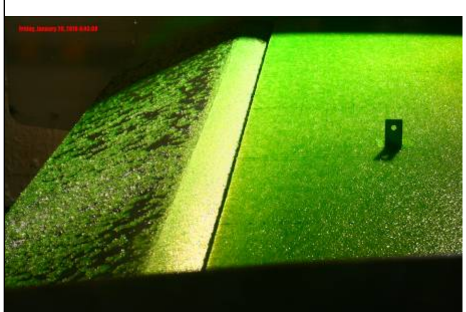


Photo 6.50: Test #100 – Before Rotation

Test #67
EG106, IP- 25 g/dm²/h, 30 min
-13°C, 8° Rotation
Visual Contamination Rating (2.2,2.2,3.2)

Start of Test



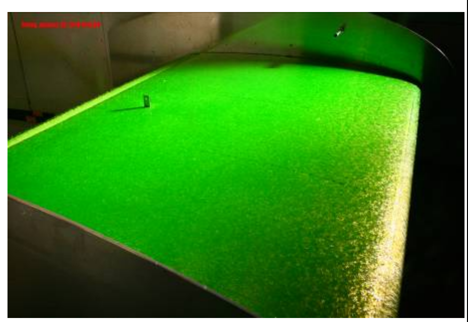


Photo 6.51: Test #100 – End of Rotation

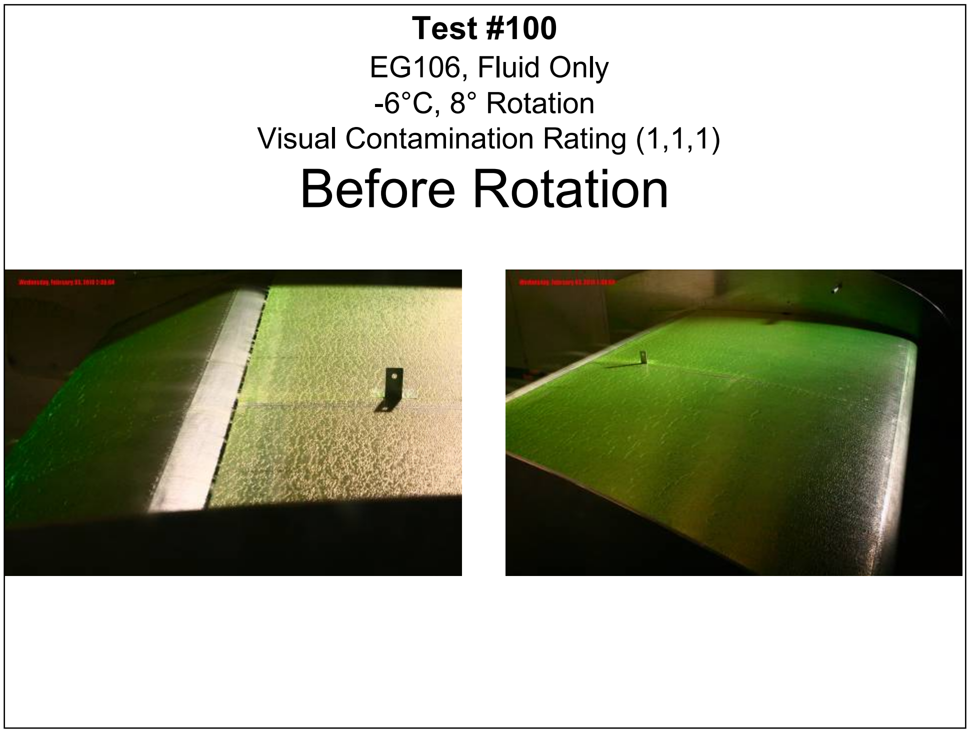


Photo 6.52: Test #100 – End of Test

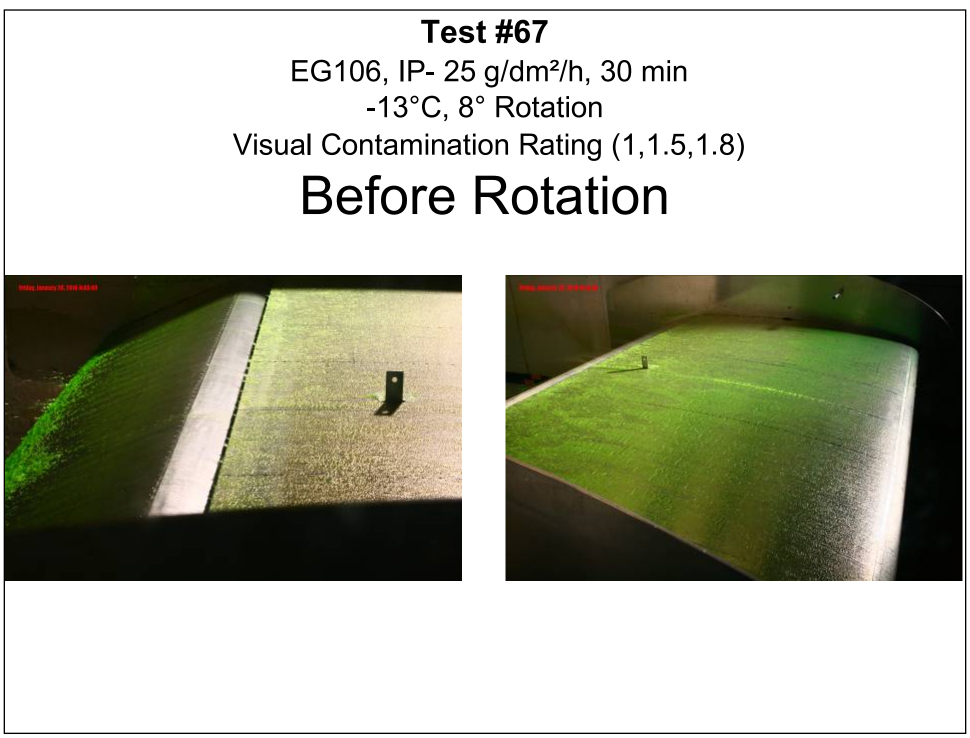


Photo 6.53: Test #67 – Start of Test

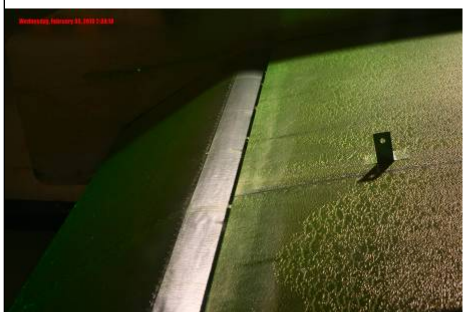
Test #100

EG106, Fluid Only

-6°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 2.28%

End of Rotation



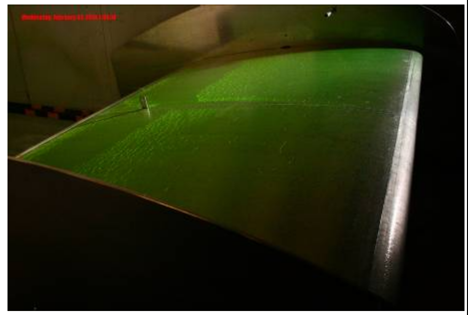


Photo 6.54: Test #67 – Before Rotation

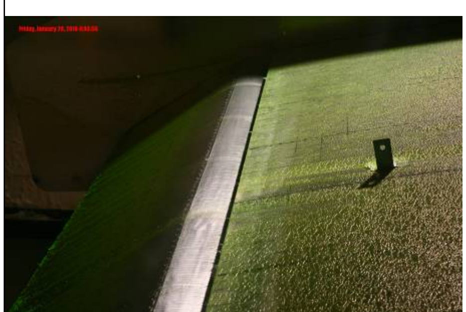
Test #67

EG106, IP- 25 g/dm²/h, 30 min

-13°C, 8° Rotation

Visual Contamination Rating (1,1.5,1.8), 8° Lift Loss = 2.23%

End of Rotation



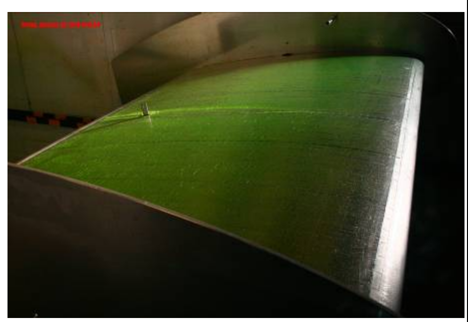


Photo 6.55: Test #67 – End of Rotation

Test #100
EG106, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

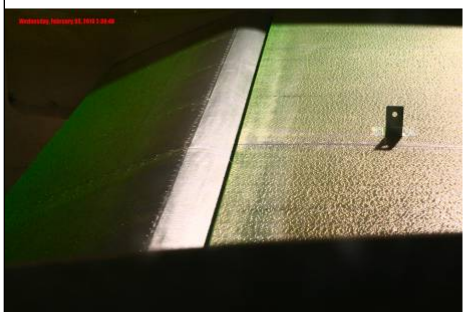
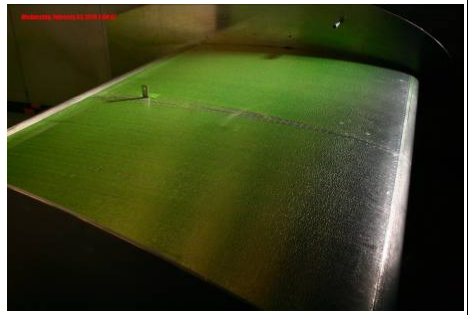



Photo 6.56: Test #67 – End of Test

Test #67
EG106, IP- 25 g/dm²/h, 30 min
-13°C, 8° Rotation
Visual Contamination Rating (1,1,1.2)
End of Test

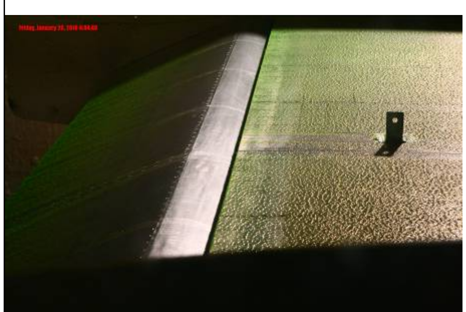
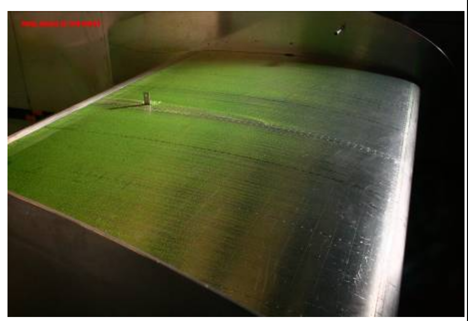



Photo 6.57: Test #70 – Start of Test

Test #70
Launch, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

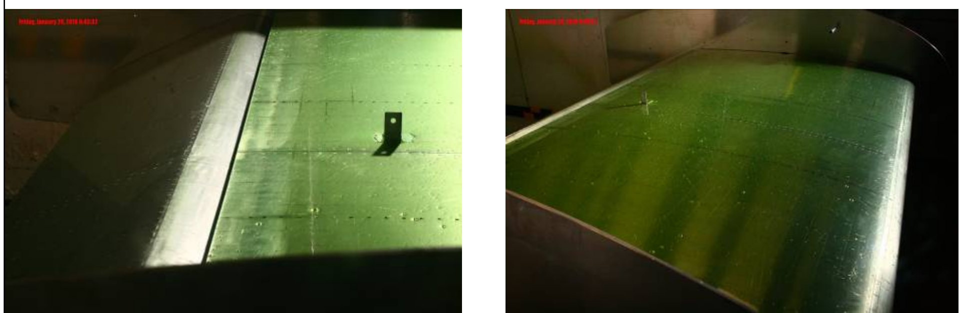


Photo 6.58: Test #70 – Before Rotation

Test #68
Launch, IP- 25 g/dm²/h, 30 min
-17°C, 8° Rotation
Visual Contamination Rating (3,2.5,3.7)
Start of Test

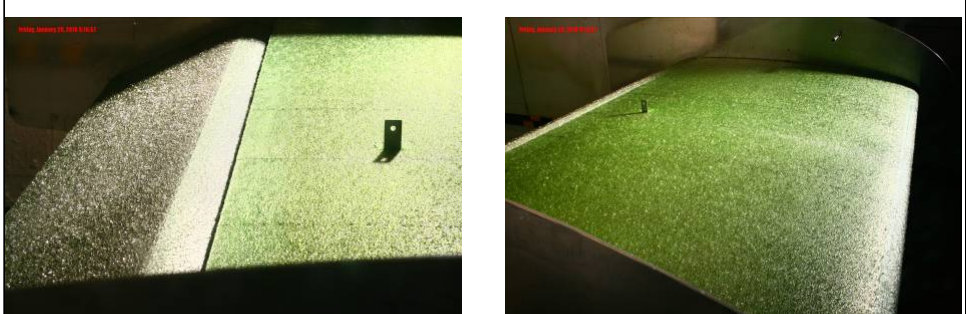


Photo 6.59: Test #70 – End of Rotation

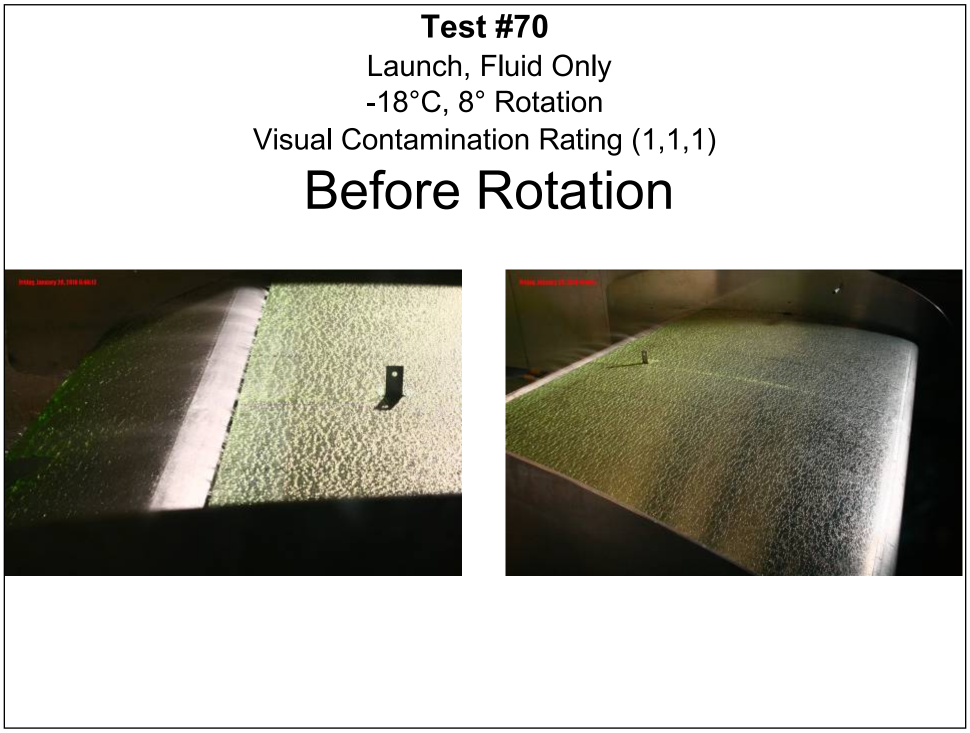


Photo 6.60: Test #70 – End of Test

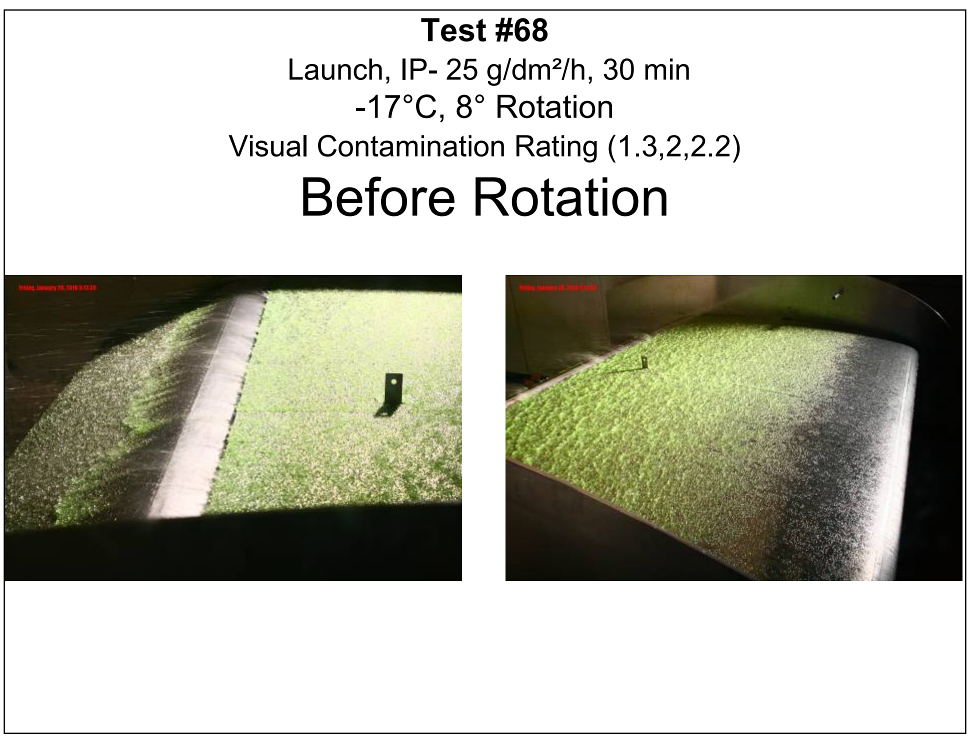


Photo 6.61: Test #68 – Start of Test

Test #70

Launch, Fluid Only

-18°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.59%

End of Rotation

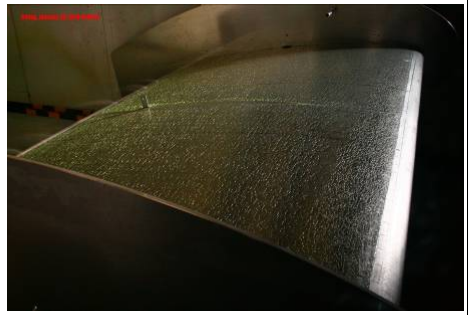


Photo 6.62: Test #68 – Before Rotation

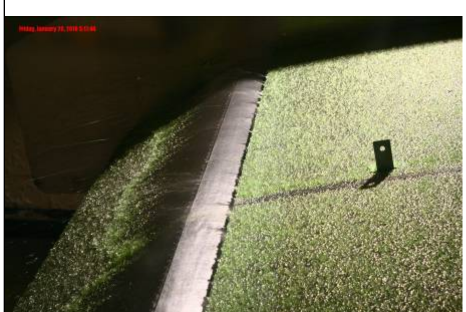
Test #68

Launch, IP- 25 g/dm²/h, 30 min

-17°C, 8° Rotation

Visual Contamination Rating (1.3,2,2.2), 8° Lift Loss = 9.60%

End of Rotation



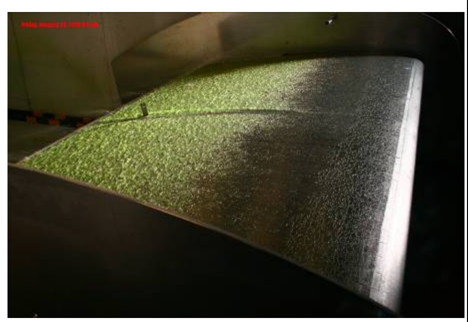


Photo 6.63: Test #68 – End of Rotation

Test #70
Launch, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

Photo 6.64: Test #68 – End of Test

Test #68
Launch, IP- 25 g/dm²/h, 30 min
-17°C, 8° Rotation
Visual Contamination Rating (1,1.8,2)
End of Test

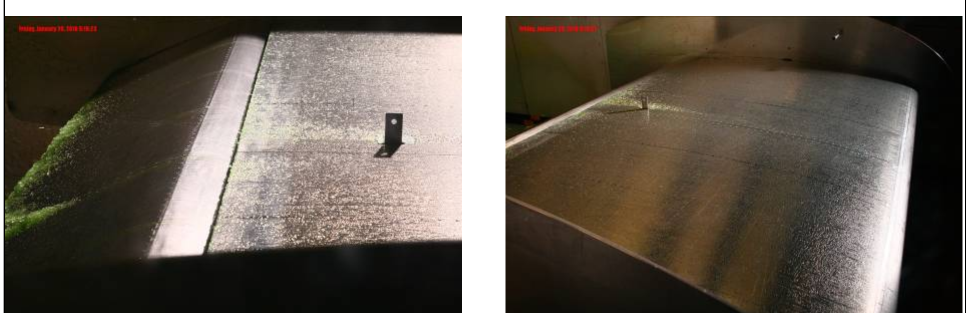
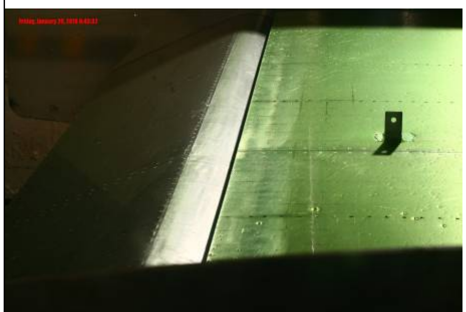


Photo 6.65: Test #70 – Start of Test

Test #70
Launch, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test



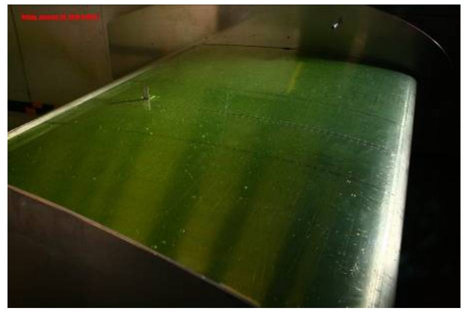
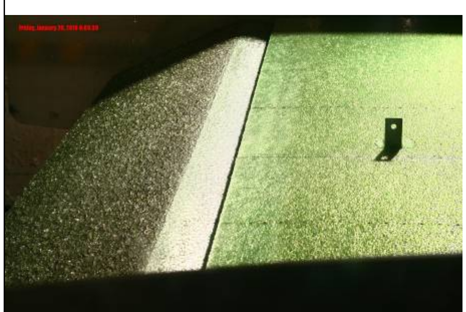


Photo 6.66: Test #70 – Before Rotation

Test #69
Launch, IP- 25 g/dm²/h, 15 min
-18°C, 8° Rotation
Visual Contamination Rating (2.8,2.5,3.5)
Start of Test



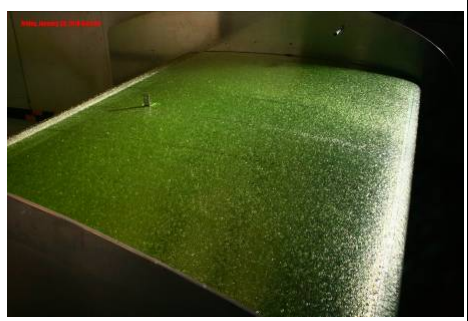


Photo 6.67: Test #70 – End of Rotation

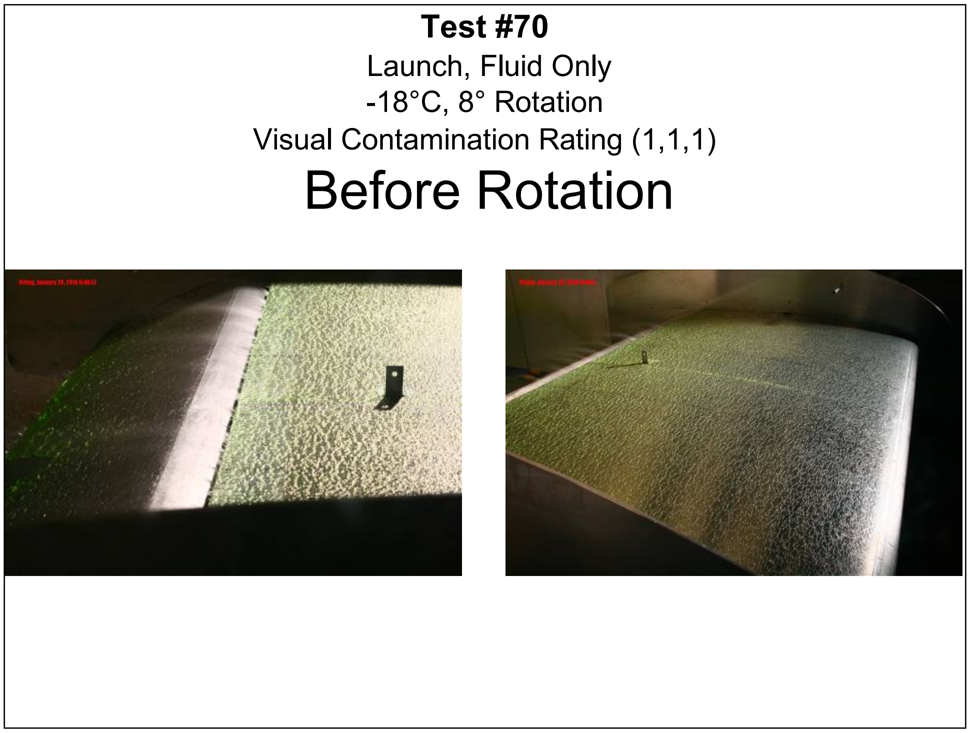


Photo 6.68: Test #70 – End of Test

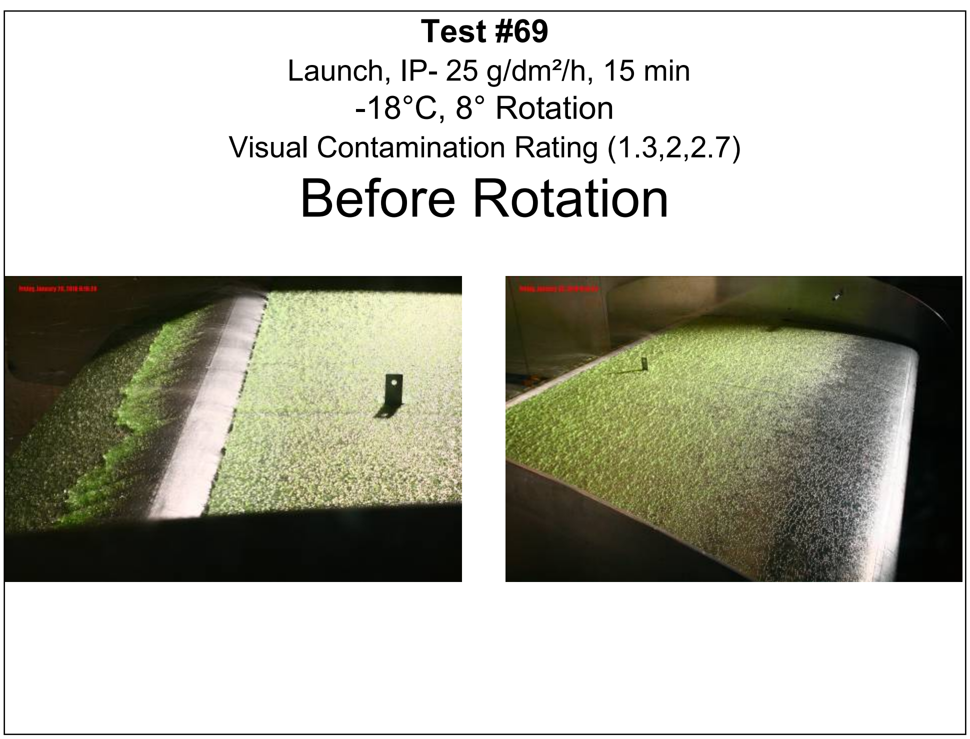


Photo 6.69: Test #69 – Start of Test

Test #70

Launch, Fluid Only

-18°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.59%

End of Rotation

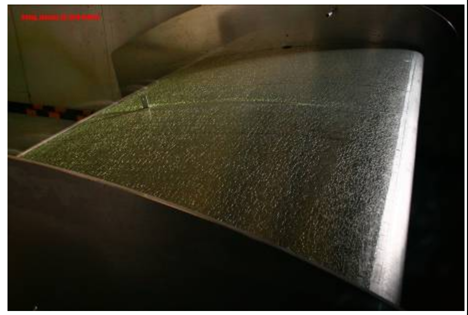


Photo 6.70: Test #69 – Before Rotation

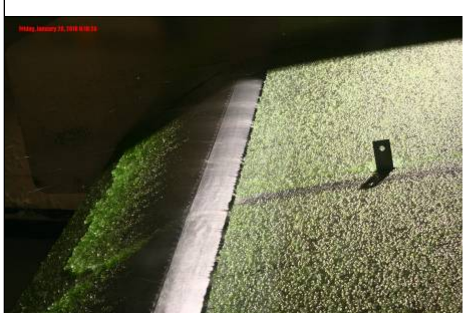
Test #69

Launch, IP- 25 g/dm²/h, 15 min

-18°C, 8° Rotation

Visual Contamination Rating (1.3,2,2.7), 8° Lift Loss = 9.60%

End of Rotation



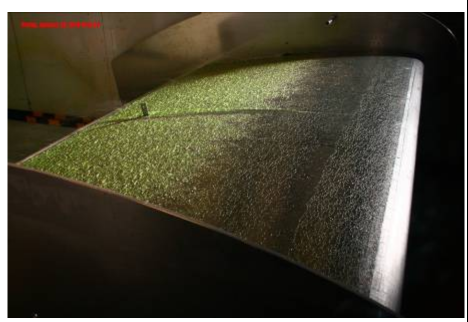


Photo 6.71: Test #69 – End of Rotation

Test #70

Launch, Fluid Only

-18°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test

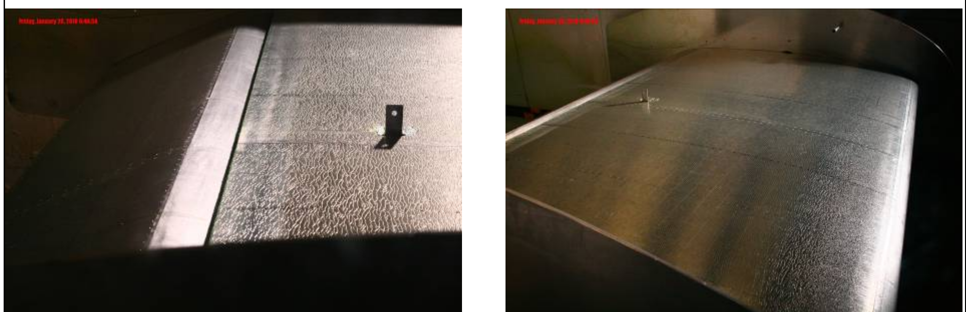


Photo 6.72: Test #69 – End of Test

Test #69

Launch, IP- 25 g/dm²/h, 15 min

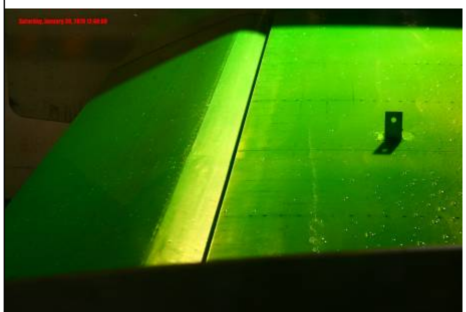
-18°C, 8° Rotation

Visual Contamination Rating (1,1,1.8)

End of Test

Photo 6.73: Test #75 – Start of Test

Test #75
EG106, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test



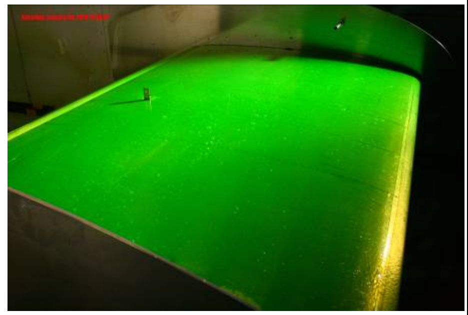
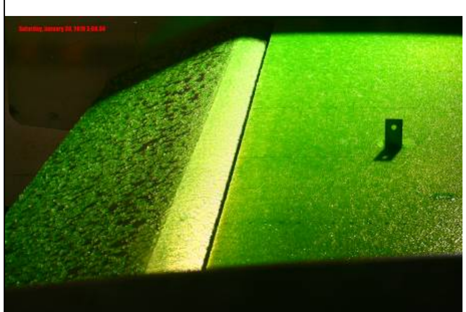


Photo 6.74: Test #75 – Before Rotation

Test #80
EG106, IP- 25 g/dm²/h, 30 min
-17°C, 8° Rotation
Visual Contamination Rating (2.5,2.2,3)
Start of Test



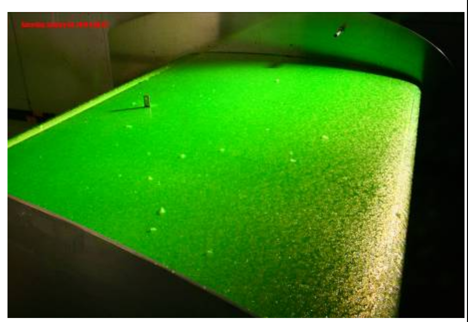


Photo 6.75: Test #75 – End of Rotation

Test #75
EG106, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

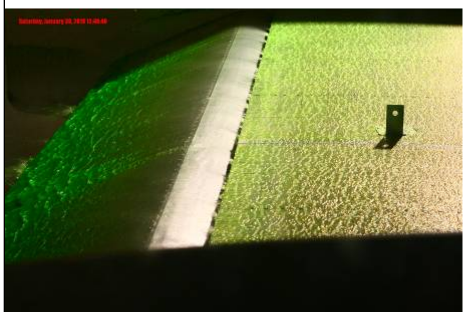
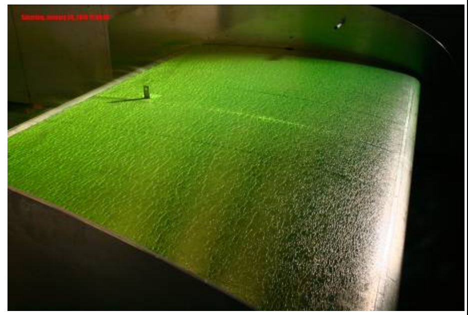



Photo 6.76: Test #75 – End of Test

Test #80
EG106, IP- 25 g/dm²/h, 30 min
-17°C, 8° Rotation
Visual Contamination Rating (1,1.25,1.7)
Before Rotation

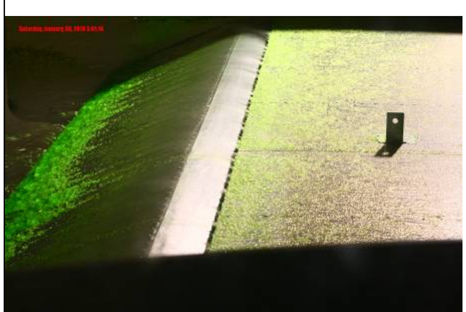
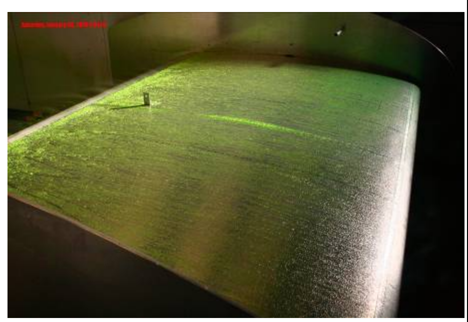



Photo 6.77: Test #80 – Start of Test

Test #75
EG106, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 4.08%

End of Rotation

Photo 6.78: Test #80 – Before Rotation

Test #80
EG106, IP- 25 g/dm²/h, 30 min
-17°C, 8° Rotation
Visual Contamination Rating (1,1.25,1.7), 8° Lift Loss = 2.98%

End of Rotation

Photo 6.79: Test #80 – End of Rotation

Test #75
EG106, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)

End of Test

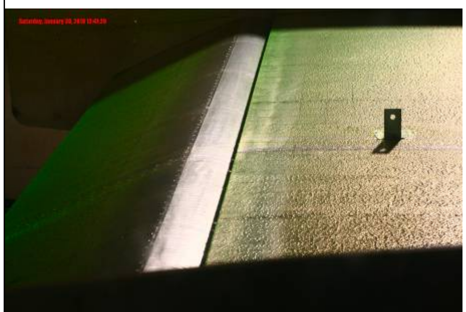
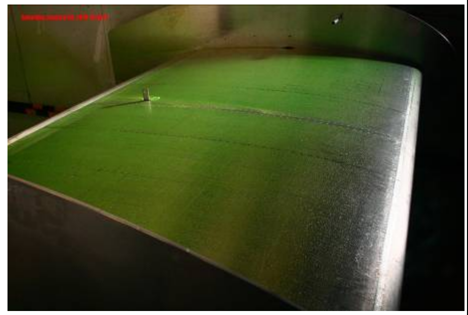



Photo 6.80: Test #80 – End of Test

Test #80
EG106, IP- 25 g/dm²/h, 30 min
-17°C, 8° Rotation
Visual Contamination Rating (1,1,1)

End of Test

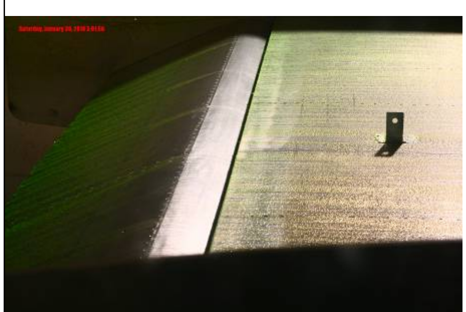
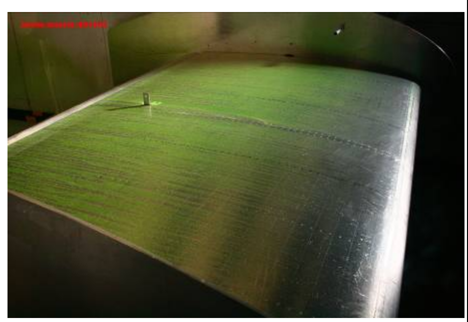



Photo 6.81: Test #64 – Start of Test

Test #64
ABC-S Plus, Fluid Only
-13°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

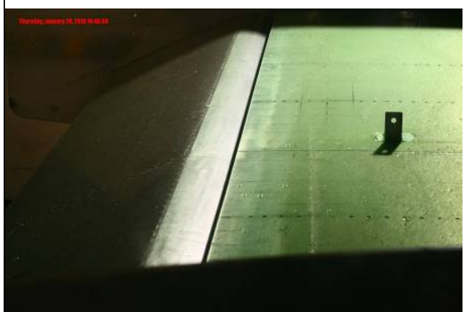



Photo 6.82: Test #64 – Before Rotation

Test #96
ABC-S Plus, IP- 25 g/dm²/h, 30 min
-8°C, 8° Rotation
Visual Contamination Rating (2.3,2,3)
Start of Test

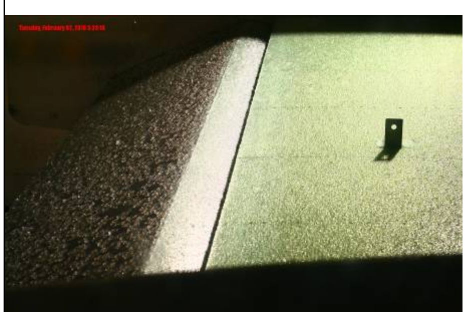



Photo 6.83: Test #64 – End of Rotation

Test #64
ABC-S Plus, Fluid Only
-13°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

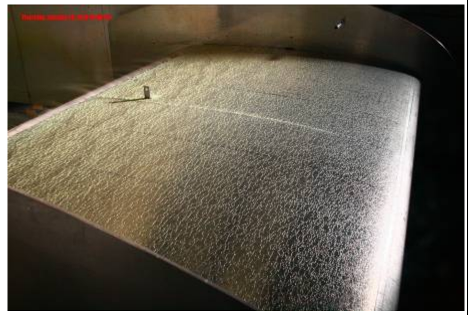
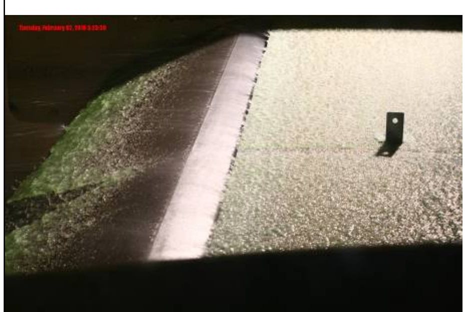


Photo 6.84: Test #64 – End of Test

Test #96
ABC-S Plus, IP- 25 g/dm²/h, 30 min
-8°C, 8° Rotation
Visual Contamination Rating (1,2,2)
Before Rotation



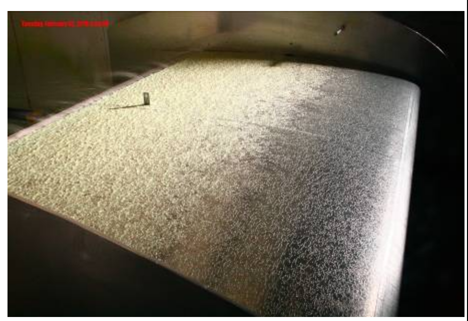


Photo 6.85: Test #96 – Start of Test

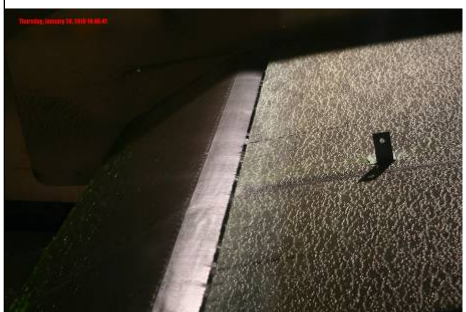
Test #64

ABC-S Plus, Fluid Only

-13°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.07%

End of Rotation



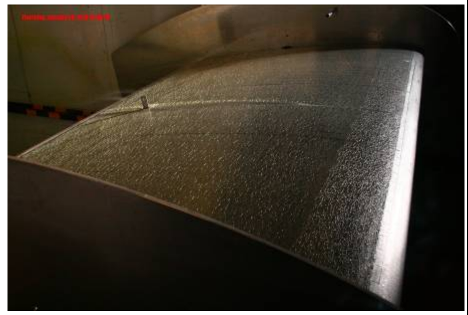


Photo 6.86: Test #96 – Before Rotation

Test #96

ABC-S Plus, IP- 25 g/dm²/h, 30 min

-8°C, 8° Rotation

Visual Contamination Rating (1,2,2), 8° Lift Loss = 6.58%

End of Rotation

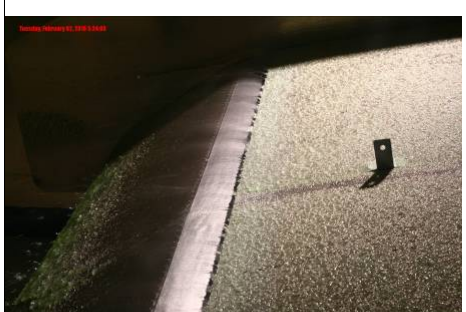
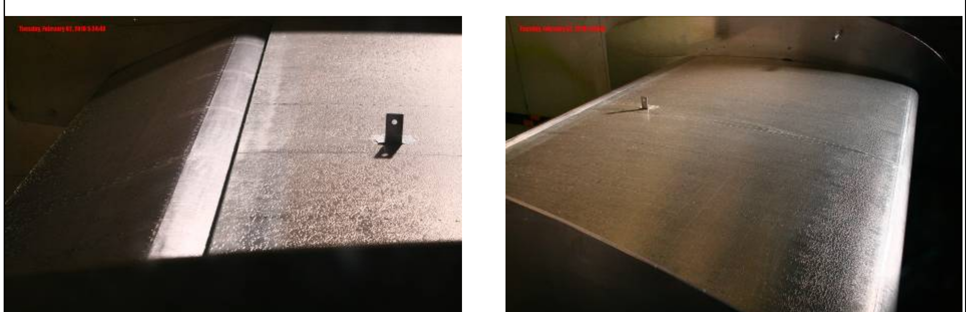


Photo 6.87: Test #96 – End of Rotation

Test #64
ABC-S Plus, Fluid Only
-13°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

Photo 6.88: Test #96 – End of Test

Test #96
ABC-S Plus, IP- 25 g/dm²/h, 30 min
-8°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test



7. MODERATE ICE PELLET ALLOWANCE TIMES

Aerodynamic testing was conducted to validate and further develop the Type IV high-speed ice pellet allowance times in the NRC wind tunnel. Previous testing in 2006-07 and 2008-09 consisted of wind tunnel tests and Falcon 20 aircraft tests to develop allowance times for mixed conditions with ice pellets. Due to the limitations of the data, some extrapolation of the results was required in order to develop a comprehensive table. It was recommended that testing be conducted at the most critical limits of the allowance times to validate the current guidance material for use with newer generation aircraft operating with supercritical wings. Additional testing was also required to provide guidance material where data was limited or non-existent. The results of this testing have been separated by test condition, and the details can be found in the following sections:

- Section 6: Light Ice Pellets;
- Section 7: Moderate Ice Pellets;
- Section 8: Light Ice Pellets and Light Freezing Rain;
- Section 9: Light Ice Pellets and Moderate Rain;
- Section 10: Light Ice Pellets and Light Snow; and
- Section 11: Light Ice Pellets and Moderate Snow.

This section provides an overview of each test conducted to substantiate and further develop the current high-speed allowance times for Type IV fluids in Moderate Ice Pellet conditions. Testing was conducted in simulated precipitation conditions. The parameters for each test are detailed, and a description of the data collected during each test is provided.

7.1 Overview of Tests

A summary of the Moderate Ice Pellet tests conducted in the wind tunnel is shown in Table 7.1. The table provides relevant information for each of the tests, as well as final values used for the data analysis. Each row contains data specific to one test. A more detailed test log of all conditions tested using the wind tunnel is provided in Subsection 4.1. A brief description of the column headings for Table 7.1 is provided in Subsection 6.1.

Table 7.1: Summary of 2009-10 Moderate Ice Pellet Testing

Test No.	Date	Fluid	Associated Baseline Test	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Flap Angle (°)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° During Rotation	8° Lift Loss (%)
10	13-Jan-10	ABC-S Plus	1	IP Mod	75	25	-7.4	-10.5	20	2, 3, 4	1, 2, 2	1.616	6.1
10A	13-Jan-10	ABC-S Plus	1	IP Mod	75	25	-5.6	-10.1	20	2, 2.8, 2.7	1, 1.8, 2	N/A	N/A
10B	13-Jan-10	ABC-S Plus	1	IP Mod	75	25	-6.2	-11.1	20	2.2, 3, 3	1, 2, 2	1.587	7.8
21	20-Jan-10	EG106	55	IP Mod	75	25	-3.6	-10.1	20	2, 2.2, 4	1, 1, 1.2	1.712	0.54
47	24-Jan-10	Launch	29	IP Mod	75	25	-4.9	-10.1	20	3.7, 3.8, 4	1, 1.7, 2.5	1.58	8.21
48	24-Jan-10	Launch	54	IP Mod	75	15	-2.7	-8.5	20	2, 2.8, 4	1, 1.7, 1.8	1.609	6.52
49	24-Jan-10	Launch	60	IP Mod	75	15	-3.1	-8.8	0	2.7, 2.8, 3	1, 1.5, 1.8	1.606	6.7
71	29-Jan-10	EG106	75	IP Mod	75	10	-17.7	-17.2	20	2.3, 2.3, 2.8	1, 1.3, 1.8	1.671	2.92
72	29-Jan-10	ABC-S Plus	76	IP Mod	75	10	-18	-17.6	20	2.8, 2.5, 3.8	1.2, 2, 2.8	1.561	9.31
73	29-Jan-10	ABC-S Plus	76	IP Mod	75	5	-18.2	-17.4	20	2.2, 2.2, 3.4	1.2, 2, 2.5	N/A	N/A
74	29-Jan-10	Launch	70	IP Mod	75	5	-18.5	-17.4	20	2.7, 2.3, 3.2	1.5, 2, 2.8	1.544	10.3
95	2-Feb-10	ABC-S Plus	64	IP Mod	75	10	-8.1	-10.4	20	2.2, 2, 2.8	1, 1.7, 2	1.602	6.93
1	3-Feb-10	ABC-S Plus	N/A	Fluid Only	N/A	N/A	-5.7	-4.6	20	1, 1, 1	1, 1, 1	1.635	5.01
29	5-Feb-10	Launch	N/A	Fluid Only	N/A	N/A	-4.8	-5.2	20	1, 1, 1	1, 1, 1	1.636	4.96
54	27-Jan-10	Launch	N/A	Fluid Only	N/A	N/A	-2.2	-0.8	20	1, 1, 1	1, 1, 1	1.66	3.56
55	27-Jan-10	EG106	N/A	Fluid Only	N/A	N/A	-2.6	-0.9	20	1, 1, 1	1, 1, 1	1.689	1.88
60	28-Jan-10	Launch	N/A	Fluid Only	N/A	N/A	-2.8	-1.9	20	1, 1, 1	1, 1, 1	1.642	4.61
64	6-Feb-10	ABC-S Plus	N/A	Fluid Only	N/A	N/A	-13.4	-11.3	20	1, 1, 1	1, 1, 1	1.634	5.07
70	7-Feb-10	Launch	N/A	Fluid Only	N/A	N/A	-17.9	-15.8	20	1, 1, 1	1, 1, 1	1.625	5.59
75	30-Jan-10	EG106	N/A	Fluid Only	N/A	N/A	-18.1	-16.9	20	1, 1, 1	1, 1, 1	1.651	4.08
76	30-Jan-10	ABC-S Plus	N/A	Fluid Only	N/A	N/A	-17.9	-17.3	20	1, 1, 1	1, 1, 1	1.62	5.89

7.2 Data Collected

7.2.1 Fluid Thickness Data

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

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

Tables 7.2 to 7.13 show the fluid thickness measurements collected during the contaminated fluid tests. The associated baseline fluid only cases are also shown in Tables 7.14 to 7.22 for comparison purposes.

Table 7.2: Test #10 Fluid Thickness Data

Test 10: ABC-S Plus, IP Mod, Tunnel OAT -7.4°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.4	2.2	N/A
2	2.5	3.1	N/A
3	3.3	3.7	N/A
4	4.5	3.9	N/A
5	5.7	5.7	N/A
6	4.5	7.0	N/A
7	3.5	4.5	N/A
8	3.3	4.5	N/A
Flap	1.0	0.1 (slush)	N/A

Table 7.3: Test #10A Fluid Thickness Data

Test 10A: ABC-S Plus, IP Mod, Tunnel OAT -5.6°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.8	2.5	0.1
2	2.5	3.1	0.2
3	3.3	3.9	0.2
4	4.5	4.5	0.2
5	5.7	5.7	0.2
6	4.5	8.9	0.1
7	5.7	5.7	0.1
8	4.5	4.5	0.1
Flap	N/A	slush	0.2

Table 7.4: Test #10B Fluid Thickness Data

Test 10B: ABC-S Plus, IP Mod, Tunnel OAT -6.2°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.4	1.8	N/A
2	2.5	3.3	N/A
3	3.1	3.3	N/A
4	4.5	4.5	N/A
5	4.5	5.7	N/A
6	4.5	5.7	N/A
7	4.5	5.7	N/A
8	3.3	4.5	N/A
Flap	N/A	slush	N/A

Table 7.5: Test #21 Fluid Thickness Data

Test 21: EG106, IP Mod, Tunnel OAT -3.6°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	2.2	1.2	0.0
2	2.5	1.7	0.0
3	2.7	2.9	0.0
4	3.3	4.5	0.1
5	4.5	5.7	0.1
6	3.1	5.7	0.0
7	3.3	5.7	0.0
8	3.1	4.5	0.0
Flap	1.0	slush	0.0

Table 7.6: Test #47 Fluid Thickness Data

Test 47: Launch, IP Mod, Tunnel OAT -4.9°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.6	1.6 (slush)	0.0
2	1.8	1.8 (slush)	0.2
3	2.2	2.5 (slush)	0.2
4	2.5	3.3 (slush)	0.3
5	2.7	4.5 (slush)	0.3
6	2.7	5.7 (slush)	0.1
7	2.5	4.5 (slush)	0.2
8	2.2	4.5 (slush)	0.1
Flap	0.7	slush	0.1

Table 7.7: Test #48 Fluid Thickness Data

Test 48: Launch, IP Mod, Tunnel OAT -2.7°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.5	2.2	0.0
2	1.8	3.1	0.2
3	2.2	3.7	0.2
4	2.7	4.5	0.2
5	2.9	4.5	0.2
6	2.9	5.7	0.1
7	2.7	4.5	0.1
8	2.2	3.9	0.1
Flap	0.7	1.3	0.3

Table 7.8: Test #49 Fluid Thickness Data

Test 49: Launch, IP Mod, Tunnel OAT -3.1°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.8	2.7 (slush)	0.0
2	2.2	3.3 (slush)	0.1
3	2.2	3.7 (slush)	0.1
4	2.9	3.9 (slush)	0.1
5	2.9	3.9 (slush)	0.1
6	3.1	3.9 (slush)	0.1
7	2.9	3.7 (slush)	0.1
8	2.9	3.7 (slush)	0.3
Flap	3.3	3.9 (slush)	0.3

Table 7.9: Test #71 Fluid Thickness Data

Test 71: EG106, IP Mod, Tunnel OAT -17.7°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.7	2.2	0.0
2	2.2	3.3	0.1
3	2.9	3.5	0.1
4	3.7	4.5	0.1
5	3.1	4.5	0.2
6	4.5	5.7	0.2
7	4.5	5.7	0.2
8	4.5	4.5	0.2
Flap	1.2	slush	0.1

Table 7.10: Test #72 Fluid Thickness Data

Test 72: ABC-S Plus, IP Mod, Tunnel OAT - 18.0°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.3	1.3	0.1
2	1.5	2.2	0.1
3	2.2	2.2	0.1
4	2.2	2.5	0.2
5	2.5	3.1	0.2
6	2.5	3.5	0.2
7	2.2	3.3	0.2
8	1.6	2.7	0.2
Flap	0.5	slush	N/A

Table 7.11: Test #73 Fluid Thickness Data

Test 73: ABC-S Plus, IP Mod, Tunnel OAT - 18.2°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.5	1.5	N/A
2	1.6	2.2	N/A
3	2.2	2.2	N/A
4	2.2	2.7	N/A
5	2.5	2.9	N/A
6	2.2	2.5	N/A
7	1.7	2.5	N/A
8	1.7	2.5	N/A
Flap	0.6	N/A	N/A

Table 7.12: Test #74 Fluid Thickness Data

Test 74: Launch, IP Mod, Tunnel OAT -18.5°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.2	1.7	0.0
2	1.3	1.8	0.1
3	1.7	1.8	0.2
4	1.7	2.2	0.2
5	2.2	2.5	0.2
6	1.7	2.2	0.2
7	1.7	2.2	0.2
8	1.3	2.2	0.3
Flap	0.6	slush	0.2

Table 7.13: Test #95 Fluid Thickness Data

Test 95: ABC-S Plus, IP Mod, Tunnel OAT -8.1°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.8	1.8	0.0
2	2.2	1.8	0.1
3	2.9	3.1	0.2
4	3.3	3.7	0.2
5	3.5	4.5	0.2
6	3.5	4.5	0.3
7	3.3	4.5	0.3
8	3.1	3.7	0.2
Flap	1.0	slush	0.2

Table 7.14: Test #1 (Baseline) Fluid Thickness Data

Test 1: ABC-S Plus, Fluid-only, Tunnel OAT -5.7°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.8	N/A	0.0
2	2.5	N/A	0.0
3	3.3	N/A	0.1
4	4.5	N/A	0.1
5	5.7	N/A	0.1
6	5.7	N/A	0.1
7	5.7	N/A	0.1
8	4.5	N/A	0.1
Flap	1.0	N/A	0.1

Table 7.15: Test #29 (Baseline) Fluid Thickness Data

Test 29: Fluid-only, Launch, Tunnel OAT -4.8°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.5	N/A	0.0
2	2.2	N/A	0.1
3	2.2	N/A	0.1
4	3.1	N/A	0.1
5	3.1	N/A	0.2
6	3.1	N/A	0.1
7	2.9	N/A	0.1
8	2.2	N/A	0.2
Flap	0.8	N/A	0.2

Table 7.16: Test #54 (Baseline) Fluid Thickness Data

Test 54: Launch, Fluid-only, Tunnel OAT -2.2°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.2	N/A	0.0
2	1.7	N/A	0.1
3	1.8	N/A	0.1
4	2.2	N/A	0.2
5	2.7	N/A	0.1
6	2.7	N/A	0.1
7	2.5	N/A	0.1
8	2.2	N/A	0.1
Flap	0.7	N/A	0.1

Table 7.17: Test #55 (Baseline) Fluid Thickness Data

Test 55: EG106, Fluid-only, Tunnel OAT -2.6°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	2.2	N/A	0.0
2	2.9	N/A	0.1
3	3.1	N/A	0.2
4	3.1	N/A	0.2
5	2.5	N/A	0.2
6	4.5	N/A	0.2
7	4.5	N/A	0.1
8	4.5	N/A	0.1
Flap	0.6	N/A	0.1

Table 7.18: Test #60 (Baseline) Fluid Thickness Data

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

Table 7.19: Test #64 (Baseline) Fluid Thickness Data

Test 64: ABC-S Plus, Fluid-only, Tunnel OAT -13.4°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.2	N/A	0.0
2	2.2	N/A	0.1
3	1.7	N/A	0.1
4	1.8	N/A	0.1
5	3.1	N/A	0.2
6	3.1	N/A	0.2
7	3.1	N/A	0.2
8	2.7	N/A	0.2
Flap	0.8	N/A	0.2

Table 7.20: Test #70 (Baseline) Fluid Thickness Data

Test 70: Launch, Fluid-only, Tunnel OAT -17.9°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.1	N/A	0.0
2	1.5	N/A	0.1
3	1.8	N/A	0.1
4	2.2	N/A	0.2
5	2.2	N/A	0.2
6	1.6	N/A	0.2
7	1.8	N/A	0.2
8	2.2	N/A	0.2
Flap	0.5	N/A	0.1

Table 7.21: Test #75 (Baseline) Fluid Thickness Data

Test 75: EG106, Fluid-only, Tunnel OAT -18.1°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	2.2	N/A	0.1
2	2.9	N/A	0.2
3	3.1	N/A	0.2
4	3.7	N/A	0.1
5	4.5	N/A	0.1
6	4.5	N/A	0.1
7	4.5	N/A	0.1
8	2.2	N/A	0.2
Flap	0.2	N/A	0.2

Table 7.22: Test #76 (Baseline) Fluid Thickness Data

Test 76: ABC-S Plus, Fluid-only, Tunnel OAT -17.9°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.3	N/A	0.1
2	1.6	N/A	0.1
3	1.8	N/A	0.1
4	2.2	N/A	0.1
5	2.2	N/A	0.2
6	2.2	N/A	0.2
7	1.8	N/A	0.2
8	1.6	N/A	0.2
Flap	0.5	N/A	0.2

7.2.2 Skin Temperature Data

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

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

Tables 7.23 to 7.34 demonstrate the wing temperature measurements collected during the contaminated fluid tests. The associated baseline fluid only cases are also shown in Tables 7.35 to 7.43 for comparison purposes.

Table 7.23: Test #10 Wing Skin Temperature Data

Test 10: ABC-S Plus, IP Mod, Tunnel OAT -7.4°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-5.3	-6.9	-11.7	N/A
T5	-4.9	-7.4	-10.0	N/A
TU	-6.8	-7.1	-9.7	N/A

Table 7.24: Test #10A Wing Skin Temperature Data

Test 10A: ABC-S Plus, IP Mod, Tunnel OAT -5.6°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-6.2	-5.0	-11.0	-5.8
T5	-6.5	-5.2	-10.0	-4.7
TU	-7.8	-5.5	-9.2	-6.7

Table 7.25: Test #10B Wing Skin Temperature Data

Test 10B: ABC-S Plus, IP Mod, Tunnel OAT -6.2°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-5.5	-5.7	-11.6	N/A
T5	-4.5	-7.5	-10.9	N/A
TU	-6.0	-5.9	-10.8	N/A

Table 7.26: Test #21 Wing Skin Temperature Data

Test 21: EG106, IP Mod, Tunnel OAT -3.6°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	N/A	-1.8	-10.4	-4.2
T5	N/A	-1.8	-9.1	-3.4
TU	N/A	-3.0	-6.1	-4.5

Table 7.27: Test #47 Wing Skin Temperature Data

Test 47: Launch, IP Mod, Tunnel OAT -4.9°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-5.6	-6.2	-11.5	-3.8
T5	-5.2	-6.3	-11.1	-3.2
TU	-6.5	-6.4	-7.7	-5.9

Table 7.28: Test #48 Wing Skin Temperature Data

Test 48: Launch, IP Mod, Tunnel OAT -2.7°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-2.5	-3.0	-9.9	-6.4
T5	-1.6	-3.1	-10.3	-5.8
TU	-3.4	-4.1	-5.4	-6.8

Table 7.29: Test #49 Wing Skin Temperature Data

Test 49: Launch, IP Mod, Tunnel OAT -3.1°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-4.0	-4.5	-10.3	-4.6
T5	-3.5	-4.6	-10.2	-4.6
TU	-4.9	-4.9	-6.0	-5.5

Table 7.30: Test #71 Wing Skin Temperature Data

Test 71: EG106, IP Mod, Tunnel OAT -17.7°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-16.5	-16.0	-18.1	-18.2
T5	-16.7	-16.4	-17.5	-17.5
TU	-16.7	-16.2	-16.0	-18.6

Table 7.31: Test #72 Wing Skin Temperature Data

Test 72: ABC-S Plus, IP Mod, Tunnel OAT - 18.0°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-15.7	-15.1	-18.2	-18.5
T5	-15.1	-15.4	-17.3	-18.4
TU	-17.4	-17.0	-17.2	-19.5

Table 7.32: Test #73 Wing Skin Temperature Data

Test 73: ABC-S Plus, IP Mod, Tunnel OAT - 18.2°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-15.2	-16.3	-17.8	N/A
T5	-14.5	-16.7	-17.1	N/A
TU	-17.1	-17	-17.2	N/A

Table 7.33: Test #74 Wing Skin Temperature Data

Test 74: Launch, IP Mod, Tunnel OAT -18.5°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-16.6	-16.1	-17.9	-17.5
T5	-16.0	-16.3	-16.7	-17.0
TU	-17.9	-17.7	-17.5	-18.9

Table 7.34: Test #95 Wing Skin Temperature Data

Test 95: ABC-S Plus, IP Mod, Tunnel OAT -8.1°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-8.5	-9.2	-12.1	-10.4
T5	-7.6	-9.1	-11.0	-9.7
TU	-9.3	-8.8	-8.2	-10.8

Table 7.35: Test #1 (Baseline) Wing Skin Temperature Data

Test 1: ABC-S Plus, Fluid-only, Tunnel OAT -5.7°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-4.5	-4.5	N/A	-3.6
T5	-5	-4.9	N/A	-3.2
TU	-5.1	-4.5	N/A	-4.3

Table 7.36: Test #29 (Baseline) Wing Skin Temperature Data

Test 29: Fluid-only, Launch, Tunnel OAT -4.8°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.0	-3.8	N/A	-6.0
T5	-2.2	-3.9	N/A	-5.4
TU	-4.5	-4.1	N/A	-6.6

Table 7.37: Test #54 (Baseline) Wing Skin Temperature Data

Test 54: Launch, Fluid-only, Tunnel OAT -2.2°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-0.2	-0.5	N/A	-2.8
T5	-0.4	-0.6	N/A	-2.9
TU	-1.2	-1.2	N/A	-2.7

Table 7.38: Test #55 (Baseline) Wing Skin Temperature Data

Test 55: EG106, Fluid-only, Tunnel OAT -2.6°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-0.6	-0.5	N/A	-1.6
T5	-0.5	-0.6	N/A	-1.5
TU	-1.4	-1.6	N/A	-2.3

Table 7.39: Test #60 (Baseline) Wing Skin Temperature Data

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

Table 7.40: Test #64 (Baseline) Wing Skin Temperature Data

Test 64: ABC-S Plus, Fluid-only, Tunnel OAT -13.4°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-11.8	-10.8	N/A	-12.2
T5	-11.9	-10.8	N/A	-12.1
TU	-12.3	-12.4	N/A	-12.4

Table 7.41: Test #70 (Baseline) Wing Skin Temperature Data

Test 70: Launch, Fluid-only, Tunnel OAT -17.9°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-16.6	-15.1	N/A	-16.0
T5	-16.2	-15.1	N/A	-15.7
TU	-17.7	-17.1	N/A	-17.0

Table 7.42: Test #75 (Baseline) Wing Skin Temperature Data

Test 75: EG106, Fluid-only, Tunnel OAT -18.1°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-16.2	-16.5	N/A	-16.4
T5	-15.8	-16.4	N/A	-15.6
TU	-17.9	-17.7	N/A	-18.4

Table 7.43: Test #76 (Baseline) Wing Skin Temperature Data

Test 76: ABC-S Plus, Fluid-only, Tunnel OAT -17.9°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-16.4	-17.1	N/A	-16.9
T5	-16.2	-17.0	N/A	-16.1
TU	-18.1	-17.8	N/A	-18.9

7.2.3 Fluid Brix Data

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

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

Tables 7.44 to 7.55 show the fluid Brix measurements collected during the contaminated fluid tests. The associated baseline fluid only cases are also shown in Tables 7.56 to 7.64 for comparison purposes.

Table 7.44: Test #10 Fluid Brix Data

Test 10: ABC-S Plus, IP Mod, Tunnel OAT -7.4°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.75	24.50	N/A
8	36.25	25.00	N/A

Table 7.45: Test #10A Fluid Brix Data

Test 10A: ABC-S Plus, IP Mod, Tunnel OAT -5.6°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.50	27.25	25.00
8	36.50	25.00	24.00

Table 7.46: Test #10B Fluid Brix Data

Test 10B: ABC-S Plus, IP Mod, Tunnel OAT -6.2°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.00	17.50	N/A
8	36.50	25.00	N/A

Table 7.47: Test #21 Fluid Brix Data

Test 21: EG106, IP Mod, Tunnel OAT -3.6°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	31.50	13.75	25.00
8	32.00	15.25	23.00

Table 7.48: Test #47 Fluid Brix Data

Test 47: Launch, IP Mod, Tunnel OAT -4.9°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.75	21.50	27.50
8	37.00	21.75	27.50

Table 7.49: Test #48 Fluid Brix Data

Test 48: Launch, IP Mod, Tunnel OAT -2.7°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.75	25.00	28.50
8	36.75	22.50	29.00

Table 7.50: Test #49 Fluid Brix Data

Test 49: Launch, IP Mod, Tunnel OAT -3.1°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.50	25.50	34.00
8	36.50	23.00	31.75

Table 7.51: Test #71 Fluid Brix Data

Test 71: EG106, IP Mod, Tunnel OAT -17.7°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.5	26.25	29.5
8	32.5	25.25	30.25

Table 7.52: Test #72 Fluid Brix Data

Test 72: ABC-S Plus, IP Mod, Tunnel OAT - 18.0°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.50	35.00	32.50
8	37.50	32.50	32.00

Table 7.53: Test #73 Fluid Brix Data

Test 73: ABC-S Plus, IP Mod, Tunnel OAT - 18.2°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.50	36.50	N/A
8	37.00	36.00	N/A

Table 7.54: Test #74 Fluid Brix Data

Test 74: Launch, IP Mod, Tunnel OAT -18.5°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.00	37.00	32.75
8	36.75	36.75	32.50

Table 7.55: Test #95 Fluid Brix Data

Test 95: ABC-S Plus, IP Mod, Tunnel OAT -8.1°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.0	36.75	32.00
8	36.50	28.00	28.50

Table 7.56: Test #1 (Baseline) Fluid Brix Data

Test 1: ABC-S Plus, Fluid-only, Tunnel OAT -5.7°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.5	N/A	39.5
8	36.5	N/A	38.25

Table 7.57: Test #29 (Baseline) Fluid Brix Data

Test 29: Fluid-only, Launch, Tunnel OAT -4.8°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.75	N/A	37.50
8	37.00	N/A	36.50

Table 7.58: Test #54 (Baseline) Fluid Brix Data

Test 54: Launch, Fluid-only, Tunnel OAT -2.2°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.50	N/A	39.75
8	36.75	N/A	39.25

Table 7.59: Test #55 (Baseline) Fluid Brix Data

Test 55: EG106, Fluid-only, Tunnel OAT -2.6°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.35	N/A	34.75
8	33.00	N/A	34.00

Table 7.60: Test #60 (Baseline) Fluid Brix Data

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

Table 7.61: Test #64 (Baseline) Fluid Brix Data

Test 64: ABC-S Plus, Fluid-only, Tunnel OAT -13.4°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.75	N/A	38.50
8	37.50	N/A	38.00

Table 7.62: Test #70 (Baseline) Fluid Brix Data

Test 70: Launch, Fluid-only, Tunnel OAT -17.9°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.50	N/A	39.25
8	37.50	N/A	38.25

Table 7.63: Test #75 (Baseline) Fluid Brix Data

Test 75: EG106, Fluid-only, Tunnel OAT -18.1°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.25	N/A	34.00
8	32.25	N/A	34.00

Table 7.64: Test #76 (Baseline) Fluid Brix Data

Test 76: ABC-S Plus, Fluid-only, Tunnel OAT -17.9°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.75	N/A	38.25
8	37.00	N/A	37.25

7.3 Photos

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

- Start of test;
- Before Rotation (just before the wing began to pitch);
- End of Rotation (end of the rotation cycle when the wing position is returned to 4 degrees); and
- End of test.

The photos taken during the Moderate Ice Pellet testing have been presented along with the fluid only (baseline) tests for comparison purposes. In each case, the fluid only photo is presented first, followed by the contaminated fluid photo. Photos 7.1 to 7.96 show the photo summaries of the tests conducted. A complete set of photos will be provided to the TDC in electronic format.

7.4 Summary of Results

7.4.1 OAT -5°C and Above

Four tests were conducted in this cell with an exposure time of 25 minutes: Tests #10, #10B, #21, and #47 (see Table 7.65). Two other tests, #48 and #49, were also used for analysis, but exposure times were below the allowance time of 30 minutes (at 15 minutes). Table 7.66 contains more details on the results of these two tests.

Test #21 was conducted using EG fluid and demonstrated very good results. The temperature during this test was -3.6°C. The 8° lift loss (0.54 percent) and visual contamination ratings showed positive results, confirming the 25-minute allowance time for EG fluids.

Test #10 was conducted with PG fluid and demonstrated satisfactory results but required further review. The temperature during this test was -7.4°C. Visual contamination results were good, satisfying all criteria. The 8° lift loss was 6.12 percent, above the 5 percent margin of safety (see Table 7.66). An examination into the ramp-up time for this test shows a time of 27 seconds to reach rotation from a speed of 40 knots, which is much greater than the average of 19 seconds. When the lift loss analysis of speeds greater than 100 knots was conducted, the semi-log of time results indicate that a speed of just under 110 knots is required to bring the lift loss to less than 5 percent (see Table 7.67 and Figure 7.1).

Test #10B was conducted using the same PG fluid as Test #10 but had the flap protected from precipitation during the first 15 minutes of contamination (see Table 7.66). The temperature during this test was -6.2°C. As a result of the flap being covered, visual contamination results were better than Test #10. The 8° lift loss during this run was 7.80 percent. A 6° rotation angle would provide a lift loss of 7.06 percent (see Table 5.7); this is an improvement from the 8° lift loss value. A ramp-up time of 17 seconds occurred during this run, below the 19-second average, indicating a possible improvement in lift loss should the extra 2 seconds have been used.

Test #47 was conducted with PG fluid and demonstrated poor results, requiring further evaluation. The temperature during this test was -4.9°C. Lift loss and visuals at the start of the test had unfavourable results (see Table 7.66). The visual ratings at the start of the test were 3.7, 3.8, and 4 on the LE, TE, and flap, respectively; these were higher than the acceptable criteria. The lift loss at 8° was 8.21 percent, beyond the 5 percent margin of safety criteria. When the lift loss analysis of speeds greater than 100 knots was conducted, the semi-log of time results indicate that a speed of approximately 105 knots is required to bring the lift loss to less than 8 percent. A speed slightly below 120 knots is required to bring the lift loss to 5 percent (see Table 7.67). This test had a 23-second ramp-up time, 4 seconds over the average.

Due to the unfavourable visual results from Test #47, Test #48 was conducted using the same PG fluid with an exposure time of 15 minutes, rather than the current 25-minute allowance time. The temperature was -2.7°C, slightly warmer than Test #47. The visual contamination ratings during this test were satisfactory, meeting all criteria. The lift loss at 8° was 6.52 percent, over the 5 percent safety criteria but below a lift loss of 8 percent. A ramp-up time of 25 seconds from 40 knots to rotation was found in this run, over the 19-second average. Examination of the lift data indicates that a lift loss of 5.48 percent would occur at a 6° rotation (see Table 5.7), an improvement from the lift loss at a 8° rotation.

Test #49 was conducted using the same test parameters as in Test #48 but had the flap set at 0° for the contamination phase due to the flap rating of 4 at the start of Test #48. Close examination of the results from Test #49 shows that the findings were essentially the same as Test #48 (see Table 7.66).

Due to unfavourable visual results on Test #47, a closer comparison of the parameters of the related PG fluid tests was undertaken.

1. The fluid used for Test #47 was Launch, and ABC-S Plus was used for Tests #10 and #10B.
2. The temperature for Test #47 was -4.9°C, while the temperatures for Tests #10 and #10B were -7.4°C and -6.2°C, respectively; the temperatures were not significantly different. In fact, they were colder in Tests #10 and #10B.
3. Close examination of the photos indicates that the visual ratings for all these tests were appropriate.
4. No other test parameters were found to have been significantly different.

This seems to indicate that the fluid brand was likely the cause for the poor visual results experienced in Test #47.

In conclusion, the current allowance time of 25 minutes is acceptable for EG fluids. An allowance time of 25 minutes is not acceptable for PG fluids as a result of unsatisfactory visual contamination results present at the start of Test #47. A repeat of Tests #48 and #49 demonstrated acceptable visual and lift loss results, but for an allowance time of 15 minutes.

Due to the recent tests conducted on the newer generation airfoils, an allowance time of 15 minutes is more appropriate for PG fluids. Because the lift losses in Tests #48 and #49 were still higher than the 5 percent safety criteria, further review is required for PG fluids.

7.4.2 OAT Less than -5°C to -10°C

One test was conducted in this cell with an exposure time of 10 minutes: Test #95. Two other tests, #10 and #71, were also used to support the analysis of this cell of the allowance time table. See Table 7.65 for a summary of the Moderate Ice Pellet runs.

Test #95 was conducted at a temperature of -8.1°C with PG fluid and demonstrated satisfactory results based on the 8° lift loss (6.93 percent) and the good visual contamination ratings (see Table 7.66). This result is above the 5 percent margin of safety criteria. An analysis of the lift loss was conducted with speeds greater than 100 knots (see Table 7.67 and Figure 7.2), and the semi-log of time results indicate a rotation speed of approximately 110 knots is required to achieve a lift loss below 5 percent. The ramp-up time for this test was below the 19-second average, at 16 seconds, indicating a possibility of lift loss improvement should the extra 3 seconds have been used.

Test #10 was used to support Test #95 during analysis (see Table 7.66). This test can be found in the Moderate Ice Pellet cell OAT -5°C and above, but had a temperature close to the current cell's target OAT. PG fluid was used during this test, which was conducted at a temperature of -7.4°C. Although exposure times were different (Test #10 at 25 minutes), the visual contamination ratings demonstrated good results despite the longer precipitation time. The 8° lift loss of 6.12 percent was above the 5 percent safety criteria, resulting in the need for further review, as with Test #95. The semi-log of time results indicate a rotation speed of just under 110 knots is required to achieve a lift loss below 5 percent.

Test #71 was also used to support Test #95 during the analysis (see Table 7.66). This test was conducted with EG fluid at a temperature of -17.7°C. The exposure time was the same, at 10 minutes. Although the temperature was much colder, the visual and lift loss results were very good.

In conclusion, the current allowance time of 10 minutes is acceptable for EG fluids. The allowance for this cell is satisfactory at this time based on the results obtained from PG fluids, but further review is required. For the PG fluids with the newer generation flat wing sections, a rotation speed of 110 knots is required to reduce the measured lift loss to less than 5 percent; this speed would also be equivalent to the 5 percent lift loss measured with the baseline PG fluid only case.

Table 7.65: Moderate Ice Pellets Allowance Time Tests Winter 2009-10

	OAT -5°C and Above	OAT Less than -5°C to -10°C	OAT Less than -10°C
Moderate Ice Pellets	25 minutes **Test # 10, 10B, 21, 47**	10 minutes **Test # 95, (10), (71)**	10 minutes **Test # 71, 72**

7.4.3 OAT Less than -10°C

Two tests were conducted in this cell with an exposure time of 10 minutes: Tests #71 and #72 (see Table 7.65). Test #74 was also used for analysis, but the exposure time was below the allowance time of 10 minutes (at 5 minutes). Table 7.66 contains more details on the results of Test #74.

Test #71 was conducted using EG fluid and demonstrated very good results. The temperature during this test was -17.7°C. The 8° lift loss was below the 5 percent safety criteria at 2.98 percent, and the visual contamination ratings showed positive results, confirming the 10-minute allowance time for EG fluids.

Test #72, conducted at a temperature of -18°C with PG fluid, demonstrated unsatisfactory results. The visual result on the LE at the time of rotation was 1.2, and the 8° lift loss was 9.31 percent; both results did not satisfy their required criteria (see Table 7.66). An examination into the ramp-up time for this test shows a time of 15 seconds to reach rotation from a speed of 40 knots. The lift loss and visual ratings could have potentially been reduced should this run have had an extra 4 seconds during ramp-up. When the lift loss analysis of speeds greater than 100 knots was conducted, the semi-log of time results indicate that a speed just above 110 knots is required to bring the lift loss to less than 8 percent. Using the methodology described to extrapolate beyond 100 knots, a speed of 135 knots would be required to bring the lift loss below the 5 percent safety margin (see Table 7.67 and Figure 7.3). This estimate is provided for reference purposes; however, it is not recommended to extrapolate the 100 knots data to the velocity of 135 knots.

Test #74 was conducted with PG fluid and also demonstrated unsatisfactory results, requiring further review. The exposure time for this test was below the allowance time, at 5 minutes. The temperature during this test was -18.4°C. The visual contamination results showed positive results at both the start of the test and at rotation. The lift loss at 8° was 10.3 percent, well above the 5 percent margin of safety criteria. As with Test #72, Test #74 had a ramp-up time below the average, at approximately 14 seconds. This would provide a possibility of an improvement in the results should an extra 5 seconds have been used during the ramp-up time. When the lift loss analysis of speeds greater than 100 knots was conducted, the semi-log of time results indicate that a speed of just under 110 knots is required to bring the lift loss to less than 8 percent. Using the methodology described to extrapolate beyond 100 knots, a speed of 130 knots would be required to bring the lift loss below 5 percent (see Table 7.67 and Figure 7.4). This estimate is provided for reference purposes; however, it is not recommended to extrapolate to this extent.

In conclusion, the current allowance time of 10 minutes is acceptable for EG fluids. With PG fluids, a speed of 115 knots or more is required to drive lift losses below 8 percent for the flatter and newer generation airfoils. At this time, the current allowance time of 10 minutes for PG fluids is acceptable with speeds of 115 knots or more, but further research and testing is required.

Table 7.66: Summary of Moderate Ice Pellets Allowance Time Test Results

	OAT -5°C and Above	OAT Less than -5°C to -10°C	OAT Less than -10°C
Moderate Ice Pellets	**25 minutes** Run 10 (Exposure Time 25 min), -7.4°C ABC-S Plus Visual At Start: GOOD (2, 3, 4) Visuals At Rotation: GOOD (1, 2, 2) LL At 100 kts: OK (6.12%) LL At 110 kts: GOOD (4.86%) LL At 115 kts: GOOD (4.40%) LL At 120 kts: GOOD (3.95%) **GOOD > 110 kts** Run 10B (Exposure Time 25 min), -6.2°C *Flap Covered for First 15 min* ABC-S Plus Visual At Start: GOOD (2.2, 3, 3) Visuals At Rotation: GOOD (1, 2, 2) LL At 100 kts: OK (7.80%) **OK At 100 kts** Run 21 (Exposure Time 25 min), -3.6°C EG106 Visual At Start: GOOD (2, 2.2, 4) Visuals At Rotation: GOOD (1, 1, 1.2) LL At 100 kts: GOOD (0.54%) **GOOD At 100 kts** Run 47 (Exposure Time 25 min), -4.9°C LAUNCH Visual At Start: BAD (3.7, 3.8, 4) Visuals At Rotation: GOOD (1, 1.7, 2.5) LL At 100 kts: BAD (8.21%) LL At 110 kts: OK (6.74%) LL At 115 kts: OK (5.71%) LL At 120 kts: GOOD (4.71%) **OK >110 kts** Run 48 (Exposure Time 15 min), -2.7°C LAUNCH Visual At Start: GOOD (2, 2.8, 4) Visuals At Rotation: GOOD (1, 1.7, 1.8) LL At 100 kts: OK (6.52%) **OK >100 kts** Run 49 (Exposure Time 15 min), -3.1°C *Flap At 0°* LAUNCH Visual At Start: GOOD (2.7, 2.8, 3) Visuals At Rotation: GOOD (1, 1.5, 1.8) LL At 100 kts: OK (6.70%) **OK >100 kts** ▪ **25 min GOOD for EG Fluid** ▪ **30 min BAD for PG Fluids Due to Visuals at the Start of Test for Run 47; Allowance Time should be Reduced to 15 min Based on Runs 48 and 49. Further Review Required.**	**10 minutes** Run 95 (Exp. Time 10 min), -8.1°C ABC-S Plus Visual At Start: GOOD (2.2, 2, 2.8) Visuals At Rotation: GOOD (1, 1.7, 2) LL At 100 kts: OK (6.93%) LL At 110 kts: OK (5.15%) LL At 115 kts: GOOD (4.24%) LL At 120 kts: GOOD (3.36%) **GOOD At 100 kts** ▪ **10 min GOOD for EG Fluid** ▪ **10 min OK for PG Fluid; Further Review Required**	**10 minutes** Run 71 (Exposure Time 10 min), -17.7°C EG106 Visual At Start: GOOD (2.3, 2.3, 2.8) Visuals At Rotation: GOOD (1, 1.3, 1.8) LL At 100 kts: GOOD (2.92%) **GOOD At 100 kts** Run 72 (Exp. Time 10 min), -18.0°C ABC-S Plus Visual At Start: GOOD (2.8, 2.5, 3.8) Visuals At Rotation: BAD (1.2, 2, 2.8) LL At 100 kts: BAD (9.31%) LL At 110 kts: BAD (8.03%) LL At 115 kts: OK (7.26%) LL At 135 kts: GOOD (4.36%) **OK >115 kts** Run 74 (Exp. Time 5 min), -18.5°C LAUNCH Visual At Start: GOOD (2.7, 2.3, 3.2) Visuals At Rotation: GOOD (1.5, 2, 2.8) LL At 100 kts: BAD (10.30%) LL At 110 kts: OK (7.51%) LL AT 115 kts: OK (6.77%) LL At 130 kts: GOOD (4.69%) **OK > 110 kts** ▪ **Higher Rotation Speeds of 115 or More are Needed to Drive LL Below 8%** ▪ **10 min GOOD for EG Fluid** ▪ **10 min OK for PG Fluid and Supercritical Wings for Speeds >115 kts**
	CONCLUSION: ALLOWANCE TIME FROM 25 MIN TO 15 MIN; FURTHER REVIEW REQUIRED	**CONCLUSION: ALLOWANCE TIME OF 10 MIN OK, FURTHER REVIEW REQUIRED**	**CONCLUSION: ALLOWANCE TIME OF 10 MIN OK FOR >115 KTS**

Table 7.67: Details of Increased Rotation Speed Analysis

Condition	Test #	Speed (Kts)	Lift Loss at 8 Degrees (%)	Visual (%)	Linear (%)	Semi-Log (Time) (%)	Polynomial (2nd Order) (%)
Moderate Ice Pellets (OAT -5°C and Above)	**10**	100	6.12				
		110		5.12	4.69	4.86	5.48
		115		4.8	4.16	4.4	5.28
		120		4.48	3.64	3.95	5.13
	47	100	8.21				
		110		-	6.34	6.74	7.82
		115		-	5.11	5.71	7.35
		120		-	3.89	4.71	7.02
Moderate Ice Pellets (OAT Less than -5°C to -10°C)	**95**	100	6.93				
		110		5.95	4.80	5.15	6.31
		115		5.51	3.73	4.24	6.02
		120		5.31	2.65	3.36	5.87
Moderate Ice Pellets (OAT Less than -10°C)	**72**	100	9.31				
		110		8.50	7.83	8.03	9.01
		115		7.92	6.95	7.26	8.83
		135		-	3.40	4.36	9.55
	74	100	10.3				
		110		7.27	7.25	7.51	7.52
		115		6.45	6.37	6.77	6.80
		130		-	3.74	4.69	4.83

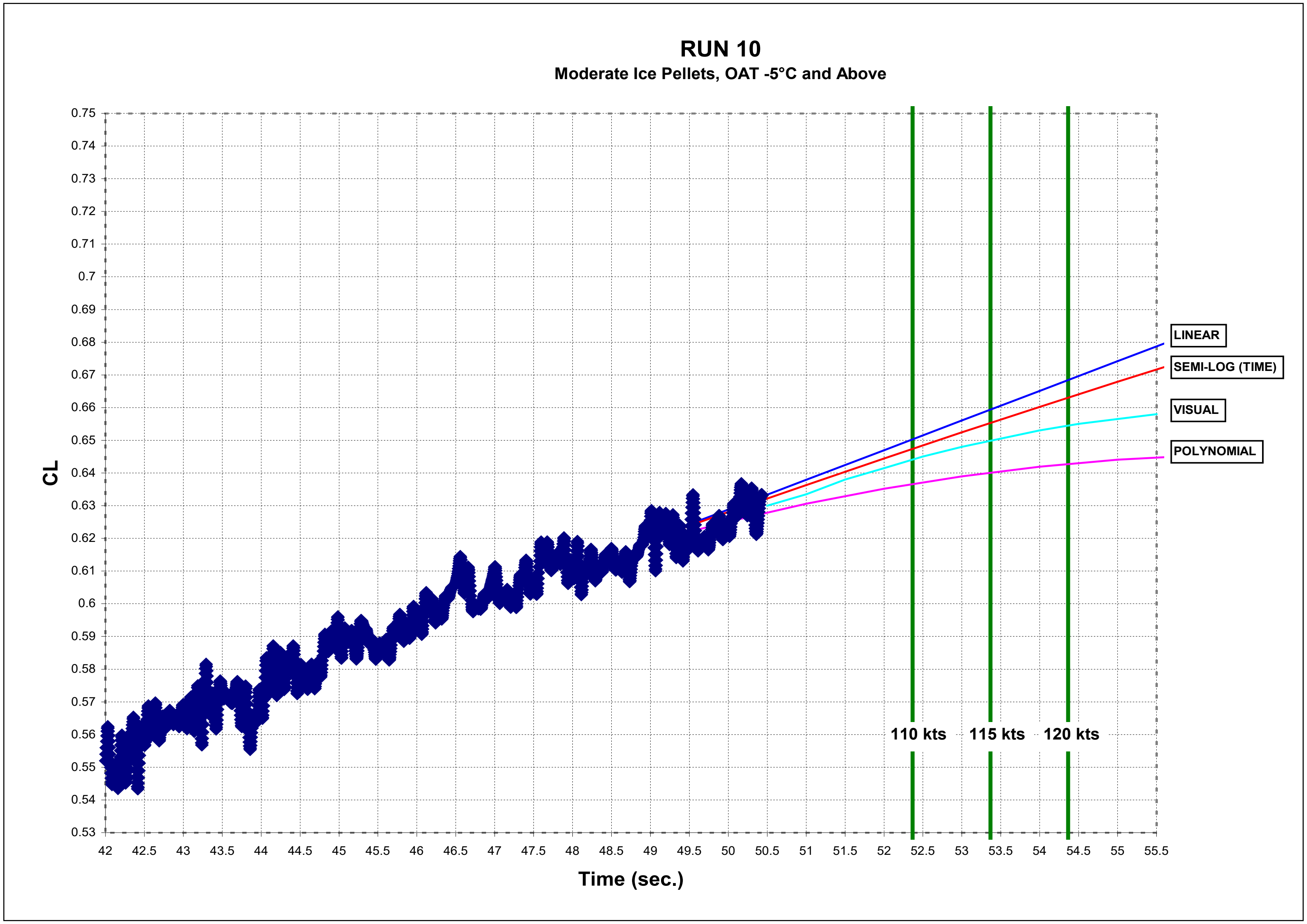


Figure 7.1: Increased Rotation Speed Extrapolation Results – Test #10

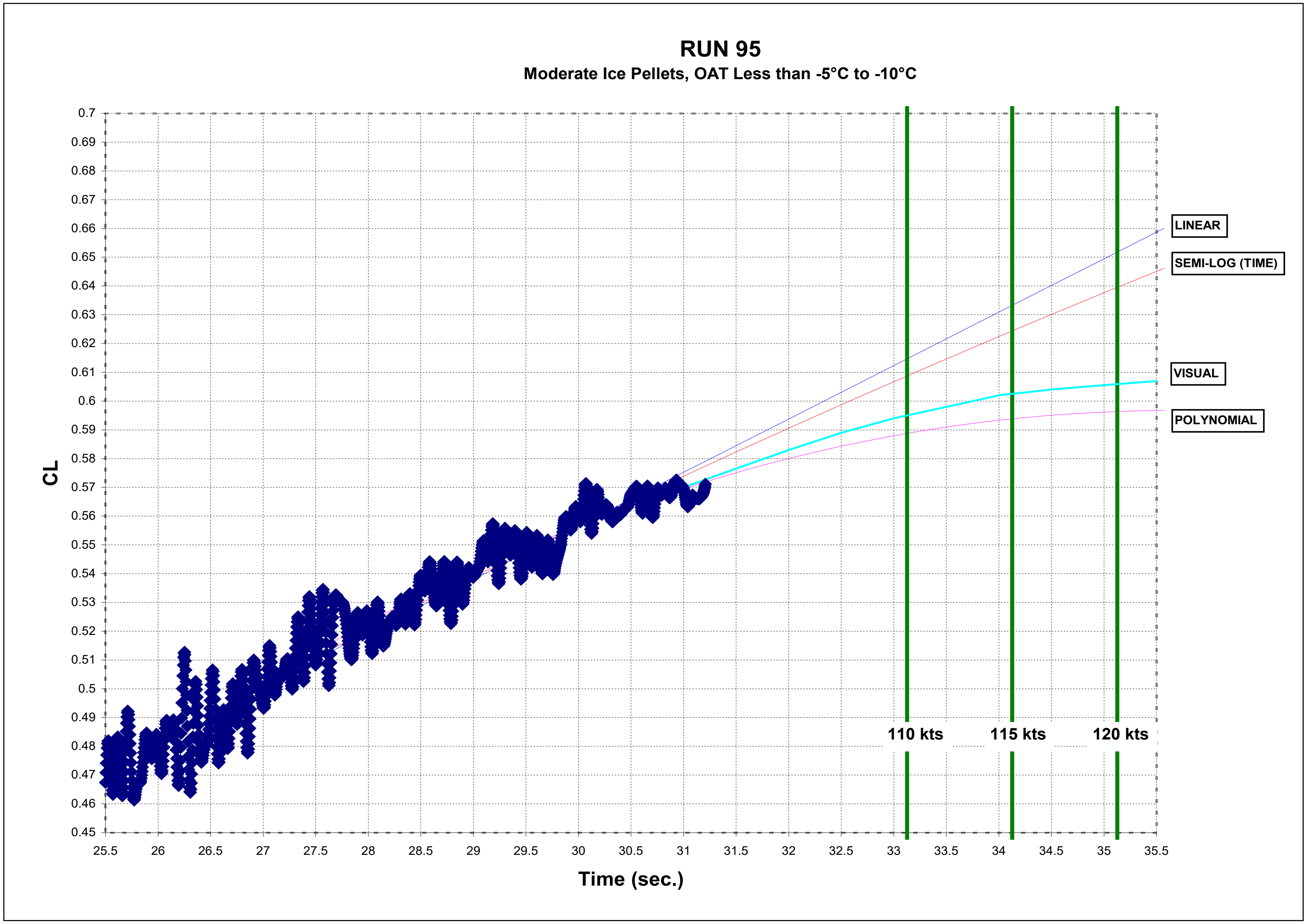


Figure 7.2: Increased Rotation Speed Extrapolation Results – Test #95

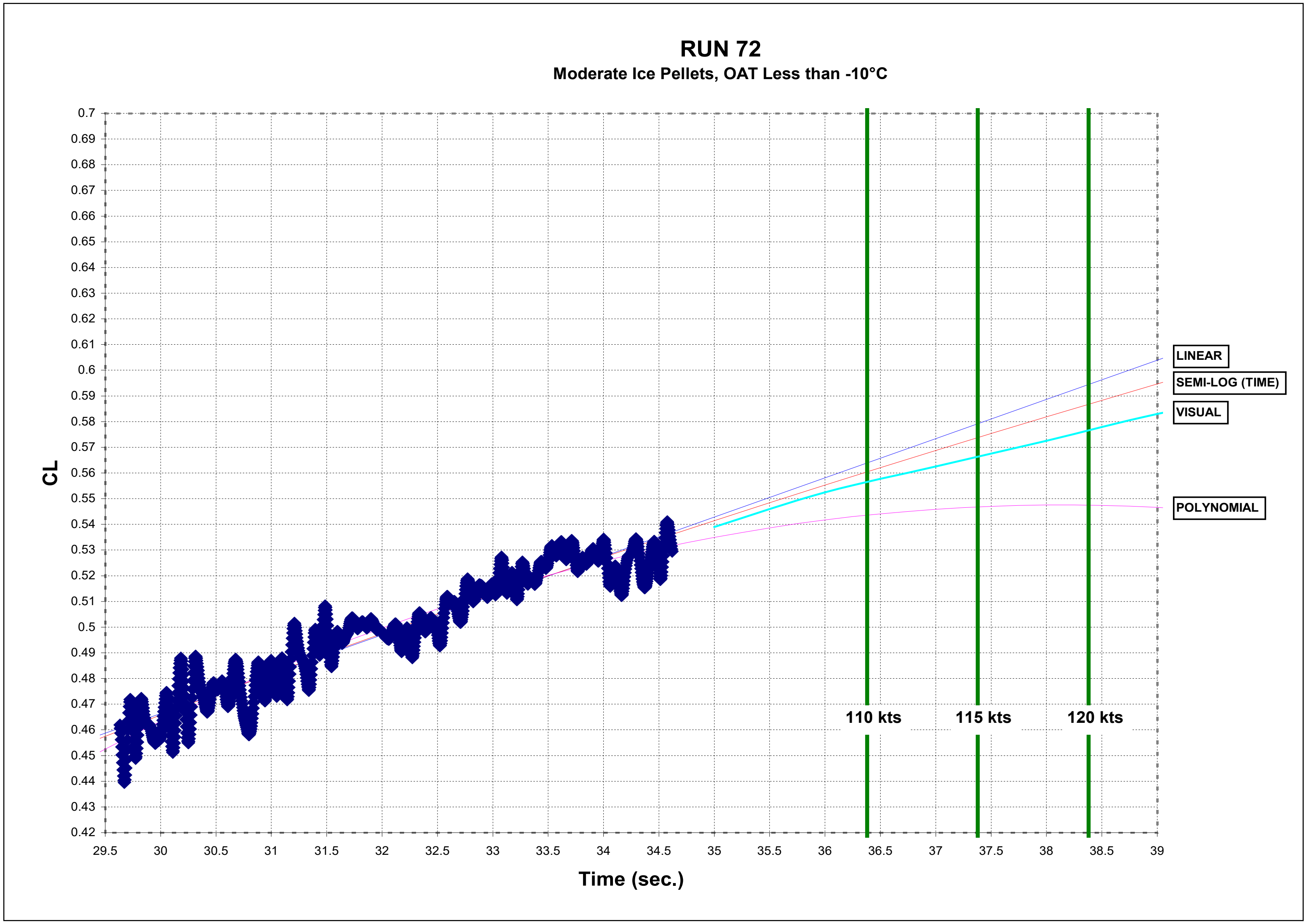


Figure 7.3: Increased Rotation Speed Extrapolation Results – Test #72

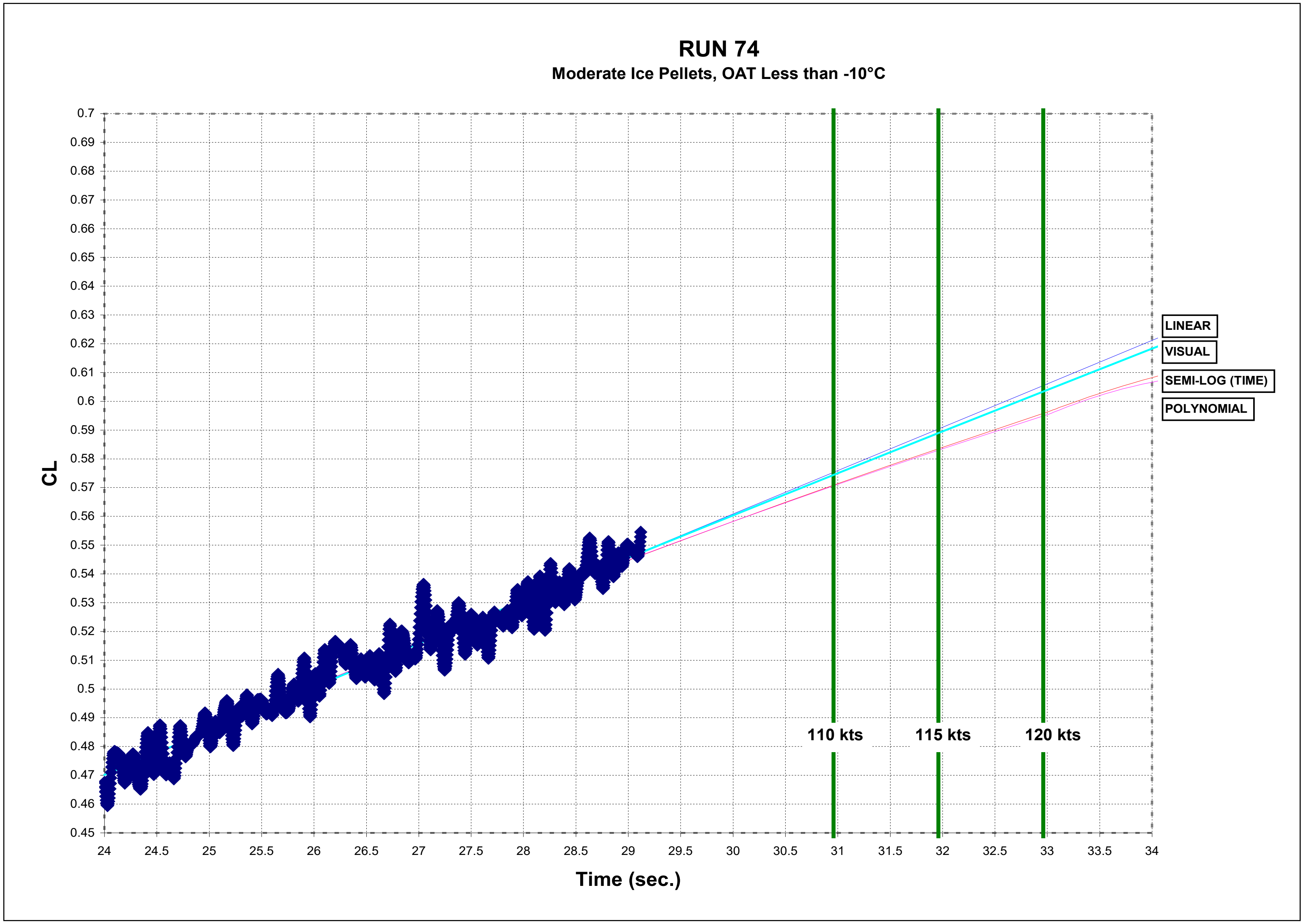


Figure 7.4: Increased Rotation Speed Extrapolation Results – Test #74

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Photo 7.1: Test #1 – Start of Test

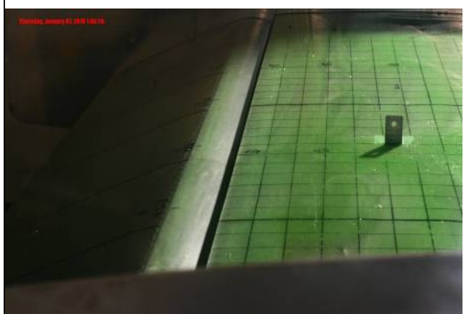
Test #1

ABC-S Plus, Fluid Only

-6°C, 8° Rotation

Visual Contamination Rating (1,1,1)

Start of Test



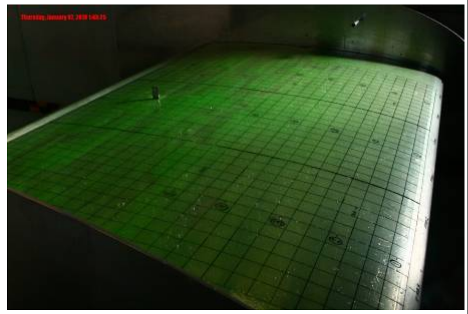


Photo 7.2: Test #1 – Before Rotation

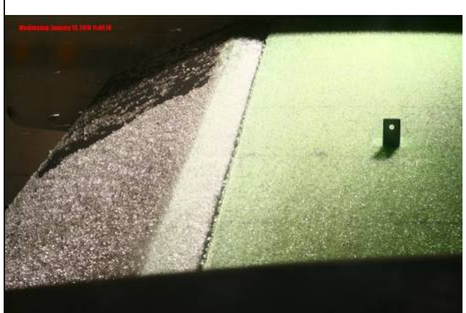
Test #10

ABC-S Plus, IP Mod 75 g/dm²/h, 25 min

-7°C, 8° Rotation

Visual Contamination Rating (2,3,4)

Start of Test



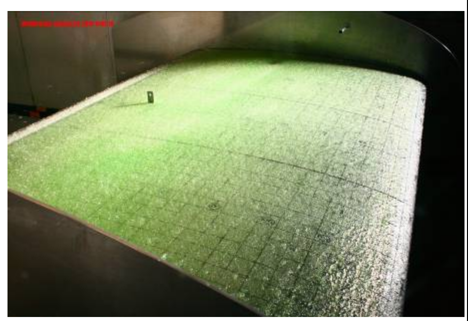
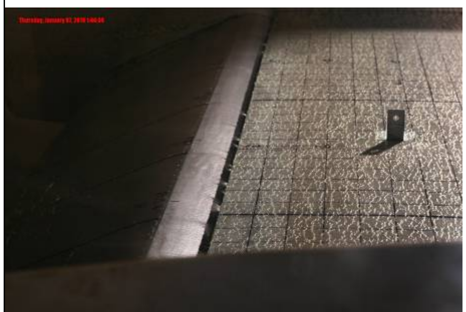


Photo 7.3: Test #1 – End of Rotation

Test #1
ABC-S Plus, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation



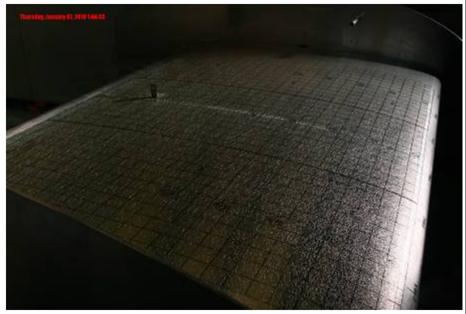
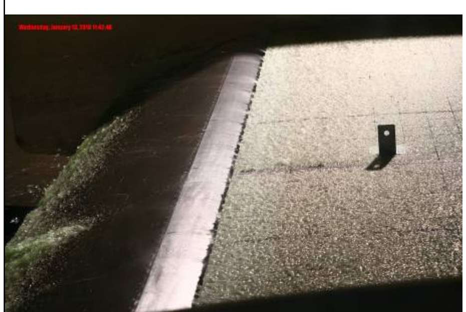


Photo 7.4: Test #1 – End of Test

Test #10
ABC-S Plus, IP Mod 75 g/dm²/h, 25 min
-7°C, 8° Rotation
Visual Contamination Rating (1,2,2)
Before Rotation



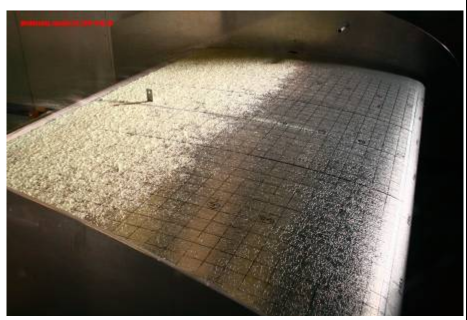


Photo 7.5: Test #10 – Start of Test

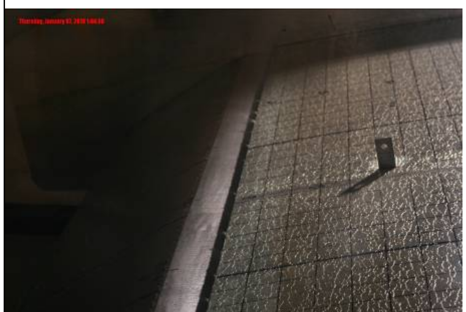
Test #1

ABC-S Plus, Fluid Only

-6°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.01%

End of Rotation



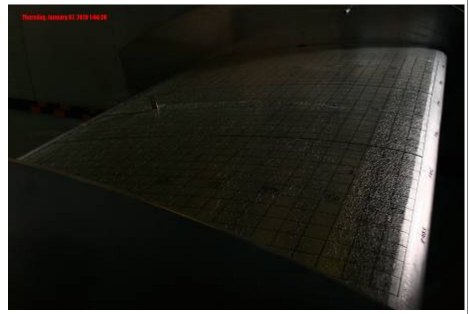


Photo 7.6: Test #10 – Before Rotation

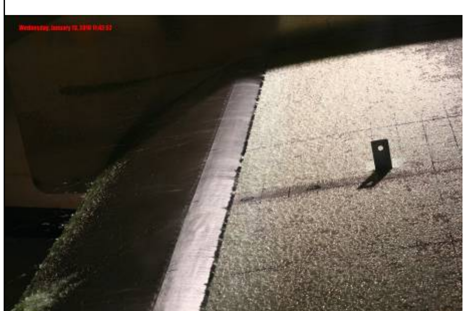
Test #10

ABC-S Plus, IP Mod 75 g/dm²/h, 25 min

-7°C, 8° Rotation

Visual Contamination Rating (1,2,2), 8° Lift Loss = 6.12%

End of Rotation



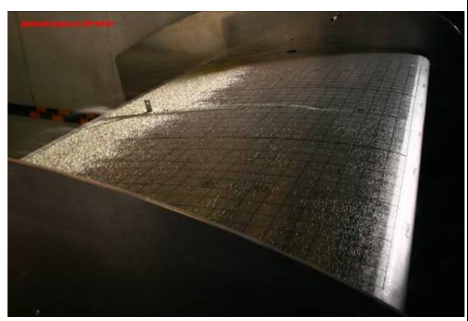


Photo 7.7: Test #10 – End of Rotation

Test #1

ABC-S Plus, Fluid Only

-6°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test

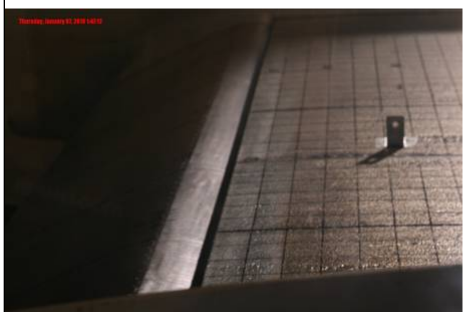


Photo 7.8: Test #10 – End of Test

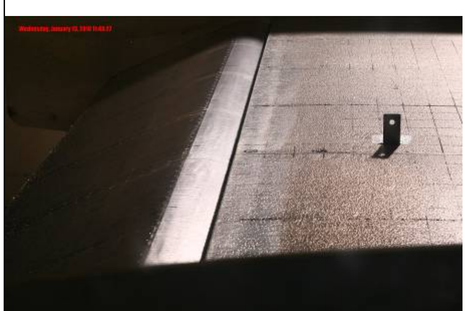
Test #10

ABC-S Plus, IP Mod 75 g/dm²/h, 25 min

-7°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test



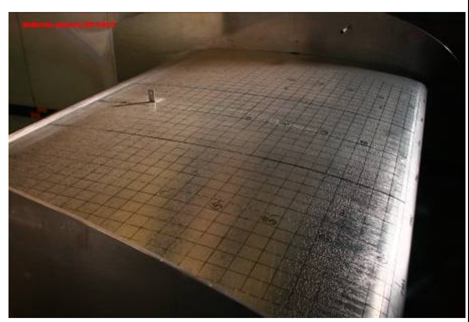
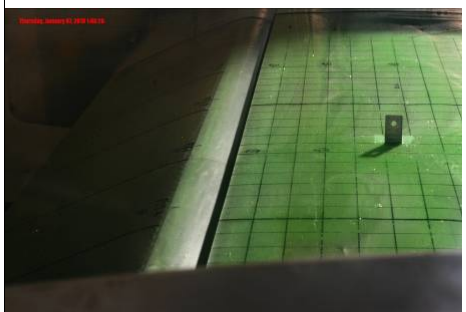


Photo 7.9: Test #1 – Start of Test

Test #1
ABC-S Plus, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test



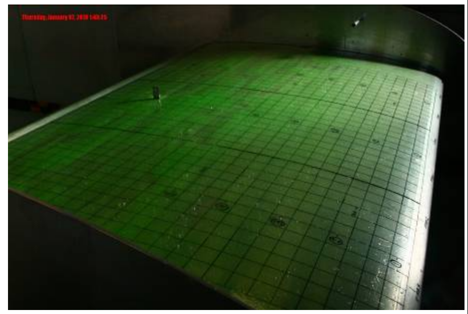
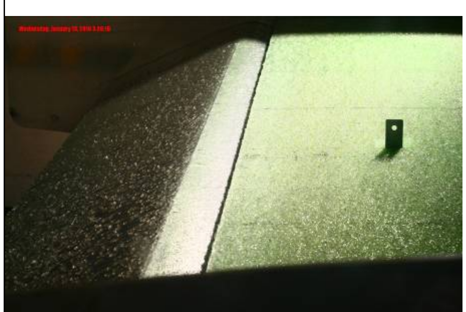


Photo 7.10: Test #1 – Before Rotation

Test #10A
ABC-S Plus, IP Mod 75 g/dm²/h, 25 min
-6°C, 8° Rotation
Visual Contamination Rating (2,2.8,2.7)
Start of Test



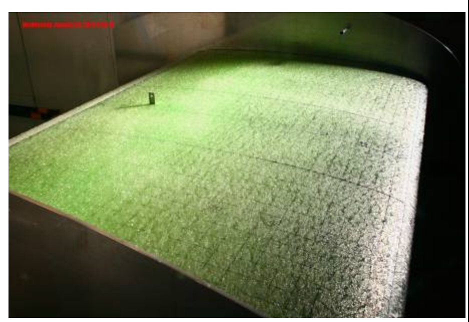
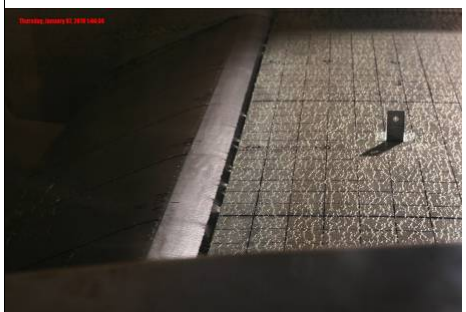


Photo 7.11: Test #1 – End of Rotation

Test #1
ABC-S Plus, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation



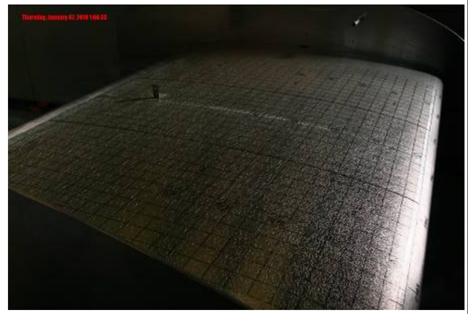
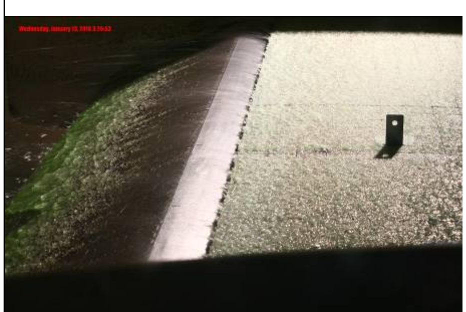


Photo 7.12: Test #1 – End of Test

Test #10A
ABC-S Plus, IP Mod 75 g/dm²/h, 25 min
-6°C, 8° Rotation
Visual Contamination Rating (1,1.8,2)
Before Rotation



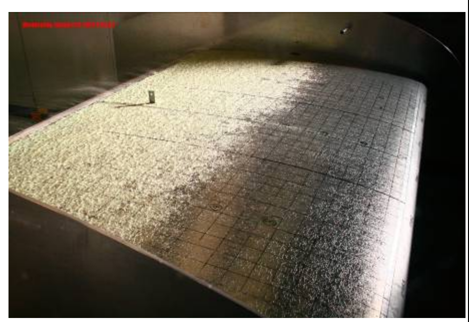


Photo 7.13: Test #10A – Start of Test

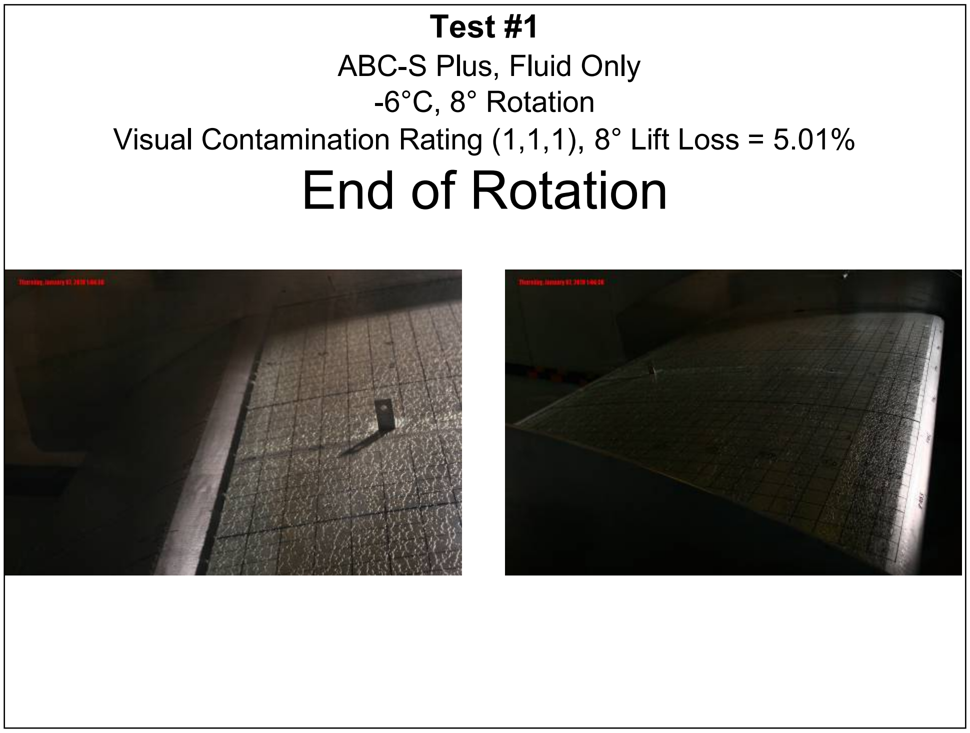


Photo 7.14: Test #10A – Before Rotation

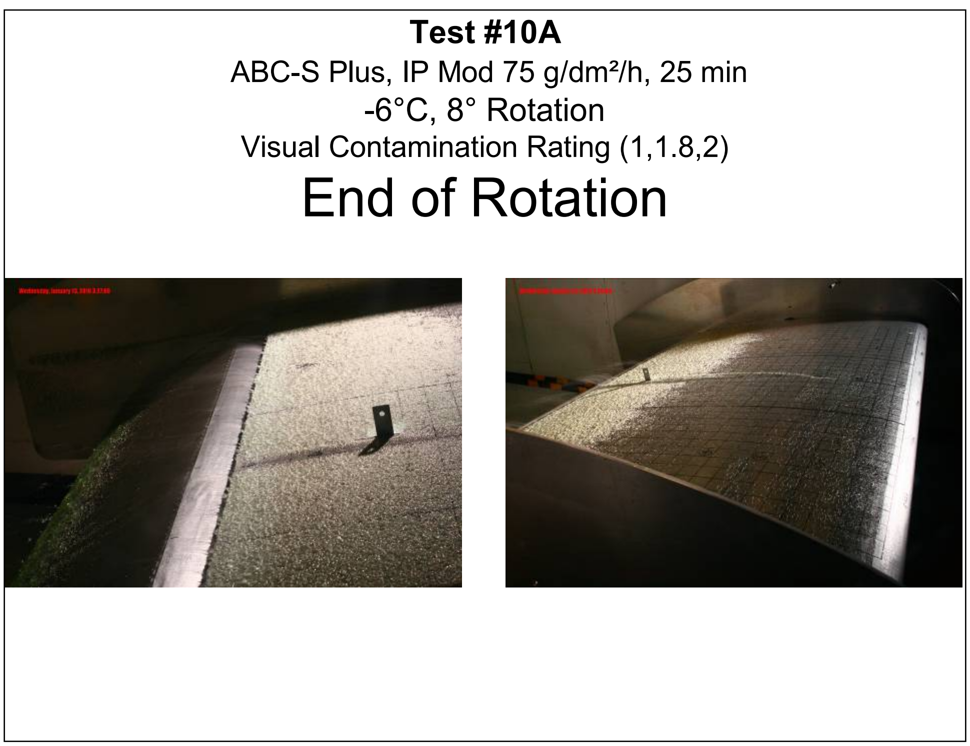


Photo 7.15: Test #10A – End of Rotation

Test #1
ABC-S Plus, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

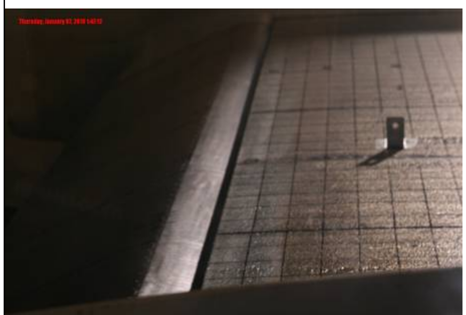
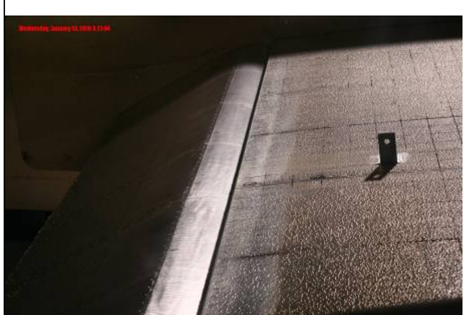


Photo 7.16: Test #10A – End of Test

Test #10A
ABC-S Plus, IP Mod 75 g/dm²/h, 25 min
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test



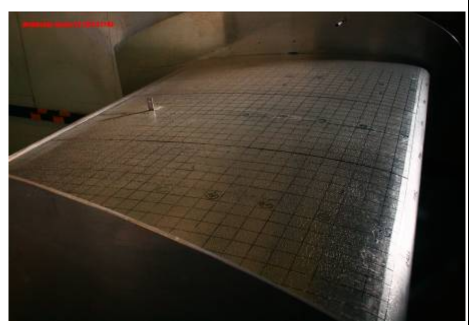


Photo 7.17: Test #1 – Start of Test

Test #1
ABC-S Plus, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

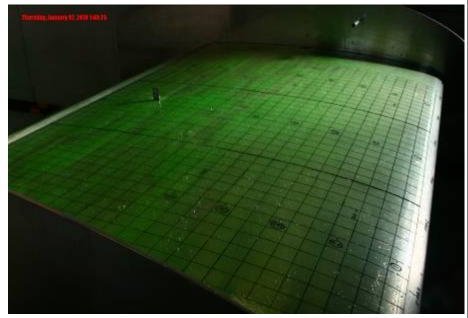
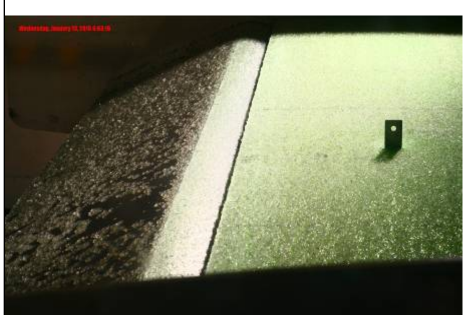


Photo 7.18: Test #1 – Before Rotation

Test #10B
ABC-S Plus, IP Mod 75 g/dm²/h, 25 min
-6°C, 8° Rotation
Visual Contamination Rating (2.2,3,3)
Start of Test



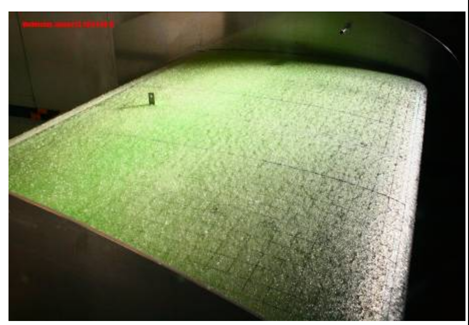


Photo 7.19: Test #1 – End of Rotation

Test #1
ABC-S Plus, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

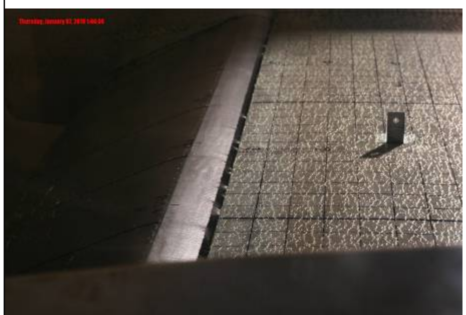
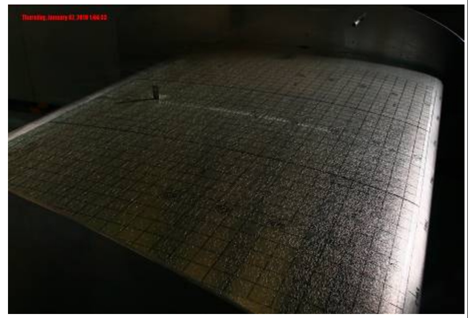



Photo 7.20: Test #1 – End of Test

Test #10B
ABC-S Plus, IP Mod 75 g/dm²/h, 25 min
-6°C, 8° Rotation
Visual Contamination Rating (1,2,2)
Before Rotation

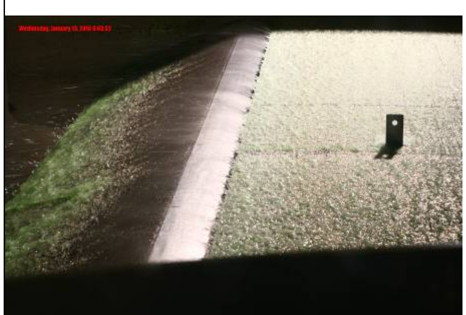
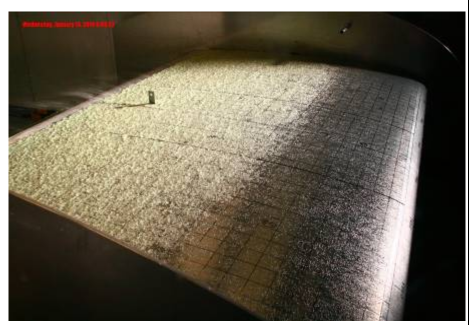



Photo 7.21: Test #10B – Start of Test

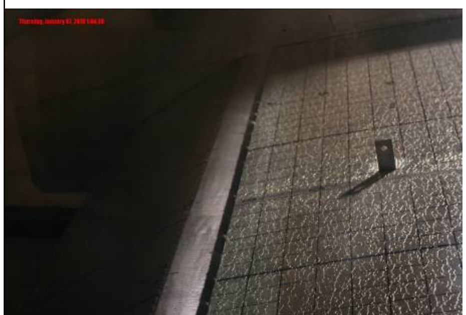
Test #1

ABC-S Plus, Fluid Only

-6°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.01%

End of Rotation



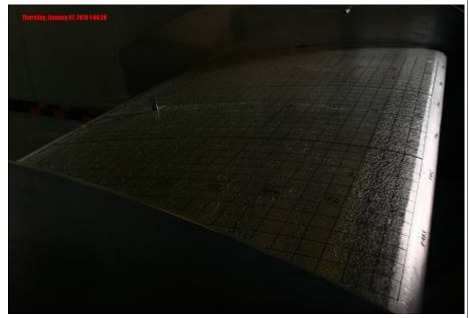


Photo 7.22: Test #10B – Before Rotation

Test #10B

ABC-S Plus, IP Mod 75 g/dm²/h, 25 min

-6°C, 8° Rotation

Visual Contamination Rating (1,2,2), 8° Lift Loss = 7.80%

End of Rotation

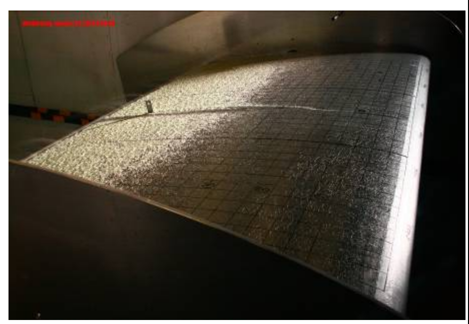


Photo 7.23: Test #10B – End of Rotation

Test #1
ABC-S Plus, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

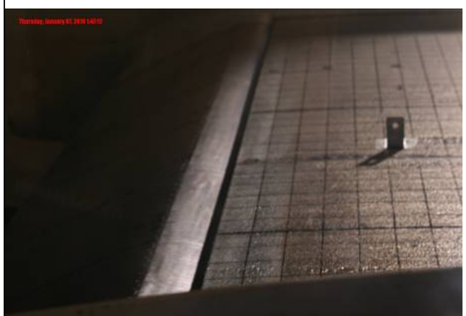
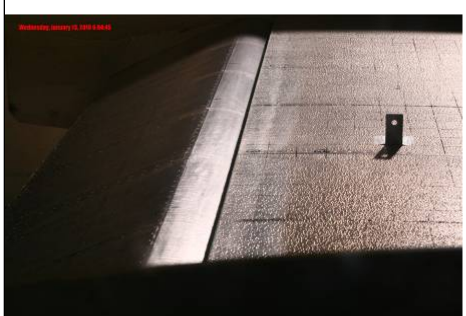


Photo 7.24: Test #10B – End of Test

Test #10B
ABC-S Plus, IP Mod 75 g/dm²/h, 25 min
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1.2)
End of Test



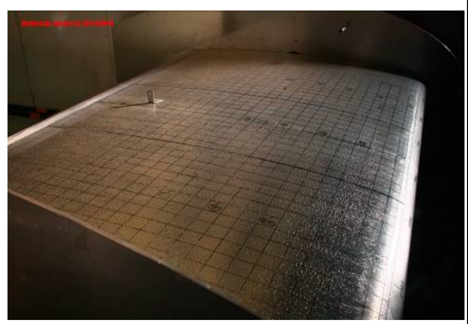


Photo 7.25: Test #55 – Start of Test

Test #55
EG106, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

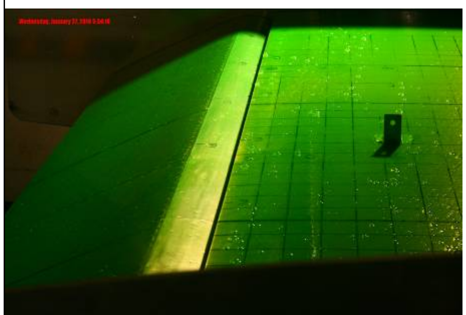
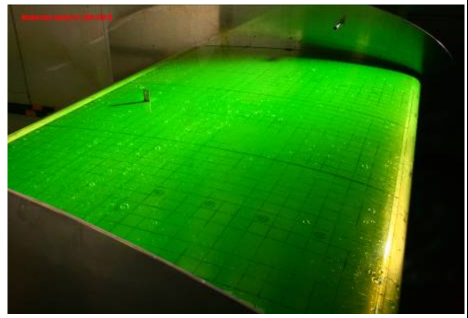



Photo 7.26: Test #55 – Before Rotation

Test #21
EG106, IP Mod 75 g/dm²/h, 25 min
-4°C, 8° Rotation
Visual Contamination Rating (2,2.2,4)
Start of Test

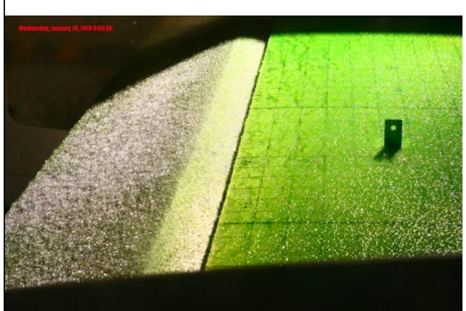



Photo 7.27: Test #55 – End of Rotation

Test #55

EG106, Fluid Only

-3°C, 8° Rotation

Visual Contamination Rating (1,1,1)

Before Rotation

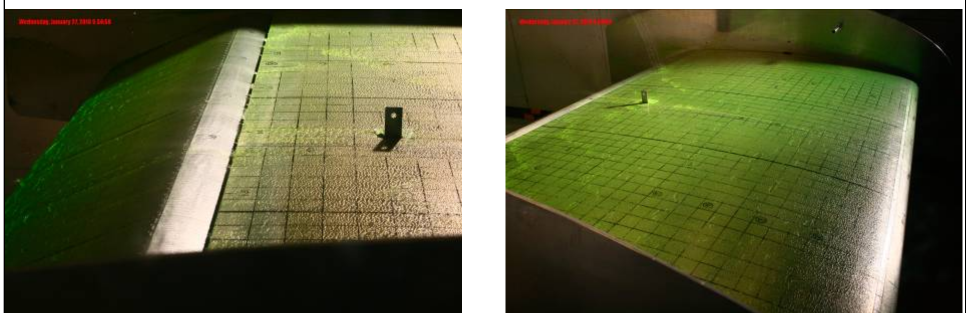


Photo 7.28: Test #55 – End of Test

Test #21

EG106, IP Mod 75 g/dm²/h, 25 min

-4°C, 8° Rotation

Visual Contamination Rating (1,1,1.2)

Before Rotation

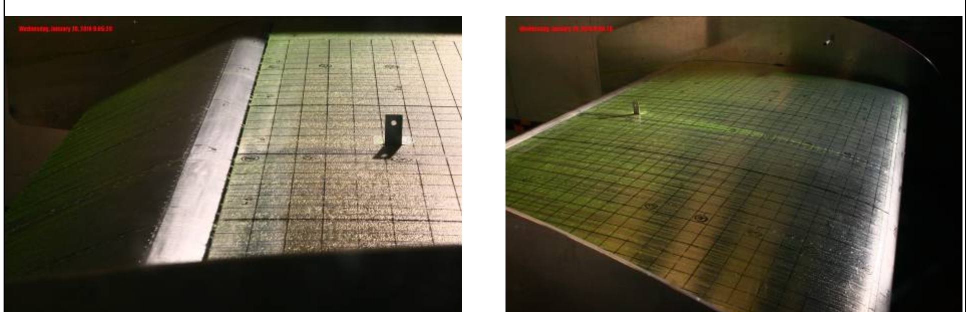
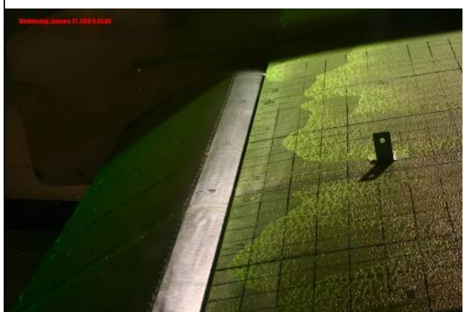


Photo 7.29: Test #21 – Start of Test

Test #55
EG106, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 1.88%
End of Rotation



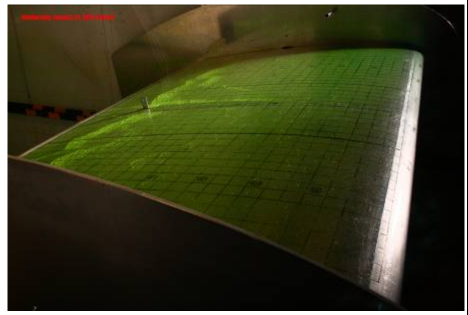
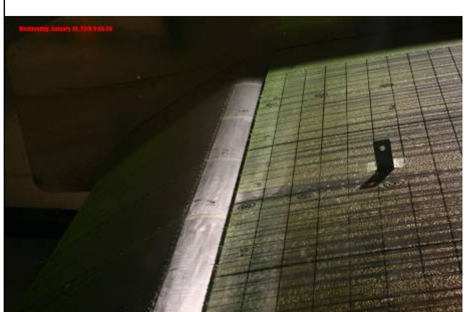


Photo 7.30: Test #21 – Before Rotation

Test #21
EG106, IP Mod 75 g/dm²/h, 25 min
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1.2), 8° Lift Loss = 0.54%
End of Rotation



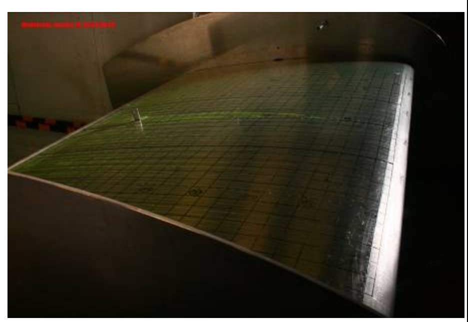
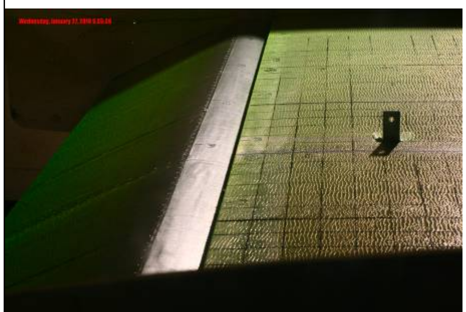


Photo 7.31: Test #21 – End of Rotation

Test #55
EG106, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test



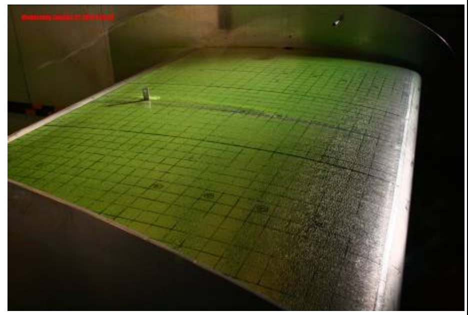
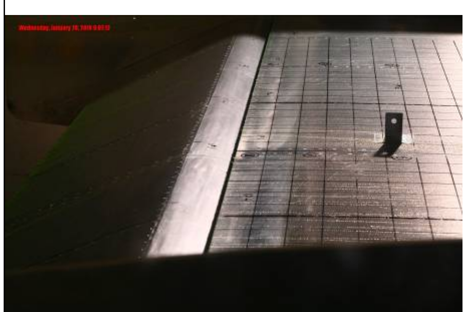


Photo 7.32: Test #21 – End of Test

Test #21
EG106, IP Mod 75 g/dm²/h, 25 min
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test



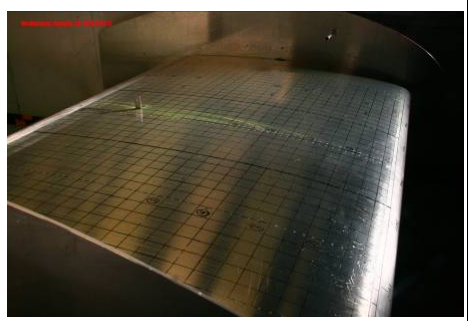


Photo 7.33: Test #29 – Start of Test

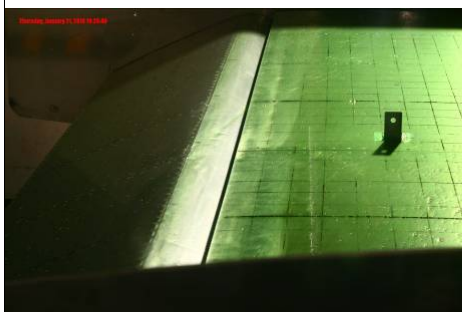
Test #29

Launch, Fluid Only

-5°C, 8° Rotation

Visual Contamination Rating (1,1,1)

Start of Test



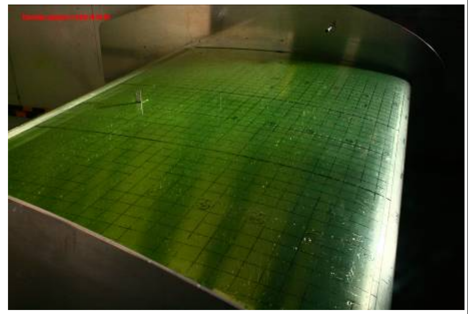


Photo 7.34: Test #29 – Before Rotation

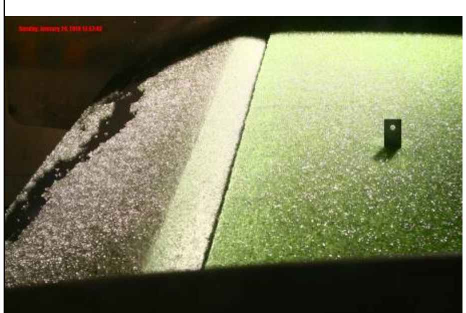
Test #47

Launch, IP Mod 75 g/dm²/h, 25 min

-5°C, 8° Rotation

Visual Contamination Rating (3.7,3.8,4)

Start of Test



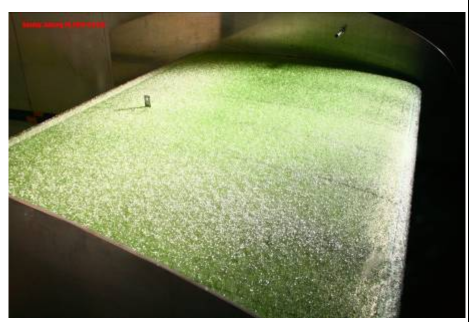


Photo 7.35: Test #29 – End of Rotation

Test #29
Launch, Fluid Only
-5°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

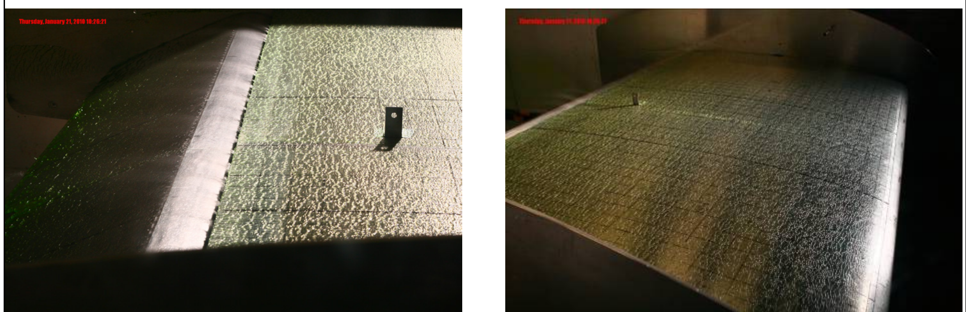


Photo 7.36: Test #29 – End of Test

Test #47
Launch, IP Mod 75 g/dm²/h, 25 min
-5°C, 8° Rotation
Visual Contamination Rating (1,1.7,2.5)
Before Rotation

Photo 7.37: Test #47 – Start of Test

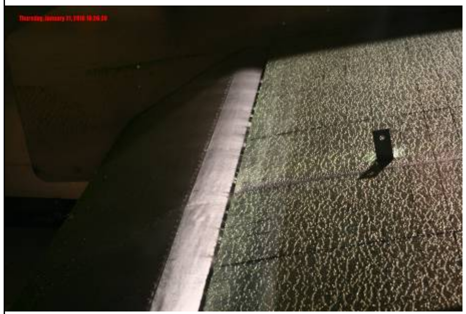
Test #29

Launch, Fluid Only

-5°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 4.96%

End of Rotation



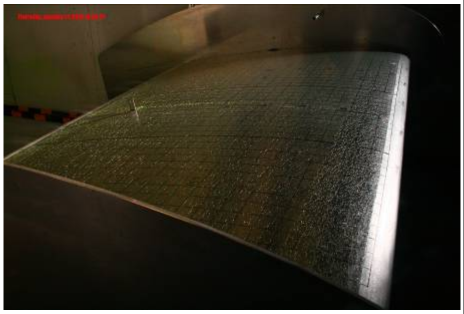


Photo 7.38: Test #47 – Before Rotation

Test #47

Launch, IP Mod 75 g/dm²/h, 25 min

-5°C, 8° Rotation

Visual Contamination Rating (1,1.7,2.5), 8° Lift Loss = 8.21%

End of Rotation

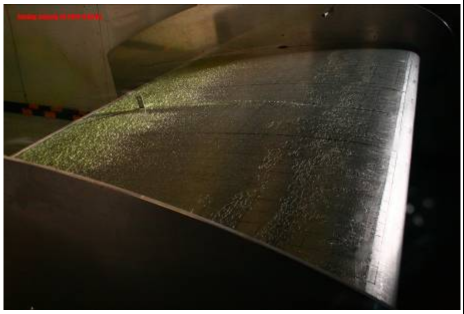


Photo 7.39: Test #47 – End of Rotation

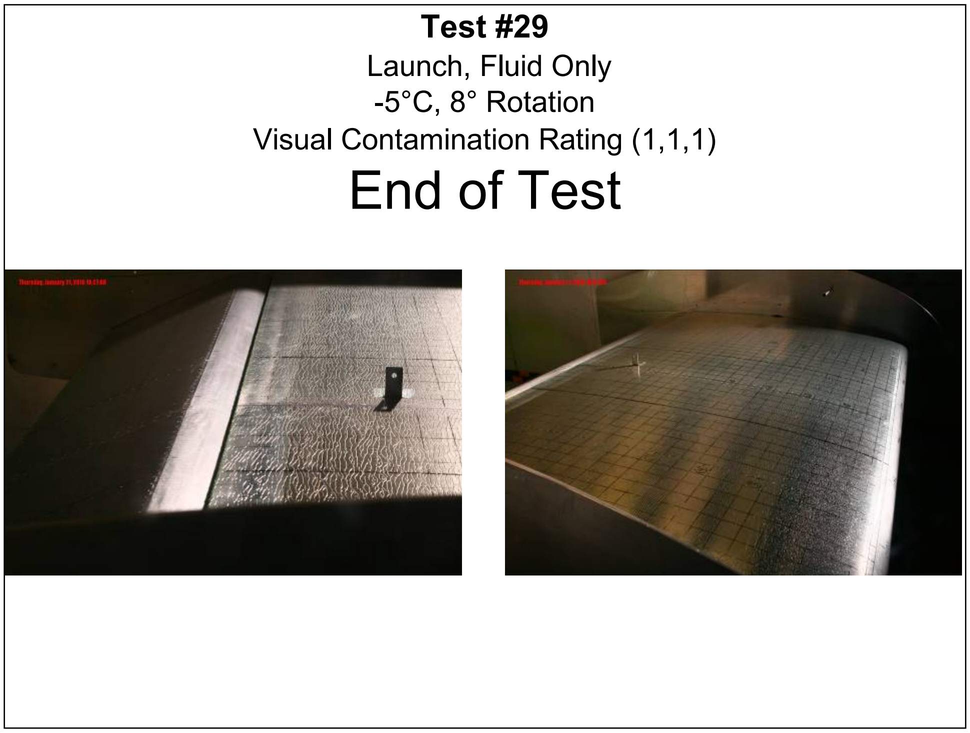


Photo 7.40: Test #47 – End of Test

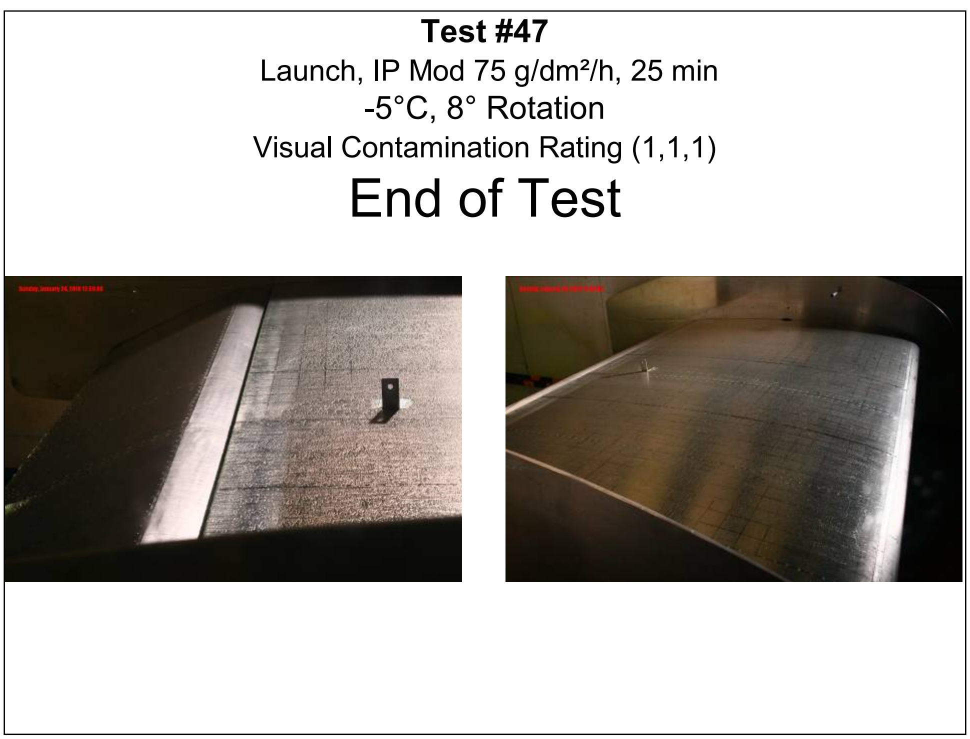


Photo 7.41: Test #54 – Start of Test

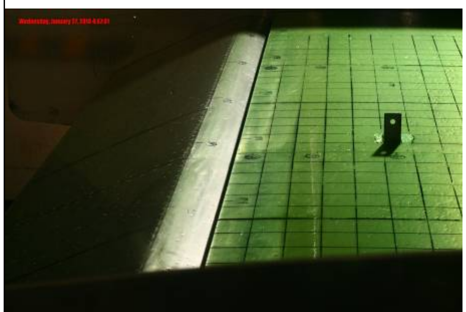
Test #54

Launch, Fluid Only

-2°C, 8° Rotation

Visual Contamination Rating (1,1,1)

Start of Test



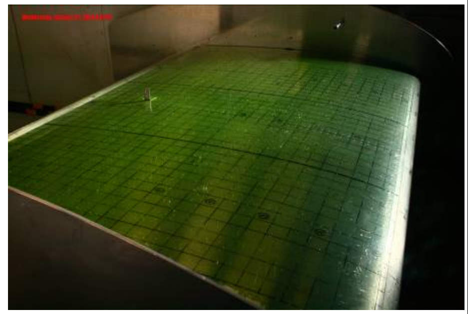


Photo 7.42: Test #54 – Before Rotation

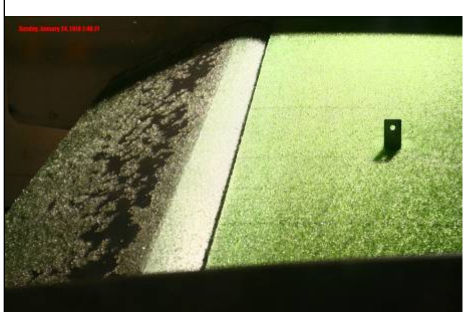
Test #48

Launch, IP Mod 75 g/dm²/h, 15 min

-3°C, 8° Rotation

Visual Contamination Rating (2,2.8,4)

Start of Test



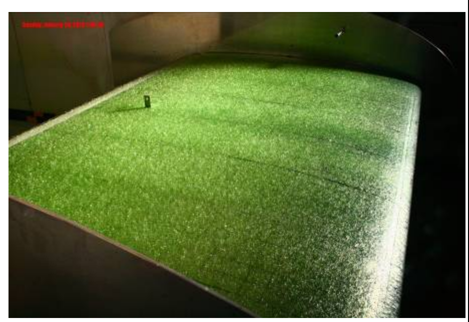


Photo 7.43: Test #54 – End of Rotation

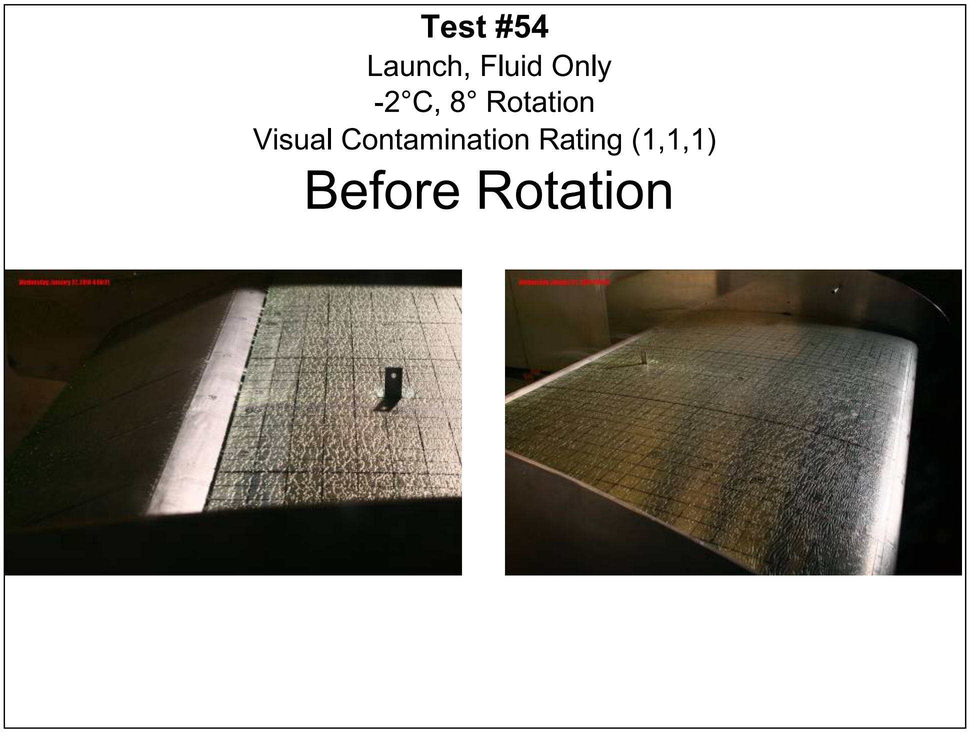


Photo 7.44: Test #54 – End of Test

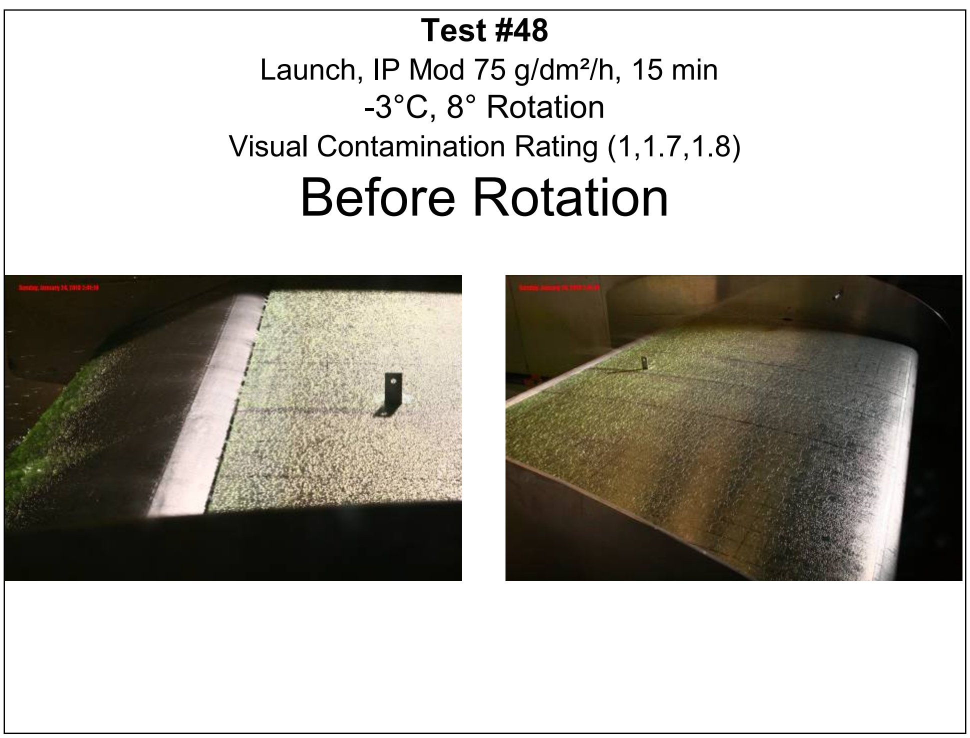


Photo 7.45: Test #48 – Start of Test

Test #54
Launch, Fluid Only
-2°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 3.56%
End of Rotation

Photo 7.46: Test #48 – Before Rotation

Test #48
Launch, IP Mod 75 g/dm²/h, 15 min
-3°C, 8° Rotation
Visual Contamination Rating (1,1.7,1.8), 8° Lift Loss = 6.52%
End of Rotation

Photo 7.47: Test #48 – End of Rotation

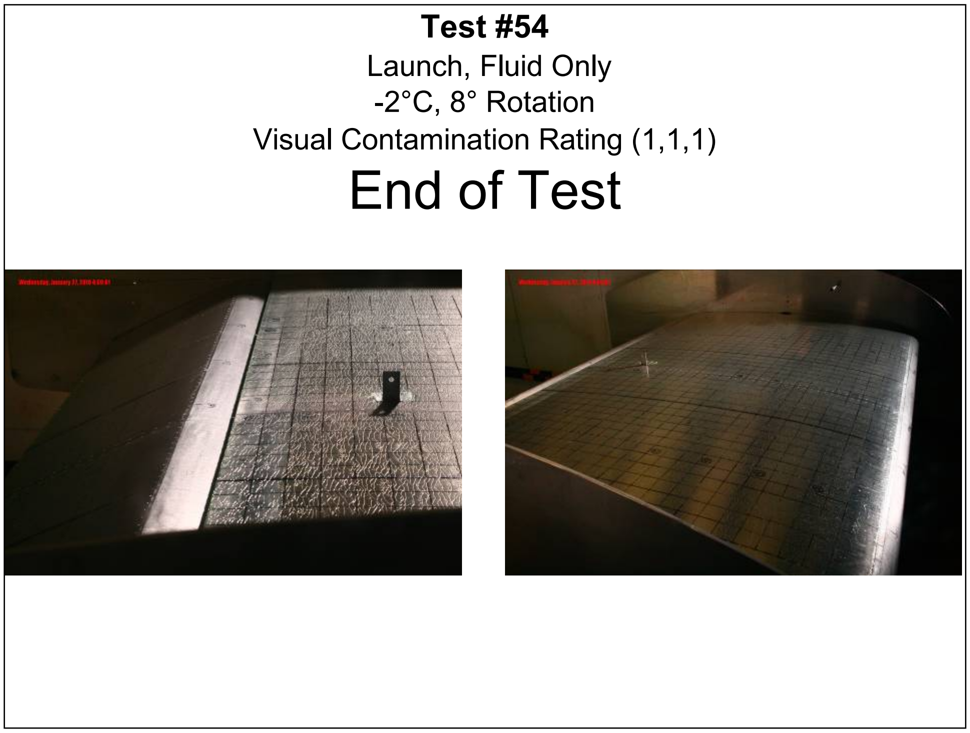


Photo 7.48: Test #48 – End of Test

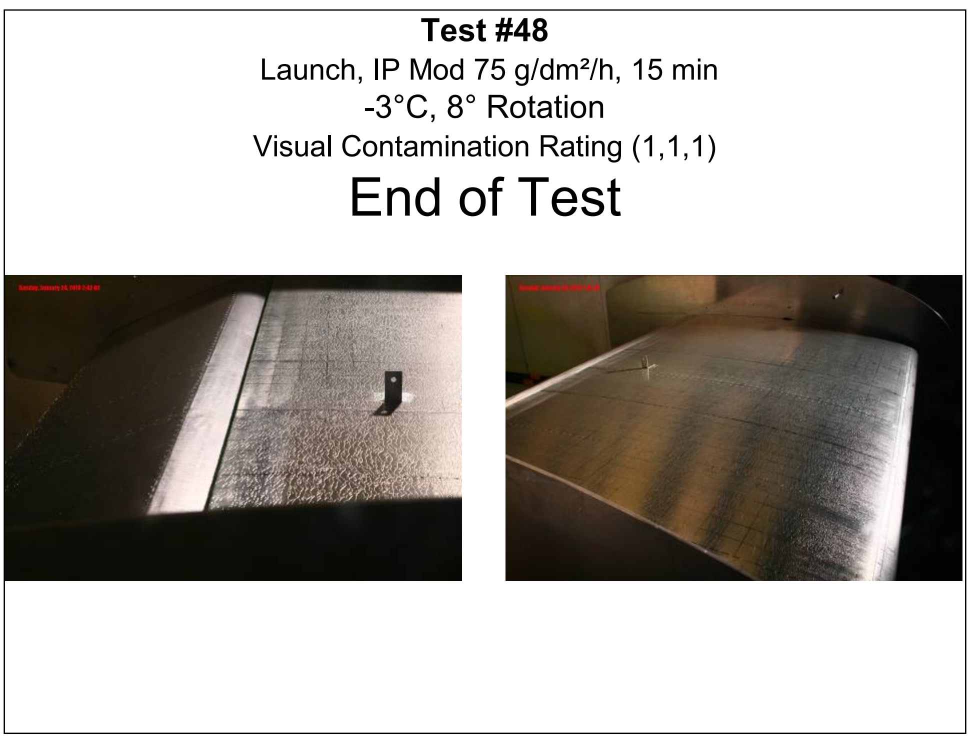


Photo 7.49: Test #60 – Start of Test

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

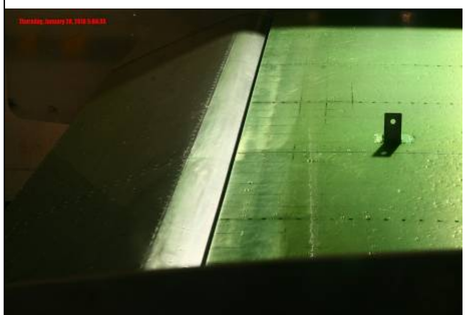
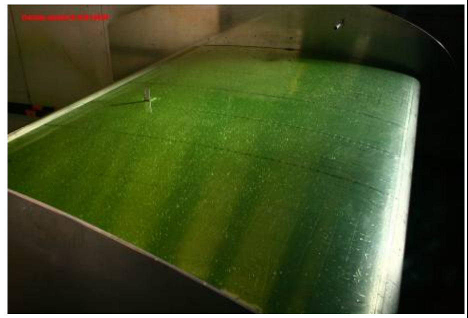



Photo 7.50: Test #60 – Before Rotation

Test #49
Launch, IP Mod 75 g/dm²/h, 15 min
-3°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (2.7,2.8,3)
Start of Test

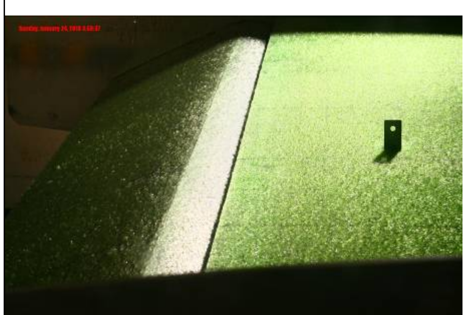
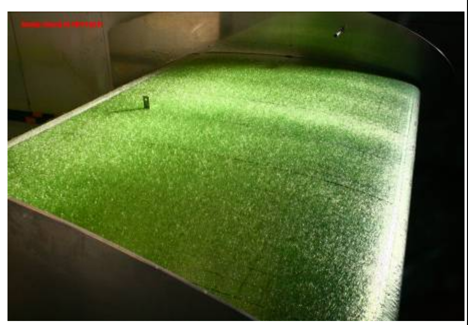



Photo 7.51: Test #60 – End of Rotation

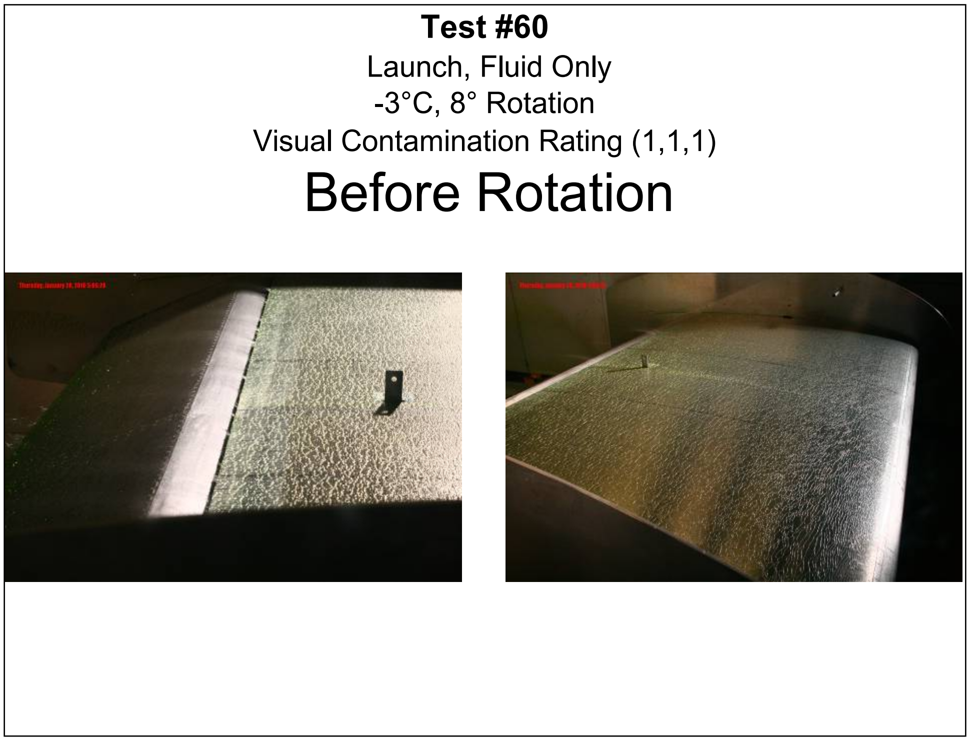


Photo 7.52: Test #60 – End of Test

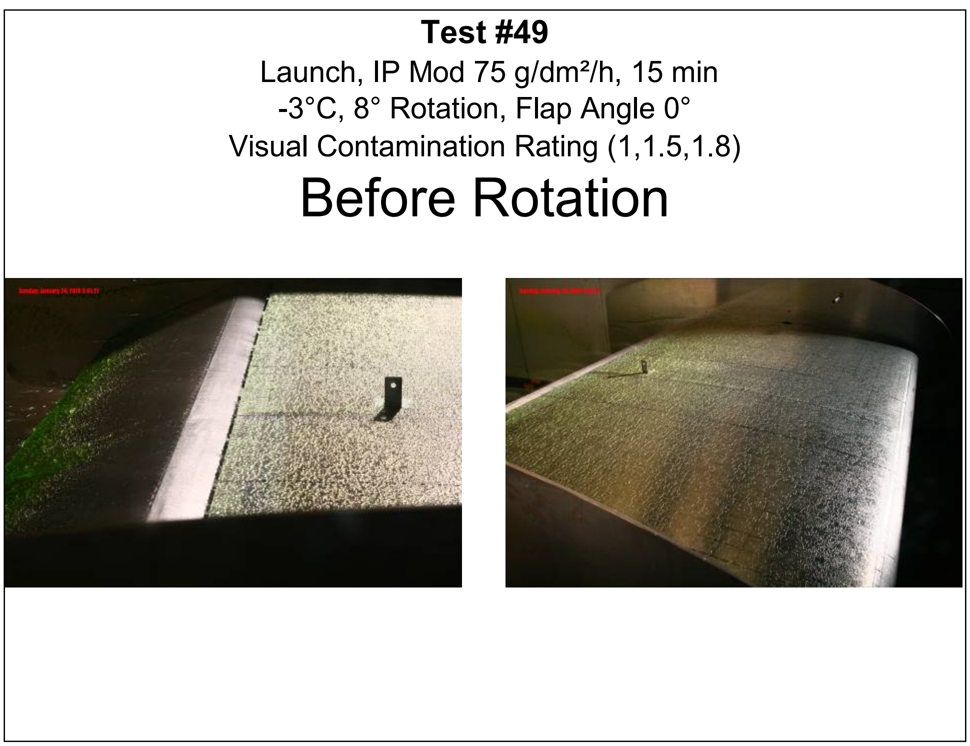


Photo 7.53: Test #49 – Start of Test

Test #60
Launch, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 4.61%
End of Rotation

Photo 7.54: Test #49 – Before Rotation

Test #49
Launch, IP Mod 75 g/dm²/h, 15 min
-3°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1,1.5,1.8), 8° Lift Loss = 6.70%
End of Rotation

Photo 7.55: Test #49 – End of Rotation

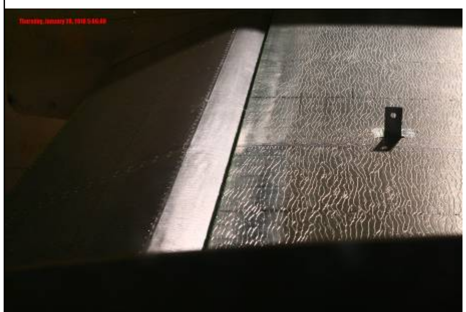
Test #60

Launch, Fluid Only

-3°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test



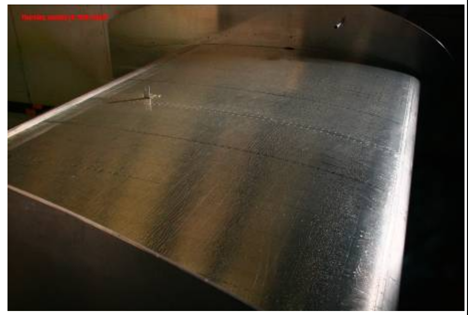


Photo 7.56: Test #49 – End of Test

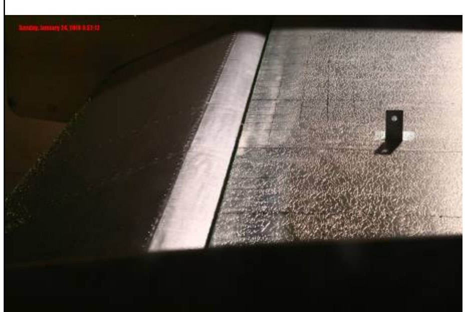
Test #49

Launch, IP Mod 75 g/dm²/h, 15 min

-3°C, 8° Rotation, Flap Angle 0°

Visual Contamination Rating (1,1,1)

End of Test



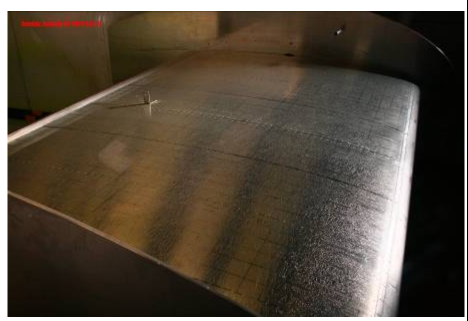


Photo 7.57: Test #75 – Start of Test

Test #75
EG106, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

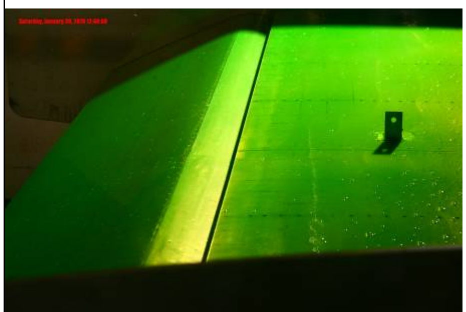
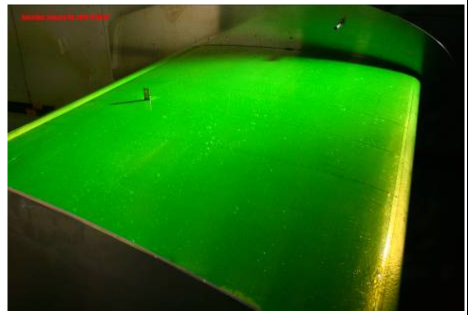



Photo 7.58: Test #75 – Before Rotation

Test #71
EG106, IP Mod 75 g/dm²/h, 10 min
-18°C, 8° Rotation
Visual Contamination Rating (2.3,2.3,2.8)
Start of Test

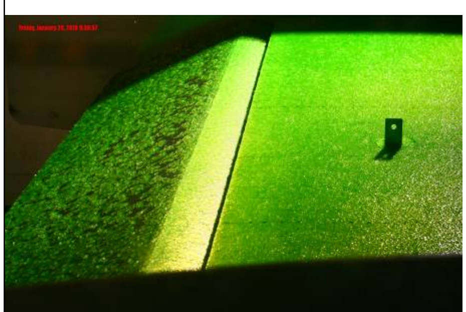
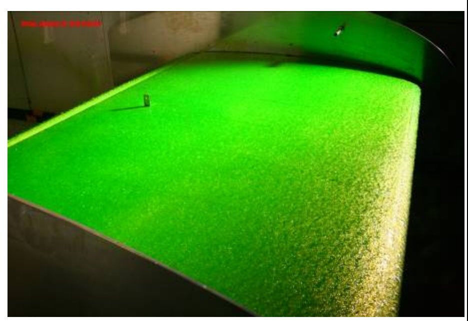



Photo 7.59: Test #75 – End of Rotation

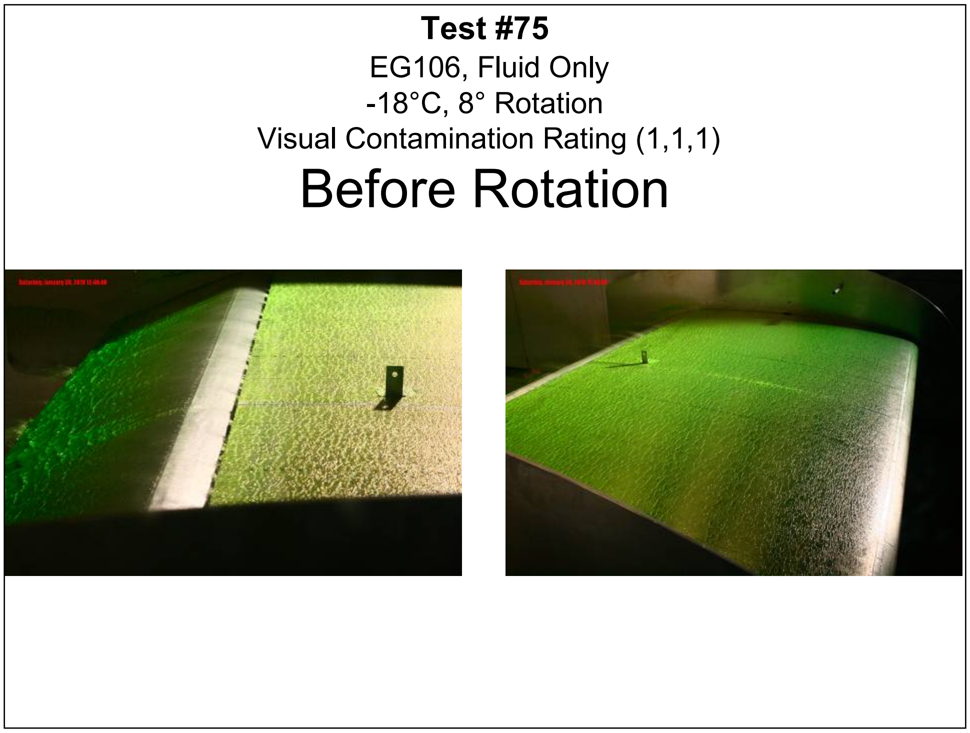


Photo 7.60: Test #75 – End of Test

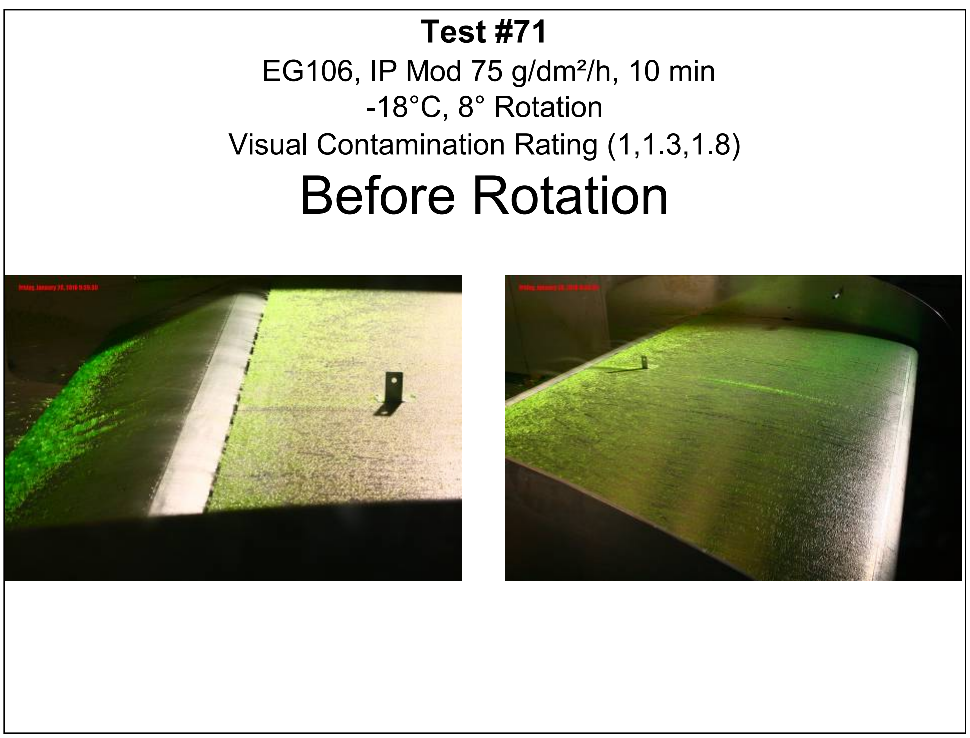


Photo 7.61: Test #71 – Start of Test

Test #75

EG106, Fluid Only

-18°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 4.08%

End of Rotation

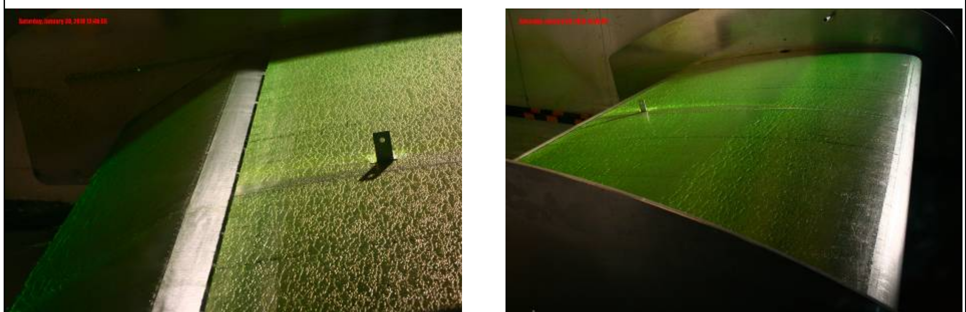


Photo 7.62: Test #71 – Before Rotation

Test #71

EG106, IP Mod 75 g/dm²/h, 10 min

-18°C, 8° Rotation

Visual Contamination Rating (1,1.3,1.8), 8° Lift Loss = 2.92%

End of Rotation

Photo 7.63: Test #71 – End of Rotation

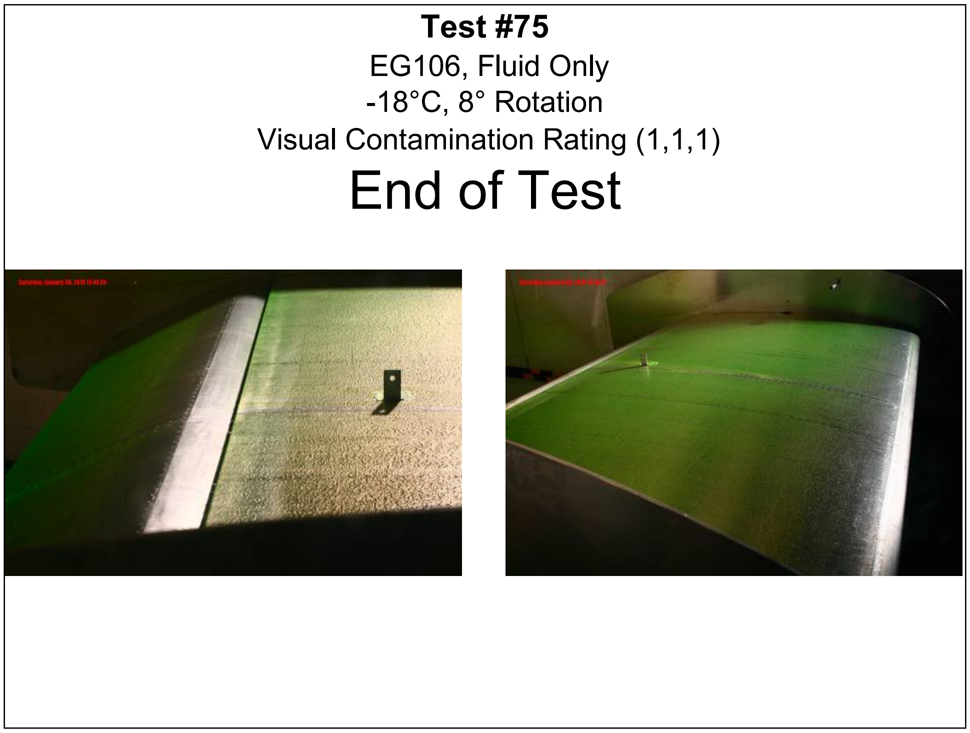


Photo 7.64: Test #71 – End of Test

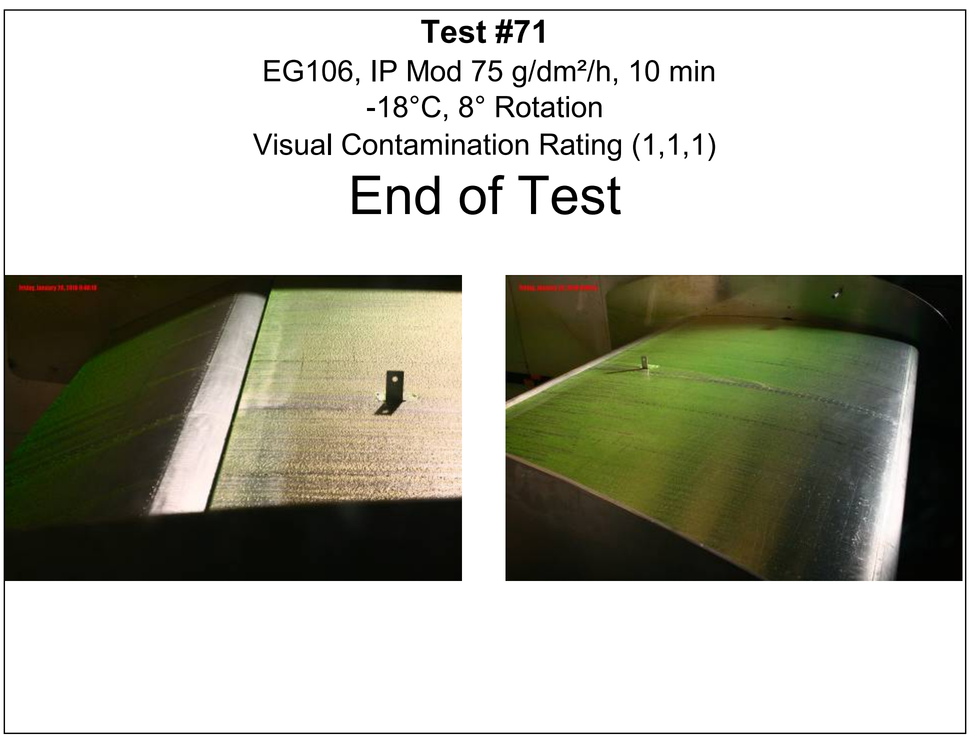


Photo 7.65: Test #76 – Start of Test

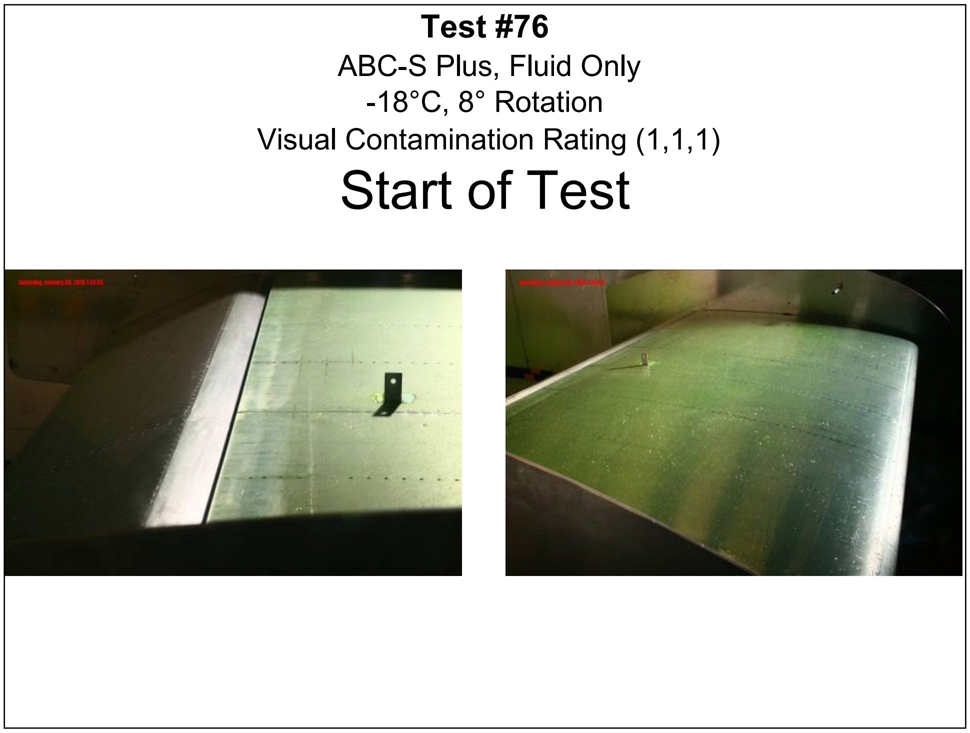


Photo 7.66: Test #76 – Before Rotation

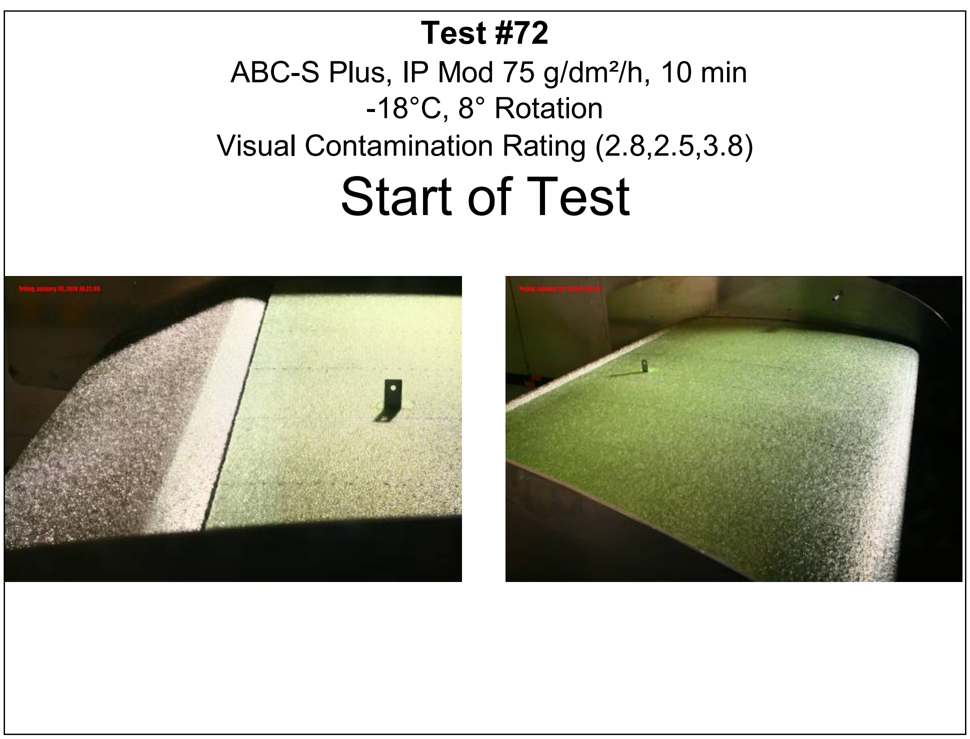
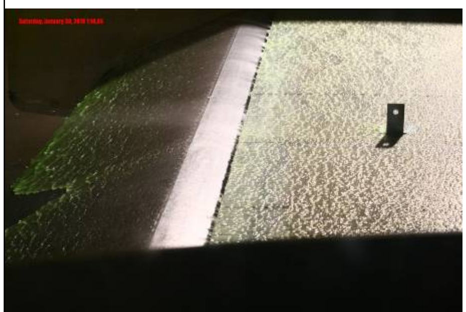


Photo 7.67: Test #76 – End of Rotation

Test #76
ABC-S Plus, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation



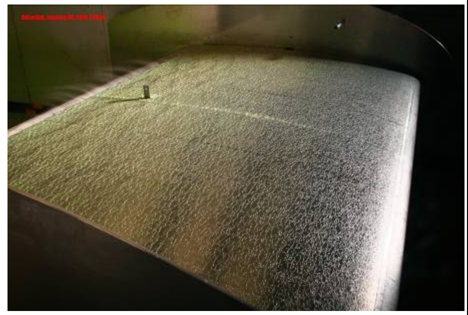


Photo 7.68: Test #76 – End of Test

Test #72
ABC-S Plus, IP Mod 75 g/dm²/h, 10 min
-18°C, 8° Rotation
Visual Contamination Rating (1.2,2,2.8)
Before Rotation

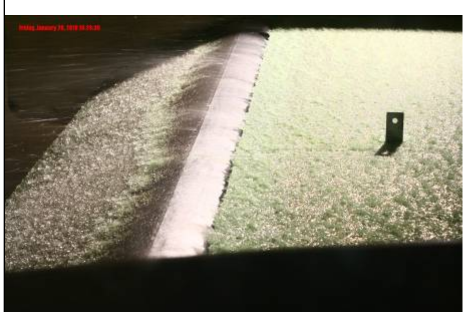


Photo 7.69: Test #72 – Start of Test

Test #76
ABC-S Plus, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.89%
End of Rotation

Photo 7.70: Test #72 – Before Rotation

Test #72
ABC-S Plus, IP Mod 75 g/dm²/h, 10 min
-18°C, 8° Rotation
Visual Contamination Rating (1.2,2,2.8), 8° Lift Loss = 9.31%
End of Rotation

Photo 7.71: Test #72 – End of Rotation

Test #76

ABC-S Plus, Fluid Only

-18°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test

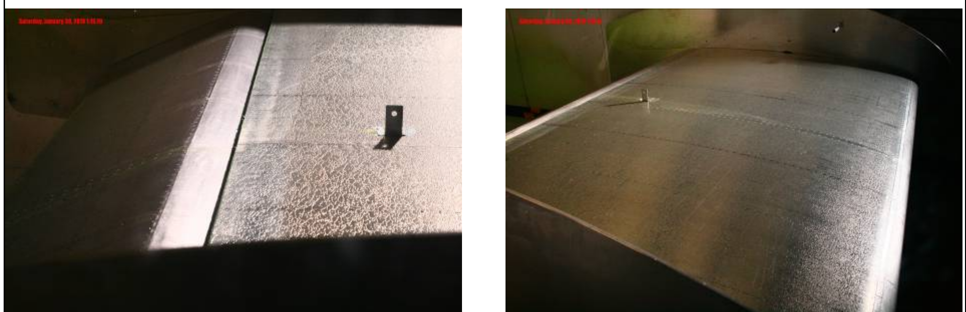


Photo 7.72: Test #72 – End of Test

Test #72

ABC-S Plus, IP Mod 75 g/dm²/h, 10 min

-18°C, 8° Rotation

Visual Contamination Rating (1,1.25,1.7)

End of Test

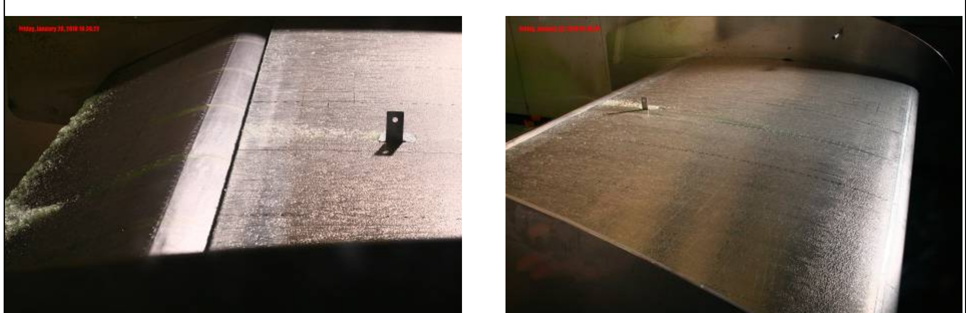
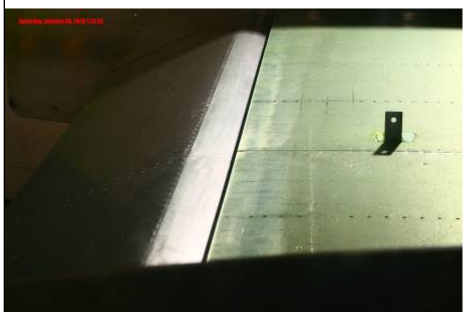


Photo 7.73: Test #76 – Start of Test

Test #76
ABC-S Plus, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test



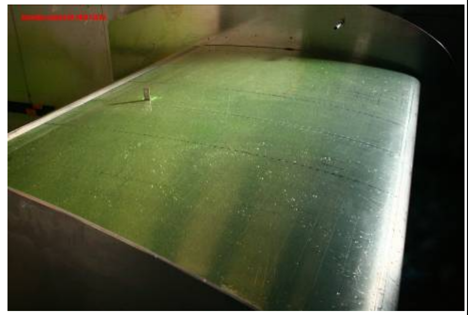
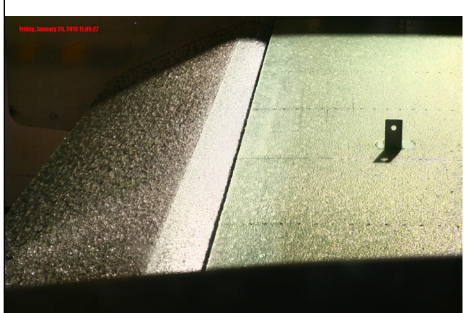


Photo 7.74: Test #76 – Before Rotation

Test #73
ABC-S Plus, IP Mod 75 g/dm²/h, 5 min
-18°C, 8° Rotation
Visual Contamination Rating (2.2,2.2,3.4)
Start of Test



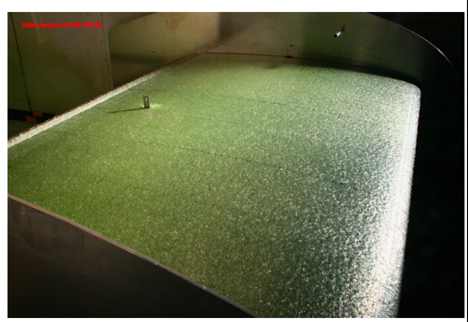


Photo 7.75: Test #76 – End of Rotation

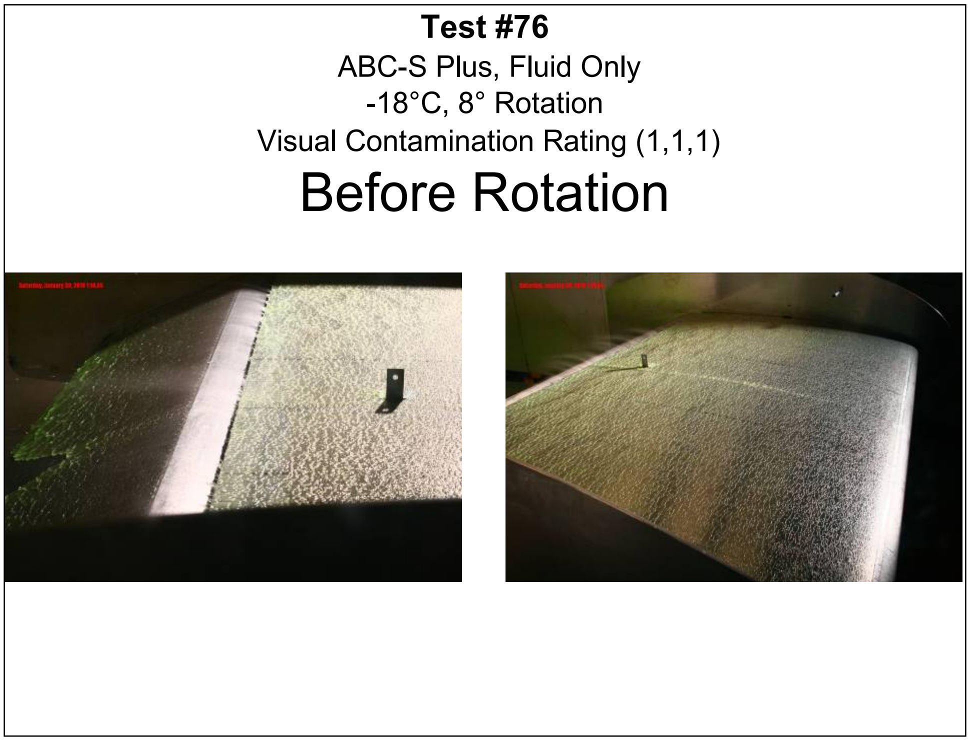


Photo 7.76: Test #76 – End of Test

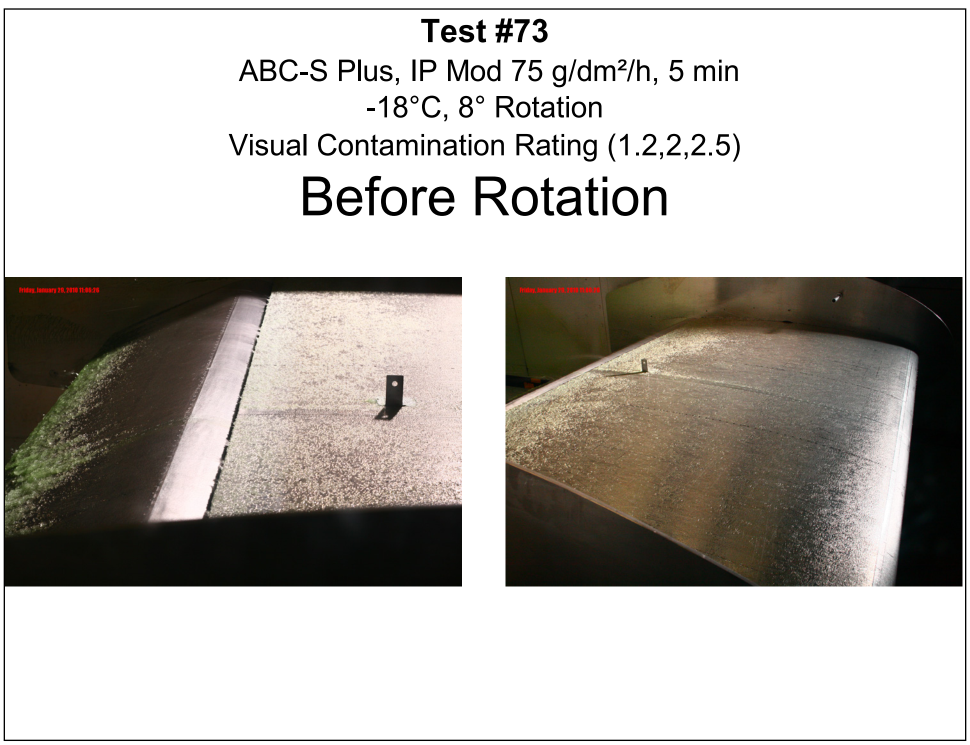


Photo 7.77: Test #73 – Start of Test

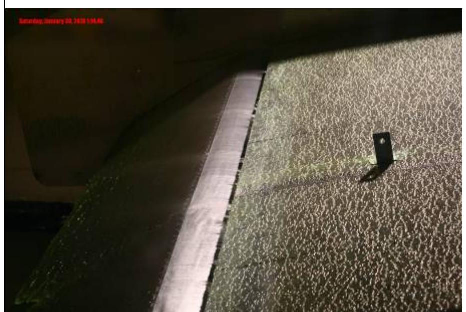
Test #76

ABC-S Plus, Fluid Only

-18°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.89%

End of Rotation



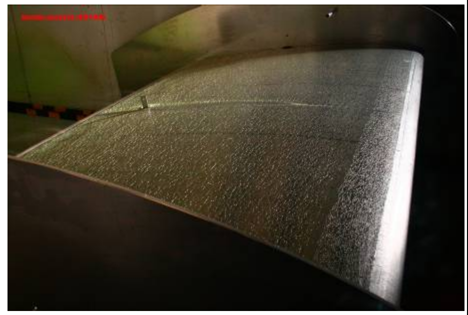


Photo 7.78: Test #73 – Before Rotation

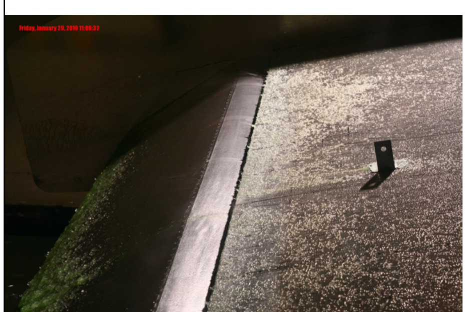
Test #73

ABC-S Plus, IP Mod 75 g/dm²/h, 5 min

-18°C, 8° Rotation

Visual Contamination Rating (1.2,2,2.5)

End of Rotation



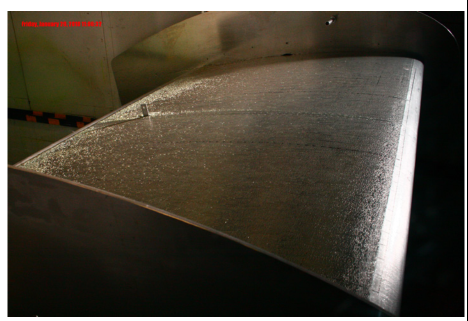


Photo 7.79: Test #73 – End of Rotation

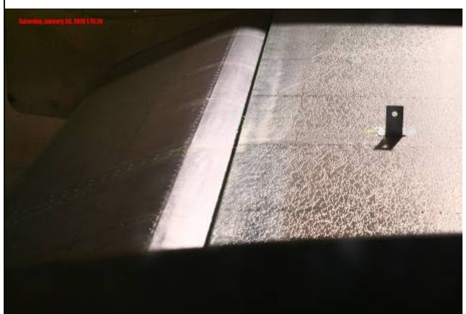
Test #76

ABC-S Plus, Fluid Only

-18°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test



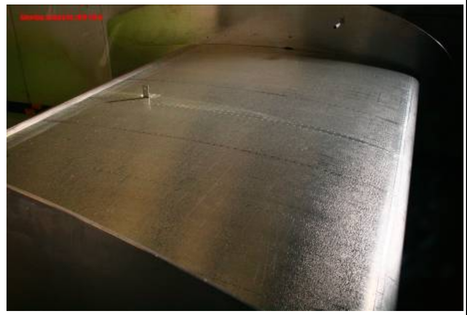


Photo 7.80: Test #73 – End of Test

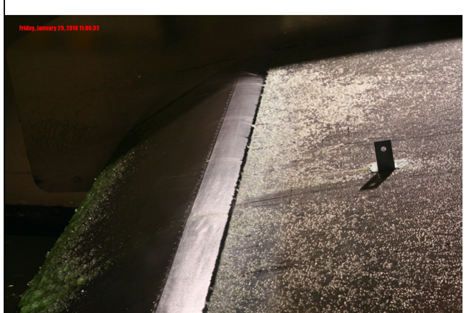
Test #73

ABC-S Plus, IP Mod 75 g/dm²/h, 5 min

-18°C, 8° Rotation

Visual Contamination Rating (1.2,2,2.5)

End of Rotation



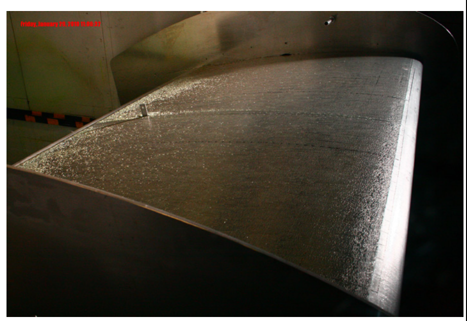
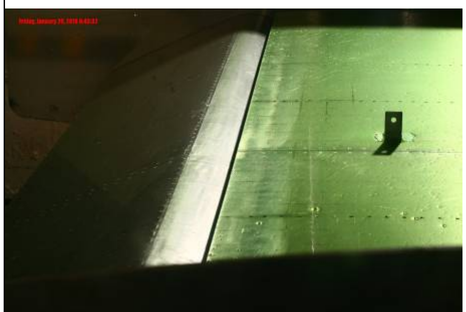


Photo 7.81: Test #70 – Start of Test

Test #70
Launch, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test



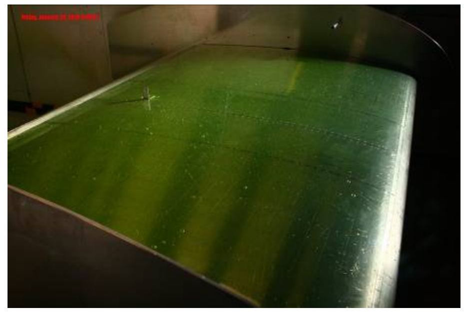


Photo 7.82: Test #70 – Before Rotation

Test #74
Launch, IP Mod 75 g/dm²/h, 5 min
-18.5°C, 8° Rotation
Visual Contamination Rating (2.7,2.3,3.2)
Start of Test

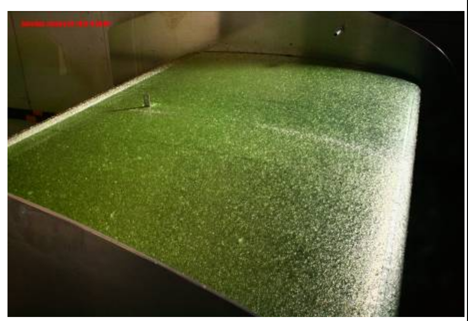


Photo 7.83: Test #70 – End of Rotation

Test #70
Launch, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

Photo 7.84: Test #70 – End of Test

Test #74
Launch, IP Mod 75 g/dm²/h, 5 min
-18.5°C, 8° Rotation
Visual Contamination Rating (1.5,2,2.8)
Before Rotation

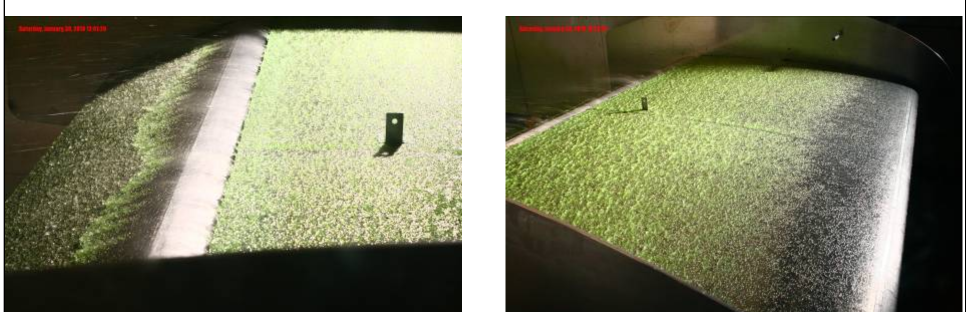


Photo 7.85: Test #74 – Start of Test

Test #70

Launch, Fluid Only

-18°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.59%

End of Rotation

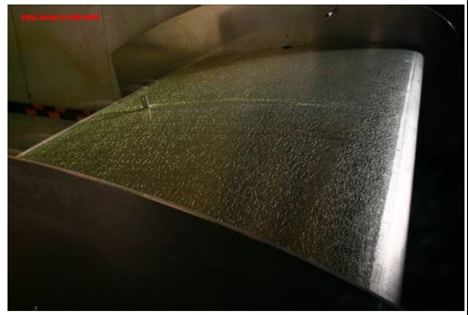


Photo 7.86: Test #74 – Before Rotation

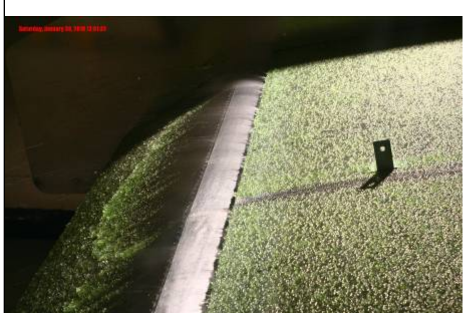
Test #74

Launch, IP Mod 75 g/dm²/h, 5 min

-18.5°C, 8° Rotation

Visual Contamination Rating (1.5,2,2.8), 8° Lift Loss = 10.30%

End of Rotation



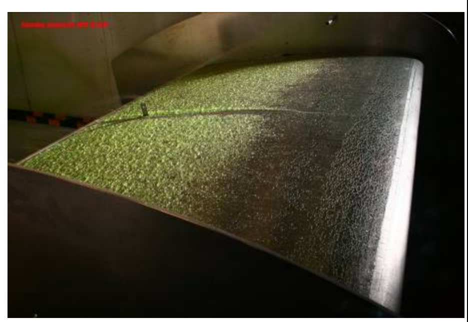


Photo 7.87: Test #74 – End of Rotation

Test #70
Launch, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

Photo 7.88: Test #74 – End of Test

Test #74
Launch, IP Mod 75 g/dm²/h, 5 min
-18.5°C, 8° Rotation
Visual Contamination Rating (1,1.5,1.9)
End of Test

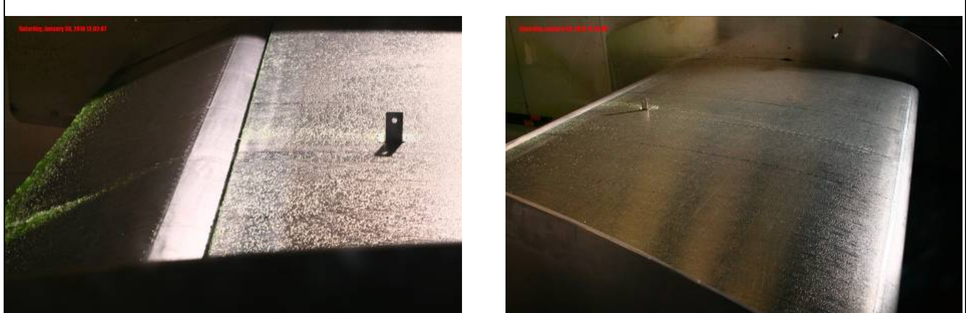


Photo 7.89: Test #64 – Start of Test

Test #64
ABC-S Plus, Fluid Only
-13°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

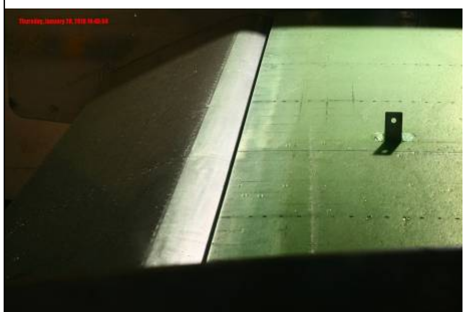



Photo 7.90: Test #64 – Before Rotation

Test #95
ABC-S Plus, IP Mod 75 g/dm²/h, 10 min
-8°C, 8° Rotation
Visual Contamination Rating (2.2,2,2.8)
Start of Test

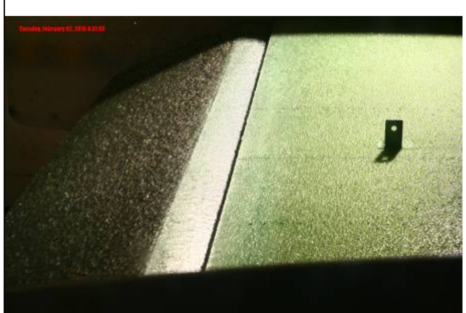



Photo 7.91: Test #64 – End of Rotation

Test #64

ABC-S Plus, Fluid Only

-13°C, 8° Rotation

Visual Contamination Rating (1,1,1)

Before Rotation

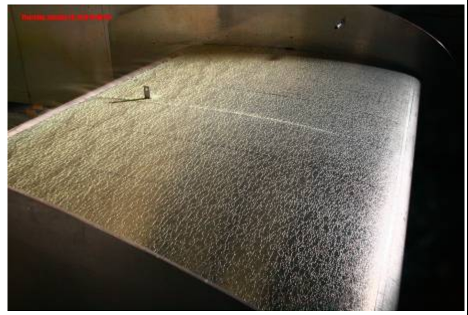


Photo 7.92: Test #64 – End of Test

Test #95

ABC-S Plus, IP Mod 75 g/dm²/h, 10 min

-8°C, 8° Rotation

Visual Contamination Rating (1,1.7,2)

Before Rotation

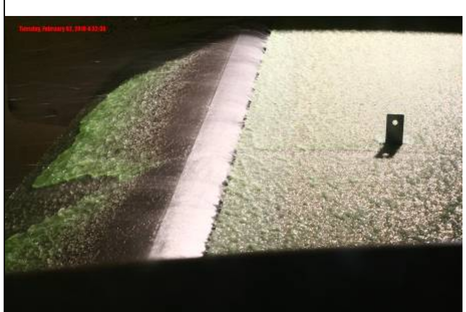


Photo 7.93: Test #95 – Start of Test

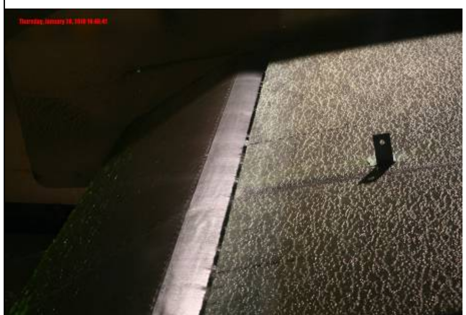
Test #64

ABC-S Plus, Fluid Only

-13°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.07%

End of Rotation



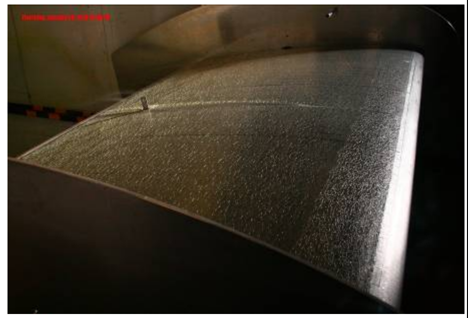


Photo 7.94: Test #95 – Before Rotation

Test #95

ABC-S Plus, IP Mod 75 g/dm²/h, 10 min

-8°C, 8° Rotation

Visual Contamination Rating (1,1.7,2), 8° Lift Loss = 6.93%

End of Rotation

Photo 7.95: Test #95 – End of Rotation

Test #64

ABC-S Plus, Fluid Only

-13°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test

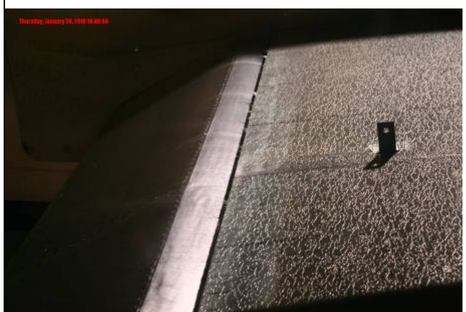


Photo 7.96: Test #95 – End of Test

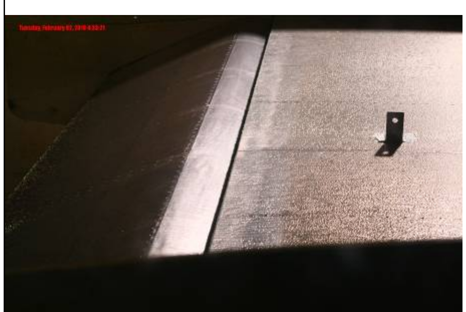
Test #95

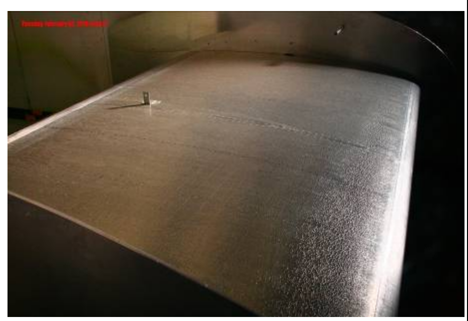
ABC-S Plus, IP Mod 75 g/dm²/h, 10 min

-8°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test





8. LIGHT ICE PELLETS MIXED WITH LIGHT FREEZING RAIN ALLOWANCE TIMES

Aerodynamic testing was conducted to validate and further develop the Type IV high-speed ice pellet allowance times in the NRC wind tunnel. Previous testing in 2006-07 and 2008-09 consisted of wind tunnel tests and Falcon 20 aircraft tests to develop allowance times for mixed conditions with ice pellets. Due to the limitations of the data, some extrapolation of the results was required in order to develop a comprehensive table. It was recommended that testing be conducted at the most critical limits of the allowance times to validate the current guidance material for use with newer generation aircraft operating with supercritical wings. Additional testing was also required to provide guidance material where data was limited or non-existent. The results of this testing have been separated by test condition, and the details can be found in the following sections:

- Section 6: Light Ice Pellets;
- Section 7: Moderate Ice Pellets;
- Section 8: Light Ice Pellets and Light Freezing Rain;
- Section 9: Light Ice Pellets and Moderate Rain;
- Section 10: Light Ice Pellets and Light Snow; and
- Section 11: Light Ice Pellets and Moderate Snow.

This section provides an overview of each test conducted to substantiate and further develop the current high-speed allowance times for Type IV fluids in Light Ice Pellet Mixed with Light Freezing Rain conditions. Testing was conducted in simulated precipitation conditions. The parameters for each test are detailed, and a description of the data collected during each test is provided.

NOTE: Testing was not conducted in Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle or Light Ice Pellets Mixed with Light Rain. These conditions are less severe compared to Light Ice Pellet Mixed with Light Freezing Rain; therefore, the allowance times developed and substantiated for this condition can also apply to in Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle and Light Ice Pellets Mixed with Light Rain.

8.1 Overview of Tests

A summary of the Light Ice Pellet Mixed with Light Freezing Rain tests conducted in the wind tunnel is shown in Table 8.1. The table provides relevant information for each of the tests, as well as 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 wind tunnel is provided in Subsection 4.1. A brief description of the column headings for Table 8.1 is provided in Subsection 6.1.

Table 8.1: Summary of 2009-10 Light Ice Pellet Mixed with Light Freezing Rain Testing

Test No.	Date	Fluid	Associated Baseline Test	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Flap Angle (°)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° During Rotation	8° Lift Loss (%)
0	7-Jan-10	ABC-S Plus	1	IP-/ZR-	25/25	25	-6.1	-6.1	20	2, 2, 4	1, 1, 3.7	1.609	6.5
26	21-Jan-10	EG106	55	IP-/ZR-	25/25	25	-1.9	-3.1	20	2.2, 1.7, 4.7	1, 1, 4	1.639	4.8
26A	21-Jan-10	EG106	25	IP-/ZR-	25/25	25	-3.3	-2.8	0	1.8, 2, 1.9	1, 1, 1	1.697	1.4
59	28-Jan-10	Launch	60	IP-/ZR-	25/25	25	-3.3	-2.2	0	2, 2, 2.2	1, 1.3, 1.5	1.651	4.1
63	28-Jan-10	ABC-S Plus	64	IP-/ZR-	25/25	10	-12.3	-11.4	20	2.3, 2.3, 3.2	1.2, 2, 2.3	1.589	7.7
98	2-Feb-10	EG106	100	IP-/ZR-	25/25	10	-6.7	-9.5	20	2, 2, 2.5	1, 1, 1.3	1.691	1.8
1	3-Feb-10	ABC-S Plus	N/A	Fluid Only	N/A	N/A	-5.7	-4.6	20	1, 1, 1	1, 1, 1	1.635	5.01
25	4-Feb-10	EG106	N/A	Fluid Only	N/A	N/A	-4	-3.4	20	1, 1, 1	1, 1, 1	1.687	1.99
55	27-Jan-10	EG106	N/A	Fluid Only	N/A	N/A	-2.6	-0.9	20	1, 1, 1	1, 1, 1	1.689	1.88
60	28-Jan-10	Launch	N/A	Fluid Only	N/A	N/A	-2.8	-1.9	20	1, 1, 1	1, 1, 1	1.642	4.61
64	6-Feb-10	ABC-S Plus	N/A	Fluid Only	N/A	N/A	-13.4	-11.3	20	1, 1, 1	1, 1, 1	1.634	5.07
100	3-Feb-10	EG106	N/A	Fluid Only	N/A	N/A	-6.3	-8.2	20	1, 1, 1	1, 1, 1	1.682	2.28

8.2 Data Collected

8.2.1 Fluid Thickness Data

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

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

Tables 8.2 to 8.7 show the fluid thickness measurements collected during the contaminated fluid tests. The associated baseline fluid only cases are also shown in Tables 8.8 to 8.13 for comparison purposes.

Table 8.2: Test #0 Fluid Thickness Data

Test 0: ABC-S Plus, IP-/ZR-, Tunnel OAT -6.1°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.8	2.2	0.0
2	2.5	2.7	0.0
3	3.3	3.5	0.1
4	4.5	4.5	0.1
5	5.7	5.7	0.1
6	5.7	7.0	0.2
7	5.7	5.7	0.3
8	4.5	4.5	0.2
Flap	1.0	slush	0.2

Table 8.3: Test #26 Fluid Thickness Data

Test 26: EG106, IP-/ZR-, Tunnel OAT -1.9°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.7	0.6	0.0
2	2.2	1.7	0.0
3	2.2	2.5	0.1
4	3.5	3.7	0.1
5	3.5	3.9	0.1
6	4.5	5.7	0.0
7	4.5	4.5	0.0
8	3.5	3.5	0
Flap	1.0	slush	0.1

Table 8.4: Test #26A Fluid Thickness Data

Test 26A: EG106, IP-/ZR-, Tunnel OAT -3.3°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.6	1.1	0.0
2	2.5	1.5	0.0
3	2.7	3.1	0.0
4	3.3	3.7	0.0
5	4.5	4.5	0.0
6	4.0	4.5	0.0
7	3.5	4.5	0.0
8	3.5	2.7	0.0
Flap	3.3	3.1	0.1

Table 8.5: Test #59 Fluid Thickness Data

Test 59: Launch, IP-/ZR-, Tunnel OAT -3.3°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.2	1.7	0.0
2	1.8	1.8	0.0
3	2.2	3.5	0.2
4	2.7	4.5	0.2
5	2.7	4.5	0.2
6	2.7	5.7	0.1
7	2.5	4.5	0.2
8	2.2	4.5	0.2
Flap	2.5	4.5	0.1

Table 8.6: Test #63 Fluid Thickness Data

Test 63: ABC-S Plus, IP-/ZR-, Tunnel OAT -12.3°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.5	1.6	0.0
2	1.8	1.8	0.2
3	2.2	2.7	0.3
4	2.9	2.9	0.1
5	2.9	2.9	0.1
6	3.3	3.5	0.3
7	3.1	3.5	0.2
8	2.9	2.9	0.3
Flap	0.7	slush	0.2

Table 8.7: Test #98 Fluid Thickness Data

Test 98: EG106, IP-/ZR-, Tunnel OAT -6.7°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	2.2	1.6	0.0
2	3.1	2.7	0.1
3	3.7	3.5	0.1
4	4.5	4.5	0.1
5	4.5	4.5	0.1
6	5.7	5.7	0.2
7	5.7	5.7	0.2
8	4.5	3.9	0.3
Flap	0.8	N/A	0.1

Table 8.8: Test #1 (Baseline) Fluid Thickness Data

Test 1: ABC-S Plus, Fluid-only, Tunnel OAT -5.7°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.8	N/A	0.0
2	2.5	N/A	0.0
3	3.3	N/A	0.1
4	4.5	N/A	0.1
5	5.7	N/A	0.1
6	5.7	N/A	0.1
7	5.7	N/A	0.1
8	4.5	N/A	0.1
Flap	1.0	N/A	0.1

Table 8.9: Test #25 (Baseline) Fluid Thickness Data

Test 25: EG106, Fluid-only, Tunnel OAT -4.0°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	2.2	N/A	0.0
2	3.1	N/A	0.1
3	3.7	N/A	0.1
4	4.5	N/A	0.2
5	4.5	N/A	0.2
6	4.5	N/A	0.1
7	4.5	N/A	0.1
8	3.5	N/A	0.1
Flap	N/A	N/A	0.1

Table 8.10: Test #55 (Baseline) Fluid Thickness Data

Test 55: EG106, Fluid-only, Tunnel OAT -2.6°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	2.2	N/A	0.0
2	2.9	N/A	0.1
3	3.1	N/A	0.2
4	3.1	N/A	0.2
5	2.5	N/A	0.2
6	4.5	N/A	0.2
7	4.5	N/A	0.1
8	4.5	N/A	0.1
Flap	0.6	N/A	0.1

Table 8.11: Test #60 (Baseline) Fluid Thickness Data

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

Table 8.12: Test #64 (Baseline) Fluid Thickness Data

Test 64: ABC-S Plus, Fluid-only, Tunnel OAT -13.4°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.2	N/A	0.0
2	2.2	N/A	0.1
3	1.7	N/A	0.1
4	1.8	N/A	0.1
5	3.1	N/A	0.2
6	3.1	N/A	0.2
7	3.1	N/A	0.2
8	2.7	N/A	0.2
Flap	0.8	N/A	0.2

Table 8.13: Test #100 (Baseline) Fluid Thickness Data

Test 100: EG106, Fluid-only, Tunnel OAT -6.3°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.6	N/A	0.0
2	2.5	N/A	0.0
3	2.7	N/A	0.1
4	3.5	N/A	0.1
5	4.5	N/A	0.1
6	5.7	N/A	0.1
7	5.7	N/A	0.2
8	4.5	N/A	0.3
Flap	0.8	N/A	0.2

8.2.2 Skin Temperature Data

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

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

Tables 8.14 to 8.19 show the wing temperature measurements recorded during the contaminated fluid tests. The associated baseline fluid only cases are also shown in Tables 8.20 to 8.25 for comparison purposes.

Table 8.14: Test #0 Wing Skin Temperature Data

Test 0: ABC-S Plus, IP-/ZR-, Tunnel OAT -6.1°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-6.0	-5.9	-6.2	-4.8
T5	-6.2	-6.0	-5.5	-4.5
TU	-6.1	-6.0	-6.3	-5.5

Table 8.15: Test #26 Wing Skin Temperature Data

Test 26: EG106, IP-/ZR-, Tunnel OAT -1.9°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-2.8	-3.0	-7.6	-3.6
T5	-2.8	-2.9	-6.6	-2.3
TU	-3.8	-3.5	-4.4	-3.5

Table 8.16: Test #26A Wing Skin Temperature Data

Test 26A: EG106, IP-/ZR-, Tunnel OAT -3.3°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-2.8	-3.3	-7.7	-4.1
T5	-2.2	-3.2	-6.6	-3.2
TU	-3.5	-3.5	-4.3	-4.5

Table 8.17: Test #59 Wing Skin Temperature Data

Test 59: Launch, IP-/ZR-, Tunnel OAT -3.3°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-2.6	-1.9	-5.4	-3.7
T5	-1.7	-2.0	-5.3	-3.0
TU	-2.3	-2.2	-3.0	-3.8

Table 8.18: Test #63 Wing Skin Temperature Data

Test 63: ABC-S Plus, IP-/ZR-, Tunnel OAT -12.3°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-11.3	-9.1	-10.8	-11.9
T5	-11.7	-9.0	-10.3	-11.5
TU	-11.2	-11.2	-11.4	-12.1

Table 8.19: Test #98 Wing Skin Temperature Data

Test 98: EG106, IP-/ZR-, Tunnel OAT -6.7°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T3	-9.6	-9.6	-8.4	-11.7
T5	-9.0	-9.4	-8.1	-11.6
TU	-9.9	-9.7	-8.6	-11.8

Table 8.20: Test #1 (Baseline) Wing Skin Temperature Data

Test 1: ABC-S Plus, Fluid-only, Tunnel OAT -5.7°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-4.5	-4.5	N/A	-3.6
T5	-5	-4.9	N/A	-3.2
TU	-5.1	-4.5	N/A	-4.3

Table 8.21: Test #25 (Baseline) Wing Skin Temperature Data

Test 25: EG106, Fluid-only, Tunnel OAT -4.0°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.6	-3.0	N/A	-3.4
T5	-3.0	-3.1	N/A	-3.2
TU	-4.4	-4.2	N/A	-3.9

Table 8.22: Test #55 (Baseline) Wing Skin Temperature Data

Test 55: EG106, Fluid-only, Tunnel OAT -2.6°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-0.6	-0.5	N/A	-1.6
T5	-0.5	-0.6	N/A	-1.5
TU	-1.4	-1.6	N/A	-2.3

Table 8.23: Test #60 (Baseline) Wing Skin Temperature Data

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

Table 8.24: Test #64 (Baseline) Wing Skin Temperature Data

Test 64: ABC-S Plus, Fluid-only, Tunnel OAT -13.4°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip Application	After Takeoff Test
T2	-11.8	-10.8	N/A	-12.2
T5	-11.9	-10.8	N/A	-12.1
TU	-12.3	-12.4	N/A	-12.4

Table 8.25: Test #100 (Baseline) Wing Skin Temperature Data

Test 100: EG106, Fluid-only, Tunnel OAT -6.3°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T3	-7.4	-8.7	N/A	-8.7
T5	-7.5	-8.3	N/A	-8.4
TU	-7.4	-7.6	N/A	-9.1

8.2.3 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the wind tunnel tests are described in Subsection 2.15.4.

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

Tables 8.26 to 8.31 show the fluid Brix measurements collected during the contaminated fluid tests. The associated baseline fluid only cases are also shown in Tables 8.32 to 8.37 for comparison purposes.

Table 8.26: Test #0 Fluid Brix Data

Test 0: ABC-S Plus, IP-/ZR-, Tunnel OAT -6.1°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.25	22.25	32.00
8	37.00	25.25	33.25

Table 8.27: Test #26 Fluid Brix Data

Test 26: EG106, IP-/ZR-, Tunnel OAT -1.9°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.00	20.25	29.50
8	32.00	14.50	28.00

Table 8.28: Test #26A Fluid Brix Data

Test 26A: EG106, IP-/ZR-, Tunnel OAT -3.3°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	31.75	17.50	25.25
8	32.00	21.50	25.00

Table 8.29: Test #59 Fluid Brix Data

Test 59: Launch, IP-/ZR-, Tunnel OAT -3.3°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.50	14.50	28.00
8	37.00	15.00	32.00

Table 8.30: Test #63 Fluid Brix Data

Test 63: ABC-S Plus, IP-/ZR-, Tunnel OAT -12.3°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.00	31.75	33.00
8	37.00	33.00	34.00

Table 8.31: Test #98 Fluid Brix Data

Test 98: EG106, IP-/ZR-, Tunnel OAT -6.7°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.75	24.50	32.50
8	32.25	21.75	32.50

Table 8.32: Test #1 (Baseline) Fluid Brix Data

Test 1: ABC-S Plus, Fluid-only, Tunnel OAT -5.7°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.5	N/A	39.5
8	36.5	N/A	38.25

Table 8.33: Test #25 (Baseline) Fluid Brix Data

Test 25: EG106, Fluid-only, Tunnel OAT -4.0°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.00	N/A	31.50
8	32.25	N/A	32.50

Table 8.34: Test #55 (Baseline) Fluid Brix Data

Test 55: EG106, Fluid-only, Tunnel OAT -2.6°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.35	N/A	34.75
8	33.00	N/A	34.00

Table 8.35: Test #60 (Baseline) Fluid Brix Data

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

Table 8.36: Test #64 (Baseline) Fluid Brix Data

Test 64: ABC-S Plus, Fluid-only, Tunnel OAT -13.4°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.75	N/A	38.50
8	37.50	N/A	38.00

Table 8.37: Test #100 (Baseline) Fluid Brix Data

Test 100: EG106, Fluid-only, Tunnel OAT -6.3°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	33.00	N/A	33.75
8	33.00	N/A	33.00

8.3 Photos

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

- Start of test;
- Before Rotation (just before the wing began to pitch);
- End of Rotation (end of the rotation cycle when the wing position is returned to 4 degrees); and
- End of test.

The photos taken during the Light Ice Pellets Mixed with Light Freezing Rain testing have been presented along with the fluid only (baseline) tests for comparison purposes. In each case, the fluid only photo is presented first, followed by the contaminated fluid photo. Photos 8.1 to 8.48 show the photo summaries of the tests conducted. A complete set of photos will be provided to the TDC in electronic format.

8.4 Summary of Results

8.4.1 OAT -5°C and Above

Four tests were conducted in this cell with an exposure time of 25 minutes: Tests #0, #26, #26A, and #59 (see Table 8.38). It is important to note the flap for Tests #26A and #59 was set to 0° during the precipitation period.

Test #26 was conducted with EG fluid and demonstrated good results overall despite a bad visual rating at the start of the test. The temperature during this test was -1.9°C. The lift loss at 8° was deemed good at 4.78 percent, below the 5 percent safety criteria. Visual contamination results on the LE and TE at the start were given good ratings, while ratings on the flap did not pass (rating of 4.7). Due to this visual rating of greater than 4 on the flap, Test #26 was repeated (Test #26A) with the flap set at 0°. The aerodynamic performance and the visual contamination ratings improved with the flap at 0°. All visuals during Test #26A passed the required criteria as well as the 8° lift loss, at 1.41 percent. Results are shown in Table 8.39.

Test #0, conducted with PG fluid at a temperature of -6.1°C, demonstrated satisfactory results. Visual contamination results were good, but further review is required based on the 8° lift loss result, at 6.52 percent (see Table 8.39). This value is above the 5 percent margin of safety criteria. The semi-log of time lift loss analysis conducted with speeds greater than 100 knots shows a reduction in the lift loss (4.91 percent) when the speed is increased to 140 knots; this is below the 5 percent safety criteria (see Table 8.40 and Figure 8.1). This is provided for reference purposes; however, it is not recommended to extrapolate to this extent. It should also be noted that it took 31 seconds rather than the average of 19 seconds to go from 40 knots to 100 knots, adding some concern to these test results. Also of note is that the fluid only lift loss in this condition is 5 percent. In addition, an examination of the lift data indicates that a lift loss of 5.87 percent would occur at a 6° rotation (see Table 5.7), which is an improvement from the lift loss at an 8° rotation.

Test #59, conducted with PG fluid, demonstrated very good results. The flap was adjusted to 0° for this test run. Visual and lift loss results (4.08 percent) were deemed good. A ramp-up time of 17 seconds occurred from a speed of 40 knots to rotation, slightly below the 19-second average. Table 8.39 provides the detailed results of this test run.

In conclusion, the current allowance time of 25 minutes is acceptable for EG fluids. The 25-minute allowance time for PG fluids is satisfactory at this time based on the results obtained, but further review is required. It is not clear why less favourable results were seen in Test #0; possible explanations may be the flap setting, the temperature, or the PG fluid that was tested (ABC-S Plus for Test #0 vs. Launch for Test #59).

Table 8.38: Light Ice Pellets Mixed with Light Freezing Rain, Light or Moderate Freezing Drizzle, and Light Rain Allowance Time Tests Winter 2009-10

	OAT -5°C and Above	**OAT Less than -5°C to -10°C**	**OAT Less than -10°C**
Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle	25 minutes	10 minutes	**Caution: No allowance times currently exist**
Light Ice Pellets Mixed with Light Freezing Rain	25 minutes **Test # 0, 26, 26A, 59**	10 minutes **Test # 63, 98**	
Light Ice Pellets Mixed with Light Rain	25 minutes		

Table 8.39: Summary of Light Ice Pellets Mixed with Light Freezing Rain, Light or Moderate Freezing Drizzle, and Light Rain Allowance Time Test Results

	OAT -5°C and Above	OAT Less than -5°C to -10°C	OAT Less than -10°C
Light Ice Pellets Mixed with Light Freezing Rain	**25 minutes** Run 0 (Exp. Time 25 min), -6.1°C ABC-S Plus Visual At Start: GOOD (2, 2, 4) Visuals At Rotation: GOOD (1, 1, 3.7) LL At 100 kts: OK (6.52%) LL At 110 kts: OK (5.75%) LL At 140 kts: GOOD (4.91%) **OK At 100 kts** Run 26 (Exp. Time 25 min), -1.9°C EG106 Visual At Start: BAD (2.2, 1.7, 4.7) Visuals At Rotation: GOOD (1, 1, 4) LL At 100 kts: GOOD (4.78%) **GOOD At 100 kts** Run 26A (Exp. Time 25 min), -3.3°C *Flap At 0°* EG106 Visual At Start: GOOD (1.8, 2, 1.9) Visuals At Rotation: GOOD (1, 1, 1)) LL At 100 kts: GOOD (1.41%) **GOOD At 100 kts** Run 59 (Exp. Time 25 min), -3.3°C *Flap At 0°* LAUNCH Visual At Start: GOOD (2, 2, 2.2) Visuals At Rotation: GOOD (1, 1.3, 1.5) LL At 100 kts: GOOD (4.08%) **GOOD At 100 kts** ▪ **25 min GOOD for EG Fluid** ▪ **25 min OK for PG Fluid; Further Review Required** **CONCLUSION: ALLOWANCE TIME OF 25 MIN OKAY, FURTHER REVIEW REQUIRED**	**10 minutes** Run 63 (Exp. Time 10 min), -12.3°C ABC-S Plus Visual At Start: GOOD (2.3, 2.3, 3.2) Visuals At Rotation: BAD (1.2, 2, 2.3) LL At 100 kts: OK (7.69%) LL At 110 kts: OK (6.56%) LL At 115 kts: OK (5.78%) LL At 120 kts: OK (5.02%) **OK At 100 kts** Run 98 (Exp. Time 10 min), -6.7°C EG106 Visual At Start: GOOD (2, 2, 2.5) Visuals At Rotation: GOOD (1, 1, 1.3) LL At 100 kts: GOOD (1.76%) **GOOD At 100 kts** ▪ **10 min GOOD for EG Fluid** ▪ **10 min OK for PG Fluid; Further Review Required** **CONCLUSION: ALLOWANCE TIME OF 10 MIN OKAY, FURTHER REVIEW REQUIRED**	**Caution: No Allowance Time Currently Exists**

Table 8.40: Details of Increased Rotation Speed Analysis

Condition	Test #	Speed (Kts)	Lift Loss at 8 Degrees (%)	Visual (%)	Linear (%)	Semi-Log (Time) (%)	Polynomial (2nd Order) (%)
Light Ice Pellets Mixed with Light Freezing Rain (OAT -5°C and Above)	**0**	100	6.52				
		110		5.89	5.61	5.75	6.46
		115		5.74	5.39	5.58	6.49
		140		-	4.54	4.91	6.83
Light Ice Pellets Mixed with Light Freezing Rain (OAT Less than -5°C and -10°C)	**63**	100	7.69				
		110		6.85	6.24	6.56	7.66
		115		6.3	5.32	5.78	7.42
		120		5.89	4.39	5.02	7.3

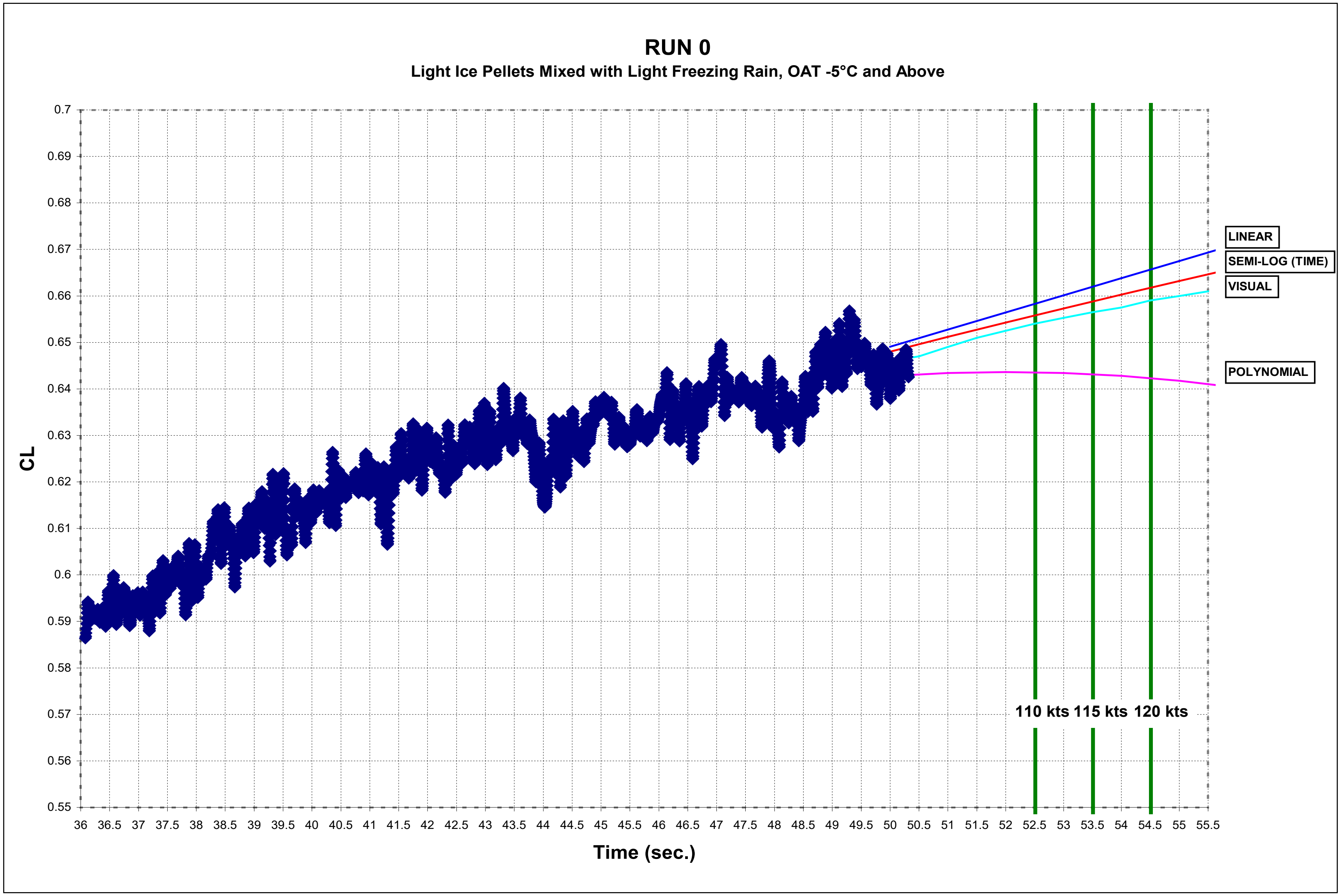


Figure 8.1: Increased Rotation Speed Extrapolation Results – Test #0

8.4.2 OAT Less than -5°C to -10°C

Two tests in this cell were conducted with an exposure time of 10 minutes: Test #63 and Test #98 (see Table 8.38).

Test #98, conducted with EG fluid, demonstrated very good results, as shown in Table 8.39. The lift loss at 8° was 1.76 percent, and the visual contamination results were given good ratings.

Test #63, conducted with PG fluid, demonstrated unsatisfactory results, requiring further review. The lift loss result at 8° was 7.69 percent, above the 5 percent margin of safety criteria. The LE visual rating result at rotation (1.2) also proved to exceed the required criteria of 1, as shown in Table 8.39. The lift loss analysis with speeds greater than 100 knots, using semi-log of time, shows a reduction in lift loss as speeds are increased (see Table 8.40 and Figure 8.2); the lift loss at 120 knots is 5.02 percent. It should be noted that the temperature for this test is slightly below the cell limit (-12.3°C vs. -10.0°C), and the ramp-up time from 40 knots to 100 knots is about 3 seconds below the average; these two factors have a tendency to provide less favourable results.

In conclusion, the current allowance time of 10 minutes is acceptable for EG fluids. The results from testing with PG fluid indicate an acceptable allowance time of 10 minutes at this time. Further review is required for PG fluids.

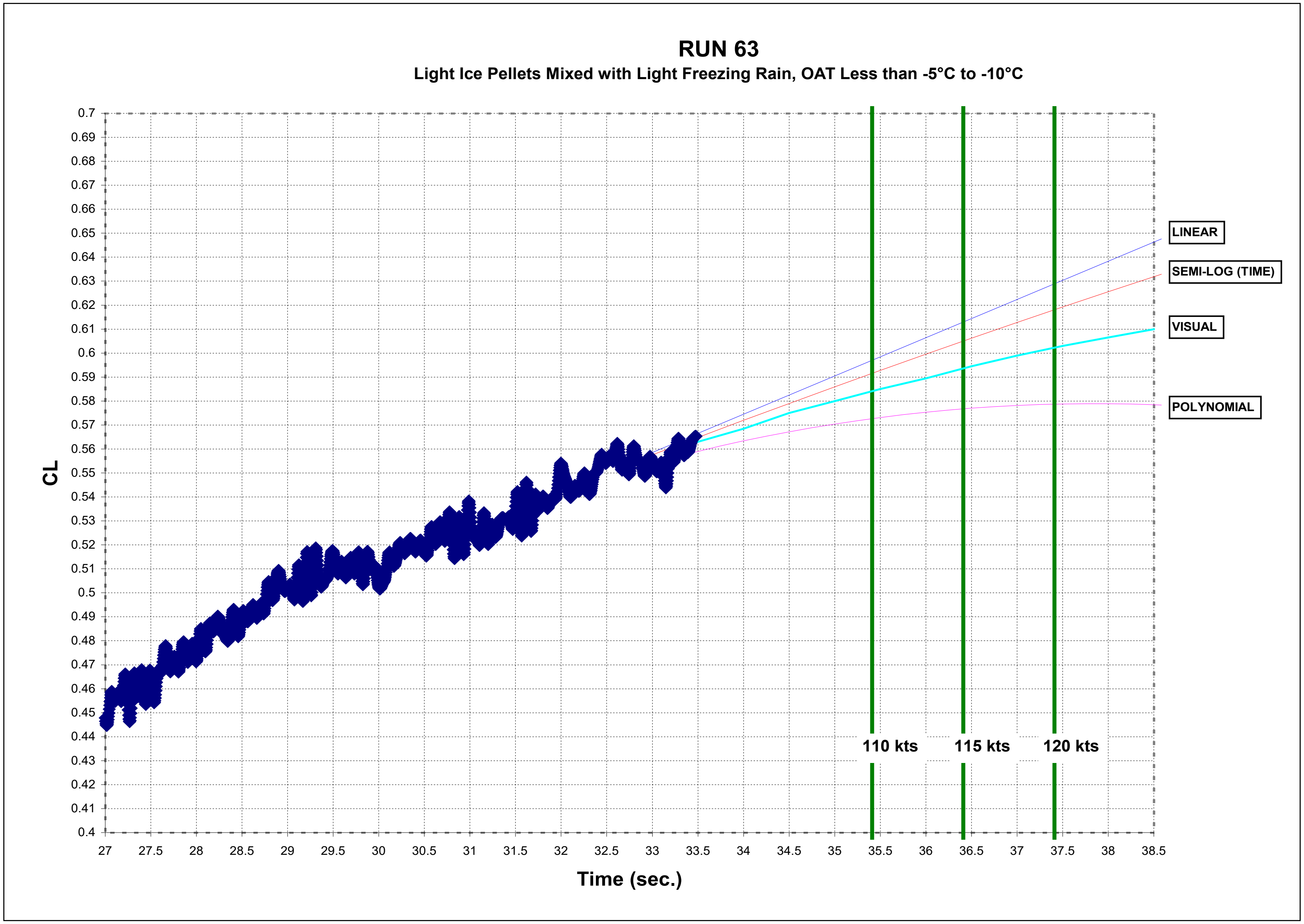


Figure 8.2: Increased Rotation Speed Extrapolation Results – Test #63

Photo 8.1: Test #1 – Start of Test

Test #1
ABC-S Plus, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

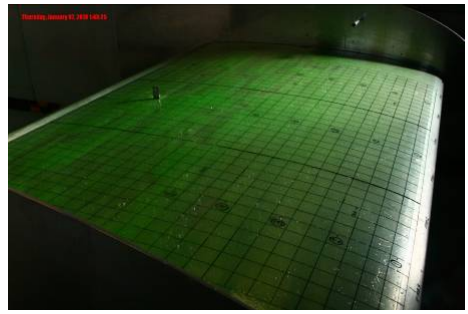



Photo 8.2: Test #0 – Start of Test

Test #0
ABC-S Plus, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-6°C, 8° Rotation
Visual Contamination Rating (2,2,4)
Start of Test

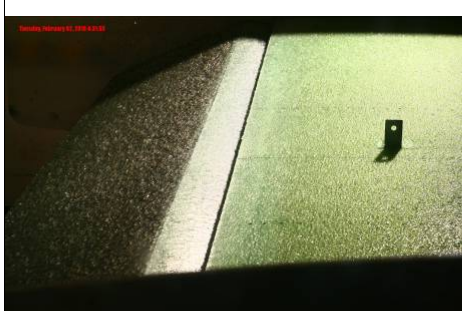



Photo 8.3: Test #1 – Before Rotation

Test #1
ABC-S Plus, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

Photo 8.4: Test #0 – Before Rotation

Test #0
ABC-S Plus, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-6°C, 8° Rotation
Visual Contamination Rating (1,1,3.7)
Before Rotation

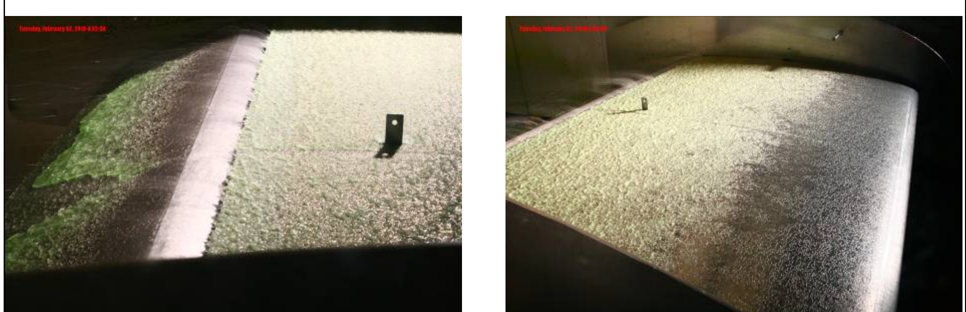
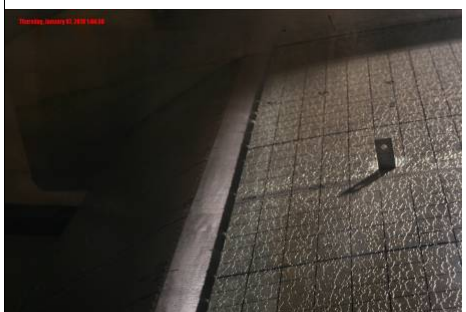


Photo 8.5: Test #1 – End of Rotation

Test #1
ABC-S Plus, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.01%
End of Rotation



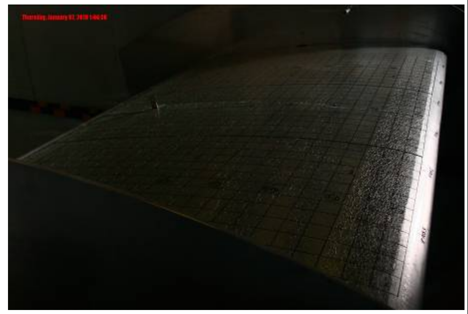


Photo 8.6: Test #0 – End of Rotation

Test #0
ABC-S Plus, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-6°C, 8° Rotation
Visual Contamination Rating (1,1,3.7), 8° Lift Loss = 6.52%
End of Rotation

Photo 8.7: Test #1 – End of Test

Test #1

ABC-S Plus, Fluid Only

-6°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test

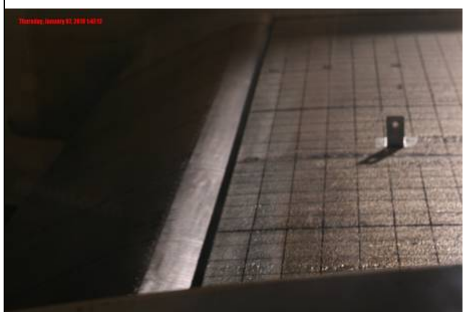


Photo 8.8: Test #0 – End of Test

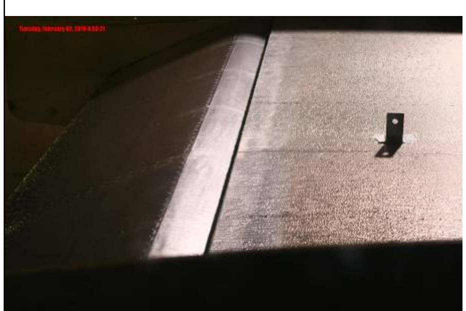
Test #0

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

-6°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test



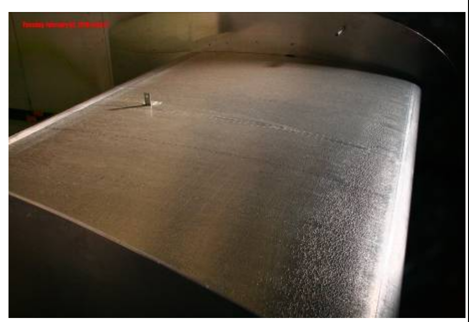


Photo 8.9: Test #55 – Start of Test

Test #55
EG106, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

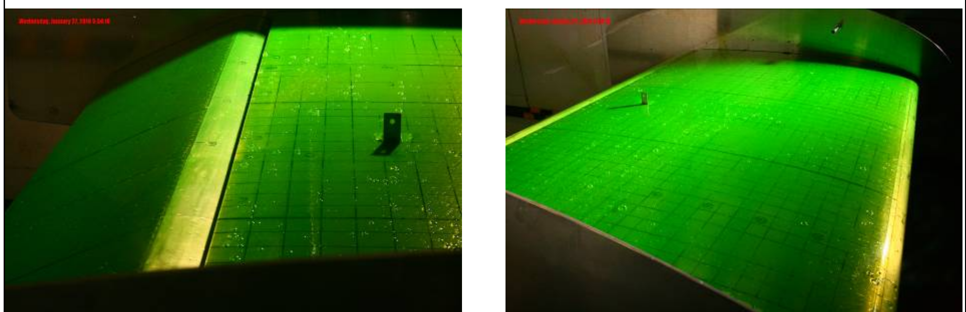


Photo 8.10: Test #26 – Start of Test

Test #26
EG106, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-2°C, 8° Rotation
Visual Contamination Rating (2.2,1.7,4.7)
Start of Test

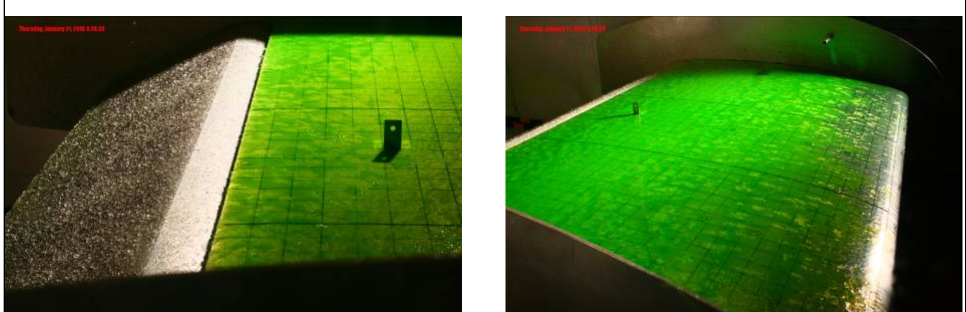
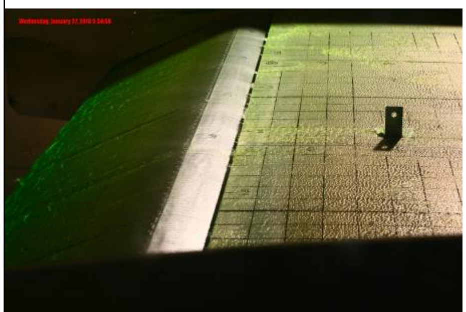


Photo 8.11: Test #55 – Before Rotation

Test #55
EG106, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation



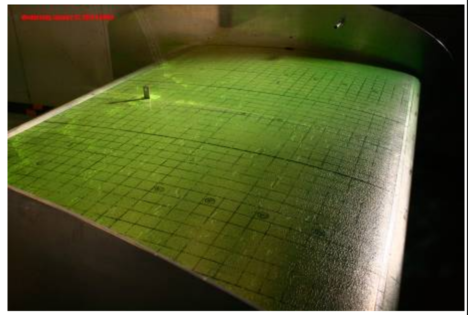
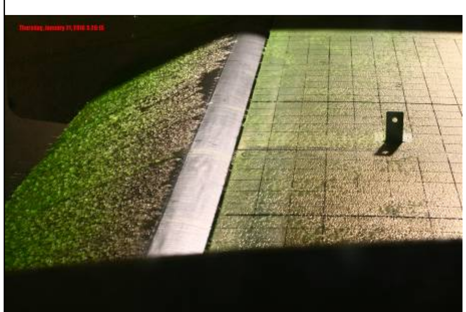


Photo 8.12: Test #26 – Before Rotation

Test #26
EG106, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-2°C, 8° Rotation
Visual Contamination Rating (1,1,4)
Before Rotation



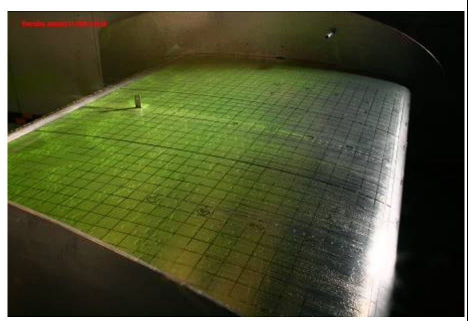


Photo 8.13: Test #55 – End of Rotation

Test #55
EG106, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 1.88%
End of Rotation

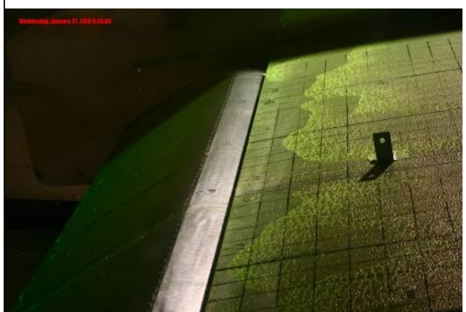
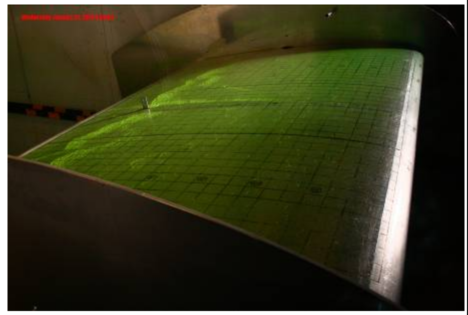



Photo 8.14: Test #26 – End of Rotation

Test #26
EG106, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-2°C, 8° Rotation
Visual Contamination Rating (1,1,4), 8° Lift Loss = 4.78%
End of Rotation

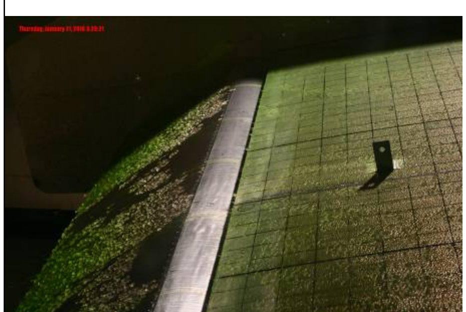
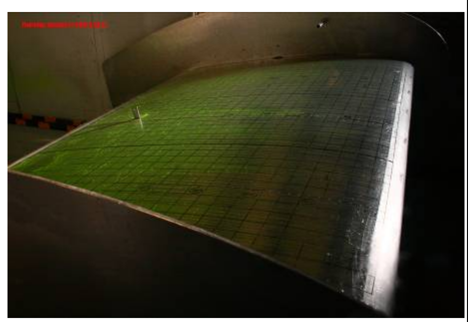
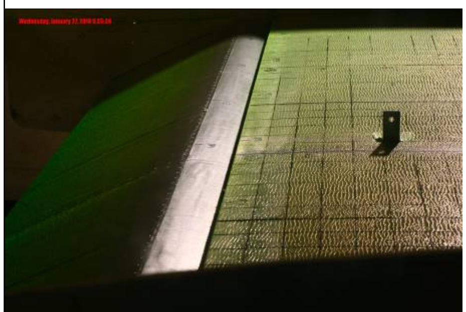



Photo 8.15: Test #55 – End of Test

Test #55
EG106, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test



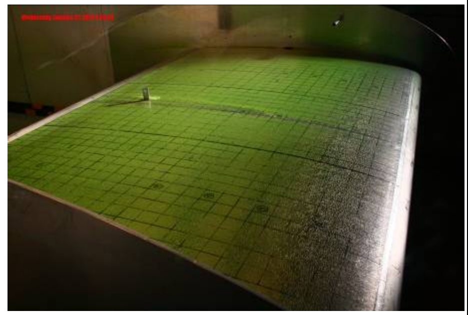
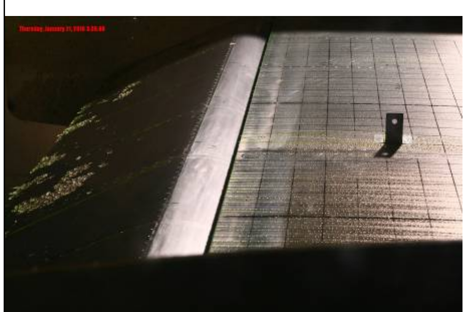


Photo 8.16: Test #26 – End of Test

Test #26
EG106, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-2°C, 8° Rotation
Visual Contamination Rating (1,1,3.5)
End of Test



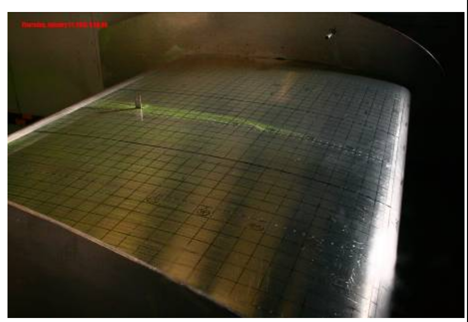
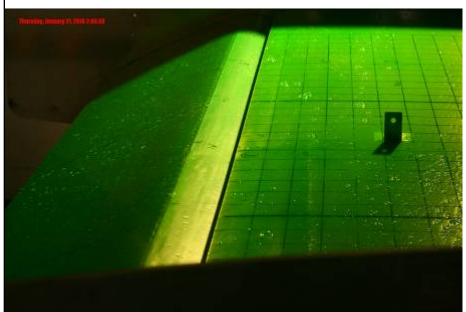


Photo 8.17: Test #25 – Start of Test

Test #25
EG106, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)

Start of Test



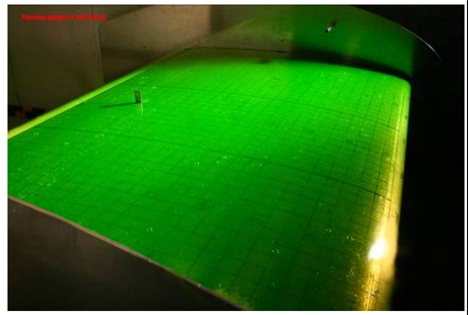
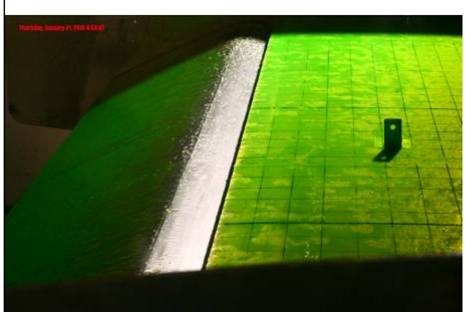


Photo 8.18: Test #26A – Start of Test

Test #26A
EG106, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-3°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1.8,2,1.9)

Start of Test



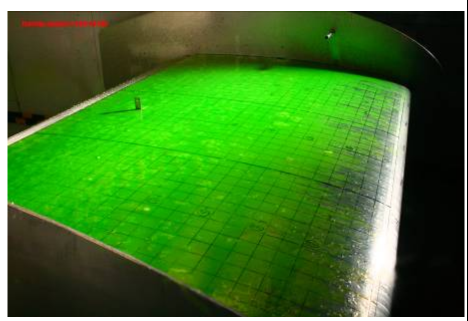
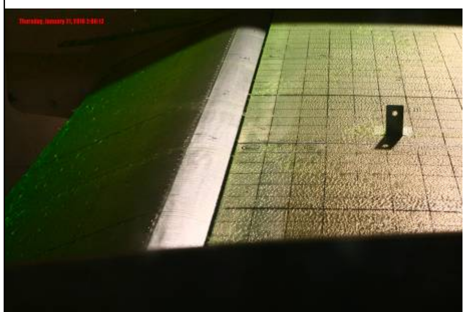


Photo 8.19: Test #25 – Before Rotation

Test #25
EG106, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation



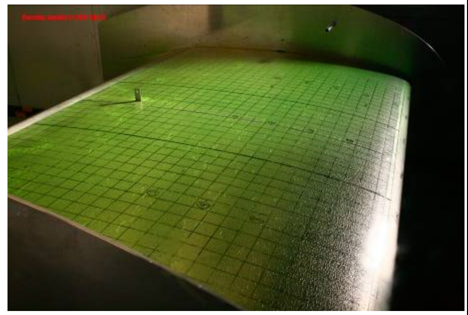
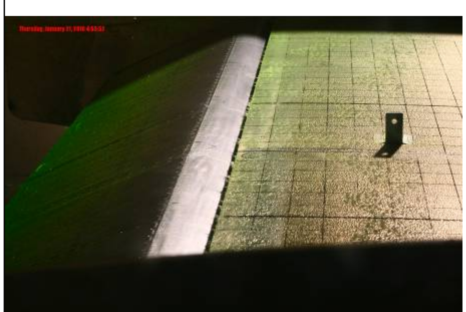


Photo 8.20: Test #26A – Before Rotation

Test #26A
EG106, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-3°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1,1,1)
Before Rotation



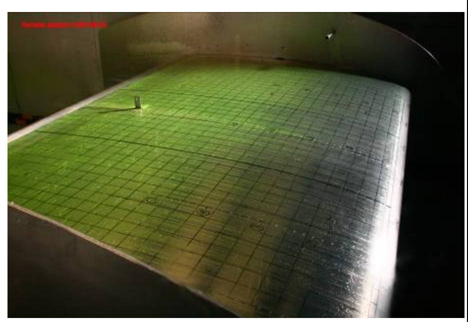


Photo 8.21: Test #25 – End of Rotation

Test #25
EG106, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 1.99%
End of Rotation

Photo 8.22: Test #26A – End of Rotation

Test #26A
EG106, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-3°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1,1,1), 8° Lift Loss = 1.41%
End of Rotation

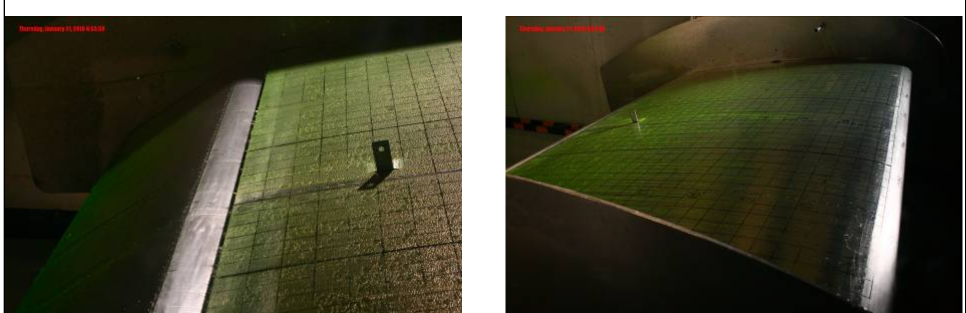


Photo 8.23: Test #25 – End of Test

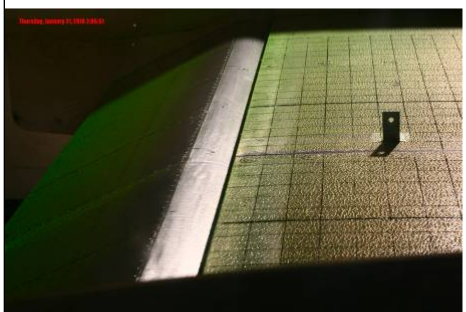
Test #25

EG106, Fluid Only

-4°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test



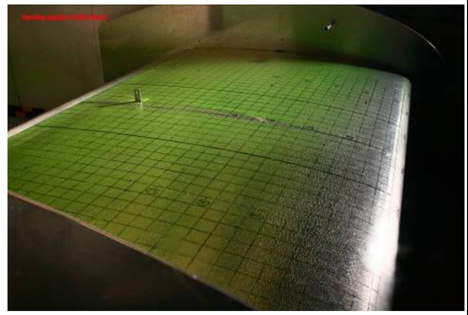


Photo 8.24: Test #26A – End of Test

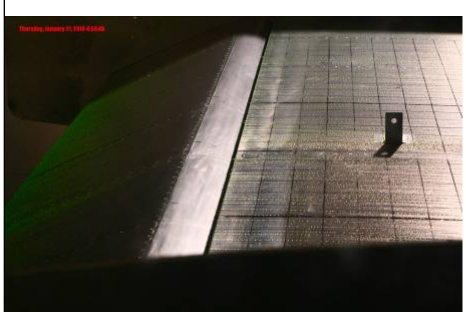
Test #26A

EG106, IP- + ZR- 25 + 25 g/dm²/h, 25 min

-3°C, 8° Rotation, Flap Angle 0°

Visual Contamination Rating (1,1,1)

End of Test



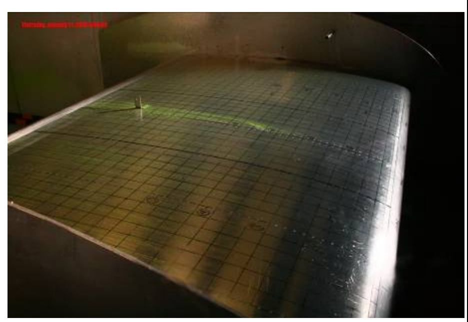
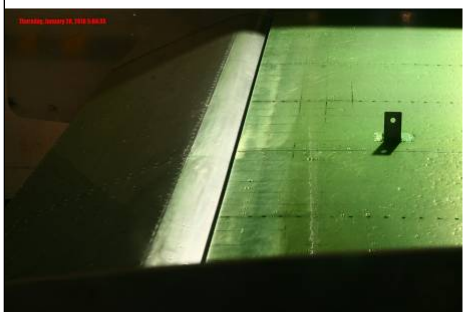


Photo 8.25: Test #60 – Start of Test

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



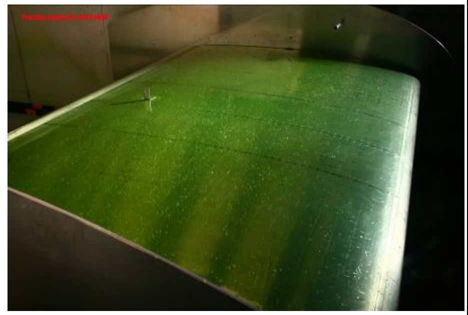
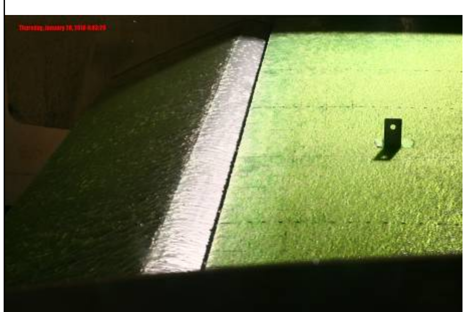


Photo 8.26: Test #59 – Start of Test

Test #59
Launch, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-3°C, 8° Rotation
Visual Contamination Rating (2,2,2.2)
Start of Test



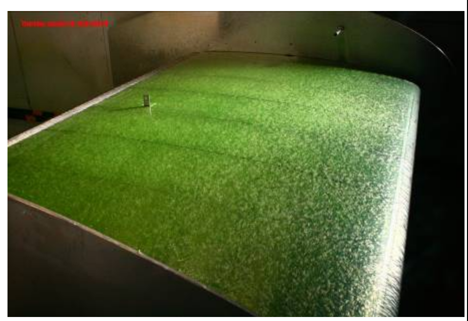


Photo 8.27: Test #60 – Before Rotation

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

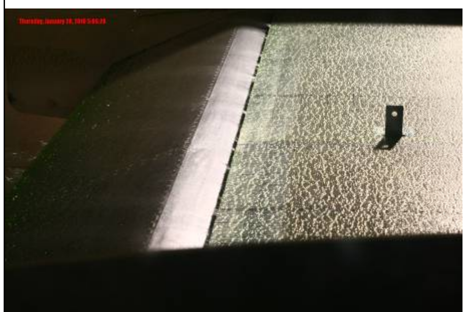
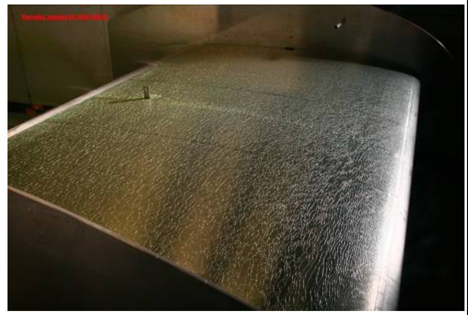



Photo 8.28: Test #59 – Before Rotation

Test #59
Launch, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-3°C, 8° Rotation
Visual Contamination Rating (1,1.3,1.5)
Before Rotation

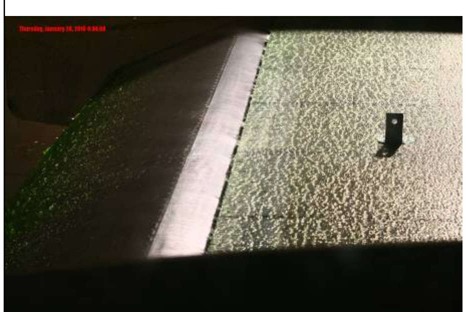
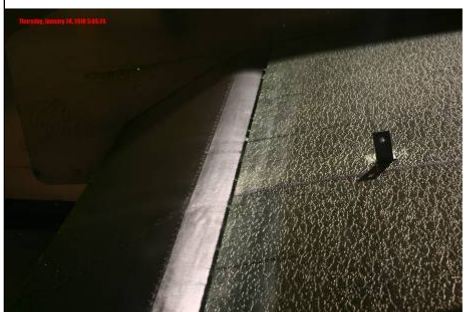



Photo 8.29: Test #60 – End of Rotation

Test #60
Launch, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 4.61%
End of Rotation



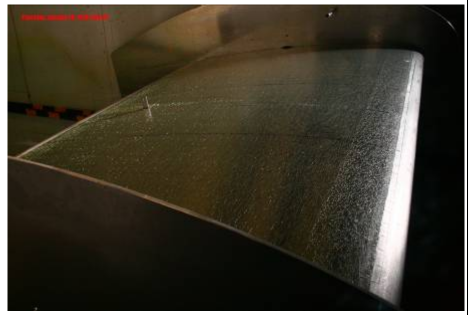
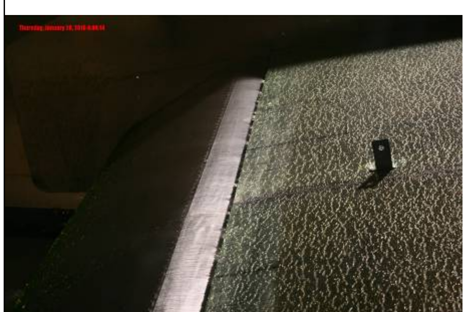


Photo 8.30: Test #59 – End of Rotation

Test #59
Launch, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-3°C, 8° Rotation
Visual Contamination Rating (1,1.3,1.5), 8° Lift Loss = 4.08%
End of Rotation



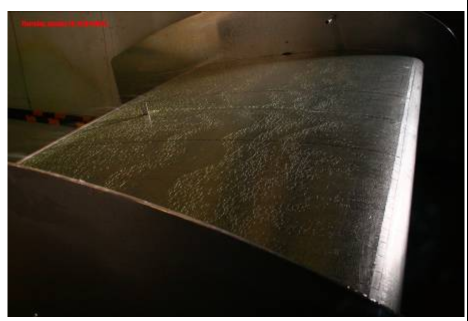
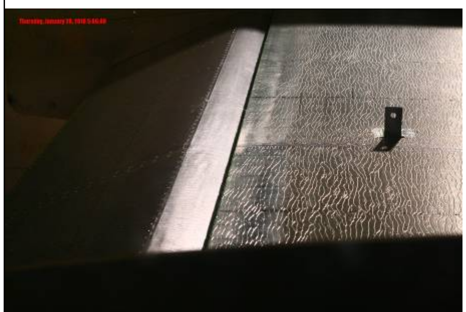


Photo 8.31: Test #60 – End of Test

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



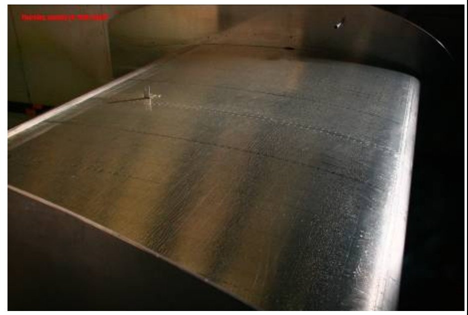
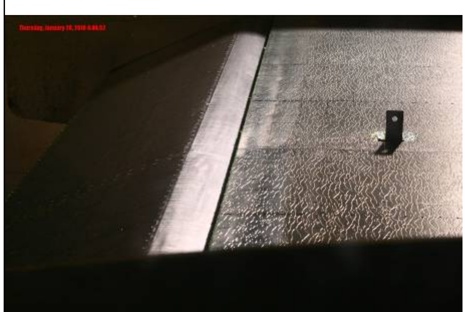


Photo 8.32: Test #59 – End of Test

Test #59
Launch, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test



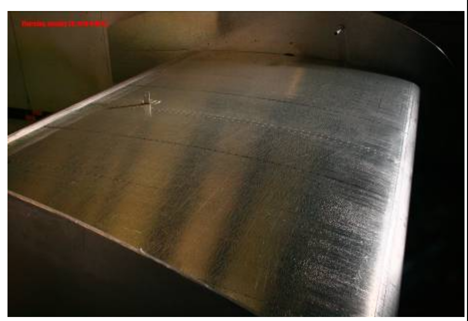


Photo 8.33: Test #64 – Start of Test

Test #64
ABC-S Plus, Fluid Only
-13°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

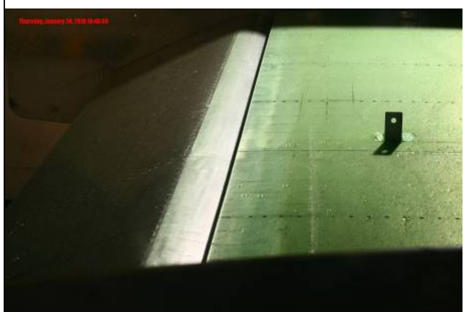
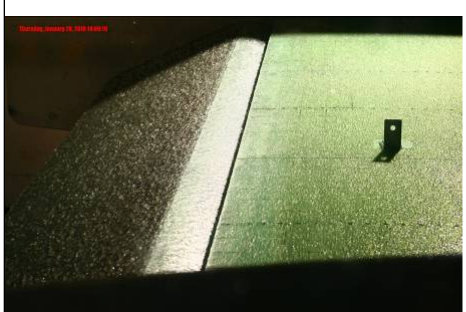


Photo 8.34: Test #63 – Start of Test

Test #63
ABC-S Plus, IP- + ZR- 25 + 25 g/dm²/h, 10 min
-12°C, 8° Rotation
Visual Contamination Rating (2.3,2.3,3.2)
Start of Test



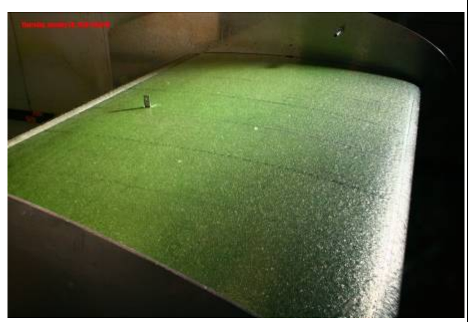


Photo 8.35: Test #64 – Before Rotation

Test #64
ABC-S Plus, Fluid Only
-13°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

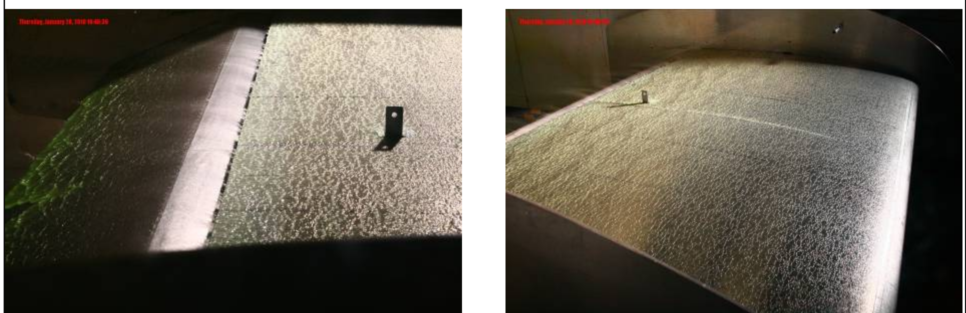


Photo 8.36: Test #63 – Before Rotation

Test #63
ABC-S Plus, IP- + ZR- 25 + 25 g/dm²/h, 10 min
-12°C, 8° Rotation
Visual Contamination Rating (1.2,2,2.3)
Before Rotation

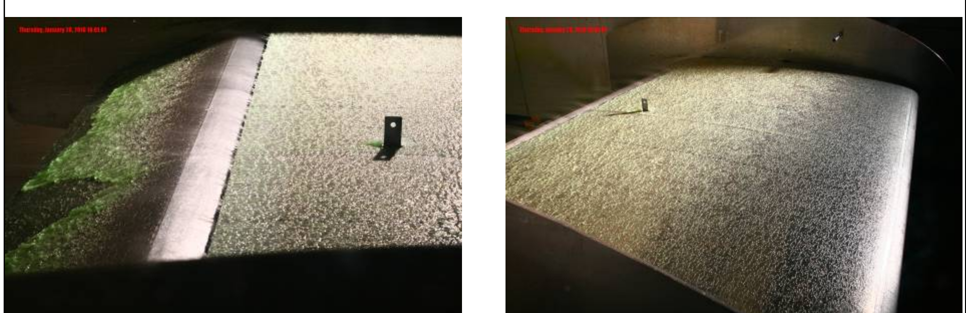


Photo 8.37: Test #64 – End of Rotation

Test #64
ABC-S Plus, Fluid Only
-13°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.07%
End of Rotation

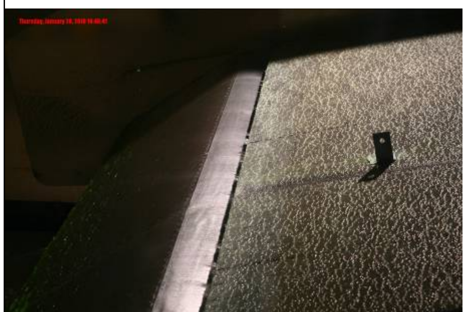
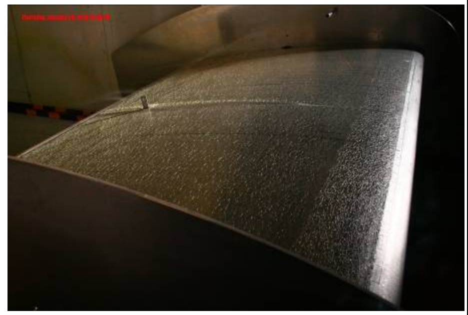



Photo 8.38: Test #63 – End of Rotation

Test #63
ABC-S Plus, IP- + ZR- 25 + 25 g/dm²/h, 10 min
-12°C, 8° Rotation
Visual Contamination Rating (1.2,2,2.3), 8° Lift Loss = 7.69%
End of Rotation

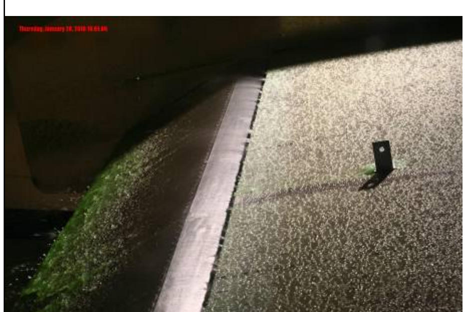



Photo 8.39: Test #64 – End of Test

Test #64
ABC-S Plus, Fluid Only
-13°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

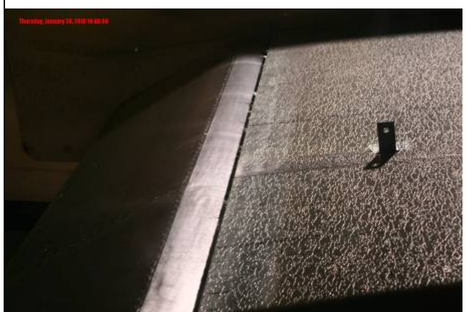



Photo 8.40: Test #63 – End of Test

Test #63
ABC-S Plus, IP- + ZR- 25 + 25 g/dm²/h, 10 min
-12°C, 8° Rotation
Visual Contamination Rating (1,1.2,1.2)
End of Test

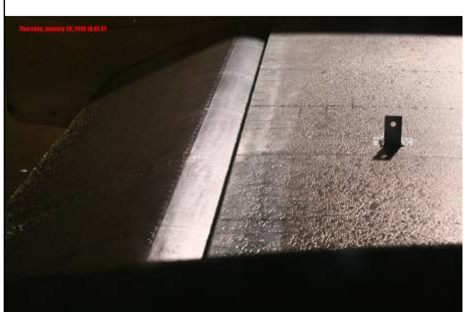



Photo 8.41: Test #100 – Start of Test

Test #100
EG106, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

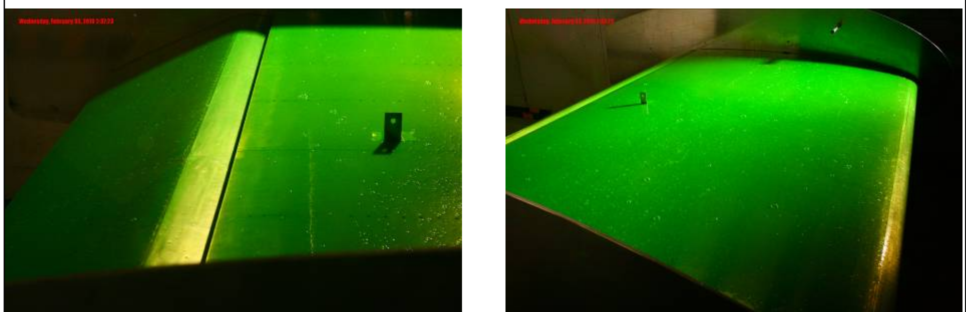


Photo 8.42: Test #98 – Start of Test

Test #98
EG106, IP- +ZR- 25 + 25 g/dm²/h, 10 min
-7°C, 8° Rotation
Visual Contamination Rating (2,2,2.5)
Start of Test

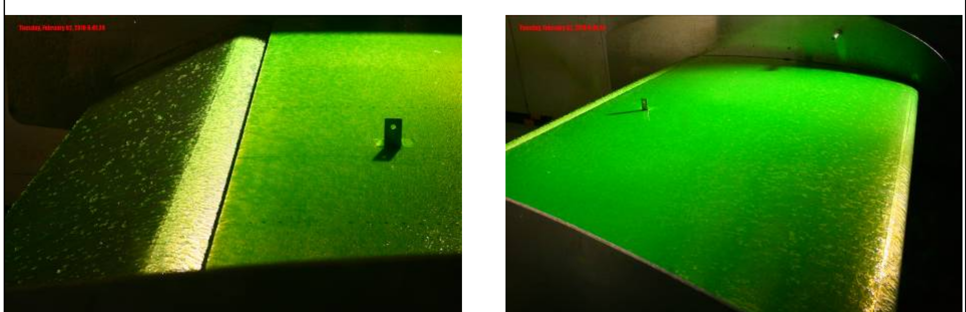


Photo 8.43: Test #100 – Before Rotation

Test #100
EG106, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

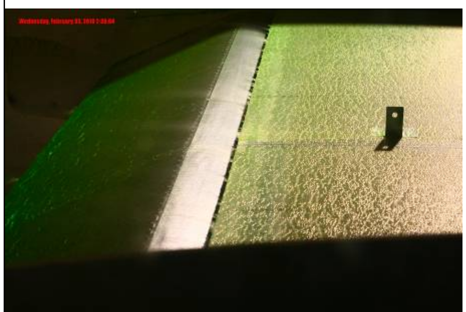
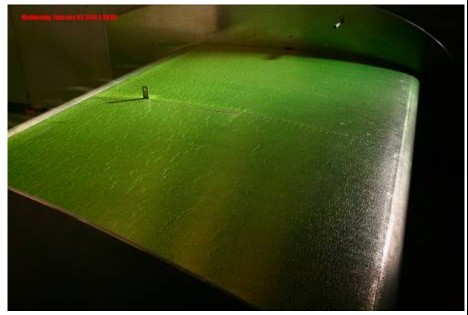



Photo 8.44: Test #98 – Before Rotation

Test #98
EG106, IP- + ZR- 25 + 25 g/dm²/h, 10 min
-7°C, 8° Rotation
Visual Contamination Rating (1,1,1.3)
Before Rotation

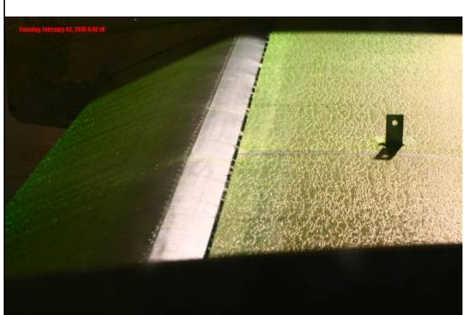
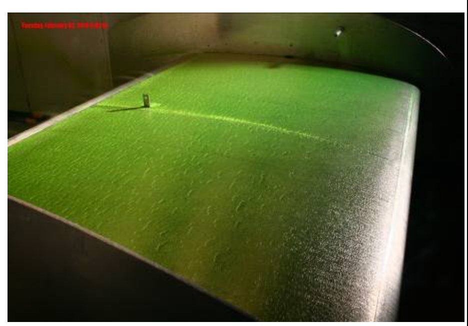



Photo 8.45: Test #100 – End of Rotation

Test #100
EG106, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 2.28%

End of Rotation

Photo 8.46: Test #98 – End of Rotation

Test #98
EG106, IP- + ZR- 25 + 25 g/dm²/h, 10 min
-7°C, 8° Rotation
Visual Contamination Rating (1,1,1.3), 8° Lift Loss = 1.76%

End of Rotation

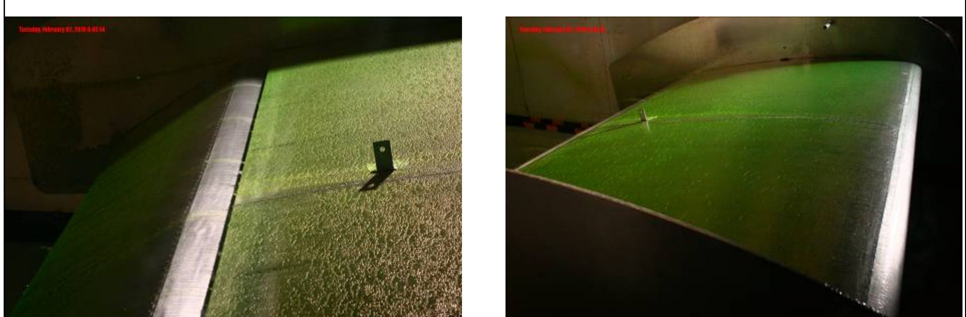


Photo 8.47: Test #100 – End of Test

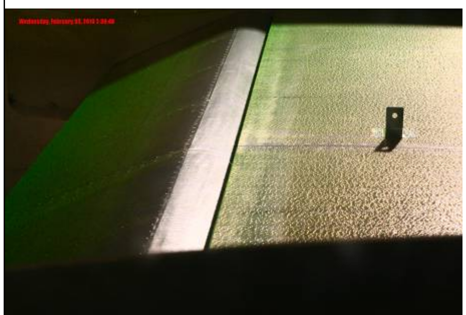
Test #100

EG106, Fluid Only

-6°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test



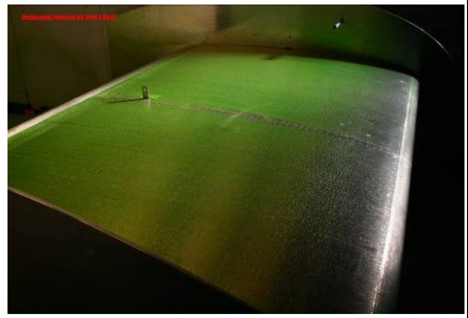


Photo 8.48: Test #98 – End of Test

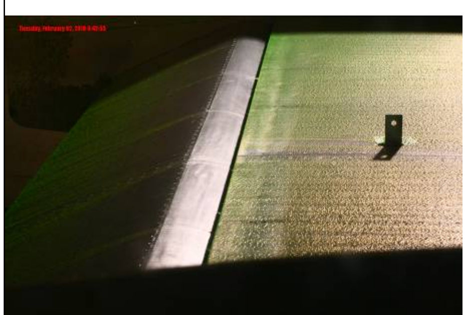
Test #98

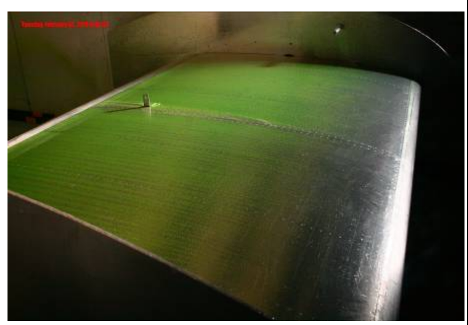
EG106, IP- + ZR- 25 + 25 g/dm²/h, 10 min

-7°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test





9. LIGHT ICE PELLETS MIXED WITH MODERATE RAIN ALLOWANCE TIMES

Aerodynamic testing was conducted to validate and further develop the Type IV high-speed ice pellet allowance times in the NRC wind tunnel. Previous testing in 2006-07 and 2008-09 consisted of wind tunnel tests and Falcon 20 aircraft tests to develop allowance times for mixed conditions with ice pellets. Due to the limitations of the data, some extrapolation of the results was required in order to develop a comprehensive table. It was recommended that testing be conducted at the most critical limits of the allowance times to validate the current guidance material for use with newer generation aircraft operating with supercritical wings. Additional testing was also required to provide guidance material where data was limited or non-existent. The results of this testing have been separated by test condition, and the details can be found in the following sections:

- Section 6: Light Ice Pellets;
- Section 7: Moderate Ice Pellets;
- Section 8: Light Ice Pellets and Light Freezing Rain;
- Section 9: Light Ice Pellets and Moderate Rain;
- Section 10: Light Ice Pellets and Light Snow; and
- Section 11: Light Ice Pellets and Moderate Snow.

This section provides an overview of each test conducted to substantiate and further develop the current high-speed allowance times for Type IV fluids in Light Ice Pellet Mixed with Moderate Rain conditions. Testing was conducted in simulated precipitation conditions. The parameters for each test are detailed, and a description of the data collected during each test is provided.

9.1 Overview of Tests

A summary of the Light Ice Pellet Mixed with Moderate Rain tests conducted in the wind tunnel is shown in Table 9.1. The table provides relevant information for each of the tests, as well as final values used for the data analysis. Each row contains data specific to one test. A more detailed test log of all conditions tested using the wind tunnel is provided in Subsection 4.1. A brief description of the column headings for Table 9.1 is provided in Subsection 6.1.

Table 9.1: Summary of 2009-10 Light Ice Pellets Mixed with Moderate Rain Testing

Test No.	Date	Fluid	Associated Baseline Test	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Flap Angle (°)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° During Rotation	8° Lift Loss (%)
20	20-Jan-10	ABC-S Plus	53	IP/R Mod	25/75	40	2.9	3.7	20	1,1,1	1,1,1	N/A	N/A
44	23-Jan-10	EG106	55	IP/R Mod	25/75	40	-0.8	-4.8	20	5,4.5,5	5,5,5	1.231	28.48
56	27-Jan-10	EG106	55	IP/R Mod	25/75	25	-1.1	-1.3	20	1.8,2,4.7	1,1,5	1.666	3.21
56A	27-Jan-10	EG106	55	IP/R Mod	25/75	25	-1.4	-3.2	0	1.8,2.2,3	1,1,4.3	1.663	3.39
53	27-Jan-10	ABC-S Plus	N/A	Fluid Only	N/A	N/A	-1.9	-0.3	20	1, 1, 1	1, 1, 1	1.654	3.91
55	27-Jan-10	EG106	N/A	Fluid Only	N/A	N/A	-2.6	-0.9	20	1, 1, 1	1, 1, 1	1.689	1.88

9.2 Data Collected

9.2.1 Fluid Thickness Data

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

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

Tables 9.2 to 9.5 show the fluid thickness measurements collected during the contaminated fluid tests. The associated baseline fluid only cases are also shown in Tables 9.6 to 9.7 for comparison purposes.

Table 9.2: Test #20 Fluid Thickness Data

Test 20: ABC-S Plus, IP/R Mod, Tunnel OAT +2.9°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip, Application	After Takeoff Test
1	1.5	0.3	N/A
2	2.2	0.5	N/A
3	2.7	0.6	N/A
4	3.1	0.6	N/A
5	3.1	0.7	N/A
6	3.1	0.5	N/A
7	3.3	0.4	N/A
8	3.3	0.4	N/A
Flap	1.0	0.1	N/A

Table 9.3: Test #44 Fluid Thickness Data

Test 44: EG106, IP/R Mod, Tunnel OAT -0.8°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip, Application	After Takeoff Test
1	1.8	slush	N/A
2	2.2	slush	N/A
3	2.5	slush	N/A
4	3.1	slush	N/A
5	3.7	slush	N/A
6	4.5	slush	N/A
7	4.5	slush	N/A
8	3.5	slush	N/A
Flap	1.1	slush	N/A

Table 9.4: Test #56 Fluid Thickness Data

Test 56: EG106, IP/R Mod, Tunnel OAT -1.1°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Test
1	1.8	0.6	0.0
2	3.1	0.8	0.0
3	3.3	1.0	0.0
4	4.5	1.5	0.0
5	4.5	2.2	0.0
6	4.5	2.5	0.0
7	4.5	1.3	0.0
8	4.5	1.0	0.0
Flap	0.8	slush	N/A

Table 9.5: Test #56A Fluid Thickness Data

Test 56A: EG106, IP/R Mod, Tunnel OAT -1.4°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip, Application	After Takeoff Test
1	1.7	0.4	0.0
2	2.5	0.8	0.0
3	3.3	1.0	0.0
4	4.5	1.1	0.0
5	4.5	1.8	0.0
6	3.7	1.3	0.0
7	4.5	1.0	0.0
8	2.7	1.0	0.0
Flap	1.0	0.4	N/A

Table 9.6: Test #53 (Baseline) Fluid Thickness Data

Test 53: ABC-S Plus, Fluid-only, Tunnel OAT -1.9°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip, Application	After Takeoff Test
1	1.5	N/A	0.1
2	2.2	N/A	0.1
3	2.5	N/A	0.2
4	3.1	N/A	0.2
5	3.5	N/A	0.2
6	3.7	N/A	0.1
7	3.7	N/A	0.1
8	3.1	N/A	0.2
Flap	1.1	N/A	0.2

Table 9.7: Test #55 (Baseline) Fluid Thickness Data

Test 55: EG106, Fluid-only, Tunnel OAT -2.6°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip, Application	After Takeoff Test
1	2.2	N/A	0.0
2	2.9	N/A	0.1
3	3.1	N/A	0.2
4	3.1	N/A	0.2
5	2.5	N/A	0.2
6	4.5	N/A	0.2
7	4.5	N/A	0.1
8	4.5	N/A	0.1
Flap	0.6	N/A	0.1

9.2.2 Skin Temperature Data

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

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

Tables 9.8 to 9.11 show the wing temperature measurements recorded during the contaminated fluid tests. The associated baseline fluid only cases are also shown in Tables 9.12 to 9.13 for comparison purposes.

Table 9.8: Test #20 Wing Skin Temperature Data

Test 20: ABC-S Plus, IP/R Mod, Tunnel OAT +2.9°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	4.0	-2.5	1.2	N/A
T5	4.0	-2.1	0.8	N/A
TU	3.2	-2.8	1.2	N/A

Table 9.9: Test #44 Wing Skin Temperature Data

Test 44: EG106, IP/R Mod, Tunnel OAT -0.8°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-4.8	-6.0	-0.5	-8.2
T5	-5.2	-5.4	-0.7	N/A
TU	-4.4	-3.7	-2.4	N/A

Table 9.10: Test #56 Wing Skin Temperature Data

Test 56: EG106, IP/R Mod, Tunnel OAT -1.1°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-1.2	-1.5	-5.3	-4.3
T5	-1.3	-1.7	-5.1	-4.0
TU	-1.5	-2.1	-2.6	-4.4

Table 9.11: Test #56A Wing Skin Temperature Data

Test 56A: EG106, IP/R Mod, Tunnel OAT -1.4°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.4	-1.7	-3.3	-3.5
T5	-2.7	-1.6	-3.0	-2.7
TU	-3.6	-3.1	-0.9	-3.4

Table 9.12: Test #53 (Baseline) Wing Skin Temperature Data

Test 53: ABC-S Plus, Fluid-only, Tunnel OAT -1.9°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-0.2	+0.1	N/A	-1.3
T5	-0.1	+0.0	N/A	-1.4
TU	-0.8	-1.1	N/A	-1.3

Table 9.13: Test #55 (Baseline) Wing Skin Temperature Data

Test 55: EG106, Fluid-only, Tunnel OAT -2.6°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-0.6	-0.5	N/A	-1.6
T5	-0.5	-0.6	N/A	-1.5
TU	-1.4	-1.6	N/A	-2.3

9.2.3 Fluid Brix Data

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

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

Tables 9.14 to 9.17 show the fluid Brix measurements collected during the contaminated fluid tests. The associated baseline fluid only cases are also shown in Tables 9.18 to 9.19 for comparison purposes.

Table 9.14: Test #20 Fluid Brix Data

Test 20: ABC-S Plus, IP/R Mod, Tunnel OAT +2.9°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.25	7.50	N/A
8	38.00	4.50	N/A

Table 9.15: Test #44 Fluid Brix Data

Test 44: EG106, IP/R Mod, Tunnel OAT -0.8°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.50	3.00	N/A
8	32.00	1.00	N/A

Table 9.16: Test #56 Fluid Brix Data

Test 56: EG106, IP/R Mod, Tunnel OAT -1.1°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.00	13.50	31.25
8	32.50	12.00	30.75

Table 9.17: Test #56A Fluid Brix Data

Test 56A: EG106, IP/R Mod, Tunnel OAT -1.4°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.25	12.00	N/A
8	32.00	10.50	29.00

Table 9.18: Test #53 (Baseline) Fluid Brix Data

Test 53: ABC-S Plus, Fluid-only, Tunnel OAT -1.9°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.25	N/A	37.75
8	36.75	N/A	37.75

Table 9.19: Test #55 (Baseline) Fluid Brix Data

Test 55: EG106, Fluid-only, Tunnel OAT -2.6°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.35	N/A	34.75
8	33.00	N/A	34.00

9.3 Photos

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

- Start of test;
- Before Rotation (just before the wing began to pitch);
- End of Rotation (end of the rotation cycle when the wing position is returned to 4 degrees); and
- End of test.

The photos taken during the Light Ice Pellets Mixed with Moderate Rain testing have been presented along with the fluid only (baseline) tests for comparison purposes. In each case, the fluid only photo is presented first, followed by the contaminated fluid photo. Photos 9.1 to 9.32 show the photo summaries of the tests conducted. A complete set of photos will be provided to the TDC in electronic format.

9.4 Summary of Results

9.4.1 OAT -5°C and Above

Two tests were conducted in this cell with an exposure time of 25 minutes: Test #56 and Test #56A (see Table 9.20). Two other tests, #20 and #44, were also used during analysis but had an exposure time of 40 minutes, above the current allowance time. Table 9.21 contains more details on the results of these tests.

Test #56, conducted with EG fluid, demonstrated satisfactory results, as shown in Table 9.21. The temperature during this test was -1.1°C. The lift loss at 8° was 3.21 percent, below the 5 percent margin of safety criteria. The visual contamination results were not acceptable due to the ratings on the flap at the start of the test that did not meet the requirements (rating of 4.7). Due to the visual rating of greater than 4 on the flap, Test #56 was repeated (Test #56A) with the flap set at 0°. The visual contamination ratings improved (rating of 3 on the flap) with the flap at 0°. The 8° lift loss during Test #56A was 3.39 percent, below the 5 percent margin of safety criteria.

Test #44, conducted with EG fluid, had an exposure time greater than the allotted allowance time of 25 minutes, at 40 minutes (see Appendix F). The temperature during this test was -0.8°C. The results from this test were unsatisfactory, not meeting any of the lift loss or visual test requirements. The visual contamination ratings were bad both at the start of the test (5, 4.5, 5) and at rotation (5, 5, 5). The 8° lift loss was 28.5 percent, not meeting the 5 percent margin of safety criteria. A 36-second ramp-up time from 40 knots to 100 knots occurred during this test, well above the 19-second average. Based on the results obtained, 40 minutes is not an acceptable exposure time for this cell.

Test #20 was also conducted with an exposure time of 40 minutes, using PG fluid at a temperature of 2.9°C. This test run was attempted; however, the angle pitched in the opposite direction, so the takeoff was aborted. The results for this test were inconclusive.

In conclusion, the 25-minute allowance time is satisfactory for EG fluids, provided that the flap is set to zero. For PG fluids, the attempted test indicated that the 25-minute allowance can remain as is; however, more data is necessary.

Table 9.20: Light Ice Pellets Mixed with Moderate Rain Allowance Time Tests Winter 2009-10

	OAT -5°C and Above	**OAT Less than -5°C to -10°C**	**OAT Less than -10°C**
Light Ice Pellets Mixed with Moderate Rain	25 minutes **Test #56, 56A**	**Caution: No allowance times currently exist**	

Table 9.21: Summary of Light Ice Pellets Mixed with Moderate Rain Allowance Time Test Results

	OAT -5°C and Above	OAT Less than -5°C to -10°C	OAT Less than -10°C
Light Ice Pellets Mixed with Moderate Rain	**25 minutes** Run 56 (Exp. Time 25 min), -1.1°C EG106 Visual At Start: BAD (1.8, 2, 4.7) Visuals At Rotation: GOOD (1, 1, 5) LL At 100 kts: GOOD (3.21%) **GOOD At 100 kts** Run 56A (Exp. Time 25 min), -1.4°C *Flap At 0°* EG106 Visual At Start: GOOD (1.8, 2.2, 3) Visuals At Rotation: GOOD (1, 1, 4.3) LL At 100 kts: GOOD (3.39%) **GOOD At 100 kts** Run 20 (Exp. Time 40 min), 2.9°C ABC-S Plus Visual At Start: GOOD/BAD (1 (3.7), 1 (4), 1)) Visuals At Rotation: GOOD (1, 1, 1) LL At 100 kts: N/A Run 44 (Exp. Time 40 min), -0.8°C EG106 Visual At Start: BAD (5, 4.5, 5) Visuals At Rotation: BAD (5, 5, 5) LL At 100 kts: BAD (28.48%) **BAD At 100 kts** ▪ **25 min OK for EG Fluid; Results Improved When Flap is Set to 0°** ▪ **25 min OK for PG Fluid; More Data Needed** **CONCLUSION: ALLOWANCE TIME OF 25 MIN OK, FURTHER REVIEW REQUIRED**	**Caution: No Allowance Time Currently Exists**	**Caution: No Allowance Time Currently Exists**

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Photo 9.1: Test #53 – Start of Test

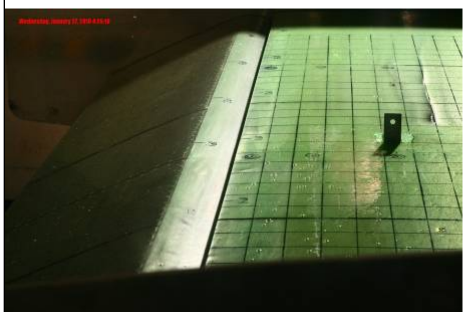
Test #53

ABC-S Plus, Fluid Only

-2°C, 8° Rotation

Visual Contamination Rating (1,1,1)

Start of Test



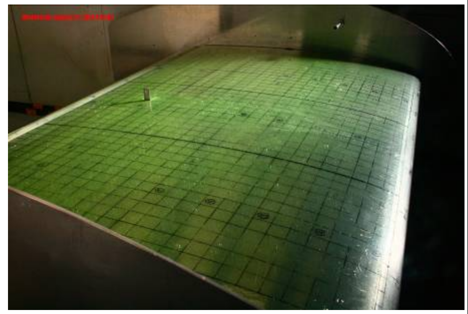


Photo 9.2: Test #20 – Start of Test

Test #20

ABC-S Plus, IP + Mod R 25 + 75 g/dm²/h, 40 min

3°C, 8° Rotation

Visual Contamination Rating (1,1,1)

Start of Test

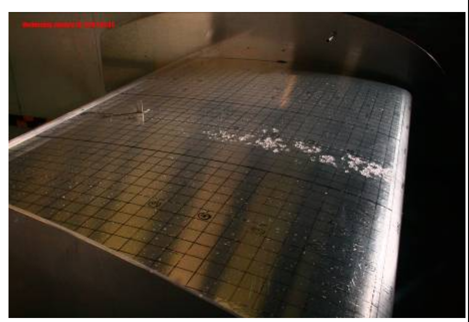


Photo 9.3: Test #53 – Before Rotation

Test #53
ABC-S Plus, Fluid Only
-2°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

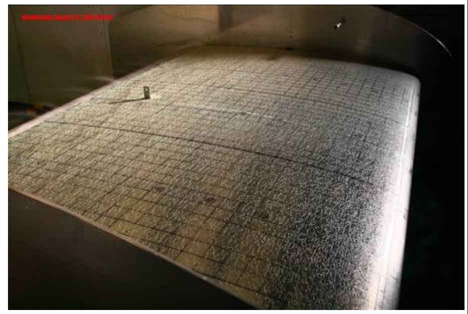
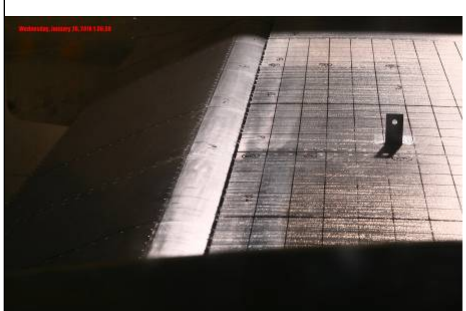


Photo 9.4: Test #20 – Before Rotation

Test #20
ABC-S Plus, IP + Mod R 25 + 75 g/dm²/h, 40 min
3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation



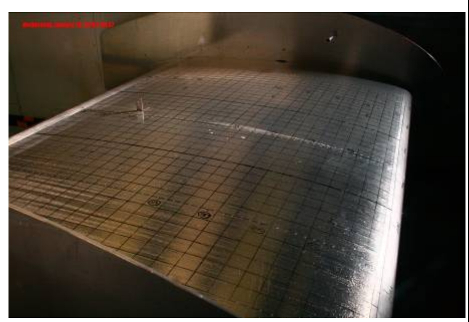
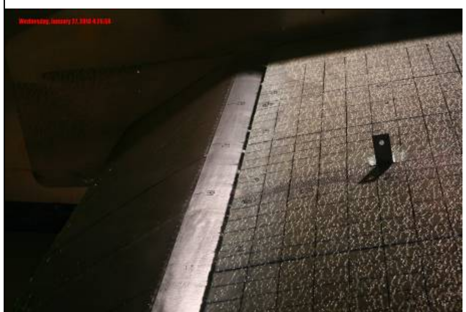


Photo 9.5: Test #53 – End of Rotation

Test #53
ABC-S Plus, Fluid Only
-2°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 3.91%
End of Rotation



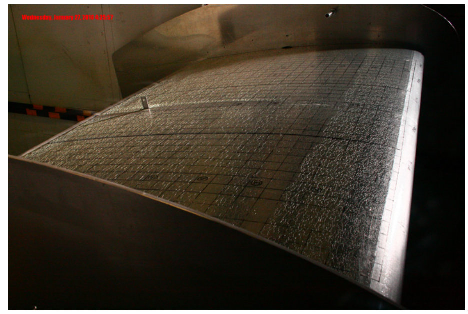


Photo 9.6: Test #20 – End of Rotation

No Photo Documentation Available

Photo 9.7: Test #53 – End of Test

Test #53

ABC-S Plus, Fluid Only

-2°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test

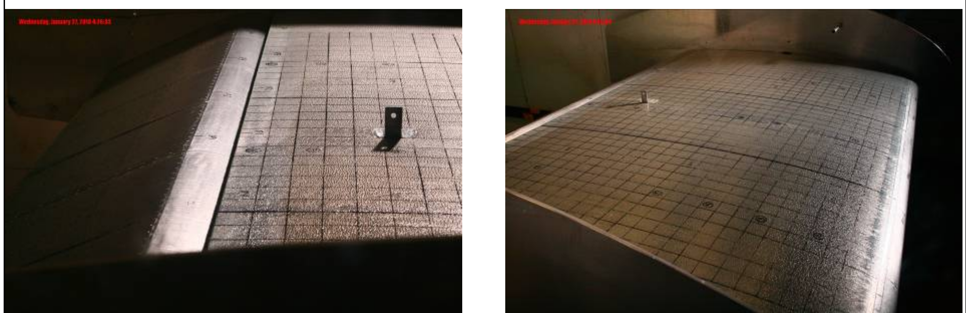


Photo 9.8: Test #20 – End of Test

No Photo Documentation Available

Photo 9.9: Test #55 – Start of Test

Test #55
EG106, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

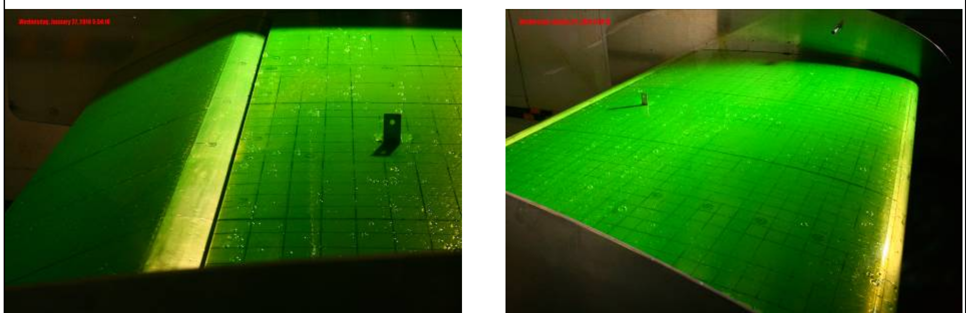


Photo 9.10: Test #44 – Start of Test

Test #44
EG106, IP + Mod R 25 + 75 g/dm²/h, 40 min
-1°C, 8° Rotation
Visual Contamination Rating (5,4.5,5)
Start of Test

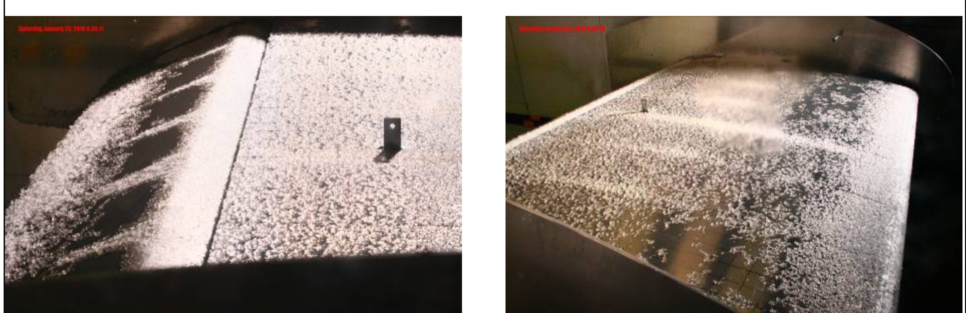
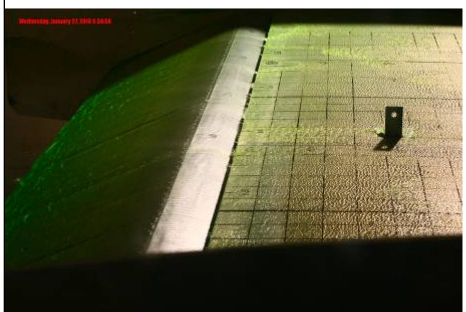


Photo 9.11: Test #55 – Before Rotation

Test #55
EG106, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation



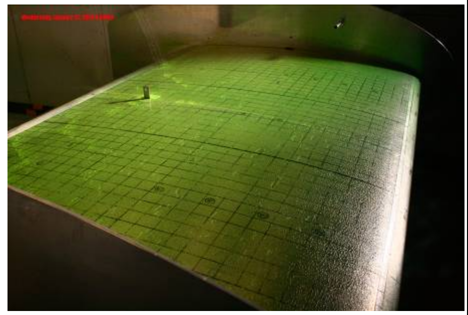


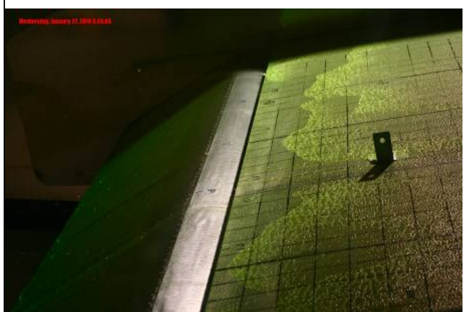
Photo 9.12: Test #44 – Before Rotation

Test #44
EG106, IP + Mod R 25 + 75 g/dm²/h, 40 min
-1°C, 8° Rotation
Visual Contamination Rating (5,5,5)
Before Rotation

Photo 9.13: Test #55 – End of Rotation

Test #55
EG106, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 1.88%

End of Rotation



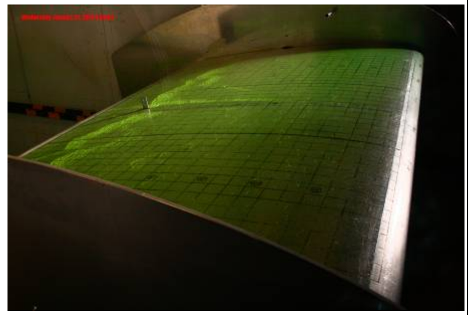


Photo 9.14: Test #44 – End of Rotation

Test #44
EG106, IP + Mod R 25 + 75 g/dm²/h, 40 min
-1°C, 8° Rotation
Visual Contamination Rating (5,5,5), 8° Lift Loss = 28.48%

End of Rotation

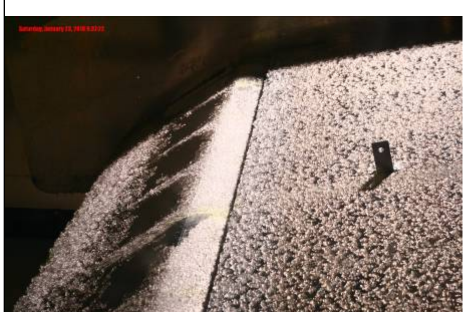
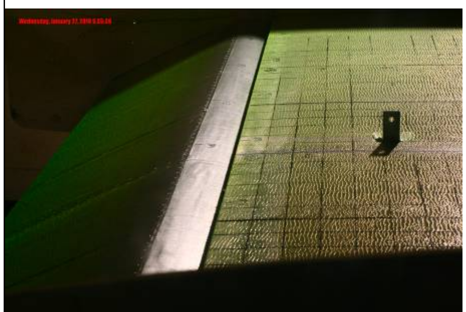


Photo 9.15: Test #55 – End of Test

Test #55
EG106, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test



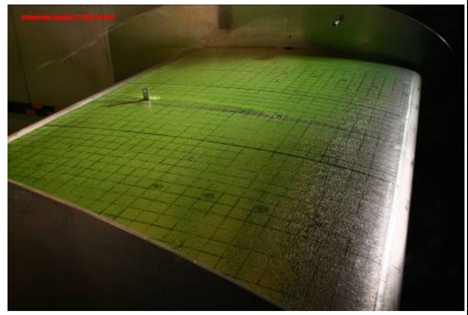


Photo 9.16: Test #44 – End of Test

Test #44
EG106, IP + Mod R 25 + 75 g/dm²/h, 40 min
-1°C, 8° Rotation
Visual Contamination Rating (5,5,5)
End of Test

Photo 9.17: Test #55 – Start of Test

Test #55
EG106, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

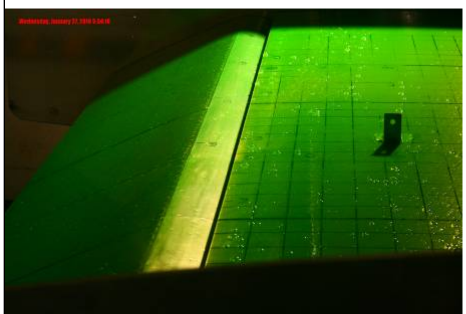
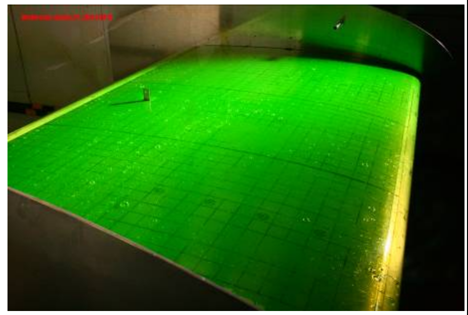



Photo 9.18: Test #56 – Start of Test

Test #56
EG106, IP + Mod R 25 + 75 g/dm²/h, 25 min
-1°C, 8° Rotation
Visual Contamination Rating (1.8,2,4.7)
Start of Test

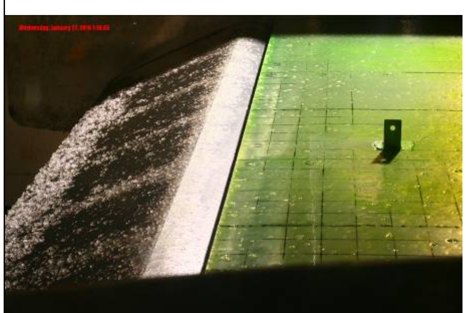
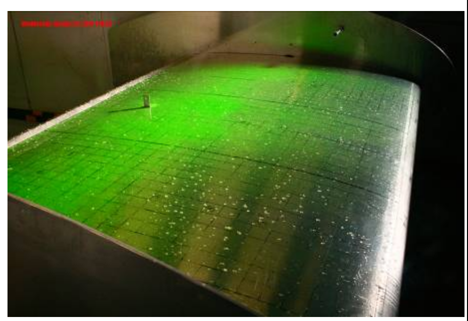



Photo 9.19: Test #55 – Before Rotation

Test #55
EG106, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

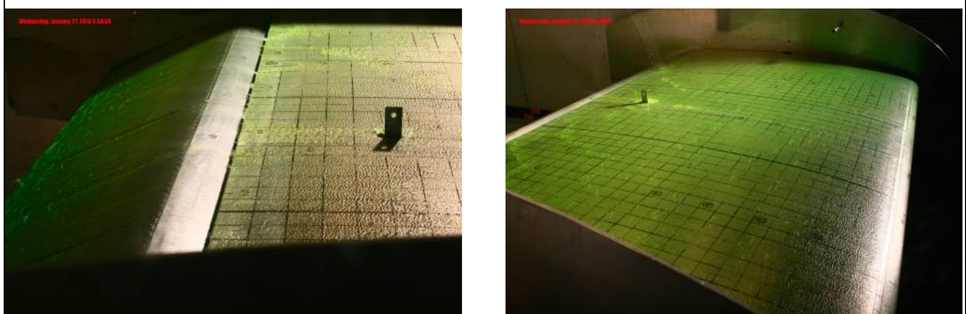


Photo 9.20: Test #56 – Before Rotation

Test #56
EG106, IP + Mod R 25 + 75 g/dm²/h, 25 min
-1°C, 8° Rotation
Visual Contamination Rating (1,1,5)
Before Rotation

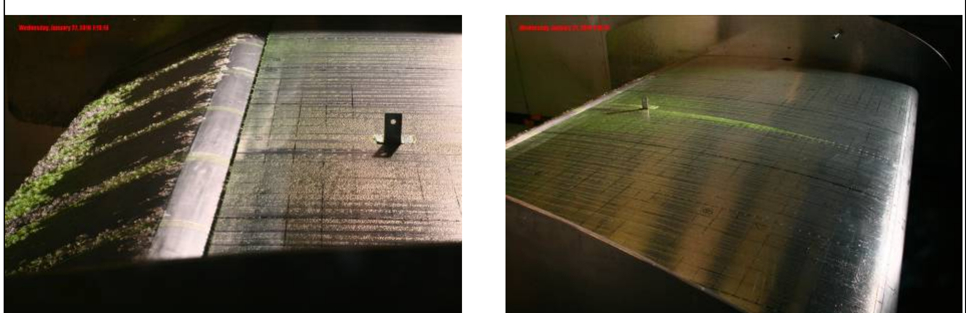
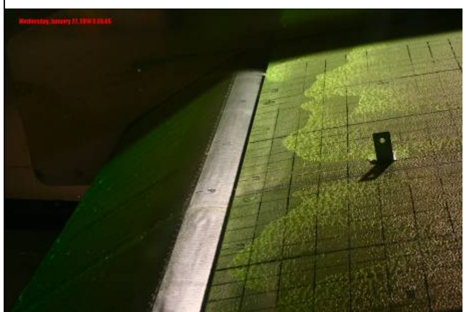


Photo 9.21: Test #55 – End of Rotation

Test #55
EG106, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 1.88%
End of Rotation



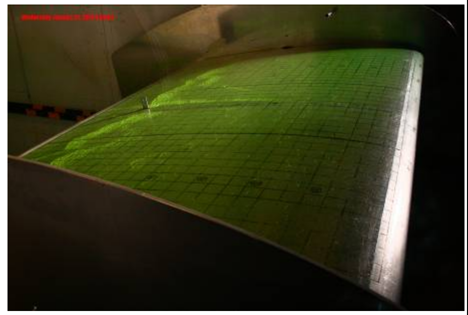
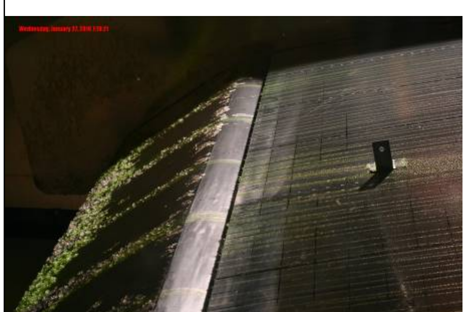


Photo 9.22: Test #56 – End of Rotation

Test #56
EG106, IP + Mod R 25 + 75 g/dm²/h, 25 min
-1°C, 8° Rotation
Visual Contamination Rating (1,1,5), 8° Lift Loss = 3.21%
End of Rotation



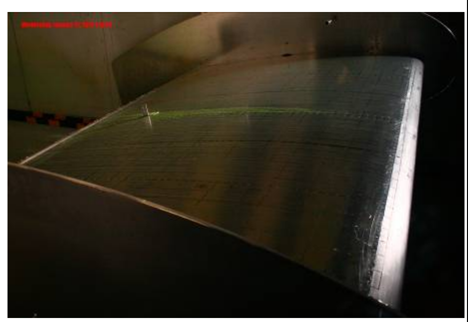


Photo 9.23: Test #55 – End of Test

Test #55
EG106, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

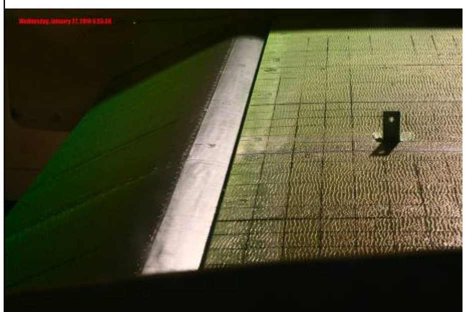
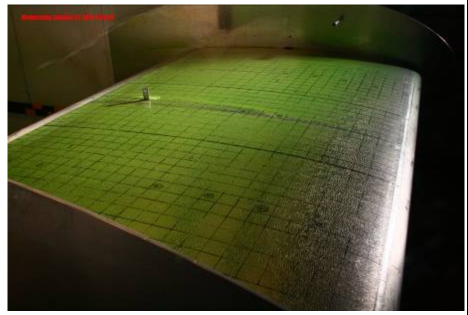



Photo 9.24: Test #56 – End of Test

Test #56
EG106, IP + Mod R 25 + 75 g/dm²/h, 25 min
-1°C, 8° Rotation
Visual Contamination Rating (1,1,5)
End of Test

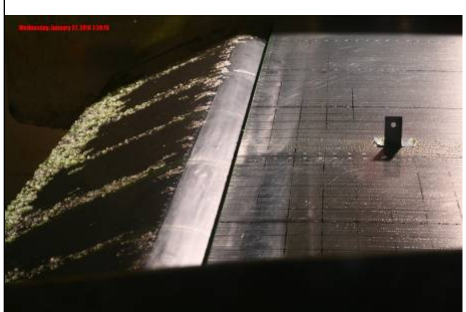
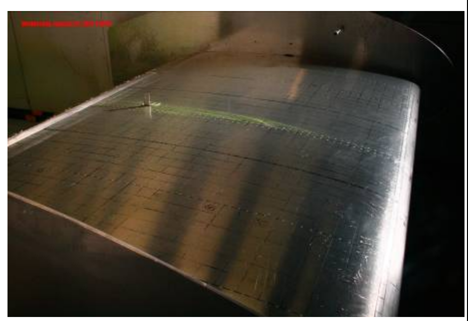



Photo 9.25: Test #55 – Start of Test

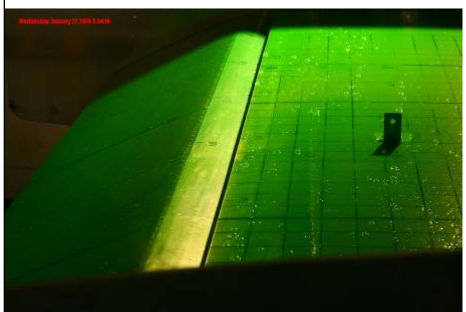
Test #55

EG106, Fluid Only

-3°C, 8° Rotation

Visual Contamination Rating (1,1,1)

Start of Test



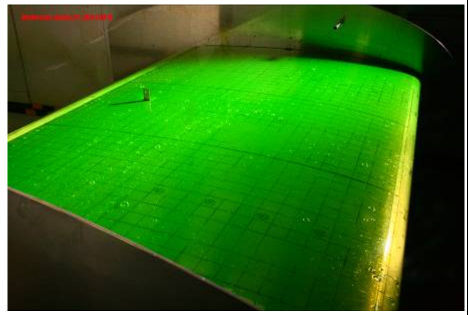


Photo 9.26: Test #56A – Start of Test

Test #56A

EG106, IP + Mod R 25 + 75 g/dm²/h, 25 min

-1°C, 8° Rotation, Flap Angle 0°

Visual Contamination Rating (1.8,2.2,3)

Start of Test

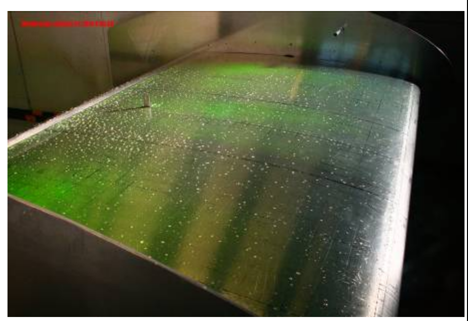


Photo 9.27: Test #55 – Before Rotation

Test #55
EG106, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)

Before Rotation

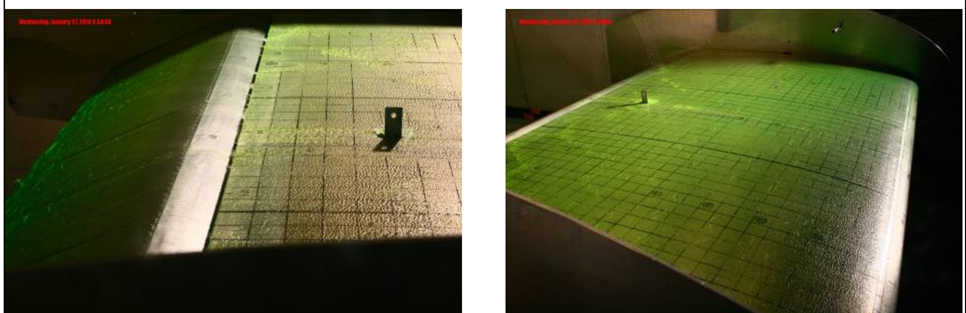


Photo 9.28: Test #56A – Before Rotation

Test #56A
EG106, IP + Mod R 25 + 75 g/dm²/h, 25 min
-1°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1,1,4.3)

Before Rotation

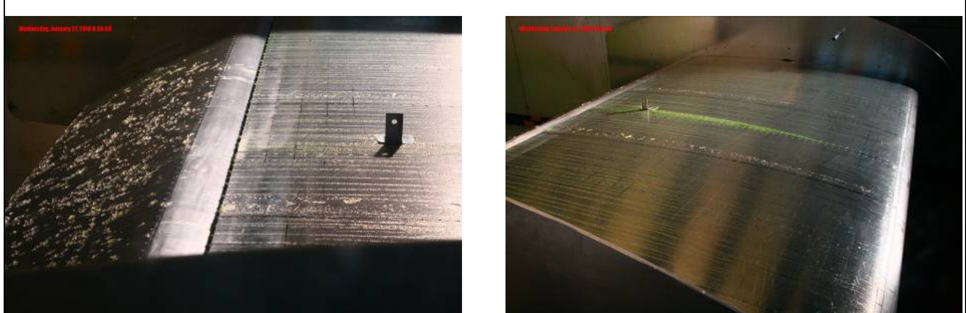


Photo 9.29: Test #55 – End of Rotation

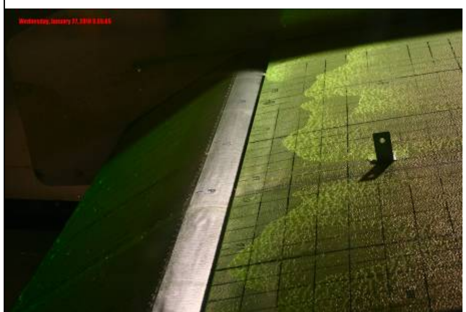
Test #55

EG106, Fluid Only

-3°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 1.88%

End of Rotation



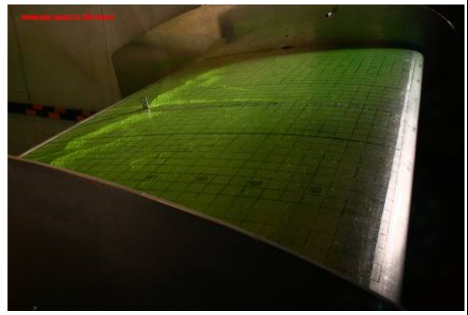


Photo 9.30: Test #56A – End of Rotation

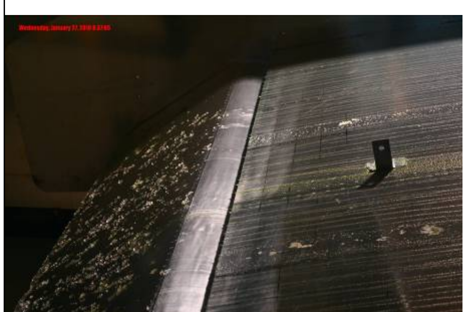
Test #56A

EG106, IP + Mod R 25 + 75 g/dm²/h, 25 min

-1°C, 8° Rotation, Flap Angle 0°

Visual Contamination Rating (1,1,4.3), 8° Lift Loss = 3.39%

End of Rotation



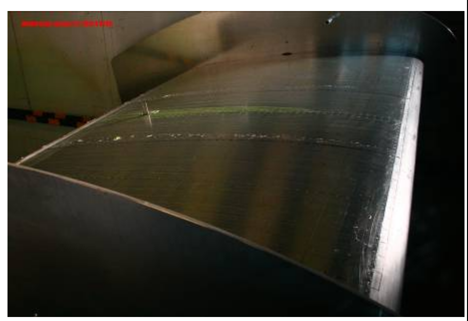
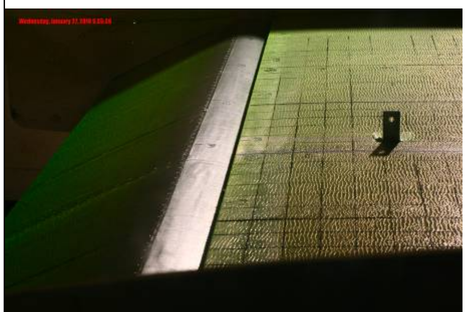


Photo 9.31: Test #55 – End of Test

Test #55
EG106, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test



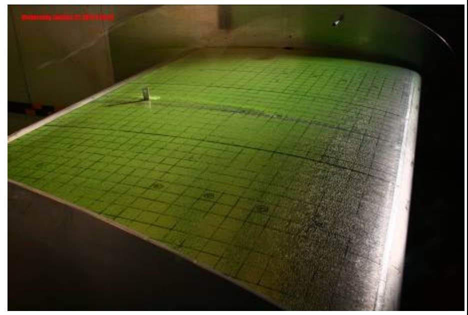
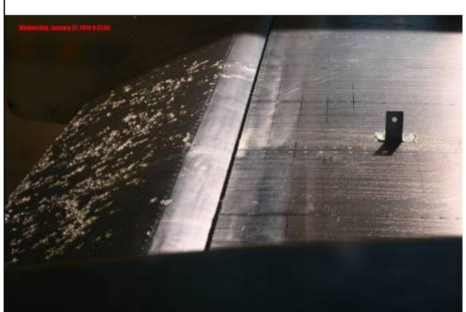
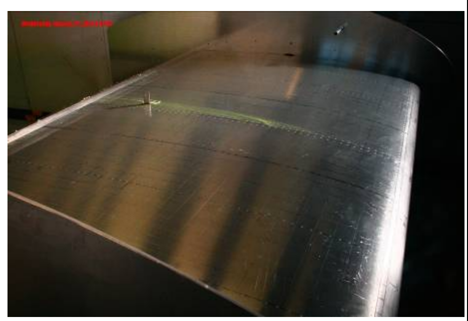


Photo 9.32: Test #56A – End of Test

Test #56A
EG106, IP + Mod R 25 + 75 g/dm²/h, 25 min
-1°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1,1,4.3)
End of Test





10. LIGHT ICE PELLETS MIXED WITH LIGHT SNOW ALLOWANCE TIMES

Aerodynamic testing was conducted to validate and further develop the Type IV high-speed ice pellet allowance times in the NRC wind tunnel. Previous testing in 2006-07 and 2008-09 consisted of wind tunnel tests and Falcon 20 aircraft tests to develop allowance times for mixed conditions with ice pellets. Due to the limitations of the data, some extrapolation of the results was required in order to develop a comprehensive table. It was recommended that testing be conducted at the most critical limits of the allowance times to validate the current guidance material for use with newer generation aircraft operating with supercritical wings. Additional testing was also required to provide guidance material where data was limited or non-existent. The results of this testing have been separated by test condition, and the details can be found in the following sections:

- Section 6: Light Ice Pellets;
- Section 7: Moderate Ice Pellets;
- Section 8: Light Ice Pellets and Light Freezing Rain;
- Section 9: Light Ice Pellets and Moderate Rain;
- Section 10: Light Ice Pellets and Light Snow; and
- Section 11: Light Ice Pellets and Moderate Snow.

This section provides an overview of each test conducted to substantiate and further develop the current high-speed allowance times for Type IV fluids in Light Ice Pellet Mixed with Light Snow conditions. Testing was conducted in simulated precipitation conditions. The parameters for each test are detailed, and a description of the data collected during each test is provided.

10.1 Overview of Tests

A summary of the Light Ice Pellet Mixed with Light Snow tests conducted in the wind tunnel is shown in Table 10.1. The table provides relevant information for each of the tests, as well as final values used for the data analysis. Each row contains data specific to one test. A more detailed test log of all conditions tested using the wind tunnel is provided in Subsection 4.1. A brief description of the column headings for Table 10.1 is provided in Subsection 6.1.

Table 10.1: Summary of 2009-10 Light Ice Pellets Mixed with Light Snow Testing

Test No.	Date	Fluid	Associated Baseline Test	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Flap Angle (°)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° During Rotation	8° Lift Loss (%)
5	11-Jan-10	ABC-S Plus	4	IP/SN-	25/10	25	-4.8	-6.7	20	2,2,3	1,1.5,1.8	1.658	3.68
11	13-Jan-10	ABC-S Plus	1	IP/SN-	25/10	40	-5.9	-8.1	20	3,2.3,4	1,1.8,2.5	1.646	4.37
23	20-Jan-10	EG106	25	IP/SN-	25/10	40	-3.2	-9	20	2.3,2.2,4	1,1.2,1.5	1.702	1.12
57	27-Jan-10	Launch	29	IP/SN-	25/10	40	-3.6	-5.4	20	2.7,2.6,4	1,1.7,2.8	1.64	4.72
57A	27-Jan-10	Launch	29	IP/SN-	25/10	40	-4.2	-5.7	0	2.6,2.6,3	1,1.3,1.7	1.671	2.92
77	30-Jan-10	ABC-S Plus	64	IP/SN-	25/10	10	-14.1	-16.1	20	2.8,2.7,3.7	3.7,1.7,2	1.551	9.89
78	30-Jan-10	ABC-S Plus	76	IP/SN-	25/10	5	-16	-14.9	20	2.3,2.2,3	1.4,2,2.7	1.573	8.62
79	30-Jan-10	EG106	75	IP/SN-	25/10	10	-14.8	-15.7	20	2.2,2,2.5	1,1.5,2	1.66	3.56
94	2-Feb-10	ABC-S Plus	1	IP/SN-	25/10	15	-6.3	-9.7	20	2.5,2,2.8	1,1.8,2	1.626	5.54
1	3-Feb-10	ABC-S Plus	N/A	Fluid Only	N/A	N/A	-5.7	-4.6	20	1, 1, 1	1, 1, 1	1.635	5.01
4	11-Jan-10	ABC-S Plus	N/A	Fluid Only	N/A	N/A	-6.6	-5.4	20	1, 1, 1	1, 1, 1	1.652	4.03
25	4-Feb-10	EG106	N/A	Fluid Only	N/A	N/A	-4	-3.4	20	1, 1, 1	1, 1, 1	1.687	1.99
29	5-Feb-10	Launch	N/A	Fluid Only	N/A	N/A	-6.8	-5.2	20	1, 1, 1	1, 1, 1	1.636	4.96
64	6-Feb-10	ABC-S Plus	N/A	Fluid Only	N/A	N/A	-13.4	-11.3	20	1, 1, 1	1, 1, 1	1.634	5.07
75	30-Jan-10	EG106	N/A	Fluid Only	N/A	N/A	-18.1	-16.9	20	1, 1, 1	1, 1, 1	1.651	4.08
76	30-Jan-10	ABC-S Plus	N/A	Fluid Only	N/A	N/A	-17.9	-17.3	20	1, 1, 1	1, 1, 1	1.62	5.89

10.2 Data Collected

10.2.1 Fluid Thickness Data

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

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

Tables 10.2 to 10.10 show the fluid thickness measurements collected during the contaminated fluid tests. The associated baseline fluid only cases are also shown in Tables 10.11 to 10.17 for comparison purposes.

Table 10.2: Test #5 Fluid Thickness Data

Test 5: ABC-S Plus, IP-/SN-, Tunnel OAT -4.8°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.8	2.5	0.0
2	2.7	3.5	0.0
3	3.7	3.9	0.1
4	4.5	4.5	0.3
5	4.5	5.7	0.2
6	3.9	5.7	0.2
7	4.5	5.7	0.2
8	3.3	4.5	0.2
Flap	1.0	0.1 (slush)	0.2

Table 10.3: Test #11 Fluid Thickness Data

Test 11: ABC-S Plus, IP-/SN-, Tunnel OAT -5.9°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.3	1.5	0.0
2	2.5	3.1	0.1
3	3.1	3.3	0.1
4	4.5	4.5	0.1
5	4.5	5.7	0.1
6	4.5	7	0.1
7	4.5	5.7	0.1
8	3.3	5.7	0.1
Flap	1.0	0.1 (slush)	0.2

Table 10.4: Test #23 Fluid Thickness Data

Test 23: EG106, IP-/SN-, Tunnel OAT -3.2°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.8	1.0	0.0
2	2.2	1.1	0.0
3	2.9	2.5	0.0
4	2.9	3.5	0.0
5	4.5	4.5	0.0
6	4.5	5.7	0.0
7	4.5	4.5	0.0
8	3.3	4.5	0.1
Flap	1.0	slush	0.1

Table 10.5: Test #57 Fluid Thickness Data

Test 57: Launch, IP-/SN-, Tunnel OAT -3.6°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	0.7	2.5	0.1
2	1.8	2.7	0.1
3	2.2	3.3	0.1
4	2.5	3.9	0.1
5	2.7	3.9	0.1
6	2.7	4.5	0.1
7	2.5	4.5	0.1
8	2.2	3.7	0.1
Flap	0.5	slush	0.2

Table 10.6: Test #57A Fluid Thickness Data

Test 57A: Launch, IP-/SN-, Tunnel OAT -4.2°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.0	2.2	0.0
2	1.8	3.5	0.1
3	2.2	4.5	0.1
4	2.7	4.5	0.1
5	3.1	4.5	0.2
6	3.1	5.7	0.1
7	2.7	4.5	0.2
8	2.2	4.5	0.2
Flap	2.2	4.5	0.1

Table 10.7: Test #77 Fluid Thickness Data

Test 77: ABC-S Plus, IP-/SN-, Tunnel OAT -14.1°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.0	1.3	0.1
2	1.6	1.6	0.1
3	1.8	1.8	0.1
4	2.2	2.2	0.1
5	2.5	2.2	0.3
6	2.2	2.7	0.3
7	1.7	2.2	0.2
8	1.3	2.2	0.3
Flap	0.5	slush	0.3

Table 10.8: Test #78 Fluid Thickness Data

Test 78: ABC-S Plus, IP-/SN-, Tunnel OAT -16.0°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.0	1	0.0
2	1.6	1.6	0.1
3	1.8	1.8	0.1
4	2.2	1.7	0.1
5	2.2	2.2	0.2
6	2.2	2.2	0.2
7	2.2	1.8	0.2
8	1.7	1.8	0.3
Flap	1.0	slush	0.2

Table 10.9: Test #79 Fluid Thickness Data

Test 79: EG106, IP-/SN-, Tunnel OAT -14.8°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.7	2.2	0.1
2	2.5	3.1	0.1
3	2.7	3.7	0.1
4	3.1	4.5	0.1
5	4.5	4.5	0.1
6	4.5	5.7	0.2
7	4.5	5.7	0.1
8	4.5	3.7	0.2
Flap	1.2	N/A	0.1

Table 10.10: Test #94 Fluid Thickness Data

Test 94: ABC-S Plus, IP-/SN-, Tunnel OAT -6.3°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.7	1.8	0.0
2	2.2	2.2	0.1
3	2.7	3.1	0.2
4	3.1	3.3	0.2
5	3.3	4.5	0.2
6	3.1	4.5	0.2
7	3.3	4.5	0.2
8	2.9	3.5	0.2
Flap	1.0	N/A	0.2

Table 10.11: Test #1 (Baseline) Fluid Thickness Data

Test 1: ABC-S Plus, Fluid-only, Tunnel OAT -5.7°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.8	N/A	0.0
2	2.5	N/A	0.0
3	3.3	N/A	0.1
4	4.5	N/A	0.1
5	5.7	N/A	0.1
6	5.7	N/A	0.1
7	5.7	N/A	0.1
8	4.5	N/A	0.1
Flap	1.0	N/A	0.1

Table 10.12: Test #4 (Baseline) Fluid Thickness Data

Test 4: ABC-S Plus, Fluid-only, Tunnel OAT -6.6°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.6	N/A	0.0
2	2.2	N/A	0.1
3	2.9	N/A	0.1
4	3.9	N/A	0.1
5	3.9	N/A	0.1
6	4.5	N/A	0.2
7	4.5	N/A	0.1
8	3.3	N/A	0.1
Flap	N/A	N/A	0.1

Table 10.13: Test #25 (Baseline) Fluid Thickness Data

Test 25: EG106, Fluid-only, Tunnel OAT -4.0°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	2.2	N/A	0.0
2	3.1	N/A	0.1
3	3.7	N/A	0.1
4	4.5	N/A	0.2
5	4.5	N/A	0.2
6	4.5	N/A	0.1
7	4.5	N/A	0.1
8	3.5	N/A	0.1
Flap	N/A	N/A	0.1

Table 10.14: Test #29 (Baseline) Fluid Thickness Data

Test 29: Fluid-only, Launch, Tunnel OAT -4.8°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.5	N/A	0.0
2	2.2	N/A	0.1
3	2.2	N/A	0.1
4	3.1	N/A	0.1
5	3.1	N/A	0.2
6	3.1	N/A	0.1
7	2.9	N/A	0.1
8	2.2	N/A	0.2
Flap	0.8	N/A	0.2

Table 10.15: Test #64 (Baseline) Fluid Thickness Data

Test 64: ABC-S Plus, Fluid-only, Tunnel OAT -13.4°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.2	N/A	0.0
2	2.2	N/A	0.1
3	1.7	N/A	0.1
4	1.8	N/A	0.1
5	3.1	N/A	0.2
6	3.1	N/A	0.2
7	3.1	N/A	0.2
8	2.7	N/A	0.2
Flap	0.8	N/A	0.2

Table 10.16: Test #75 (Baseline) Fluid Thickness Data

Test 75: EG106, Fluid-only, Tunnel OAT -18.1°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	2.2	N/A	0.1
2	2.9	N/A	0.2
3	3.1	N/A	0.2
4	3.7	N/A	0.1
5	4.5	N/A	0.1
6	4.5	N/A	0.1
7	4.5	N/A	0.1
8	2.2	N/A	0.2
Flap	0.2	N/A	0.2

Table 10.17: Test #76 (Baseline) Fluid Thickness Data

Test 76: ABC-S Plus, Fluid-only, Tunnel OAT -17.9°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.3	N/A	0.1
2	1.6	N/A	0.1
3	1.8	N/A	0.1
4	2.2	N/A	0.1
5	2.2	N/A	0.2
6	2.2	N/A	0.2
7	1.8	N/A	0.2
8	1.6	N/A	0.2
Flap	0.5	N/A	0.2

10.2.2 Skin Temperature Data

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

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

Tables 10.18 to 10.26 show the wing temperature measurements recorded during the contaminated fluid tests. The associated baseline fluid only cases are also shown in Tables 10.27 to 10.33 for comparison purposes.

Table 10.18: Test #5 Wing Skin Temperature Data

Test 5: ABC-S Plus, IP-/SN-, Tunnel OAT -4.8°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-4.2	-4.2	-7.8	-3.0
T5	-3.6	-4.4	-7.0	-2.9
TU	-5.0	-4.6	-5.2	-4.0

Table 10.19: Test #23 Wing Skin Temperature Data

Test 23: EG106, IP-/SN-, Tunnel OAT -3.2°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.6	-2.1	-11.5	-4.1
T5	-3.0	-2.0	-9.4	-3.4
TU	-3.5	-3.4	-6.1	-4.2

Table 10.20: Test #11 Wing Skin Temperature Data

Test 11: ABC-S Plus, IP-/SN-, Tunnel OAT -5.9°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-4.6	-4.8	-8.7	-6.2
T5	-3.2	-5.3	-8	-6.5
TU	-5.5	-5.5	-7.7	-7.3

Table 10.21: Test #57 Wing Skin Temperature Data

Test 57: Launch, IP-/SN-, Tunnel OAT -3.6°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.4	-2.5	-6.9	-4.6
T5	-3.3	-2.4	-6.8	-4.2
TU	-3.0	-3.1	-2.6	-4.9

Table 10.22: Test #57A Wing Skin Temperature Data

Test 57A: Launch, IP-/SN-, Tunnel OAT -4.2°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.9	-3.0	-7.1	-5.1
T5	-3.3	-3.0	-7.2	-4.8
TU	-4.6	-4.3	-2.7	-5.3

Table 10.23: Test #77 Wing Skin Temperature Data

Test 77: ABC-S Plus, IP-/SN-, Tunnel OAT -14.1°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-15.0	-16.8	-16.8	N/A
T5	-14.1	-17.1	-15.6	N/A
TU	-17.1	-17.3	-16.0	N/A

Table 10.24: Test #78 Wing Skin Temperature Data

Test 78: ABC-S Plus, IP-/SN-, Tunnel OAT -16.0°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-15.2	-17.0	-15.4	-16.0
T5	-14.9	-16.4	-14.5	-15.2
TU	-17.5	-17.4	-14.9	-18.1

Table 10.25: Test #79 Wing Skin Temperature Data

Test 79: EG106, IP-/SN-, Tunnel OAT -14.8°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-15.7	-17.6	-16.4	-17.4
T5	-15	-17.0	-15.6	-16.6
TU	-18	-17.4	-15.0	-18.9

Table 10.26: Test #94 Wing Skin Temperature Data

Test 94: ABC-S Plus, IP-/SN-, Tunnel OAT -6.3°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T3	-7.0	-8.7	-11	-10.8
T5	-6.3	-9.0	-9.8	-11.1
TU	-7.9	-7.6	-8.2	-11.6

Table 10.27: Test #1 (Baseline) Wing Skin Temperature Data

Test 1: ABC-S Plus, Fluid-only, Tunnel OAT -5.7°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-4.5	-4.5	N/A	-3.6
T5	-5	-4.9	N/A	-3.2
TU	-5.1	-4.5	N/A	-4.3

Table 10.28: Test #4 (Baseline) Wing Skin Temperature Data

Test 4: ABC-S Plus, Fluid-only, Tunnel OAT -6.6°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-5.8	-5.2	N/A	-4.2
T5	-5.0	-5.2	N/A	-3.6
TU	-5.8	-5.8	N/A	-5.0

Table 10.29: Test #25 (Baseline) Wing Skin Temperature Data

Test 25: EG106, Fluid-only, Tunnel OAT -4.0°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.6	-3.0	N/A	-3.4
T5	-3.0	-3.1	N/A	-3.2
TU	-4.4	-4.2	N/A	-3.9

Table 10.30: Test #29 (Baseline) Wing Skin Temperature Data

Test 29: Fluid-only, Launch, Tunnel OAT -4.8°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.0	-3.8	N/A	-6.0
T5	-2.2	-3.9	N/A	-5.4
TU	-4.5	-4.1	N/A	-6.6

Table 10.31: Test #31 (Baseline) Wing Skin Temperature Data

Test 64: ABC-S Plus, Fluid-only, Tunnel OAT -13.4°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-11.8	-10.8	N/A	-12.2
T5	-11.9	-10.8	N/A	-12.1
TU	-12.3	-12.4	N/A	-12.4

Table 10.32: Test #32 (Baseline) Wing Skin Temperature Data

Test 75: EG106, Fluid-only, Tunnel OAT -18.1°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-16.2	-16.5	N/A	-16.4
T5	-15.8	-16.4	N/A	-15.6
TU	-17.9	-17.7	N/A	-18.4

Table 10.33: Test #76 (Baseline) Wing Skin Temperature Data

Test 76: ABC-S Plus, Fluid-only, Tunnel OAT -17.9°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-16.4	-17.1	N/A	-16.9
T5	-16.2	-17.0	N/A	-16.1
TU	-18.1	-17.8	N/A	-18.9

10.2.3 Fluid Brix Data

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

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

Tables 10.34 to 10.42 show the fluid Brix measurements collected during the contaminated fluid tests. The associated baseline fluid only cases are also shown in Tables 10.43 to 10.49 for comparison purposes.

Table 10.34: Test #5 Fluid Brix Data

Test 5: ABC-S Plus, IP-/SN-, Tunnel OAT -4.8°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.00	21.50	29.50
8	36.75	18.00	29.25

Table 10.35: Test #11 Fluid Brix Data

Test 11: ABC-S Plus, IP-/SN-, Tunnel OAT -5.9°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.00	22.25	22.50
8	36.25	21.50	18.50

Table 10.36: Test #23 Fluid Brix Data

Test 23: EG106, IP-/SN-, Tunnel OAT -3.2°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	31.50	19.50	26.50
8	32.00	13.50	26.00

Table 10.37: Test #57 Fluid Brix Data

Test 57: Launch, IP-/SN-, Tunnel OAT -3.6°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.25	15.00	26.25
8	36.75	14.50	26.00

Table 10.38: Test #57A Fluid Brix Data

Test 57A: Launch, IP-/SN-, Tunnel OAT -4.2°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.50	13.50	24.25
8	36.75	7.50	27.50

Table 10.39: Test #77 Fluid Brix Data

Test 77: ABC-S Plus, IP-/SN-, Tunnel OAT -14.1°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	38.00	33.00	24.50
8	37.50	29.50	29.50

Table 10.40: Test #78 Fluid Brix Data

Test 78: ABC-S Plus, IP-/SN-, Tunnel OAT -16.0°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.50	34.00	34.50
8	37.25	36.50	33.00

Table 10.41: Test #79 Fluid Brix Data

Test 79: EG106, IP-/SN-, Tunnel OAT -14.8°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.50	22.00	32.75
8	32.00	23.00	31.50

Table 10.42: Test #94 Fluid Brix Data

Test 94: ABC-S Plus, IP-/SN-, Tunnel OAT -6.3°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.50	21.50	30.00
8	36.50	29.00	29.50

Table 10.43: Test #1 (Baseline) Fluid Brix Data

Test 1: ABC-S Plus, Fluid-only, Tunnel OAT -5.7°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.5	N/A	39.5
8	36.5	N/A	38.25

Table 10.44: Test #4 (Baseline) Fluid Brix Data

Test 4: ABC-S Plus, Fluid-only, Tunnel OAT -6.6°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.00	N/A	34.00
8	36.75	N/A	36.50

Table 10.45: Test #25 (Baseline) Fluid Brix Data

Test 25: EG106, Fluid-only, Tunnel OAT -4.0°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.00	N/A	31.50
8	32.25	N/A	32.50

Table 10.46: Test #29 (Baseline) Fluid Brix Data

Test 29: Fluid-only, Launch, Tunnel OAT -4.8°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.75	N/A	37.50
8	37.00	N/A	36.50

Table 10.47: Test #64 (Baseline) Fluid Brix Data

Test 64: ABC-S Plus, Fluid-only, Tunnel OAT -13.4°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.75	N/A	38.50
8	37.50	N/A	38.00

Table 10.48: Test #75 (Baseline) Fluid Brix Data

Test 75: EG106, Fluid-only, Tunnel OAT -18.1°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.25	N/A	34.00
8	32.25	N/A	34.00

Table 10.49: Test #76 (Baseline) Fluid Brix Data

Test 76: ABC-S Plus, Fluid-only, Tunnel OAT -17.9°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.75	N/A	38.25
8	37.00	N/A	37.25

10.3 Photos

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

- Start of test;
- Before Rotation (just before the wing began to pitch);
- End of Rotation (end of the rotation cycle when the wing position is returned to 4 degrees); and
- End of test.

The photos taken during the Light Ice Pellets Mixed with Light Snow testing have been presented along with the fluid only (baseline) tests for comparison purposes. In each case, the fluid only photo is presented first, followed by the contaminated fluid photo. Photos 10.1 to 10.72 show the photo summaries of the tests conducted. A complete set of photos will be provided to the TDC in electronic format.

10.4 Summary of Results

10.4.1 OAT -5°C and Above

One test was conducted in this cell with an exposure time of 25 minutes: Test #5 (see Table 10.50). In an attempt to expand the current allowance time, four additional tests were conducted with exposure times of 40 minutes, above the current allowance time (see Table 10.51).

Test #5, conducted at a 14° rotation angle using PG fluid, demonstrated very good results (see Table 10.51). The temperature during this test was -4.8°C. Both lift loss (3.68 percent) and visual ratings gave positive results, satisfying all criteria.

Test #23, conducted with EG fluid at a temperature of -3.2°C, demonstrated very good results. Both lift loss (1.12 percent) and visual ratings were deemed positive, satisfying all criteria. The 40-minute exposure time during this test was above the current allowance time of 25 minutes, indicating a potential to increase the allowance time for EG fluids.

Test #11, conducted with PG fluid, also demonstrated very good results. The temperature was at -5.9°C during this test. Lift loss and visual contamination ratings satisfied all required criteria; the lift loss result at 8° was 4.37 percent, below the 5 percent margin of safety criteria. An examination into the ramp-up time for this test shows a time of 28 seconds to reach rotation from a speed of 40 knots, which is much greater than the average of 19 seconds.

Tests #57 and #57A were both conducted with the same PG fluid. Temperatures were -3.6°C and -4.2°C, respectively. Results from these two tests were very good. Test #57 had positive visual ratings and lift loss results (4.72 percent). Because the visual rating on the flap for Test #57 was 4 at the start of the test, the test was repeated (Test #57A) with the flap set at 0° for the contamination phase. Although both tests were deemed good, the aerodynamic performance and visual contamination results were better during Test #57A with the flap at 0° during contamination (2.92 percent lift loss). The ramp-up times for these two tests were near the 19-second average.

In conclusion, the current allowance time of 25 minutes for EG and PG fluids in this cell is satisfactory. The results obtained for both fluids indicate a potential to increase the current allowance time to 40 minutes.

Table 10.50: Light Ice Pellets Mixed with Light Snow Allowance Time Tests Winter 2009-10

	OAT -5°C and Above	**OAT Less than -5°C to -10°C**	**OAT Less than -10°C**
Light Ice Pellets Mixed with Light Snow	25 minutes **Test # 5**	15 minutes **Test # 94**	

Table 10.51: Summary of Light Ice Pellets Mixed with Light Snow Allowance Time Test Results

	OAT -5°C and Above	OAT Less than -5°C to -10°C	OAT Less than -10°C
Light Ice Pellets Mixed with Light Snow	**25 minutes** Run 5 (Exposure Time 25 min), -4.8°C *14° Rotation Angle* ABC-S Plus Visual At Start: GOOD (2, 2, 3) Visuals At Rotation: GOOD (1, 1.5, 1.8) LL At 100 kts: GOOD (3.68%) **GOOD At 100 kts** Run 11 (Exposure Time 40 min), -5.9°C ABC-S Plus Visual At Start: GOOD (3, 2.3, 4) Visuals At Rotation: GOOD (1, 1.8, 2.5) LL At 100 kts: GOOD (4.37%) **GOOD At 100 kts** Run 23 (Exposure Time 40 min), -3.2°C EG106 Visual At Start: GOOD (2.3, 2.2, 4) Visuals At Rotation: GOOD (1, 1.2, 1.5) LL At 100 kts: GOOD (1.12%) **GOOD At 100 kts** Run 57 (Exposure Time 40 min), -3.6°C LAUNCH Visual At Start: GOOD (2.7, 2.6, 4) Visuals At Rotation: GOOD (1, 1.7, 2.8) LL At 100 kts: GOOD (4.72%) **GOOD At 100 kts** Run 57A (Exposure Time 40 min), -4.2°C *Flap At 0°* LAUNCH Visual At Start: GOOD (2.6, 2.6, 3) Visuals At Rotation: GOOD (1, 1.3, 1.7) LL At 100 kts: GOOD (2.92%) **GOOD At 100 kts** ▪ **25 min GOOD for EG Fluid** ▪ **25 min GOOD for PG Fluid; Results Improved when Flap is Set At 0°**	**15 minutes** Run 94 (Exposure Time 15 min), -6.3°C ABC-S Plus Visual At Start: GOOD (2.5, 2, 2.8) Visuals At Rotation: GOOD (1, 1.8, 2) LL At 100 kts: OK (5.54%) LL At 105 kts: GOOD (4.24%) LL At 110 kts: GOOD (3.33%) LL At 120 kts: GOOD (1.60%) **GOOD At 105 kts** ▪ **No EG Tests Conducted; 15 min to Remain in this Cell** ▪ **15 min OK for PG Fluid; Further Review Required**	**Caution: No Allowance Time Currently Exists** Run 77 (Exposure Time 10 min), -14.1°C ABC-S Plus Visual At Start: GOOD (2.8, 2.7, 3.7) Visuals At Rotation: BAD (1.7, 2, 2.8) LL At 100 kts: BAD (9.89%) **BAD At 100 kts** Run 79 (Exposure Time 10 min), -14.8°C EG106 Visual At Start: GOOD (2.2, 2, 2.5) Visuals At Rotation: GOOD (1, 1.5, 2) LL At 100 kts: GOOD (3.56%) **GOOD At 100 kts** Run 78 (Exposure Time 5 min), -16.0°C ABC-S Plus Visual At Start: GOOD (2.3, 2.2, 3) Visuals At Rotation: BAD (1.4, 2, 2.7) LL At 100 kts: BAD (8.62%) **BAD At 100 kts** ▪ **10 min GOOD for EG Fluid; Could Potentially Expand** ▪ **No Allowance Time for PG Fluid Based on Results**
	CONCLUSION: ALLOWANCE TIME OF 25 MIN GOOD, POTENTIAL TO INCREASE TO 40 MINS	**CONCLUSION: ALLOWANCE TIME OF 15 MIN OK, FURTHER REVIEW REQUIRED**	**CONCLUSION: NO ALLOWANCE TIME CURRENTLY EXISTS; POTENTIAL ALLOWANCE TIME OF 10 MIN FOR EG FLUID**

10.4.2 OAT Less than -5°C to -10°C

Only one test was conducted in this cell with an exposure time of 15 minutes: Test #94 (see Table 10.50).

Test #94, conducted with PG fluid, demonstrated satisfactory results based on the 8° lift loss findings (see Table 10.51). The temperature during this test was slightly warm for this cell, at -6.3°C. A lift loss result slightly above the 5 percent margin of safety criteria (at 5.54 percent) occurred, indicating a need for further review. An analysis of the lift loss was conducted for speeds greater than 100 knots for this test run (see Table 10.52 and Figure 10.1), and the semi-log of time results indicate a speed just below 105 knots is needed to reduce lift loss to 5 percent. A ramp-up time of 16 seconds from 40 knots to rotation occurred during this run, below the 19-second average.

In conclusion, the current allowance time of 15 minutes for this cell is satisfactory at this time based on the results obtained. Although the lift loss at 8° was slightly above the 5 percent safety margin, no significant issues arose during the analysis of this cell to indicate a need to change the current allowance time of 15 minutes. No EG tests were conducted in this cell; allowance times are to remain at 15 minutes. Data is needed for EG fluid.

10.4.3 OAT Less than -10°C

Although no allowance time currently exists in this cell, three tests were conducted with exposure times of 10 and 5 minutes: Tests #77 and #79 (10 minutes) and Test #78 (5 minutes). For further details on these tests, refer to Table 10.51 and Appendix F.

Test #79, conducted with EG fluid with an exposure time of 10 minutes, demonstrated good results. The temperature during this test was -14.8°C. The visual contamination results all passed the necessary criteria and proved very positive. The 8° lift loss was 3.56 percent, below the 5 percent margin of safety criteria. A look into the ramp-up time from 40 knots to rotation indicated a time of 16 seconds occurred during this test run, which is 3 seconds below the average.

Test #77, conducted with PG fluid with an exposure time of 10 minutes, demonstrated poor results. The temperature during this test was -14.1°C. Due to the LE rating at rotation that exceeded the criteria (1.7), the visual results were deemed unacceptable. The lift loss result at 8° was also unacceptable at 9.89 percent, beyond the 5 percent safety criteria. An examination into the ramp-up time during this run showed a time of 15 seconds to reach rotation from 40 knots.

This is below the average of 19 seconds, indicating the possibility of improvement in the visual and lift loss results should an extra 4 seconds have been present.
Test #78, conducted with the same PG fluid with an exposure time of 5 minutes, also demonstrated poor results, requiring a need for further review. The temperature during this test was -16.0°C. A rating of 1.4 on the LE at rotation exceeded the required criteria; therefore, the visual results were deemed unacceptable. The lift loss result at 8° was also unacceptable at 8.62 percent. An examination into the ramp-up time during this run showed a time of 15 seconds to reach rotation from 40 knots. This is below the average of 19 seconds, also indicating the possibility of improvement in the visual and lift loss results should an extra 4 seconds have been present.

To conclude, no allowance time currently exists for PG and EG fluids. Based on the results obtained, there is a potential for an allowance time of 10 minutes or more for EG fluid. Results for PG fluid indicate that an allowance time should not be provided.

Table 10.52: Details of Increased Rotation Speed Analysis

Condition	Test #	Speed (Kts)	Lift Loss at 8 Degrees (%)	Visual (%)	Linear (%)	Semi-Log (Time) (%)	Polynomial (2nd Order) (%)
Light Ice Pellets Mixed with Light Snow (OAT Less than -5°C and -10°C)	**94**	100	5.54				
		105		-	4.00	4.24	5.46
		110		4.30	2.94	3.33	5.35
		120		3.37	0.83	1.60	5.71

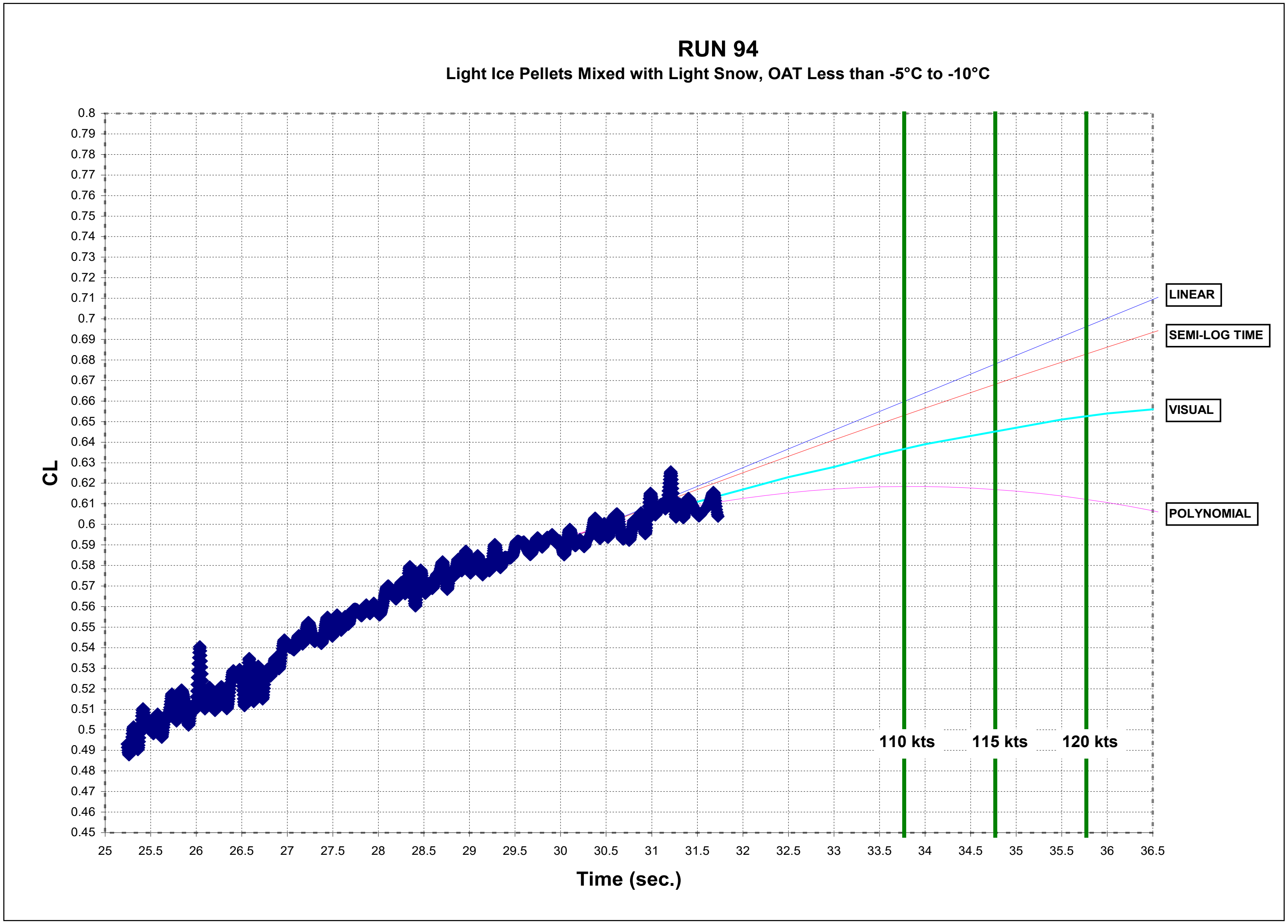


Figure 10.1: Increased Rotation Speed Extrapolation Results – Test #94

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Photo 10.1: Test #4 – Start of Test

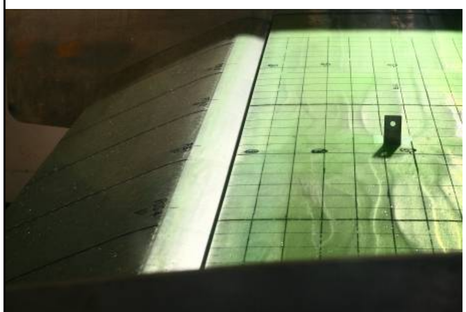
Test #4

ABC-S Plus, Fluid Only

-7°C, 14° Rotation

Visual Contamination Rating (1,1,1)

Start of Test



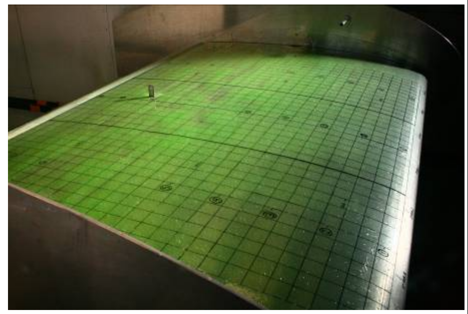


Photo 10.2: Test #5 – Start of Test

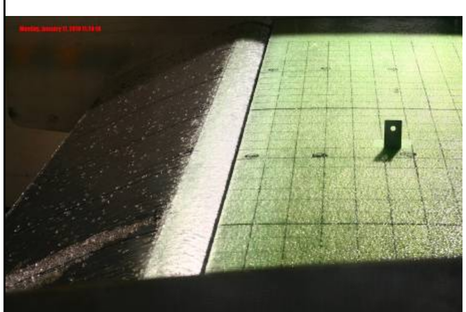
Test #5

ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 25 min

-5°C, 14° Rotation

Visual Contamination Rating (2,2,3)

Start of Test



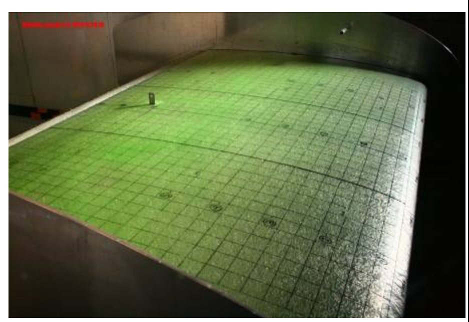


Photo 10.3: Test #4 – Before Rotation

No Photo Documentation Available

Photo 10.4: Test #5 – Before Rotation

Test #5

ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 25 min

-5°C, 14° Rotation

Visual Contamination Rating (1,1.5,1.8)

Before Rotation

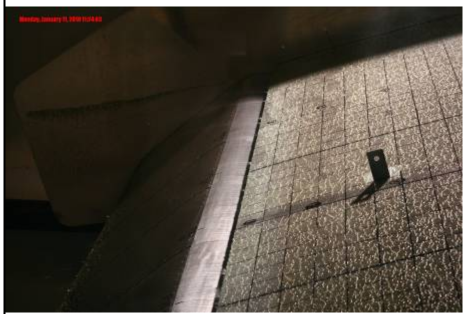
Photo 10.5: Test #4 – End of Rotation

No Photo Documentation Available

Photo 10.6: Test #5 – End of Rotation

Test #5
ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 25 min
-5°C, 14° Rotation
Visual Contamination Rating (1,1.5,1.8), 8° Lift Loss = 3.68%

End of Rotation



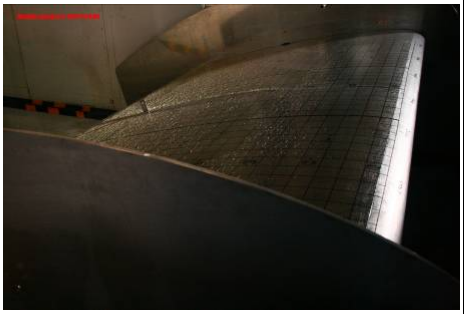


Photo 10.7: Test #4 – End of Test

No Photo Documentation Available

Photo 10.8: Test #5 – End of Test

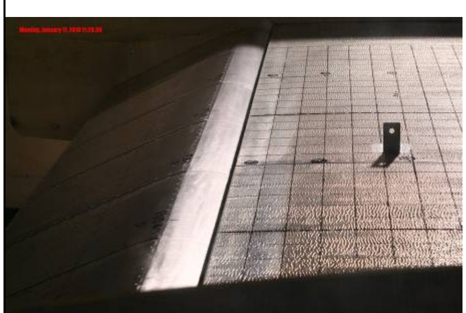
Test #5

ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 25 min

-5°C, 14° Rotation

Visual Contamination Rating (1,1.5,1.8)

End of Test



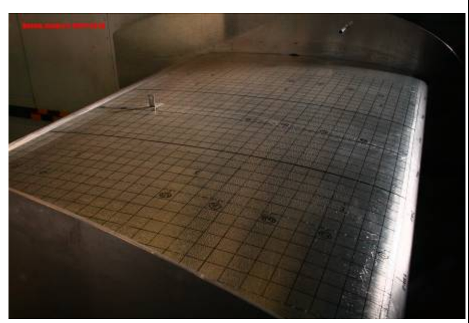


Photo 10.9: Test #1 – Start of Test

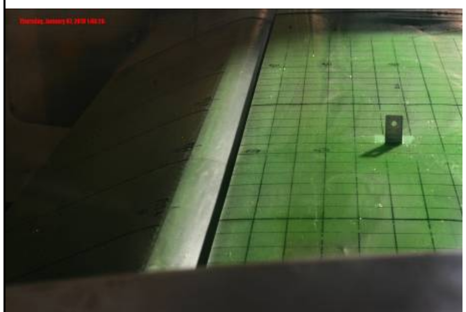
Test #1

ABC-S Plus, Fluid Only

-6°C, 8° Rotation

Visual Contamination Rating (1,1,1)

Start of Test



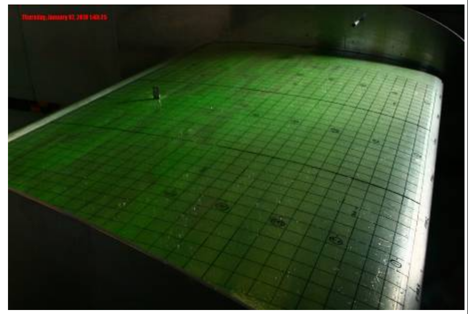


Photo 10.10: Test #11 – Start of Test

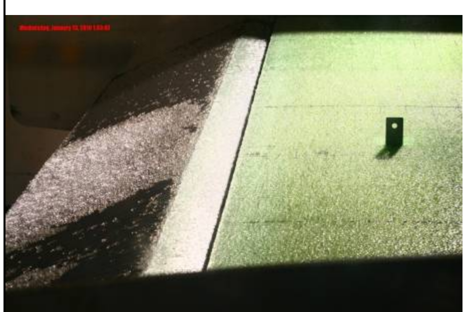
Test #11

ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 40 min

-6°C, 8° Rotation

Visual Contamination Rating (3,2.3,4)

Start of Test



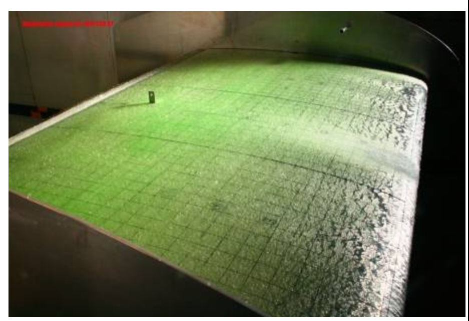


Photo 10.11: Test #1 – Before Rotation

Test #1
ABC-S Plus, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

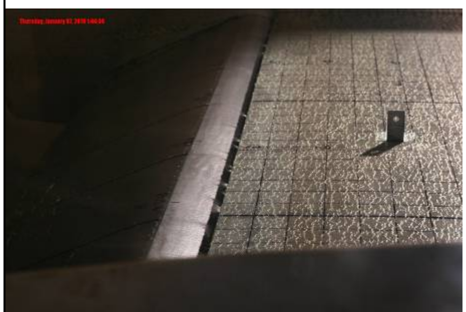
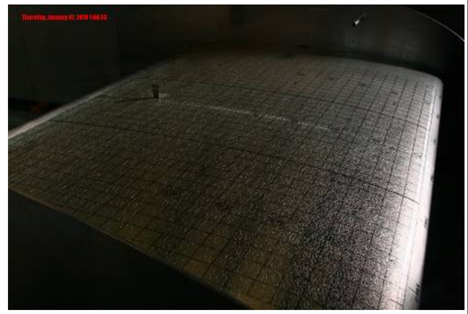



Photo 10.12: Test #11 – Before Rotation

Test #11
ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 40 min
-6°C, 8° Rotation
Visual Contamination Rating (1,1.8,2.5)
Before Rotation

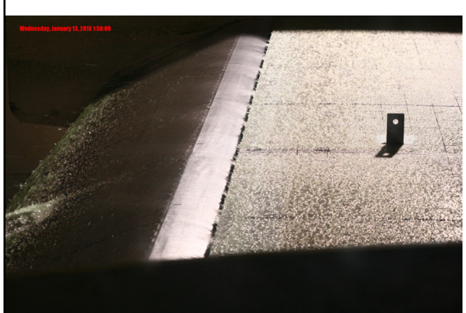
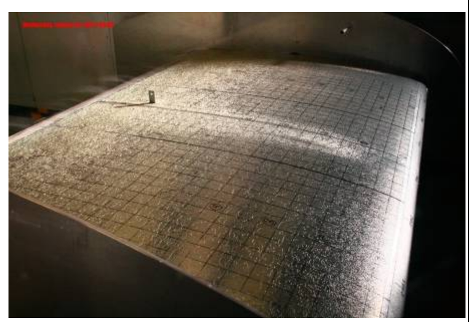
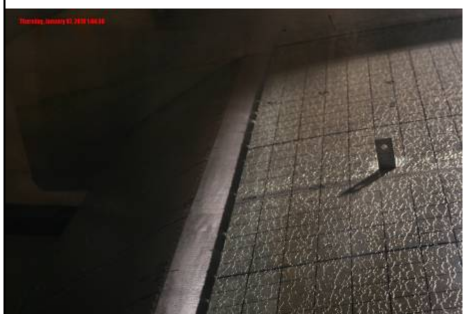



Photo 10.13: Test #1 – End of Rotation

Test #1
ABC-S Plus, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.01%

End of Rotation



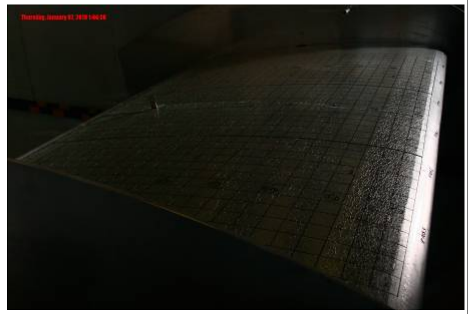


Photo 10.14: Test #11 – End of Rotation

Test #11
ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 40 min
-6°C, 8° Rotation
Visual Contamination Rating (1,1.8,2.5), 8° Lift Loss = 4.37%

End of Rotation

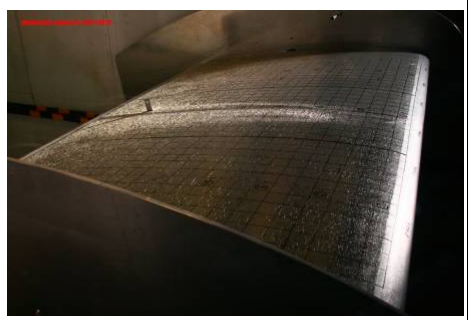


Photo 10.15: Test #1 – End of Test

Test #1
ABC-S Plus, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

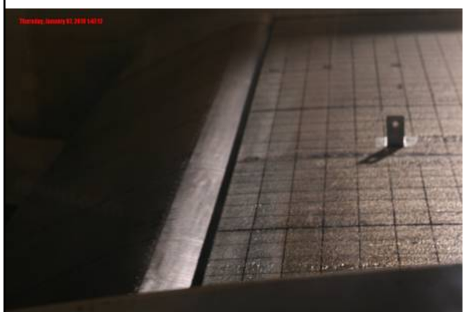



Photo 10.16: Test #11 – End of Test

Test #11
ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 40 min
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

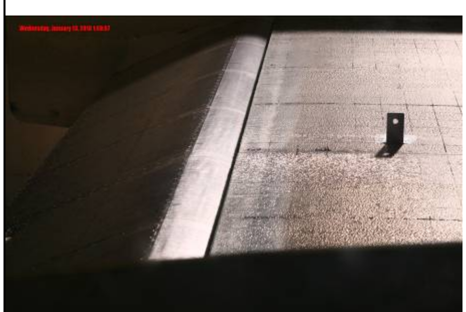
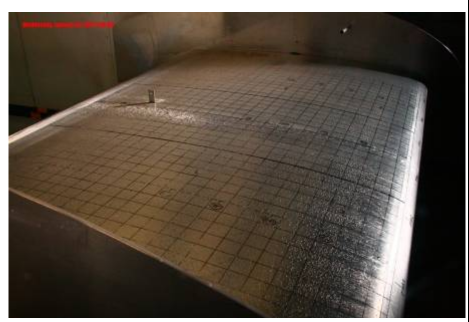
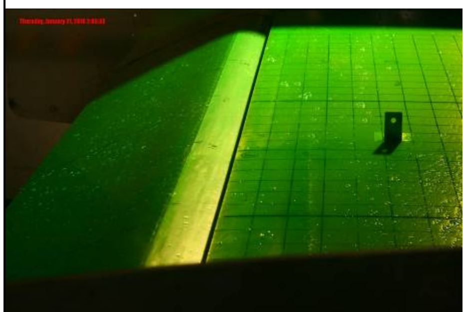



Photo 10.17: Test #25 – Start of Test

Test #25
EG106, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)

Start of Test



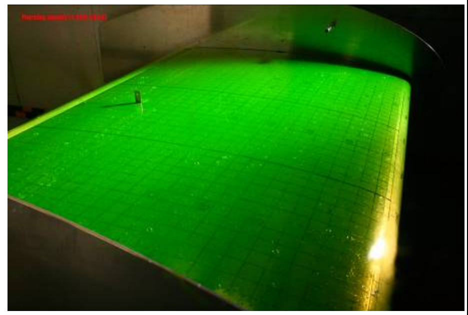
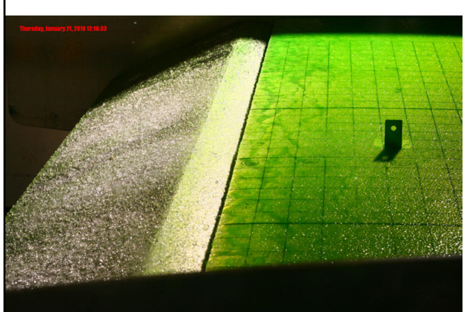


Photo 10.18: Test #23 – Start of Test

Test #23
EG106, IP- + SN- 25 + 10 g/dm²/h, 40 min
-3°C, 8° Rotation
Visual Contamination Rating (2.3,2.2,4)

Start of Test



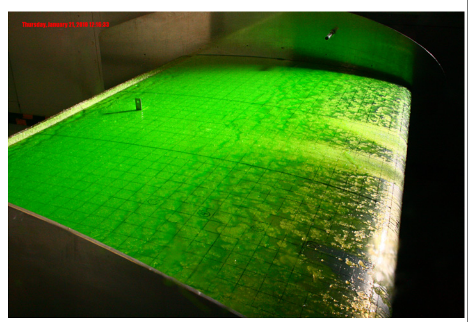


Photo 10.19: Test #25 – Before Rotation

Test #25

EG106, Fluid Only

-4°C, 8° Rotation

Visual Contamination Rating (1,1,1)

Before Rotation

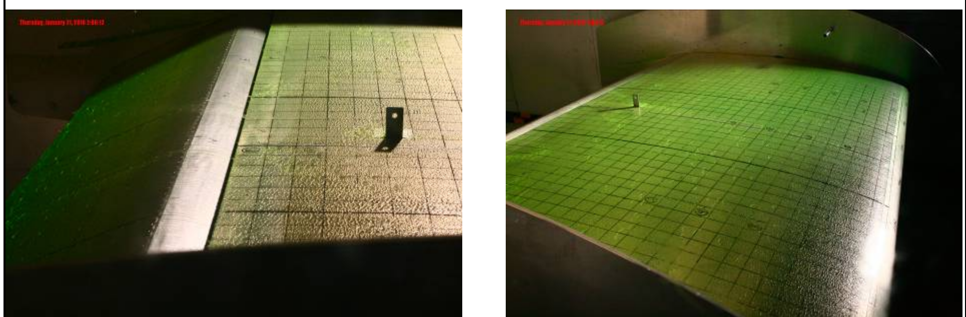


Photo 10.20: Test #23 – Before Rotation

Test #23

EG106, IP- + SN- 25 + 10 g/dm²/h, 40 min

-3°C, 8° Rotation

Visual Contamination Rating (1,1.2,1.5)

Before Rotation

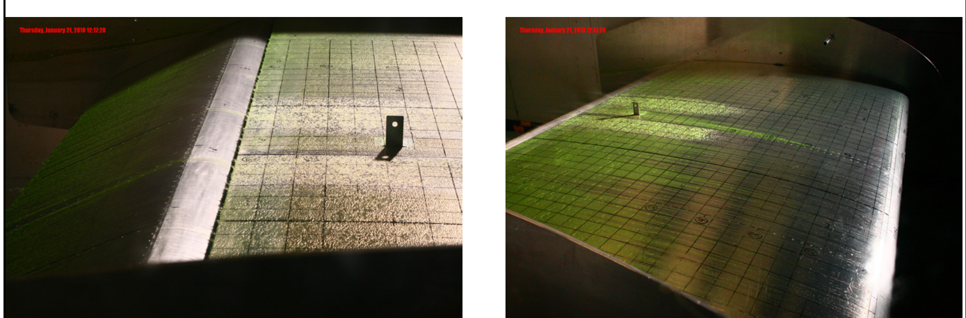


Photo 10.21: Test #25 – End of Rotation

Test #25
EG106, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 1.99%
End of Rotation

Photo 10.22: Test #23 – End of Rotation

Test #23
EG106, IP- + SN- 25 + 10 g/dm²/h, 40 min
-3°C, 8° Rotation
Visual Contamination Rating (1,1.2,1.5), 8° Lift Loss = 1.12%
End of Rotation

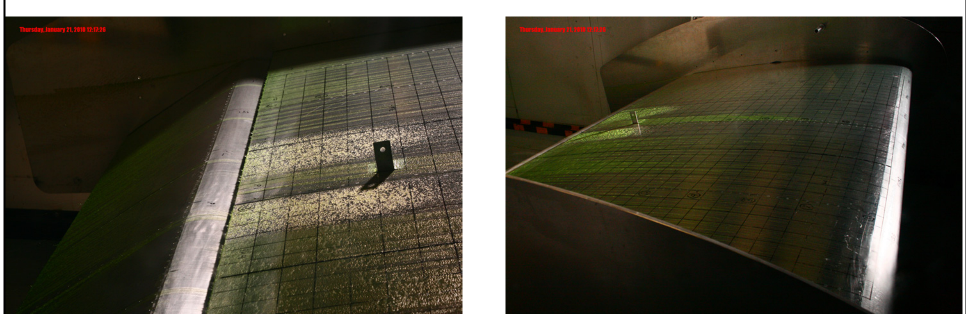
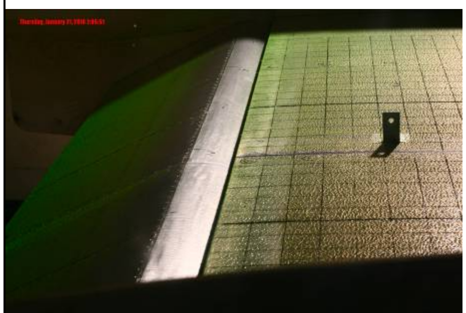


Photo 10.23: Test #25 – End of Test

Test #25
EG106, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test



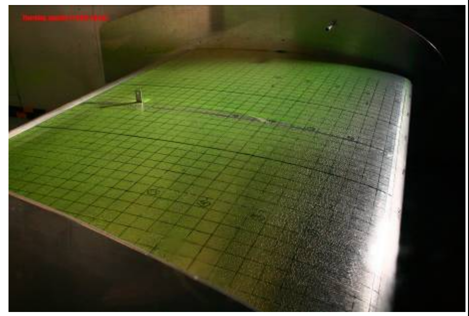
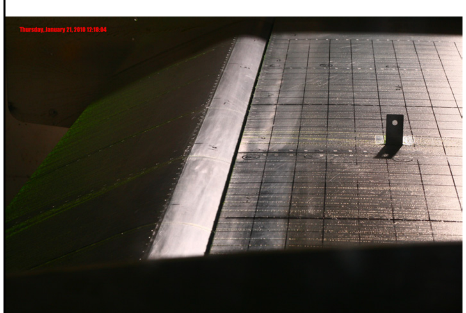


Photo 10.24: Test #23 – End of Test

Test #23
EG106, IP- + SN- 25 + 10 g/dm²/h, 40 min
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test



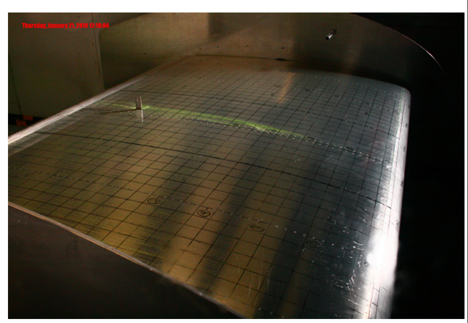
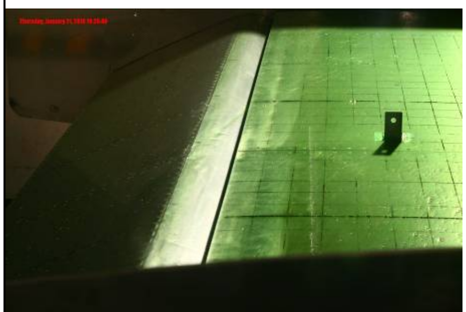


Photo 10.25: Test #29 – Start of Test

Test #29
Launch, Fluid Only
-5°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test



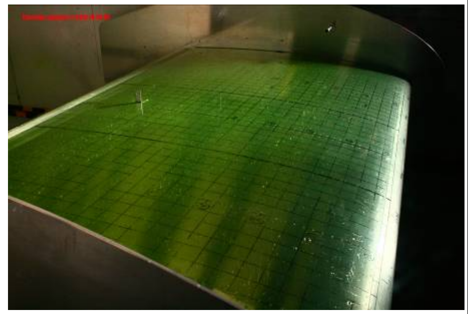
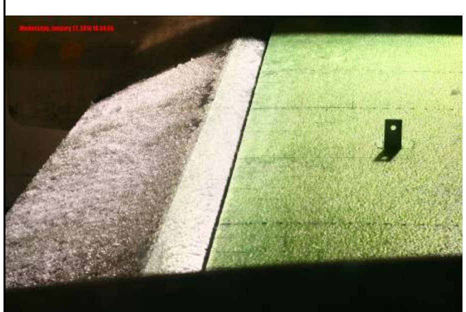


Photo 10.26: Test #57 – Start of Test

Test #57
Launch, IP- + SN- 25 + 10 g/dm²/h, 40 min
-4°C, 8° Rotation
Visual Contamination Rating (2.7,2.6,4)
Start of Test



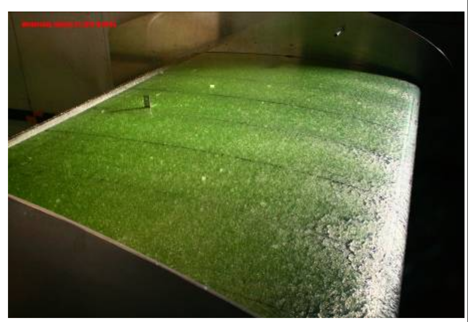


Photo 10.27: Test #29 – Before Rotation

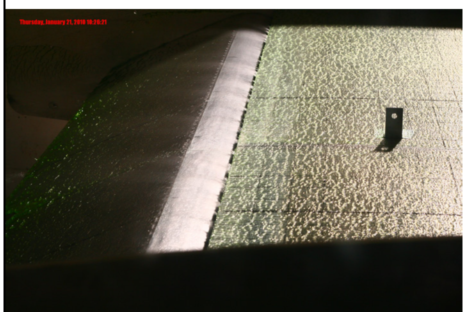
Test #29

Launch, Fluid Only

-5°C, 8° Rotation

Visual Contamination Rating (1,1,1)

Before Rotation



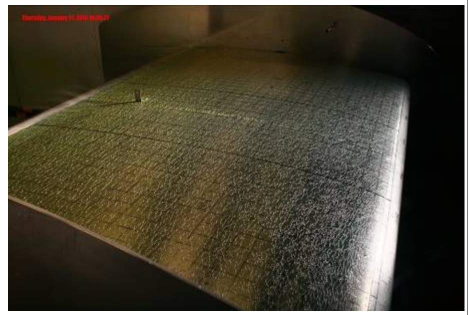


Photo 10.28: Test #57 – Before Rotation

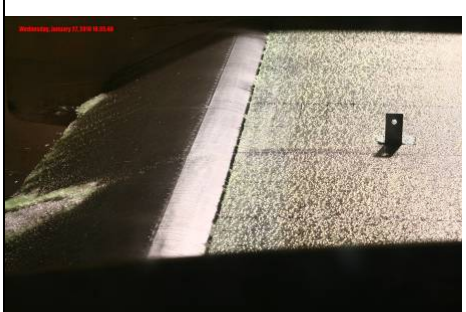
Test #57

Launch, IP- + SN- 25 + 10 g/dm²/h, 40 min

-4°C, 8° Rotation

Visual Contamination Rating (1,1.7,2.8)

Before Rotation



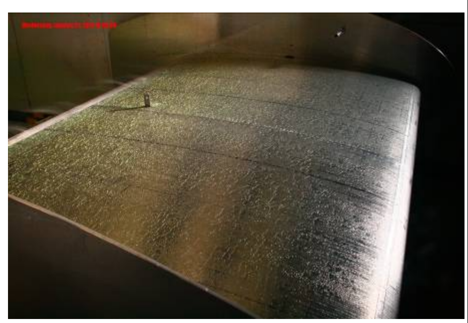


Photo 10.29: Test #29 – End of Rotation

Test #29

Launch, Fluid Only

-5°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 4.96%

End of Rotation

Photo 10.30: Test #57 – End of Rotation

Test #57

Launch, IP- + SN- 25 + 10 g/dm²/h, 40 min

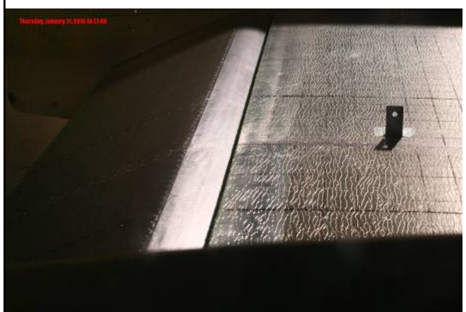
-4°C, 8° Rotation

Visual Contamination Rating (1,1.7,2.8), 8° Lift Loss = 4.72%

End of Rotation

Photo 10.31: Test #29 – End of Test

Test #29
Launch, Fluid Only
-5°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test



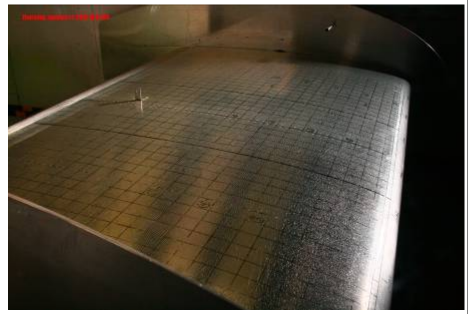
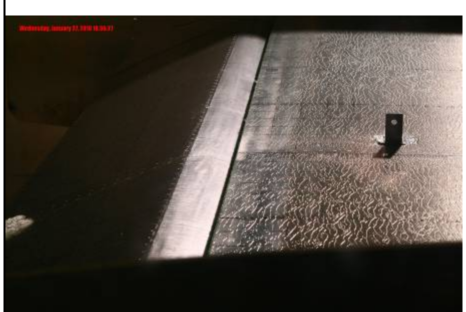


Photo 10.32: Test #57 – End of Test

Test #57
Launch, IP- + SN- 25 + 10 g/dm²/h, 40 min
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1.3)
End of Test



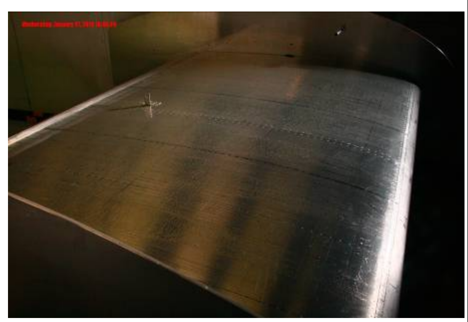
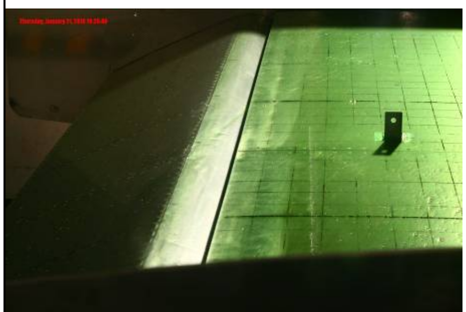


Photo 10.33: Test #29 – Start of Test

Test #29
Launch, Fluid Only
-5°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test



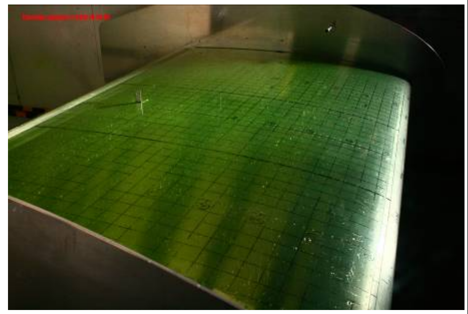
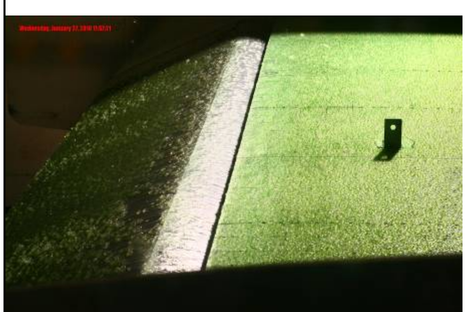


Photo 10.34: Test #57A – Start of Test

Test #57A
Launch, IP- + SN- 25 + 10 g/dm²/h, 40 min
-4°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (2.6,2.6,3)
Start of Test



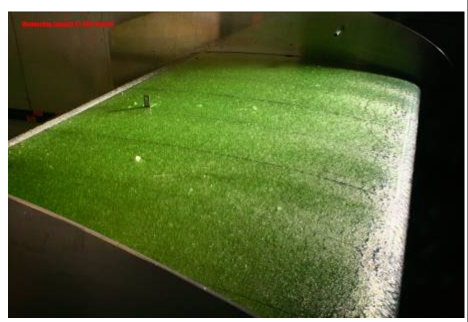


Photo 10.35: Test #29 – Before Rotation

Test #29
Launch, Fluid Only
-5°C, 8° Rotation
Visual Contamination Rating (1,1,1)

Before Rotation

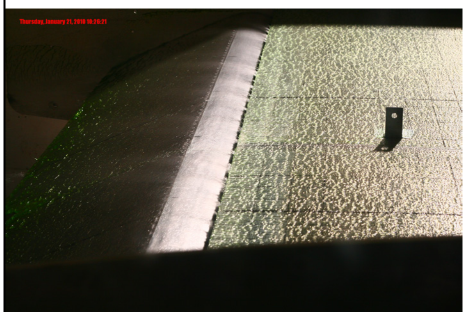
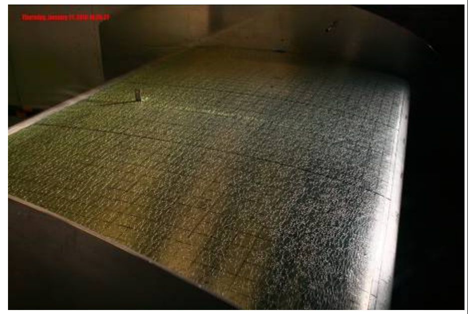



Photo 10.36: Test #57A – Before Rotation

Test #57A
Launch, IP- + SN- 25 + 10 g/dm²/h, 40 min
-4°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1,1.3,1.7)

Before Rotation

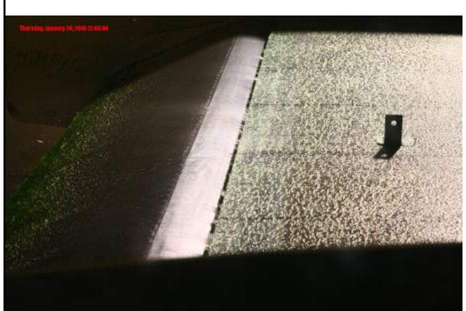
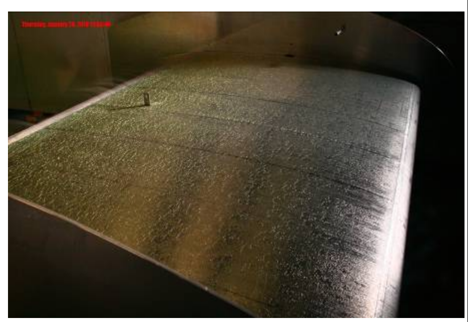



Photo 10.37: Test #29 – End of Rotation

Test #29
Launch, Fluid Only
-5°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 4.96%

End of Rotation

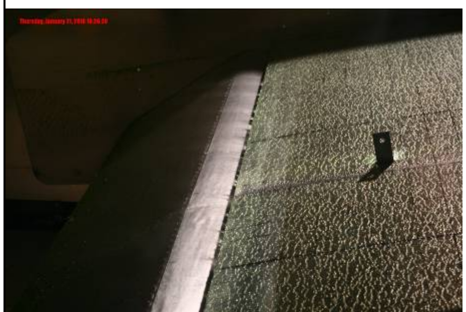
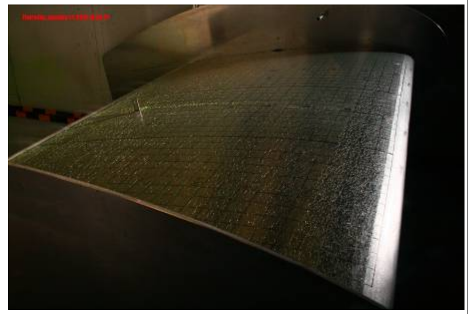



Photo 10.38: Test #57A – End of Rotation

Test #57A
Launch, IP- + SN- 25 + 10 g/dm²/h, 40 min
-4°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1,1.3,1.7), 8° Lift Loss = 2.92%

End of Rotation

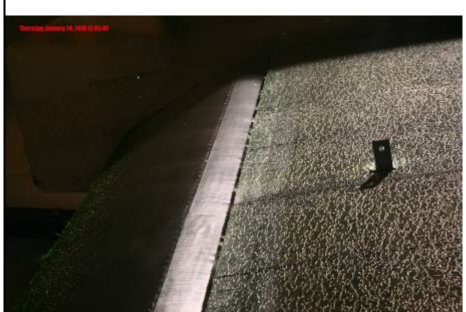
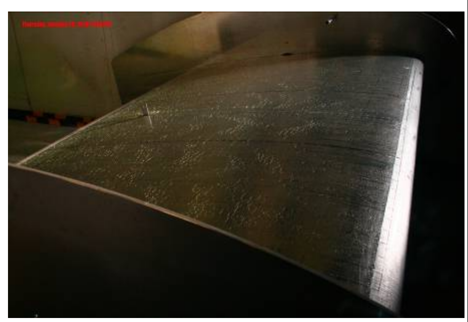



Photo 10.39: Test #29 – End of Test

Test #29

Launch, Fluid Only

-5°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test

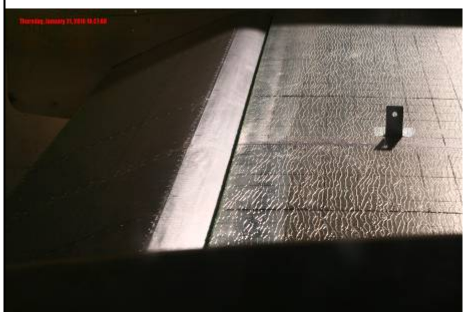
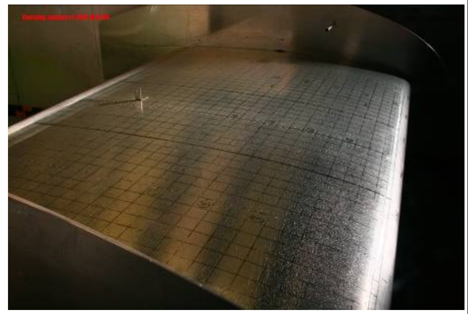



Photo 10.40: Test #57A – End of Test

Test #57A

Launch, IP- + SN- 25 + 10 g/dm²/h, 40 min

-4°C, 8° Rotation, Flap Angle 0°

Visual Contamination Rating (1,1,1)

End of Test

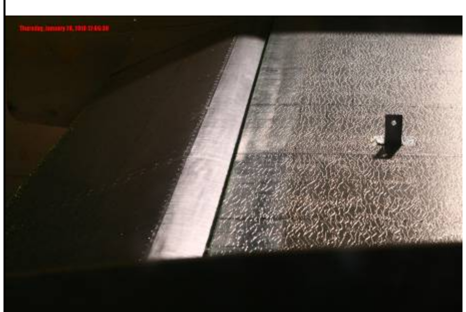
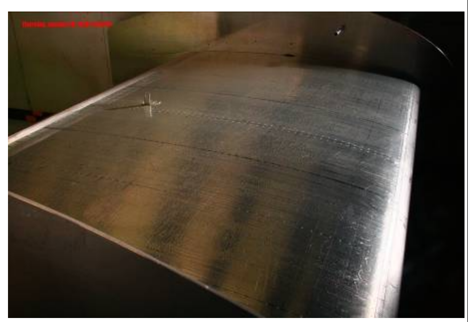



Photo 10.41: Test #64 – Start of Test

Test #64

ABC-S Plus, Fluid Only

-13°C, 8° Rotation

Visual Contamination Rating (1,1,1)

Start of Test

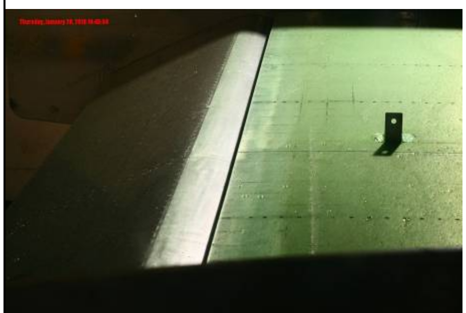


Photo 10.42: Test #77 – Start of Test

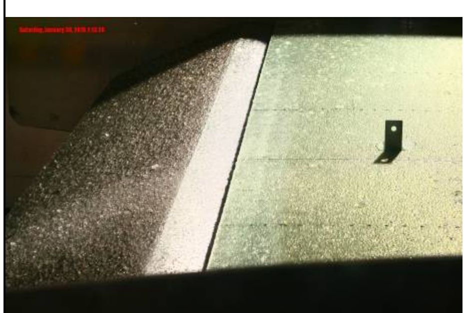
Test #77

ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 10 min

-14°C, 8° Rotation

Visual Contamination Rating (2.8,2.7,3.7)

Start of Test



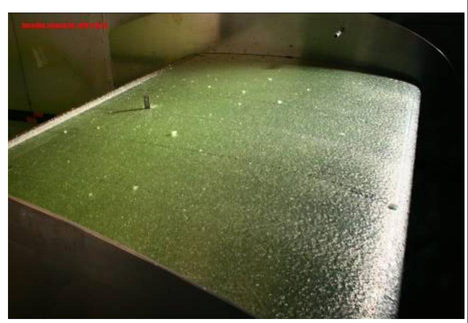


Photo 10.43: Test #64 – Before Rotation

Test #64
ABC-S Plus, Fluid Only
-13°C, 8° Rotation
Visual Contamination Rating (1,1,1)

Before Rotation

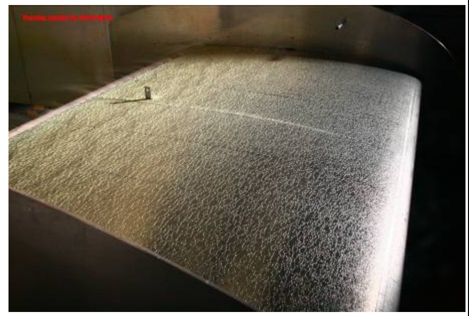


Photo 10.44: Test #77 – Before Rotation

Test #77
ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 10 min
-14°C, 8° Rotation
Visual Contamination Rating (1.7,2,2.8)

Before Rotation

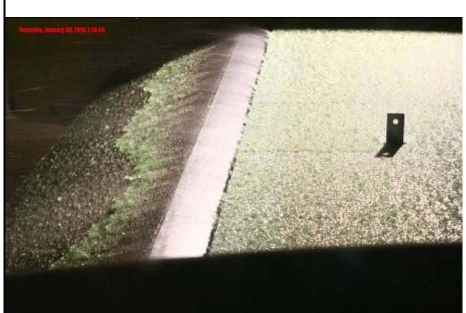
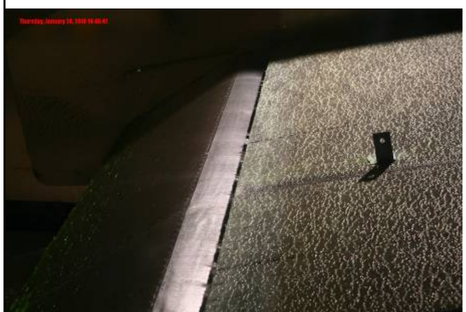


Photo 10.45: Test #64 – End of Rotation

Test #64
ABC-S Plus, Fluid Only
-13°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.07%

End of Rotation



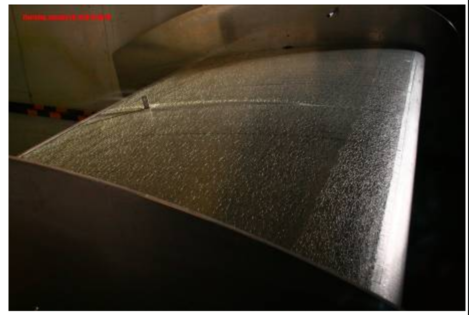


Photo 10.46: Test #77 – End of Rotation

Test #77
ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 10 min
-14°C, 8° Rotation
Visual Contamination Rating (1.7,2,2.8), 8° Lift Loss = 9.89%

End of Rotation

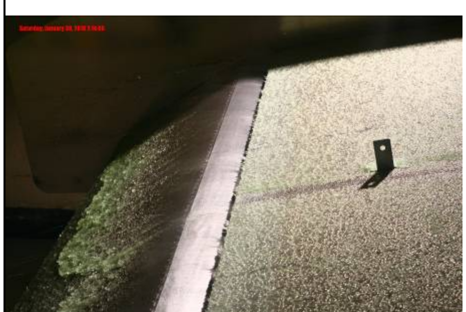


Photo 10.47: Test #64 – End of Test

Test #64

ABC-S Plus, Fluid Only

-13°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test

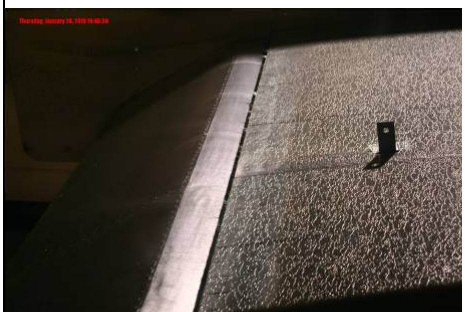


Photo 10.48: Test #77 – End of Test

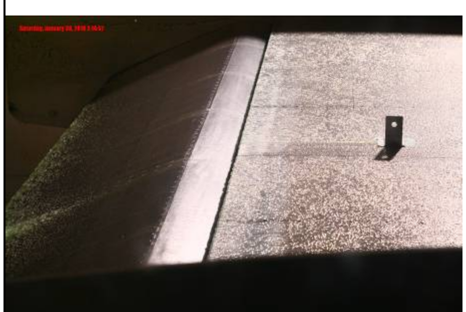
Test #77

ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 10 min

-14°C, 8° Rotation

Visual Contamination Rating (1,1.7,1.5)

End of Test



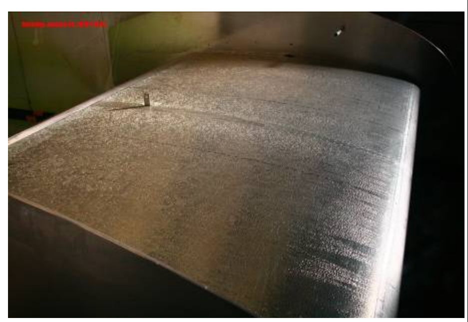
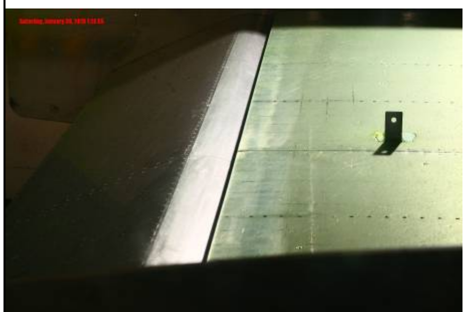


Photo 10.49: Test #76 – Start of Test

Test #76
ABC-S Plus, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test



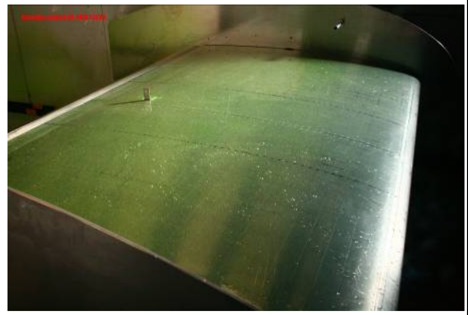
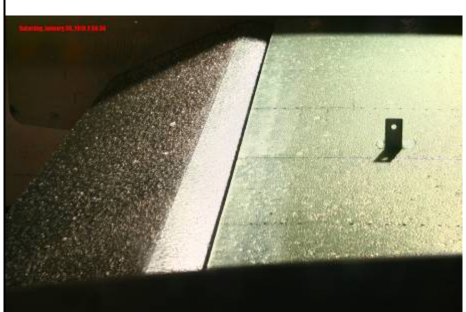


Photo 10.50: Test #78 – Start of Test

Test #78
ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 5 min
-16°C, 8° Rotation
Visual Contamination Rating (2.3,2.2,3)
Start of Test



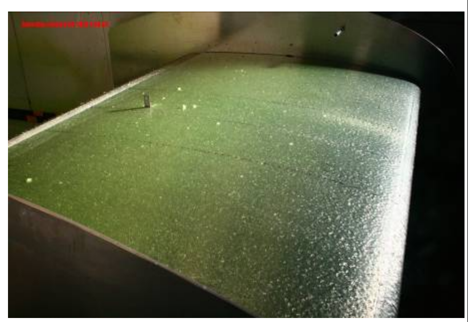


Photo 10.51: Test #76 – Before Rotation

Test #76
ABC-S Plus, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

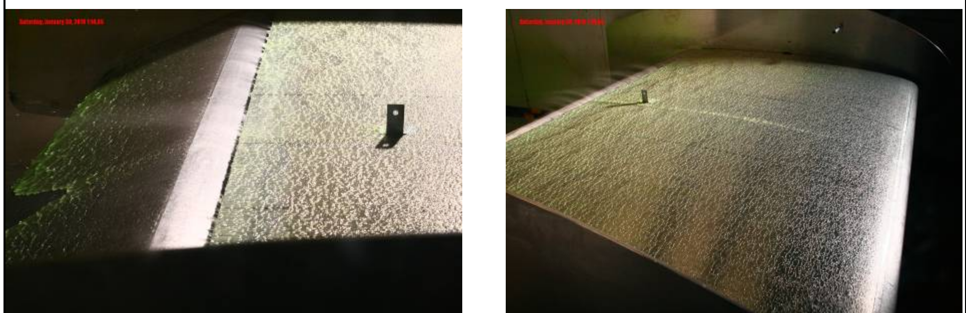
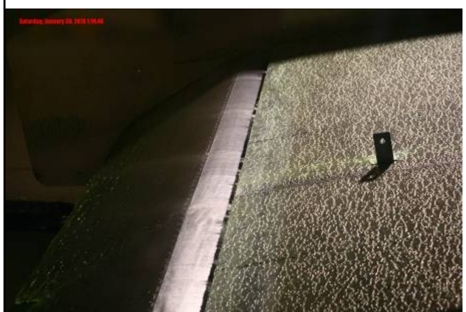


Photo 10.52: Test #78 – Before Rotation

Test #78
ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 5 min
-16°C, 8° Rotation
Visual Contamination Rating (1.4,2,2.7)
Before Rotation

Photo 10.53: Test #76 – End of Rotation

Test #76
ABC-S Plus, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.89%
End of Rotation



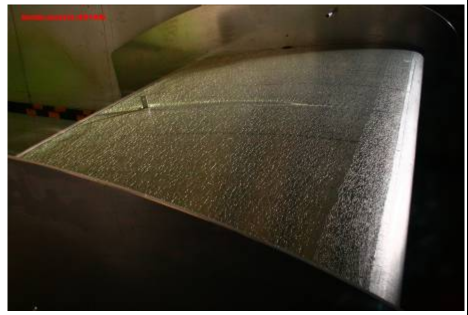


Photo 10.54: Test #78 – End of Rotation

Test #78
ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 5 min
-16°C, 8° Rotation
Visual Contamination Rating (1.4,2,2.7), 8° Lift Loss = 8.62%
End of Rotation

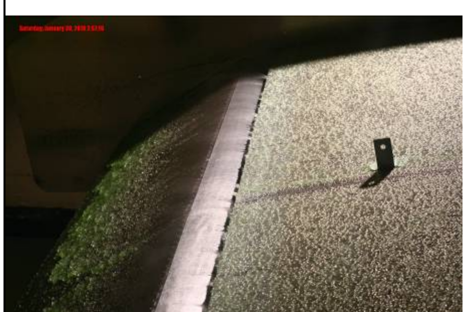


Photo 10.55: Test #76 – End of Test

Test #76
ABC-S Plus, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

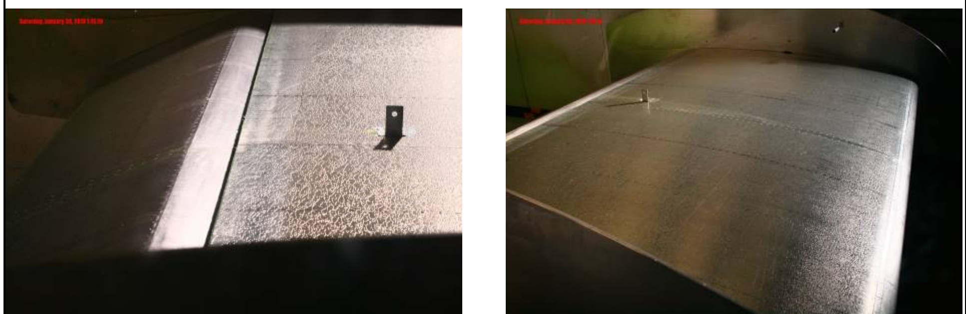


Photo 10.56: Test #78 – End of Test

Test #78
ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 5 min
-16°C, 8° Rotation
Visual Contamination Rating (1,1.2,1.5)
End of Test

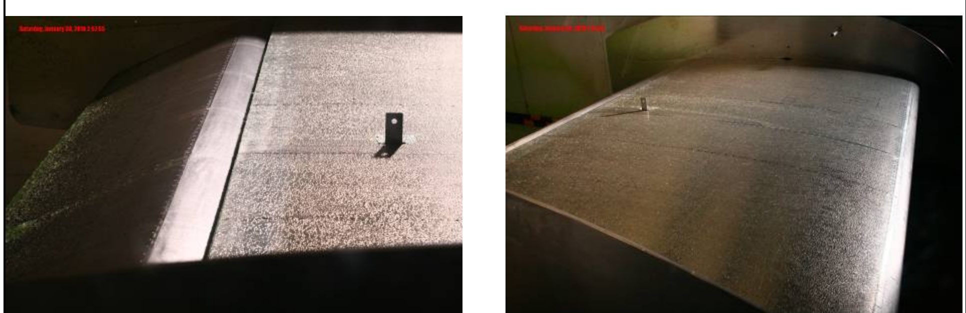
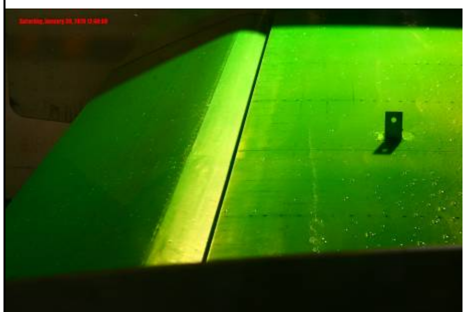


Photo 10.57: Test #75 – Start of Test

Test #75
EG106, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)

Start of Test



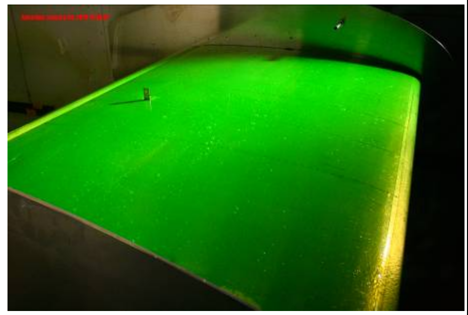
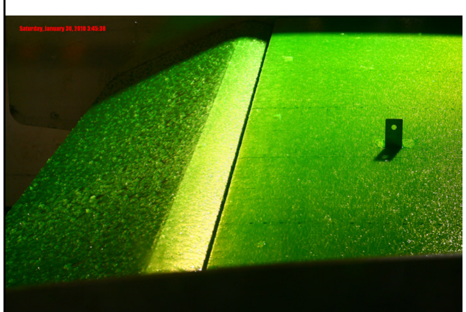


Photo 10.58: Test #79 – Start of Test

Test #79
EG106, IP- + SN- 25 + 10 g/dm²/h, 10 min
-15°C, 8° Rotation
Visual Contamination Rating (2.2,2,2.5)

Start of Test



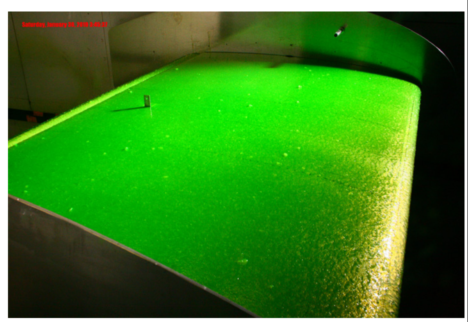


Photo 10.59: Test #75 – Before Rotation

Test #75
EG106, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

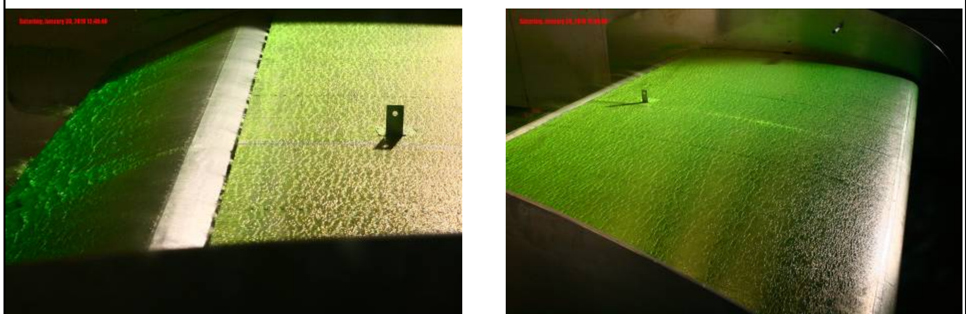


Photo 10.60: Test #79 – Before Rotation

Test #79
EG106, IP- + SN- 25 + 10 g/dm²/h, 10 min
-15°C, 8° Rotation
Visual Contamination Rating (1,1.5,2)
Before Rotation

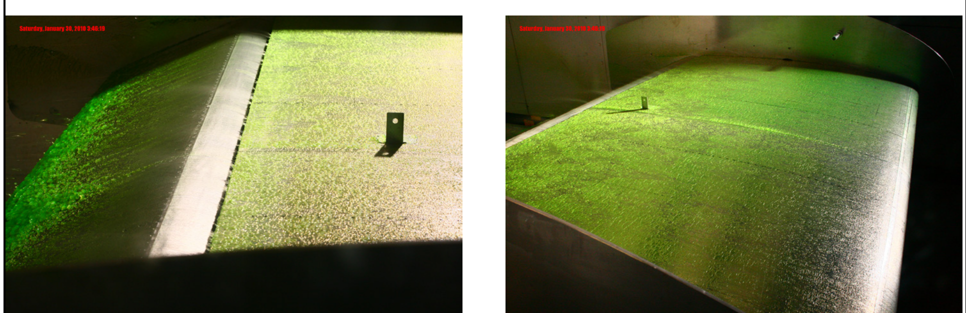


Photo 10.61: Test #75 – End of Rotation

Test #75

EG106, Fluid Only

-18°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 4.08%

End of Rotation

Photo 10.62: Test #79 – End of Rotation

Test #79

EG106, IP- + SN- 25 + 10 g/dm²/h, 10 min

-15°C, 8° Rotation

Visual Contamination Rating (1,1.5,2), 8° Lift Loss = 3.56%

End of Rotation

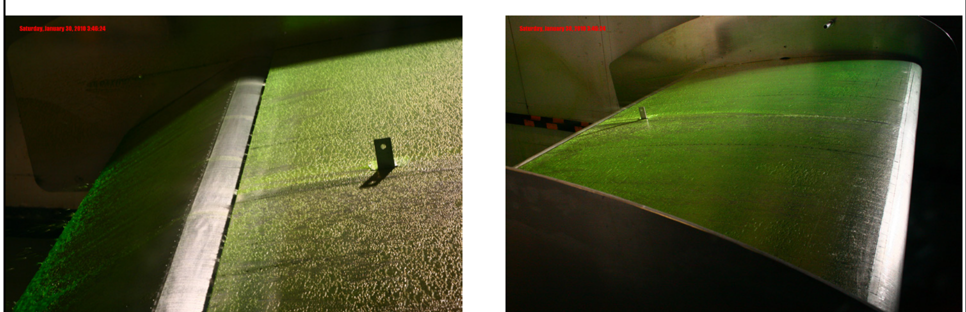


Photo 10.63: Test #75 – End of Test

Test #75
EG106, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

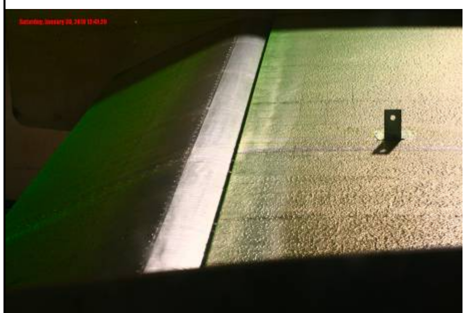
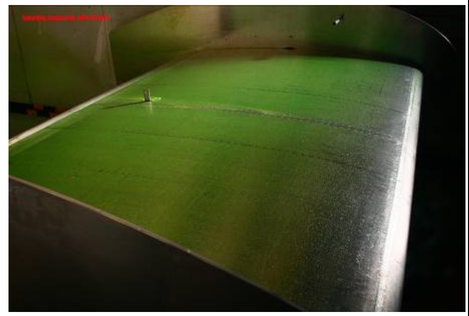



Photo 10.64: Test #79 – End of Test

Test #79
EG106, IP- + SN- 25 + 10 g/dm²/h, 10 min
-15°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

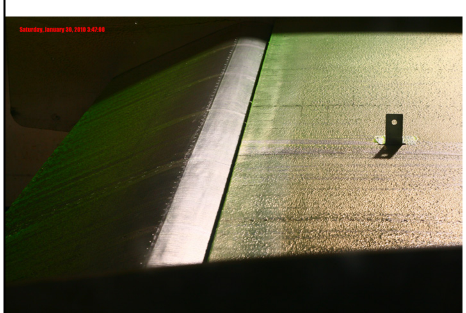
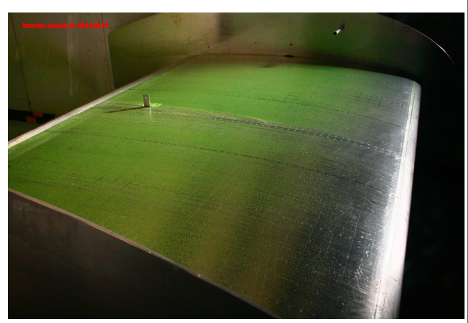



Photo 10.65: Test #1 – Start of Test

Test #1
ABC-S Plus, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

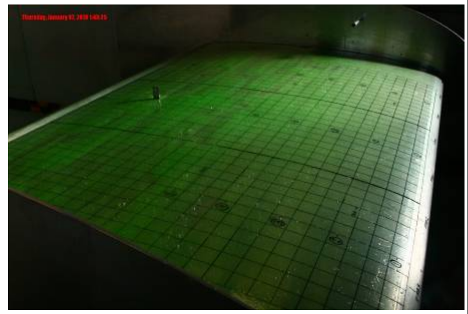
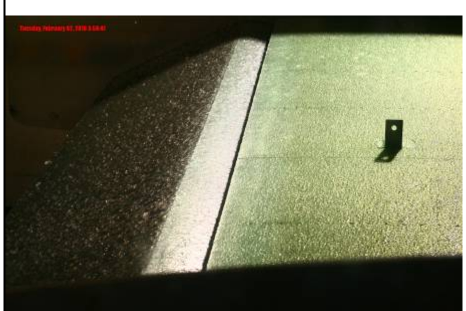


Photo 10.66: Test #94 – Start of Test

Test #94
ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 15 min
-6°C, 8° Rotation
Visual Contamination Rating (2.5,2,2.8)
Start of Test



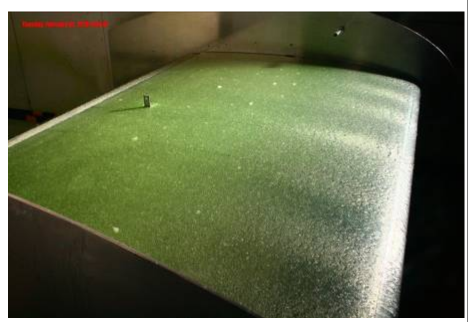
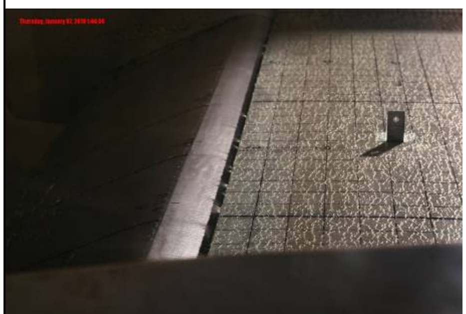


Photo 10.67: Test #1 – Before Rotation

Test #1
ABC-S Plus, Fluid Only
-6°C, 8° Rotation
Visual Contamination Rating (1,1,1)

Before Rotation



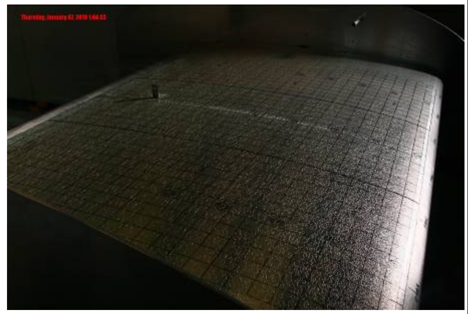
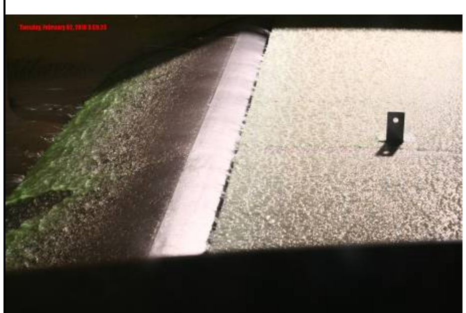


Photo 10.68: Test #94 – Before Rotation

Test #94
ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 15 min
-6°C, 8° Rotation
Visual Contamination Rating (1,1.8,2)

Before Rotation



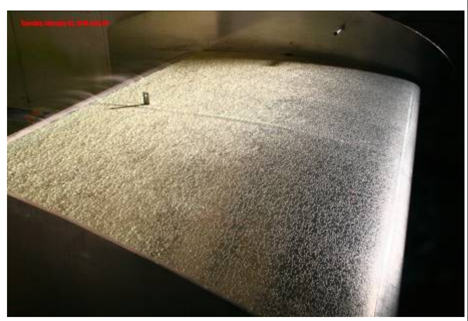


Photo 10.69: Test #1 – End of Rotation

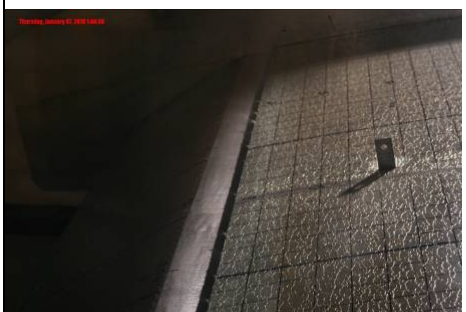
Test #1

ABC-S Plus, Fluid Only

-6°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.01%

End of Rotation



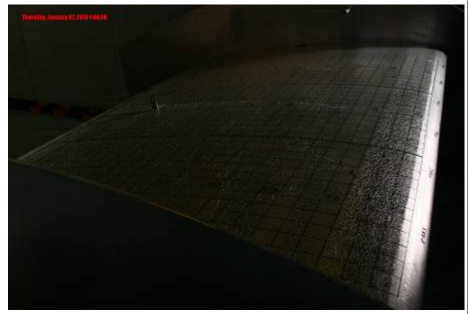


Photo 10.70: Test #94 – End of Rotation

Test #94

ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 15 min

-6°C, 8° Rotation

Visual Contamination Rating (1,1.8,2), 8° Lift Loss = 5.54%

End of Rotation

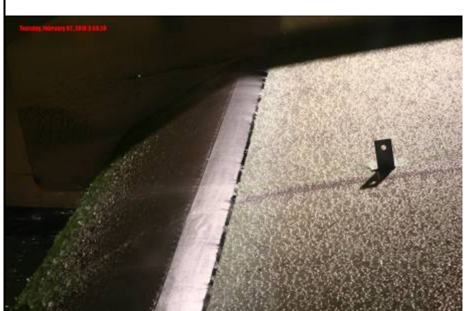


Photo 10.71: Test #1 – End of Test

Test #1

ABC-S Plus, Fluid Only

-6°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test

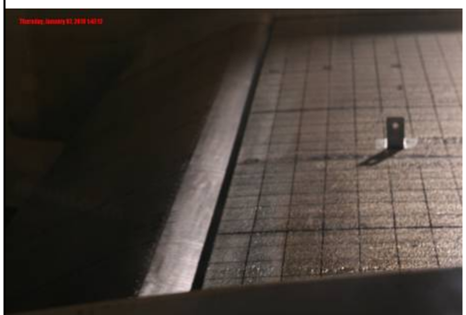


Photo 10.72: Test #94 – End of Test

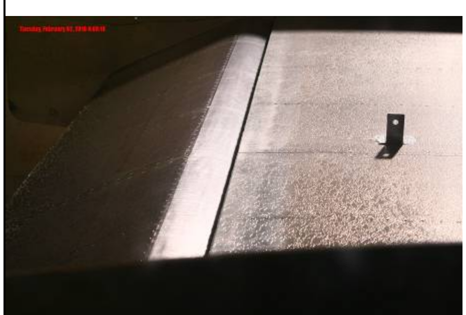
Test #94

ABC-S Plus, IP- + SN- 25 + 10 g/dm²/h, 15 min

-6°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test



11. LIGHT ICE PELLETS MIXED WITH MODERATE SNOW ALLOWANCE TIMES

Aerodynamic testing was conducted to validate and further develop the Type IV high-speed ice pellet allowance times in the NRC wind tunnel. Previous testing in 2006-07 and 2008-09 consisted of wind tunnel tests and Falcon 20 aircraft tests to develop allowance times for mixed conditions with ice pellets. Due to the limitations of the data, some extrapolation of the results was required in order to develop a comprehensive table. It was recommended that testing be conducted at the most critical limits of the allowance times to validate the current guidance material for use with newer generation aircraft operating with supercritical wings. Additional testing was also required to provide guidance material where data was limited or non-existent. The results of this testing have been separated by test condition, and the details can be found in the following sections:

- Section 6: Light Ice Pellets;
- Section 7: Moderate Ice Pellets;
- Section 8: Light Ice Pellets and Light Freezing Rain;
- Section 9: Light Ice Pellets and Moderate Rain;
- Section 10: Light Ice Pellets and Light Snow; and
- Section 11: Light Ice Pellets and Moderate Snow.

This section provides an overview of each test conducted to substantiate and further develop the current high-speed allowance times for Type IV fluids in Light Ice Pellet Mixed with Moderate Snow conditions. Testing was conducted in simulated precipitation conditions. The parameters for each test are detailed, and a description of the data collected during each test is provided.

11.1 Overview of Tests

A summary of the Light Ice Pellet Mixed with Moderate Snow tests conducted in the wind tunnel is shown in Table 11.1. The table provides relevant information for each of the tests, as well as 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 wind tunnel is provided in Subsection 4.1. A brief description of the column headings for Table 11.1 is provided in Subsection 6.1.

Table 11.1: Summary of 2009-10 Light Ice Pellets Mixed with Moderate Snow Testing

Test No.	Date	Fluid	Associated Baseline Test	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Flap Angle (°)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° During Rotation	8° Lift Loss (%)
13	14-Jan-10	ABC-S Plus	17	IP-/SN	25/25	20	-4.6	-7.9	20	3, 2, 3.5	1, 1.8, 2.7	1.617	6.1
14	14-Jan-10	ABC-S Plus	17	IP-/SN	25/25	15	-4.4	-8.1	20	2.2, 2, 2.8	1, 1.5, 1.5	1.626	5.5
15	14-Jan-10	ABC-S Plus	17	IP-/SN	25/25	10	-4.3	-5.8	20	1.8, 2, 2.7	1, 1.3, 1.7	1.633	5.1
16	14-Jan-10	ABC-S Plus	17	IP-/SN	25/25	5	-4.2	-4.7	20	1.4, 1.7, 1.8	1, 1, 1.3	1.622	5.8
24	21-Jan-10	EG106	25	IP-/SN	25/25	20	-3.7	N/A	20	2.5, 1.8, 4	1, 1.2, 1	1.699	1.3
58	28-Jan-10	LAUNCH	60	IP-/SN	25/25	20	-3.1	-6.8	0	2.8, 2.6, 3	1, 1.5, 2	1.638	4.8
81	30-Jan-10	EG106	75	IP-/SN	25/25	5	-17.3	-17.1	20	1.8, 2, 2.3	1, 1.5, 2	1.656	3.8
82	30-Jan-10	ABC-S Plus	76	IP-/SN	25/25	5	-15.8	-16.0	20	2.5, 2.2, 3.2	1.5, 1.5, 1.8	1.563	9.2
97	2-Feb-10	ABC-S Plus	64	IP-/SN	25/25	10	-8.3	-10.1	20	2.9, 2.3, 3	1.3, 1.8, 2.5	1.590	7.6
17	14-Jan-10	ABC-S Plus	N/A	Fluid Only	N/A	N/A	-3.9	-4.4	20	1, 1, 1	1, 1, 1	1.636	5.0
25	4-Feb-10	EG106	N/A	Fluid Only	N/A	N/A	-4	-3.4	20	1, 1, 1	1, 1, 1	1.687	1.99
60	28-Jan-10	Launch	N/A	Fluid Only	N/A	N/A	-2.8	-1.9	20	1, 1, 1	1, 1, 1	1.642	4.61
64	6-Feb-10	ABC-S Plus	N/A	Fluid Only	N/A	N/A	-13.4	-11.3	20	1, 1, 1	1, 1, 1	1.634	5.07
75	30-Jan-10	EG106	N/A	Fluid Only	N/A	N/A	-18.1	-16.9	20	1, 1, 1	1, 1, 1	1.651	4.08
76	30-Jan-10	ABC-S Plus	N/A	Fluid Only	N/A	N/A	-17.9	-17.3	20	1, 1, 1	1, 1, 1	1.62	5.89

11.2 Data Collected

11.2.1 Fluid Thickness Data

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

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

Tables 11.2 to 11.10 show the fluid thickness measurements collected during the contaminated fluid tests. The associated baseline fluid only cases are also shown in Tables 11.11 to 11.16 for comparison purposes.

Table 11.2: Test #13 Fluid Thickness Data

Test 13: ABC-S Plus, IP-/SN, Tunnel OAT - 4.6°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.7	1.8	0.0
2	2.2	3.3	0.1
3	3.3	3.5	0.2
4	4.5	4.5	0.1
5	4.5	5.7	0.1
6	4.5	5.7	0.1
7	3.3	5.7	0.1
8	3.3	3.5	0.1
Flap	1.0	slush	0.2

Table 11.3: Test #14 Fluid Thickness Data

Test 14: ABC-S Plus, IP-/SN, Tunnel OAT -4.4°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.8	1.5	0.0
2	2.5	2.5	0.1
3	3.1	3.5	0.3
4	4.5	4.5	0.2
5	4.5	5.7	0.2
6	3.9	5.7	0.2
7	3.1	4.5	0.2
8	3.1	3.5	0.2
Flap	1.1	slush	0.2

Table 11.4: Test #15 Fluid Thickness Data

Test 15: ABC-S Plus, IP-/SN, Tunnel OAT-4.3°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.6	1.7	0.1
2	2.2	2.5	0.1
3	2.9	3.1	0.2
4	3.3	3.5	0.2
5	3.5	3.9	0.2
6	3.9	4.5	0.2
7	4.5	4.5	0.2
8	3.3	3.7	0.2
Flap	1.0	1.7	0.2

Table 11.5: Test #16 Fluid Thickness Data

Test 16: ABC-S Plus, IP-/SN, Tunnel OAT -4.2°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.6	N/A	0.1
2	2.2	2.7	0.2
3	2.9	N/A	0.2
4	3.1	N/A	0.2
5	3.5	3.7	0.2
6	3.9	4.5	0.2
7	4.5	N/A	0.1
8	3.5	3.5	0.2
Flap	1.1	N/A	0.2

Table 11.6: Test #24 Fluid Thickness Data

Test 24: EG106, IP-/SN, Tunnel OAT -3.7°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.8	0.3	0.0
2	2.9	3.3	0.0
3	2.9	3.9	0.0
4	3.1	4.5	0.0
5	3.9	4.5	0.1
6	3.7	4.5	0.0
7	3.5	4.5	0.0
8	3.1	3.3	0.0
Flap	1.2	0.6	0.1

Table 11.7: Test #58 Fluid Thickness Data

Test 58: Launch, IP-/SN, Tunnel OAT - 3.1°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.6	2.2	0.1
2	2.2	2.7	0.1
3	2.5	3.3	0.2
4	2.9	3.5	0.2
5	3.3	4.5	0.2
6	3.1	4.5	0.1
7	3.1	4.5	0.2
8	2.5	3.7	0.2
Flap	3.1	5.7	0.2

Table 11.8: Test #81 Fluid Thickness Data

Test 81: EG106, IP-/SN, Tunnel OAT -17.3°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	2.5	2.2	0.0
2	3.5	2.9	0.1
3	3.5	4.5	0.2
4	4.5	4.5	0.2
5	4.5	4.5	0.1
6	4.5	5.7	0.2
7	4.5	4.5	0.2
8	3.9	4.5	0.2
Flap	1.3	slush	0.1

Table 11.9: Test #82 Fluid Thickness Data

Test 82: ABC-S Plus, IP-/SN, Tunnel OAT -15.8°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.5	1.5	0.0
2	1.7	1.7	0.1
3	1.8	1.8	0.1
4	2.2	2.2	0.2
5	2.2	2.2	0.2
6	2.2	2.2	0.3
7	1.7	1.7	0.4
8	1.6	1.7	0.5
Flap	0.5	slush	0.2

Table 11.10: Test #97 Fluid Thickness Data

Test 97: ABC-S Plus, IP-/SN, Tunnel OAT -8.3°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.7	1.7	0.1
2	2.2	2.2	0.1
3	3.1	2.9	0.1
4	3.3	3.7	0.1
5	3.3	3.9	0.1
6	3.3	3.9	0.2
7	3.3	3.9	0.2
8	2.7	3.1	0.3
Flap	1.0	N/A	0.2

Table 11.11: Test #17 (Baseline) Fluid Thickness Data

Test 17: ABC-S Plus, Fluid-only, Tunnel OAT -3.9°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.5	N/A	0.0
2	2.2	N/A	0.2
3	2.7	N/A	0.2
4	3.3	N/A	0.2
5	3.5	N/A	0.2
6	3.9	N/A	0.2
7	3.9	N/A	0.2
8	3.5	N/A	0.2
Flap	1.0	N/A	0.2

Table 11.12: Test #25 (Baseline) Fluid Thickness Data

Test 25: EG106, Fluid-only, Tunnel OAT -4.0°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	2.2	N/A	0.0
2	3.1	N/A	0.1
3	3.7	N/A	0.1
4	4.5	N/A	0.2
5	4.5	N/A	0.2
6	4.5	N/A	0.1
7	4.5	N/A	0.1
8	3.5	N/A	0.1
Flap	N/A	N/A	0.1

Table 11.13: Test #60 (Baseline) Fluid Thickness Data

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

Table 11.14: Test #64 (Baseline) Fluid Thickness Data

Test 64: ABC-S Plus, Fluid-only, Tunnel OAT -13.4°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.2	N/A	0.0
2	2.2	N/A	0.1
3	1.7	N/A	0.1
4	1.8	N/A	0.1
5	3.1	N/A	0.2
6	3.1	N/A	0.2
7	3.1	N/A	0.2
8	2.7	N/A	0.2
Flap	0.8	N/A	0.2

Table 11.15: Test #75 (Baseline) Fluid Thickness Data

Test 75: EG106, Fluid-only, Tunnel OAT -18.1°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	2.2	N/A	0.1
2	2.9	N/A	0.2
3	3.1	N/A	0.2
4	3.7	N/A	0.1
5	4.5	N/A	0.1
6	4.5	N/A	0.1
7	4.5	N/A	0.1
8	2.2	N/A	0.2
Flap	0.2	N/A	0.2

Table 11.16: Test #76 (Baseline) Fluid Thickness Data

Test 76: ABC-S Plus, Fluid-only, Tunnel OAT -17.9°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.3	N/A	0.1
2	1.6	N/A	0.1
3	1.8	N/A	0.1
4	2.2	N/A	0.1
5	2.2	N/A	0.2
6	2.2	N/A	0.2
7	1.8	N/A	0.2
8	1.6	N/A	0.2
Flap	0.5	N/A	0.2

11.2.2 Skin Temperature Data

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

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

Tables 11.17 to 11.25 show the wing temperature measurements recorded during the contaminated fluid tests. The associated baseline fluid only cases are also shown in Tables 11.26 to 11.31 for comparison purposes.

Table 11.17: Test #13 Wing Skin Temperature Data

Test 13: ABC-S Plus, IP-/SN, Tunnel OAT - 4.6°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-5.7	-3.3	-10.2	-5.1
T5	-5.8	-3.9	-8.7	-4.5
TU	-3.0	-3.5	-4.8	-5.8

Table 11.18: Test #14 Wing Skin Temperature Data

Test 14: ABC-S Plus, IP-/SN, Tunnel OAT -4.4°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-4.2	-5.2	-10.9	-3.7
T5	-3.7	-5.7	-8.2	-2.8
TU	-5.0	-5.1	-5.3	-5.0

Table 11.19: Test #15 Wing Skin Temperature Data

Test 15: ABC-S Plus, IP-/SN, Tunnel OAT-4.3°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.6	-3.9	-7.7	-4.0
T5	-2.7	-4.1	-5.1	-3.2
TU	-4.7	-4.7	-4.6	-5.5

Table 11.20: Test #16 Wing Skin Temperature Data

Test 16: ABC-S Plus, IP-/SN, Tunnel OAT -4.2°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.9	-4.7	-4.5	-3.4
T5	-3.1	-4.9	-4.6	-3.0
TU	-5.3	-5.2	-5.1	-4.7

Table 11.21: Test #24 Wing Skin Temperature Data

Test 24: EG106, IP-/SN, Tunnel OAT -3.7°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.6	N/A	-7.3	-3.4
T5	-3.4	N/A	-9.7	-2.6
TU	-4.2	N/A	-5.0	-4.3

Table 11.22: Test #58 Wing Skin Temperature Data

Test 58: Launch, IP-/SN, Tunnel OAT - 3.1°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-4.0	-3.3	-8.7	-4.8
T5	-3.5	-3.4	-8.2	-3.9
TU	-4.7	-4.1	-3.5	-2.0

Table 11.23: Test #81 Wing Skin Temperature Data

Test 81: EG106, IP-/SN, Tunnel OAT -17.3°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-16.3	-16.9	-16.8	-19.4
T5	-15.2	-16.6	-16.4	-18.9
TU	-18	-18.4	-18.1	-20.1

Table 11.24: Test #82 Wing Skin Temperature Data

Test 82: ABC-S Plus, IP-/SN, Tunnel OAT -15.8°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-16.5	-17.6	-16.5	-15.8
T5	-16.0	-17.5	-15.1	-15.2
TU	-18.4	-18.2	-16.4	-15.9

Table 11.25: Test #97 Wing Skin Temperature Data

Test 97: ABC-S Plus, IP-/SN, Tunnel OAT -8.3°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-9.2	-9.4	-11.6	-9.9
T5	-8.3	-9.4	-10.1	-9.0
TU	-9.9	-9.3	-8.6	-10.5

Table 11.26: Test #17 (Baseline) Wing Skin Temperature Data

Test 17: ABC-S Plus, Fluid-only, Tunnel OAT -3.9°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.4	-4.0	N/A	-4.8
T5	-3.0	-4.5	N/A	-3.2
TU	-4.7	-4.7	N/A	-4.8

Table 11.27: Test #25 (Baseline) Wing Skin Temperature Data

Test 25: EG106, Fluid-only, Tunnel OAT -4.0°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.6	-3.0	N/A	-3.4
T5	-3.0	-3.1	N/A	-3.2
TU	-4.4	-4.2	N/A	-3.9

Table 11.28: Test #60 (Baseline) Wing Skin Temperature Data

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

Table 11.29: Test #64 (Baseline) Wing Skin Temperature Data

Test 64: ABC-S Plus, Fluid-only, Tunnel OAT -13.4°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-11.8	-10.8	N/A	-12.2
T5	-11.9	-10.8	N/A	-12.1
TU	-12.3	-12.4	N/A	-12.4

Table 11.30: Test #75 (Baseline) Wing Skin Temperature Data

Test 75: EG106, Fluid-only, Tunnel OAT -18.1°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-16.2	-16.5	N/A	-16.4
T5	-15.8	-16.4	N/A	-15.6
TU	-17.9	-17.7	N/A	-18.4

Table 11.31: Test #76 (Baseline) Wing Skin Temperature Data

Test 76: ABC-S Plus, Fluid-only, Tunnel OAT -17.9°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-16.4	-17.1	N/A	-16.9
T5	-16.2	-17.0	N/A	-16.1
TU	-18.1	-17.8	N/A	-18.9

11.2.3 Fluid Brix Data

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

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

Tables 11.32 to 11.40 show the fluid Brix measurements collected during the contaminated fluid tests. The associated baseline fluid only cases are also shown in Tables 11.41 to 11.46 for comparison purposes.

Table 11.32: Test #13 Fluid Brix Data

Test 13: ABC-S Plus, IP-/SN, Tunnel OAT - 4.6°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.50	18.25	23.25
8	36.25	18.50	19.00

Table 11.33: Test #14 Fluid Brix Data

Test 14: ABC-S Plus, IP-/SN, Tunnel OAT -4.4°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.75	18.50	21.25
8	36.75	24.50	24.00

Table 11.34: Test #15 Fluid Brix Data

Test 15: ABC-S Plus, IP-/SN, Tunnel OAT-4.3°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.50	19.50	23.00
8	36.50	23.50	28.00

Table 11.35: Test #16 Fluid Brix Data

Test 16: ABC-S Plus, IP-/SN, Tunnel OAT -4.2°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.75	27.00	32.25
8	36.50	34.00	33.75

Table 11.36: Test #25 Fluid Brix Data

Test 25: EG106, Fluid-only, Tunnel OAT -4.0°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.00	N/A	31.50
8	32.25	N/A	32.50

Table 11.37: Test #64 Fluid Brix Data

Test 64: ABC-S Plus, Fluid-only, Tunnel OAT -13.4°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.75	N/A	38.50
8	37.50	N/A	38.00

Table 11.38: Test #60 Fluid Brix Data

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

Table 11.39: Test #75 Fluid Brix Data

Test 75: EG106, Fluid-only, Tunnel OAT -18.1°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.25	N/A	34.00
8	32.25	N/A	34.00

Table 11.40: Test #76 Fluid Brix Data

Test 76: ABC-S Plus, Fluid-only, Tunnel OAT -17.9°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.75	N/A	38.25
8	37.00	N/A	37.25

Table 11.41: Test #17 (Baseline) Fluid Brix Data

Test 17: ABC-S Plus, Fluid-only, Tunnel OAT -3.9°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.00	N/A	35.25
8	36.50	N/A	36.50

Table 11.42: Test #25 (Baseline) Fluid Brix Data

Test 25: EG106, Fluid-only, Tunnel OAT -4.0°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.00	N/A	31.50
8	32.25	N/A	32.50

Table 11.43: Test #60 (Baseline) Fluid Brix Data

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

Table 11.44: Test #64 (Baseline) Fluid Brix Data

Test 64: ABC-S Plus, Fluid-only, Tunnel OAT -13.4°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.75	N/A	38.50
8	37.50	N/A	38.00

Table 11.45: Test #75 (Baseline) Fluid Brix Data

Test 75: EG106, Fluid-only, Tunnel OAT -18.1°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.25	N/A	34.00
8	32.25	N/A	34.00

Table 11.46: Test #76 (Baseline) Fluid Brix Data

Test 76: ABC-S Plus, Fluid-only, Tunnel OAT -17.9°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.75	N/A	38.25
8	37.00	N/A	37.25

11.3 Photos

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

- Start of test;
- Before Rotation (just before the wing began to pitch);
- End of Rotation (end of the rotation cycle when the wing position is returned to 4 degrees); and
- End of test.

The photos taken during the Light Ice Pellets Mixed with Moderate Snow testing have been presented along with the fluid only (baseline) tests for comparison purposes. In each case, the fluid only photo is presented first, followed by the contaminated fluid photo. Photos 11.1 to 11.72 show the photo summaries of the tests conducted. A complete set of photos will be provided to the TDC in electronic format.

11.4 Summary of Results

11.4.1 OAT -5°C and Above

One test was conducted in this cell with an exposure time of 10 minutes: Test #15 (see Table 11.49). Several other tests were conducted in this condition with varying exposure times: Tests #13, #14, #16, #24, and #58 (see Table 11.48 for details).

Test #15, conducted with PG fluid at the current allowance time, demonstrated satisfactory results. The temperature during this test was -4.3°C. Visual results were deemed good, passing all the required criteria. The 8° lift loss was slightly above the 5 percent safety criteria, at 5.13 percent (see Table 11.47 and Figure 11.1). Based on the lift loss result, further review is required. The ramp-up time during this run showed a time around the average, at 20 seconds.

Test #24 was conducted using EG fluid and demonstrated very good results. This test was conducted with a 20-minute exposure time, above the current allowance time of 10 minutes. The temperature during this test was -3.7°C. Lift loss and visual contamination ratings passed all required criteria, proving positive results. The 8° lift loss was 1.30 percent, below the 5 percent margin of safety criteria.

Test #16, conducted with PG fluid with an exposure time of 5 minutes, demonstrated satisfactory results. The temperature during this test was -4.2°C. The visual results passed all criteria, and the 8° lift loss was 5.77 percent, above the 5 percent safety criteria. The ramp-up time during this run showed a time of around the average, at 18 seconds; this may explain the slightly higher lift loss in Test #16 compared to Test #15.

Test #14, conducted with PG fluid, also demonstrated satisfactory results. The exposure time during this test was 15 minutes. The temperature was -4.4°C. The satisfactory results were based primarily on the 8° lift loss result of 5.54 percent, which is above the required 5 percent safety criteria. The visual results were good, passing all criteria. This test had a ramp-up time of 22 seconds, which is above the average at 19 seconds.

The two remaining tests, #13 and #58, were conducted with an exposure time of 20 minutes using two different PG fluids. The temperatures were -4.6° and -3.1°C, respectively. Test #13 demonstrated satisfactory results with a lift loss of 6.06 percent, which is slightly above the 5 percent margin of safety criteria. The visual ratings during this test were good, satisfying all criteria. Results from this test indicate a need for further review. Test #58 demonstrated very good results compared to Test #13. This test was conducted with the flap set at 0°. Visual and lift loss (4.84 percent) results passed all required criteria.

In conclusion, the current allowance time of 10 minutes for this cell has been validated and accepted at this time. Results from testing with EG fluid indicate a potential to increase the current allowance time to 20 minutes. Several tests with PG fluid were conducted with varying exposure times. Results indicate a potential to also increase the current allowance time to 20 minutes, but further review is needed for PG fluid.

Table 11.47: Light Ice Pellets Mixed with Moderate Snow Allowance Time Tests Winter 2009-10

	OAT -5°C and Above	OAT Less than -5°C to -10°C	OAT Less than -10°C
Light Ice Pellets Mixed with Moderate Snow	10 minutes **Test # 15**	**Caution: No allowance times currently exist**	

Table 11.48: Summary of Light Ice Pellets Mixed with Moderate Snow Allowance Time Test Results

	OAT -5°C and Above	OAT Less than -5°C to -10°C	OAT Less than -10°C
Light Ice Pellets Mixed with Moderate Snow	**10 minutes** Run 15 (Exposure Time 10 min), -4.3°C ABC-S Plus Visual At Start: GOOD (1.8, 2, 2.7) Visuals At Rotation: GOOD (1, 1.3, 1.7) LL At 100 kts: OK (5.13%) LL At 105 kts: GOOD (4.98%) LL At 115 kts: GOOD (3.80%) LL At 120 kts: GOOD (3.24%) **GOOD At 105 kts** Run 16 (Exposure Time 5 min), -4.2°C ABC-S Plus Visual At Start: GOOD (1.4, 1.7, 1.8) Visuals At Rotation: GOOD (1, 1, 1.3) LL At 100 kts: OK (5.77%) **OK At 100 kts** Run 14 (Exposure Time 15 min), -4.4°C ABC-S Plus Visual At Start: GOOD (2.2, 2, 2.8) Visuals At Rotation: GOOD (1, 1.5, 1.5) LL At 100 kts: OK (5.54%) **OK At 100 kts** Run 13 (Exposure Time 20 min), -4.6°C ABC-S Plus Visual At Start: GOOD (3, 2, 3.5) Visuals At Rotation: GOOD (1, 1.8, 2.7) LL At 100 kts: OK (6.06%) **OK At 100 kts** Run 24 (Exposure Time 20 min), -3.7°C EG106 Visual At Start: GOOD (2.5, 1.8, 4) Visuals At Rotation: GOOD (1, 1.2, 1) LL At 100 kts: OK (1.30%) **GOOD At 100 kts** Run 58 (Exposure Time 20 min), -4.3°C *Flap At 0°* LAUNCH Visual At Start: GOOD (2.8, 2.6, 3) Visuals At Rotation: GOOD (1, 1.5, 2) LL At 100 kts: GOOD (4.84%) **GOOD At 100 kts** ▪ **10 min GOOD for EG Fluid; Potential to Increase to 20 min** ▪ **10 GOOD for PG Fluid; Potential to Increase to 20 min. Further Review Required**	**Caution: No Allowance Time Currently Exists** Run 97 (Exposure Time 10 min), -8.3°C ABC-S Plus Visual At Start: GOOD (2.9, 2.3, 3) Visuals At Rotation: BAD (1.3, 1.8, 2.5) LL At 100 kts: OK (7.63%) **BAD At 100 kts** ▪ **No EG Tests Conducted; Data Needed. Potential of 5 min Based on Test #81** ▪ **No Allowance Time PG Fluid Based on Results; Further Review Required**	**Caution: No Allowance Time Currently Exists** Run 81 (Exposure Time 5 min), -17.3°C EG106 Visual At Start: GOOD (1.8, 2, 2.3) Visuals At Rotation: GOOD (1, 1.5, 2) LL At 100 kts: GOOD (3.79%) **GOOD At 100 kts** Run 82 (Exposure Time 5 min), -15.8°C ABC-S Plus Visual At Start: GOOD (2.5, 2.2, 3.2) Visuals At Rotation: BAD (1.5, 1.5, 1.8) LL At 100 kts: BAD (9.20%) **BAD At 100 kts** ▪ **5 min GOOD for EG Fluid; Could Potentially Expand** ▪ **No Allowance Time for PG Fluid Based on Results; Further Review Required**
	CONCLUSION: ALLOWANCE TIME OF 10 MIN OK, FURTHER REVIEW REQUIRED	**CONCLUSION: NO ALLOWANCE TIME CURRENTLY EXISTS; POTENTIAL ALLOWANCE TIME OF 5 MIN FOR EG FLUID**	**CONCLUSION: NO ALLOWANCE TIME CURRENTLY EXISTS; POTENTIAL ALLOWANCE TIME OF 5 MIN FOR EG FLUID**

11.4.2 OAT Less than -5°C to -10°C

Although no allowance time currently exists in this cell, Test #97 was conducted with a 10-minute exposure time (see Table 11.48 for details).

Test #97, conducted with PG fluid at a temperature of -8.3°C, demonstrated unsatisfactory results based on lift loss data. The 8° lift loss was 7.63 percent, above the 5 percent safety criteria. The LE visual result at the time of rotation was 1.3, slightly above the required criteria of 1. Based on these findings, further review is required. The ramp-up time from 40 knots to rotation for this test run was under the average, at 16 seconds. Should the ramp-up time have been closer to the 19-second average, visual and lift loss results could have potentially been improved.

In conclusion, no allowance time currently exists in this cell at this time. No EG tests were conducted in this cell, but data from Test #81 conducted in the OAT less than -10°C cell show positive results, indicating a potential for an allowance time of 5 minutes for EG fluid. With PG fluid, it may be possible to provide an allowance time of 5 or 10 minutes; however, further testing and review are required.

11.4.3 OAT Less than -10°C

Although no allowance time currently exists in this cell, two tests were conducted with an exposure time of 5 minutes: Tests #81 and #82 (see Table 11.48 for details).

Test #81, conducted with EG fluid, demonstrated very good results. The temperature during this test was -17.3°C. Visual contamination ratings were positive, satisfying all criteria. The 8° lift loss was 3.79 percent, below the 5 percent margin of safety criteria.

Test #82 was conducted using PG fluid at a temperature of -15.8°C and demonstrated poor results. The LE visual contamination results at the time of rotation did not pass the required rating of 1 (rating of 1.5). The lift loss at 8° was 9.20 percent, above the 5 percent criteria.

At this time, no allowance time currently exists in this cell. For EG fluid, results indicate a potential for an allowance time of 5 minutes, but more data is needed. Based on PG fluid results, no allowance time is suitable at this time; however, further review is required.

Table 11.49: Details of Increased Rotation Speed Analysis

Condition	Test #	Speed (Kts)	Lift Loss at 8 Degrees (%)	Visual (%)	Linear (%)	Semi-Log (Time) (%)	Polynomial (2nd Order) (%)
Light Ice Pellets Mixed with Moderate Snow (OAT -5°C and Above)	**15**	100	5.13				
		105		-	4.88	4.98	5.69
		115		4.53	3.56	3.80	5.66
		120		4.33	2.89	3.24	5.84

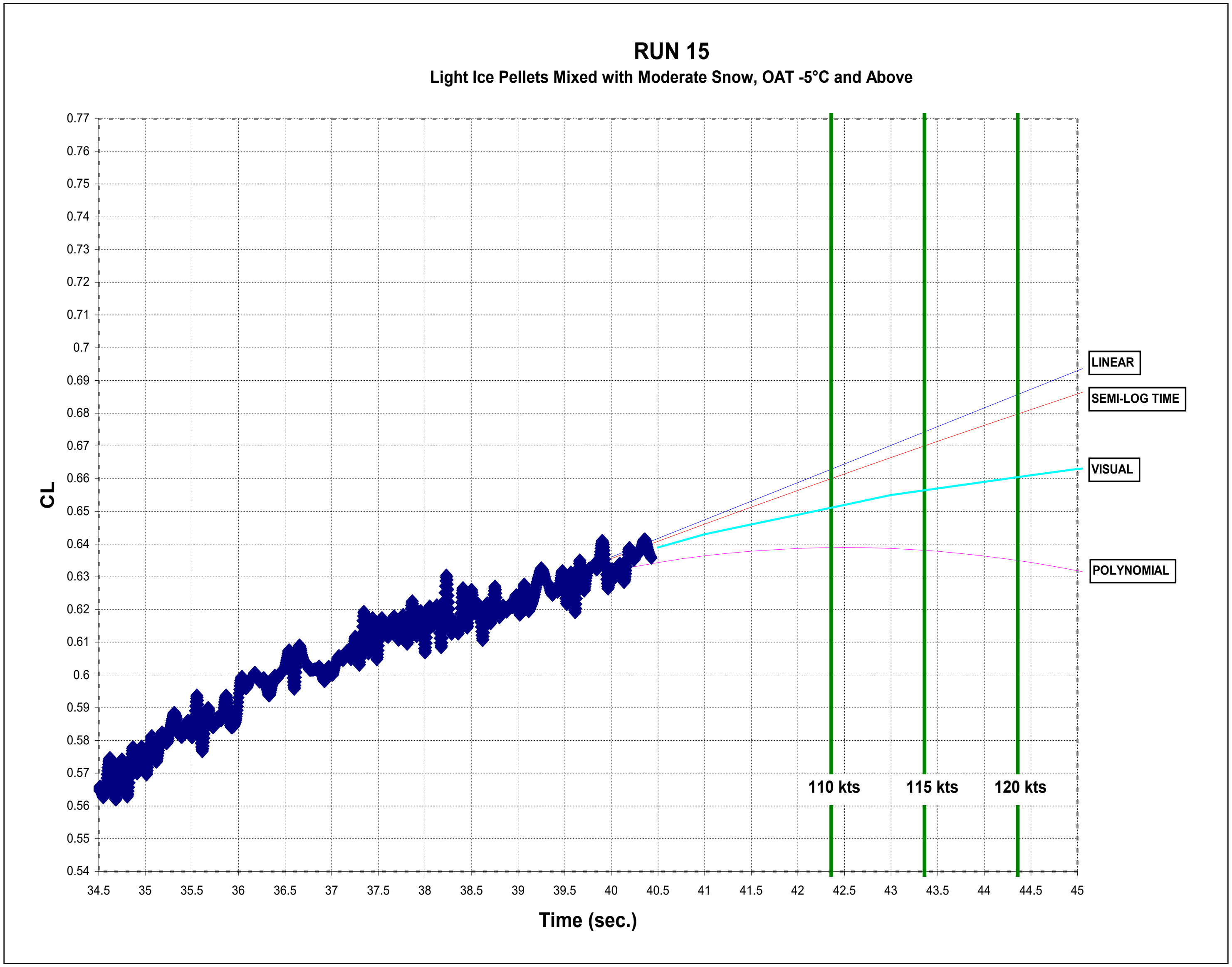


Figure 11.1: Increased Rotation Speed Extrapolation Results – Test #15

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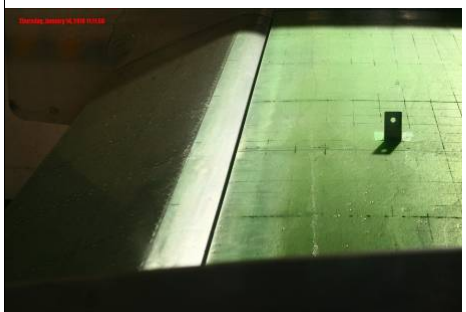
Photo 11.1: Test #17 – Start of Test

Test #17
ABC-S Plus, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test



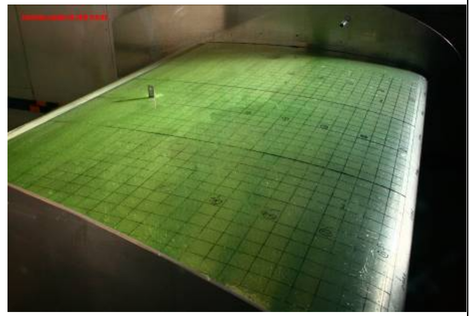
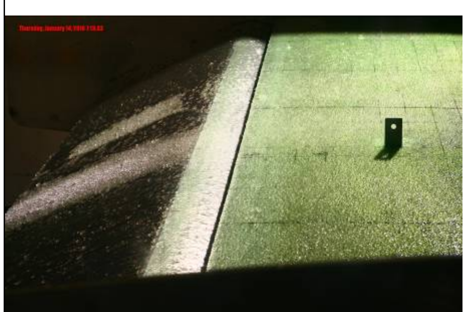


Photo 11.2: Test #13 – Start of Test

Test #13
ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 20 min
-5°C, 8° Rotation
Visual Contamination Rating (3,2,3.5)
Start of Test



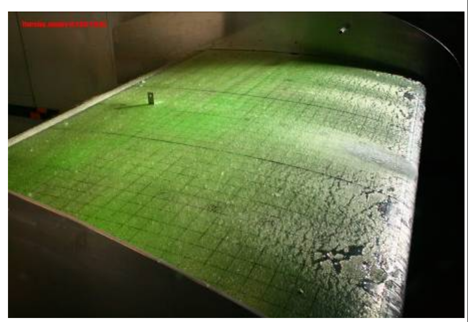


Photo 11.3: Test #17 – End of Rotation

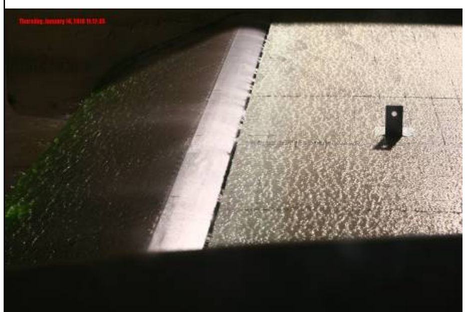
Test #17

ABC-S Plus, Fluid Only

-4°C, 8° Rotation

Visual Contamination Rating (1,1,1)

Before Rotation



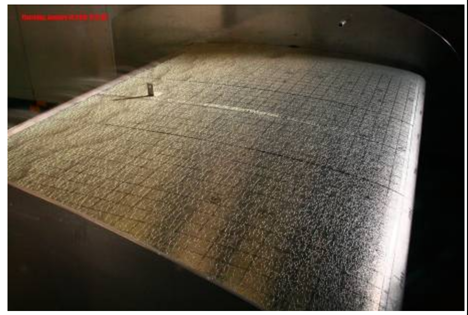


Photo 11.4: Test #13 – Before Rotation

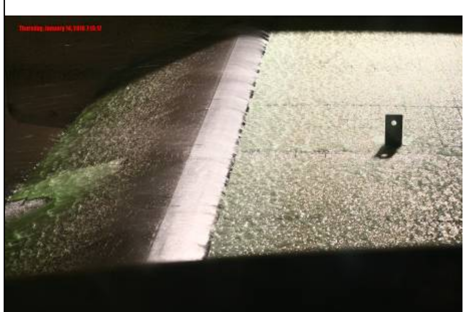
Test #13

ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 20 min

-5°C, 8° Rotation

Visual Contamination Rating (1,1.8,2.7)

Before Rotation



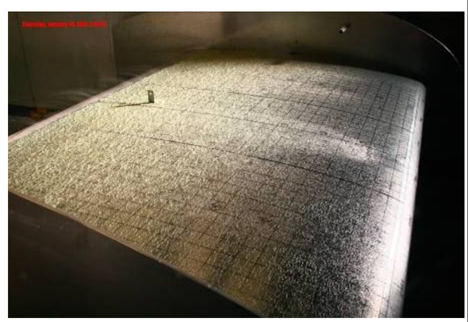


Photo 11.5: Test #17 – End of Rotation

Test #17
ABC-S Plus, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 4.96%
End of Rotation

Photo 11.6: Test #13 – End of Rotation

Test #13
ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 20 min
-5°C, 8° Rotation
Visual Contamination Rating (1,1.8,2.7), 8° Lift Loss = 6.06%
End of Rotation

Photo 11.7: TTest #17 – End of Test

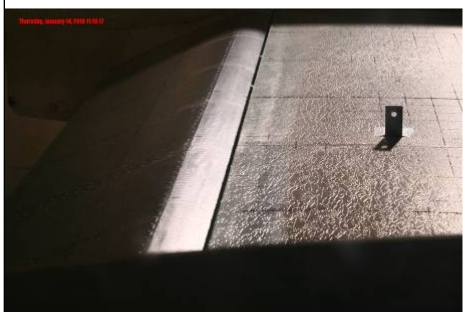
Test #17

ABC-S Plus, Fluid Only

-4°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test



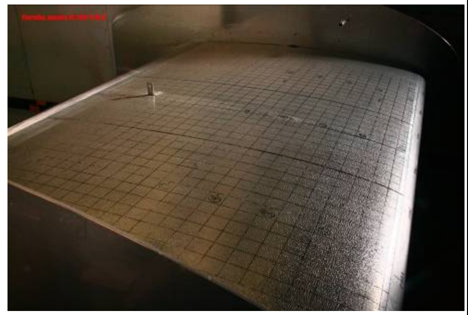


Photo 11.8: Test #13 – End of Test

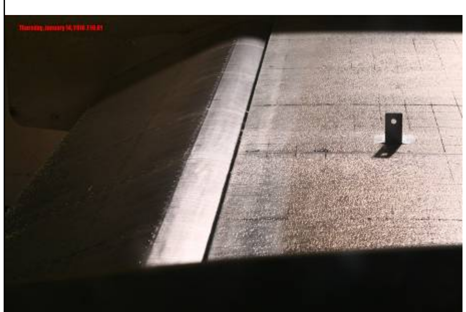
Test #13

ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 20 min

-5°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test



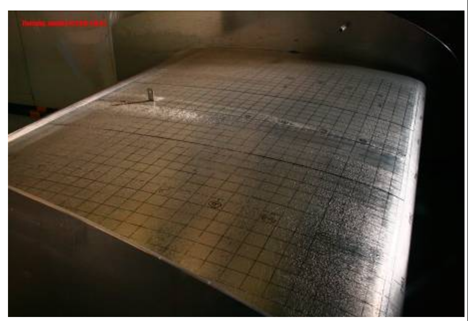
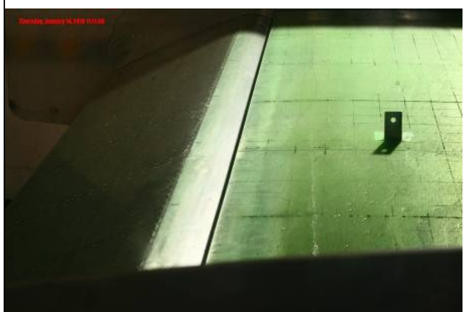


Photo 11.9: Test #17 – Start of Test

Test #17
ABC-S Plus, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test



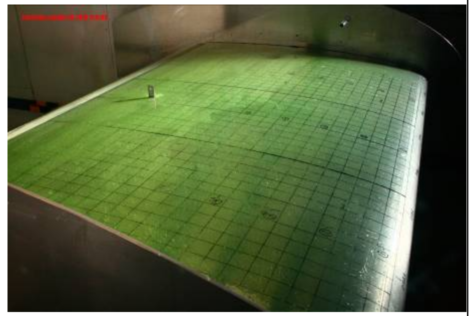
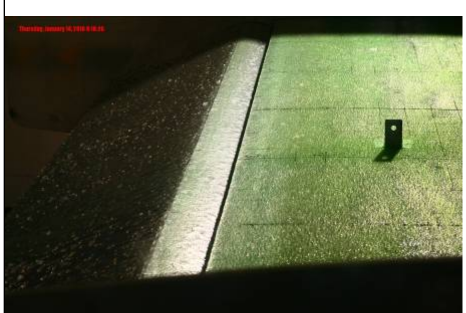


Photo 11.10: Test #14 – Start of Test

Test #14
ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 15 min
-4°C, 8° Rotation
Visual Contamination Rating (2.2,2,2.8)
Start of Test



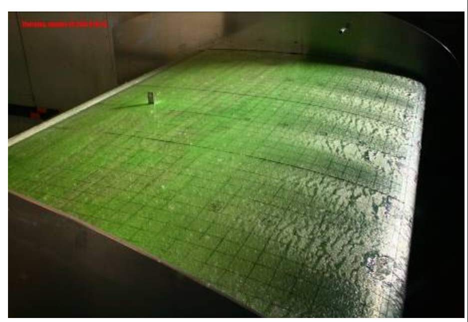


Photo 11.11: Test #17 – Before Rotation

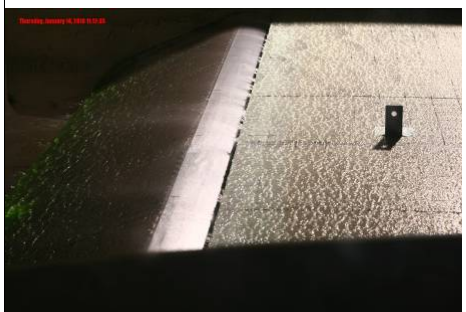
Test #17

ABC-S Plus, Fluid Only

-4°C, 8° Rotation

Visual Contamination Rating (1,1,1)

Before Rotation



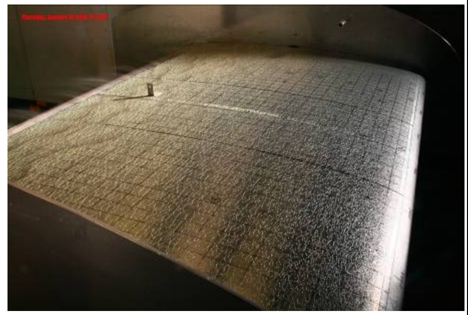


Photo 11.12: Test #14 – Before Rotation

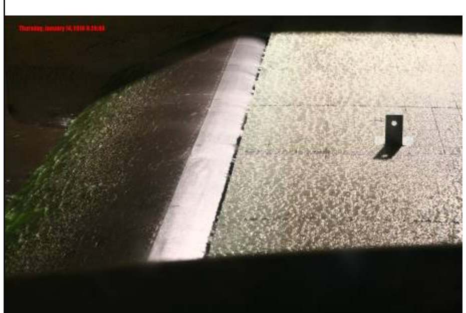
Test #14

ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 15 min

-4°C, 8° Rotation

Visual Contamination Rating (1,1.5,1.5)

Before Rotation



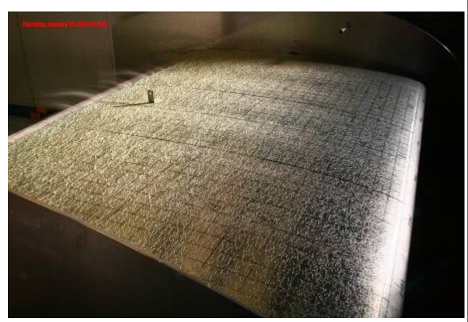


Photo 11.13: Test #17 – End of Rotation

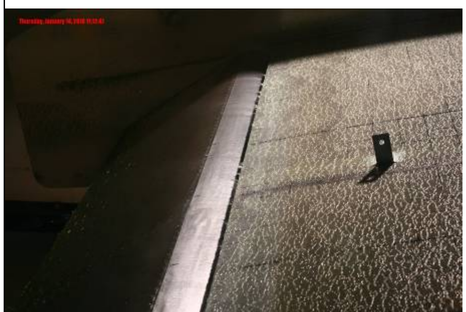
Test #17

ABC-S Plus, Fluid Only

-4°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 4.96%

End of Rotation



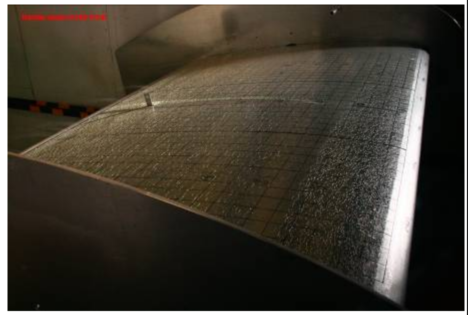


Photo 11.14: Test #14 – End of Rotation

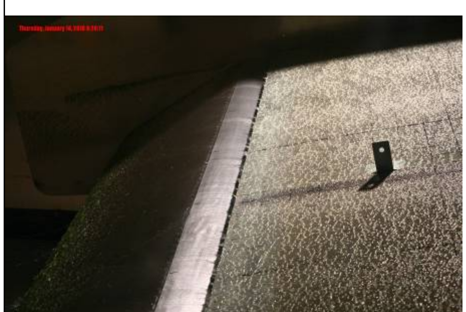
Test #14

ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 15 min

-4°C, 8° Rotation

Visual Contamination Rating (1,1.5,1.5), 8° Lift Loss = 5.54%

End of Rotation



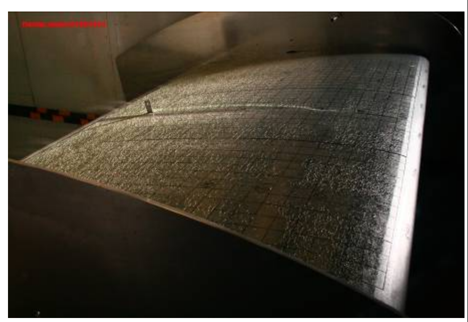


Photo 11.15: Test #17 – End of Test

Test #17
ABC-S Plus, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

Photo 11.16: Test #14 – End of Test

Test #14
ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 15 min
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

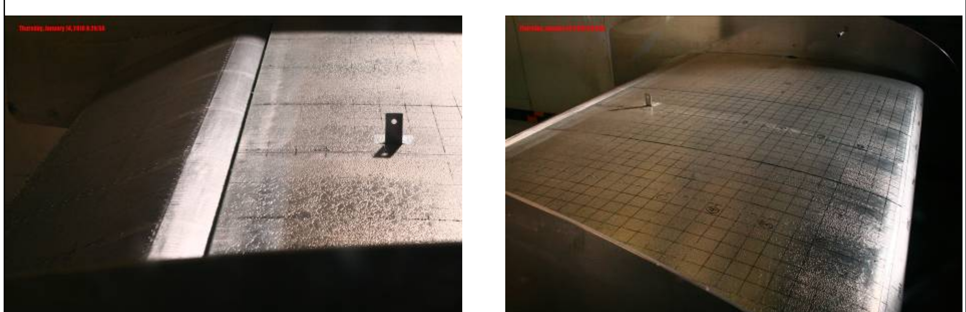
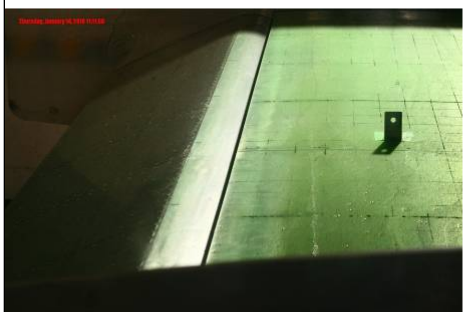


Photo 11.17: Test #17 – Start of Test

Test #17
ABC-S Plus, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test



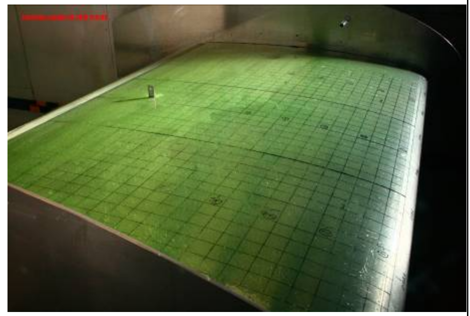
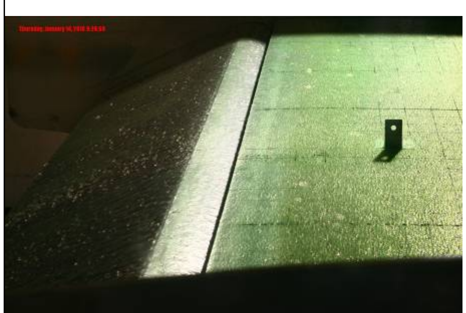


Photo 11.18: Test #15 – Start of Test

Test #15
ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 10 min
-4°C, 8° Rotation
Visual Contamination Rating (1.8,2,2.7)
Start of Test



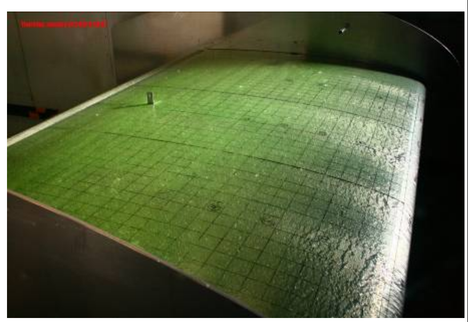


Photo 11.19: Test #17 – Before Rotation

Test #17
ABC-S Plus, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

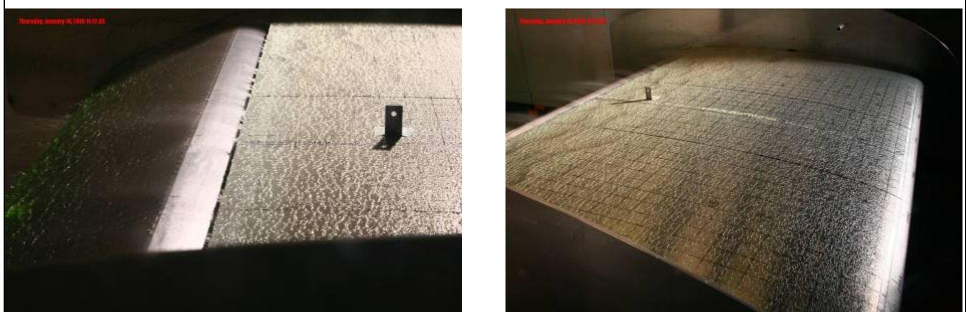


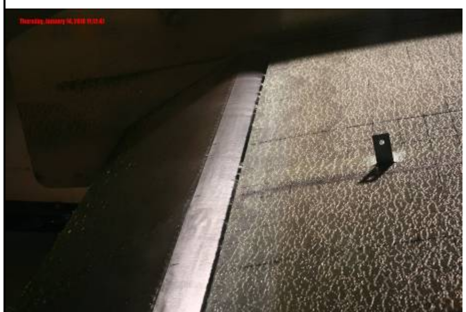
Photo 11.20: Test #15 – Before Rotation

Test #15
ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 10 min
-4°C, 8° Rotation
Visual Contamination Rating (1,1.3,1.7)
Before Rotation

Photo 11.21: Test #17 – End of Rotation

Test #17
ABC-S Plus, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 4.96%

End of Rotation



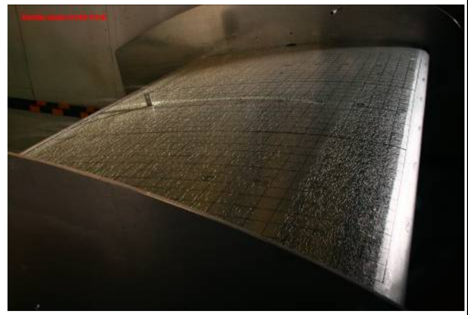
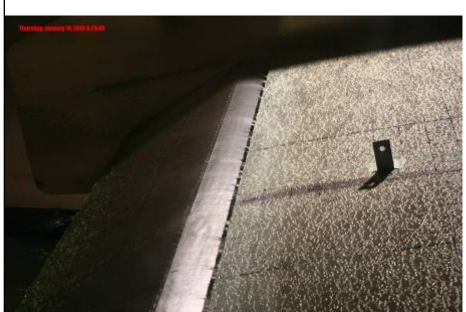


Photo 11.22: Test #15 – End of Rotation

Test #15
ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 10 min
-4°C, 8° Rotation
Visual Contamination Rating (1,1.3,1.7), 8° Lift Loss = 5.13%

End of Rotation



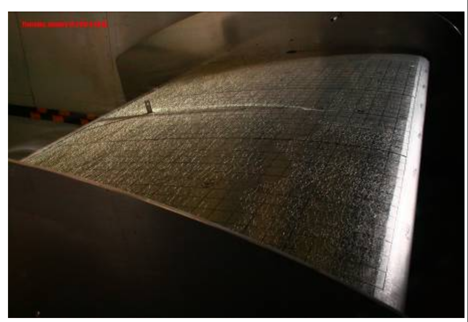


Photo 11.23: Test #17 – End of Test

Test #17
ABC-S Plus, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

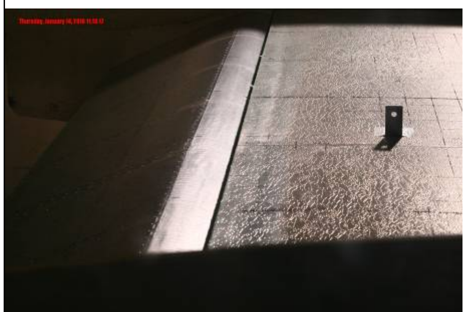
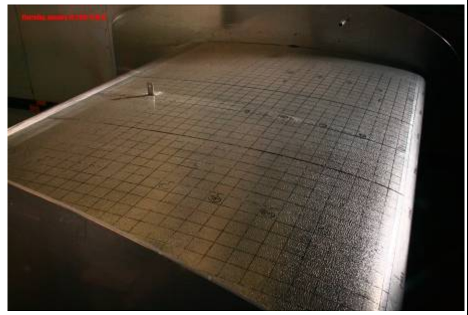



Photo 11.24: Test #15 – End of Test

Test #15
ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 10 min
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

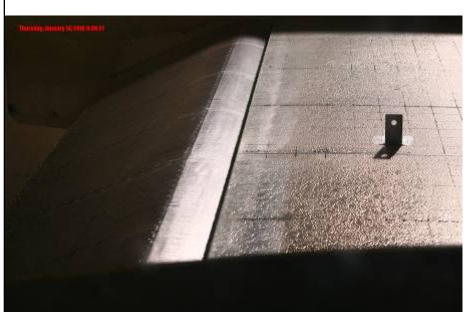
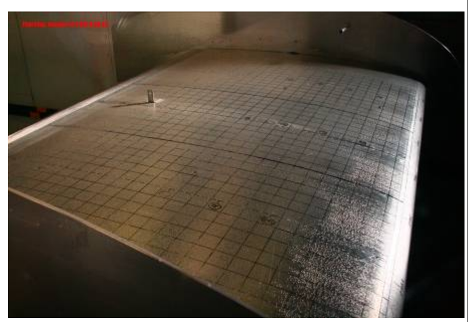



Photo 11.25: Test #17 – Start of Test

Test #17
ABC-S Plus, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

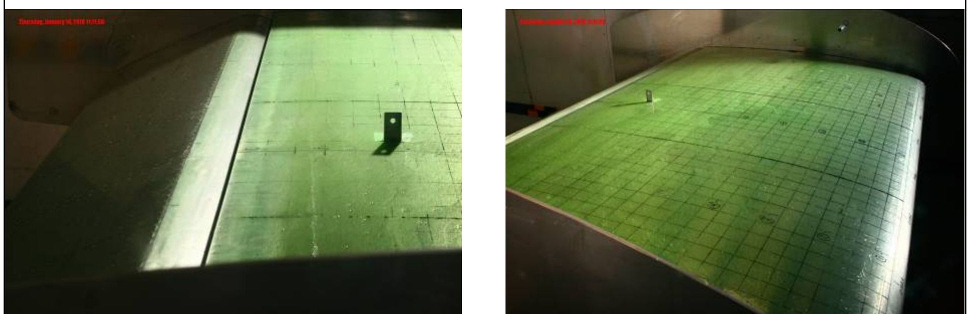


Photo 11.26: Test #16 – Start of Test

Test #16
ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 5 min
-4°C, 8° Rotation
Visual Contamination Rating (1.4,1.7,1.8)
Start of Test

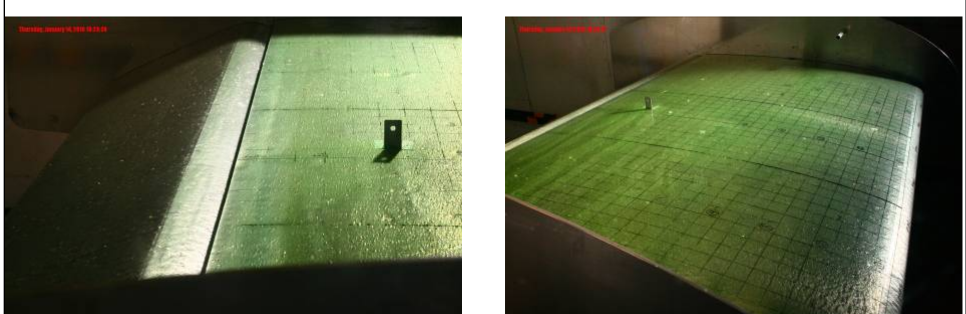
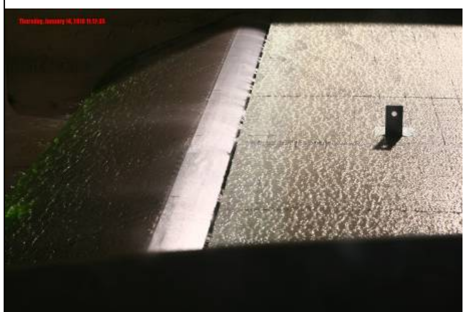


Photo 11.27: Test #17 – Before Rotation

Test #17
ABC-S Plus, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation



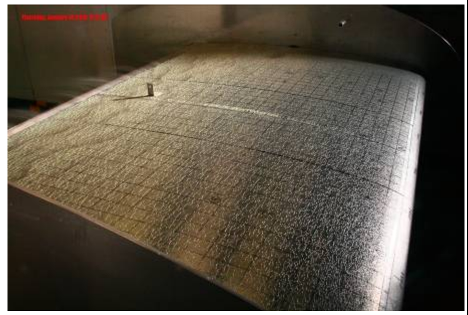


Photo 11.28: Test #16 – Before Rotation

Test #16
ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 5 min
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1.3)
Before Rotation

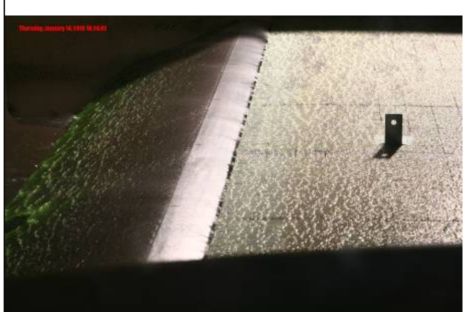
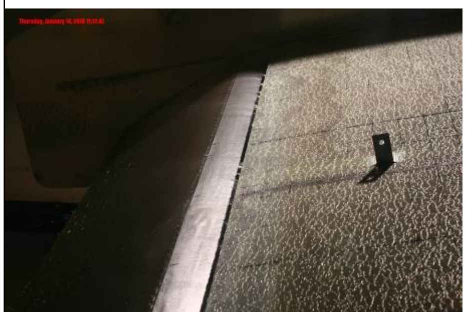


Photo 11.29: Test #17 – End of Rotation

Test #17
ABC-S Plus, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 4.96%

End of Rotation



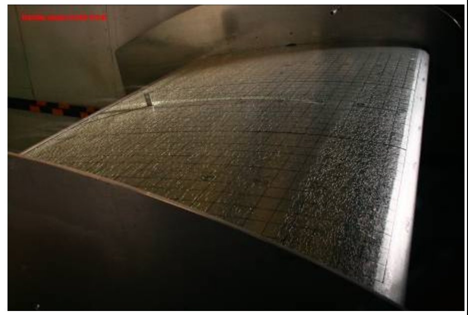


Photo 11.30: Test #16 – End of Rotation

Test #16
ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 5 min
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1.3), 8° Lift Loss = 5.77%

End of Rotation

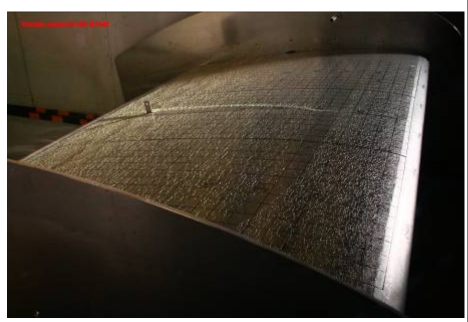
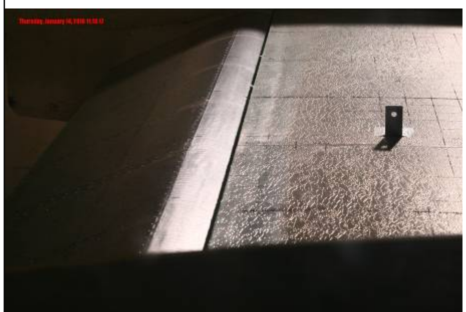


Photo 11.31: Test #17 – End of Test

Test #17
ABC-S Plus, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test



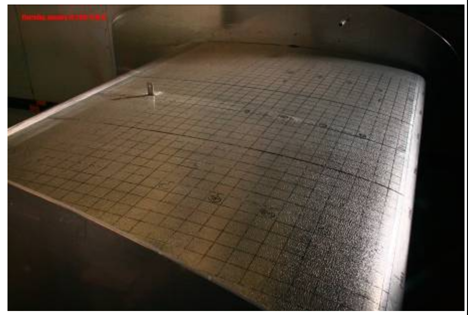
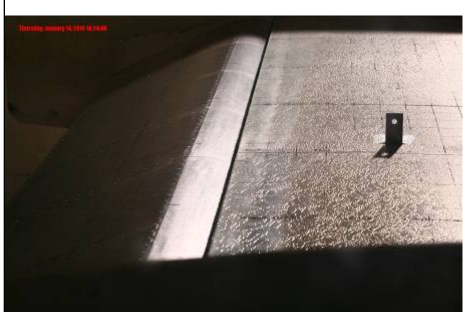


Photo 11.32: Test #16 – End of Test

Test #16
ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 5 min
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test



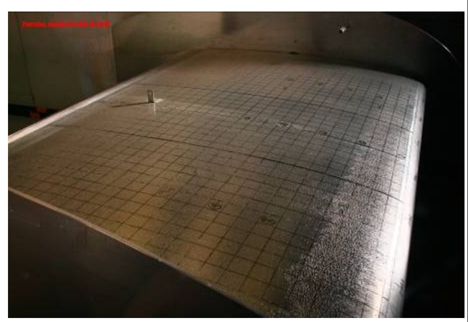


Photo 11.33: Test #25 – Start of Test

Test #25
EG106, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

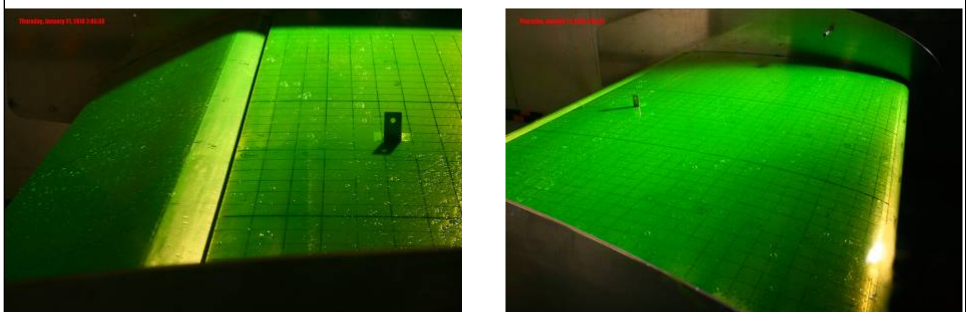


Photo 11.34: Test #24 – Start of Test

Test #24
EG106, IP- + Mod SN 25 + 25 g/dm²/h, 20 min
-4°C, 8° Rotation
Visual Contamination Rating (2.5,1.8,4)
Start of Test

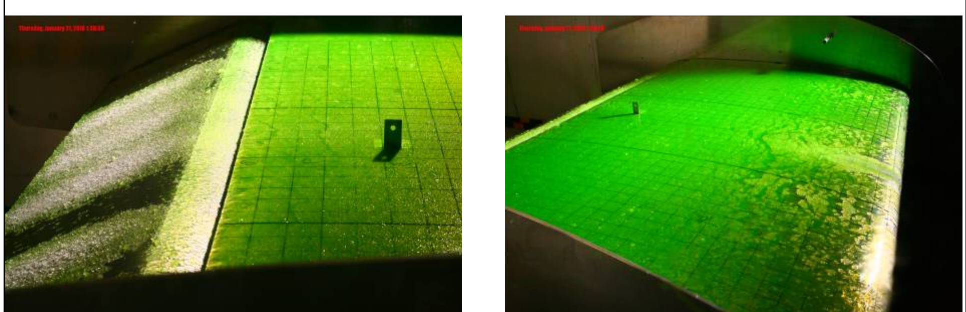


Photo 11.35: Test #25 – Before Rotation

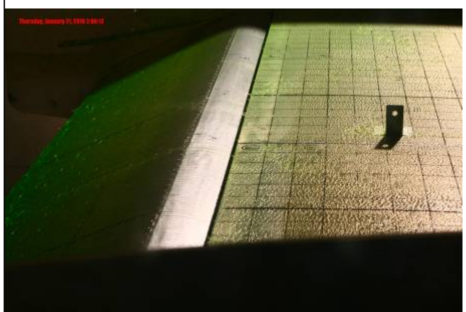
Test #25

EG106, Fluid Only

-4°C, 8° Rotation

Visual Contamination Rating (1,1,1)

Before Rotation



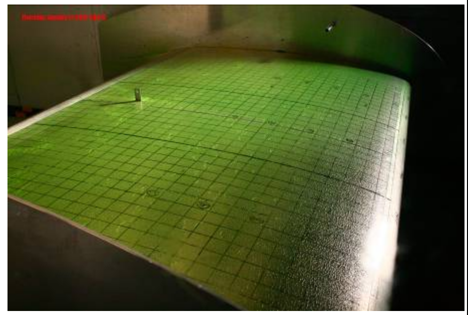


Photo 11.36: Test #24 – Before Rotation

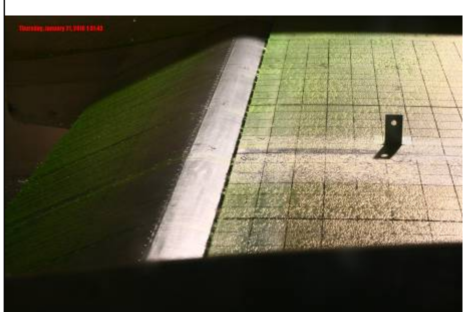
Test #24

EG106, IP- + Mod SN 25 + 25 g/dm²/h, 20 min

-4°C, 8° Rotation

Visual Contamination Rating (1,1.2,1)

Before Rotation



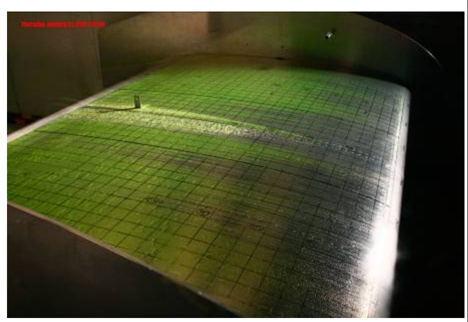


Photo 11.37: Test #25 – End of Rotation

Test #25
EG106, Fluid Only
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 1.99%
End of Rotation

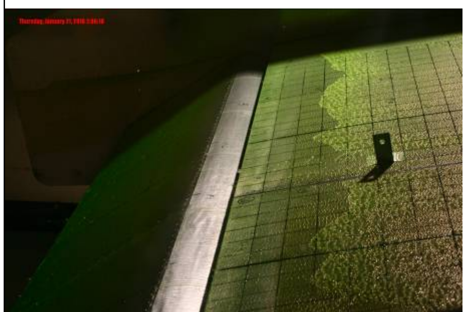
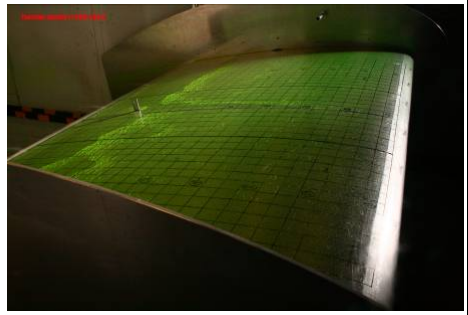



Photo 11.38: Test #24 – End of Rotation

Test #24
EG106, IP- + Mod SN 25 + 25 g/dm²/h, 20 min
-4°C, 8° Rotation
Visual Contamination Rating (1,1.2,1), 8° Lift Loss = 1.30%
End of Rotation

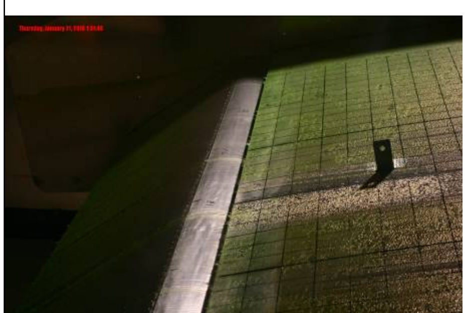
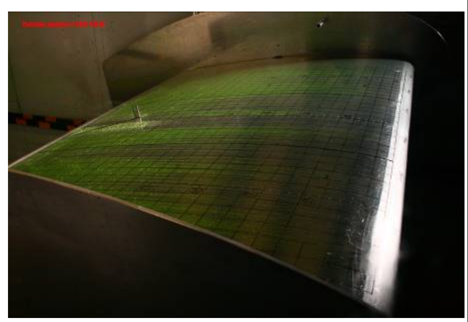



Photo 11.39: Test #25 – End of Test

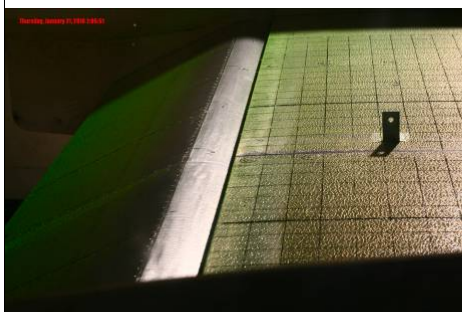
Test #25

EG106, Fluid Only

-4°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test



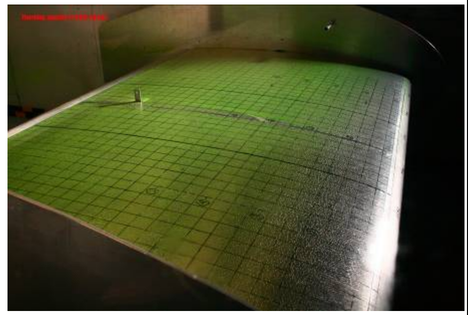


Photo 11.40: Test #24 – End of Test

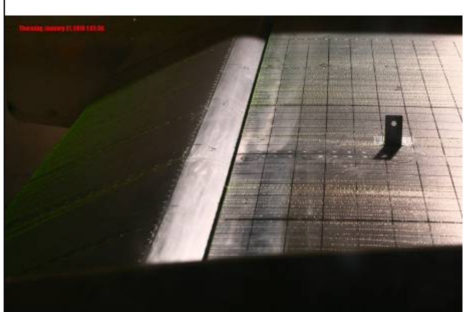
Test #24

EG106, IP- + Mod SN 25 + 25 g/dm²/h, 20 min

-4°C, 8° Rotation

Visual Contamination Rating (1,1,1)

End of Test



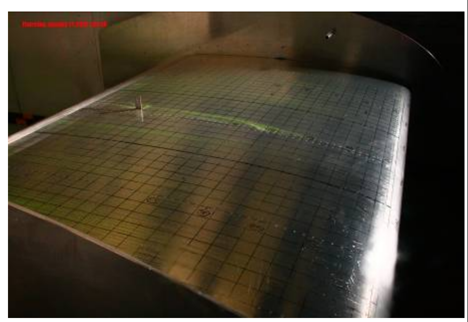


Photo 11.41: Test #60 – Start of Test

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

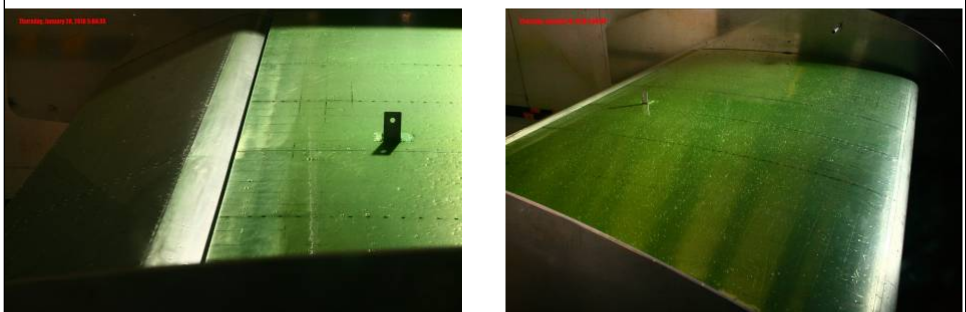


Photo 11.42: Test #58 – Start of Test

Test #58
Launch, IP- + Mod SN 25 + 25 g/dm²/h, 20 min
-3°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (2.8,2.6,3)
Start of Test

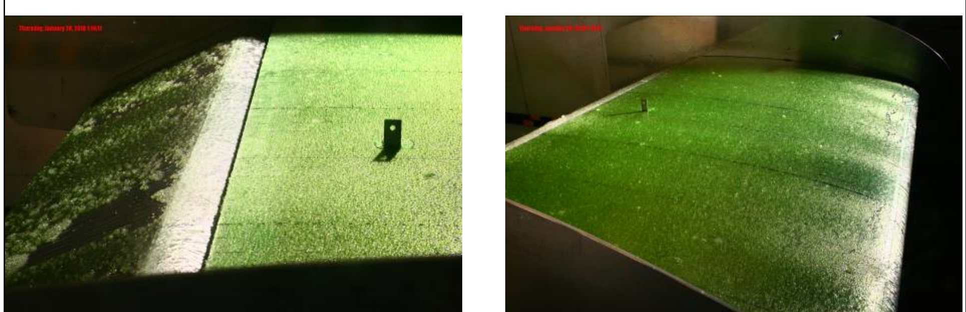
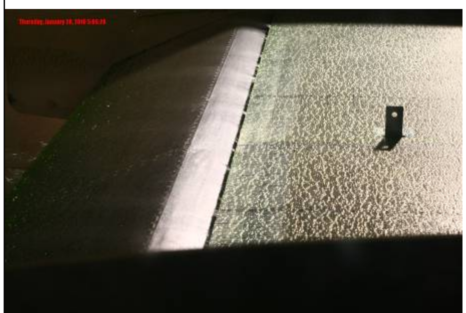


Photo 11.43: Test #60 – Before Rotation

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



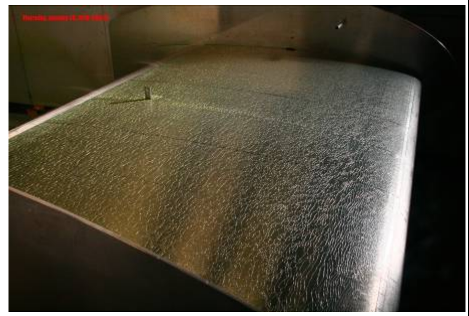


Photo 11.44: Test #58 – Before Rotation

Test #58
Launch, IP- + Mod SN 25 + 25 g/dm²/h, 20 min
-3°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1,1.5,2)
Before Rotation

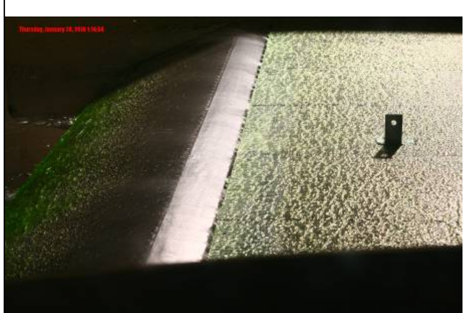
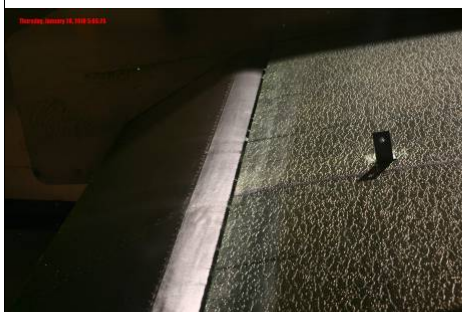


Photo 11.45: Test #60 – End of Rotation

Test #60
Launch, Fluid Only
-3°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 4.61%

End of Rotation



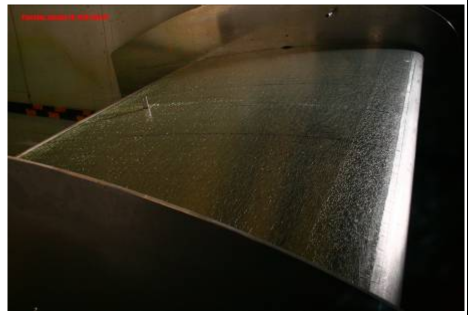


Photo 11.46: Test #58 – End of Rotation

Test #58
Launch, IP- + Mod SN 25 + 25 g/dm²/h, 20 min
-3°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1,1.5,2), 8° Lift Loss = 4.84%

End of Rotation

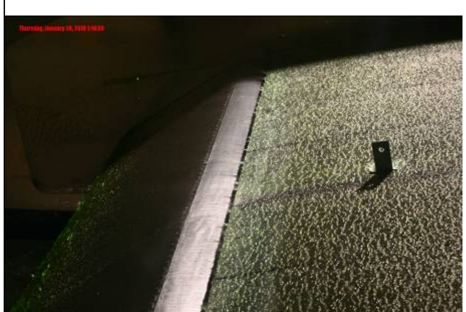


Photo 11.47: Test #60 – End of Test

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

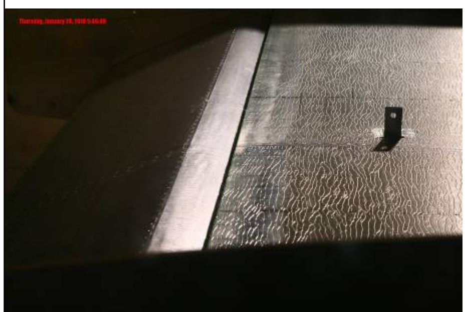
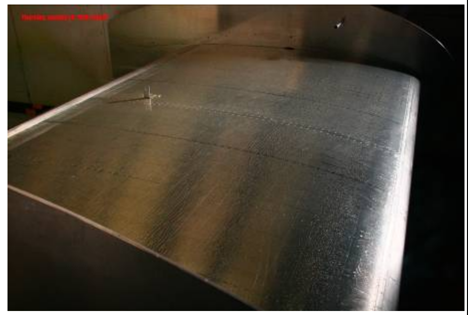



Photo 11.48: Test #58 – End of Test

Test #58
Launch, IP- + Mod SN 25 + 25 g/dm²/h, 20 min
-3°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1,1,1)
End of Test

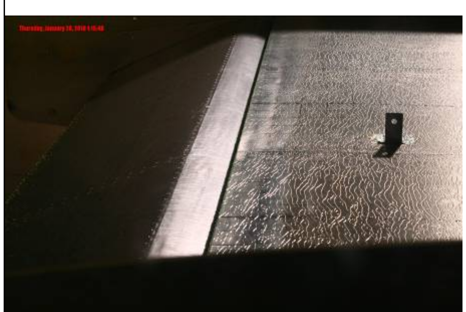
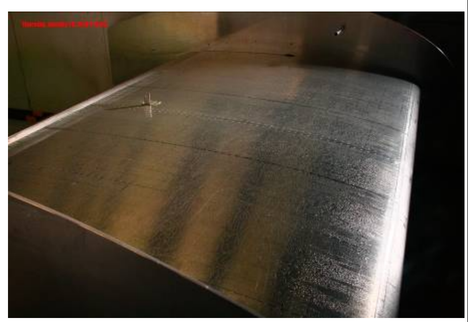
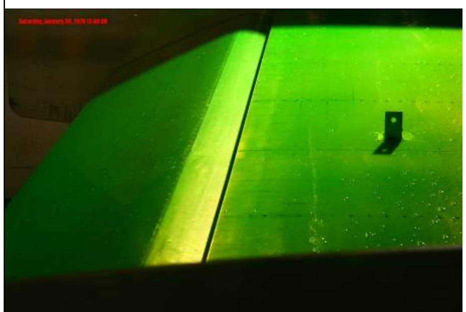



Photo 11.49: Test #75 – Start of Test

Test #75
EG106, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test



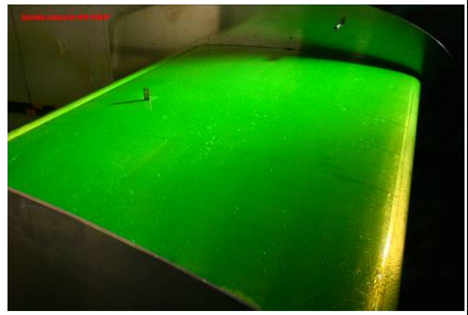
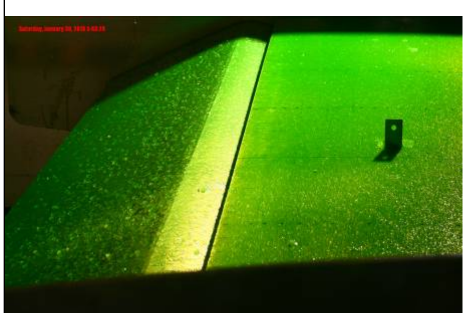


Photo 11.50: Test #81 – Start of Test

Test #81
EG106, IP- + Mod SN 25 + 25 g/dm²/h, 5 min
-17°C, 8° Rotation
Visual Contamination Rating (1.8,2,2.3)
Start of Test



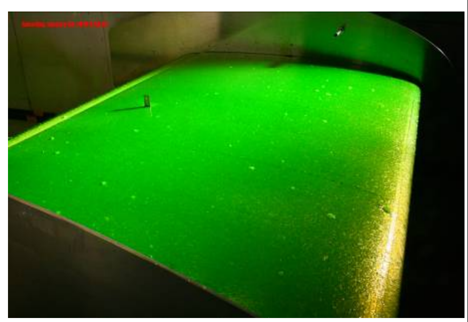
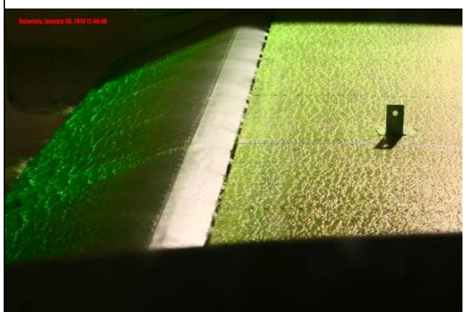


Photo 11.51: Test #75 – Before Rotation

Test #75
EG106, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)

Before Rotation



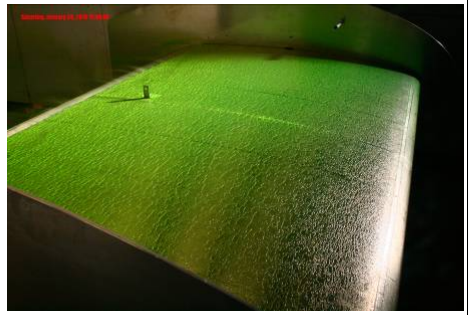
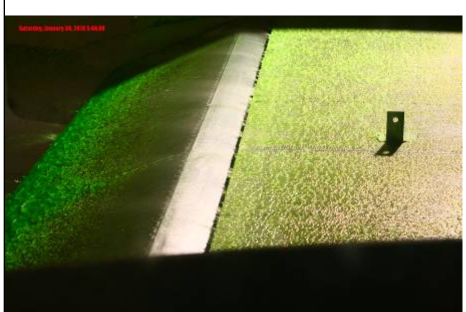


Photo 11.52: Test #81 – Before Rotation

Test #81
EG106, IP- + Mod SN 25 + 25 g/dm²/h, 5 min
-17°C, 8° Rotation
Visual Contamination Rating (1,1.5,2)

Before Rotation



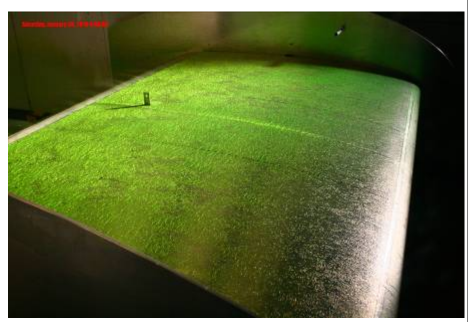


Photo 11.53: Test #75 – End of Rotation

Test #75
EG106, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 4.08%

End of Rotation

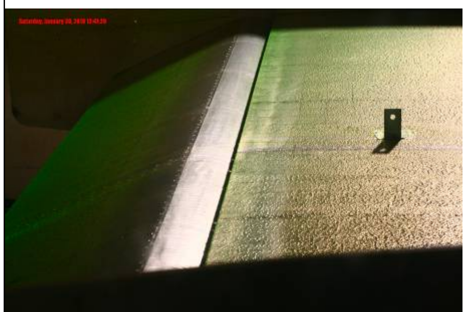
Photo 11.54: Test #81 – End of Rotation

Test #81
EG106, IP- + Mod SN 25 + 25 g/dm²/h, 5 min
-17°C, 8° Rotation
Visual Contamination Rating (1,1.5,2), 8° Lift Loss = 3.79%

End of Rotation

Photo 11.55: Test #75 – End of Test

Test #75
EG106, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test



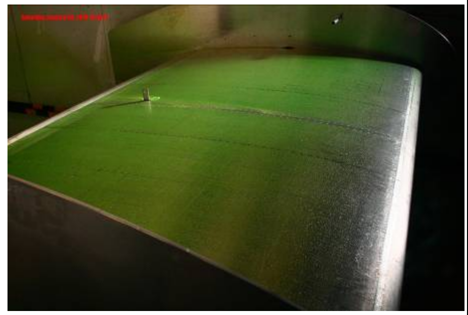
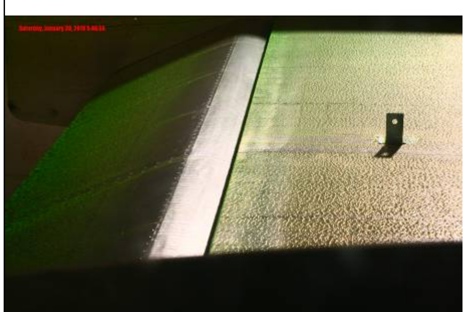


Photo 11.56: Test #81 – End of Test

Test #81
EG106, IP- + Mod SN 25 + 25 g/dm²/h, 5 min
-17°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test



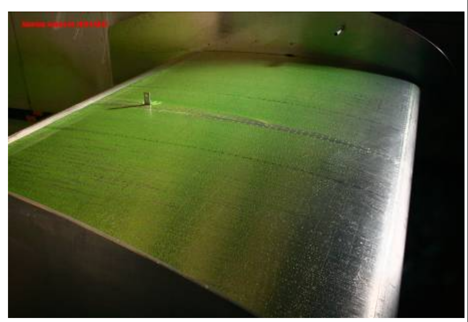


Photo 11.57: Test #76 – Start of Test

Test #76
ABC-S Plus, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

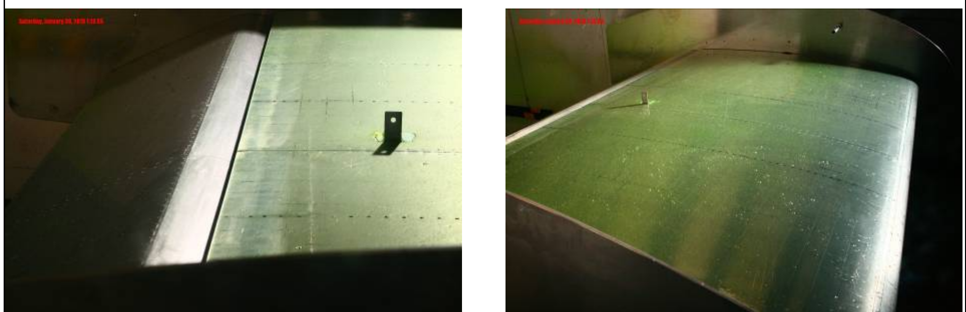


Photo 11.58: Test #82 – Start of Test

Test #82
ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 5 min
-16°C, 8° Rotation
Visual Contamination Rating (2.5,2.2,3.2)
Start of Test

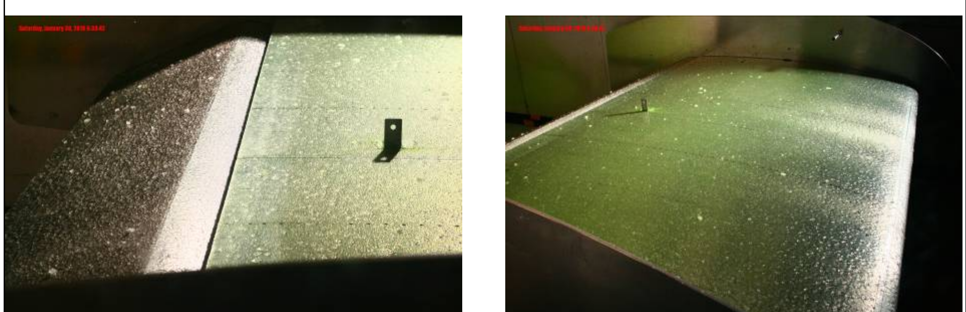


Photo 11.59: Test #76 – Before Rotation

Test #76

ABC-S Plus, Fluid Only

-18°C, 8° Rotation

Visual Contamination Rating (1,1,1)

Before Rotation

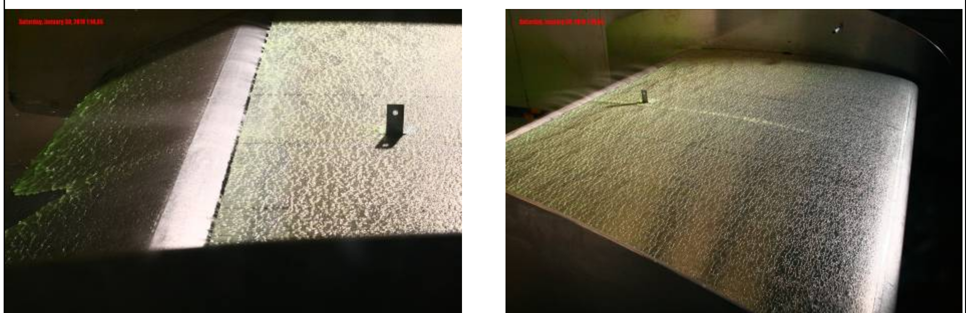


Photo 11.60: Test #82 – Before Rotation

Test #82

ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 5 min

-16°C, 8° Rotation

Visual Contamination Rating (1.5,1.5,1.8)

Before Rotation

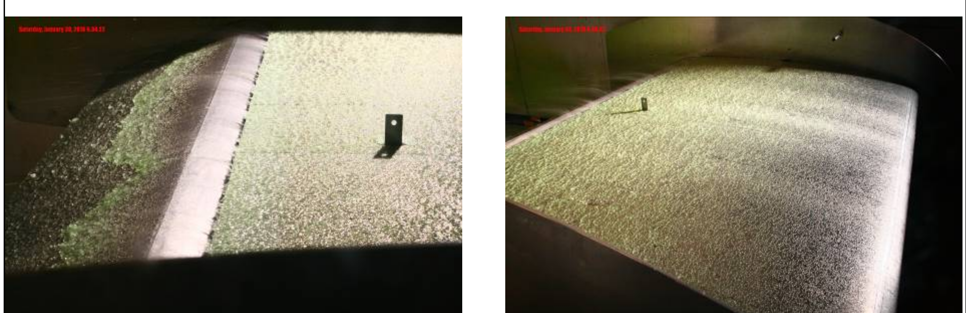


Photo 11.61: Test #76 – End of Rotation

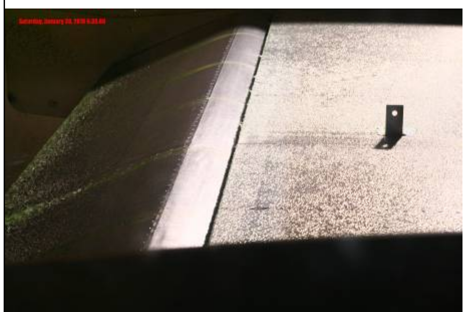
Test #76
ABC-S Plus, Fluid Only
-18°C, 8° Rotation
Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.89%
End of Rotation

Photo 11.62: Test #82 – End of Rotation

Test #82
ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 5 min
-16°C, 8° Rotation
Visual Contamination Rating (1.5,1.5,1.8) 8° Lift Loss = 9.20%
End of Rotation

Photo 11.63: Test #76 – End of Test

Test #82
ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 5 min
-16°C, 8° Rotation
Visual Contamination Rating (1.1,1.7,1.8)
End of Test



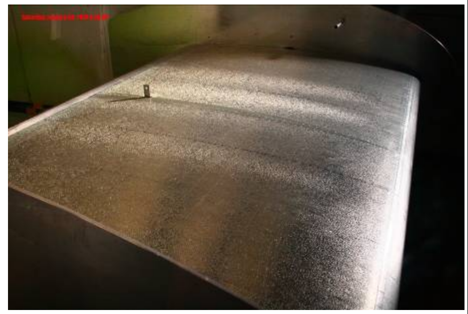
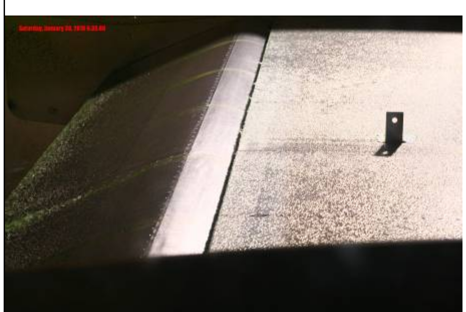


Photo 11.64: Test #82 – End of Test

Test #82
ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 5 min
-16°C, 8° Rotation
Visual Contamination Rating (1.1,1.7,1.8)
End of Test



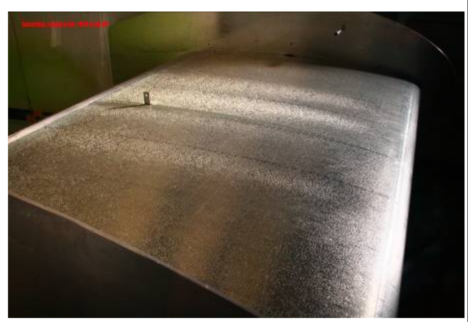


Photo 11.65: Test #64 – Start of Test

Test #64
ABC-S Plus, Fluid Only
-13°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Start of Test

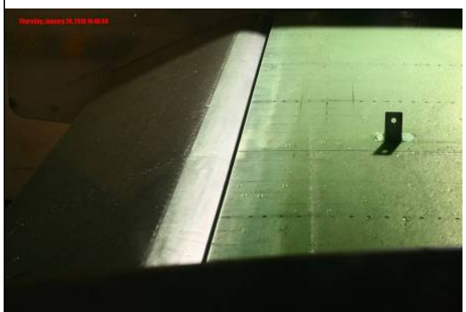
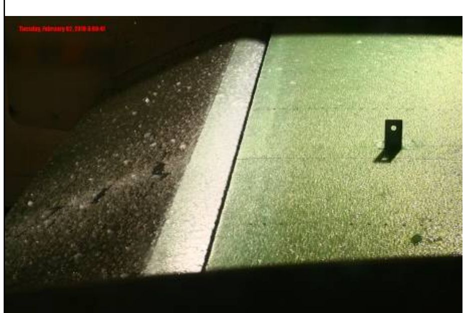


Photo 11.66: Test #97 – Start of Test

Test #97
ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 10 min
-8°C, 8° Rotation
Visual Contamination Rating (2.9,2.3,3)
Start of Test



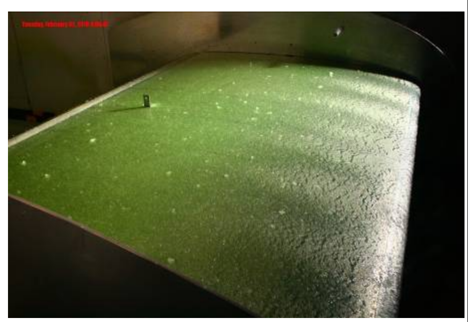


Photo 11.67: Test #64 – Before Rotation

Test #64
ABC-S Plus, Fluid Only
-13°C, 8° Rotation
Visual Contamination Rating (1,1,1)
Before Rotation

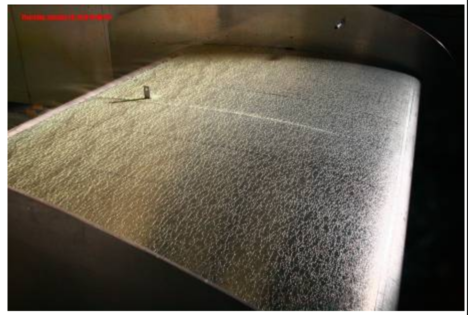


Photo 11.68: Test #97 – Before Rotation

Test #97
ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 10 min
-8°C, 8° Rotation
Visual Contamination Rating (1.3,1.8,2.5)
Before Rotation

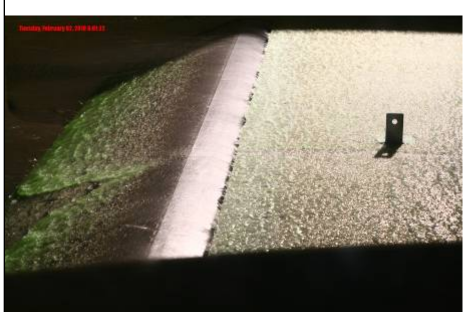


Photo 11.69: Test #64 – End of Rotation

Test #64

ABC-S Plus, Fluid Only

-13°C, 8° Rotation

Visual Contamination Rating (1,1,1), 8° Lift Loss = 5.07%

End of Rotation

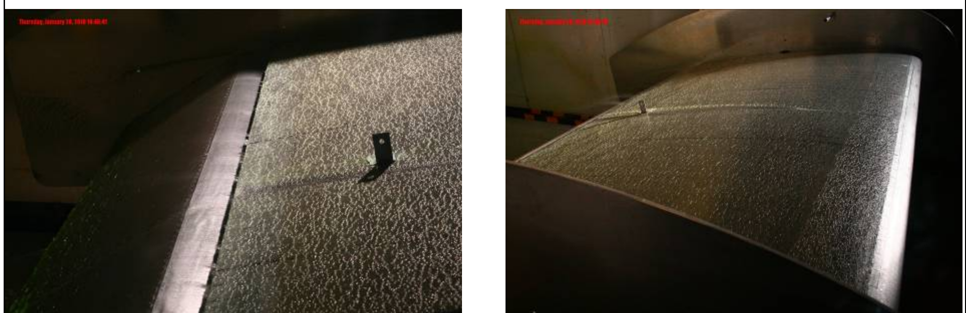


Photo 11.70: Test #97 – End of Rotation

Test #97

ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 10 min

-8°C, 8° Rotation

Visual Contamination Rating (1.3,1.8,2.5), 8° Lift Loss = 7.63%

End of Rotation

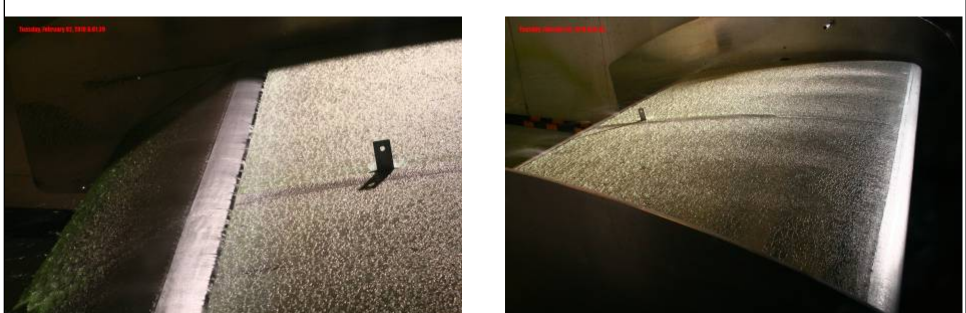


Photo 11.71: Test #64 – End of Test

Test #64
ABC-S Plus, Fluid Only
-13°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test

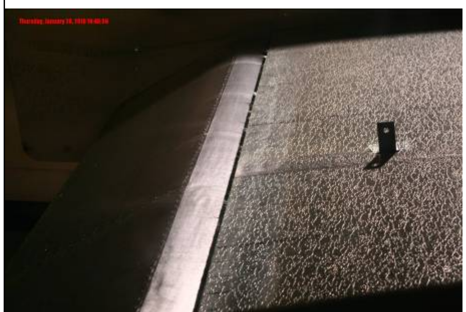
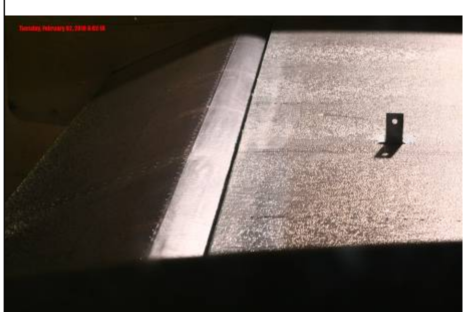
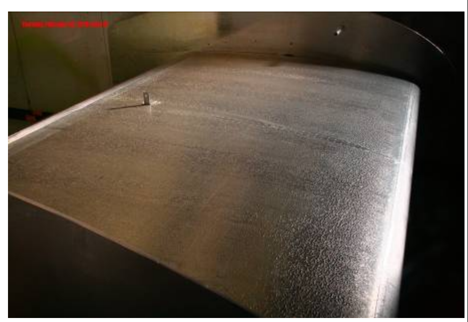


Photo 11.72: Test #97 – End of Test

Test #97
ABC-S Plus, IP- + Mod SN 25 + 25 g/dm²/h, 10 min
-8°C, 8° Rotation
Visual Contamination Rating (1,1,1.2)
End of Test





12. FLAP RETRACTED (UP) VS. FLAP EXTENDED (DOWN)

This section describes the results from the comparative testing conducted with flap retracted versus flap extended.

12.1 Background

The 2009-10 wing section was fitted with a hinged flap. The flap position was fixed at a 20º setting (actual angle of the top surface of the flap was approximately 10° higher) and was not intended to be changed during testing. As testing progressed, a need to be able to change the flap setting from 0º to 20º was necessary; contrary to a nested flap, which is typically protected during precipitation, a hinged flap is always exposed, and results indicated earlier failures due to the steeper angle of the hinged flap. Early results indicated early failure on the flap (compared to the rest of the wing) and resulted in a severe condition of the flap at the end of the allowance time; when fluid is applied, fluid on the flap flows off faster and results in shorter endurance times. As a result, modifications were made by the NRC (after Run #26) to allow the flap setting to be changed between the two settings of 0º and 20º for the fluid application and contamination periods; however, all takeoff simulations were conducted with the flap set to 20º.

Following the modification, some tests that resulted in severe visual ratings on the flap set at 20º were repeated with the flap set at 0º for the duration of the contamination period; this was primarily done for tests that generated good visual flow-off on the main wing and generated close to 5 percent lift loss.

12.2 Overview of Tests

A summary of the comparative Flap Up (retracted) Versus Flap Down (extended) tests conducted in the wind tunnel is shown in Table 12.1. The table provides relevant information for each of the tests, as well as final values used for the data analysis. Each row contains data specific to one test. A more detailed test log of all conditions tested using the wind tunnel is provided in Subsection 4.1. A brief description of the column headings for Table 12.1 is provided in Subsection 6.1.

Table 12.1: Summary of 2009-Flap Up vs. Flap Down Testing

Test No.	Date	Fluid	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Flap Angle (°)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° During Rotation	8° Lift Loss (%)
26	21-Jan-10	EG106	IP- / ZR-	25 / 25	25	-1.9	-6.2	20	2.2/1.7/4.7	1/1/4	1.639	4.78
26A	21-Jan-10	EG106	IP- / ZR-	25 / 25	25	-3.3	-6.2	0	1.8/2/1.9	1/1/1	1.697	1.41
28	21-Jan-10	Launch	IP-	25	50	-4.2	-3.6	20	2/2/3.7	1/1.7/2	1.648	4.26
28A	21-Jan-10	Launch	IP-	25	25	-5.5	-7.4	0	2/2/2.7	1//1.5/2	1.655	3.85
56	27-Jan-10	EG106	IP / R Mod	25 / 75	25	-1.1	-4.3	20	1.8/2/4.7	1/1/5	1.666	3.21
56A	27-Jan-10	EG106	IP / R Mod	25 / 75	25	-1.4	-2.4	0	1.8/2.2/3	1/1/4.3	1.663	3.39
57	27-Jan-10	Launch	IP- / SN-	25 / 10	40	-3.6	-5.4	20	2.7/2.6/4	1/1.7/2.8	1.64	4.72
57A	27-Jan-10	Launch	IP- / SN-	25 / 10	40	-4.2	-5.7	0	2.6/2.6/3	1/1.3/1.7	1.671	2.92

12.3 Data Collected

12.3.1 Fluid Thickness Data

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

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

Tables 12.2 to 12.9 show the fluid thickness measurements collected during the contaminated fluid tests.

Table 12.2: Test #26 Fluid Thickness Data

Test 26: EG106, IP-/ZR-, Tunnel OAT -1.9°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.7	0.6	0.0
2	2.2	1.7	0.0
3	2.2	2.5	0.1
4	3.5	3.7	0.1
5	3.5	3.9	0.1
6	4.5	5.7	0.0
7	4.5	4.5	0.0
8	3.5	3.5	0
Flap	1.0	slush	0.1

Table 12.3: Test #26A Fluid Thickness Data

Test 26A: EG106, IP-/ZR-, Tunnel OAT -3.3°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.6	1.1	0.0
2	2.5	1.5	0.0
3	2.7	3.1	0.0
4	3.3	3.7	0.0
5	4.5	4.5	0.0
6	4.0	4.5	0.0
7	3.5	4.5	0.0
8	3.5	2.7	0.0
Flap	3.3	3.1	0.1

Table 12.4: Test #28 Fluid Thickness Data

Test 28: Launch, IP-, Tunnel OAT -4.2°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.3	2.2	0.0
2	1.8	3.9	0.1
3	2.2	4.5	0.1
4	2.7	4.5	0.2
5	2.9	4.5	0.3
6	3.1	5.7	0.2
7	2.7	4.5	0.2
8	2.2	4.5	0.2
Flap	0.7	slush	0.2

Table 12.5: Test #28A Fluid Thickness Data

Test 28A: Launch, IP-, Tunnel OAT -5.5°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.0	slush	0.0
2	1.6	1.8	0.0
3	1.8	3.3	0.0
4	2.2	4.5	0.1
5	2.2	4.5	0.1
6	2.2	4.5	0.2
7	1.8	4.5	0.2
8	1.5	3.7	0.2
Flap	2.2	3.5	0.1

Table 12.6: Test #56 Fluid Thickness Data

Test 56: EG106, IP/R Mod, Tunnel OAT -1.1°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Test
1	1.8	0.6	0.0
2	3.1	0.8	0.0
3	3.3	1.0	0.0
4	4.5	1.5	0.0
5	4.5	2.2	0.0
6	4.5	2.5	0.0
7	4.5	1.3	0.0
8	4.5	1.0	0.0
Flap	0.8	slush	N/A

Table 12.7: Test #56A Fluid Thickness Data

Test 56A: EG106, IP/R Mod, Tunnel OAT -1.4°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.7	0.4	0.0
2	2.5	0.8	0.0
3	3.3	1.0	0.0
4	4.5	1.1	0.0
5	4.5	1.8	0.0
6	3.7	1.3	0.0
7	4.5	1.0	0.0
8	2.7	1.0	0.0
Flap	1.0	0.4	N/A

Table 12.8: Test #57 Fluid Thickness Data

Test 57: Launch, IP-/SN-, Tunnel OAT -3.6°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	0.7	2.5	0.1
2	1.8	2.7	0.1
3	2.2	3.3	0.1
4	2.5	3.9	0.1
5	2.7	3.9	0.1
6	2.7	4.5	0.1
7	2.5	4.5	0.1
8	2.2	3.7	0.1
Flap	0.5	slush	0.2

Table 12.9: Test #57A Fluid Thickness Data

Test 57A: Launch, IP-/SN-, Tunnel OAT -4.2°C			
FLUID THICKNESS (mm)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
1	1.0	2.2	0.0
2	1.8	3.5	0.1
3	2.2	4.5	0.1
4	2.7	4.5	0.1
5	3.1	4.5	0.2
6	3.1	5.7	0.1
7	2.7	4.5	0.2
8	2.2	4.5	0.2
Flap	2.2	4.5	0.1

12.3.2 Skin Temperature Data

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

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

Tables 12.10 to 12.17 show the wing temperature measurements recorded during the contaminated fluid tests.

Table 12.10: Test #26 Wing Skin Temperature Data

Test 26: EG106, IP-/ZR-, Tunnel OAT -1.9°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-2.8	-3.0	-7.6	-3.6
T5	-2.8	-2.9	-6.6	-2.3
TU	-3.8	-3.5	-4.4	-3.5

Table 12.11: Test #26A Wing Skin Temperature Data

Test 26A: EG106, IP-/ZR-, Tunnel OAT -3.3°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-2.8	-3.3	-7.7	-4.1
T5	-2.2	-3.2	-6.6	-3.2
TU	-3.5	-3.5	-4.3	-4.5

Table 12.12: Test #28 Wing Skin Temperature Data

Test 28: Launch, IP-, Tunnel OAT -4.2°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-1.2	-1.6	-7.3	-5.0
T5	-0.4	-1.6	-7.6	-4.4
TU	-1.6	-1.6	-3.9	-5.7

Table 12.13: Test #28A Wing Skin Temperature Data

Test 28A: Launch, IP-, Tunnel OAT -5.5°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.4	-3.3	-8.5	-7.4
T5	-2.8	-3.4	-8.3	-7.3
TU	-5.1	-4.6	-5.4	-7.8

Table 12.14: Test #56 Wing Skin Temperature Data

Test 56: EG106, IP/R Mod, Tunnel OAT -1.1°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-1.2	-1.5	-5.3	-4.3
T5	-1.3	-1.7	-5.1	-4.0
TU	-1.5	-2.1	-2.6	-4.4

Table 12.15: Test #56A Wing Skin Temperature Data

Test 56A: EG106, IP/R Mod, Tunnel OAT -1.4°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.4	-1.7	-3.3	-3.5
T5	-2.7	-1.6	-3.0	-2.7
TU	-3.6	-3.1	-0.9	-3.4

Table 12.16: Test #57 Wing Skin Temperature Data

Test 57: Launch, IP-/SN-, Tunnel OAT -3.6°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.4	-2.5	-6.9	-4.6
T5	-3.3	-2.4	-6.8	-4.2
TU	-3.0	-3.1	-2.6	-4.9

Table 12.17: Test #57A Wing Skin Temperature Data

Test 57A: Launch, IP-/SN-, Tunnel OAT -4.2°C				
WING TEMPERATURE (°C)				
Wing Position	Before Fluid Application	After Fluid Application	After Precip. Application	After Takeoff Test
T2	-3.9	-3.0	-7.1	-5.1
T5	-3.3	-3.0	-7.2	-4.8
TU	-4.6	-4.3	-2.7	-5.3

12.3.3 Fluid Brix Data

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

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

Tables 12.18 to 12.25 show the fluid Brix measurements collected during the contaminated fluid tests.

Table 12.18: Test #26 Fluid Brix Data

Test 26: EG106, IP-/ZR-, Tunnel OAT -1.9°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Test
2	32.00	20.25	29.50
8	32.00	14.50	28.00

Table 12.19: Test #26A Fluid Brix Data

Test 26A: EG106, IP-/ZR-, Tunnel OAT -3.3°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	31.75	17.50	25.25
8	32.00	21.50	25.00

Table 12.20: Test #28 Fluid Brix Data

Test 28: Launch, IP-, Tunnel OAT -4.2°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	35.75	15.75	23.00
8	36.50	14.75	24.00

Table 12.21: Test #28A Fluid Brix Data

Test 28A: Launch, IP-, Tunnel OAT -5.5°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.25	18.50	29.25
8	37.00	19.00	21.00

Table 12.22: Test #56 Fluid Brix Data

Test 56: EG106, IP/R Mod, Tunnel OAT -1.1°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.00	13.50	31.25
8	32.50	12.00	30.75

Table 12.23: Test #57 Fluid Brix Data

Test 57: Launch, IP-/SN-, Tunnel OAT -3.6°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	36.25	15.00	26.25
8	36.75	14.50	26.00

Table 12.24: Test #56A Fluid Brix Data

Test 56A: EG106, IP/R Mod, Tunnel OAT -1.4°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	32.25	12.00	N/A
8	32.00	10.50	29.00

Table 12.25: Test #57A Fluid Brix Data

Test 57A: Launch, IP-/SN-, Tunnel OAT -4.2°C			
FLUID BRIX (°)			
Wing Position	After Fluid Application	After Precip. Application	After Takeoff Test
2	37.50	13.50	24.25
8	36.75	7.50	27.50

12.4 Photos

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

- Start of test;
- Before Rotation (just before the wing began to pitch);

- End of Rotation (end of the rotation cycle when the wing position is returned to 4 degrees); and
- End of test.

The photos taken during the Flap Retracted Versus Flap Extended testing have been presented. Photos 12.1 to 12.32 show the photo summaries of the tests conducted and are organized for easy comparison. A complete set of photos will be provided to the TDC in electronic format.

12.5 Summary of Results

A summary of the lift losses observed during the comparative tests is demonstrated in Table 12.26. The following are details regarding the comparative tests.

Table 12.26: Lift Loss Comparison for Flap Up vs. Flap Down Tests

Test #	% LL from Dry (Flap Down)	% LL from Dry (Flap Up)	Delta Difference Flap Down - Flap Up (%)
26 / 26A	4.78	1.41	3.37
28 / 28A	4.26	3.85	0.41
56 / 56A	3.21	3.39	-0.17
57 / 57A	4.72	2.92	1.80
		Average	**1.35**

During the first comparative test set, Test #26 and #26A, testing was conducted with EG106 fluid in mixed light ice pellet and light freezing rain conditions. In both cases, the level of contamination on the main wing section was acceptable and comparable at the start of the test (both leading edge and trailing edge visual ratings were below 3 for both tests). However, the trailing edge visual rating was more severe during Test #26 with the flap down (visual rating of 4.7 on the flap) compared to Test #26A conducted with the flap up (visual rating of 1.9 on the flap). At the time of rotation, the main wing section was clean and comparable for both tests; however, a significant amount of contamination was still present on the flap for Test #26 (contaminated with the flap down) compared to Test #26A (contaminated with the flap up). The lift data at the time of rotation supported the visual observations and recorded a 3.4 percent improvement in lift loss from 4.8 percent to 1.4 percent when compared to the dry wing for Tests #26 and #26A, respectively.

During the second comparative test set, Tests #28 and #28A, testing was conducted with Launch fluid in light ice pellet conditions. In both cases, the level of contamination on the main wing section was acceptable and comparable at the start of the test (both leading edge and trailing edge visual ratings were below 3 for both tests). However, the trailing edge visual rating was more severe during Test #28 with the flap up (visual rating of 3.7 on the flap) compared to Test #28A conducted with the flap down (visual rating of 2.7 on the flap). At the time of rotation, the main wing section was clean and comparable for both tests. In addition, comparable levels of contamination were also present on the flap at the time of rotation for both tests (visual contamination rating of 2). The lift data at the time of rotation supported the visual observations and recorded comparable lift losses. A 0.4 percent improvement in lift loss was recorded from 4.3 percent to 3.9 percent when compared to the dry wing for Tests #28 and #28A, respectively.

During the third comparative test set, Tests #56 and #56A, testing was conducted with EG106 fluid in light ice pellet conditions. In both cases, the level of contamination on the main wing section was acceptable and comparable at the start of the test (both leading edge and trailing edge visual ratings were below 3 for both tests). However, the trailing edge visual rating was more severe during Test #56 with the flap up (visual rating of 4.7 on the flap) compared to Test #56A conducted with the flap down (visual rating of 3 on the flap). At the time of rotation, the main wing section was clean and comparable for both tests. In addition, comparable levels of contamination were present on the flap at the time of rotation for both tests (visual contamination rating of 5 for Test #56 compared to rating of 4.3 for Test #56A). The lift data at the time of rotation supported the visual observations and recorded comparable lift losses. Minimal differences in lift loss were recorded; lift losses were 3.2 percent and 3.4 percent when compared to the dry wing for Tests #56 and #56A, respectively.

During the last comparative test set, Tests #57 and #57A, testing was conducted with Launch fluid in mixed light ice pellet and light snow conditions. In both cases, the level of contamination on the main wing section was acceptable and comparable at the start of the test (both leading edge and trailing edge visual ratings were below 3 for both tests). However, the trailing edge visual rating was more severe during Test #57 with the flap down (visual rating of 4 on the flap) compared to Test #57A conducted with the flap up (visual rating of 3 on the flap). At the time of rotation, the main wing section was clean and comparable for both tests; however, a significant amount of contamination was still present on the flap for Test #57 (contaminated with the flap down) compared to Test #57A (contaminated with the flap up). The lift data at the time of rotation supported the visual observations and recorded a 1.8 percent improvement in lift loss from 4.7 percent to 2.9 percent when compared to the dry wing for Tests #57 and #57A, respectively.

In general, the results indicated that a heavily contaminated flap could have adverse effects on aerodynamic performance. On average, the test results showed an average 1.4 percent improvement in lift loss (with a maximum of 3.4 percent recorded during Tests #26 and #26A) when the flap was up (retracted) during the contamination period. Currently, there is no set standard specifying when the flap should be extended prior to takeoff. The results of this work have indicated that keeping the flaps retracted for as long as practical before takeoff will help ensure adequate protection time from the fluid applied to the flap section.

12.6 Additional Analysis of Flap Failure

Due to the early failure observed on the flap section, it was recommended that the condition of the wing be monitored and recorded. As a low priority action item, the time at which the flap condition started to show loose bridging contamination (a visual observation rating of 3) was recorded. As a general rule, a visual contamination rating of “3” on the leading edge and trailing edge is considered acceptable, whereas greater than “3” is considered severe.

Ten tests for which data was available were analysed, and the results are demonstrated in Table 12.27. The table includes the test number, test condition, allowance time (which is equivalent to the total exposure time of the test), along with the visual observation ratings for the main wing section at the end of the allowance time, the time at which the flap condition was deemed a “3” according to the visual observation criteria. Based on this data, a ratio was calculated to provide a preliminary indication as to how much earlier failure was occurring on the flap section.

The results indicated that, on average, the flap visual contamination rating was a “3” at approximately 60 percent of the allowance time. It should, however, be noted that most of the tests included had ratings less than “3” on the leading and trailing edge at the end of the allowance time; therefore, the 60 percent ratio is not directly applicable. It can be assumed that the flap will fail faster compared to the main wing section by a factor of less than 60 percent (likely closer to 50 percent of the main wing section protection time); however, data comparing equal levels of contamination on the main wing section and on the flap is required to provide a proper estimate.

Table 12.27: Analysis of Visual Failure Time on Flap vs. Main Wing Section

		(A)		(B)	
Test #	**Condition**	**Allowance Time (min.)**	**LE & TE Visual Rating at End of Allowance Time (LE,TE)**	**Time When Flap Visual Rating Became "3" (min.)**	**% Ratio (B) / (A)**
9	IP-	50	2, 2	25	50%
11	IP-/SN-	40	3, 2.3	25	63%
13	IP-/SN	20	3, 2	19	95%
24	IP-/SN	20	2.5, 1.8	12	60%
26	IP-/ZR-	25	2.2, 1.7	15	60%
28	IP-	50	2, 2	25	50%
56	IP-/R	25	1.8, 2	13	52%
58	IP-/SN	20	2.8, 2.6	10	50%
63	IP-/ZR-	10	2.3, 2.3	4	40%
65	IP-	30	2.8, 2.8	20	67%
				Average	**59%**

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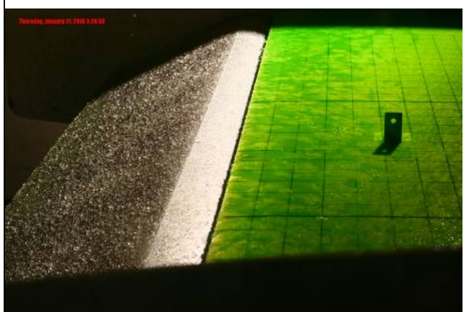
Photo 12.1: Test #26 – Start of Test

Test #26
EG106, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-2°C, 8° Rotation
Visual Contamination Rating (2.2,1.7,4.7)
Start of Test



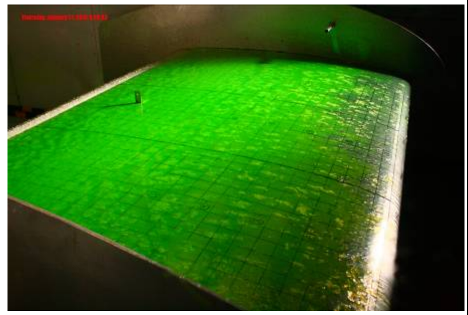
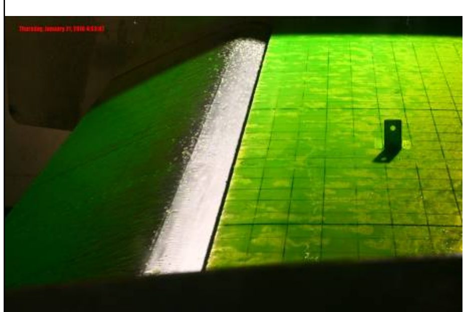


Photo 12.2: Test #26A – Start of Test

Test #26A
EG106, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-3°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1.8,2,1.9)
Start of Test



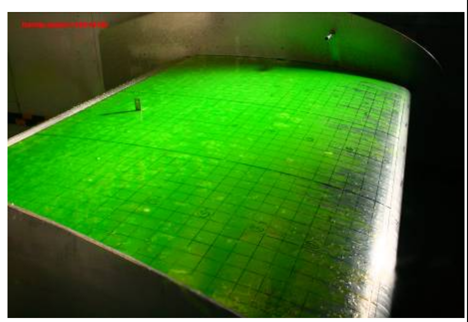
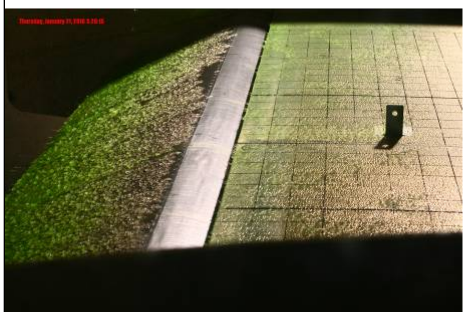


Photo 12.3: Test #26 – Before Rotation

Test #26
EG106, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-2°C, 8° Rotation
Visual Contamination Rating (1,1,4)
Before Rotation



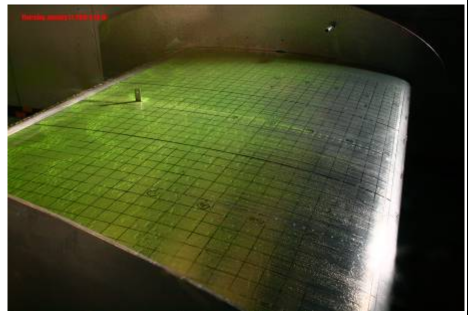
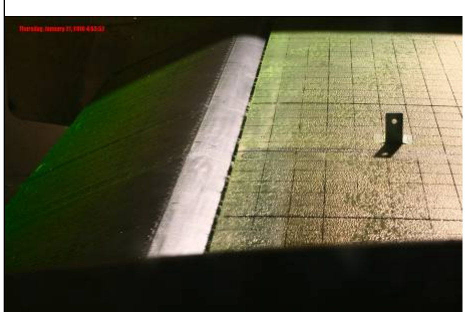


Photo 12.4: Test #26A – Before Rotation

Test #26A
EG106, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-3°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1,1,1)
Before Rotation



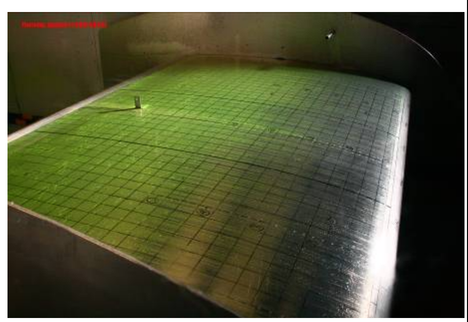
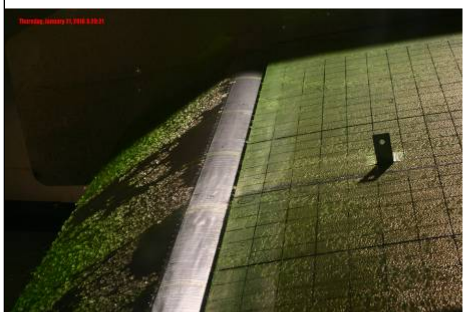


Photo 12.5: Test #26 – End of Rotation

Test #26
EG106, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-2°C, 8° Rotation
Visual Contamination Rating (1,1,4), 8° Lift Loss = 4.78%

End of Rotation



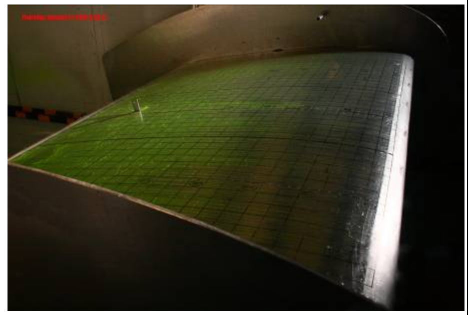
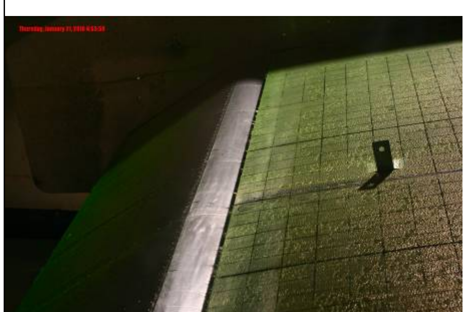


Photo 12.6: Test #26A – End of Rotation

Test #26A
EG106, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-3°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1,1,1), 8° Lift Loss = 1.41%

End of Rotation



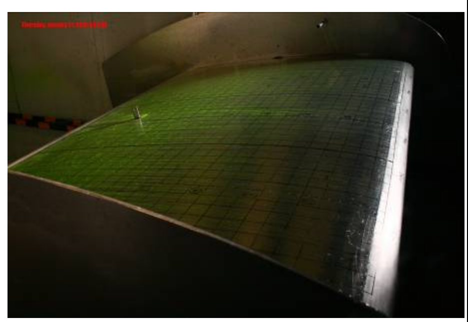
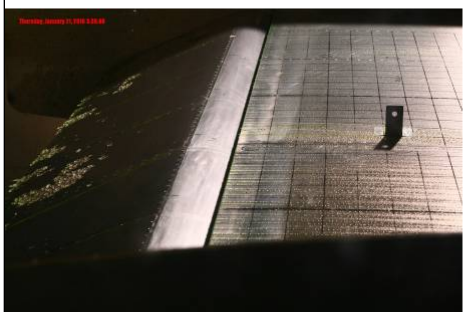


Photo 12.7: Test #26 – End of Test

Test #26
EG106, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-2°C, 8° Rotation
Visual Contamination Rating (1,1,3.5)
End of Test



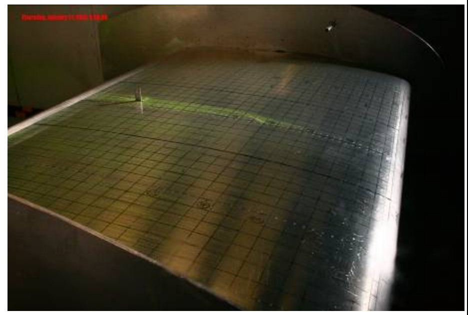
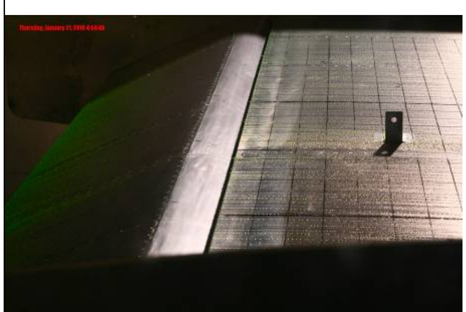


Photo 12.8: Test #26A – End of Test

Test #26A
EG106, IP- + ZR- 25 + 25 g/dm²/h, 25 min
-3°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1,1,1)
End of Test



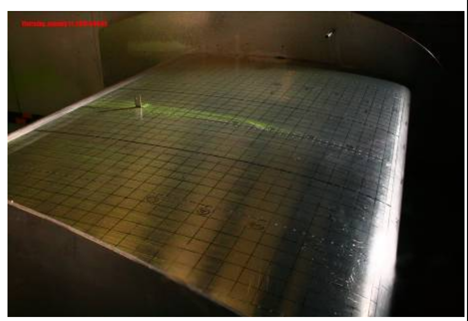
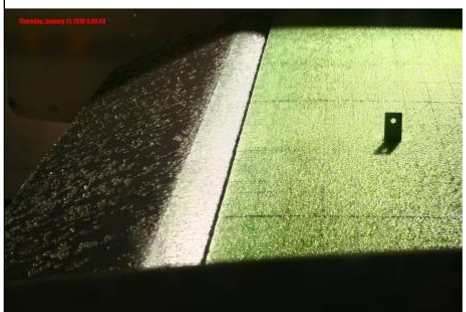


Photo 12.9: Test #28 – Start of Test

Test #28
Launch, IP- 25 g/dm²/h, 50 min
-4°C, 8° Rotation
Visual Contamination Rating (2,2,3.7)
Start of Test



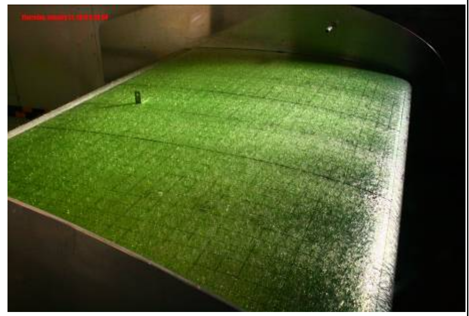
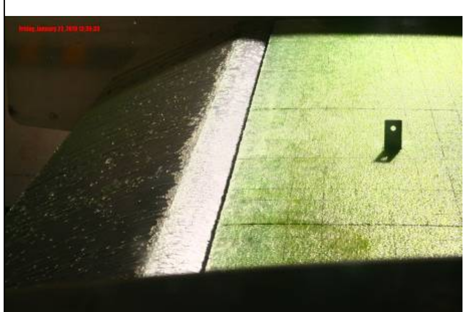


Photo 12.10: Test #28A – Start of Test

Test #28A
Launch, IP- 25 g/dm²/h, 50 min
-6°C, Flap Angle 0°, 8° Rotation
Visual Contamination Rating (2,2,2.7)
Start of Test



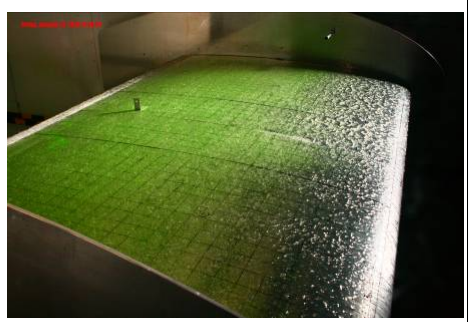


Photo 12.11: Test #28 – Before Rotation

Test #28

Launch, IP- 25 g/dm²/h, 50 min

-4°C, 8° Rotation

Visual Contamination Rating (1,1.7,2)

Before Rotation

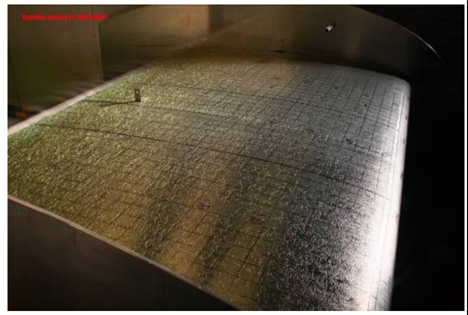


Photo 12.12: Test #28A – Before Rotation

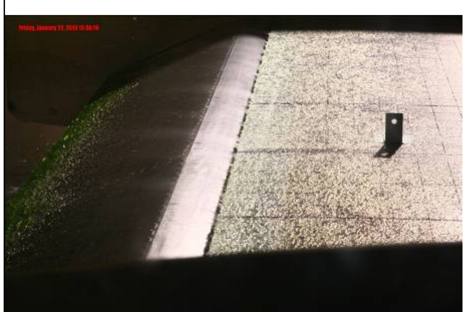
Test #28A

Launch, IP- 25 g/dm²/h, 50 min

-6°C, Flap Angle 0°, 8° Rotation

Visual Contamination Rating (1,1.5,2)

Before Rotation



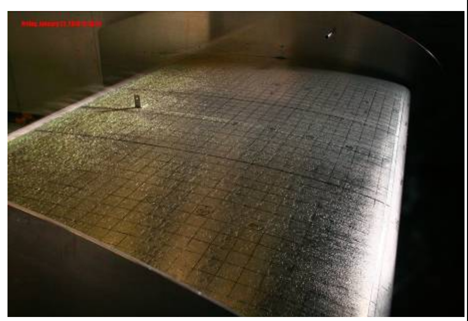


Photo 12.13: Test #28 – End of Rotation

Test #28

Launch, IP- 25 g/dm²/h, 50 min

-4°C, 8° Rotation

Visual Contamination Rating (1,1.7,2), 8° Lift Loss = 4.26%

End of Rotation

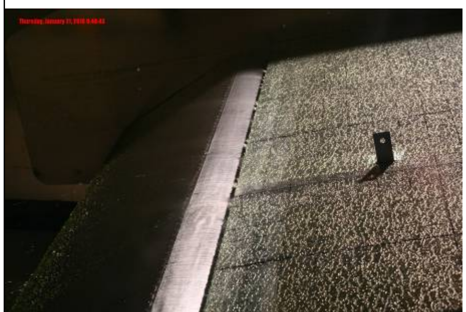


Photo 12.14: Test #28A – End of Rotation

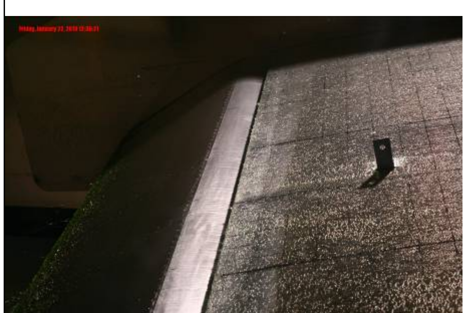
Test #28A

Launch, IP- 25 g/dm²/h, 50 min

-6°C, Flap Angle 0°, 8° Rotation

Visual Contamination Rating (1,1.5,2), 8° Lift Loss = 3.85%

End of Rotation



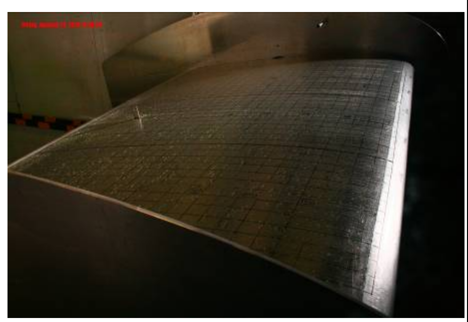
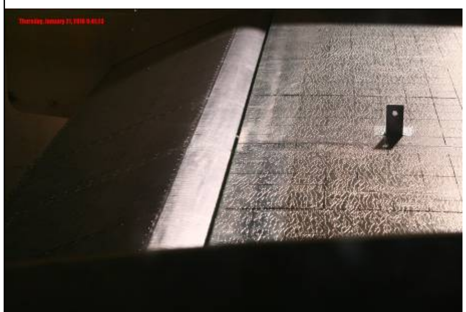


Photo 12.15: Test #28 – End of Test

Test #28
Launch, IP- 25 g/dm²/h, 50 min
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test



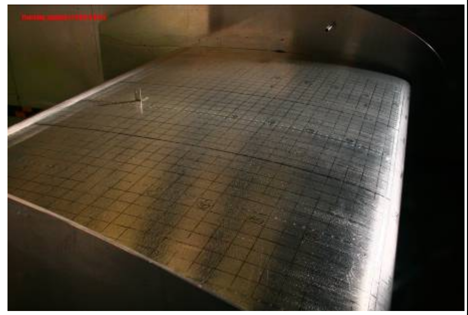
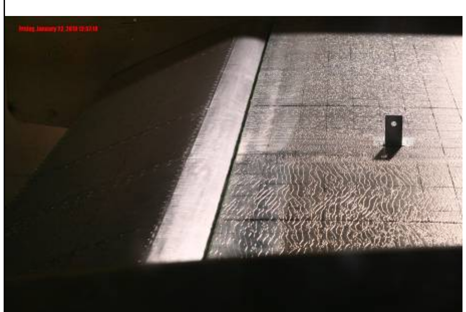


Photo 12.16: Test #28A – End of Test

Test #28A
Launch, IP- 25 g/dm²/h, 50 min
-6°C, Flap Angle 0°, 8° Rotation
Visual Contamination Rating (1,1,1)
End of Test



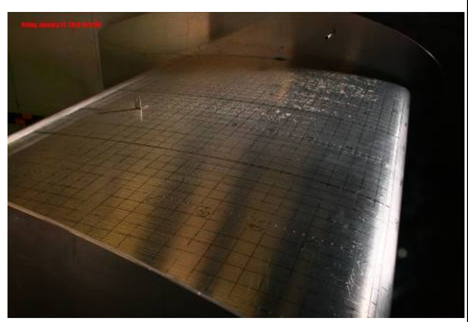
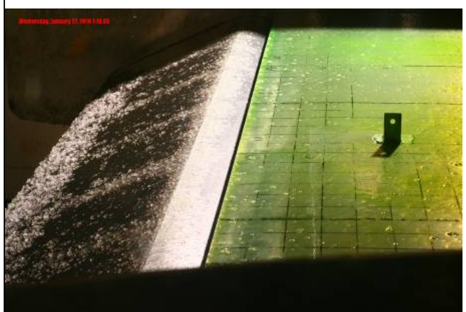


Photo 12.17: Test #56 – Start of Test

Test #56
EG106, IP + Mod R 25 + 75 g/dm²/h, 25 min
-1°C, 8° Rotation
Visual Contamination Rating (1.8,2,4.7)
Start of Test



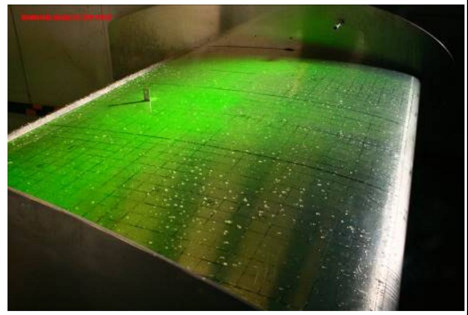


Photo 12.18: Test #56A – Start of Test

Test #56A
EG106, IP + Mod R 25 + 75 g/dm²/h, 25 min
-1°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1.8,2.2,3)
Start of Test

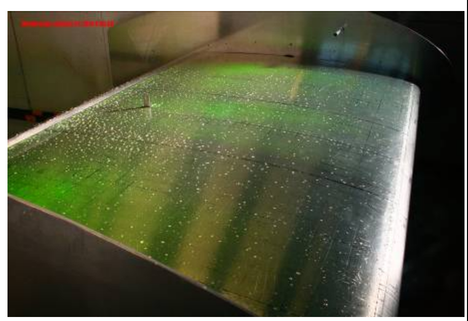


Photo 12.19: Test #56 – Before Rotation

Test #56
EG106, IP + Mod R 25 + 75 g/dm²/h, 25 min
-1°C, 8° Rotation
Visual Contamination Rating (1,1,5)
Before Rotation

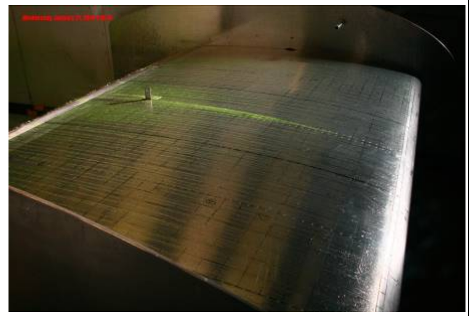



Photo 12.20: Test #56A – Before Rotation

Test #56A
EG106, IP + Mod R 25 + 75 g/dm²/h, 25 min
-1°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1,1,4.3)
Before Rotation

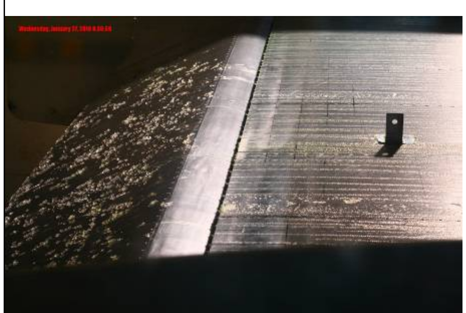
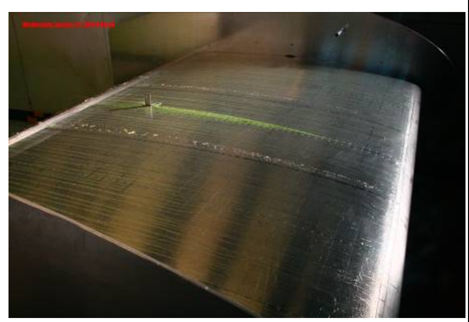
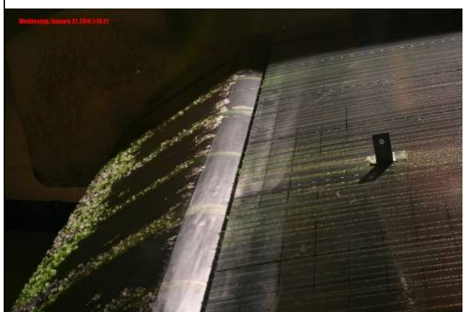



Photo 12.21: Test #56 – End of Rotation

Test #56
EG106, IP + Mod R 25 + 75 g/dm²/h, 25 min
-1°C, 8° Rotation
Visual Contamination Rating (1,1,5), 8° Lift Loss = 3.21%
End of Rotation



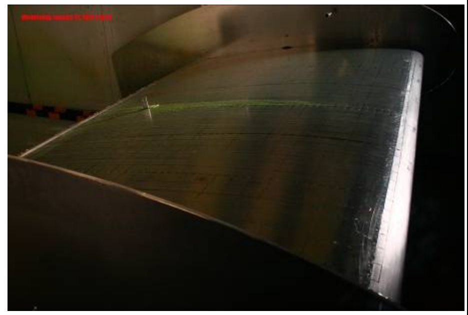
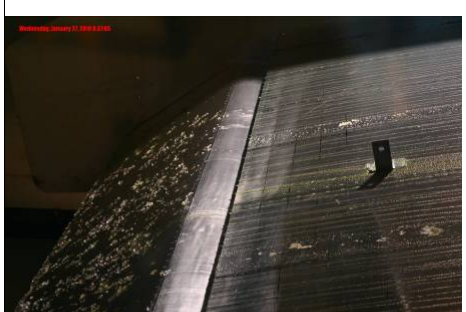


Photo 12.22: Test #56A – End of Rotation

Test #56A
EG106, IP + Mod R 25 + 75 g/dm²/h, 25 min
-1°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1,1,4.3), 8° Lift Loss = 3.39%
End of Rotation



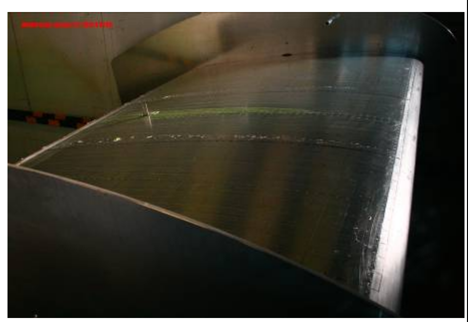


Photo 12.23: Test #56 – End of Test

Test #56

EG106, IP + Mod R 25 + 75 g/dm²/h, 25 min

-1°C, 8° Rotation

Visual Contamination Rating (1,1,5)

End of Test

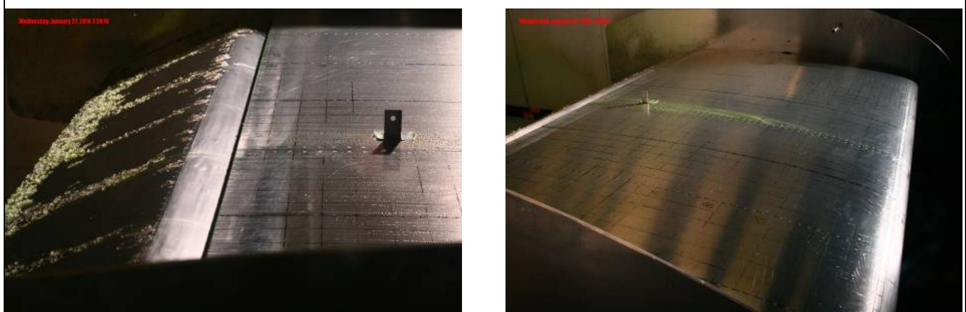


Photo 12.24: Test #56A – End of Test

Test #56A

EG106, IP + Mod R 25 + 75 g/dm²/h, 25 min

-1°C, 8° Rotation, Flap Angle 0°

Visual Contamination Rating (1,1,4.3)

End of Test

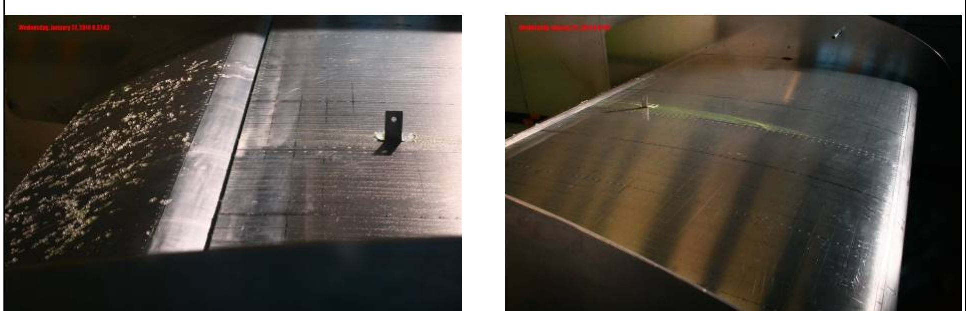
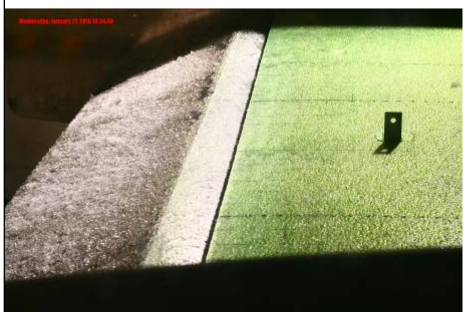


Photo 12.25: Test #57 – Start of Test

Test #57
Launch, IP- + SN- 25 + 10 g/dm²/h, 40 min
-4°C, 8° Rotation
Visual Contamination Rating (2.7,2.6,4)
Start of Test



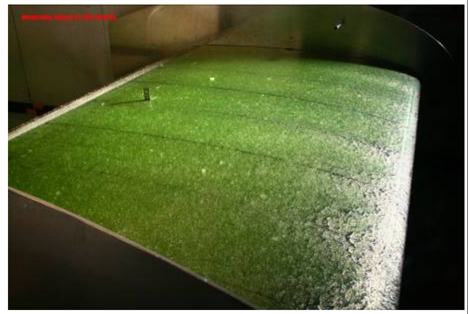
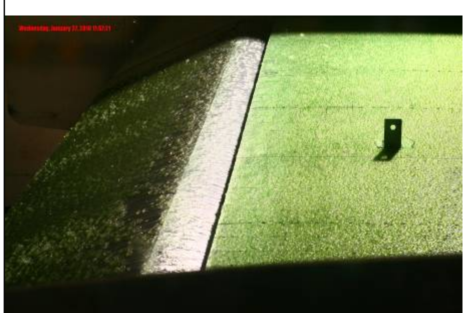


Photo 12.26: Test #57A – Start of Test

Test #57A
Launch, IP- + SN- 25 + 10 g/dm²/h, 40 min
-4°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (2.6,2.6,3)
Start of Test



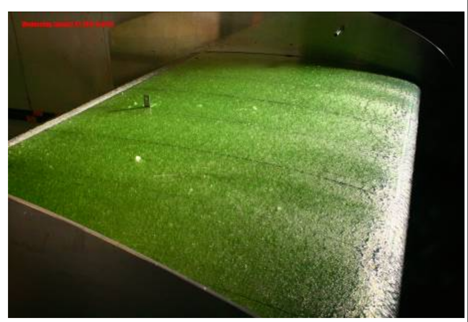
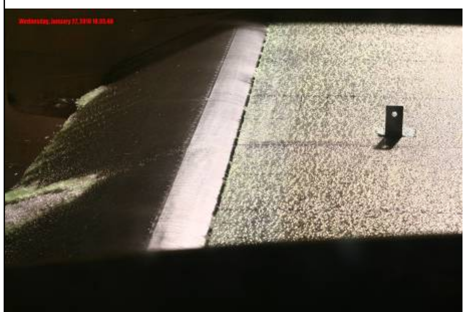


Photo 12.27: Test #57 – Before Rotation

Test #57
Launch, IP- + SN- 25 + 10 g/dm²/h, 40 min
-4°C, 8° Rotation
Visual Contamination Rating (1,1.7,2.8)
Before Rotation



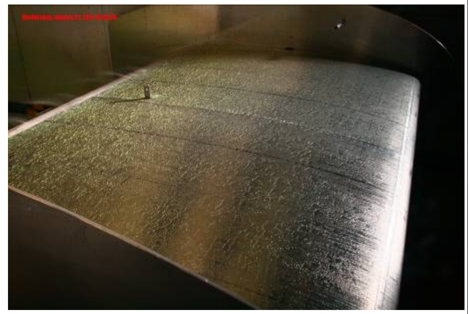
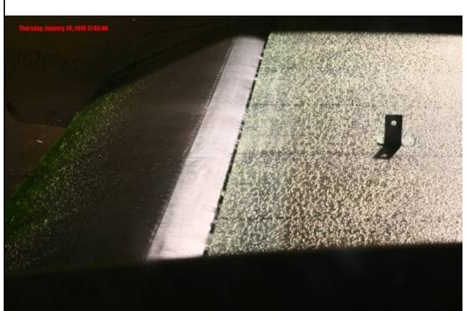


Photo 12.28: Test #57A – Before Rotation

Test #57A
Launch, IP- + SN- 25 + 10 g/dm²/h, 40 min
-4°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1,1.3,1.7)
Before Rotation



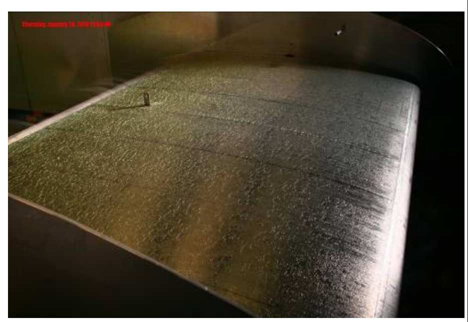


Photo 12.29: Test #57 – End of Rotation

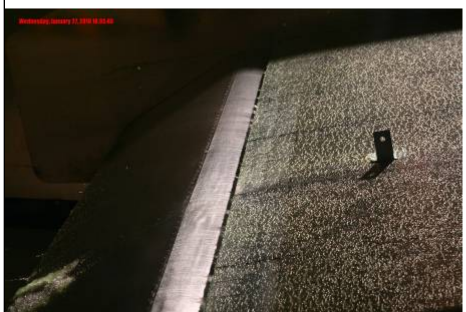
Test #57

Launch, IP- + SN- 25 + 10 g/dm²/h, 40 min

-4°C, 8° Rotation

Visual Contamination Rating (1,1.7,2.8), 8° Lift Loss = 4.72%

End of Rotation



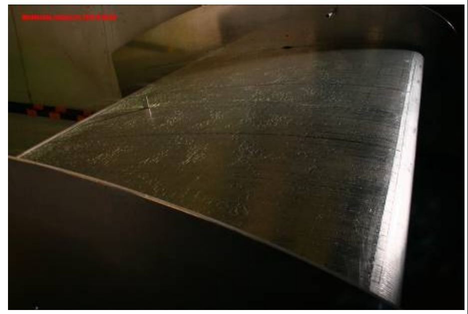


Photo 12.30: Test #57A – End of Rotation

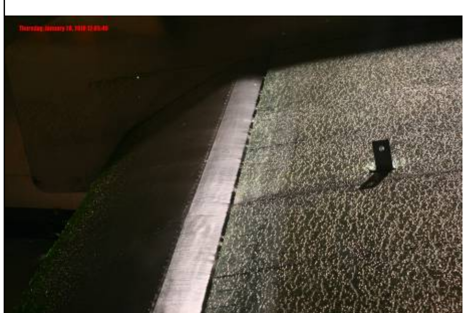
Test #57A

Launch, IP- + SN- 25 + 10 g/dm²/h, 40 min

-4°C, 8° Rotation, Flap Angle 0°

Visual Contamination Rating (1,1.3,1.7), 8° Lift Loss = 2.92%

End of Rotation



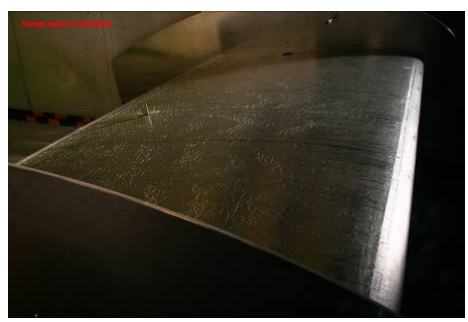
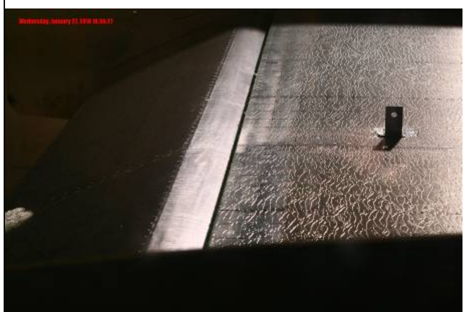


Photo 12.31: Test #57 – End of Test

Test #57
Launch, IP- + SN- 25 + 10 g/dm²/h, 40 min
-4°C, 8° Rotation
Visual Contamination Rating (1,1,1.3)
End of Test



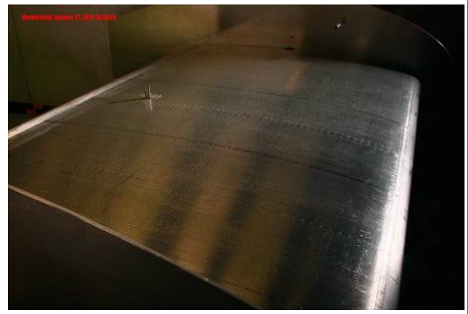
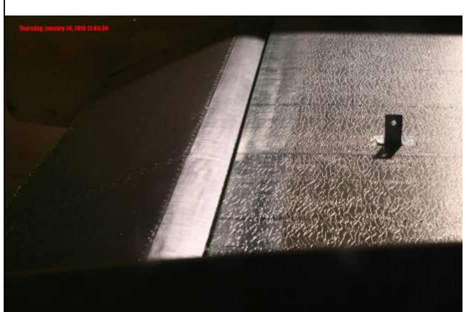
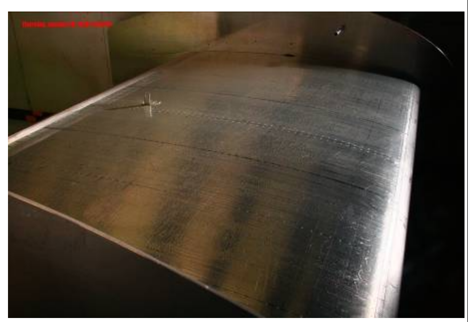


Photo 12.32: Test #57A – End of Test

Test #57A
Launch, IP- + SN- 25 + 10 g/dm²/h, 40 min
-4°C, 8° Rotation, Flap Angle 0°
Visual Contamination Rating (1,1,1)
End of Test





13. CONCLUSIONS AND OBSERVATIONS

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

13.1 Type IV High-Speed Allowance Times

In comparison to previous tests on other airfoils, fluid flow-off issues with the supercritical wing were observed with PG fluids at the lower temperatures. More specifically, lift losses greater than 8 percent on the 2D model were recorded during light ice pellet and moderate ice pellet conditions below -10ºC; visual observations supported the lift loss data collected. As a result, rather than restrict the allowance times to EG fluids only, the PG data collected was re-analysed simulating higher rotation speeds. The analysis indicated that the allowance times would be acceptable for rotation speeds of 115 knots or greater (compared to 100 knots or greater). It was recommended that a footnote restricting the use of PG fluids to aircraft with rotation greater than 115 knots during light ice pellet and moderate ice pellet conditions below -10ºC be included in the allowance time table for the winter of 2010-11.

In addition, fluid failure issues with the supercritical wing were observed with PG fluids during moderate ice pellets above -5ºC. The relatively flat surface of the wing had less fluid flow-off and resulted in an earlier fluid failure for PG fluids. Data collected indicated that an allowance time of 15 minutes would be more appropriate. It was recommended that a footnote reducing the allowance time to 15 minutes for PG fluids during moderate ice pellet conditions above -5ºC be included in the allowance time table for the winter of 2010-11.

In general, it was found that the tests conducted in all other conditions generated acceptable lift losses based on the current evaluation criteria: i.e., lift loss less than 5 percent was considered “good,” between 5 percent and 8 percent was considered “ok” (acceptable), whereas tests with lift losses above 8 percent were considered “bad” and required further review. Typically, the EG fluids performed better, especially in the colder temperatures, and generated lower lift losses as compared to the PG fluids.

In general, higher lift losses were observed with the supercritical wing compared to previous wings tested. Although initially 5 percent was used as the initial cut-off for evaluating each test, this was expanded to 8 percent based on the data collected; 8 percent lift loss correlated well with the visual observations recorded. Additional analysis paired with wind tunnel and full-scale aircraft testing is recommended to develop a correlation between the lift losses observed in the wind tunnel and those seen on an operational aircraft with newer generation supercritical wings.

13.2 Lift Coefficient Data vs. Visual Contamination Ratings

The preliminary analysis identified a potential correlation between the visual observations recorded during the tests and the lift losses calculated based on the lift coefficient data collected; this is particularly true for visual observations taken for the leading edge at the start of rotation. Visual observations should continue to be recorded for future wind tunnel testing, as they have proven to be of value as an analysis tool.

13.3 Comparison of Fluid Certification BLDT Results vs. NRC Wind Tunnel Lift Loss Results

The preliminary 2D results from this analysis indicate that 5 percent lift loss may not be appropriate as the lift loss cut-off. When correlating to the fluid certification results, a higher lift loss cut-off may be more appropriate based on the Launch, ABC-S Plus, and EG106 data. It is recommended that future testing be done to simulate fluid certification results in the NRC wind tunnel at specific temperatures to substantiate the correlation observed in this preliminary analysis.

13.4 Probability of Ice Pellet Occurrences for Use with Allowance Times

Ice pellet precipitation data was acquired from instruments located at six stations in Quebec, Canada, from the MSC. This data was collected as part of an ongoing study to evaluate the suitability of the current format of the HOT tables [see TC report, TP 15051E, *Winter Weather Impact on Holdover Time Table Format (1995-2010)* (14)]. The results were translated into the likelihood of ice pellet occurrence in each cell of the allowance time table. The outcome is shown in Table 13.1

Values in italics in Table 13.1 indicate conditions where no allowance times currently exist. Based on this limited data, it appears a significant portion of light ice pellets mixed with light snow precipitation occurs below -10°C and light ice pellets mixed with moderate snow precipitation occurs below -5°C to -10°C, where no allowance times currently exist. It is recommended that future research target these conditions in order to allow greater flexibility to operators in conditions of mixed ice pellets with light or moderate snow.

Table 13.1: Likelihood of Occurrence for Use with Ice Pellet Allowance Times

Condition	Possible Rate	OAT -5°C and Above	OAT less than -5°C to -10°C	OAT less than -10°C	Total
Light Ice Pellets	(0 to 25 $g/dm^2/h$)	84.9%	11.9%	0%	**100%**
Moderate Ice Pellets	(25 to 75 $g/dm^2/h$)	3.2%	0%	0%	
***Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle**	(0 to 38 $g/dm^2/h$)	89.8%	10.2%	*0%*	**100%**
***Light Ice Pellets Mixed with Light Freezing Rain**	(0 to 50 $g/dm^2/h$)				
***Light Ice Pellets Mixed with Light Rain**	(0 to 50 $g/dm^2/h$)	98.5%[1]	*0%*	*0%*	
***Light Ice Pellets Mixed with Moderate Rain**	(25 to 100 $g/dm^2/h$)	13.8%[2]	*0%*	*0%*	
***Light Ice Pellets Mixed with Light Snow**	(0 to 35 $g/dm^2/h$)	65.5%	14%[3]	*16.6%*	
***Light Ice Pellets Mixed with Moderate Snow**	(10 to 50 $g/dm^2/h$)	20.9%[4]	*7.9%*	*1.0%*	

*Analysis based upon a cumulative rate of both precipitation types and assumes ice pellet intensity does not exceed "light" or 25 $g/dm^2/h$

FOOTNOTES

[1] If the weather report is ice pellets mixed with rain, there is a 98.5% likelihood of light ice pellets mixed with light rain with a possible rate from 0 to 50 $g/dm^2/h$ (at OAT -5°C and above).
[2] If the weather report is ice pellets mixed with rain, there is a 13.8% likelihood of light ice pellets mixed with moderate rain with a possible rate from 25 to 100 $g/dm^2/h$ (at OAT -5°C and above).
[3] If the weather report is ice pellets mixed with snow, there is a 14% likelihood of light ice pellets mixed with light snow with a possible rate from 0 to 35 $g/dm^2/h$ (at OAT -5°C to -10°C).
[4] If the weather report is ice pellets mixed with snow, there is a 20.9% likelihood of light ice pellets mixed with moderate snow with a possible rate from 10 to 50 $g/dm^2/h$ (at OAT -5°C and above).

13.5 Flap Retracted (UP) vs. Flap Extended (DOWN)

In general, the results indicated that a heavily contaminated flap could have adverse effects on aerodynamic performance. On average, the test results showed an average 1.4 percent improvement in lift loss (with a maximum of 3.4 percent) when the flap was up (retracted) during the contamination period. It can be assumed that the flap will fail faster compared to the main wing section by a factor of less than 60 percent (likely closer to 50 percent of the main wing section protection time); however, data comparing equal levels of contamination on the main wing section and on the flap is required to provide a proper estimate.

14. RECOMMENDATIONS

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

14.1 Newly Proposed (and Adopted) Type IV High-Speed Allowance Time Table

Based on the 2009-10 wind tunnel test results, a newly updated version of the Type IV allowance time table has been developed, proposed, and adopted for the 2010-11 version of the HOT Guidelines. This work was presented at the SAE G-12 meeting in Berlin in May 2010; a copy of the presentation is included in TC report, TP 15053E, *Aircraft Ground Icing General Research Activities During the 2009-10 Winter* (15). The updated allowance time table is shown in Table 14.1.

Table 14.1: 2010-11 Ice Pellet Allowance Time Table

ICE PELLET ALLOWANCE TIMES FOR WINTER 2010-2011

	OAT -5°C and above	OAT less than -5°C to -10°C	OAT less than -10°C
Light Ice Pellets	50 minutes	30 minutes	30 minutes[1]
Moderate Ice Pellets	25 minutes[2]	10 minutes	10 minutes[1]
Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle	25 minutes	10 minutes	Caution: No allowance times currently exist
Light Ice Pellets Mixed with Light Freezing Rain	25 minutes	10 minutes	
Light Ice Pellets Mixed with Light Rain	25 minutes		
Light Ice Pellets Mixed with Moderate Rain	25 minutes		
Light Ice Pellets Mixed with Light Snow	25 minutes	15 minutes	
Light Ice Pellets Mixed with Moderate Snow	10 minutes		

NOTES

1 No allowance times exist for propylene glycol (PG) fluids, when used on aircraft with rotation speeds less than 115 knots. (For these aircraft, if the fluid type is not known, assume zero allowance time).

2 Allowance time is 15 minutes for propylene glycol (PG) fluids, or when the fluid type is unknown.

14.2 Future Research

14.2.1 Type IV High-Speed Allowance Times

Historical winter weather data has indicated that a significant portion of light ice pellets mixed with light snow precipitation occurs below -10°C and light ice pellets mixed with moderate snow precipitation occurs below -5ºC to -10°C where no allowance times currently exist. It is recommended that future research target these conditions in order to allow greater flexibility to operators in conditions of mixed ice pellets with light or moderate snow.

Additional testing is also recommended in light and moderate ice pellet conditions close to the lower end of the -10ºC to -25ºC range (where data is limited) and in moderate ice pellet conditions above -5ºC to validate the changes made to the allowance time table for the winter of 2010-11. Testing should also include different fluids to further validate the current allowance times.

14.2.2 Additional Testing and Analysis to Further Investigate Supercritical Wing Lift Losses

Additional analysis paired with wind tunnel and full-scale aircraft testing is recommended to develop a correlation between the lift losses observed in the wind tunnel and those seen on an operational aircraft with newer generation supercritical wings.

14.2.2.1 Full-Scale Aircraft Testing

Full-scale aircraft testing with the NRC Falcon 20 or FAA Technical Centre Global Express could be used to validate the wind tunnel test results.

14.2.2.2 100 vs. 115 Knots Rotation Speed

Testing is recommended to investigate the increase in fluid flow-off as a result of higher rotation speeds (100 knots vs. 115 knots) and to validate the analysis methodology used to extrapolate the lift coefficient data.

14.2.2.3 Comparative Testing - Fluid Certification BLDT Results vs. NRC Wind Tunnel Lift Loss Results

Comparative testing should be conducted in the wind tunnel to obtain directly comparable data to the fluid certification BLDT results. This data could provide insight for developing a correlation between the lift losses observed in the wind tunnel and the fluid certification test.

14.2.2.4 Investigation of 2D vs. 3D Effects

Discussions with industry members have indicated that potential 2D versus 3D effects may be responsible for some of the increased lift losses observed in the wind tunnel. An analytical study (and potential testing if possible) should be conducted to evaluate and quantify the effect of this phenomenon on the testing protocol.

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APPENDIX A

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

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

5.3 Aircraft Performance Research

5.3.1 Wind Tunnel Testing to Refine Allowance Times

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

b) Participate in the development and construction of a new super-critical airfoil model to be used for testing;

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

d) Perform wind tunnel tests to possibly expand current allowance times published by TC and FAA and to validate the results for super-critical airfoils. Testing will also be conducted to potentially develop an allowance time table for use with Type III fluid;

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

f) Perform wind tunnel tests to simulate low speed and high speed takeoffs in accordance with the speed and angle of attack profiles provided by TDC and airframe manufacturers. The simulated take-off profile will target the clean wing stall angle as the maximum angle of attack in order to better quantify the observed lift losses. The analysis will evaluate the lift results at an angle approximately halfway between the typical angle of attack at rotation and the stall angle;

g) During contaminated test runs, a baseline fluid only case will be run immediately before, or after the contaminated test run to provide a direct correlation of the results;

h) Collect the following data during the tests:

    i. Type and amount of fluid applied;

    ii. Type and rate of contamination applied; and

    iii. Extent of fluid contamination prior to the test run.

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

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

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

APPENDIX B

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

CM2169.002

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

Winter 2009-10

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Marco Ruggi

Reviewed by: John D'Avirro

APS Aviation Inc.

December 23, 2009
Final Version 1.0

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

1. BACKGROUND

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

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

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

During the following winter of 2006-07, the FAA provided a 25 minute allowance as a preliminary guideline; TC issued a note indicating that no changes would be made to the HOT guidelines. This allowance was based on the previous research conducted during the winter of 2005-06, primarily as a result of Falcon 20 aerodynamic research (see TP 14716E); these results were presented at the Society of Automotive Engineers (SAE) meeting in Lisbon in May 2006. To address the option of a pre-take off contamination check, the 20 minute targeted allowance was extended to 25 minutes; pre-take off contamination checks would no longer apply. This allowance was followed by a list of conditions; one restriction was that operations would be limited to ice pellets alone (no mixed conditions).

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

During the winter of 2007-08, the TC and FAA provided allowance time guidance material for operations in mixed conditions with ice pellets guideline. These allowance times were based on the research conducted during the winter of 2006-07 (see TP 14779E). The recommended allowance times were based on aerodynamic research conducted using the 3 m x 6 m Open Circuit Propulsion and Icing Wind Tunnel (PIWT) and the NRC Falcon 20 aircraft; these results were presented at the SAE meeting in San Diego in May 2007. These allowance time guidelines were followed by a list of restrictions based on the results obtained through the research conducted, and the lack of data in specific conditions.

During the winter of 2008-09, additional endurance time testing and aerodynamic research was conducted to support and further expand the ice pellet allowance times (see TP 14935E). Full-scale testing with the NRC PIWT was conducted in mixed conditions with ice pellets and in non precipitation conditions. Testing was geared towards validating the current ice pellet allowance times, and potentially expanding the guidance material to include different conditions, fluids, and acceleration profiles. A revised version of the ice pellet allowance times was published for the winter of 2009-10; changes were made to the high speed table allowance times only.

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

2. OBJECTIVES

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

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

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

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

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

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

To satisfy these objectives, a super-critical wing section (Figure 2.1) will be subjected to a series of tests in the NRC wind tunnel. The dimensions indicated are in inches. This wing section was constructed by NRC specifically for the conduct of these tests following extensive consultations with an airframe manufacturer to ensure a representative super-critical design.

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

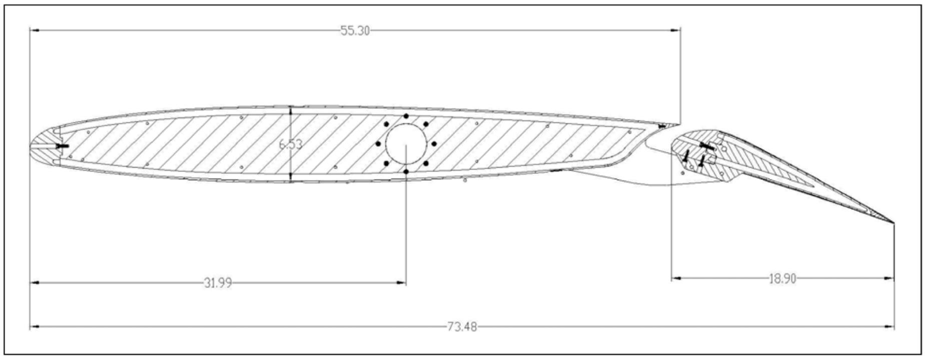


Figure 2.1: Super-Critical Wing Section

3. TEST PLAN

The NRC wind tunnel is an open circuit tunnel. The temperature inside the wind tunnel is dependent on the outside ambient temperature. Prior to testing, the weather should be monitored to ensure proper temperatures for testing.

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

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

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

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

Table 3.1: Preliminary Test Calendar

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

Table 3.2: Proposed Test Plan

Test Plan #	Objective	Priority	Test Condition	Fluid	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	ZR Rate (g/dm²/h)	R Rate (g/dm²/h)	Exposure Time	Target OAT (°C)	Ramp (kts)
P1	IP Validation	1	IP-	EG 106	25	-	-	-	50	-5	100
P2	IP Validation	1	IP-	ABC-S Plus	25	-	-	-	50	-5	100
P3	IP Validation	2	IP-	Launch	25	-	-	-	50	-5	100
P4	IP Validation	1	IP Mod	EG 106	75	-	-	-	25	-5	100
P5	IP Validation	1	IP Mod	ABC-S Plus	75	-	-	-	25	-5	100
P6	IP Validation	2	IP Mod	Launch	75	-	-	-	25	-5	100
P7	IP Validation	1	IP- / ZR-	EG 106	25	-	25	-	25	-5	100
P8	IP Validation	1	IP- / ZR-	ABC-S Plus	25	-	25	-	25	-5	100
P9	IP Validation	2	IP- / ZR-	Launch	25	-	25	-	25	-5	100
P10	IP Validation	1	IP- / SN-	EG 106	25	10	-	-	25	-5	100
P11	IP Validation	1	IP- / SN-	ABC-S Plus	25	10	-	-	25	-5	100
P12	IP Validation	2	IP- / SN-	Launch	25	10	-	-	25	-5	100
P13	IP Validation	1	IP- / SN	EG 106	25	25	-	-	10	-5	100
P14	IP Validation	1	IP- / SN	ABC-S Plus	25	25	-	-	10	-5	100
P15	IP Validation	2	IP- / SN	Launch	25	25	-	-	10	-5	100
P16	IP Validation	1	IP-	EG 106	25	-	-	-	30	-10	100
P17	IP Validation	1	IP-	ABC-S Plus	25	-	-	-	30	-10	100
P18	IP Validation	2	IP-	Launch	25	-	-	-	30	-10	100
P19	IP Validation	1	IP Mod	EG 106	75	-	-	-	10	-10	100
P20	IP Validation	1	IP Mod	ABC-S Plus	75	-	-	-	10	-10	100
P21	IP Validation	2	IP Mod	Launch	75	-	-	-	10	-10	100
P22	IP Validation	1	IP- / ZR-	EG 106	25	-	25	-	10	-10	100
P23	IP Validation	1	IP- / ZR-	ABC-S Plus	25	-	25	-	10	-10	100
P24	IP Validation	2	IP- / ZR-	Launch	25	-	25	-	10	-10	100
P25	IP Validation	1	IP- / SN-	EG 106	25	10	-	-	15	-10	100
P26	IP Validation	1	IP- / SN-	ABC-S Plus	25	10	-	-	15	-10	100
P27	IP Validation	2	IP- / SN-	Launch	25	10	-	-	15	-10	100
P28	IP Validation	1	IP-	EG 106	25	-	-	-	30	-25	100
P29	IP Validation	1	IP-	ABC-S Plus	25	-	-	-	30	-25	100
P30	IP Validation	2	IP-	Launch	25	-	-	-	30	-25	100
P31	IP Validation	1	IP Mod	EG 106	75	-	-	-	10	-25	100
P32	IP Validation	1	IP Mod	ABC-S Plus	75	-	-	-	10	-25	100
P33	IP Validation	2	IP Mod	Launch	75	-	-	-	10	-25	100
P34	IP Expansion	1	IP- / SN-	EG 106	25	10	-	-	40	-5	100
P35	IP Expansion	1	IP- / SN-	ABC-S Plus	25	10	-	-	40	-5	100
P36	IP Expansion	2	IP- / SN-	Launch	25	10	-	-	40	-5	100
P37	IP Expansion	1	IP- / SN	EG 106	25	25	-	-	15-20	-5	100
P38	IP Expansion	1	IP- / SN	ABC-S Plus	25	25	-	-	15-20	-5	100
P39	IP Expansion	2	IP- / SN	Launch	25	25	-	-	15-20	-5	100
P40	IP Expansion	1	IP / R Mod	EG 106	25	-	-	75	40	-5	100
P41	IP Expansion	1	IP / R Mod	ABC-S Plus	25	-	-	75	40	-5	100
P42	IP Expansion	2	IP / R Mod	Launch	25	-	-	75	40	-5	100
P43	IP Expansion	1	IP- / SN-	EG 106	25	10	-	-	18	-10	100

Table 3.2 (cont'd): Proposed Test Plan

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

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

Table 3.2 (cont'd): Proposed Test Plan

Test Plan #	Objective	Priority	Test Condition	Fluid	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	ZR Rate (g/dm²/h)	R Rate (g/dm²/h)	Exposure Time	Target OAT (°C)	Ramp (kts)
P89	Type III LS	2	IP-	2031 - Hot	25	-	-	-	10	-25	80
P90	Type III LS	2	IP Mod	2031 - Hot	75	-	-	-	5	-25	80
P91	Type III LS	2	IP-	2031 - Cold	25	-	-	-	10	-5	80
P92	Type III LS	2	IP Mod	2031 - Cold	75	-	-	-	5	-5	80
P93	Type III LS	2	IP- / ZR-	2031 - Cold	25	-	25	-	7	-5	80
P94	Type III LS	2	IP- / SN-	2031 - Cold	25	10	-	-	10	-5	80
P95	Type III LS	2	IP- / SN	2031 - Cold	25	25	-	-	10	-5	80
P96	Type III LS	2	IP-	2031 - Cold	25	-	-	-	10	-10	80
P97	Type III LS	2	IP Mod	2031 - Cold	75	-	-	-	5	-10	80
P98	Type III LS	2	IP- / ZR-	2031 - Cold	25	-	25	-	5	-10	80
P99	Type III LS	2	IP- / SN-	2031 - Cold	25	10	-	-	10	-10	80
P100	Type III LS	2	IP- / SN	2031 - Cold	25	25	-	-	5	-10	80
P101	Type III LS	2	IP-	2031 - Cold	25	-	-	-	10	-25	80
P102	Type III LS	2	IP Mod	2031 - Cold	75	-	-	-	5	-25	80
P103	Heavy Snow	1	S	ABC-S Plus	-	25	-	-	See HOT	< -5	100
P104	Heavy Snow	1	S++	ABC-S Plus	-	50	-	-	1/2 of HOT	< -5	100
P105	Heavy Snow	1	S++	ABC-S Plus	-	50	-	-	3/4 of HOT	< -5	100
P106	Heavy Snow	1	S	Launch	-	25	-	-	See HOT	< -5	100
P107	Heavy Snow	1	S++	Launch	-	50	-	-	1/2 of HOT	< -5	100
P108	Heavy Snow	1	S++	Launch	-	50	-	-	3/4 of HOT	< -5	100
P109	Heavy Snow	1	S	EG 106	-	25	-	-	See HOT	< -5	100
P110	Heavy Snow	1	S++	EG 106	-	50	-	-	1/2 of HOT	< -5	100
P111	Heavy Snow	1	S++	EG 106	-	50	-	-	3/4 of HOT	< -5	100
P112	Heavy Snow	1	S	2031 - Cold	-	25	-	-	See HOT	< -5	100
P113	Heavy Snow	1	S++	2031 - Cold	-	50	-	-	1/2 of HOT	< -5	100
P114	Heavy Snow	1	S++	2031 - Cold	-	50	-	-	3/4 of HOT	< -5	100
P115	SCrit Airfoil Comp	2	None	Dry	See Details in Procedure				-	< -5	100
P116	SCrit Airfoil Comp	2	None	Any	See Details in Procedure				-	< -5	100
P117	SN w/ No Fluid	2	None	Dry - Cold Wing	See Details in Procedure				-	< -5	100
P118	SN w/ No Fluid	2	None	Dry - Warm Wing	See Details in Procedure				-	< -5	100
P119	Frost	2	Frost	Any	See Details in Procedure				until Failure	<-5	100
P120	Frost	2	Frost	Any	See Details in Procedure				No Fail	<-5	100
P121	Runway Deicier	3	ZR	Safeway +Any	See Details in Procedure				See HOT	< -5	100
P122	Composite	3	ZR	Octaflo	See Details in Procedure				See HOT	< -5	100
P123	Composite	3	ZR	Octaflo	See Details in Procedure				HOT +30%	< -5	100
P124	LS Type IV IP	3	IP-	Type IV	Extra tests in separate log				-	< -5	80
P125	LZR / SN	3	LZR / SN	Type IV	-	25	25	-	See HOT	< -5	100
P126	67 vs 80	3	None	Type IV	See Details in Procedure				-	< -5	100
P127	Roughness	3	ZR/IP/SN	Dry	See Details in Procedure				-	< -5	100
P128	Snow Pellets	2	SP and S	Diluted TIV	See Details in Procedure				See HOT	<-5	100
P129	Ice Phobic	4	ZR	Type IV	See Details in Procedure				See HOT	< -5	100
P130	Type II IP	4	All	Type IV	Need T II fluid to conduct tests				-	< -5	100

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

A rating system has been developed and will be filled out by the onsite experts (Attachment XIV). The overall rating will provide insight into the severity of the conditions observed. A test failure (failure to shed the fluid at time of rotation) shall be determined by the on-site experts based on residual contamination. The first test in each series will closely emulate expected holdover time or allowance time. The second test will effectively double or halve the first time depending on whether failure to clear has occurred. The third test will double or halve the previous time or halve the interval to the previous test depending on the failure history. This decision matrix is shown in Figure 3.1 with a beginning exposure time of 60 minutes.

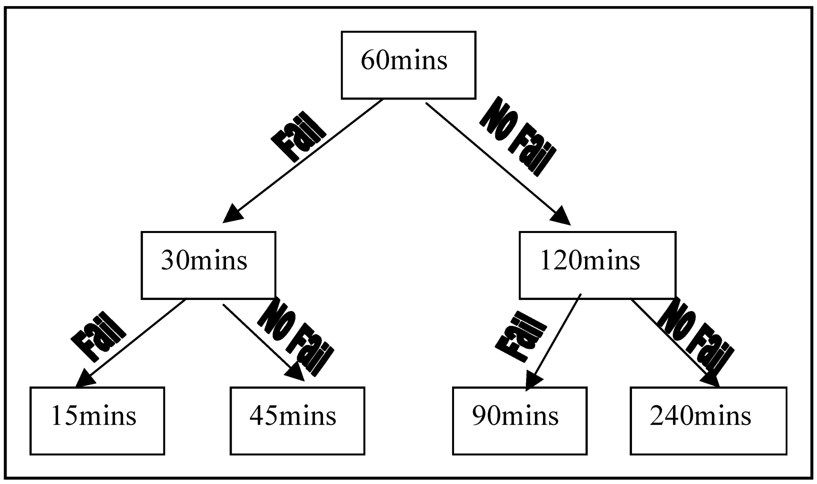


Figure 3.1: Decision Matrix for Each Test Series

4. PRE-TEST SETUP

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

- Co-ordinate with NRC wind tunnel personnel;
- Co-ordinate with APS photographer;
- Conduct dry photography test of old vs. new camera positioning;
- Document new final camera and flash locations;
- Arrange for hotel accommodations for APS personnel;
- Ensure availability of de/anti-icing fluid (shipped directly to NRC);
- Conduct falling ball tests on received fluids;

- Collect fluid samples for viscosity verification at APS office;
- Arrange personnel travel to Ottawa;
- Ensure proper functioning of ice pellet dispenser equipment;
- Ensure proper functioning of freezing rain sprayer equipment;
- Mark wing data collection locations and draw grid on the wing (refer to Feasibility report for diagrams);
- Prepare and arrange for transport of equipment to Ottawa;
- Co-ordinate fabrication of ice pellets/snow/snow pellets; and
- Arrange for storage of ice pellets/snow/snow pellets.

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

5. DATA FORMS

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

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

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

6. PROCEDURE

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

6.1 Initial Test Conditions Survey

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

6.2 Fluid Application (Pour)

- Hand pour 20L of anti-icing fluid over the test area (fluid can be poured directly out of pales or transferred into smaller 3L jugs);
- Record fluid application times (Attachment IX);
- Record fluid application quantities (Attachment IX);
- Let fluid settle for 5 minutes;
- Measure fluid thickness at pre-determined locations on the wing (Attachment X);
- Record wing temperature (Attachment X).
- Measure fluid Brix value (Attachment X); and
- Photograph and videotape the appearance of the fluid on the wing;

Note: At the request of TC/FAA, a standard aluminum test plate will be positioned on the wing in order to run a simultaneous endurance time test.

6.3 Application of Contamination

6.3.1 Ice Pellet/Snow Dispenser Calibration and Set-Up

Calibration work was performed during the winter of 2007-08 on the modified ice pellet/snow dispensers prior to testing with the Falcon 20. The purpose of this calibration work was to attain the dispenser's distribution footprint for both ice pellets and snow. A series of tests were performed in various conditions:

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

These tests were conducted using 121 collection pans, each measuring 6 x 6 inches, over an area 11 x 11 feet. Pre-measured amounts of ice pellets/snow were dispersed over this area and the amount collected by each pan was recorded. A distribution footprint of the dispenser was attained and efficiency for the dispenser was computed.

6.3.2 Dispensing Ice Pellets/Snow for Wind Tunnel Tests

Using the results from these calibration tests, a decision was made to use two dispensers on each of the leading and trailing edges of wing; each of the four dispensers are moved to four different positions along each edge during the dispensing process. Attachments XI and XII display the data sheets that will be used during testing in the wind tunnel. These data sheets will provide all the necessary information related to the amount of ice pellets/snow needed, effective rates and dispenser positions.

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

6.3.3 Application of Freezing Rain/Drizzle

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

6.4 Prior to Engines-On Wind Tunnel Test

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

Note: In order to minimize the measurement time post precipitation, temperature should be measured 5 minutes before the end of precipitation, thickness measured 3 minutes before the end of precipitation, and Brix measured when the precipitation ends. Also consider reducing the number of measures that are taken for this phase (i.e. locations 2 and 5 only).

6.5 During Wind Tunnel Test:

- Take still pictures/videotape the behavior of the fluid on the wing during the takeoff run, capturing any movement of fluid/contamination;
- Fill out visual evaluation rating form at the time of rotation (Attachment XIV);and
- Record wind tunnel operation start and stop times.

6.6 After the Wind Tunnel Test:

- Measure fluid thickness at the pre-determined locations on the wing (Attachment X);
- Measure fluid Brix value (Attachment X);
- Record wing temperatures (Attachment X);
- Observe and record the status of the fluid/contamination (Attachment XV);
- Fill out visual evaluation rating form (Attachment XIV);
- Obtain lift data (excel file) from NRC; and
- Update APS test log with pertinent information.

6.7 Fluid Sample Collection for Viscosity Testing

Two litres of each fluid to be tested are to be collected on the first day of testing. The fluid receipt form (Attachment XVI) should be completed indicating quantity of fluid and date received. Any samples extracted for viscosity purposes should be documented in the log of fluid samples data form (Attachment XVII). A falling ball viscosity test should be performed on site to confirm that fluid viscosity is appropriate before testing.

6.8 At the End of Each Test Session

If required, APS personnel will collect the waste solution. At the end of the testing period, the services of Safety-Kleen (or other glycol recovery service) will be employed to safely dispose of the waste glycol fluid.

6.9 Camera Setup

It is anticipated that the camera setup will be similar to the setup used during the winter of 2008-09. Modifications may be necessary to account for the different airfoil. The flashes will be positioned on the control-room side of the tunnel, and the cameras will be positioned on the opposite side. The final positioning of the cameras and flashes should be documented to identify any deviation from the previous year's setup.

6.10 Demonstration of a Typical Wind Tunnel Test Sequence

Table 6.1 demonstrates a typical Wind Tunnel test sequence of activities, assuming the test starts at 08:00:00. Figure 6.1 demonstrates a typical wind tunnel run timeline.

Table 6.1: Typical Wind Tunnel Test

TIME	TASK
8:00:00	START OF TEST. ALL EQUIPMENT READY.
8:00:00	- Record test conditions.
8:05:00	- Prepare wing for fluid application (clean wing, etc).
8:15:00	- Measure wing temperature. - Ensure clean wing for fluid application
8:20:00	- Pour fluid over test area.
8:30:00	- Measure Brix, thickness, wing temperature. - Photograph test area.
8:35:00	- Apply contamination over test area. (i.e. 30 min)
9:05:00	- Measure Brix, thickness, wing temperature. - Photograph test area.
9:10:00	- Clear area and start wind tunnel
9:25:00	- Wind tunnel stopped
9:35:00	- Measure Brix, thickness, wing temperature. - Photograph test area. - Record test observations
9:45:00	END OF TEST

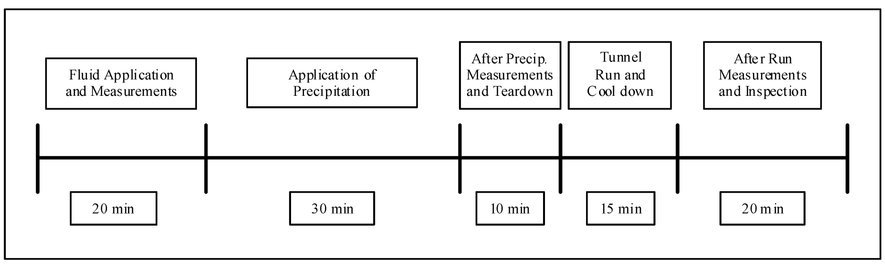


Figure 6.1: Typical Wind Tunnel Run Timeline

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

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

6.12 Procedures for R&D Activities

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

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

As these full-scale R&D activities have in general not been previously attempted, brief summaries of the anticipated procedures have been prepared to provide guidance at the time of testing. These procedures are attached to this document as indicated in parentheses above. The procedures are preliminary and may change based on the results obtained in the wind tunnel.

7. EQUIPMENT

Equipment to be employed is shown in Table 7.1.

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

Table 7.1: Test Equipment Checklist

EQUIPMENT	*STATUS*
General Support Equipment	
Large tape measure	
Fluids (ORDER and SHIP to Ottawa)	
Horse and tap for fluid barrel x 2	
Funnels	
Sample bottles for viscosity measurement	
Squeegees	
Isopropyl	
Gloves, paper towel	
Extension cords	
Clipboards, pencils, wing markers for sample locations and solvent	
Large Clock x1	
Printer, printer paper, and ink cartridge	
Walkie Talkies x8	
Envelopes and labels	
Previous 05-06, 06-07, 07-08, and 08-09 F20/WT reports	
Grid Section + Location docs	
Large Sharpies for Gird Section	
Projector for laptop	
YOW employee contracts	
Blow Horns x4	
Small 90º Ruler	
Camera Equipment	
Digital still cameras x4 (with lenses, chargers, batteries, etc)	
Test Equipment	
Test Procedures, data forms, printer paper	
Electronic copy of the whole wind tunnel procedure folder, incl all forms and working docs (maybe Falcon too).	
Hard Drive	
Test Plate	
Speed tape	
Thickness Gauges	
Temperature Probe x 2 and spare batteries	
Brixometers X3	
Adherence Probes (Oral B) x4 with tips and charger	
Fluid pouring jugs x30 (6 per fluid + extra)	
Ice pellets dispersers x6	
Stands for ice pellets dispensing devices x6	
Ice Pellet control wires and boxes (all)	
Ice pellet box supports for railing x4	
Hot Plate x3 and Large Pots with rubber handles	
Watmans Paper and conversion charts	
Snow Pellet and Snow Large Dispensing Spoon x6	
Long Ruler for marking wing x2	
Small 90º aluminum ruler for wing	
20L containers (DY order from YUL)	
hard water chemicals	
Ice Phobic Product (Nusil or PowerNano)	
Poster board (8"x3") for flap section	

EQUIPMENT	*STATUS*
Ice Pellets Fabrication Equipment	
Refrigerated Truck	
Ice pellets Styrofoam containers x20++	
Ice bags	
Ice bags storage freezer	
Blenders x6+	
Ice pellets sieves	
Folding tables	
Measuring cups	
Wooden Spoons	
Rubber Mats	
Extension Cords	
Freezing Rain Equipment	
NRC Freezing rain sprayer	
APS PC equipped with rate station software	
White plastic rate pans (100) wooden boards, and rubber suction cup feet	
Sartorius Wiegh Scale x1 + NCAR Scale x 1	
Black Shelving Unit	
Portable hard drive and memory card reader	

8. FLUIDS

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

Table 8.1: Fluid Requirements for Wind Tunnel Tests

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

9. PERSONNEL

Five APS staff members are required for the tests at the NRC wind tunnel. Four additional persons will be required from Ottawa for making and dispensing the ice pellets and snow. One additional person from Ottawa will be required to photograph the testing. Table 9.1 demonstrates the personnel required and their associated tasks.

Fluid and ice pellets applications will be performed by APS/YOW personnel at the NRC wind tunnel. NRC personnel will operate the NRC wind tunnel and operate the freezing rain/drizzle sprayer.

Table 9.1: Personnel List

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

* Consider Ryan, Mike or Eric for YOW positions

NRC Institute of Aerospace Research

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

10. SAFETY

- All personnel must be familiar with the Material Safety Data Sheets (MSDS) for fluids;
- Prior to operating the wind tunnel, loose objects should be removed from the vicinity;
- When wind tunnel is operating, ensure that ear plugs are worn if necessary and personnel keep safe distances;
- When working on ladders, ensure equipment is stable;
- Appropriate footwear and clothing for frigid temperatures are to be worn by all personnel;
- Caution should be taken when walking in the test section due to slippery floors, and dripping fluid from the wing section;
- If fluid comes into contact with skin, rinse hands under running water; and
- If fluid comes into contact with eyes, flush with the portable eye wash station.

ATTACHMENT I – Generic Type I Holdover Time Table

TABLE 1

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

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

Outside Air Temperature[5]		Approximate Holdover Times Under Various Weather Conditions (minutes)							
Degrees Celsius	Degrees Fahrenheit	Freezing Fog	Snow or Snow Grains[1] Very Light[6]	Snow or Snow Grains[1] Light[6]	Snow or Snow Grains[1] Moderate	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[2]
-3 and above	27 and above	11 – 17	18	11 – 18	6 – 11	9 – 13	4 – 6	2 – 5	CAUTION: No holdover time guidelines exist
below -3 to -6	below 27 to 21	8 – 13	14	8 – 14	5 – 8	5 – 9	4 – 6	CAUTION: No holdover time guidelines exist	
below -6 to -10	below 21 to 14	6 – 10	11	6 – 11	4 – 6	4 – 7	2 – 5		
Below -10	below 14	5 – 9	7	4 – 7	2 – 4				

NOTES

1. To use these times, the fluid must be heated to a minimum temperature providing 60°C (140°F) at the nozzle and an average rate of at least 1 litre/m² (2 gal./100 sq. ft.) must be applied to deiced surfaces, OTHERWISE TIMES WILL BE SHORTER.
2. Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
3. Type I Fluid / Water Mixture is selected so that the freezing point of the mixture is at least 10°C (18°F) below outside air temperature.
4. Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5. Ensure that the lowest operational use temperature (LOUT) is respected.
6. Use light freezing rain holdover times in conditions of light snow mixed with light rain.

CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

ATTACHMENT II – Generic Type II Holdover Time Table

TABLE 2-Generic

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

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

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

NOTES

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

CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

ATTACHMENT III – Generic Type III Holdover Time Table

TABLE 3

SAE TYPE III FLUID HOLDOVER GUIDELINES FOR WINTER 2009-2010

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

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

NOTES

1 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
2 Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
3 Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I when Type III fluid cannot be used.
4 Use light freezing rain holdover times in conditions of light snow mixed with light rain.

CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

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

TABLE 4-D-E106

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

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

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

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

CAUTIONS
- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

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

TABLE 4-K-ABC-S PLUS

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

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

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

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

CAUTIONS
- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

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

TABLE 4-C-Launch

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

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

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

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

CAUTIONS
- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

ATTACHMENT VII – Ice Pellet Allowance Time Table

TABLE 10

ICE PELLET ALLOWANCE TIMES FOR WINTER 2009-2010

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

ATTACHMENT VIII – Task List for Setup and Actual Tests

No.	Task	Person	Status
	Planning and Preparation		
1	Co-ordinate with NRC wind tunnel personnel	MR/JD	
2	Ensure fluid is received and is stored outdoors	MR/JD	
3	Co-ordinate with APS photographer	MR	
4	Arrange for hotel accommodations for APS personnel	MP	
5	Arrange personnel travel to Ottawa;	MP/VZ	
6	Hire YOW personnel	DY/MP	
7	Ensure proper functioning of ice pellet dispenser equipment;	MR/VZ	
8	Ensure proper functioning of freezing rain sprayer equipment;	MR	
9	Prepare and Arrange Office Materials to YOW	MP	
10	Prepare and Arrange Site Equipment to YOW	DY/VZ	
11	Prepare Data forms and procedure	MP	
12	Prepare Test Log (See JD with it)	MP	
13	Finalize and complete list of equipment/materials required	DY/MR	
14	Arrange for freezer storage of ice pellets/snow/snow pellets.	DY	
15	Investigate IP/ZR/SN dispersal techniques and location	JT/VZ/MR	
16	Update IP Rate File	JT/VZ	
17	Check with NRC the status of the testing site, tunnel etc	MR	
18	Check weather prior to establishing test dates	MR	
19	Investigate method of lifting 1000L Totes 15-20" of ground (How many cement blocks)	DY/MR	
20	Purchase new 20 L containers	DY	
	Monday Jan 4		
21	Pack and leave YUL for YOW on Jan 4th	APS	
22	Complete contract for YOW personnel	MP/YOW	
23	Safety Briefing & Training	MR	
24	Unload Truck	APS	
25	Organize all Equipment in Lower Level of Wind Tunnel	DY/YOW	
26	Setup rate station	DY	
27	Setup Projector	MP	
28	Setup printer	MP	
29	Setup IP/SN manufacturing material	VZ	
30	Test and prepare IP dispensing equipment	VZ	
31	Ice and freezer delivery	DY	
32	Organize Fluid Outside (labels and fluid receipt forms)	MP/DY/YOW	
33	Transfer Fluids from 1000 L Totes to 20 L containers.	MP/DY/YOW	
	Tuesday Jan 5		
34	Verify ZR sprayer installation	MR	
35	Train IP making personnel	VZ/YOW	Mike and Eric will train others
36	Conduct dry photography test of old vs. new camera positioning;	BG/MR	Jessie
37	Document new final camera and flash locations	VZ/BG	
38	Conduct falling ball tests on received fluids;	MP/DY	
39	Collect fluid samples for viscosity verification at APS office;	MP/DY	
40			
41	Mark wing data collection locations and draw grid on the wing (refer to Feasibility report for diagrams);	VZ/DY	
42	Co-ordinate fabrication of ice pellets/snow/snow pellets	VZ	
43	ZR Calibration	DY/MP	
44	IP/SN Calibration (confirm rates with spot check with rate pan)	DY/VZ	
45	IP manufacturing	YOW's	
46	Dry Run of tests (APS / NRC)	APS/NRC	
	Each Testing Day		
47	Check with NRC the status of the testing site, tunnel etc	MR	
48	Check weather prior to establishing test dates	MR	
49	Prepare equipment and fluid to be used for test	DY	
50	Manufacture ice pellets	VZ/YOW	
51	Arrange for photo doc. of the test	MR	
52	Prepare data forms for test	MP	
53	Conduct tests based on test plan	APS	
54	Modify test plan based on results obtained	WU/JD/MR	
55	Update IP/S Inventory	VZ/YOW	
56	Update Ice Quantity	VZ/YOW	
57	Update Fluid Quantity	MP/DY	
58	Update Test Plan	MP	

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

DATE: ____________ FLUID APPLIED: ____________ RUN #: ____________

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

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

WIND TUNNEL START TIME: ____________ WIND TUNNEL STOP TIME: ____________

FLUID APPLICATION			
Actual start time:		Actual End Time:	
Fluid Brix:		Amount of Fluid (L):	
Fluid Temperature (°C):		Fluid Application Method:	POUR

ICE PELLETS APPLICATION (if applicable)			
Actual start time:		Actual End Time:	
Rate of Ice Pellets Applied (g/dm²h):		Ice Pellets Size (mm):	
Total Time:			

FREEZING RAIN/DRIZZLE APPLICATION (if applicable)			
Actual start time:		Actual End Time:	
Rate of Precipitation Applied (g/dm²h):		Droplet Size (mm):	
Total Time:		Needle:	
		Flow:	
		Pressure	

SNOW APPLICATION (if applicable)			
Actual start time:		Actual End Time:	
Rate of Snow Applied (g/dm²h):		Snow Size (mm):	
Total Time:			

COMMENTS ____________

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

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

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: ______________________ Run: ________________

WING TEMPERATURE

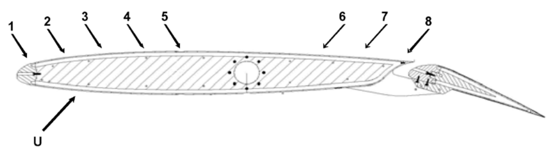
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
T2				
T5				
TU				
Time				

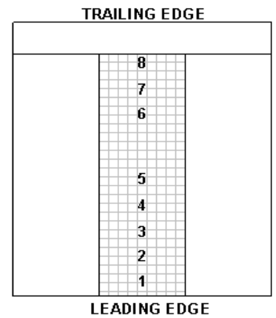
FLUID BRIX

Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2			
8			
Time:			

FLUID THICKNESS

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





Wing Position 1: On the leading edge;

Wing Position 2, 3, 4, 5: At equal distances (approximately 15 cm) between rivets along the wing chord;

Wing Position 6: Approximately 30 cm from trailing edge;

Wing Position 7: Approximately 15 cm from trailing edge;

Wing Position 8: Approximately 2.5 cm from trailing edge; and

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

Comments: ______________________________

OBSERVER: ______________________

ASSISTED BY: ______________________

ATTACHMENT XI – Ice Pellet Dispensing Form

WING TRAILING EDGE

8 ft = 24.4 dm

6 ft = 18.3 dm

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

WING LEADING EDGE

Precipitation Type	IP	Date		Run #	

* *Field to be manipulated*

Target Rate	**50**	**g/dm²/h**
Duration	**5**	**minutes**

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

IP needed per 5min

In each position	147	g
In each Dispensor	587	g

IP needed for entire test

Total amount of IP in Each Dispensor	587	g
Total Amount IP Needed for Entire Test	2347	g

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

NOTE:

- Leading Edge (LE): Centre Pole of the Dispensor Stands must be 1-foot (12 inches) from the Leading Edge (LE)

-Trailing Edge (TE): Centre Pole of the Dispensor Stands must be 10-inches from the Trailing Edge (TE) Flap.The use of Dispensor Stand Extention is needed.

- Height of the Stand must be 4-feet from bottom of the dispensor

ATTACHMENT XII – Snow Dispensing Form

WING TRAILING EDGE

8 ft = 24.4 dm

6 ft = 18.3 dm

DISPENSOR #3								DISPENSOR #4							
1	1ft	2	1ft	3	1ft	4		1	1ft	2	1ft	3	1ft	4	
23.1	24.8	27.2	25.5	27.4	25.5	27.4	25.5	27.4	25.5	27.4	25.5	27.4	25.4	26.6	19.7
27.1	35.5	34.9	36.7	35.1	36.7	35.1	36.7	35.1	36.7	35.1	36.7	35.0	36.3	33.9	29.8
24.6	39.4	36.4	41.4	36.8	41.5	36.8	41.5	36.8	41.5	36.8	41.5	36.7	41.1	35.5	35.2
14.4	26.3	25.3	28.6	25.7	28.7	25.7	28.7	25.7	28.7	25.7	28.7	25.6	28.4	24.7	24.3
8.8	15.2	16.4	17.4	17.0	17.6	17.2	17.6	17.2	17.6	17.2	17.6	17.0	17.2	15.9	14.2
6.1	9.4	10.6	11.2	11.1	11.4	11.2	11.4	11.2	11.4	11.2	11.3	11.0	10.9	9.8	7.9
7.9	9.8	10.9	11.0	11.3	11.2	11.4	11.2	11.4	11.2	11.4	11.1	11.2	10.6	9.4	6.1
14.2	15.9	17.2	17.0	17.6	17.2	17.6	17.2	17.6	17.2	17.6	17.0	17.4	16.4	15.2	8.8
24.3	24.7	28.4	25.6	28.7	25.7	28.7	25.7	28.7	25.7	28.7	25.7	28.6	25.3	26.3	14.4
35.2	35.5	41.1	36.7	41.5	36.8	41.5	36.8	41.5	36.8	41.5	36.8	41.4	36.4	39.4	24.6
29.8	33.9	36.3	35.0	36.7	35.1	36.7	35.1	36.7	35.1	36.7	35.1	36.7	34.9	35.5	27.1
19.7	26.6	25.4	27.4	25.5	27.4	25.5	27.4	25.5	27.4	25.5	27.4	25.5	27.2	24.8	23.1
	4	1ft	3	1ft	2	1ft	1		4	1ft	3	1ft	2	1ft	1
	DISPENSOR #2								DISPENSOR #1						

WING LEADING EDGE

Precipitation Type	Snow

Date	

Run #	

* *Field to be manipulated*

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

Footprint Rate	25	g/dm²/h
Stdev of Rate	10	g/dm²/h

Snow needed per 5 minutes

In each position	60	g
In each Dispensor	240	g

Snow needed for entire test

In each Dispensor	240	g
Total Amount Snow Needed for Entire Test	960	g

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

NOTE:

- Leading Edge (LE): Centre Pole of the Dispensor Stands must be 1-foot (12 inches) from the Leading Edge (LE)

-Trailing Edge (TE): Centre Pole of the Dispensor Stands must be 10-inches from the Trailing Edge (TE) Flap. The use of Dispensor Stand Extention is needed.

- Height of the Stand must be 4-feet from bottom of the dispensor

ATTACHMENT XIII – Sprayer Calibration Form

WIND TUNNEL FREEZING RAIN SPRAYER CALIBRATION

Trail No	Aprox Start Time	Sprayer Settings							Precipitation Rate (g/dm^2/h)	Comments
		Translation		Nozzles	Speed	Water Flow Rate (mL/min/nozzle)	Air Pressure	Software Setting		
		x	y							
2-Feb-09		Full 24 Scans	Full 335 Steps	2x20		500 mL/min	45		50	x-axis=24 Scans, 66.24º. y-axis=60.3º
4-Feb-09		Full 24 Scans	Full 335 Steps	2x20		250 mL/min	45		25	MVD=1-1.2mm. x-axis=24 Scans, 66.24º. y-axis=60.3º
25-Feb-09		Full 24 Scans	Full 335 Steps	2x17		750 mL/min	45		75	x-axis=24 Scans, 66.24º. y-axis=60.3º
1-Mar-09		Full 24 Scans	Full 335 Steps	2x20		150 mL/min	45		15	x-axis=24 Scans, 66.24º. y-axis=60.3º

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

ATTACHMENT XIV – Visual Evaluation Rating Form

VISUAL EVALUATION RATING OF CONDITION OF WING

Date: ___________________ Run Number: _______

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

Before Take-off Run

Area	Visual Severity Rating (1-5)
Leading Edge	
Trailing Edge	

At Rotation

Area	Visual Severity Rating (1-5)
Leading Edge	
Trailing Edge	

After Take-off Run

Area	Visual Severity Rating (1-5)
Leading Edge	
Trailing Edge	

Additional Observations: ____________________

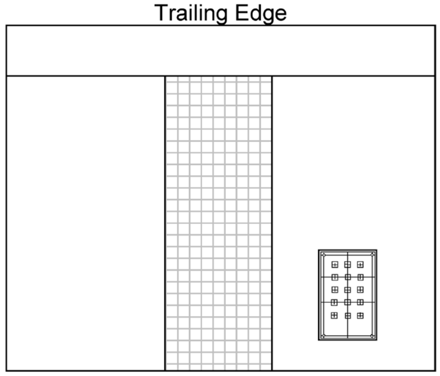
OBSERVER: ____________________

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

Date: ____________________ Run Number: _______

Wing and Plate Condition Before the Takeoff Run (Time _____________________)

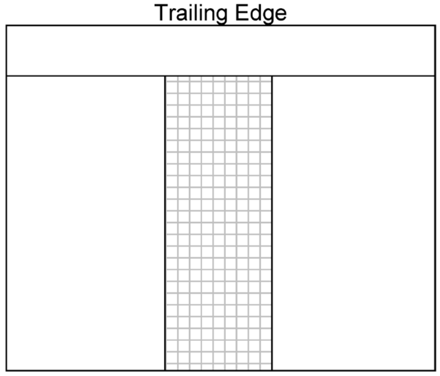
Trailing Edge



Leading Edge

Wing Condition After the Takeoff Run (Time: ___________________________)

Trailing Edge



Leading Edge

Observations: ____

____

____

____

____

OBSERVER: ___________________________ **ASSISTED BY:** ______________________

ATTACHMENT XVI – Fluid Receipt Form

SECTION A - SITE

☐ HOT SAMPLE ☐ RESEARCH/OTHER SAMPLE

Receiving Location: ____________________ **Date of Receiving:** ____________________

Manufacturer: ________________ **Fluid Name:** ____________________ **Fluid Type:** _______

Date of Production: ____________________ **Batch #:** ____________________

Fluid Dilution: _______ _______ _______

Fluid Quantity: ___ x ___ L = _____ L ___ x ___ L = _____ L ___ x ___ L = _____ L

APS Measured BRIX: _______ _______ _______

Note any additional information included on fluid containers:

Received by: ____________________
(PRINT NAME)

on: ____________________
(DATE)

SECTION B - OFFICE

Fluid Code Assigned: 100/0 _______ 75/25 _______ 50/50 _______ Type I _______

Viscosity Information Received:[1] ☐ **Viscosity Measured:**[1] ☐

WSET Sample Sent to AMIL: ☐ **WSET Result Received:** ☐

FFP Curves Received:[2] ☐

[1] Type II/III/IV fluids only

[2] Type I fluids only

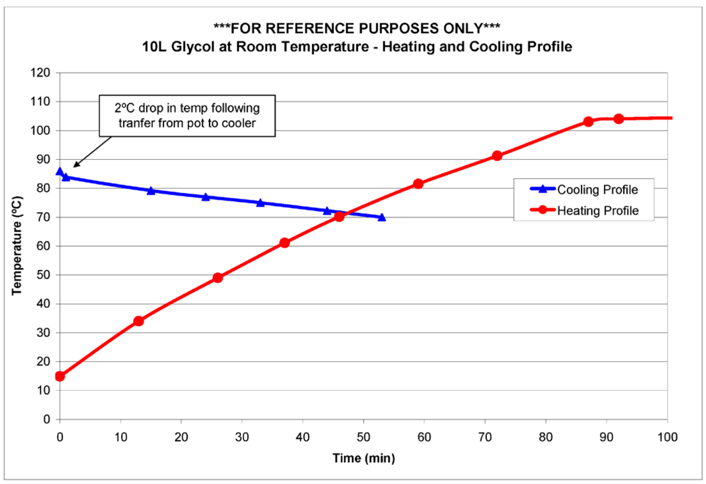
ATTACHMENT XVII – Log of Fluid Sample Bottles

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

ATTACHMENT XVIII– Procedure: Application of Heated Type III Fluid for Wind Tunnel Tests

Heating

- Type III should be stored indoors at room temperature to minimize heating required;
- Heat Type III fluid 10L at a time using a hotplate and an aluminum cooking pot with a lid. The hotplate should be set to the "Max" setting. Two pots should be heated simultaneously to prepare the 20L required for each test;
- Fluid temperature should be monitored every 10 minutes, and the fluid should be stirred frequently;
- Once a temperature of 70°C is achieved (approx 45 minutes), the two 10L pots of fluid should be transferred to individual warm insulated coolers.
- *Note: Although 60°C is the target application temperature, the fluid will be transferred into the coolers at 70°C to allow for some cooling during transportation to the test section and transfer into the pouring jug*s.



Application

NOTE: It is critical that all precipitation dispensing equipment be ready to go prior to fluid application. Application of precipitation should occur immediately after the fluid application is complete to minimize heat loss from the wing.

- Heated Type III fluid should be transferred from the insulated coolers into hand held 2-3L pour containers;
- 20 L (see "Application Quantity" section for details) of fluid should be applied evenly to the whole wing section using the typical methodology for applying

fluid in the wind tunnel. Two people will be required to pour 10L from the leading edge and 10L from the trailing edge.
- Precipitation shall be timed to start immediately after the completion of the fluid application. Thickness and Brix measures can be omitted for the "after pour" application.

Application Quantity

Note: Quantities in brackets (xx L) will be total volume required based on wind tunnel wing section area.

- HOT guidelines recommend 1L/m² (3.7L) as final step
- Original APS assumption was to use about five times the amount, so about 5.4L/m(20L)
- FAA original recommendation was < (20L), but > (3.7L), and suggested (6-8 L)
- A review was conducted of operator data for "one-step de/anti-icing procedures using Type I"
    - Details in the report "Research Data to Support the Development of the Airport De-Icer Management System Model (ADMS)

Fluid quantities for one-step de/anti-icing procedures using Type I
Based on review of report data for Moderate Snow and Freezing Rain conditions

- Large Canadian Operator for Commuter Aircraft (Dash 8 or CRJ)
    - 5 L/m² (19L) and 10L/m² (37L)
- Large US Operator for Commuter Aircraft (Dash 8 or CRJ)
    - 2L/m² (7L) and 3L/m² (11L)
- Large Canadian Operator for Large W/B Aircraft (A340)
    - 3 L/m² (11L) and 6L/m² (22L)
- Servisair Recommended Spray Quantities for Commuter Aircraft (Dash 8 or CRJ)
    - Waiting on data, will update once received.

Conclusion:

Review of data provides a range of 2L/m² (7L) to 10L/m² (37L).

Following a discussion of this data, it is recommended that initial testing be conducted with both 2.7L/m² (10L) and 5.4L/m² (20L) to evaluate the severity of the heat involved. Following a review of the test data, a decision may be made to proceed with either the larger or smaller amount.

ATTACHMENT XIX – Procedure: Super-Critical vs. Low Speed Airfoil

Background

Previous testing in the wind tunnel was conducted with low speed airfoils. To simulate the newer generation aircraft, a super-critical wing section was designed and constructed for the 2009-10 winter testing. In order to objectively evaluate the tests conducted, the new super-critical wing performance must be compared to the low speed airfoils previously used for testing.

Objective

To investigate the aerodynamic performance of the new super-critical airfoil as compared to the previous low speed airfoils used.

Methodology

- Testing should be conducted in dry wing and fluid only conditions.
- Testing should try to recreate the weather conditions for select baseline dry and fluid only tests conducted in 2008-09 in order to have low speed airfoil comparison data points.
- Characteristics such as lift and stall angle should be compared in both dry and fluid only cases.

Test Plan

Five tests are anticipated: a dry test, and four tests with the representative Type III and Type IV fluids selected for testing.

ATTACHMENT XX – Procedure: Heavy Snow

Background

As a direct result of the ice pellet research conducted, the use of HOTs for determining the protection time provided by anti-icing fluids was questioned. The focus has turned towards "aerodynamic failure" which can be defined as a significant lift loss resulting from contaminated anti-icing fluid. Heavy snow conditions has been selected for this study for two reasons. First, snow conditions account for the most significant portion of de-icing operations globally. Secondly, there has been a recent industry interest for holdover time for heavy snow conditions. Preliminary aerodynamic testing was conducted during the winter of 2006-07 and 2008-09.

Objective

To investigate the fluid aerodynamic flow-off characteristics of anti-icing fluid contaminated with simulated heavy snow versus moderate snow.

Methodology

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

- For a chosen fluid, conduct a test simulating moderate snow conditions (rate of 25 $g/dm^2/h$) for an exposure time derived from the HOT table based on the tunnel temperature at the time of the test
- Record lift data, visual observations, and manually collected data;
- Conduct two comparative tests simulating heavy snow conditions (rate of 50 $g/dm^2/h$) for the same exposure time used during the moderate snow test;
- Record lift data, visual observations, and manually collected data;
- Compare the heavy snow results to the moderate snow results. If the heavy snow results are worse, repeat the heavy snow test with a reduced exposure time, if the results are better, repeat the heavy snow test with an increased exposure time.
- Repeat until similar lift data, and visual observations are achieved for both heavy snow and moderate snow; and
- Document the percentage of the moderate snow HOT that is acceptable for heavy snow conditions.

Test Plan

Ten to twelve comparative tests are anticipated.

ATTACHMENT XXI – Procedure: Low Speed Ramp Testing

Background

The current low speed aerodynamic acceptance test for anti-icing fluids simulates a rotation speed of 67 knots on a flat plate; this takeoff profile was developed based on older generation low speed aircraft. In recent years, the newer generation low speed aircraft have rotation speeds closer to 80 to 85 knots. As all of the low speed testing conducted in the wind tunnel has been performed simulating an 80 knot rotation speed (representing the newer generation aircraft), it was recommended to verify the fluid flow-off properties of anti-icing fluid using the historical 67 knot rotation speed takeoff profile used for the aerodynamic acceptance tests.

Objective

To investigate the fluid flow-off performance during low speed ramp take-off.

Methodology

- Testing should be conducted in fluid only conditions;
- Testing will consist of two comparative tests done sequentially with the same fluid in similar weather conditions:
    - 67 knots rotation;
    - 80 knots rotation;
- Compare lift data, visual observations, and manually collected data;

Test Plan

Four to six tests are anticipated with two to three different fluids.

ATTACHMENT XXII – Procedure: Effect of Ice Phobic Coatings on Contaminated Airfoil Aerodynamic Performance

Background

There has been a recent industry interest in the use of ice phobic coatings to protect aircraft critical surfaces. Currently, some non-commercial operators are using ice phobic coatings on the aircraft radome and other aircraft surfaces. It was recommended that testing be conducted to investigate the protective properties of these coatings in precipitation conditions, and to verify the compatibility of these products with glycol de/anti-icing fluids.

Objective

To investigate the aerodynamic flow-off characteristics and lift losses associated with a wing section treated with ice-phobic coatings following contamination, with and without anti-icing fluid.

Methodology

- The wing should be clean and dry before the start of test;
- The wing section should be covered with speed tape. If it is not feasible to cover the entire wing, the first 12-24" of the leading edge should be covered with speed tape;
- The wing should be sectioned in half: un-treated and treated with ice-phobic coating;
- One side should be treated with the ice phobic coating as per the manufacturer specification. The other side should be left untreated;
- The first test should be conducted with no fluid protection during light freezing rain conditions;
- Run wind tunnel and collect data;
- The following test should be conducted with anti-icing fluid protection. The wing should be exposed to simulated light freezing rain at a rate of 25 $g/dm^2/h$ and the time of exposure should be chosen based on OAT and fluid specific HOT's;
- Run wind tunnel and collect data;
- The performance of the treated and un-treated sections of the wing should be compared.

Test Plan

Two to four tests are anticipated.

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

Background

Previous comparative flat plate testing was conducted using aluminum and composite surfaces. Results indicated that anti-icing fluid endurance times were comparable, however Type I fluids experienced HOT reductions when applied to composite surfaces. The Type I HOT's were approximately 30% shorter on composite surfaces in natural snow conditions. Full-scale data is required to verify the aerodynamic impact of reduced Type I HOT's on composite surfaces.

Objective

To investigate the aerodynamic flow-off characteristics and lift losses associated with reduced Type I HOT's on composite surfaces.

Methodology

- To simulate aluminum wing, apply heated Type I fluid to wing section (heated to 60°C);
- Expose wing section to simulated snow at a rate of 25 g/dm²/h until fluid is failed;
- Run wind tunnel and collect lift loss data;
- To simulate composite wing, apply heated Type I fluid to wing section (heated to 60°C);
- Expose wing section to simulated snow at a rate of 25 g/dm²/h. Time of exposure should be 30% longer than previous test
    - Exposure time = 1.3 * ET of simulated aluminum wing test;
- Run wind tunnel and collect lift loss data;
- Compare results of both tests;

Note: Testing can also be done by simulating both alumunim and composite Type I tests on the same wing section using two separate strips of fluid. If this procedure if preferred, the composite test section should be exposed to precipitation first to ensure that the precipitation is stopped simultaneously for both sections.

Test Plan

Two comparative sets of tests are anticipated.

ATTACHMENT XXIV – Procedure: Aerodynamic Impact of Wing Surface Roughness

Background

Previous testing in the wind tunnel demonstrated that although contamination was present on the wing section, significant lift losses were not apparent. Lift losses were incurred upon application of anti-icing fluid (when compared to a bare wing) however, the presence of contamination, whether adhered or not, did not generate significant list losses when compared to the uncontaminated fluid. Although the presence of adhered contamination may be hazardous with regards to control surfaces, the impact of the surface roughness on the overall aerodynamic performance of the wing needs to be investigated.

Objective

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

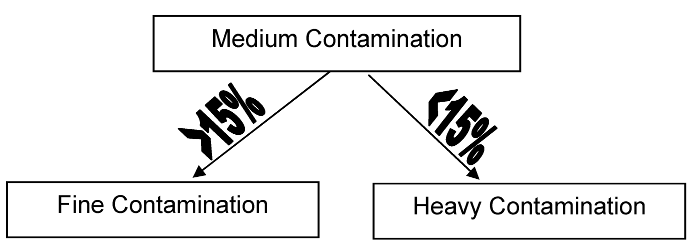
Methodology

Contamination can be in the form of abrasive sandpaper (similar to what is used by the NRC Flight Laboratory) or frozen precipitation on a bare wing. During the winter of 2008-09, adhered freezing rain, ice pellets, and snow were used to create a rough surface on the wing section.

- Apply abrasive material or contamination to full length of the leading edge of wing section;
- Run wind tunnel test, collect lift loss data, compare to fluid only results;
- Increase grit of sandpaper level of frozen contamination until appreciable lift losses are observed (greater than 15%); and
- Document type and level of contamination and resulting effects on lift loss.

Test Plan

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



ATTACHMENT XXV – Procedure: Effect of Snow Pellets on Fluid Flow Off

Background

Previous comparative flat plate testing was conducted in simulated snow pellets and simulated snow. Results indicated that anti-icing fluid endurance times were comparable in both conditions. Additional plate testing will be conducted to support the recommendation to incorporate snow pellets into the snow HOT column. Aerodynamic data is required to verify that both snow and snow pellets have similar fluid flow off characteristics.

Objective

To investigate the fluid aerodynamic flow-off characteristics of anti-icing fluid contaminated with simulated snow pellets versus simulated snow.

Methodology

- Testing should be conducted on two 2 foot wide chords of the wing section (one section will be for snow pellets and the other for snow);
- Manufacture snow pellets (**Note: this process is labor intensive and should be planned well ahead of the anticipated test**);
- Depending on the OAT, choose a diluted fluid with the shortest HOT;
- Apply two strips of fluid to the wing section;
- Simultaneously dispense simulated snow pellets on one test section and snow on the other test section (ensure equal rate of precipitation and distribution);
- Expose both sections to equal amounts of contamination for equal amounts of time (the expected fluid HOT);
- Run wind tunnel; and
- Compare visual fluid flow-off behavior of both contaminated sections;

Test Plan

Due to the labor intensive process of manufacturing snow pellet, a maximum of two tests are anticipated.

ATTACHMENT XXVI – Procedure: Light Freezing Rain and Moderate Snow

Background

As the accuracy of meteorological reporting continues to improve, there has been a need to provide improved guidance material during these transitional periods of mixed precipitation. During the winter of 2008-09, guidance material was developed for operations during light snow mixed with light rain conditions. As a result of this work, there was industry interest in guidance material for operations during light freezing rain and moderate snow conditions. The objective of these tests is to collect data to determine if the current HOT guidelines can be expanded to include mixed conditions of light freezing rain and moderate snow conditions.

Objective

To investigate if the current HOT guidelines can be expanded to include mixed conditions of light freezing rain and moderate snow conditions.

Methodology

The general methodology to be used during these tests is in accordance with the methodologies used for typical snow and light freezing rain tests conducted in the wind tunnel. The light freezing rain and moderate snow endurance times will be compared to the light freezing rain only HOT's.

- For a chosen fluid, conduct a test simulating light freezing rain and moderate snow conditions for an exposure time derived from the HOT table based on light freezing rain conditions.
- Record lift data, visual observations, and manually collected data;
- Conduct a comparative test simulating light freezing rain conditions for the same exposure time used during the light freezing rain and moderate snow test;
- Record lift data, visual observations, and manually collected data;
- Compare the light freezing rain and moderate snow conditions results to the light freezing rain results. If the light freezing rain and moderate snow results are worse, repeat the test with a reduced exposure time, if the results are better, repeat the test with a increased exposure time.
- Repeat until similar lift data, and visual observations are achieved for both heavy snow and moderate snow; and
- Document the percentage of the moderate snow HOT that is acceptable for heavy snow conditions.

Test Plan

Four to six comparative tests are anticipated.

ATTACHMENT XXVII – Procedure: Snow on an Un-Protected Wing

Background

In colder northern operations, it is common for aircraft to depart with "loose, dry, un-adhered snow" on present on their wing sections. Although it is assumed most or all of this contamination will be removed at the time of rotation, it is unknown whether a certain level of contamination will reduce aerodynamic performance. Full-scale testing is required to investigate the aerodynamic performance of a wing section contaminated with dry, un-adhered snow.

Objective

To investigate the aerodynamic performance of a wing section contaminated with dry, un-adhered snow.

Methodology

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

- Ensure the wing section and tunnel temperature are well below freezing (-5°C and below);
- Ensure the wing section is clean, dry, and free of any forms of contamination;
- Apply loose, dry snow contamination to the wing section;
- Record lift data, visual observations, and manually collected data;
- Compare the results to baseline fluid only and dry wing test results;

Test Plan

Three to four comparative tests are anticipated.

ATTACHMENT XXVIII – Procedure: Degraded Anti-icing Fluid Performance Following Contamination with Runway Deicing Fluid

Background

Recent operational reports have indicated a significant degradation effect as a result of cross-contamination of thickened anti-icing fluids with runway deicing fluids. This is especially of concern for landings on a wet runway with reverse thrusters followed by preventative anti-icing applications. Full-scale data is required to verify the aerodynamic impact of degraded anti-icing fluid flow off following contamination.

Objective

To investigate the aerodynamic flow-off characteristics and lift losses associated with degraded anti-icing fluid flow off following contamination.

Methodology

- The wing should be clean and dry before the start of test;
- The wing should be sectioned in half: good side and degraded fluid side;
- The degraded fluid side should be treated with a spray of diluted runway deicer fluid;
- Anti-icing fluid should be applied to the whole wing (both good and degraded fluid side);
- Expose wing section to simulated light freezing rain at a rate of 25 g/dm²/h. Time of exposure should be chosen based on OAT and fluid specific HOT's;
- Run wind tunnel and collect data;
- Repeat test and reduce or increase amount of runway deicer fluid applied;

Test Plan

Four to six tests are anticipated with various Type III and Type IV fluids.

ATTACHMENT XXIX – Procedure: Type I Deicing and Spot During CSW Frost Conditions

Background

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

Objective

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

Methodology

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

Test Plan

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

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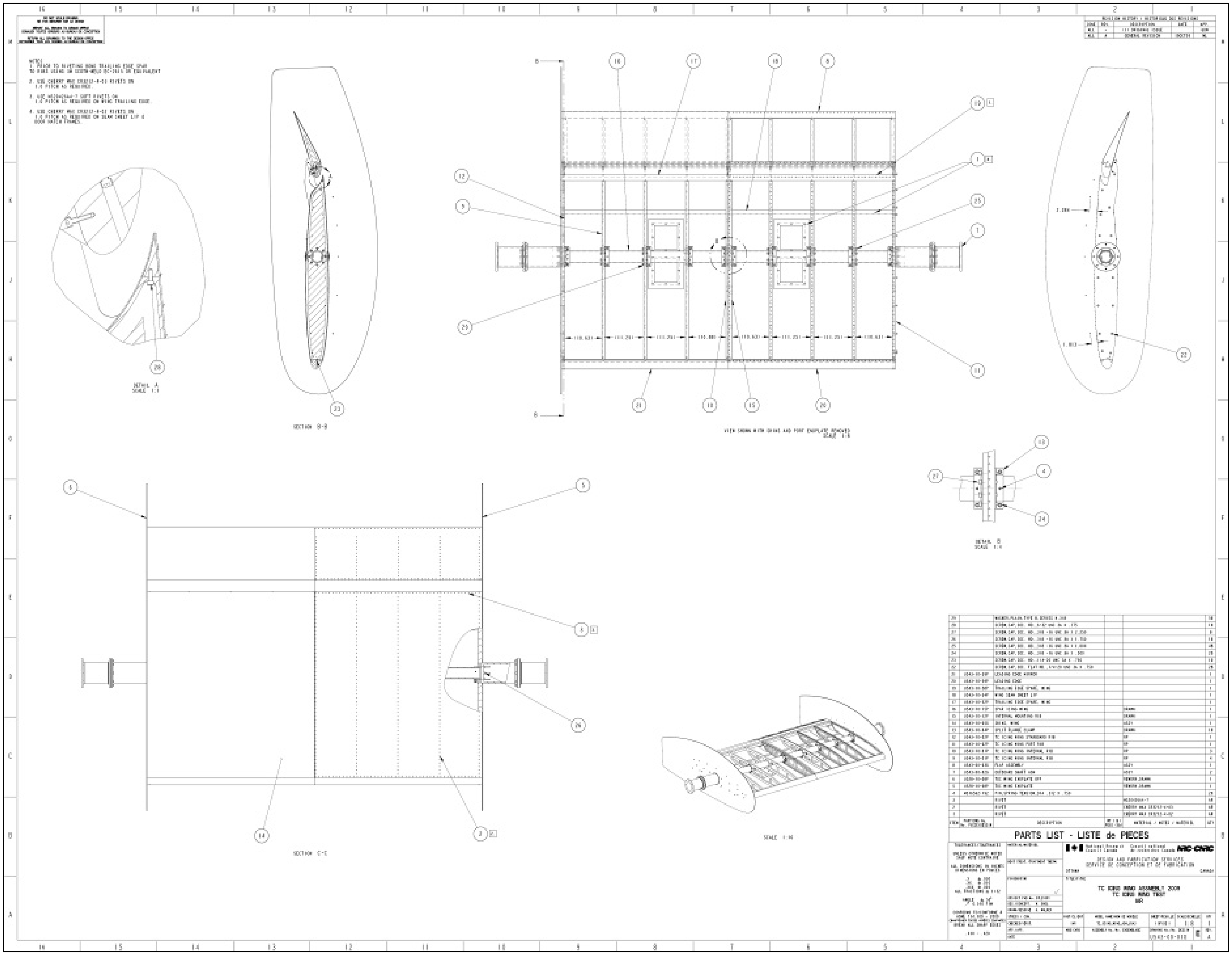
APPENDIX C

WING COORDINATES

Main Airfoil (Flap 0º) Coordinates		Main Airfoil (Flap 0º) Coordinates Cont'd		Main Airfoil (Flap 0º) Coordinates Cont'd		Flap Deployed (20º) Coordinates		Main Aft Coordinates	
1.000	-0.0011	0.069	-0.0240	0.375	0.0540	1.017	-0.0849	0.773	0.0314
0.999	-0.0011	0.065	-0.0235	0.400	0.0536	1.009	-0.0823	0.772	0.0311
0.997	-0.0012	0.060	-0.0228	0.425	0.0531	1.001	-0.0794	0.770	0.0309
0.995	-0.0012	0.055	-0.0221	0.450	0.0524	0.992	-0.0762	0.769	0.0305
0.990	-0.0013	0.049	-0.0213	0.475	0.0515	0.982	-0.0727	0.767	0.0302
0.985	-0.0014	0.043	-0.0205	0.500	0.0506	0.971	-0.0688	0.765	0.0297
0.980	-0.0015	0.037	-0.0195	0.525	0.0495	0.960	-0.0647	0.764	0.0294
0.970	-0.0017	0.032	-0.0185	0.550	0.0482	0.947	-0.0604	0.762	0.0289
0.960	-0.0020	0.026	-0.0174	0.575	0.0469	0.934	-0.0559	0.760	0.0283
0.950	-0.0022	0.021	-0.0161	0.600	0.0454	0.921	-0.0514	0.758	0.0278
0.940	-0.0024	0.016	-0.0148	0.620	0.0441	0.907	-0.0469	0.757	0.0273
0.930	-0.0027	0.012	-0.0132	0.640	0.0427	0.893	-0.0424	0.755	0.0267
0.920	-0.0030	0.009	-0.0116	0.660	0.0413	0.879	-0.0380	0.753	0.0256
0.910	-0.0034	0.006	-0.0098	0.680	0.0398	0.865	-0.0338	0.750	0.0247
0.900	-0.0038	0.004	-0.0080	0.700	0.0382	0.852	-0.0298	0.749	0.0240
0.880	-0.0048	0.002	-0.0061	0.720	0.0364	0.840	-0.0260	0.747	0.0231
0.860	-0.0058	0.001	-0.0043	0.740	0.0346	0.828	-0.0225	0.745	0.0222
0.840	-0.0071	0.000	-0.0027	0.760	0.0327	0.817	-0.0193	0.744	0.0213
0.820	-0.0084	0.000	-0.0012	0.780	0.0307	0.807	-0.0164	0.741	0.0199
0.800	-0.0099	0.000	0.0000	0.800	0.0286	0.798	-0.0137	0.739	0.0188
0.780	-0.0114	0.000	0.0013	0.820	0.0264	0.790	-0.0114	0.738	0.0177
0.760	-0.0129	0.000	0.0029	0.840	0.0241	0.783	-0.0093	0.736	0.0167
0.740	-0.0145	0.001	0.0049	0.860	0.0217	0.777	-0.0075	0.735	0.0158
0.720	-0.0162	0.001	0.0071	0.880	0.0192	0.771	-0.0058	0.733	0.0142
0.700	-0.0179	0.002	0.0096	0.900	0.0166	0.766	-0.0043	0.731	0.0129
0.680	-0.0196	0.004	0.0124	0.910	0.0152	0.762	-0.0023	0.729	0.0117
0.660	-0.0213	0.006	0.0152	0.920	0.0139	0.760	0.0002	0.727	0.0100
0.640	-0.0231	0.010	0.0181	0.930	0.0125	0.758	0.0030	0.725	0.0081
0.620	-0.0248	0.013	0.0210	0.940	0.0110	0.758	0.0058	0.724	0.0066
0.600	-0.0265	0.018	0.0237	0.950	0.0096	0.758	0.0081	0.723	0.0055
0.575	-0.0285	0.023	0.0261	0.960	0.0081	0.759	0.0104	0.721	0.0041
0.550	-0.0303	0.029	0.0282	0.970	0.0065	0.761	0.0126	0.720	0.0032
0.525	-0.0319	0.035	0.0300	0.980	0.0048	0.764	0.0149	0.719	0.0020
0.500	-0.0333	0.041	0.0316	0.985	0.0039	0.767	0.0171	0.718	0.0007
0.475	-0.0345	0.047	0.0331	0.990	0.0030	0.771	0.0192	0.717	-0.0009
0.450	-0.0356	0.053	0.0345	0.995	0.0021	0.776	0.0209	0.716	-0.0023
0.425	-0.0364	0.059	0.0356	0.997	0.0017	0.782	0.0225	0.714	-0.0036
0.400	-0.0370	0.065	0.0366	0.999	0.0013	0.789	0.0238	0.713	-0.0049
0.375	-0.0375	0.070	0.0374	1.000	0.0011	0.796	0.0247	0.712	-0.0058
0.350	-0.0378	0.074	0.0381			0.805	0.0247	0.711	-0.0067
0.325	-0.0379	0.082	0.0393			0.815	0.0234	0.709	-0.0080
0.300	-0.0379	0.090	0.0405			0.825	0.0203	0.708	-0.0090
0.280	-0.0377	0.098	0.0417			0.836	0.0159	0.706	-0.0107
0.260	-0.0373	0.108	0.0429			0.847	0.0103	0.704	-0.0116
0.240	-0.0368	0.117	0.0440			0.859	0.0041	0.703	-0.0126
0.220	-0.0362	0.127	0.0451			0.872	-0.0024	0.701	-0.0136
0.200	-0.0354	0.138	0.0462			0.885	-0.0092	0.699	-0.0145
0.187	-0.0347	0.150	0.0473			0.899	-0.0163	0.698	-0.0150
0.174	-0.0340	0.162	0.0483			0.912	-0.0235	0.696	-0.0159
0.161	-0.0332	0.174	0.0494			0.925	-0.0307	0.695	-0.0164
0.149	-0.0323	0.187	0.0504			0.938	-0.0377	0.693	-0.0169
0.138	-0.0315	0.200	0.0512			0.951	-0.0446	0.692	-0.0174
0.127	-0.0305	0.220	0.0522			0.963	-0.0513	0.690	-0.0179
0.117	-0.0296	0.240	0.0529			0.974	-0.0575	0.688	-0.0183
0.107	-0.0286	0.260	0.0535			0.985	-0.0634	0.687	-0.0186
0.098	-0.0276	0.280	0.0539			0.994	-0.0689	0.684	-0.0191
0.089	-0.0265	0.300	0.0541			1.003	-0.0740	0.681	-0.0195
0.081	-0.0255	0.325	0.0543			1.011	-0.0787		
0.073	-0.0246	0.350	0.0543			1.018	-0.0829		


PARTS LIST - LISTE de PIECES

APPENDIX D

LIFT COEFFICIENT DATA PROVIDED BY NRC

LIST OF FIGURES

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LIGHT ICE PELLETS

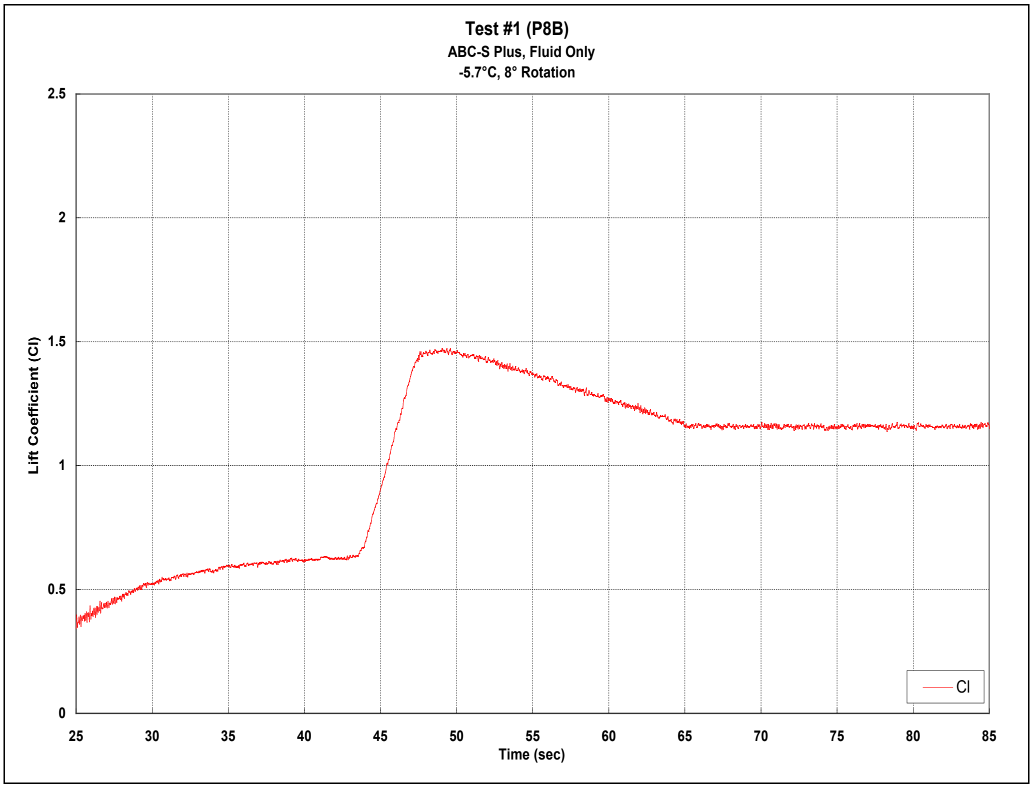

Figure D1: Run #1

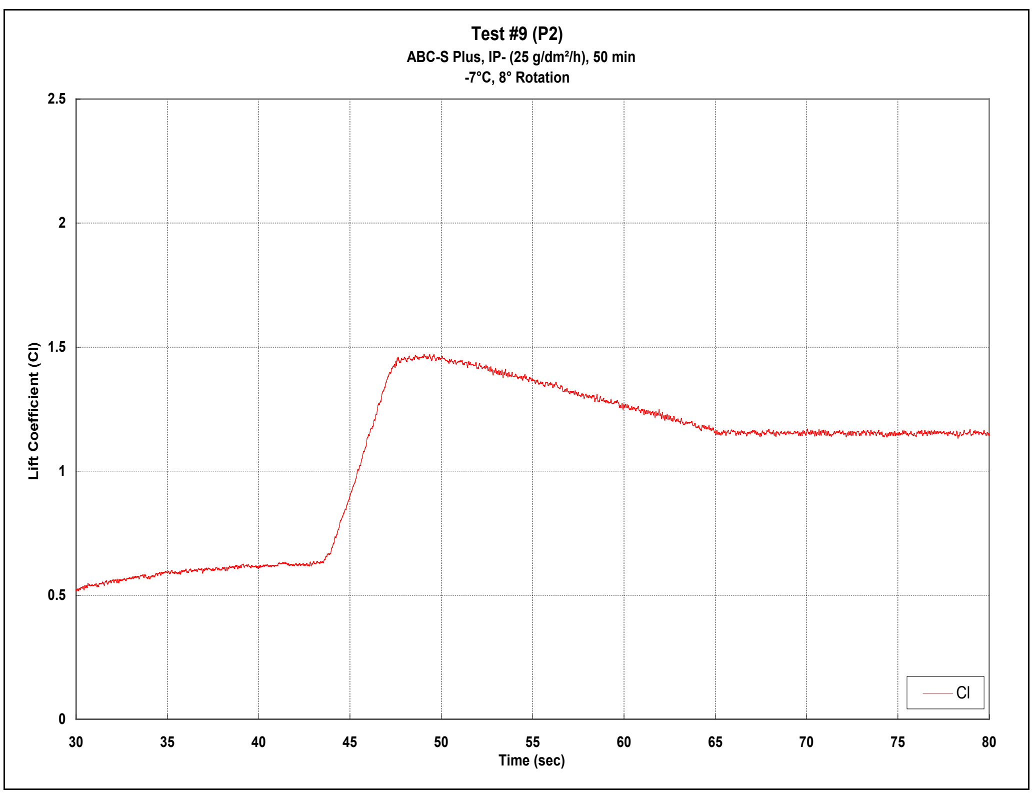

Figure D2: Run #9

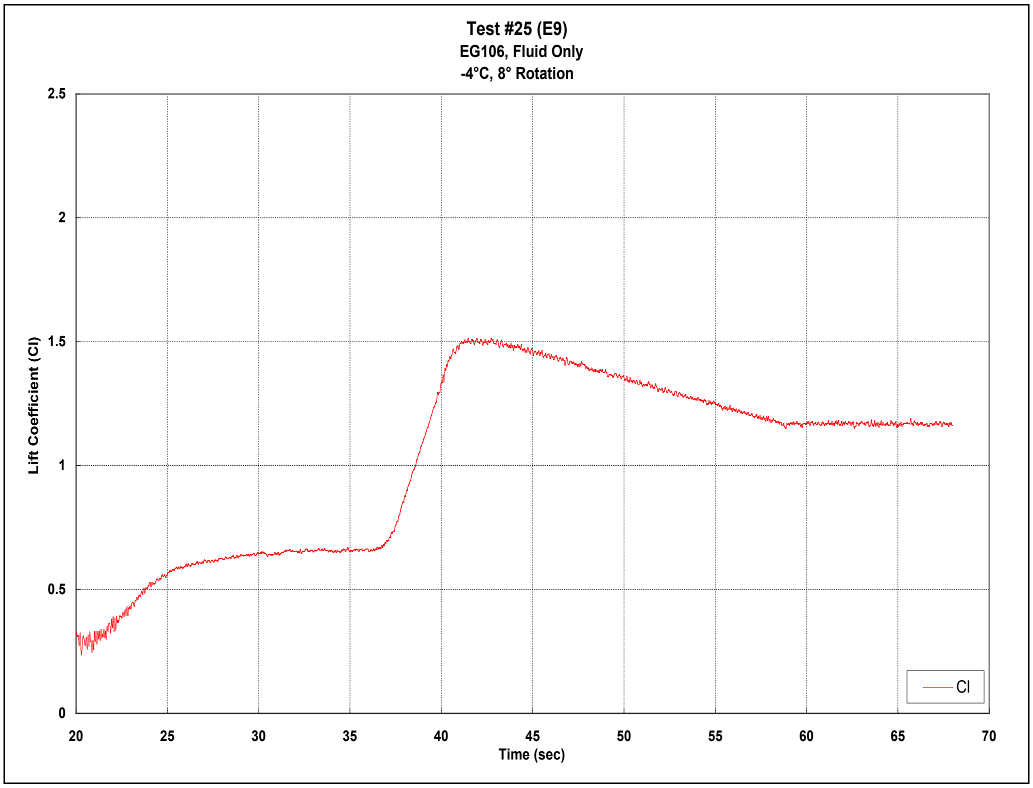

Figure D3: Run #25

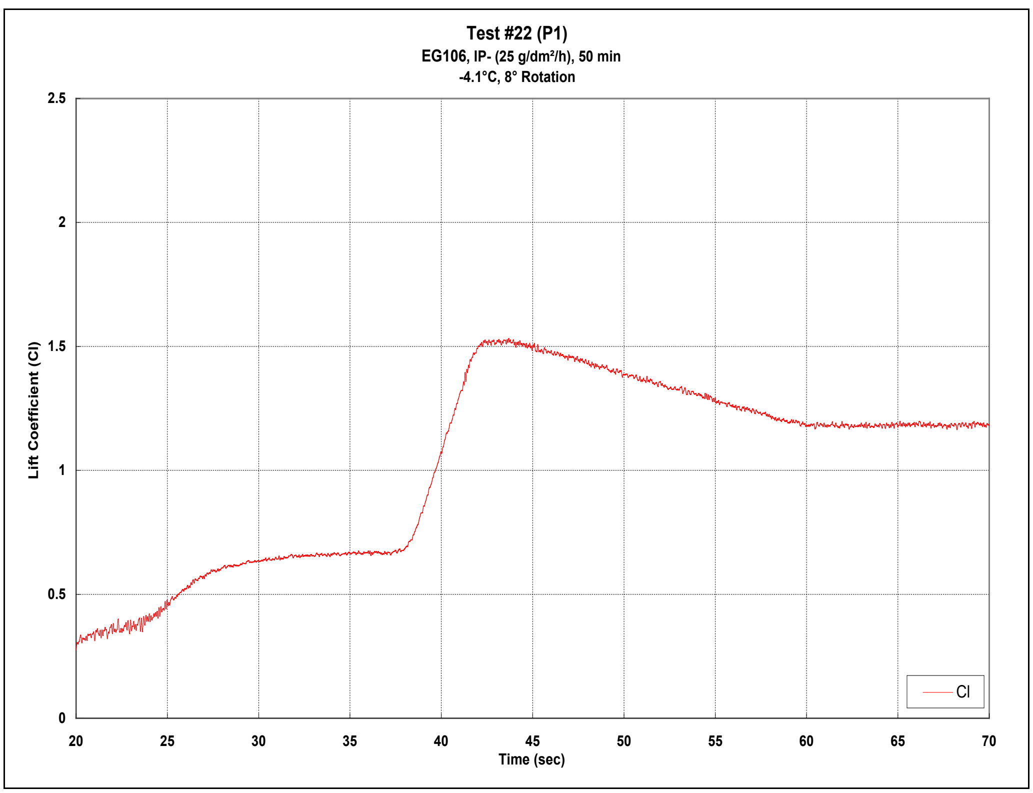

Figure D4: Run #22

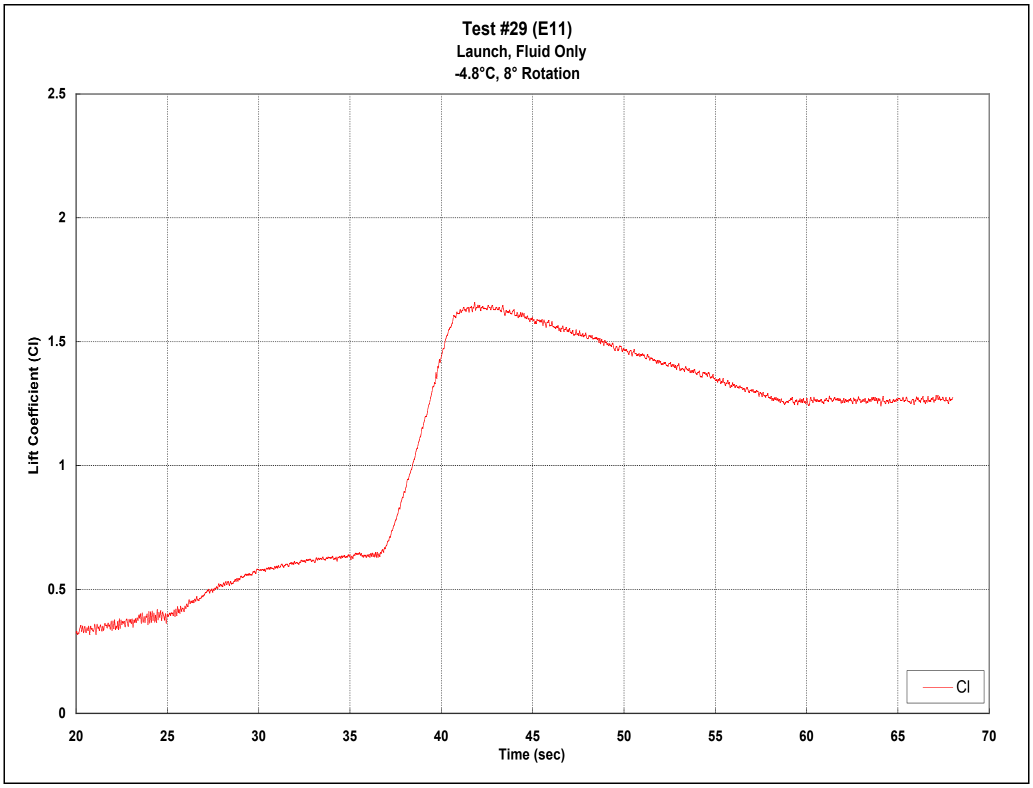

Figure D5: Run #29

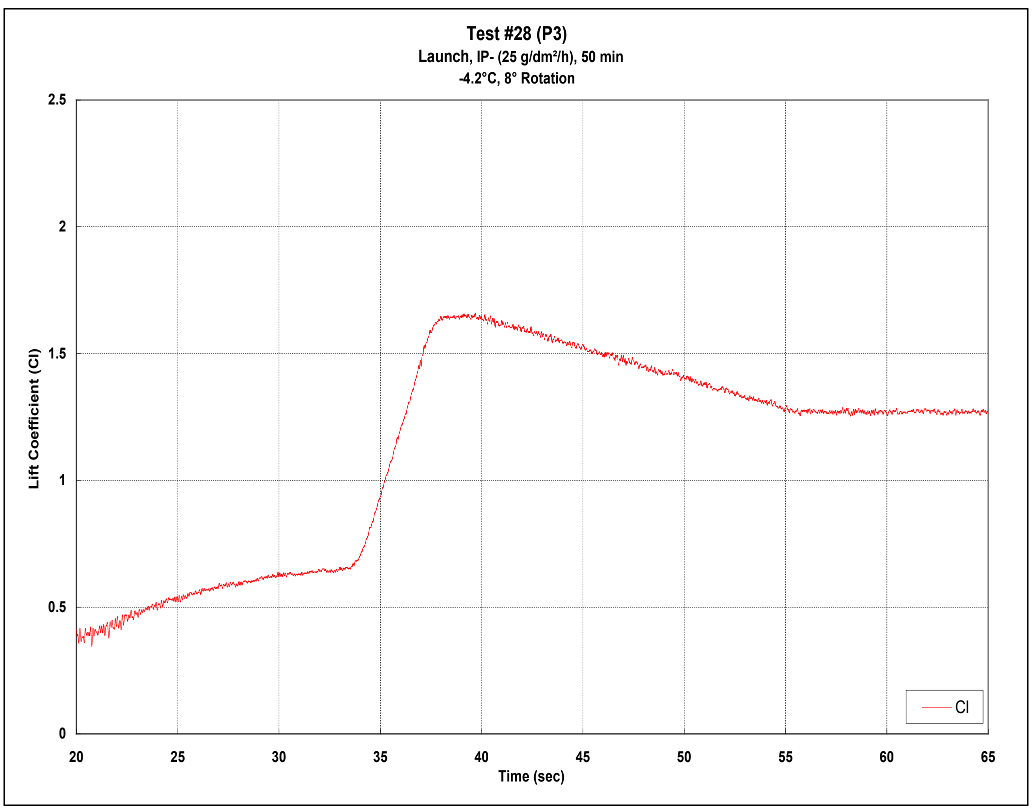

Figure D6: Run #28

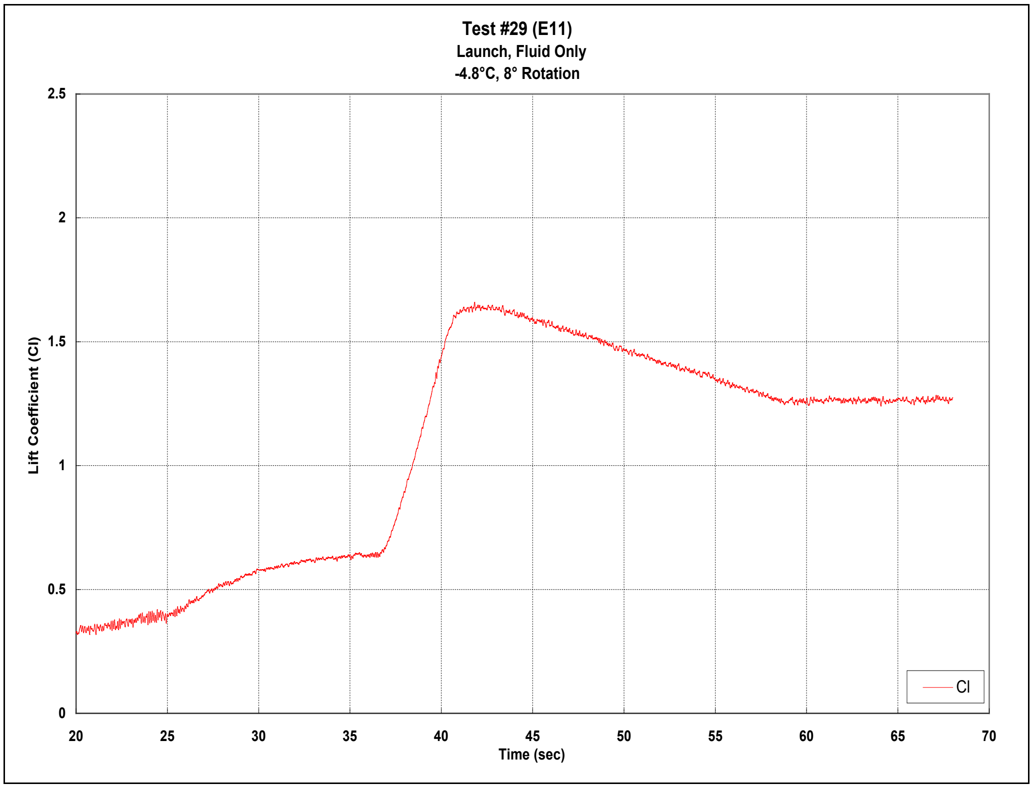

Figure D7: Run #29

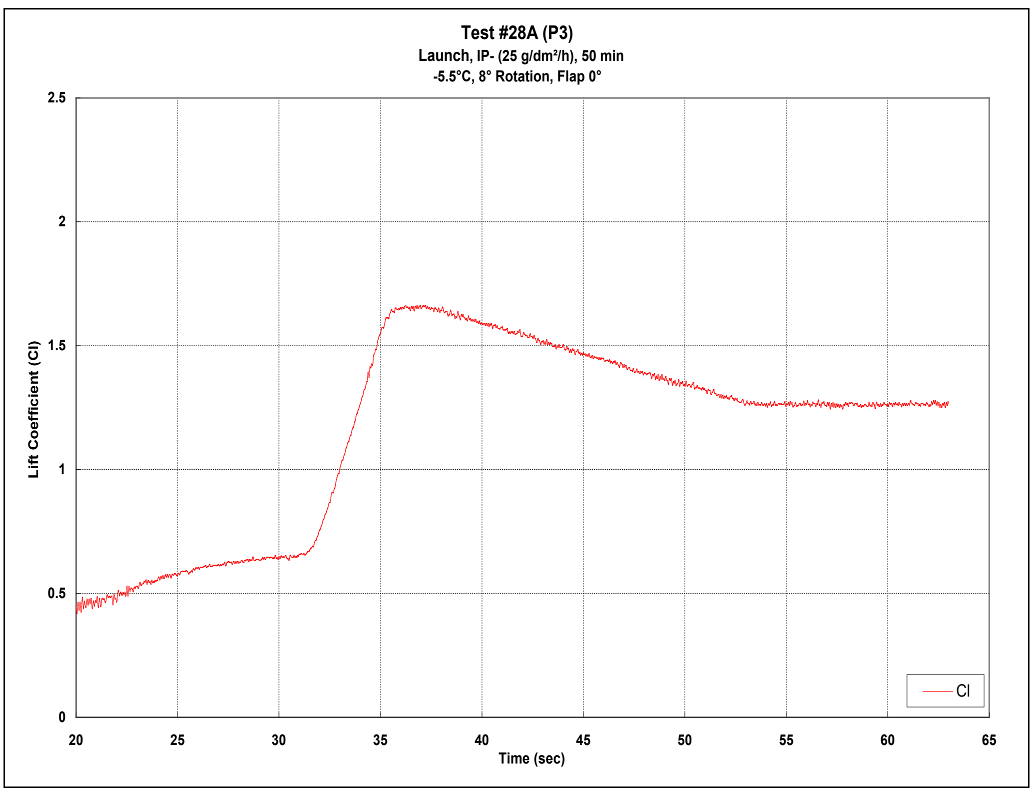

Figure D8: Run #28A

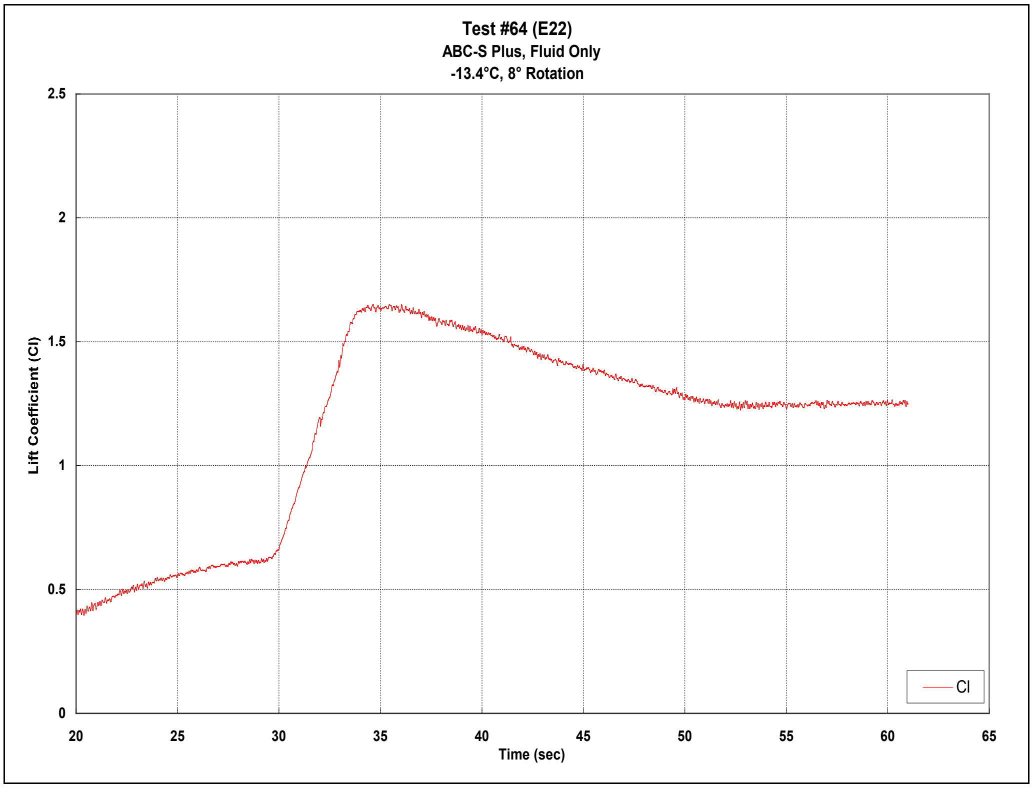

Figure D9: Run #64

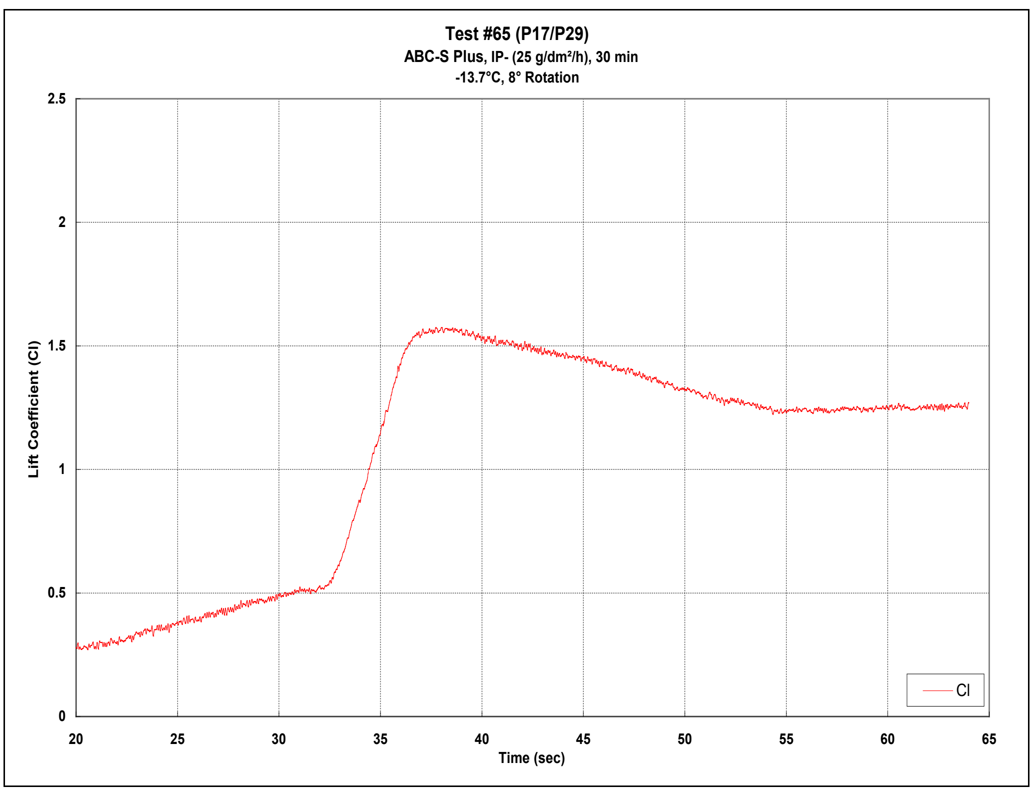

Figure D10: Run #65

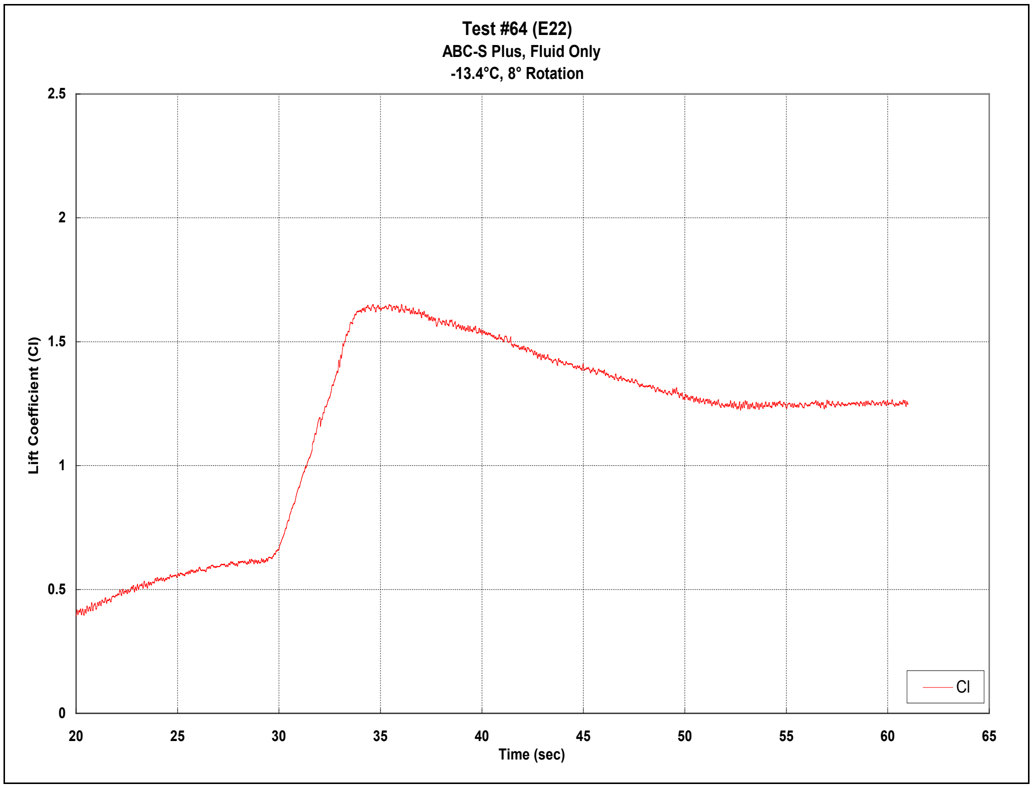

Figure D11: Run #64

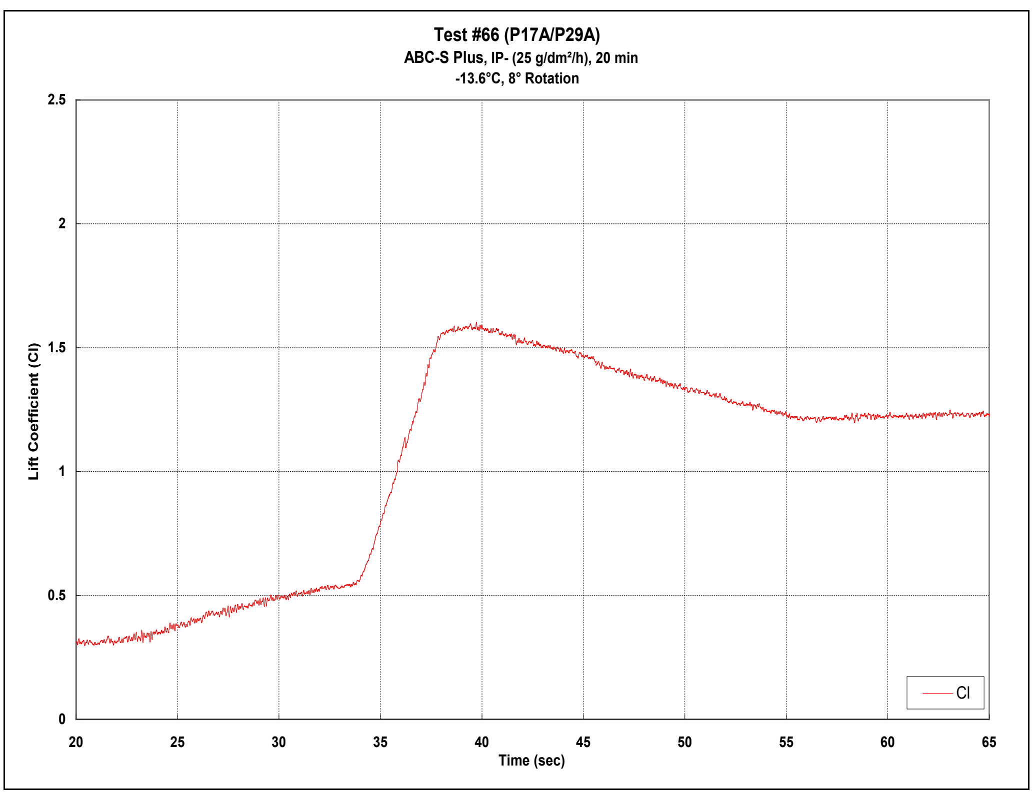

Figure D12: Run #66

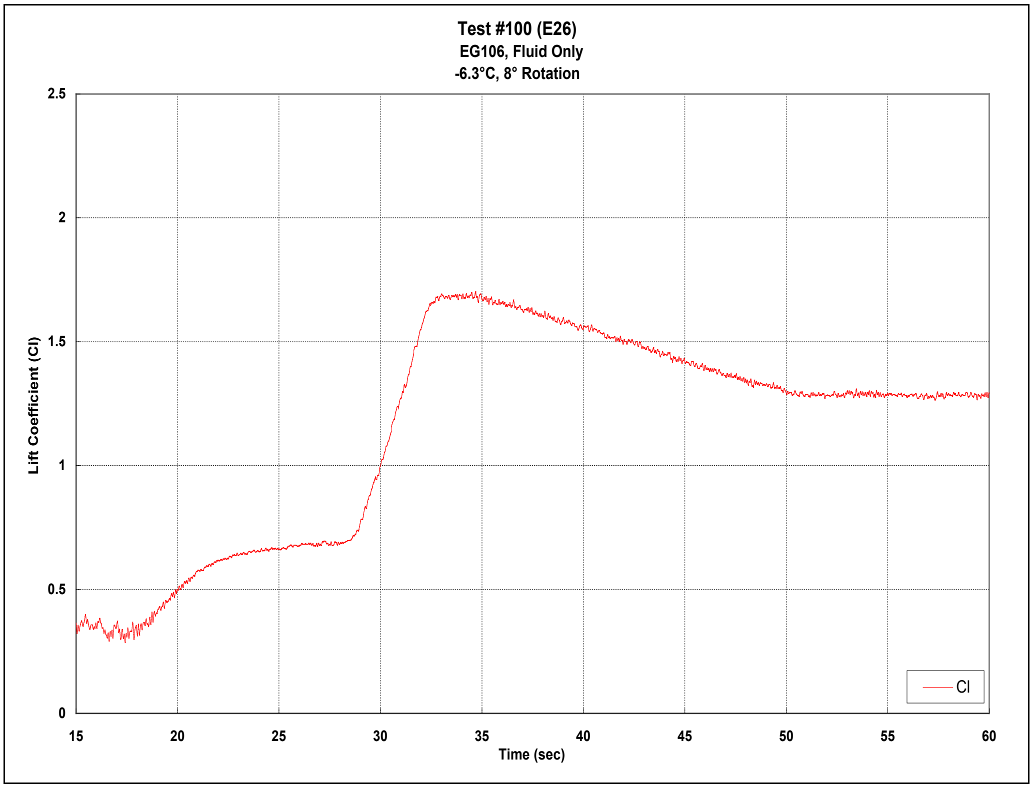

Figure D13: Run #100

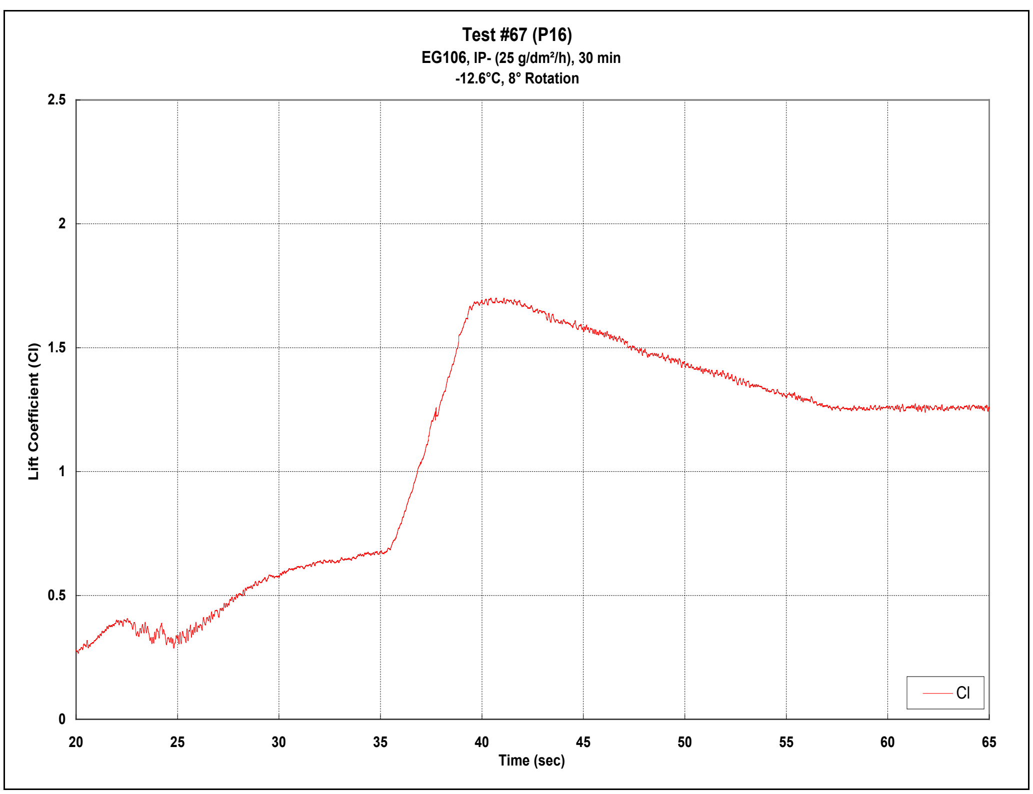

Figure D14: Run #67

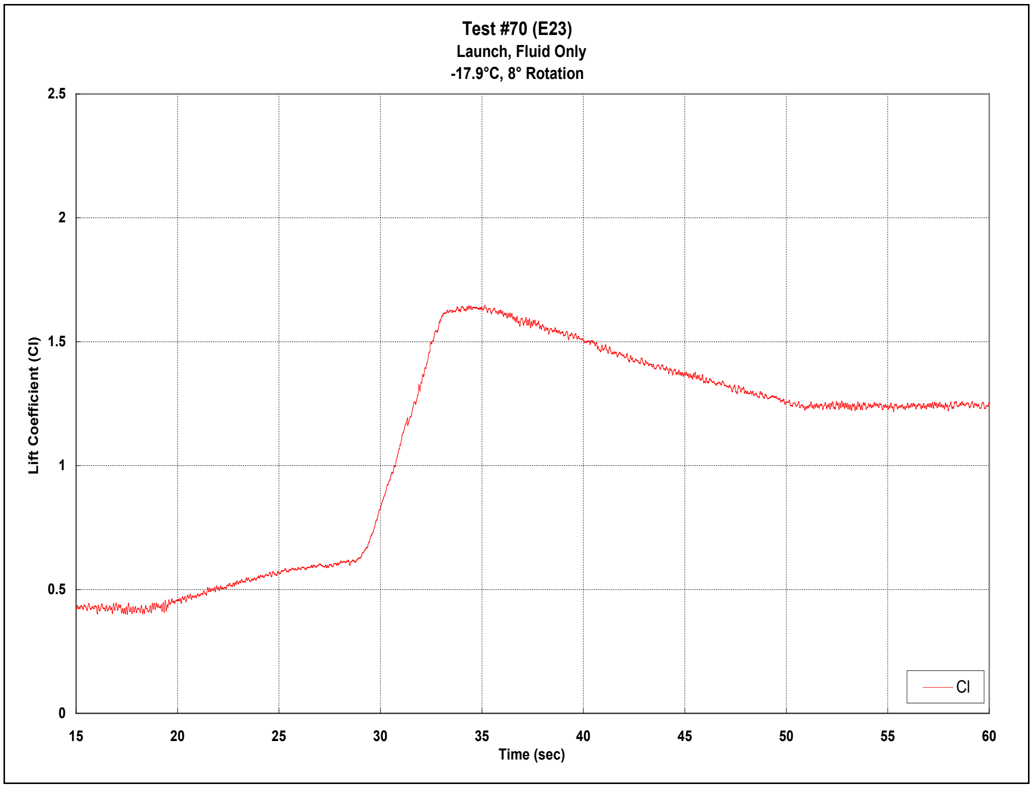

Figure D15: Run #70

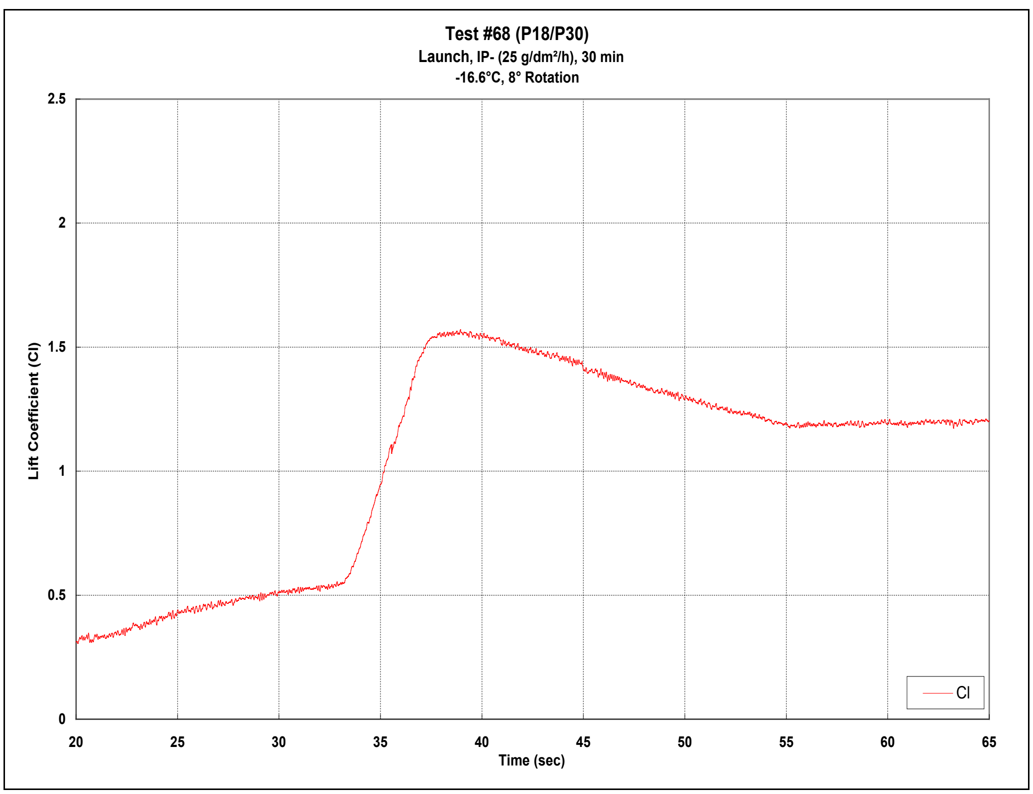

Figure D16: Run #68

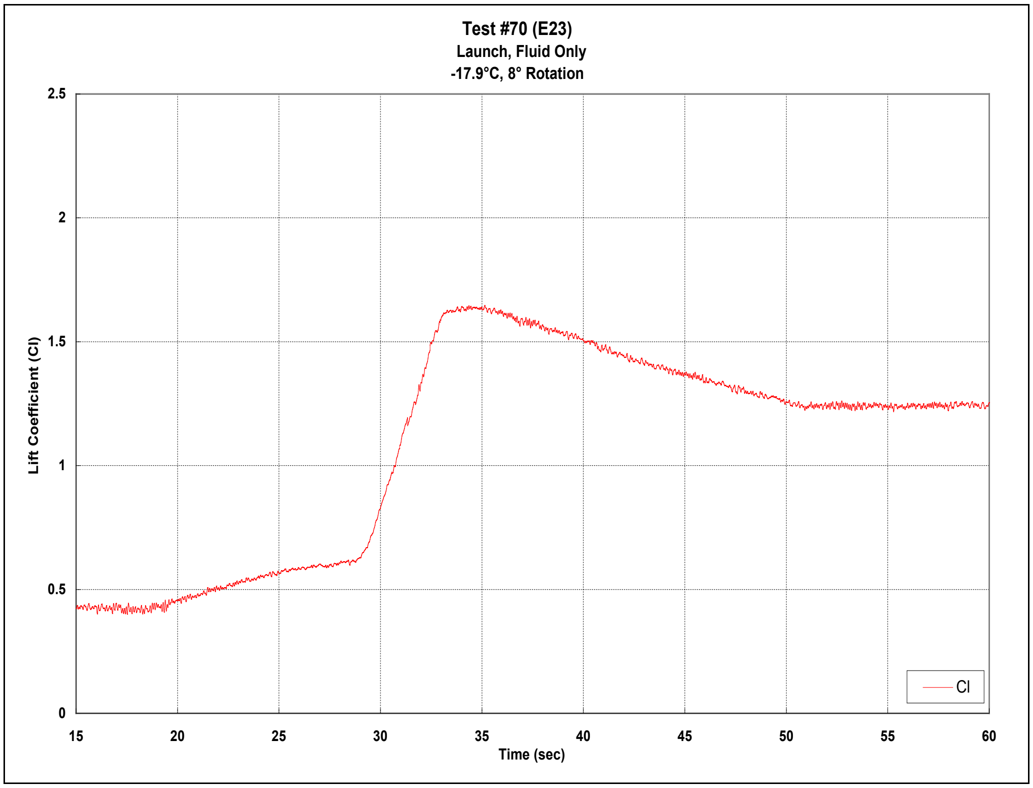

Figure D17: Run #70

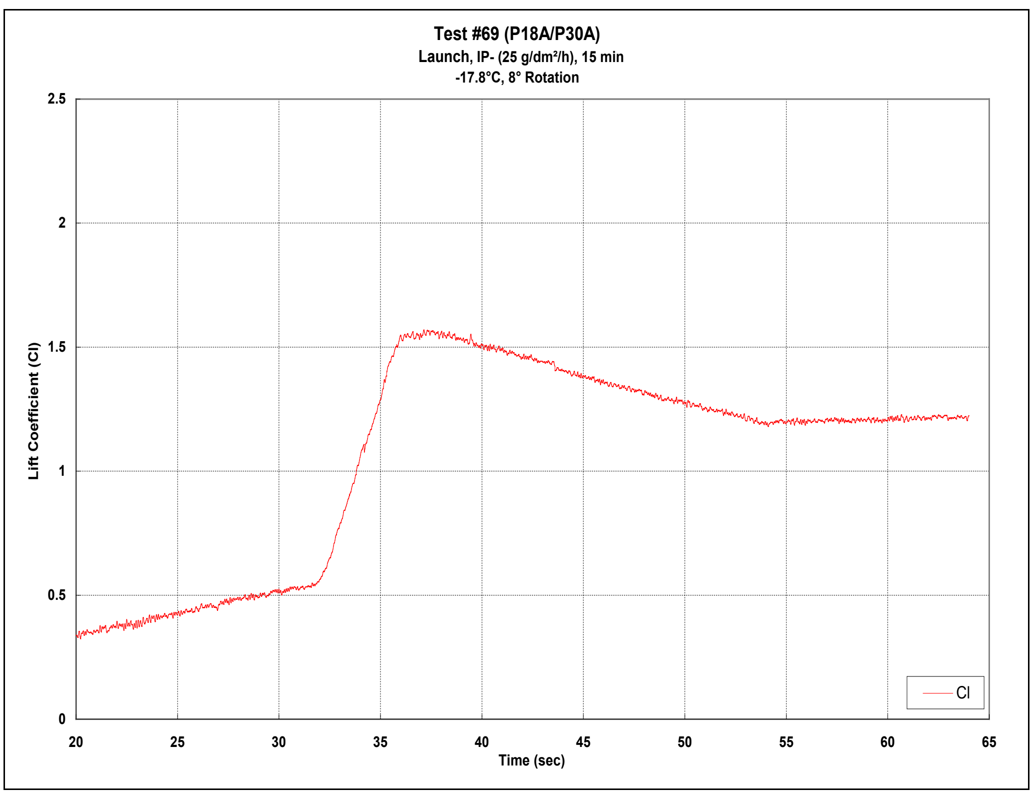

Figure D18: Run #69

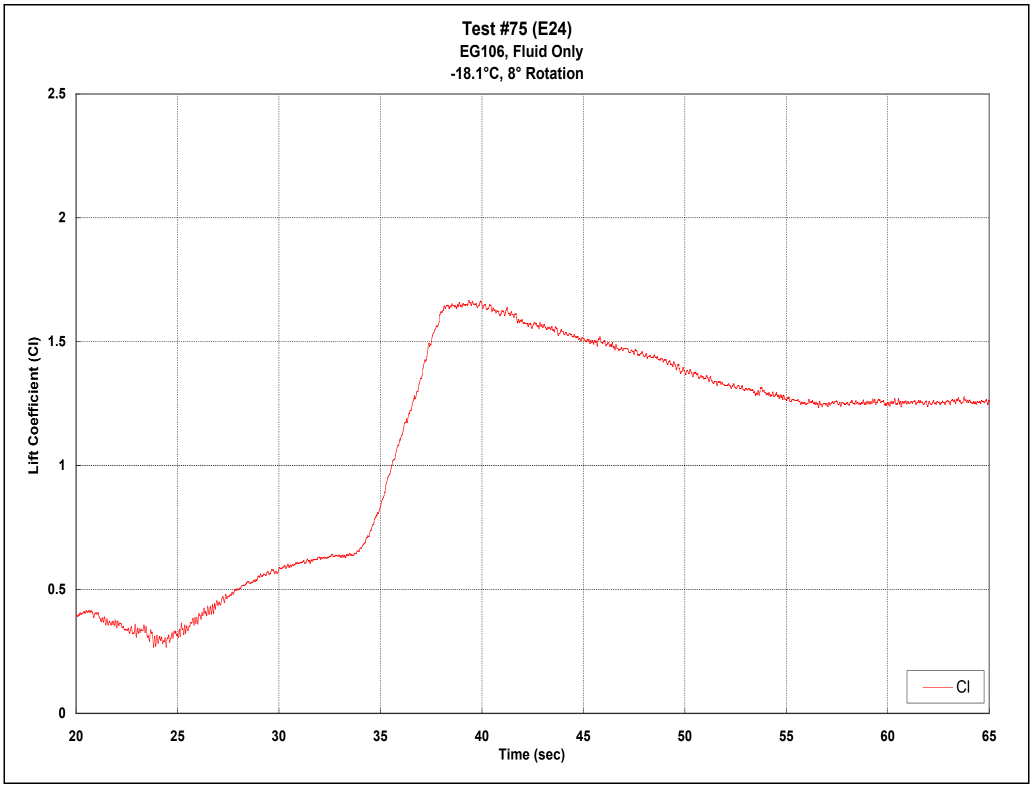

Figure D19: Run #75

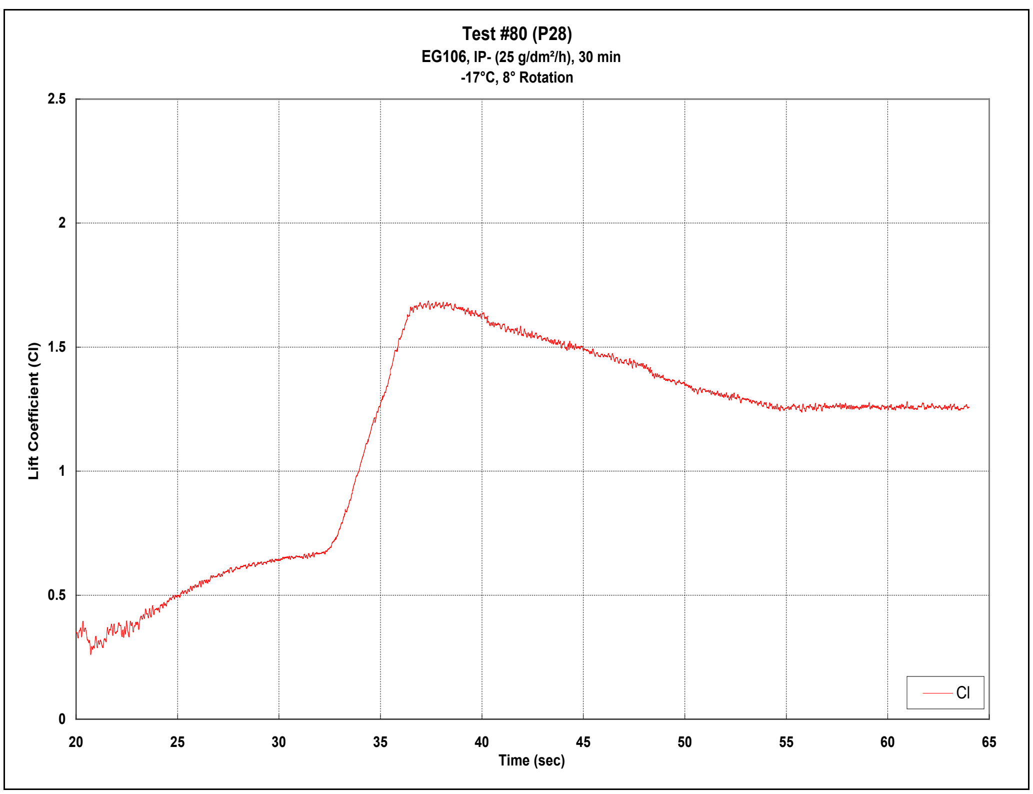

Figure D20: Run #80

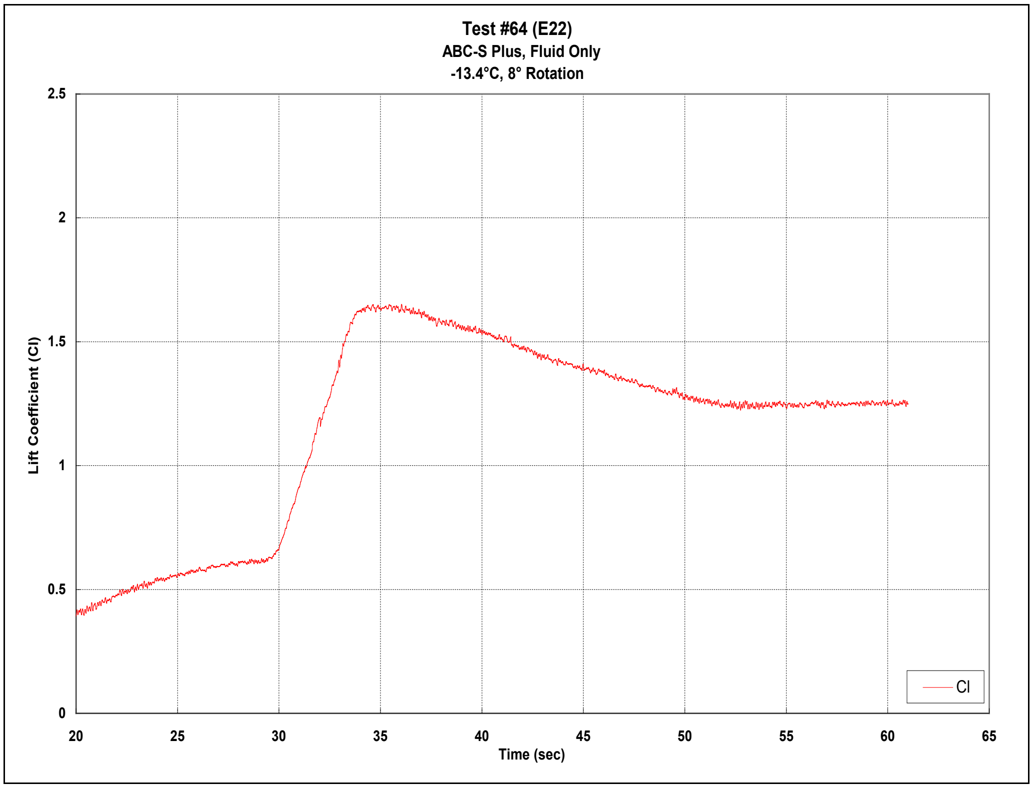

Figure D21: Run #64

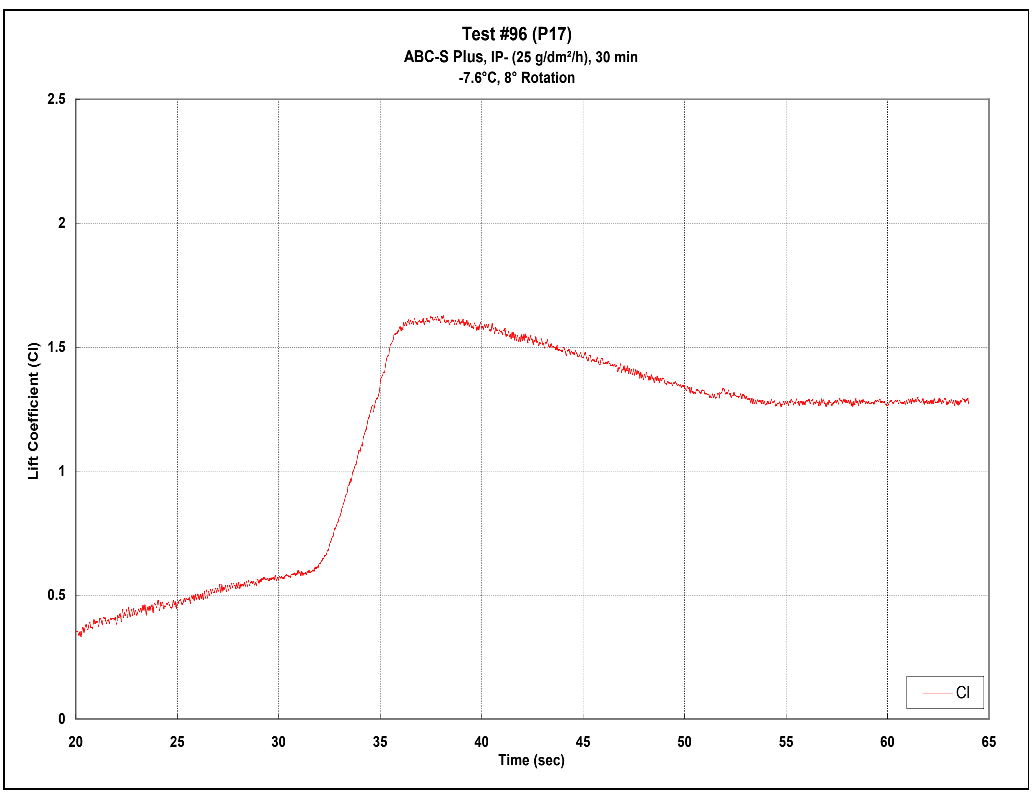

Figure D22: Run #96

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MODERATE ICE PELLETS

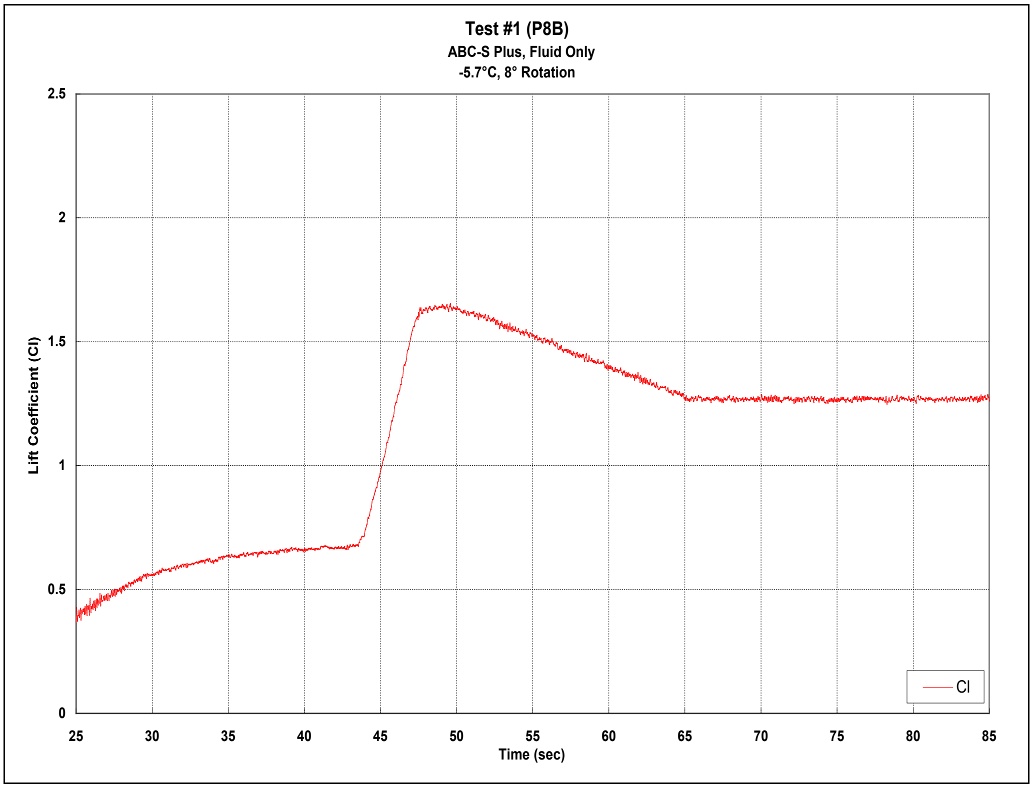

Figure D23: Run #1

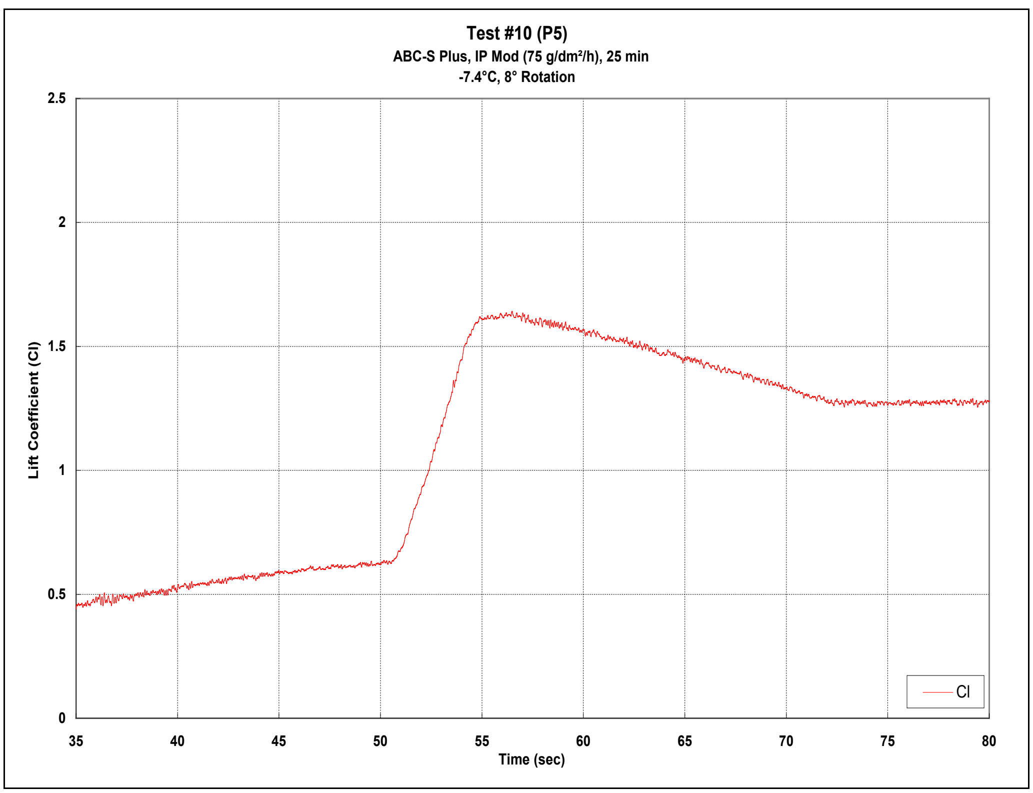

Figure D24: Run #10

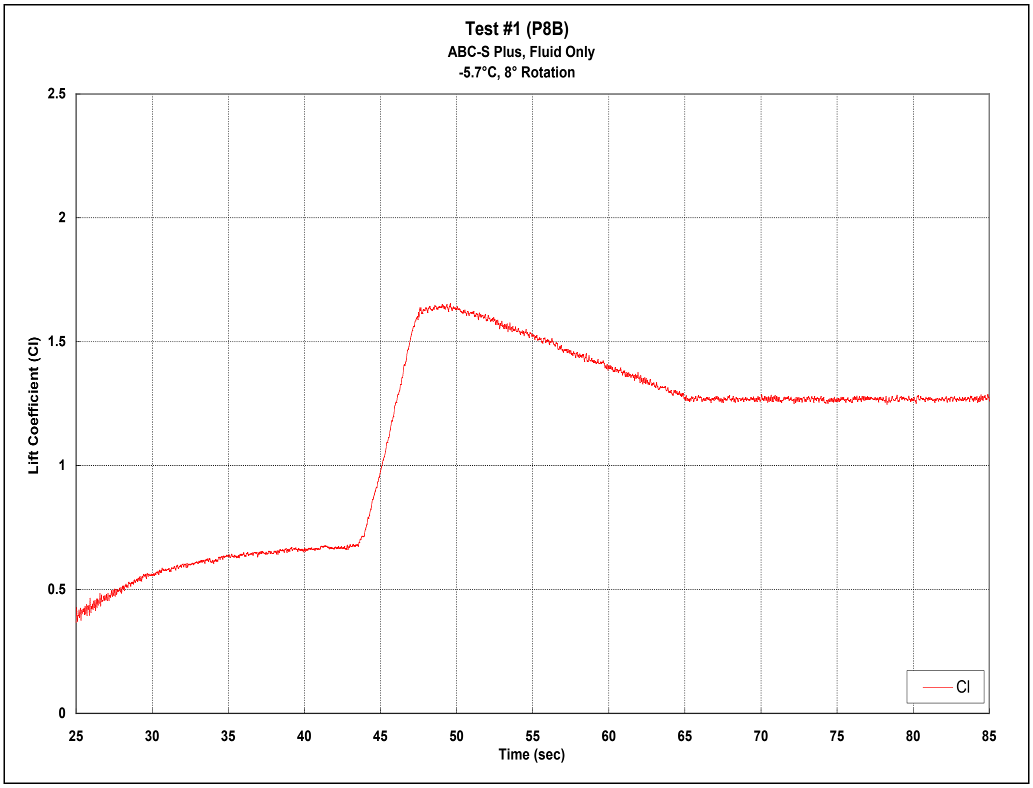

Figure D25: Run #1

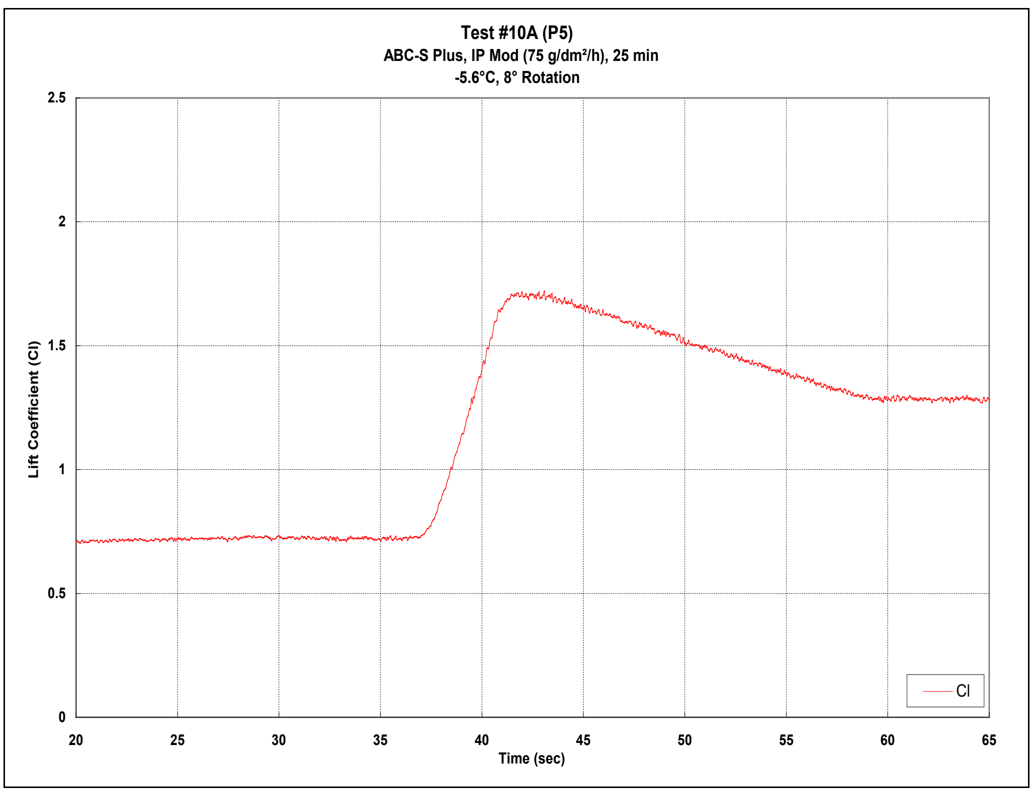

Figure D26: Run #10A

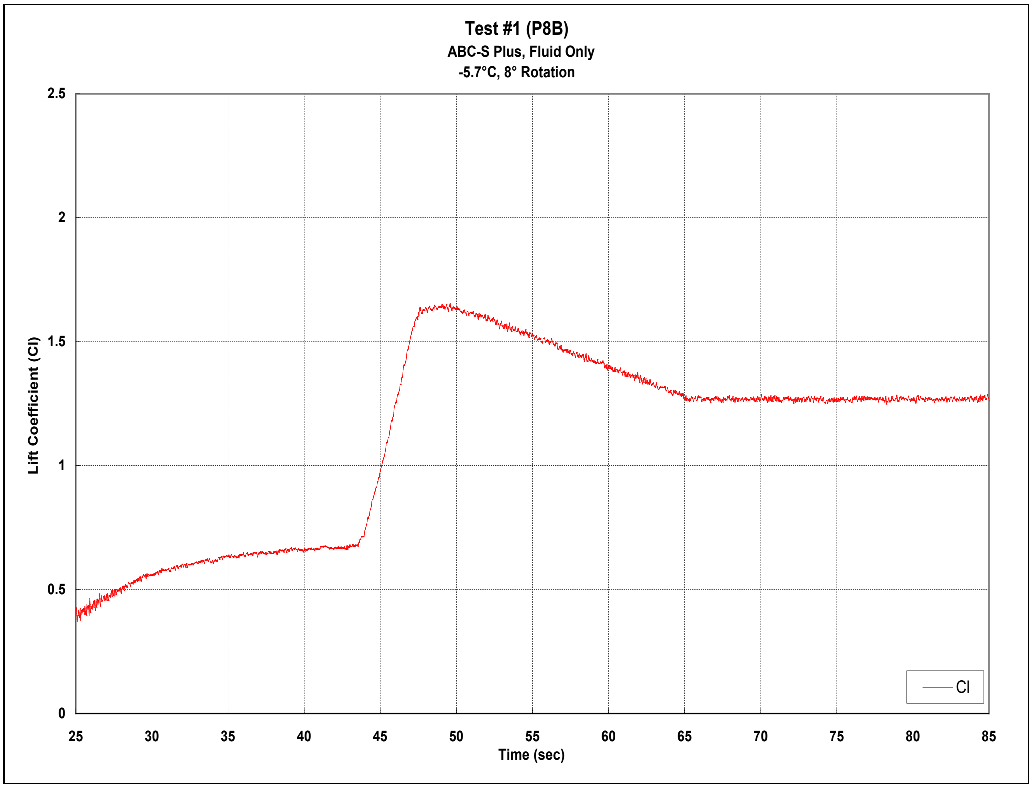

Figure D27: Run #1

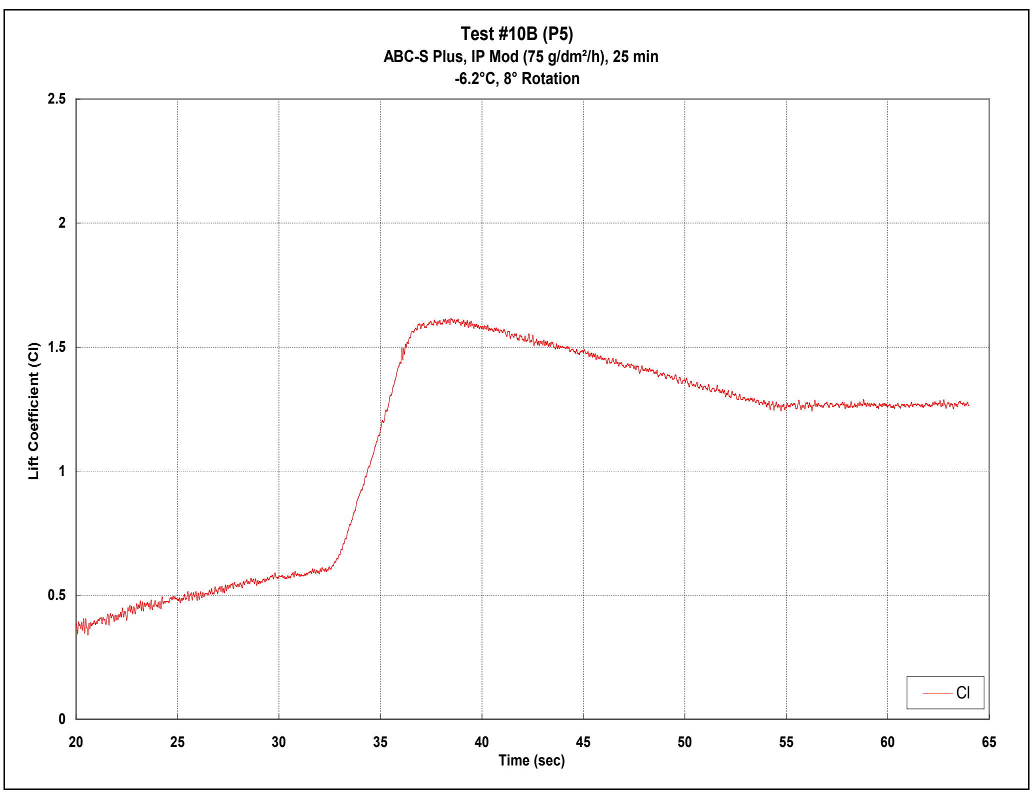

Figure D28: Run #10B

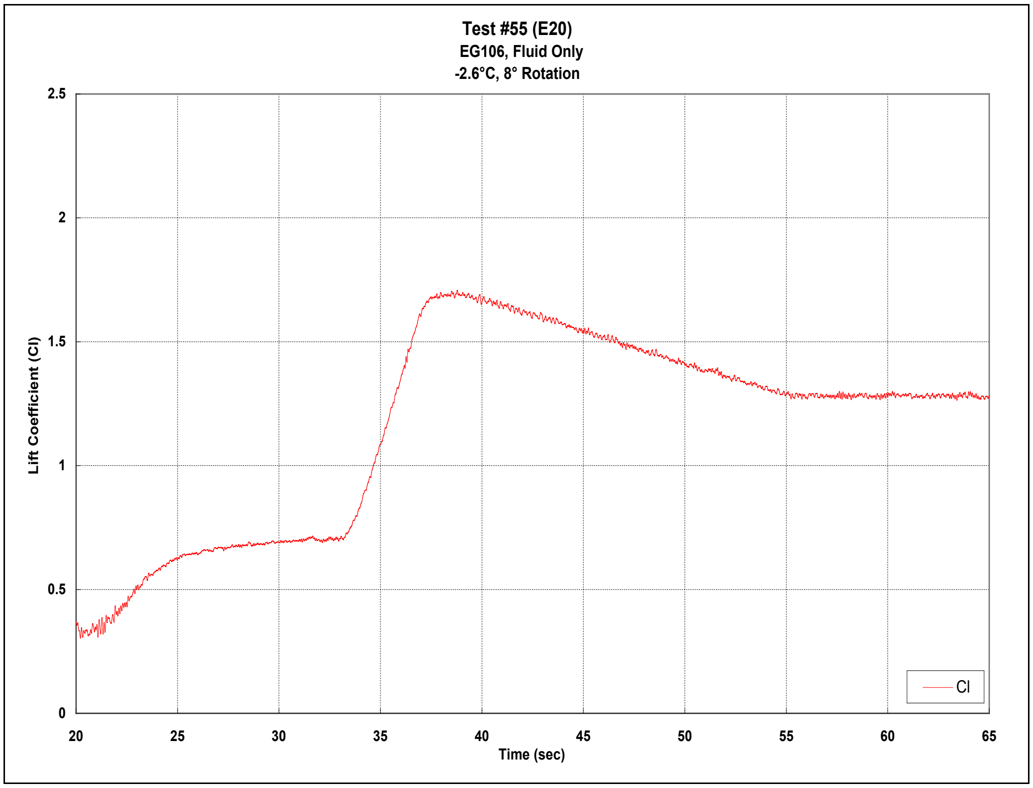

Figure D29: Run #55

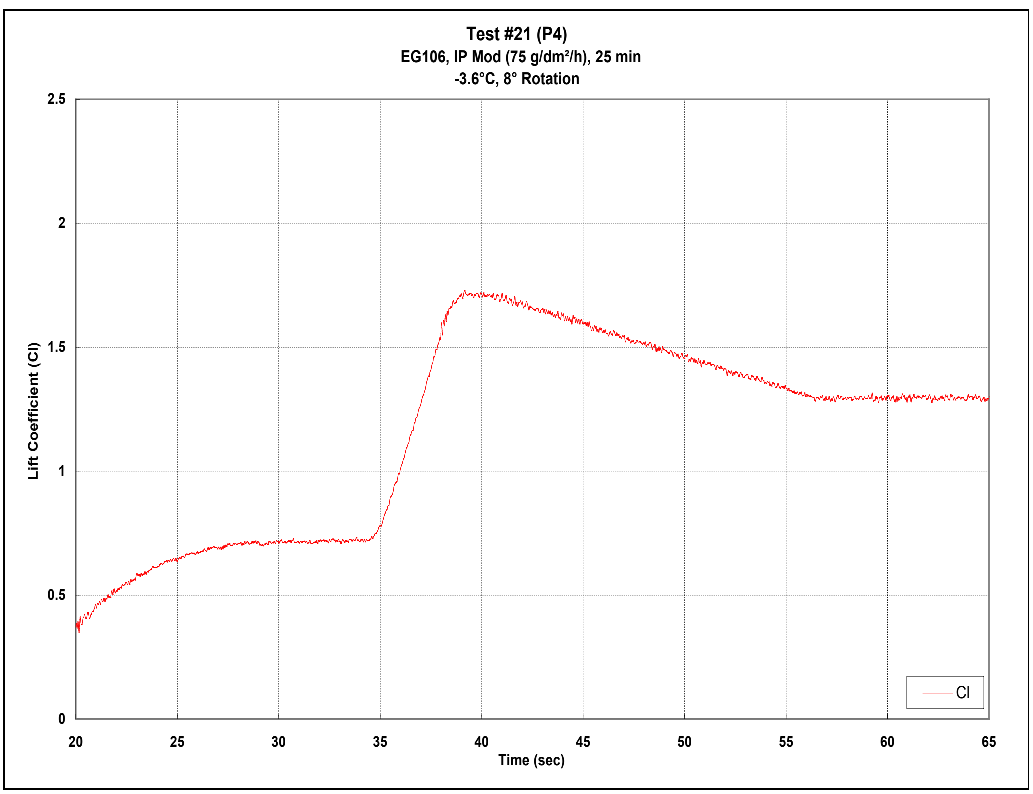

Figure D30: Run #21

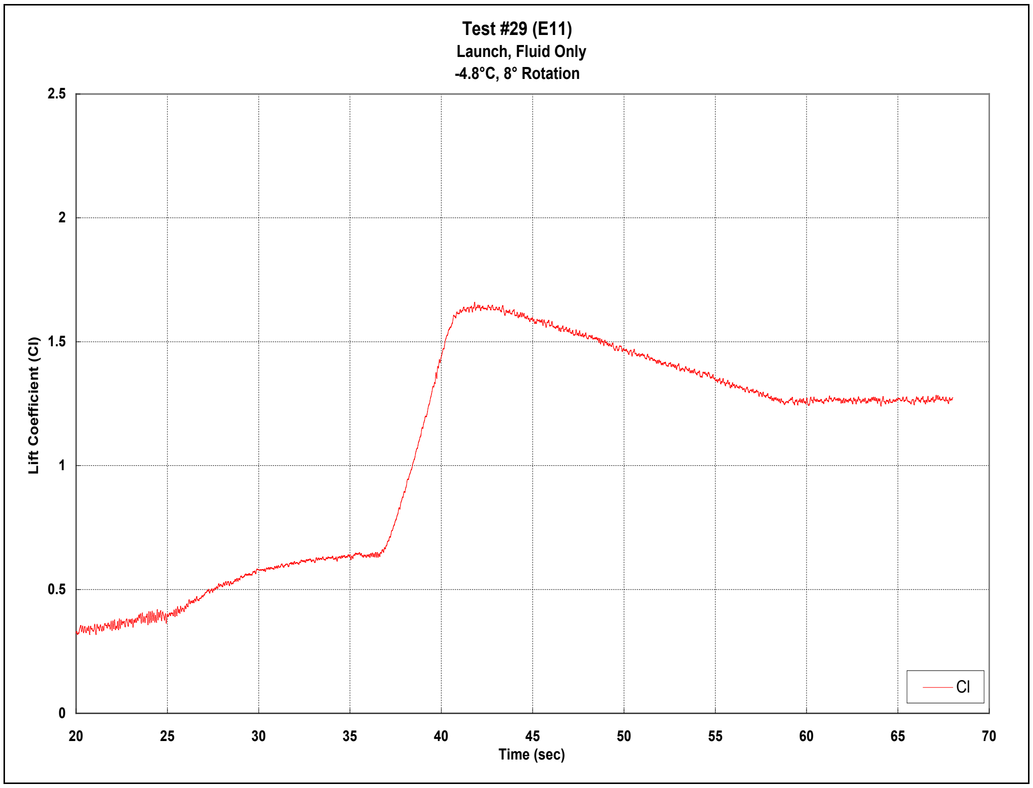

Figure D31: Run #29

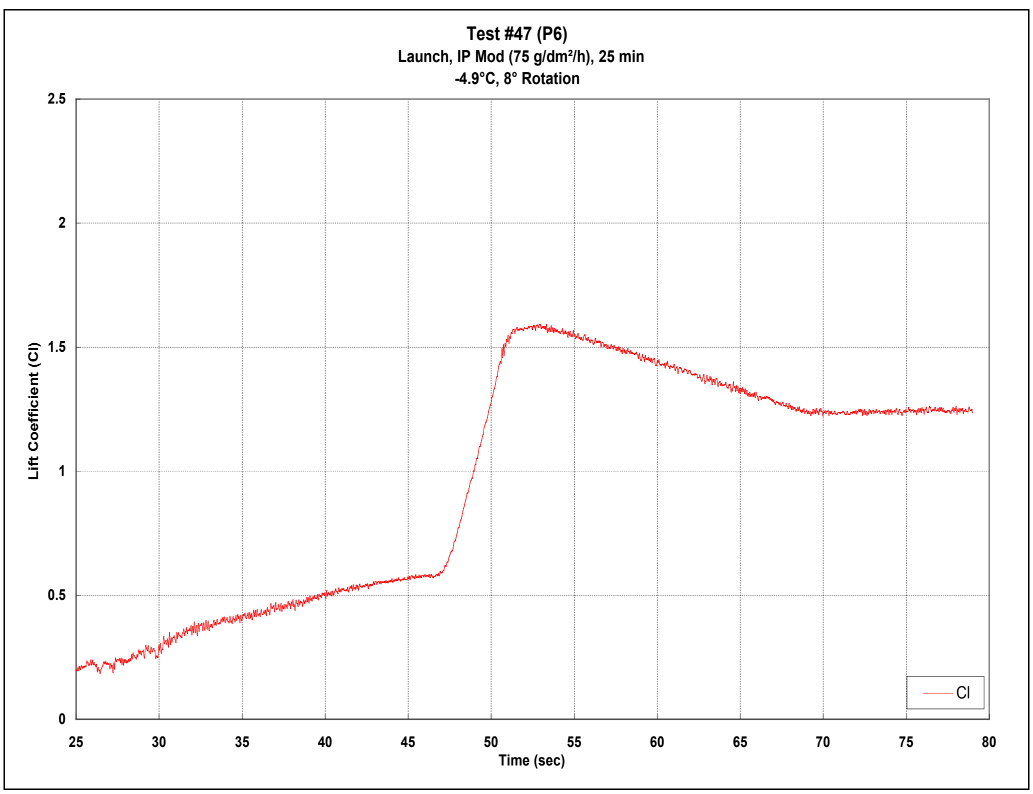

Figure D32: Run #47

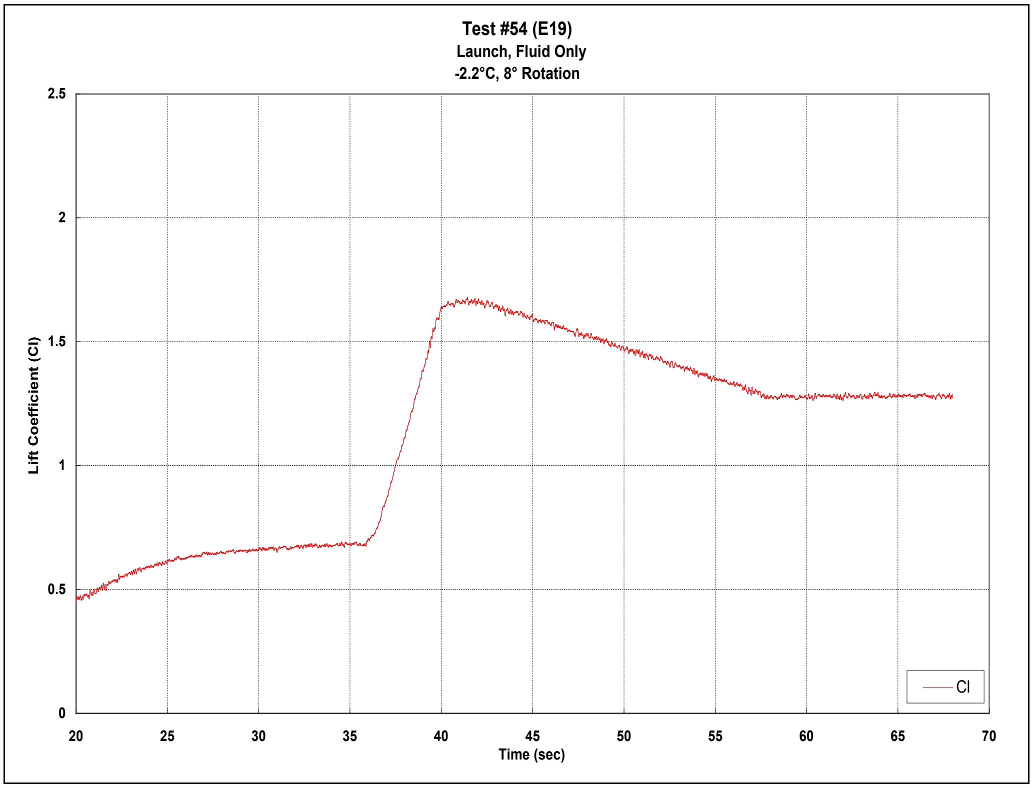

Figure D33: Run #54

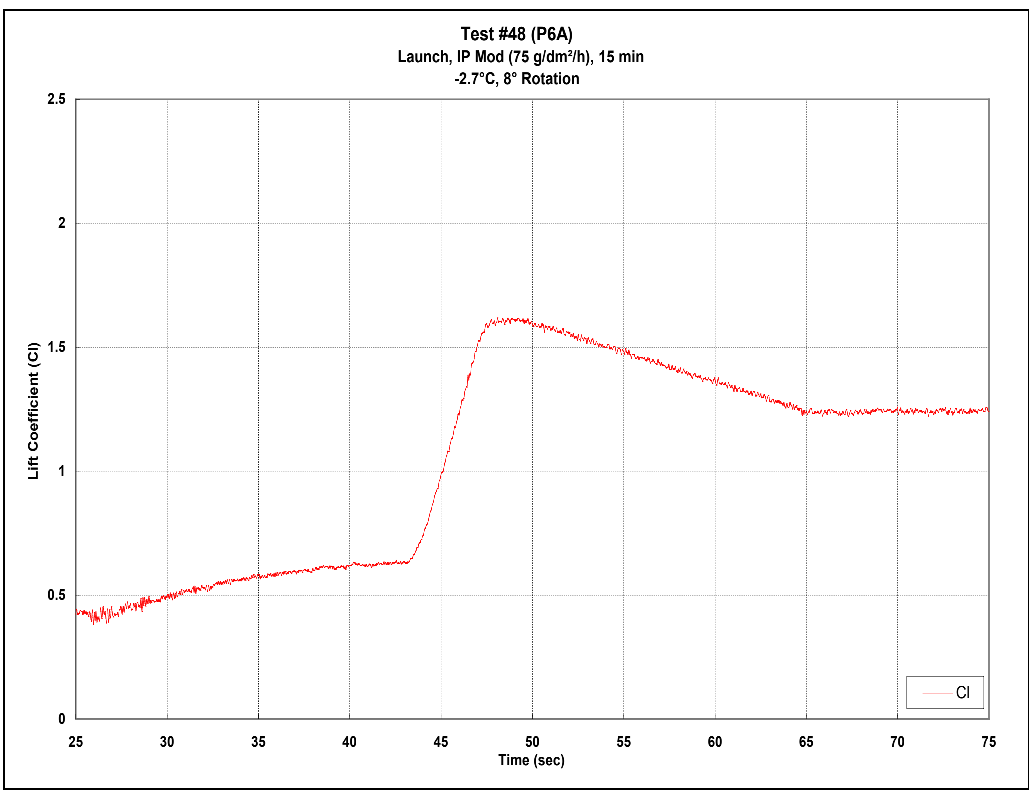

Figure D34: Run #48

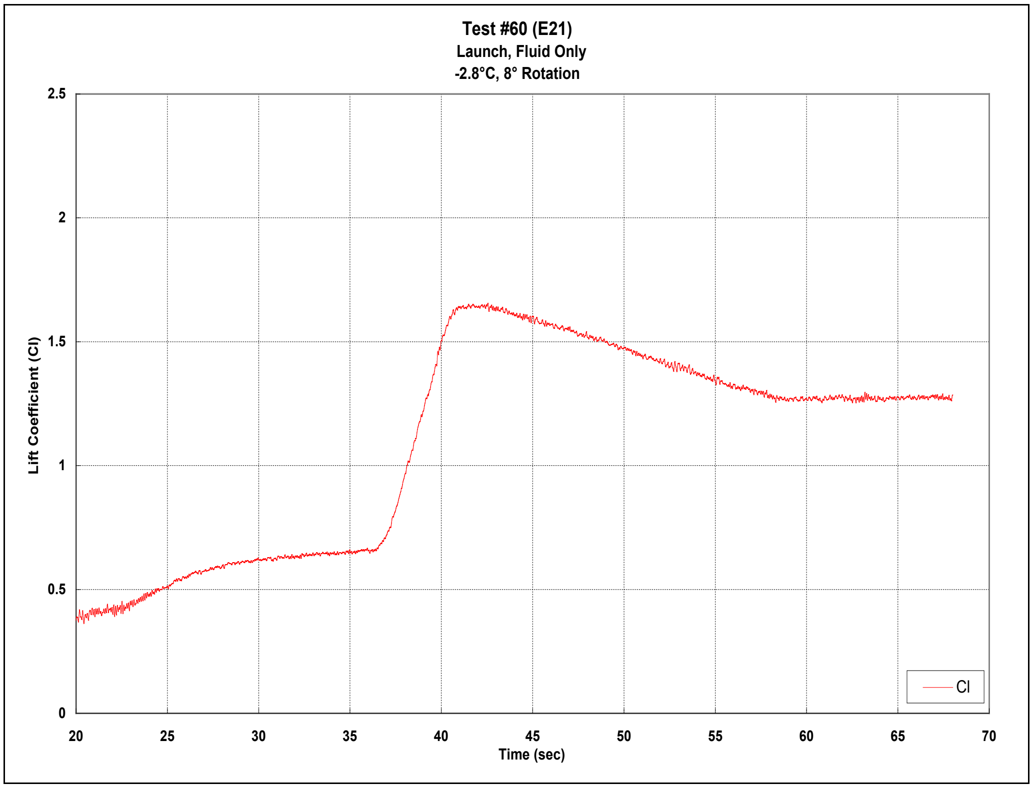

Figure D35: Run #60

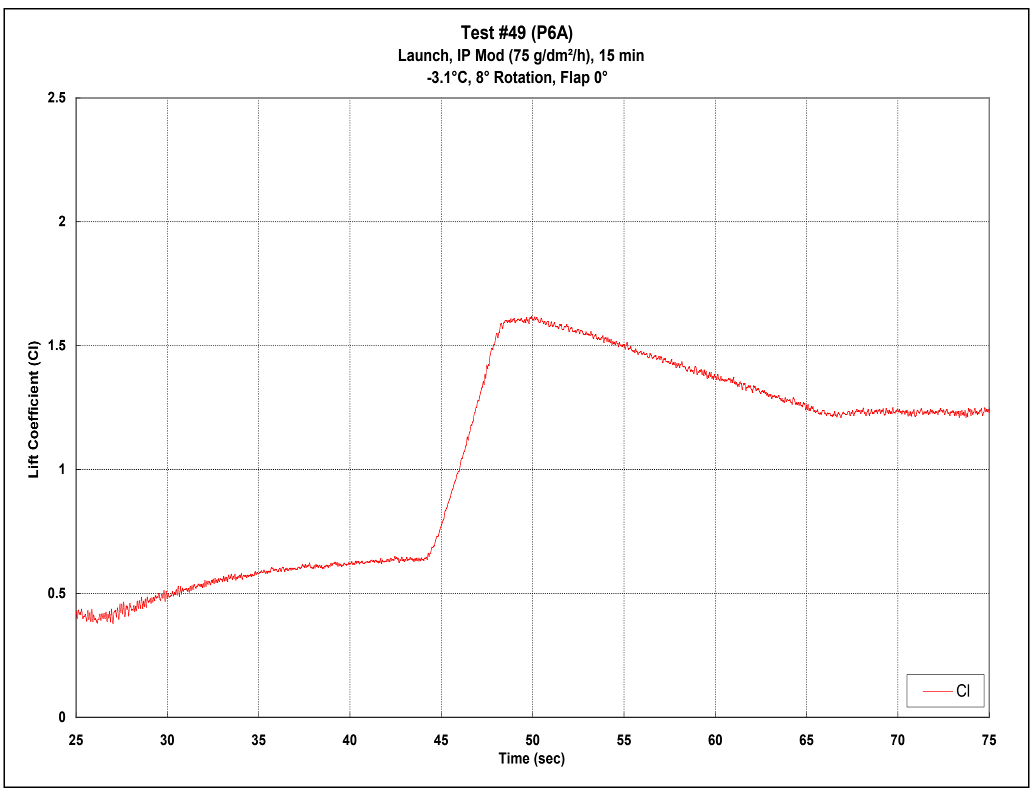

Figure D36: Run #49

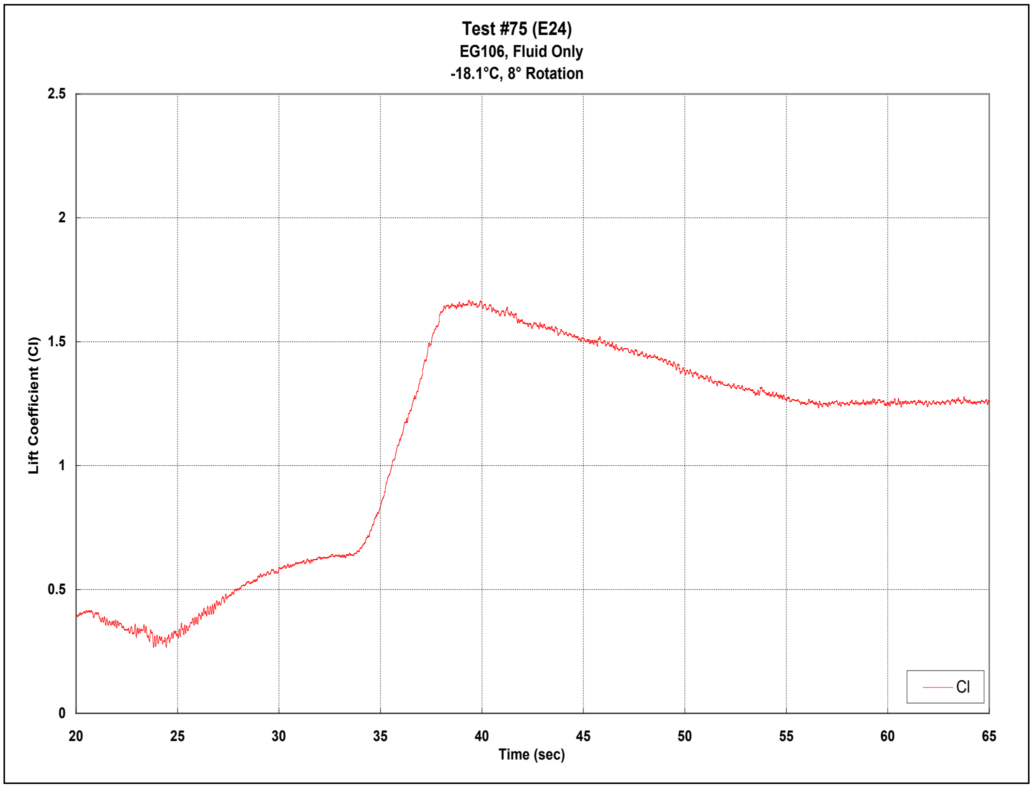

Figure D37: Run #75

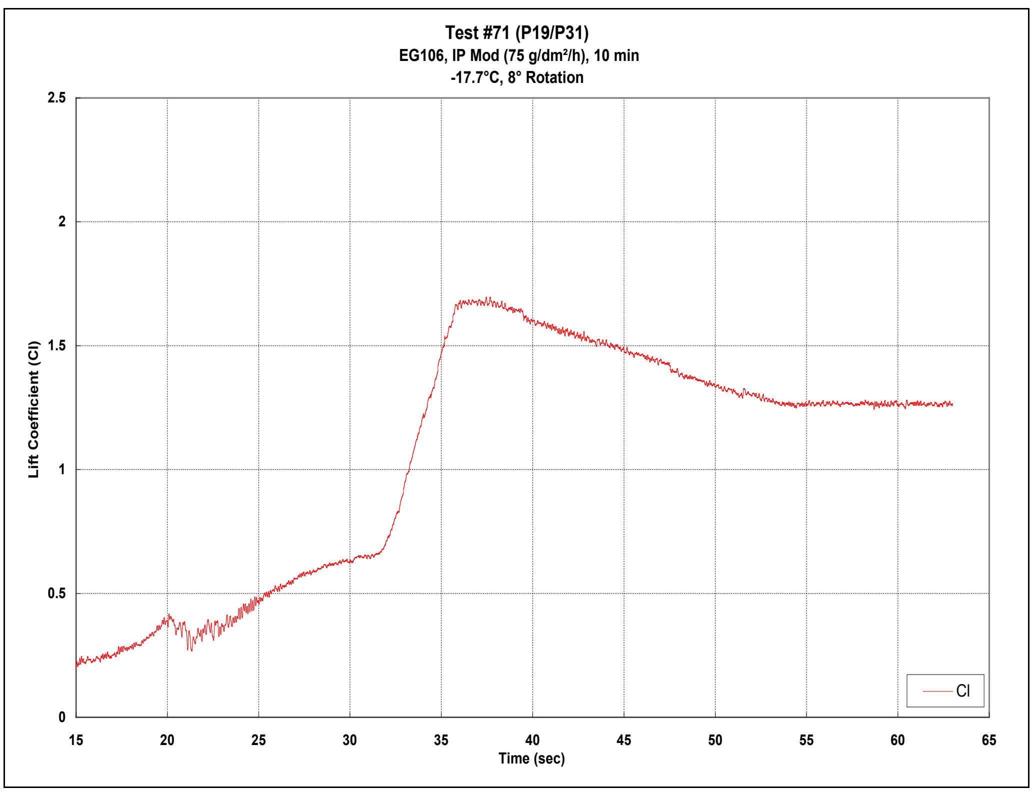

Figure D38: Run #71

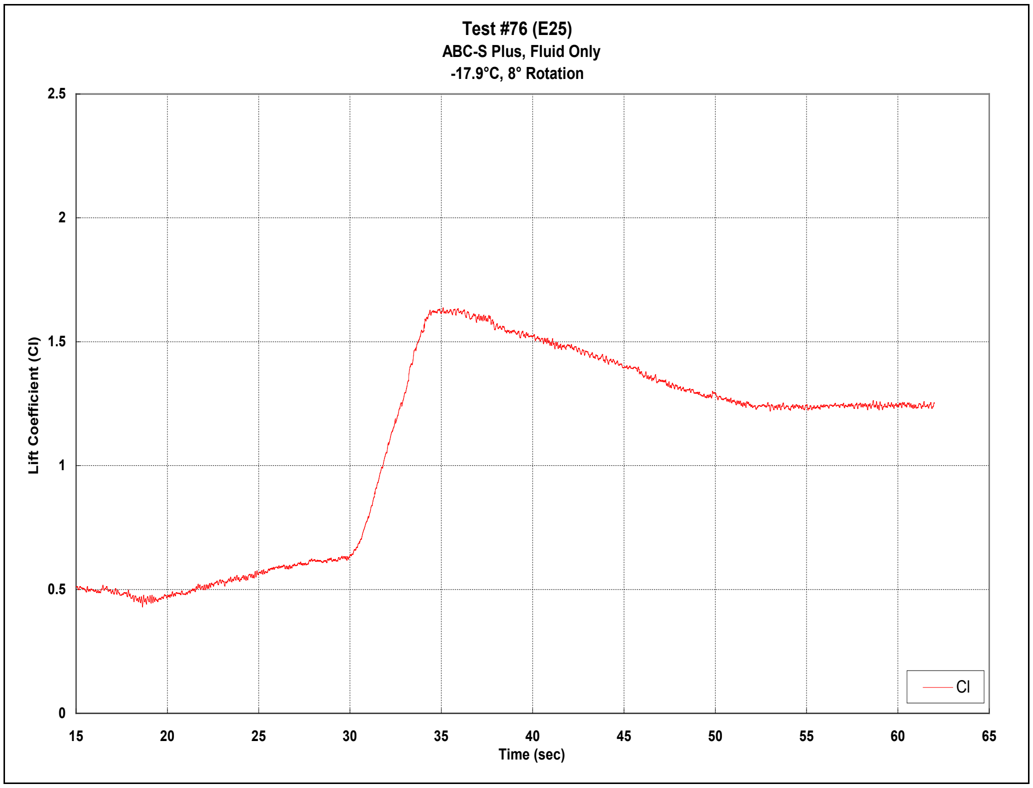

Figure D39: Run #76

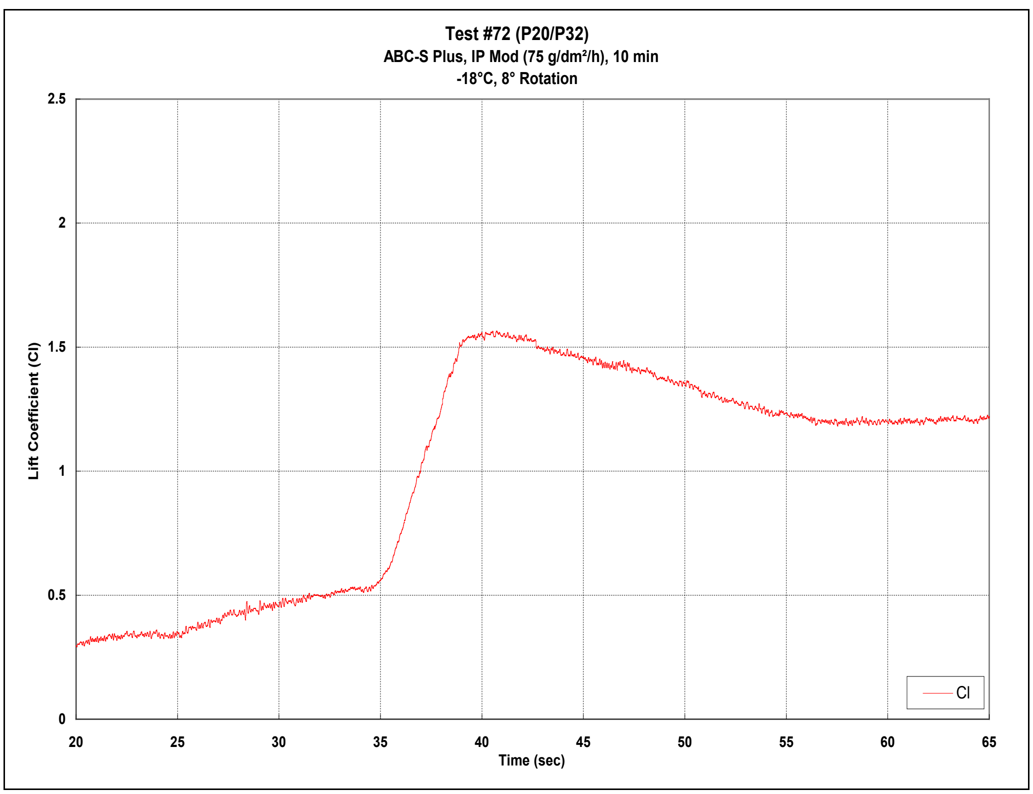

Figure D40: Run #72

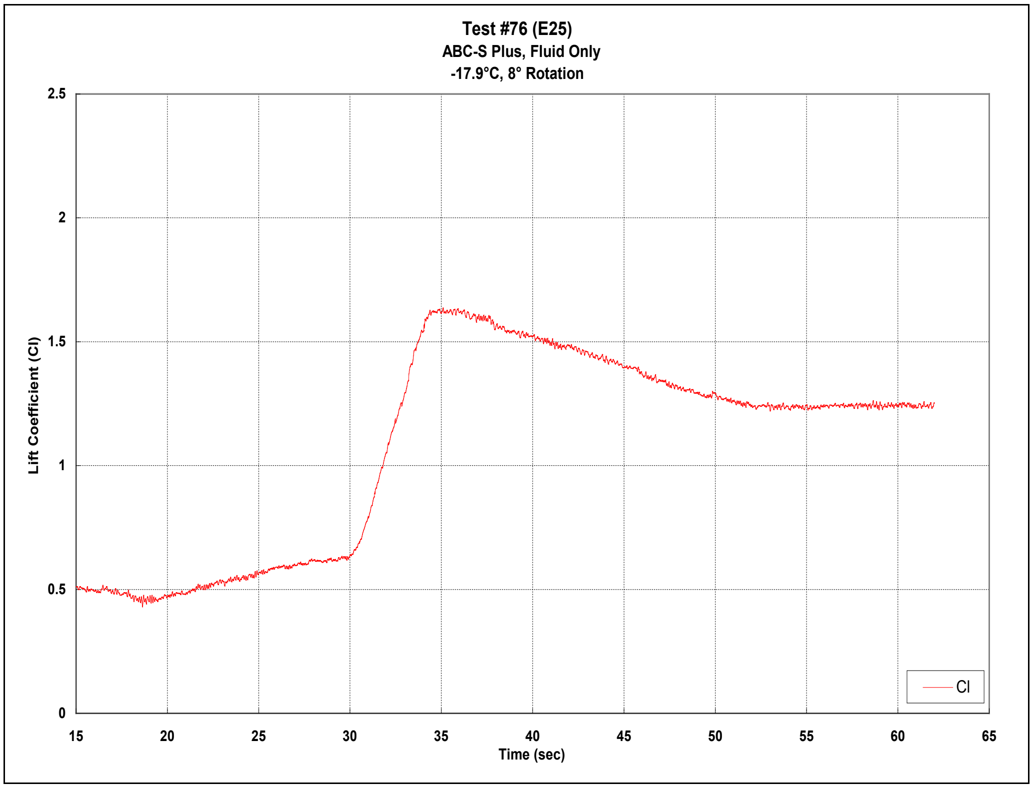

Figure D41: Run #76

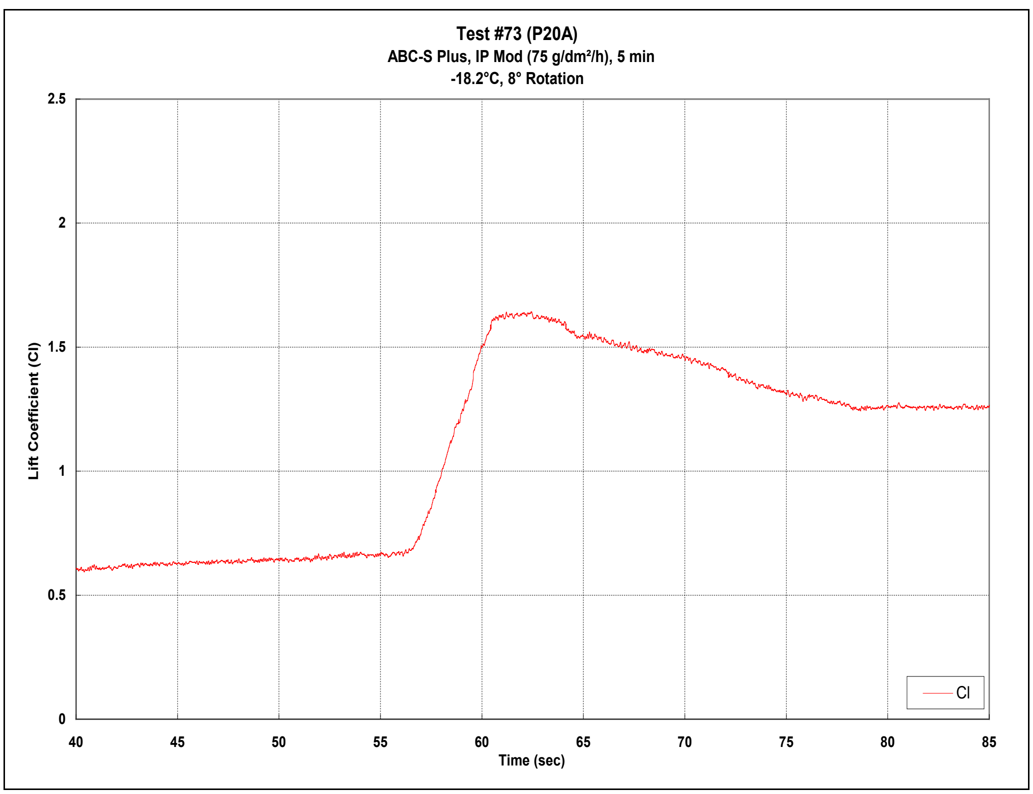

Figure D42: Run #73

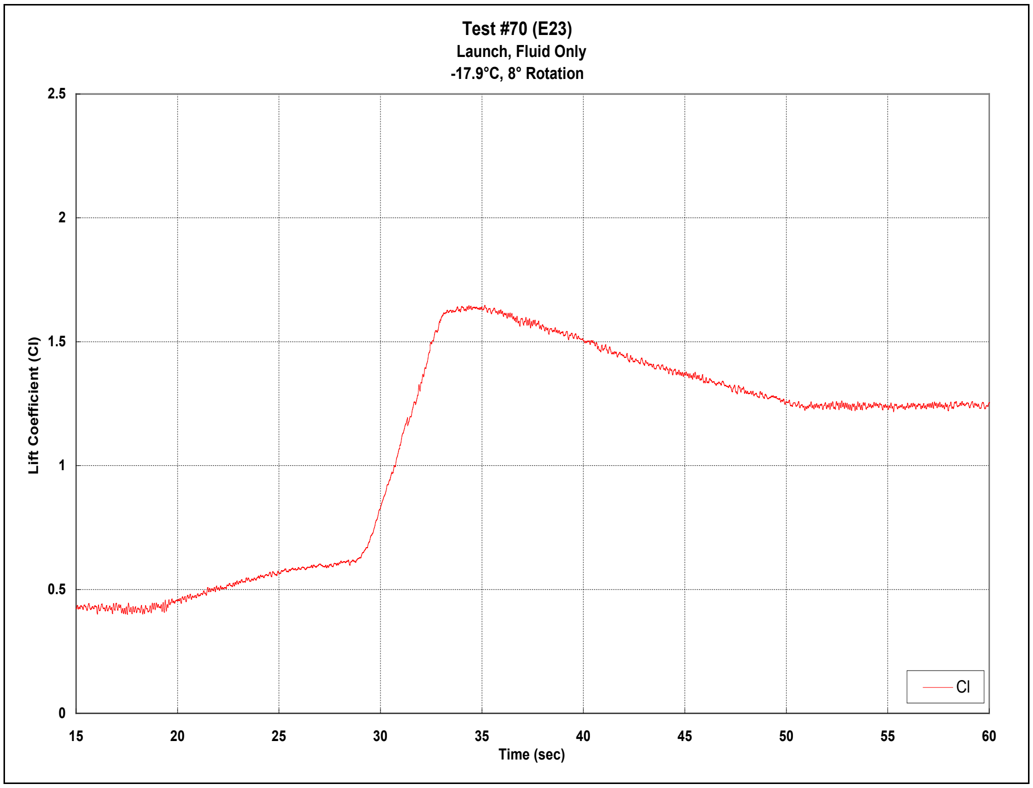

Figure D43: Run #70

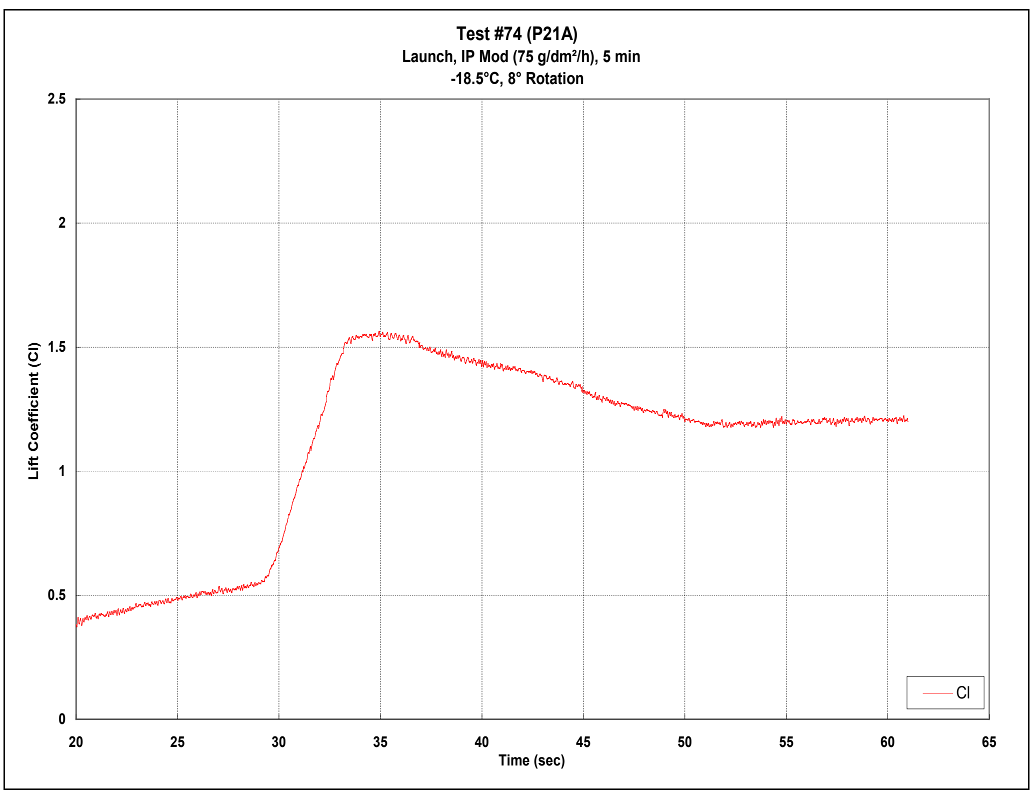

Figure D44: Run #74

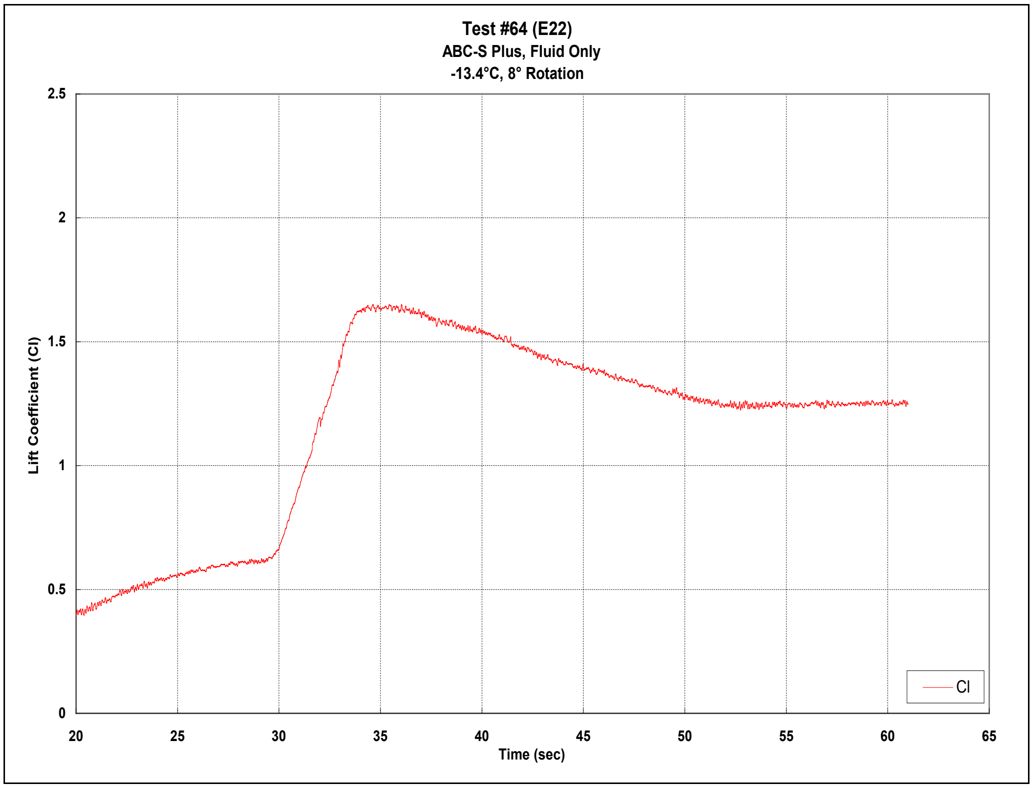

Figure D45: Run #64

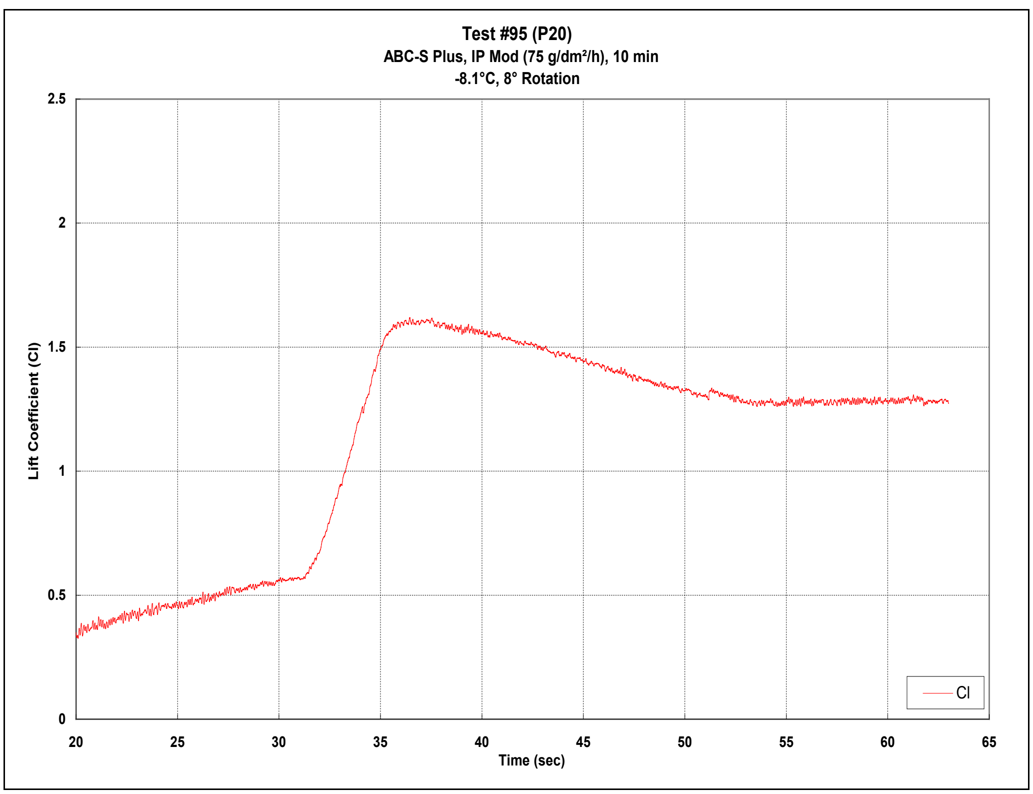

Figure D46: Run #95

LIGHT ICE PELLETS MIXED WITH LIGHT FREEZING RAIN

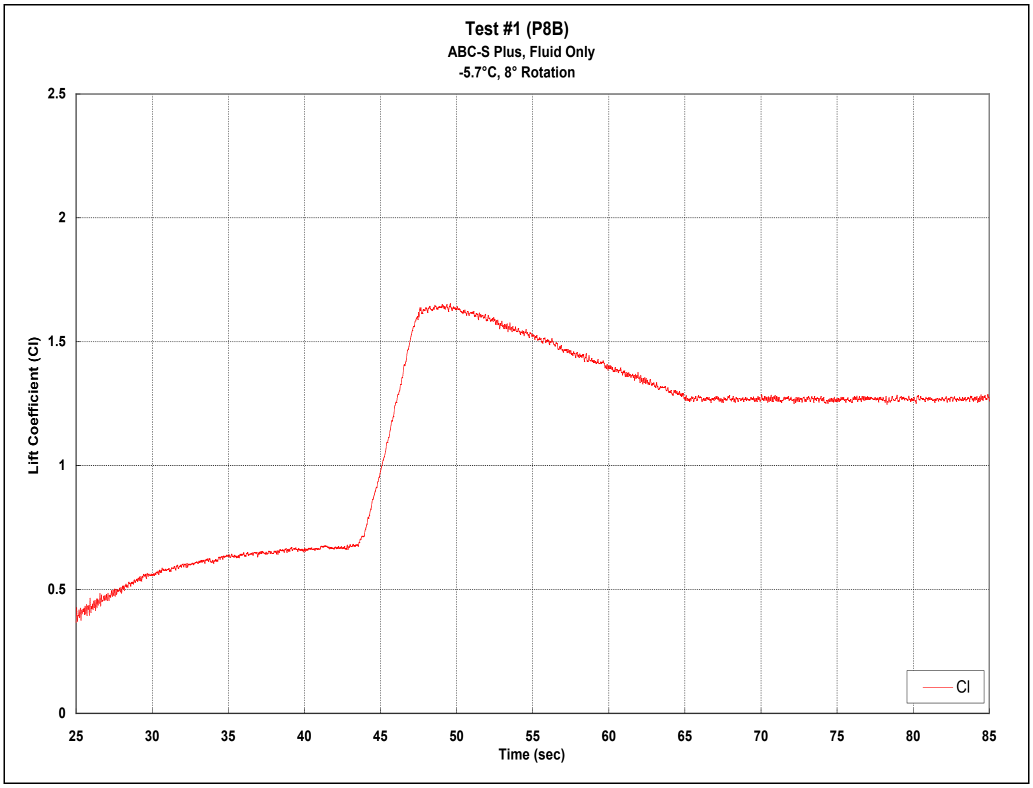

Figure D47: Run #1

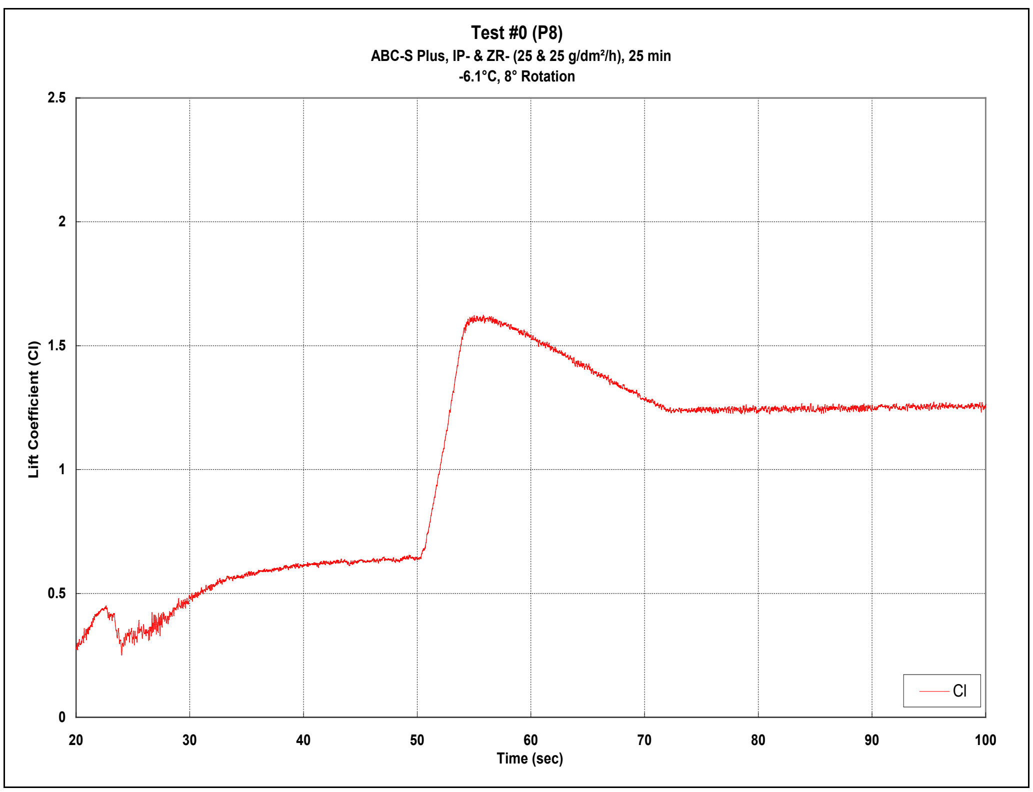

Figure D48: Run #0

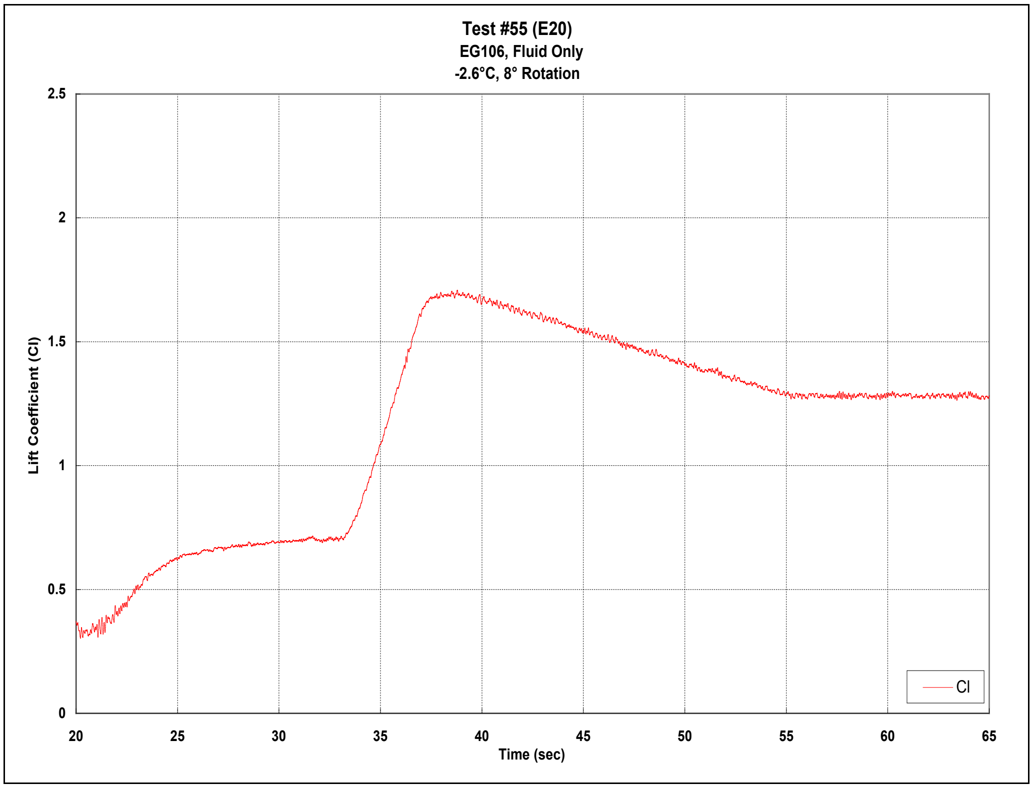

Figure D49: Run #55

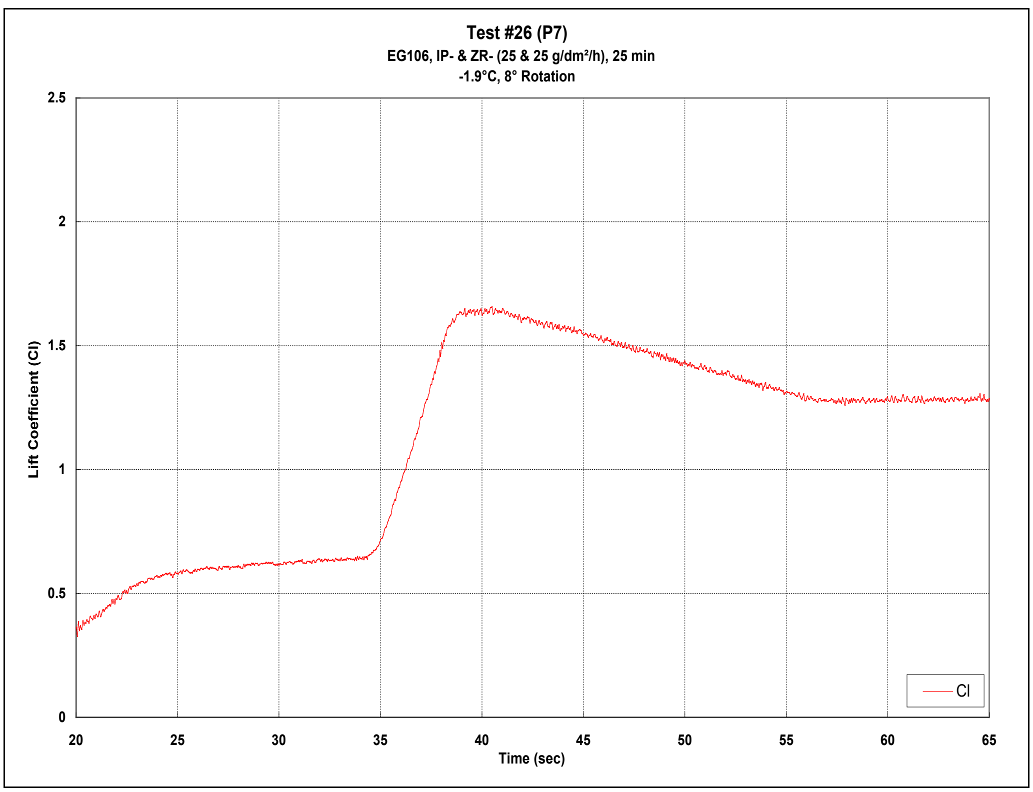

Figure D50: Run #26

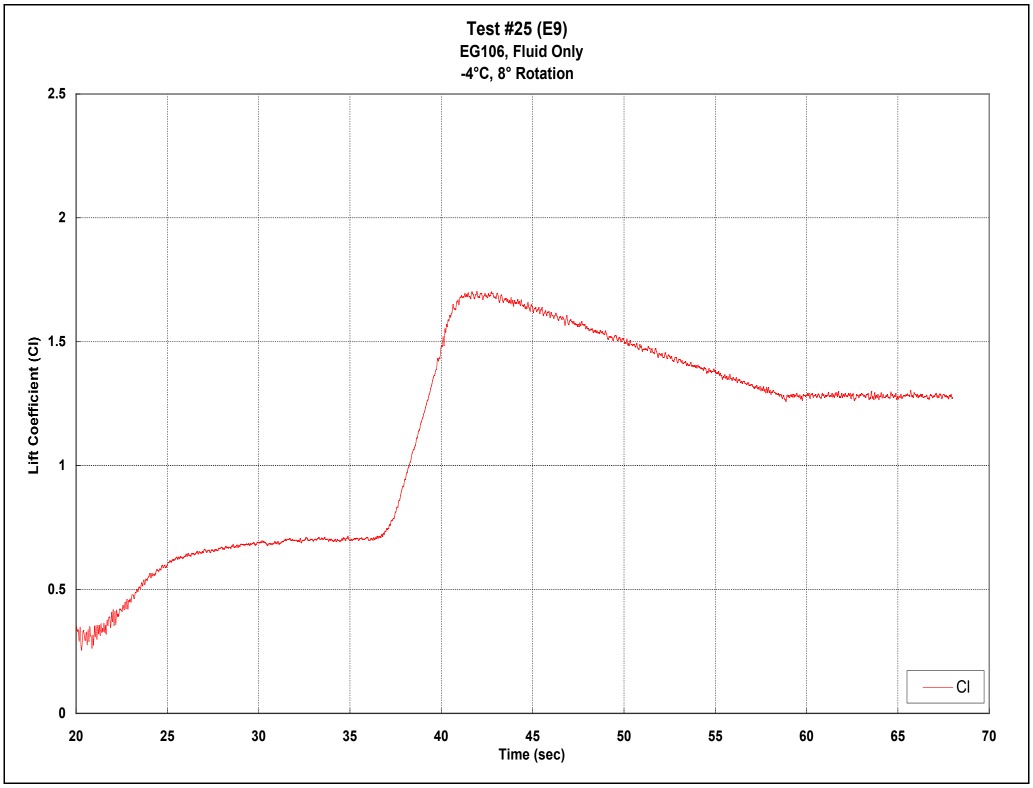

Figure D51: Run #25

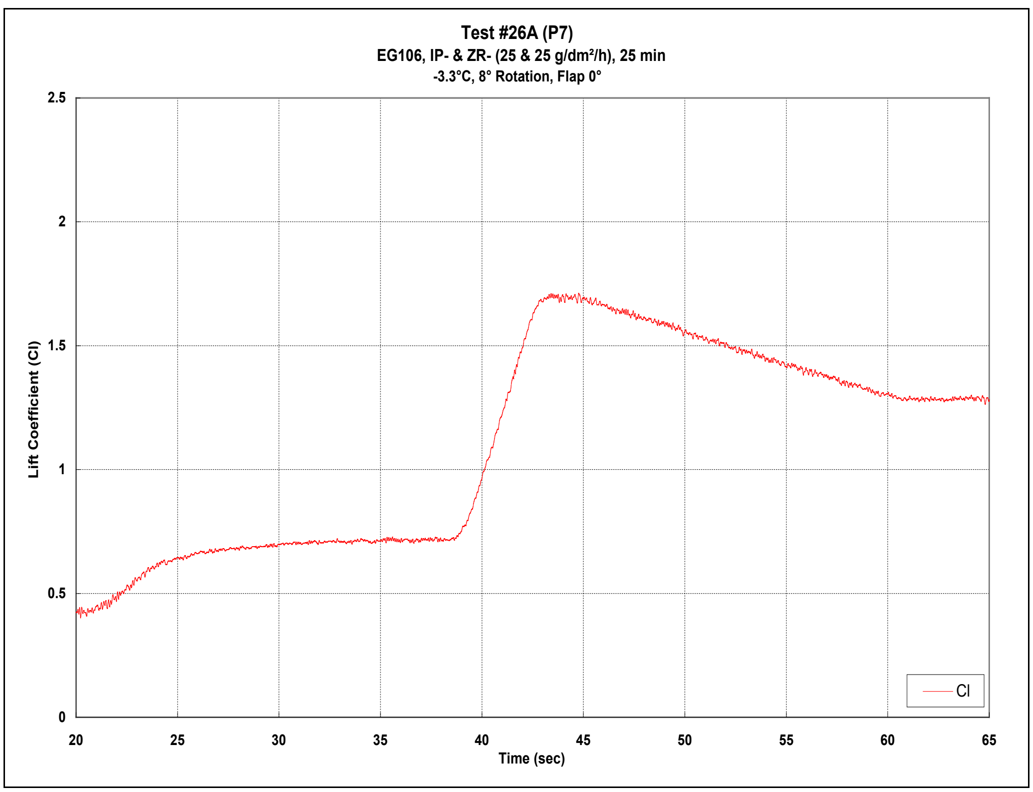

Figure D52: Run #26A

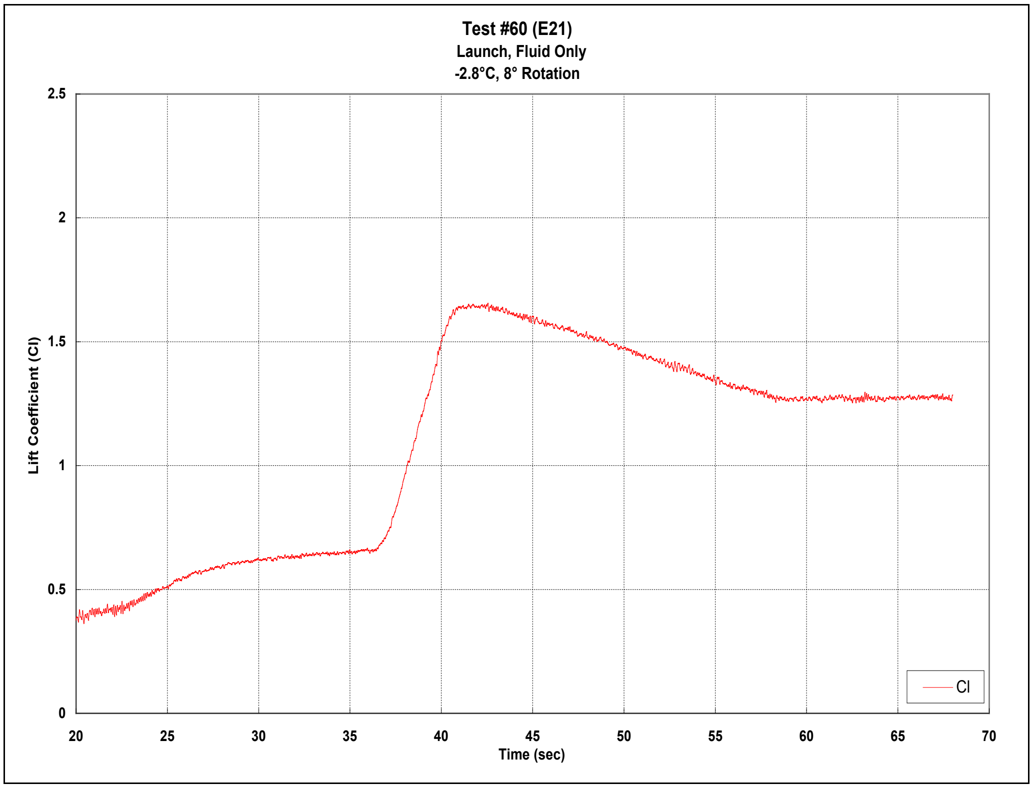

Figure D53: Run #60

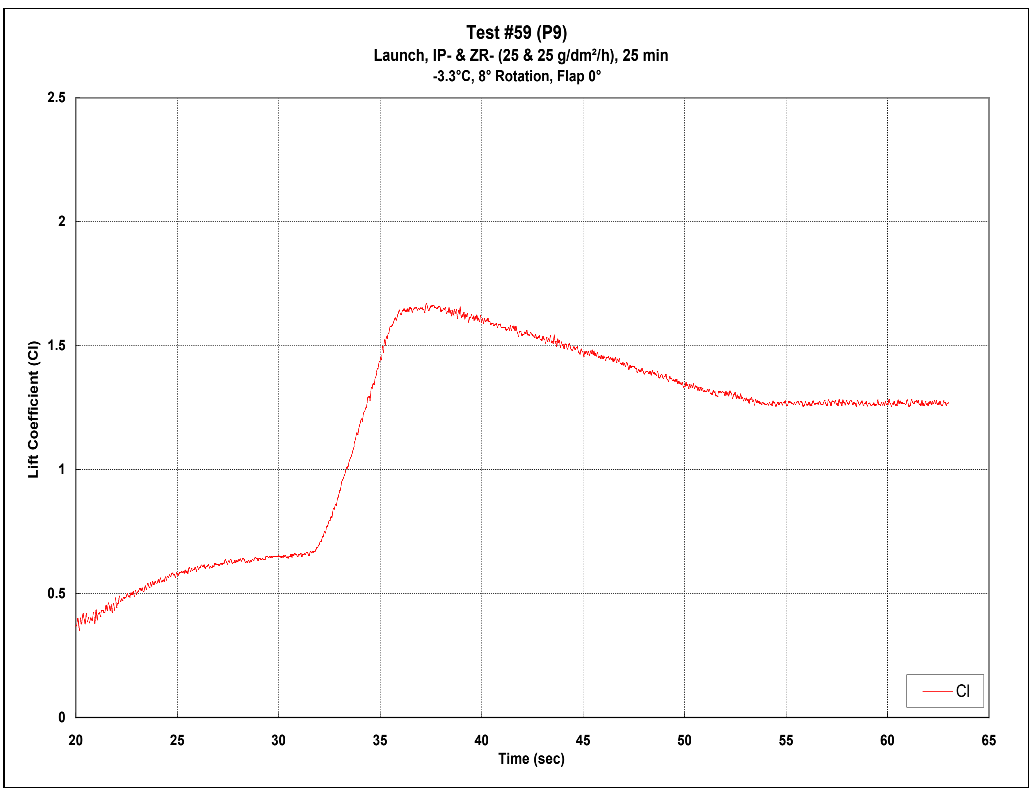

Figure D54: Run #59

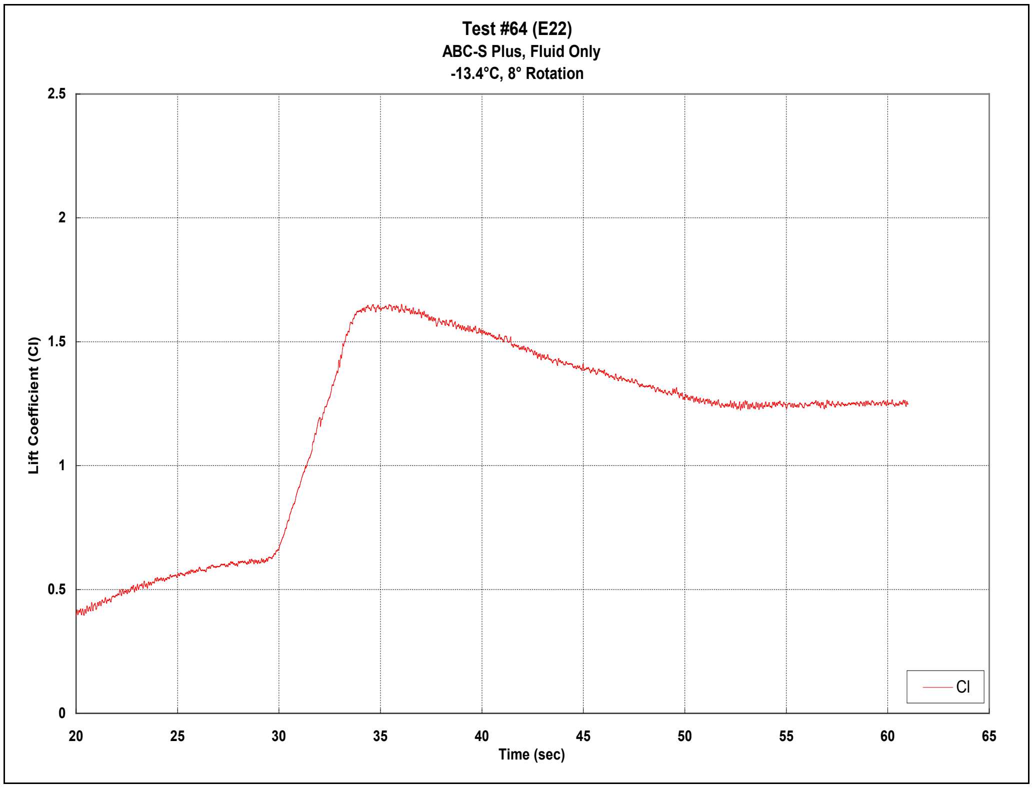

Figure D55: Run #64

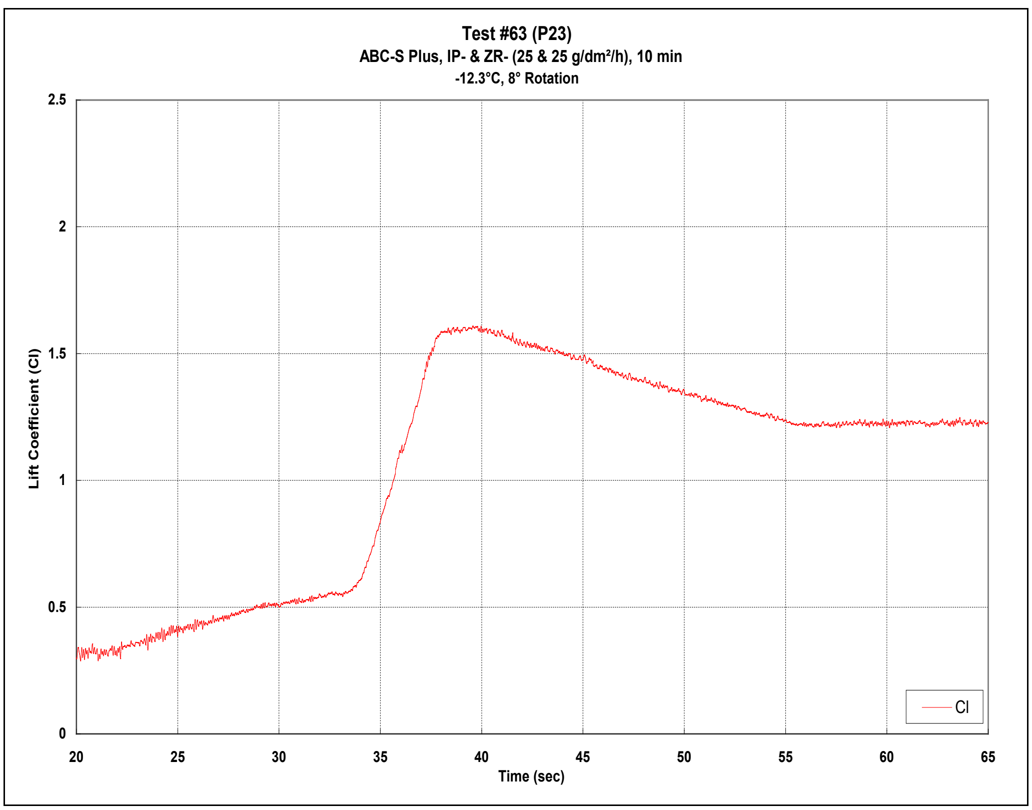

Figure D56: Run #63

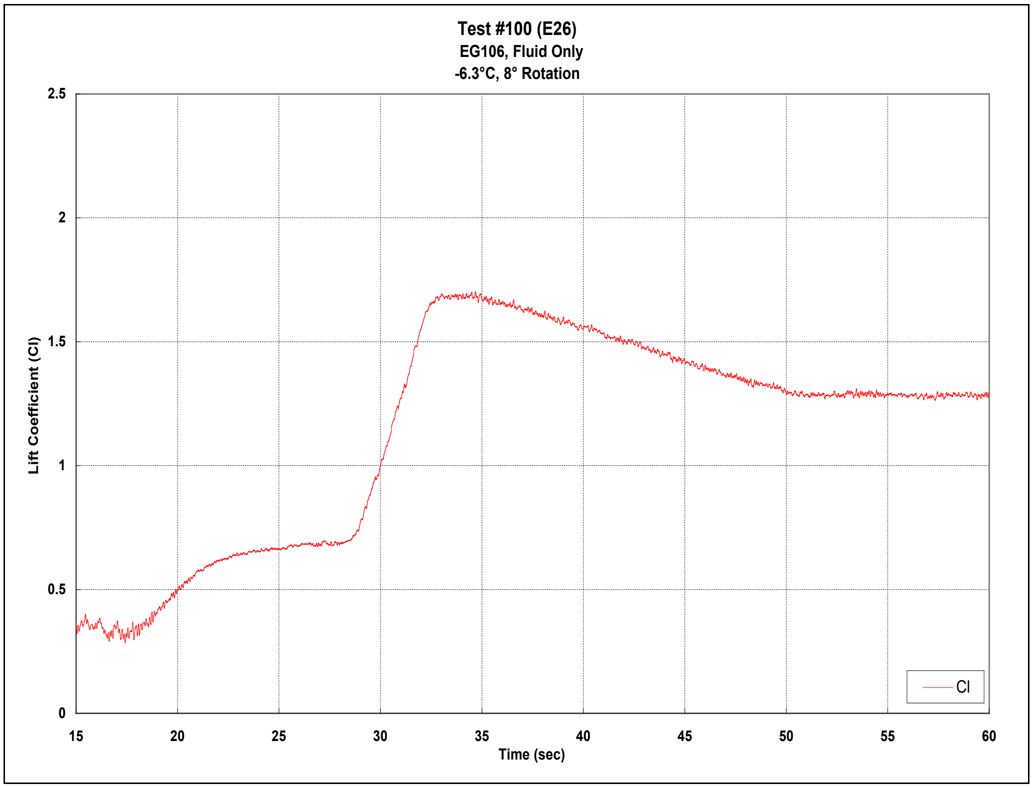

Figure D57: Run #100

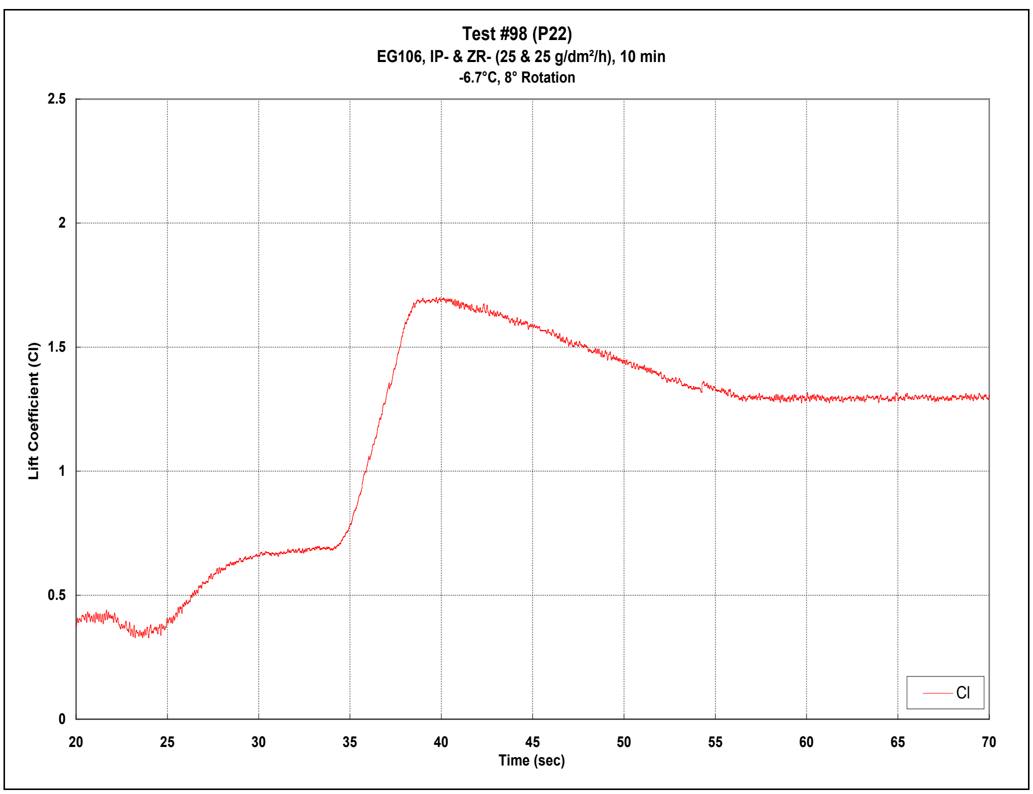

Figure D58: Run #98

LIGHT ICE PELLETS MIXED WITH MODERATE RAIN

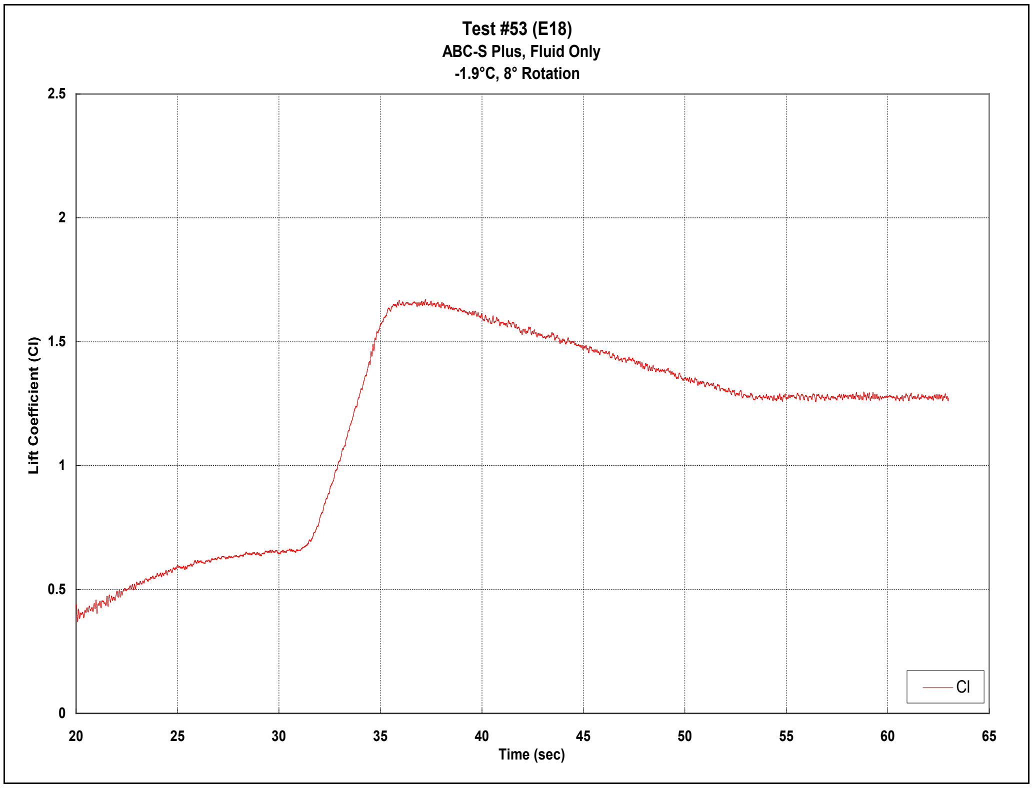

Figure D59: Run #53

Run 23: No Data Available

Figure D60: Run #20

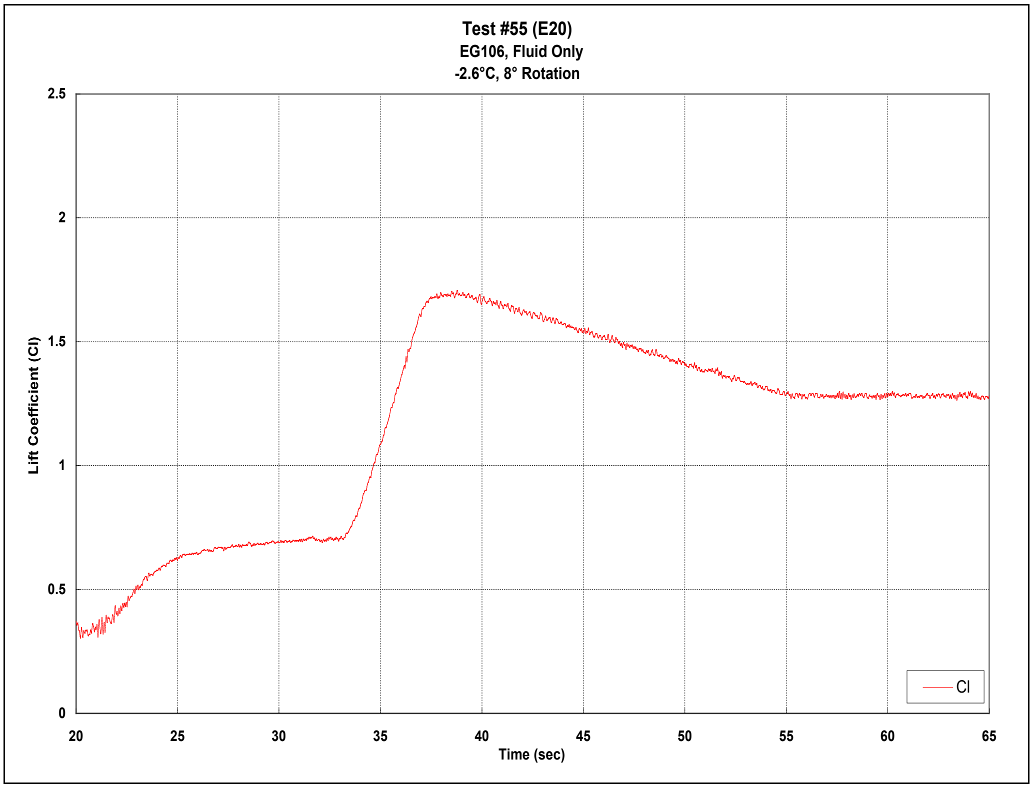

Figure D61: Run #55

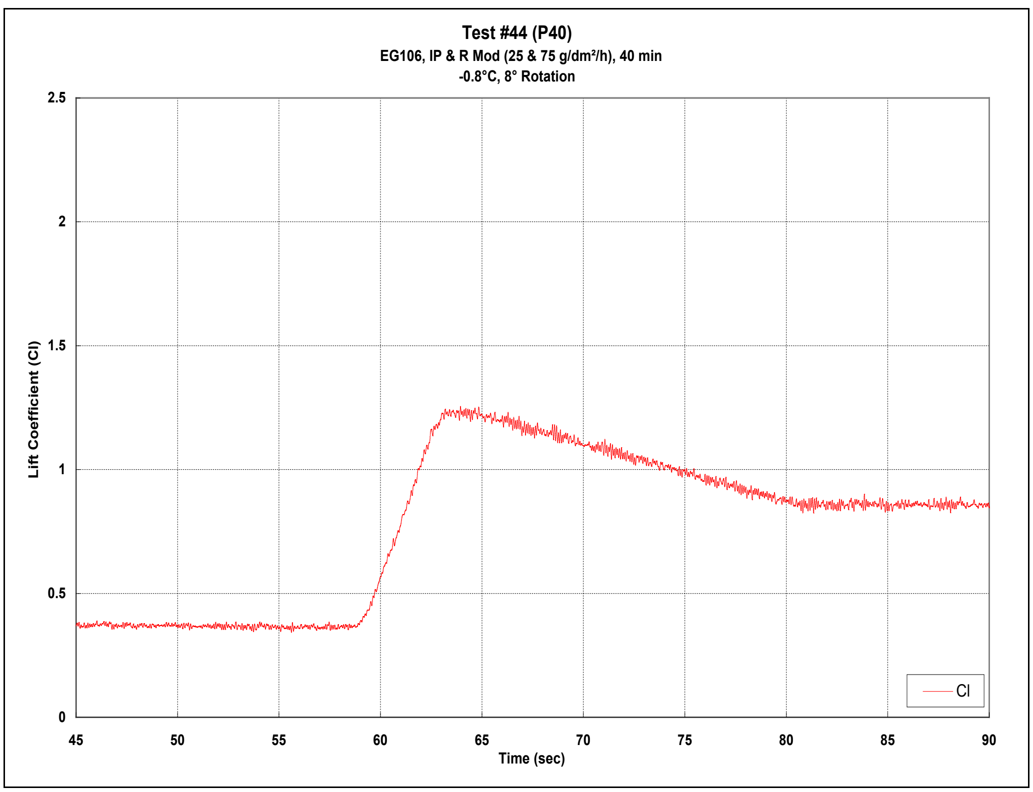

Figure D62: Run #44

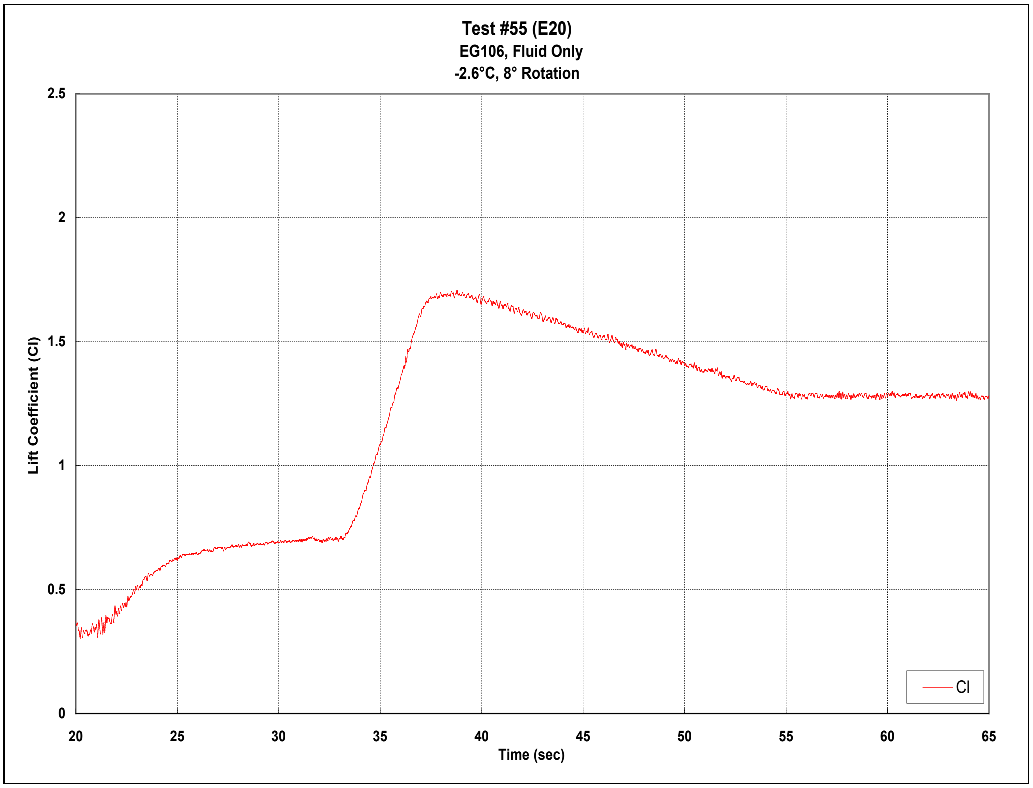

Figure D63: Run #55

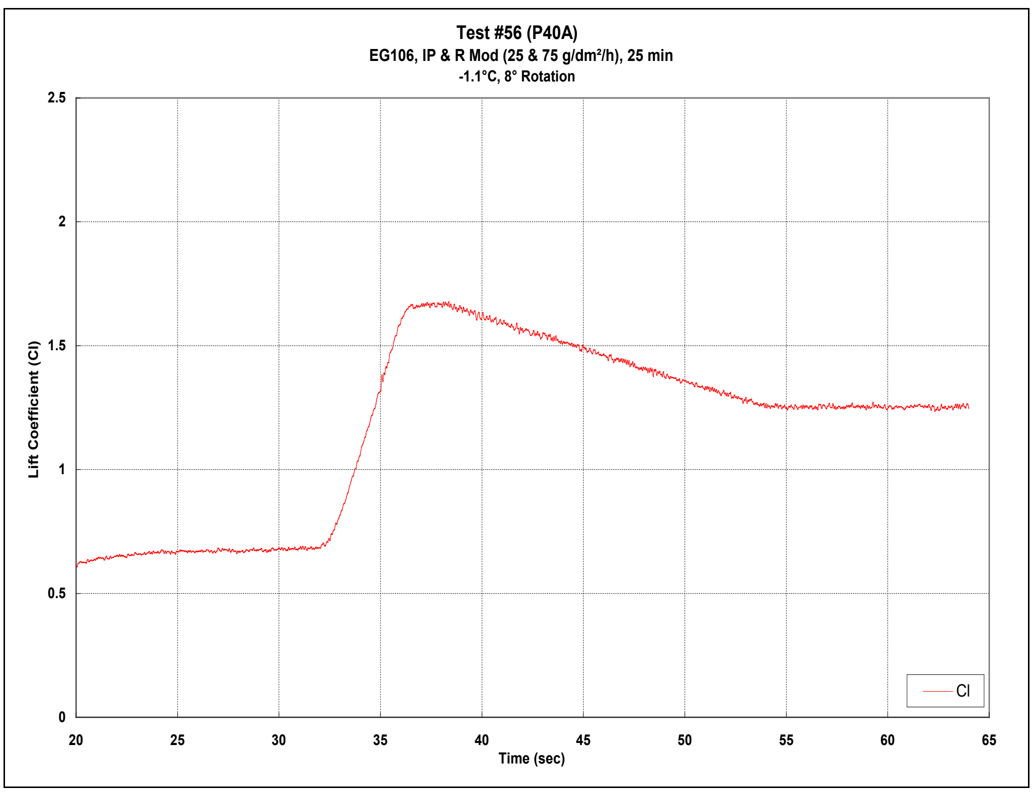

Figure D64: Run #56

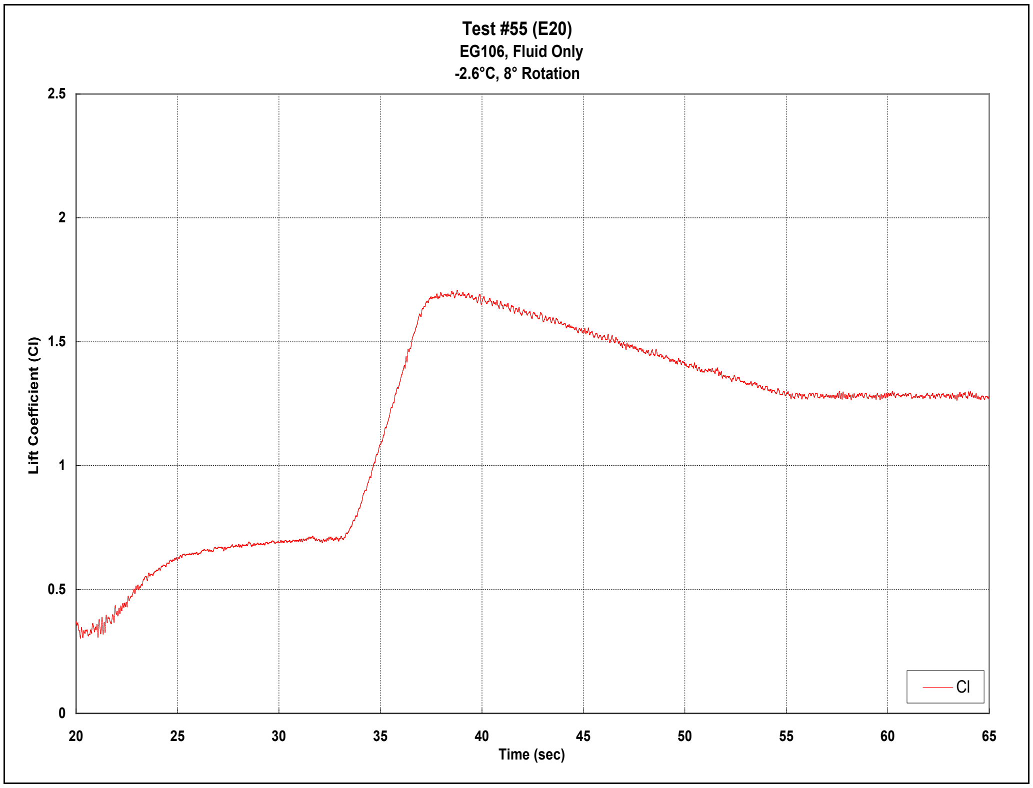

Figure D65: Run #55

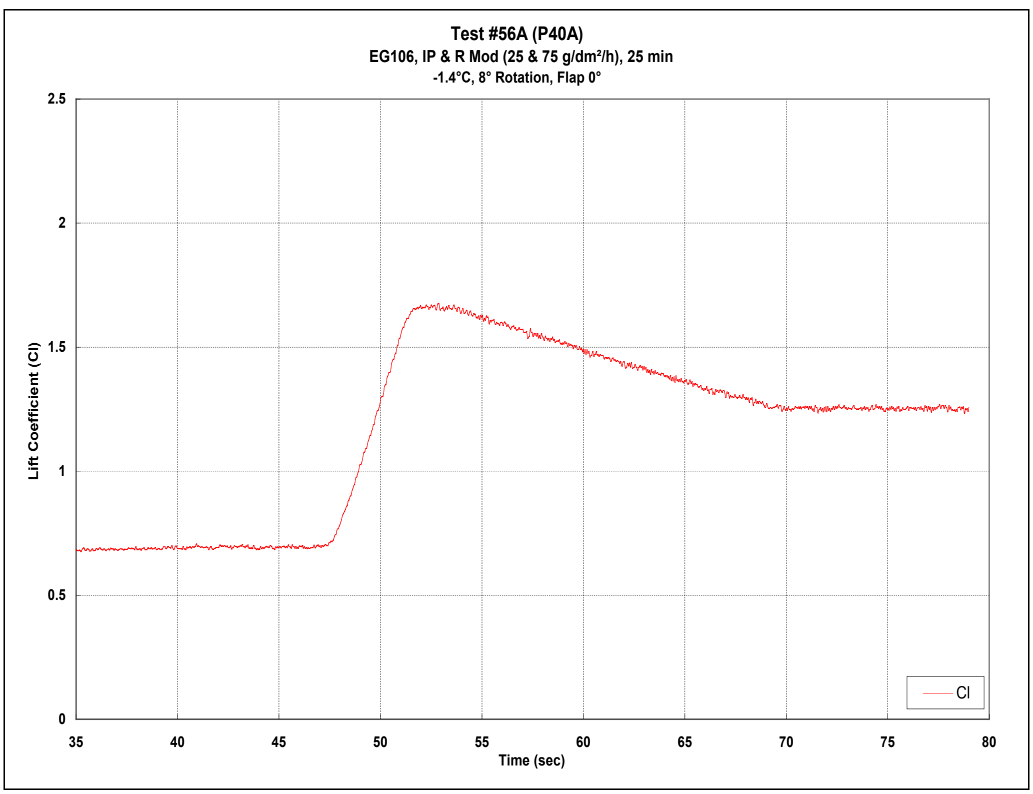

Figure D66: Run #56A

LIGHT ICE PELLETS MIXED WITH LIGHT SNOW

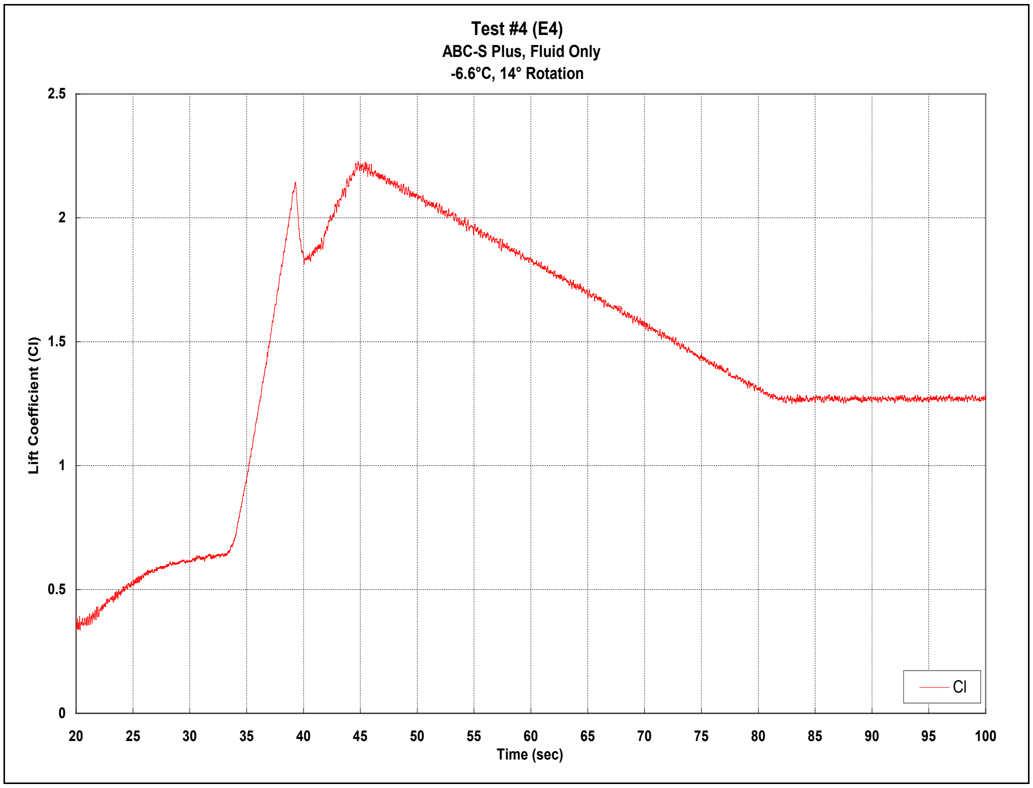

Figure D67: Run #4

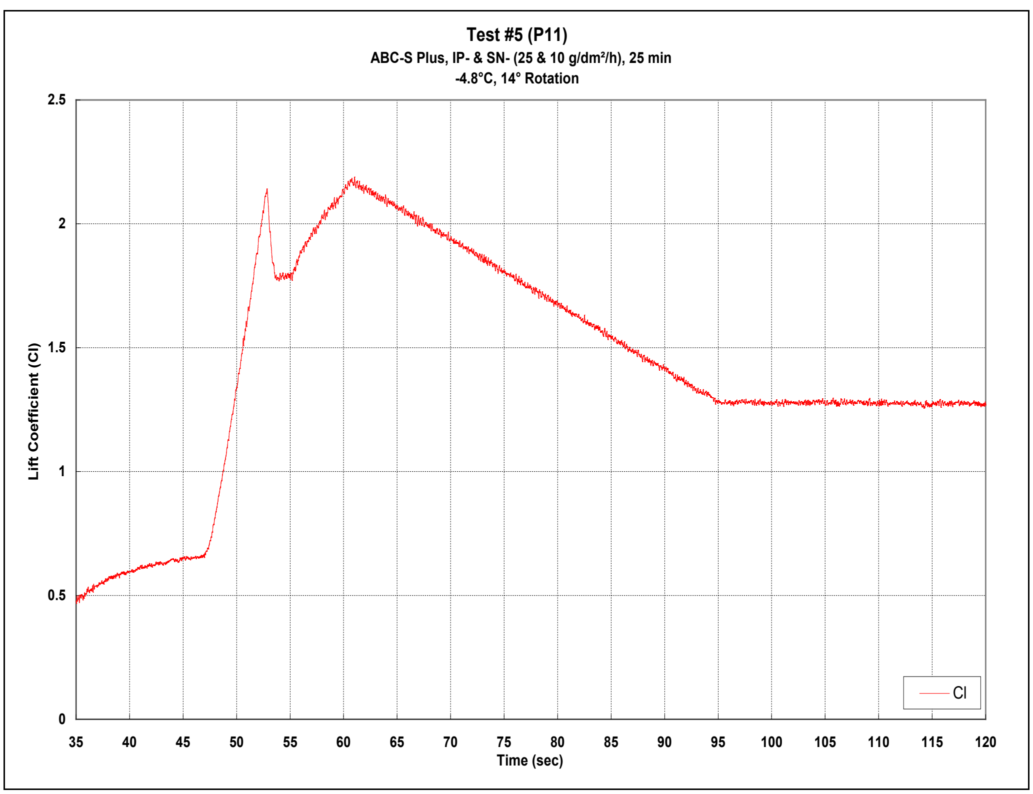

Figure D68: Run #5

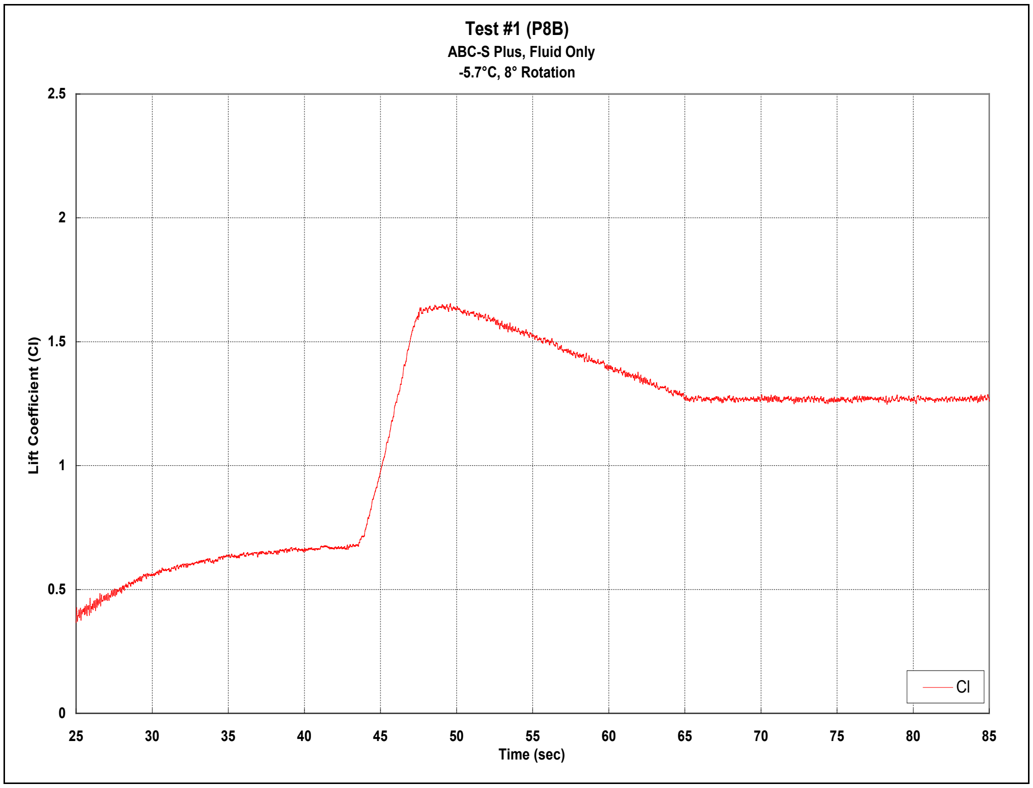

Figure D69: Run #1

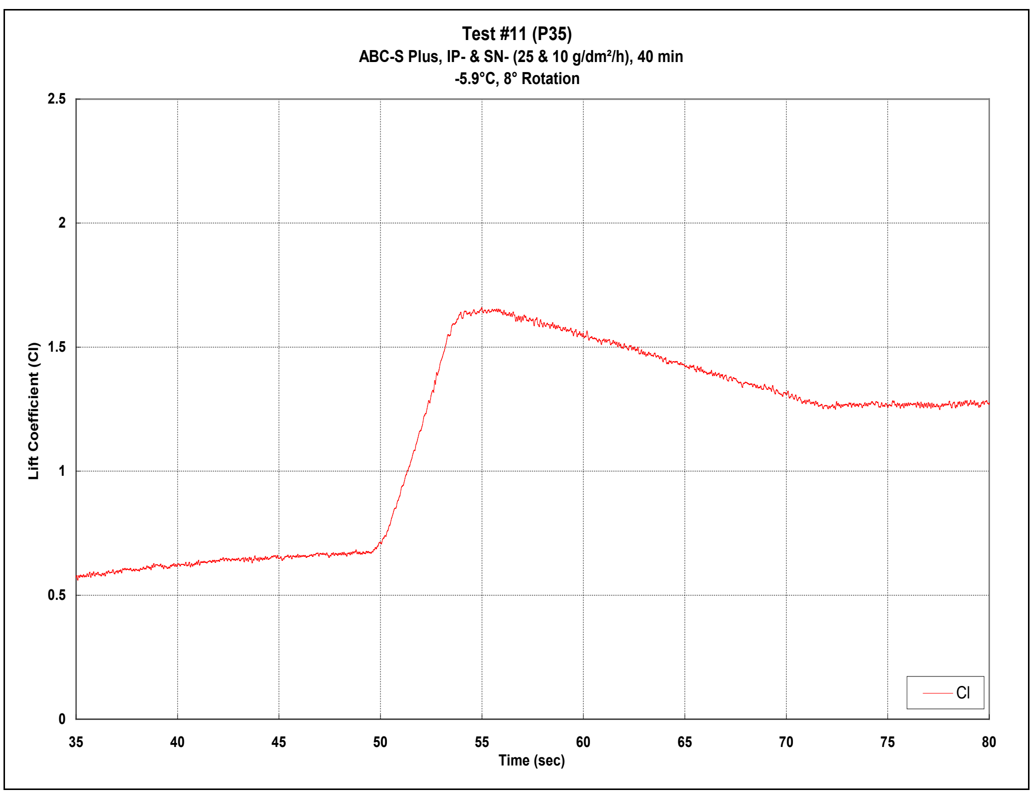

Figure D70: Run #11

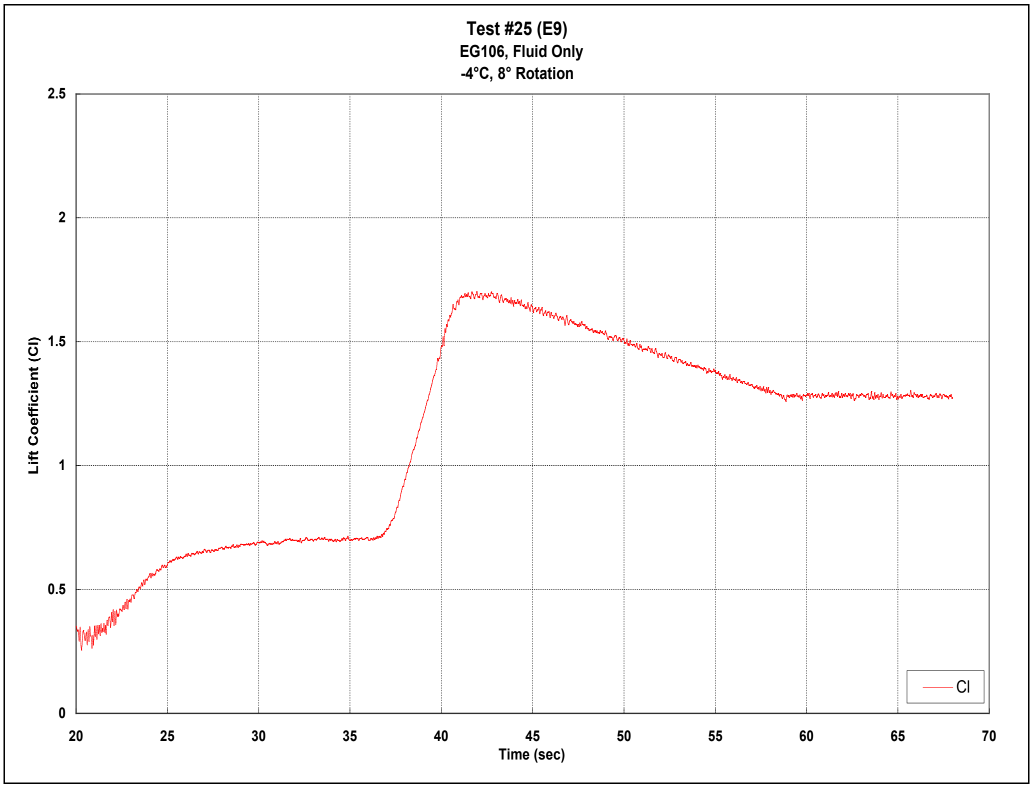

Figure D71: Run #25

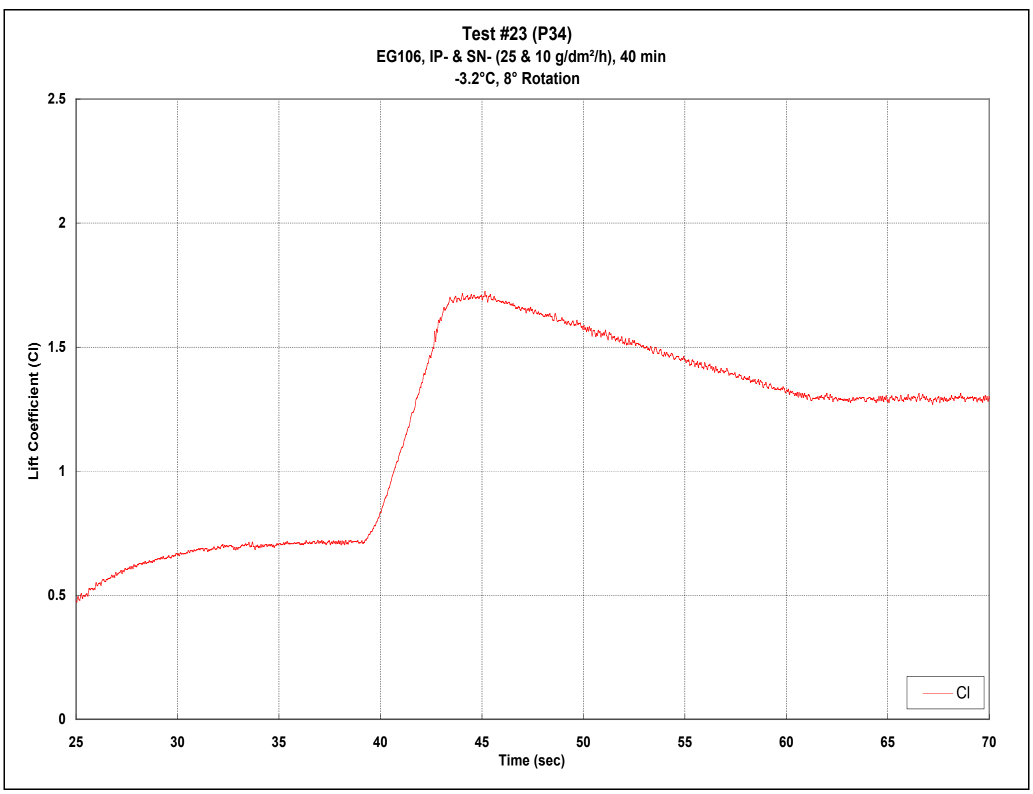

Figure D72: Run #23

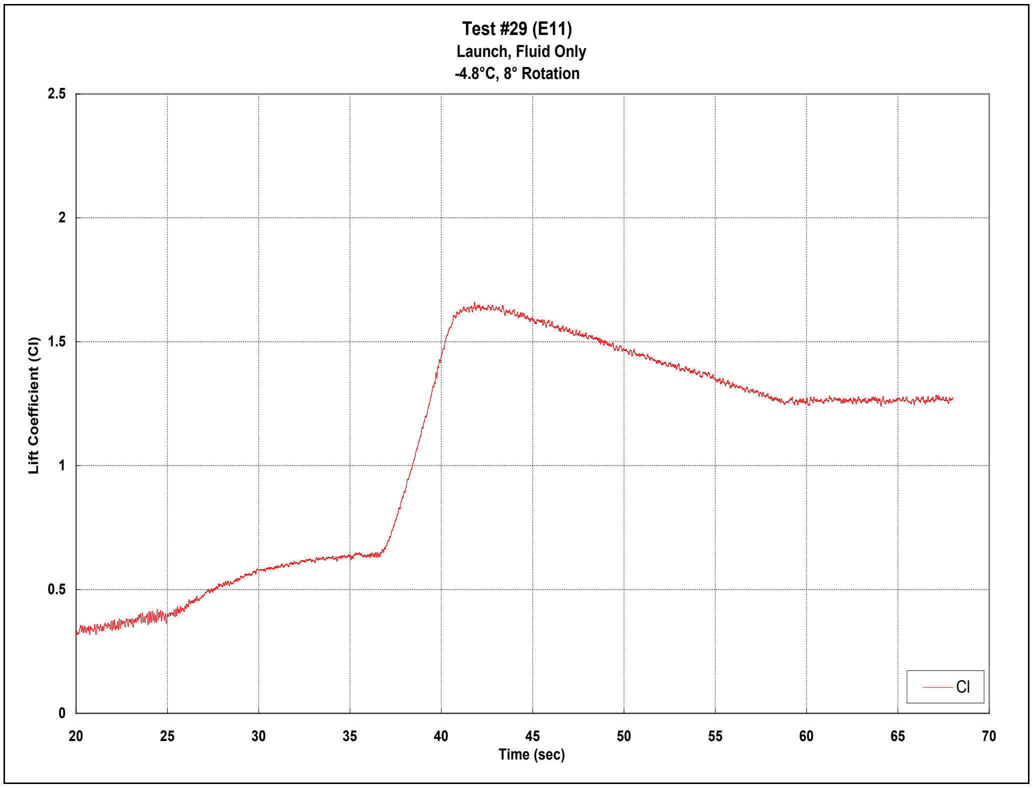

Figure D73: Run #29

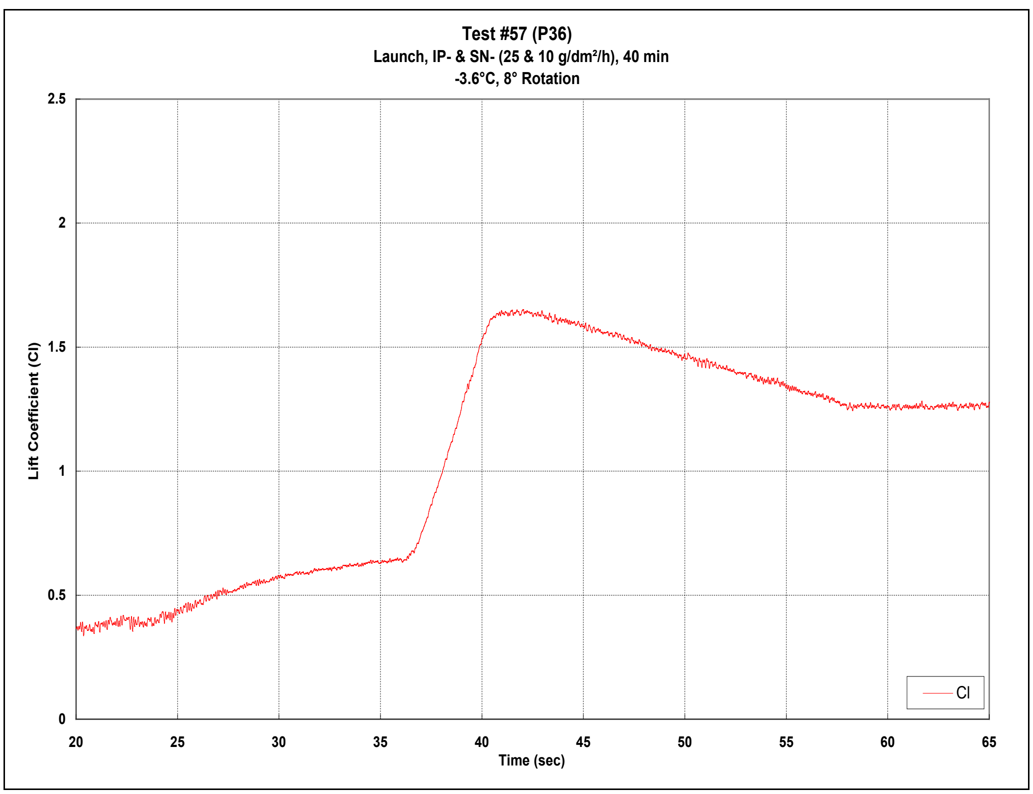

Figure D74: Run #57

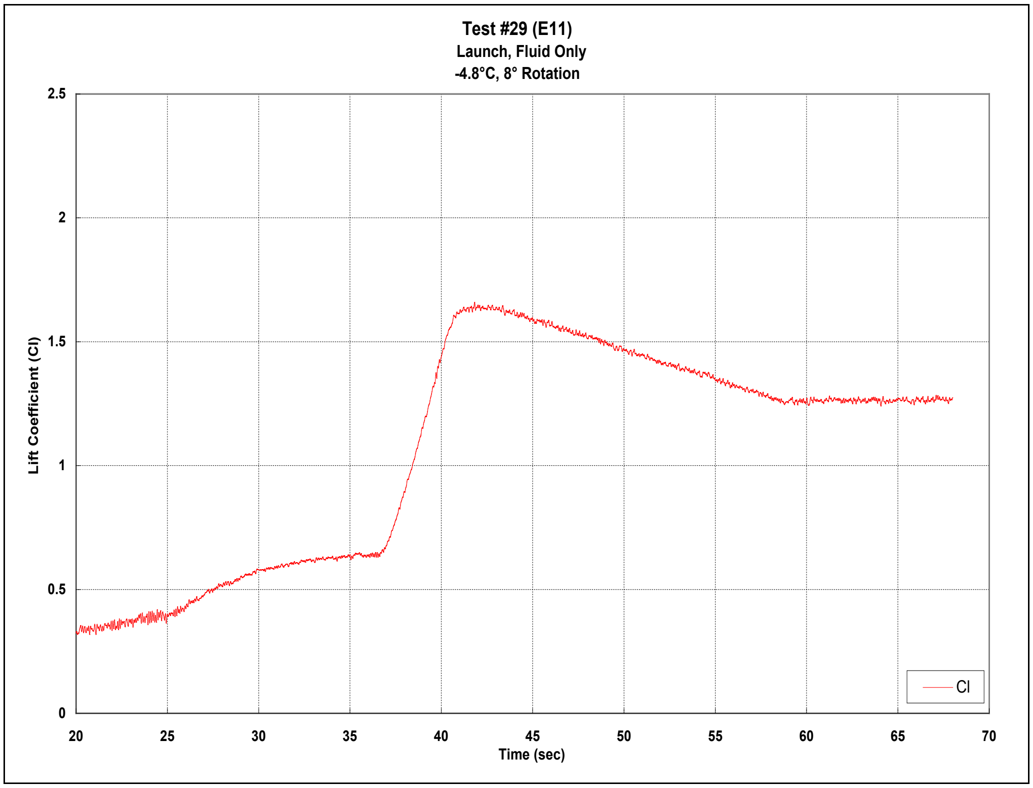

Figure D75: Run #29

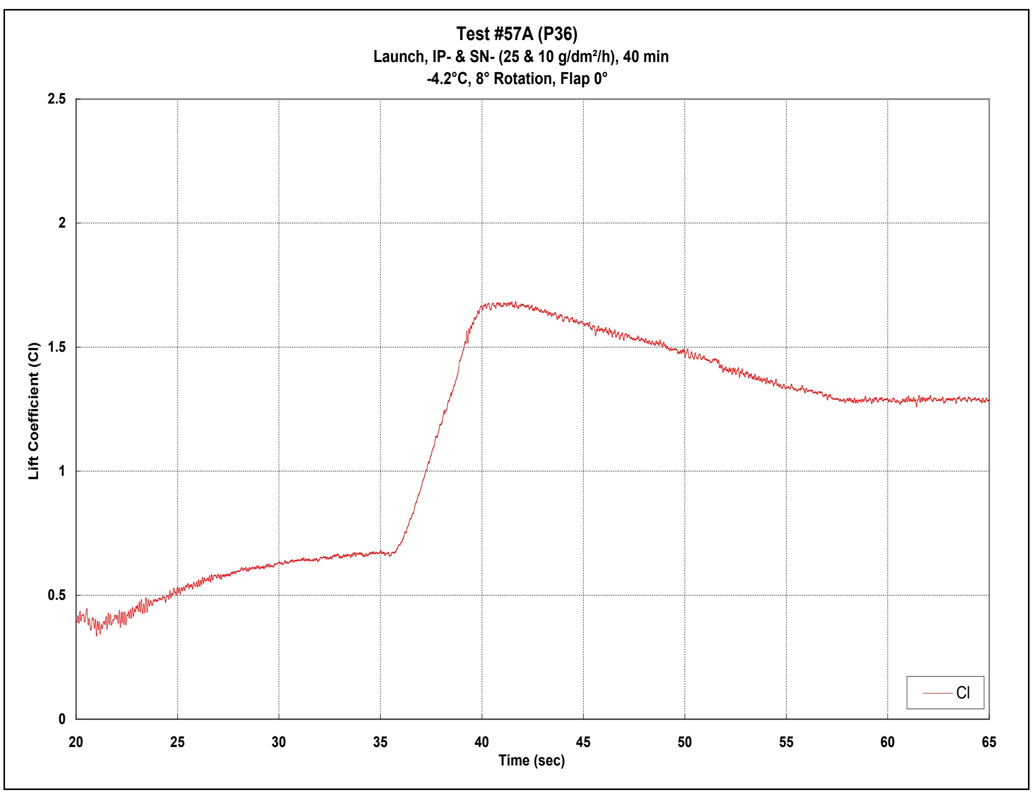

Figure D76: Run #57A

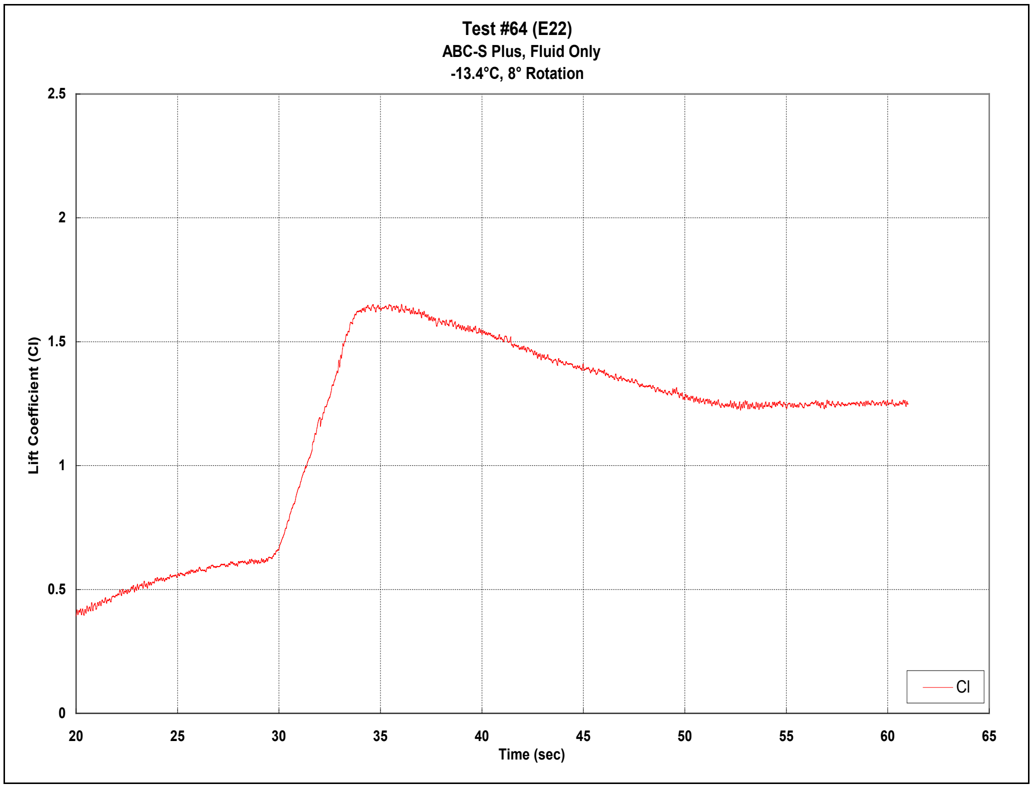

Figure D77: Run #64

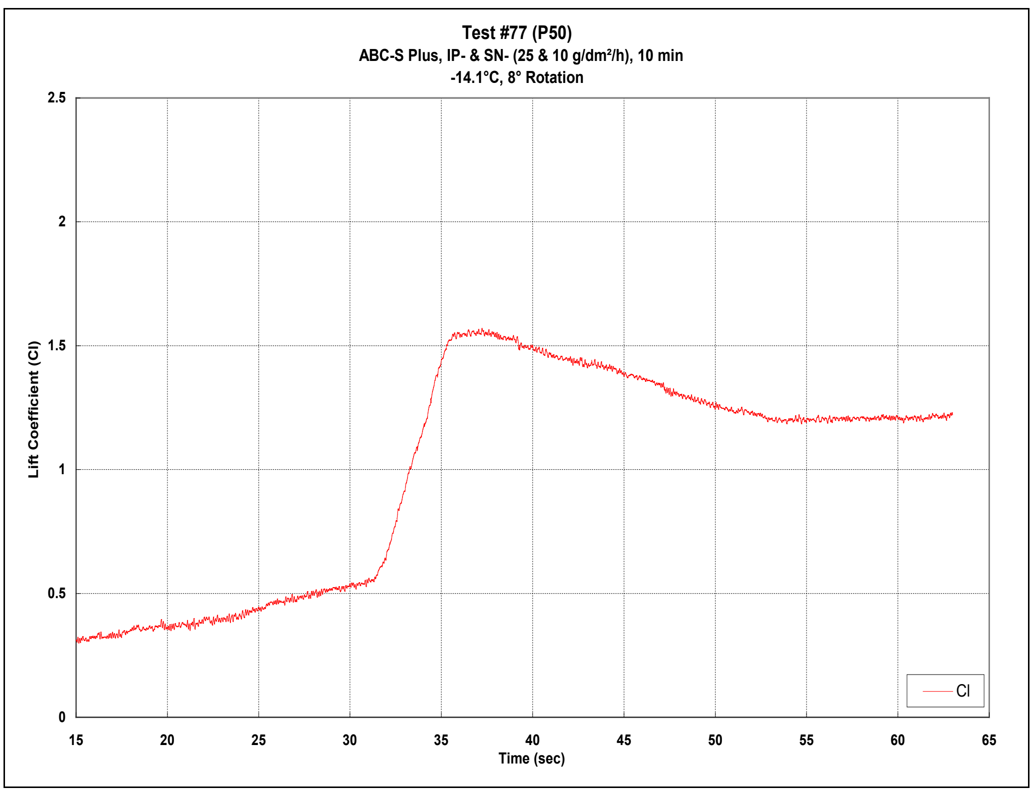

Figure D78: Run #77

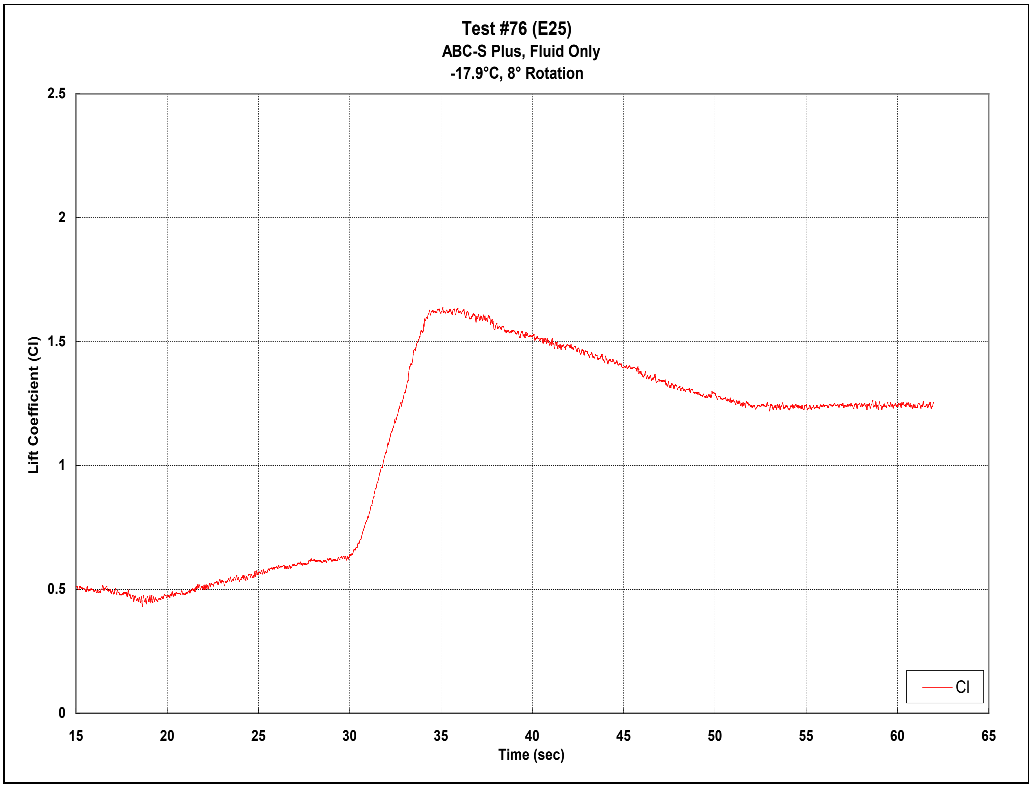

Figure D79: Run #76

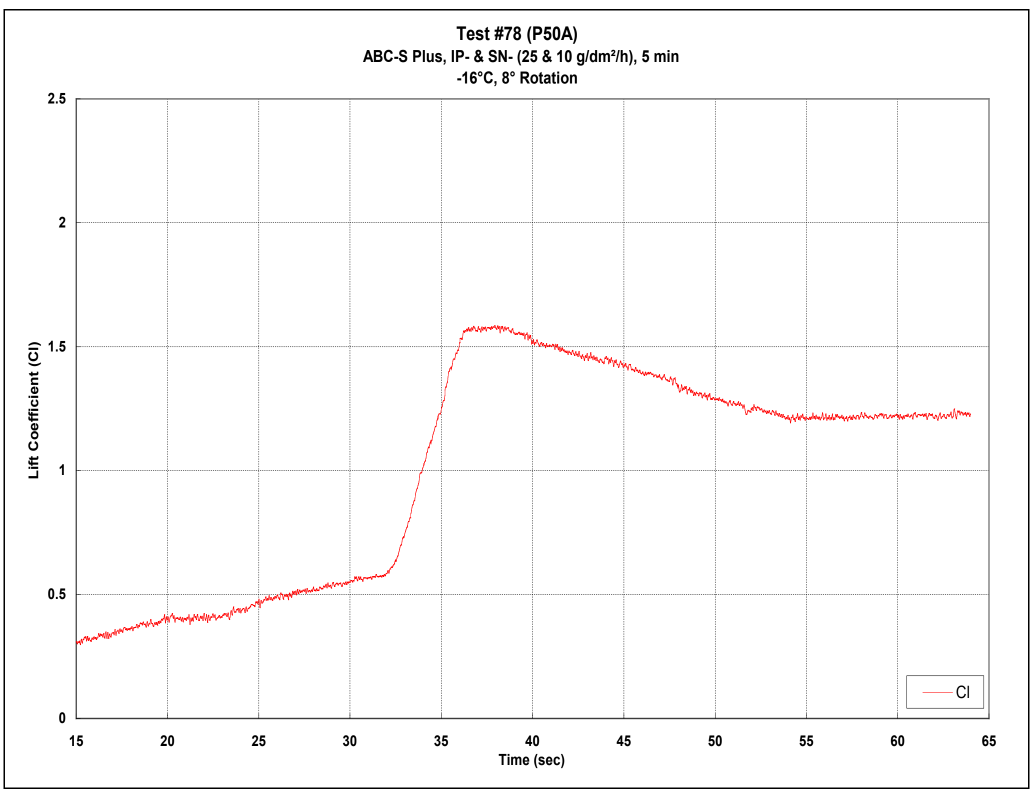

Figure D80: Run #78

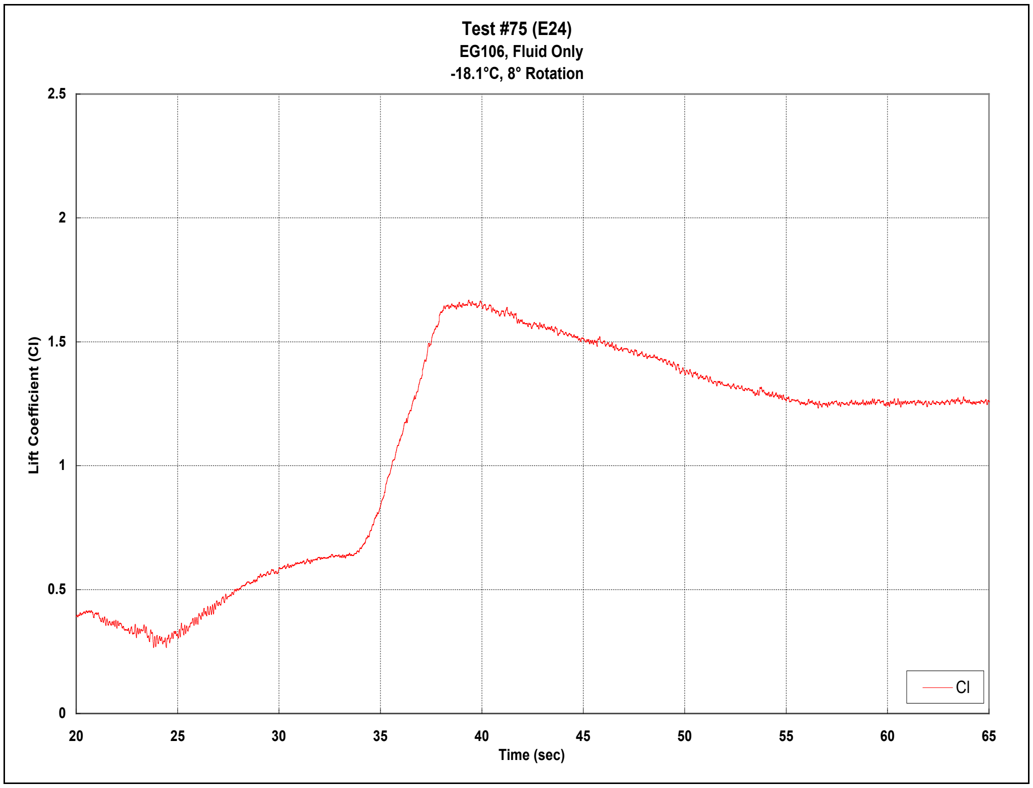

Figure D81: Run #75

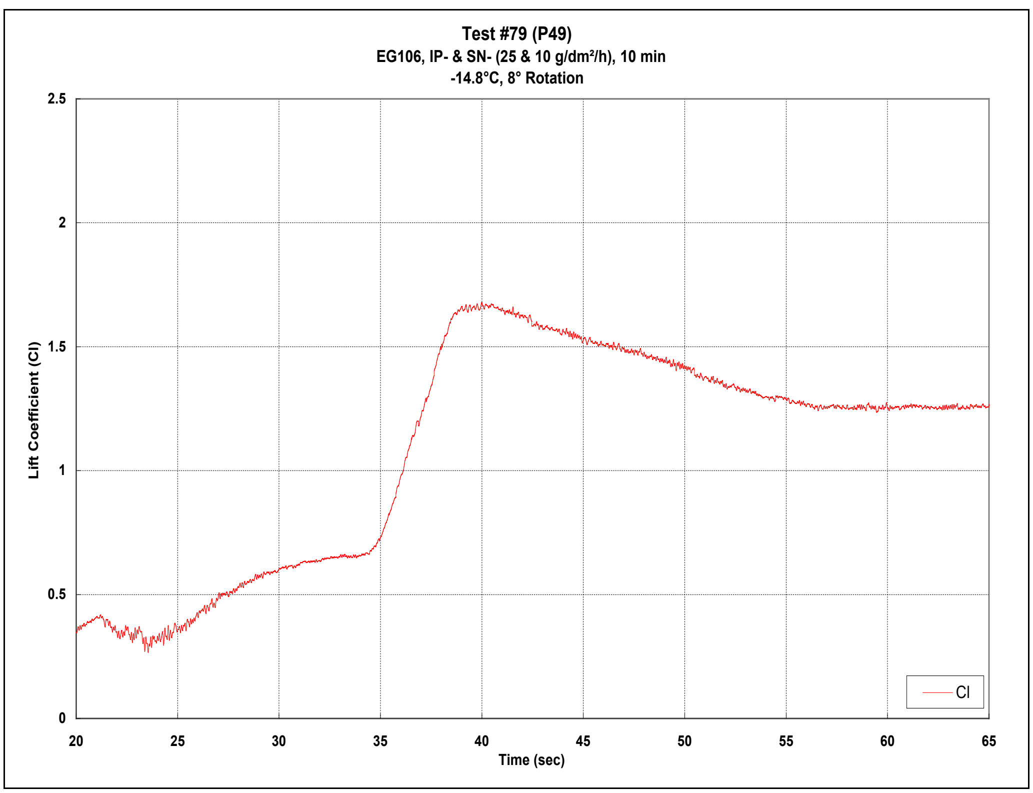

Figure D82: Run #79

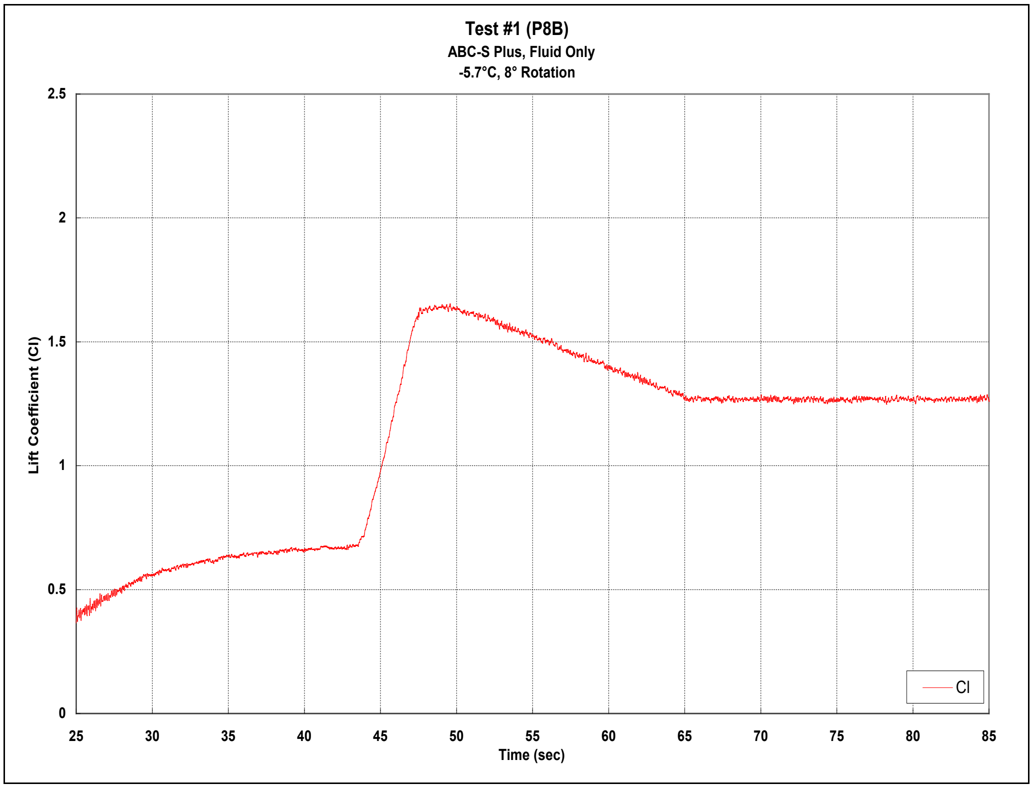

Figure D83: Run #1

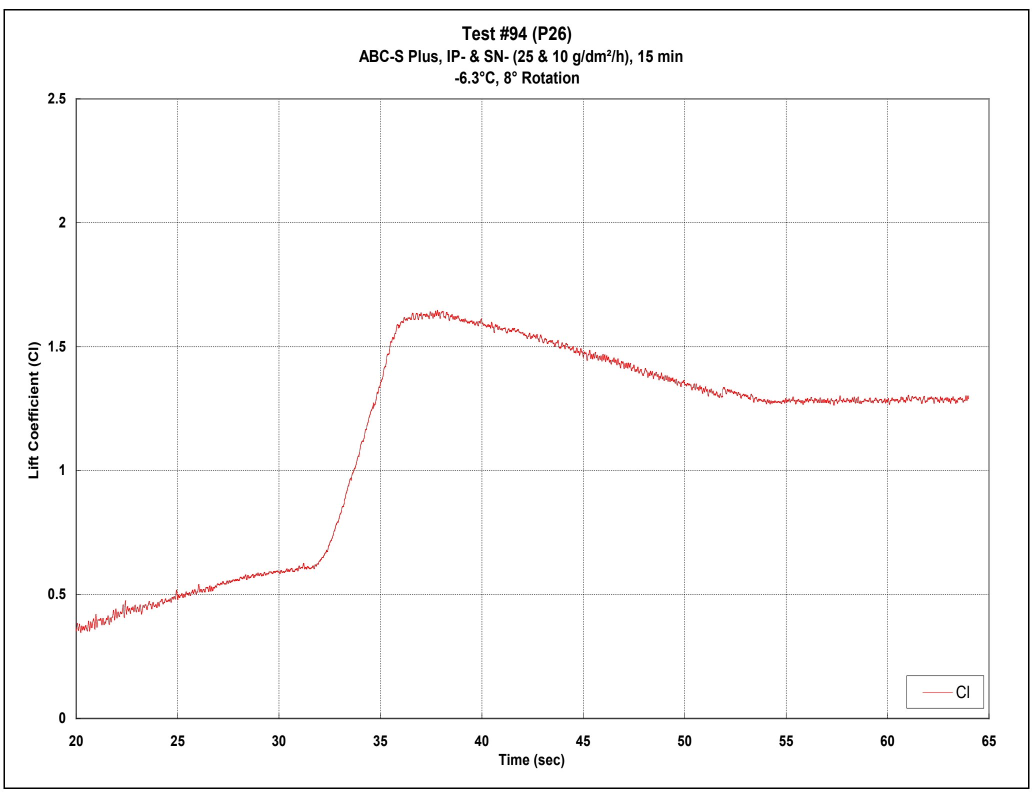

Figure D84: Run #94

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LIGHT ICE PELLETS MIXED WITH MODERATE SNOW

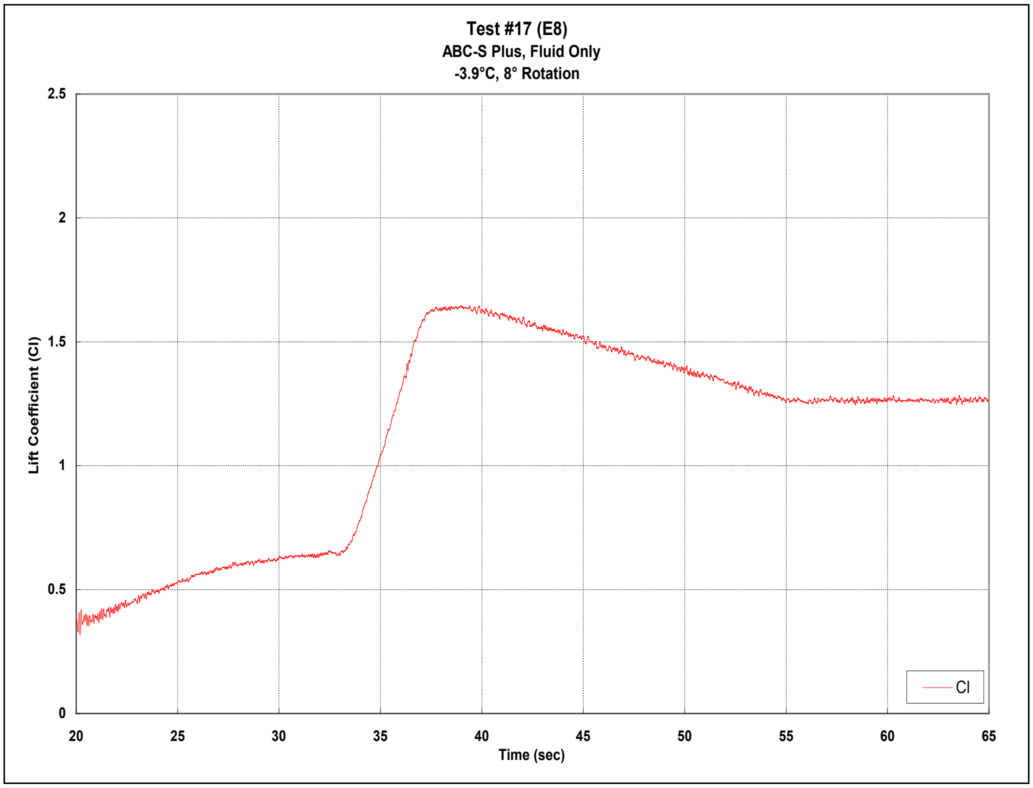

Figure D85: Run #17

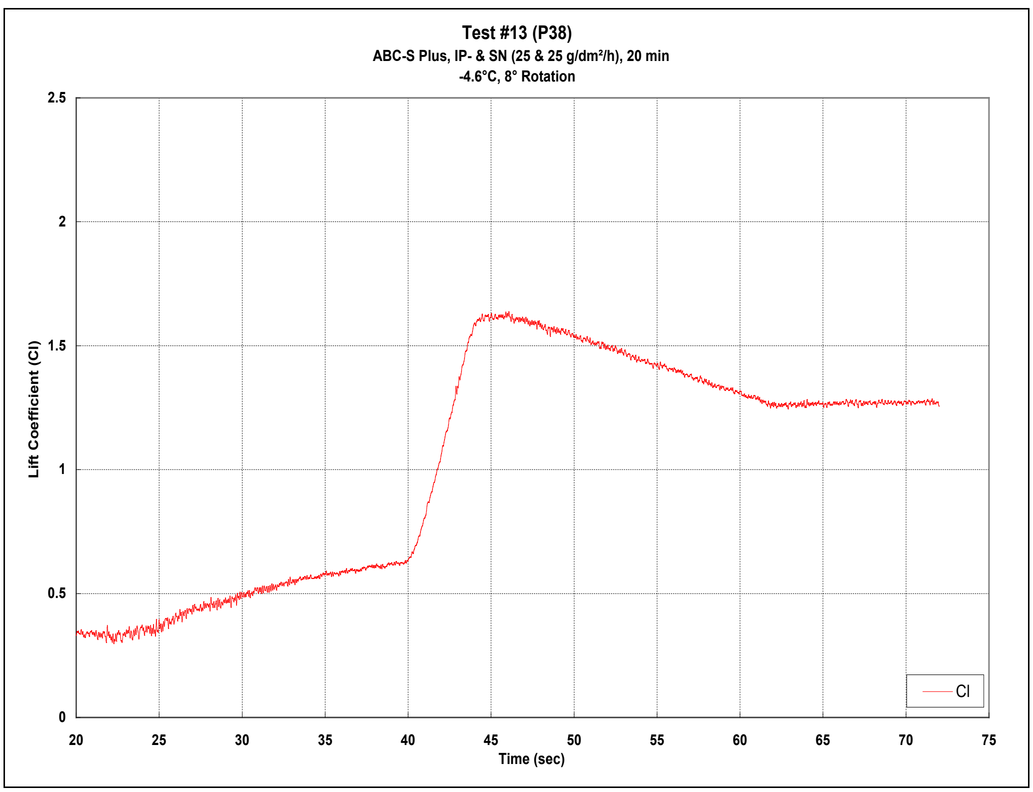

Figure D86: Run #13

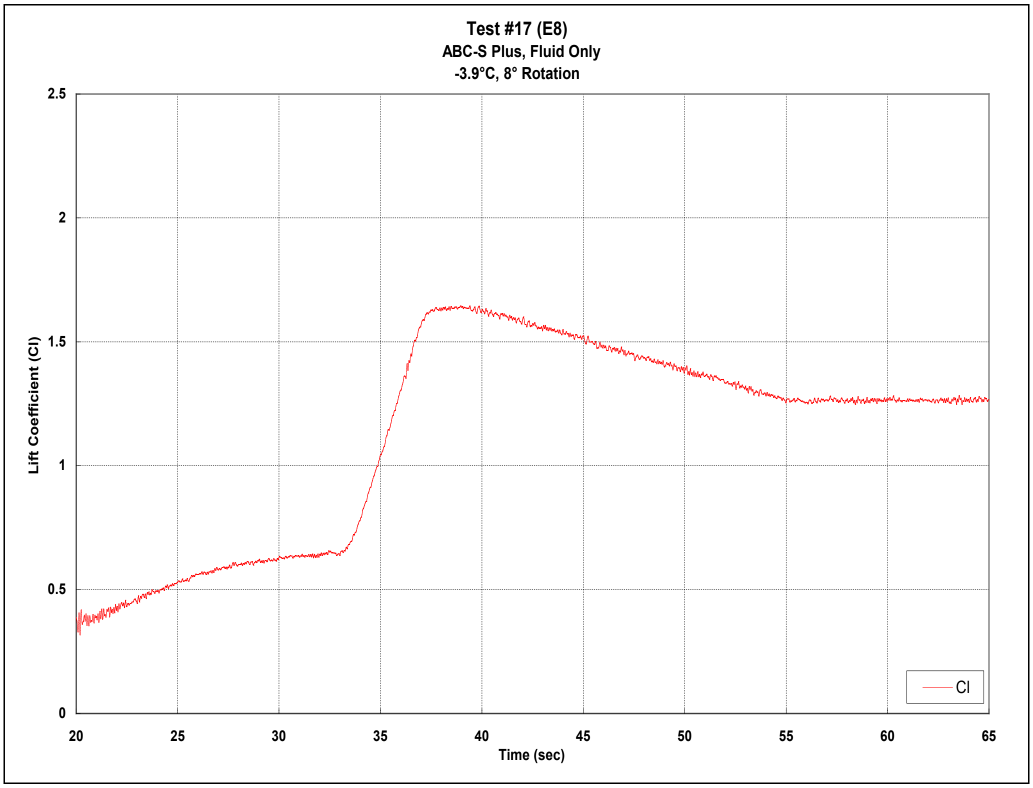

Figure D87: Run #17

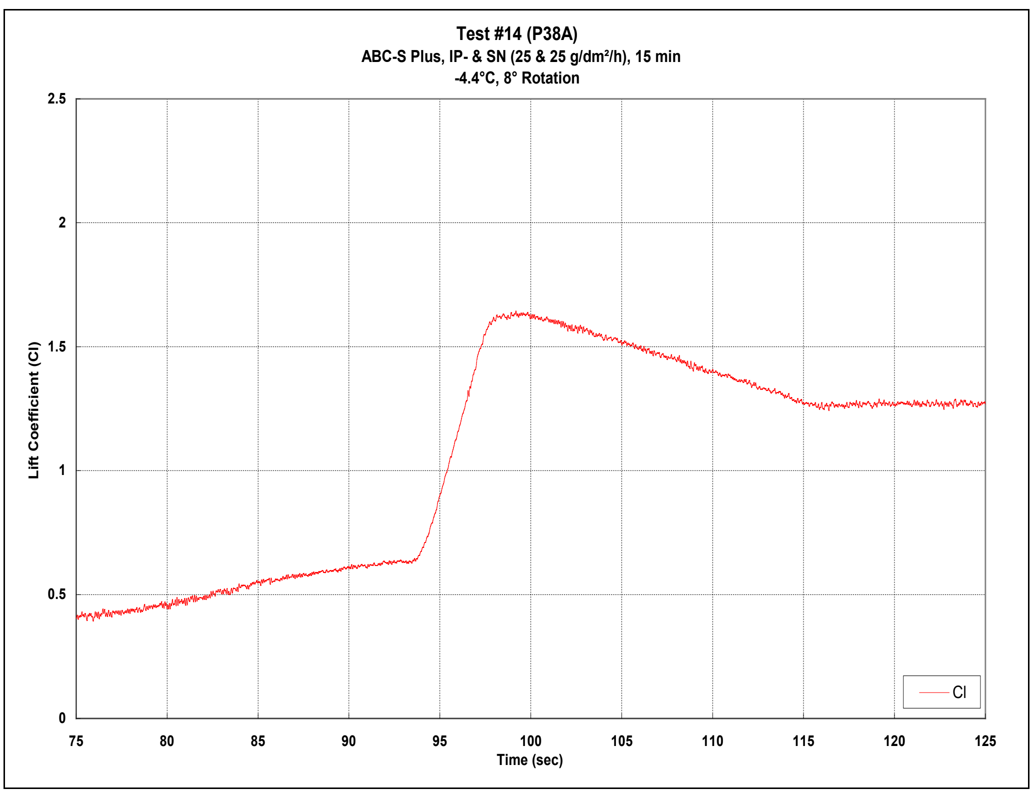

Figure D88: Run #14

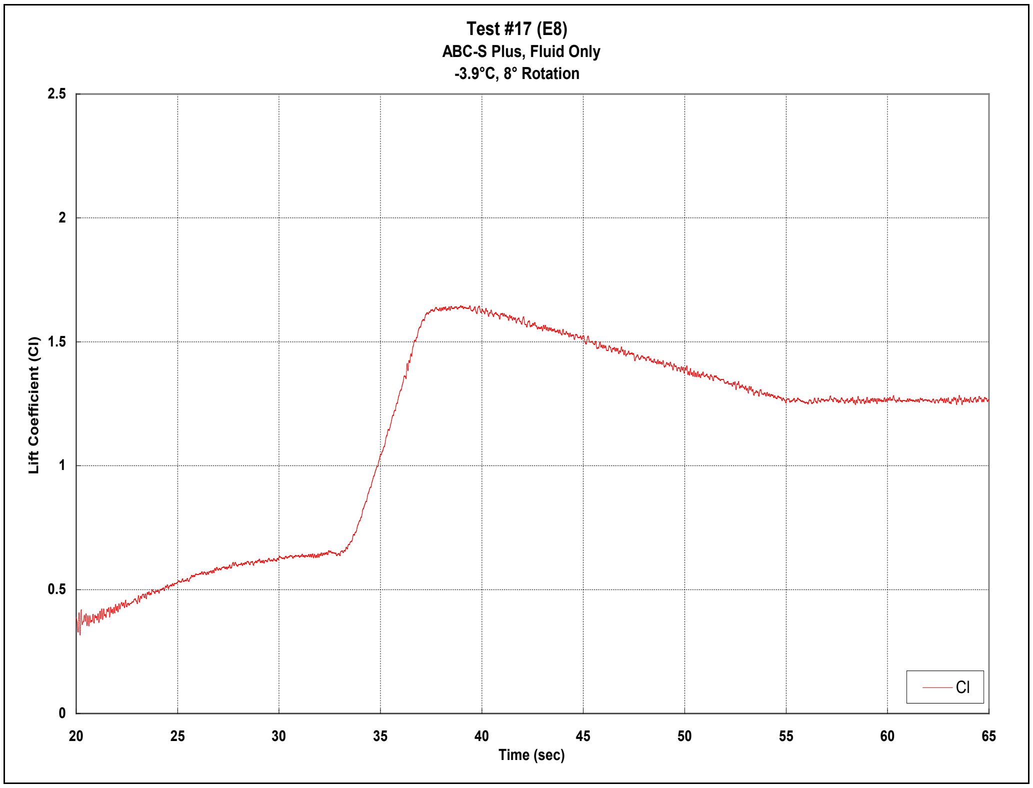

Figure D89: Run #17

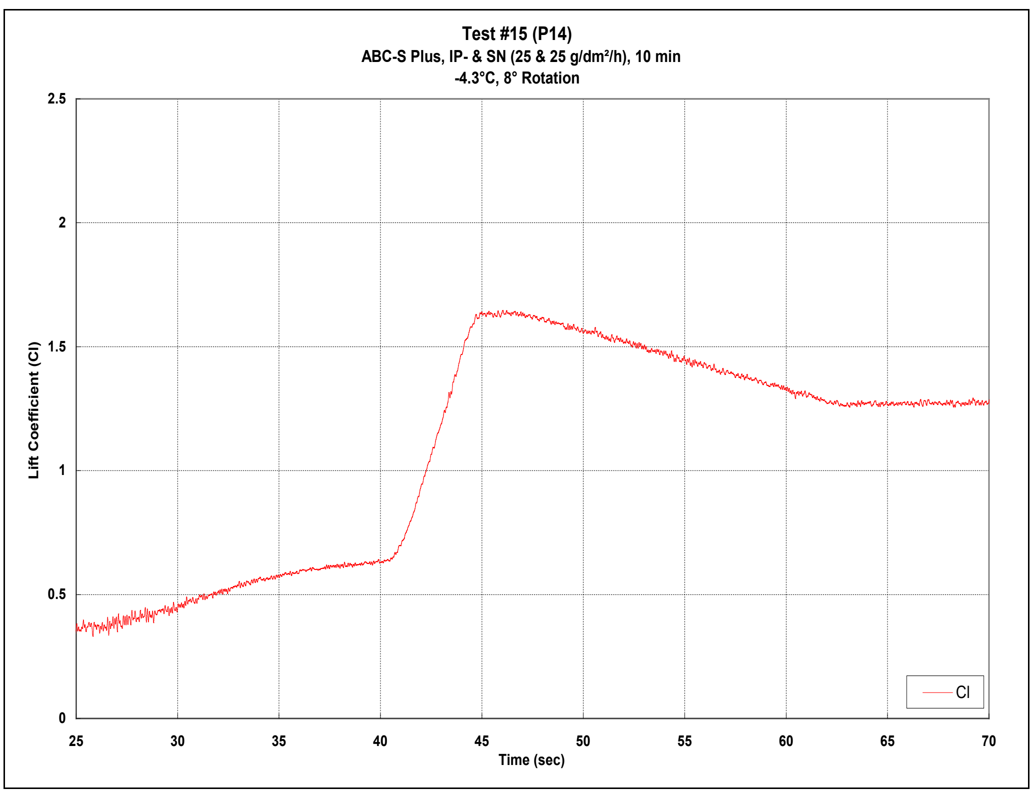

Figure D90: Run #15

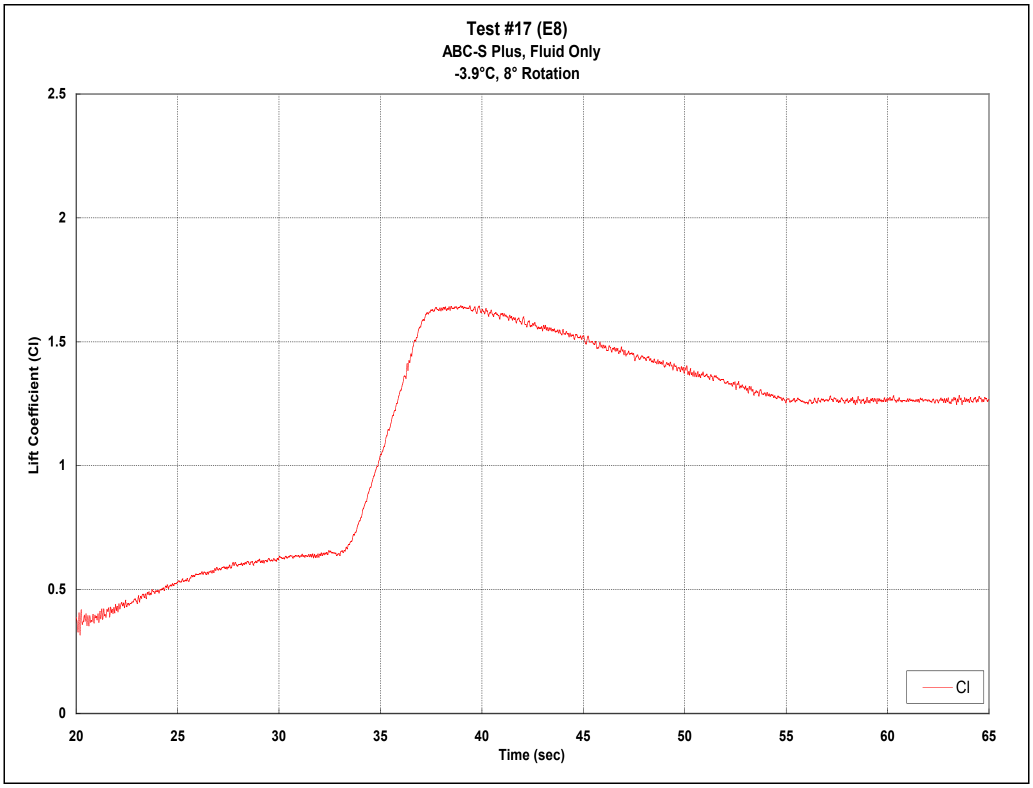

Figure D91: Run #17

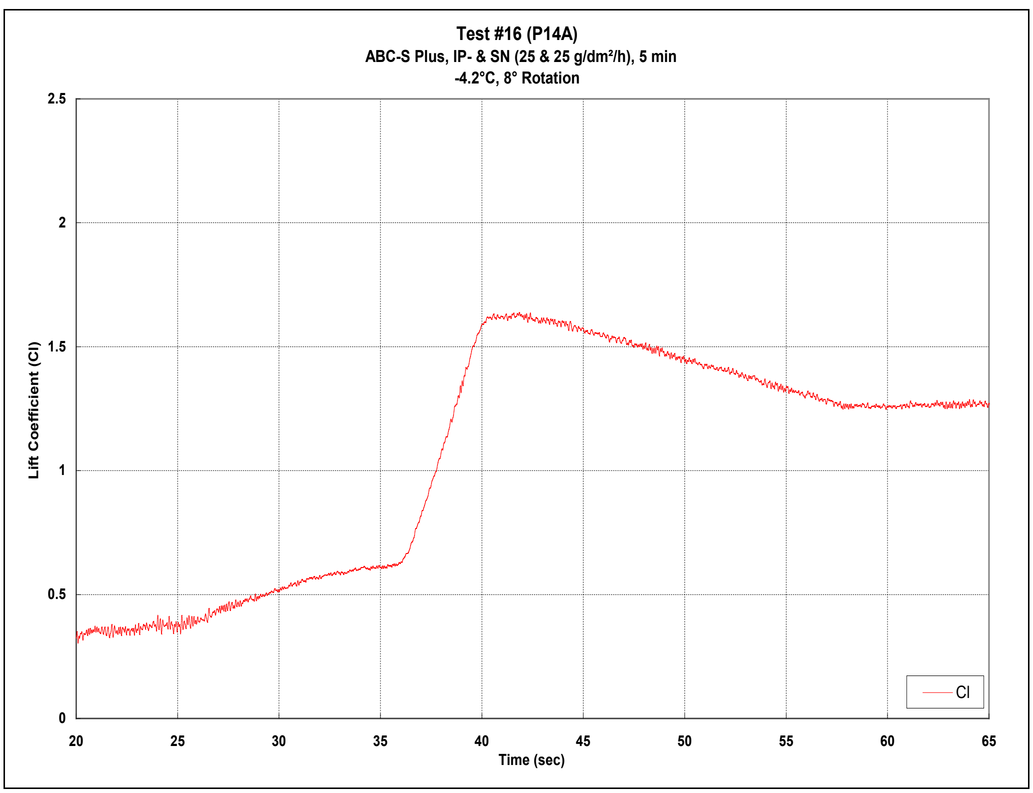

Figure D92: Run #16

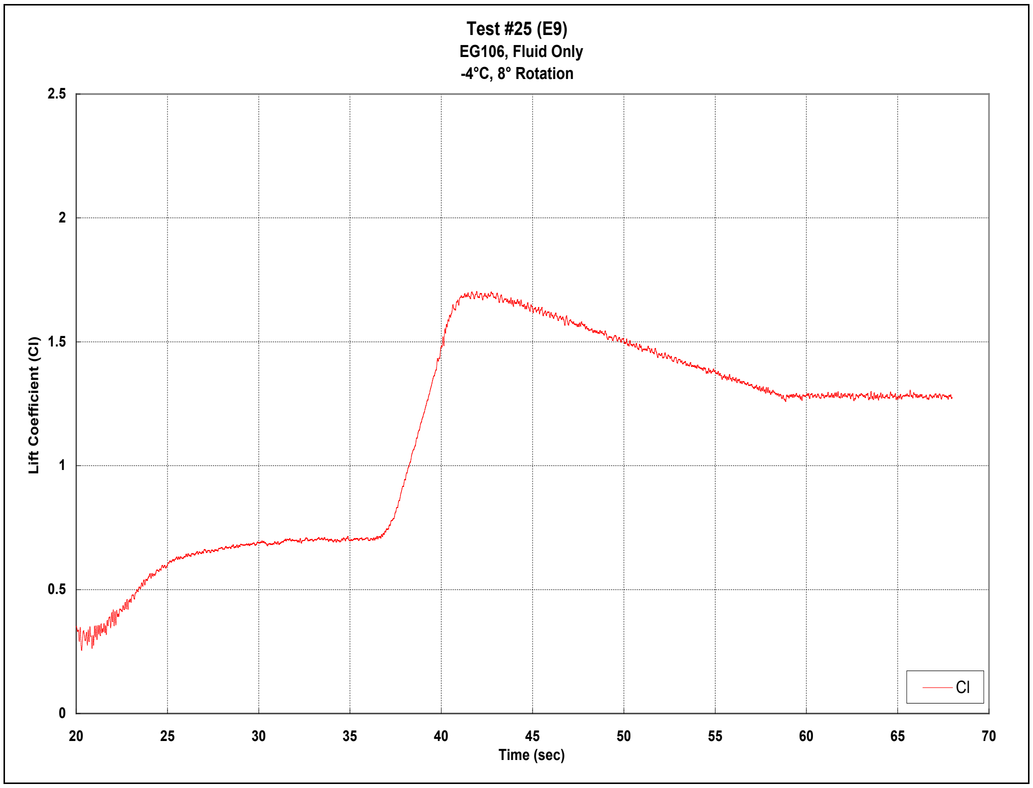

Figure D93: Run #25

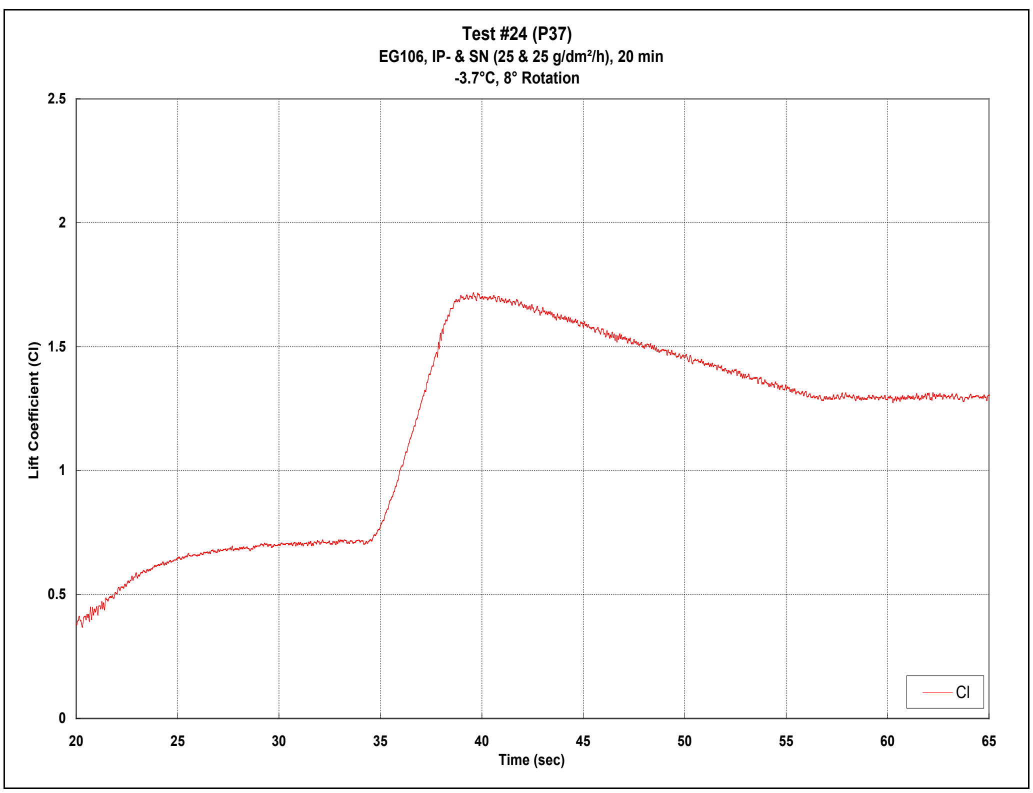

Figure D94: Run #24

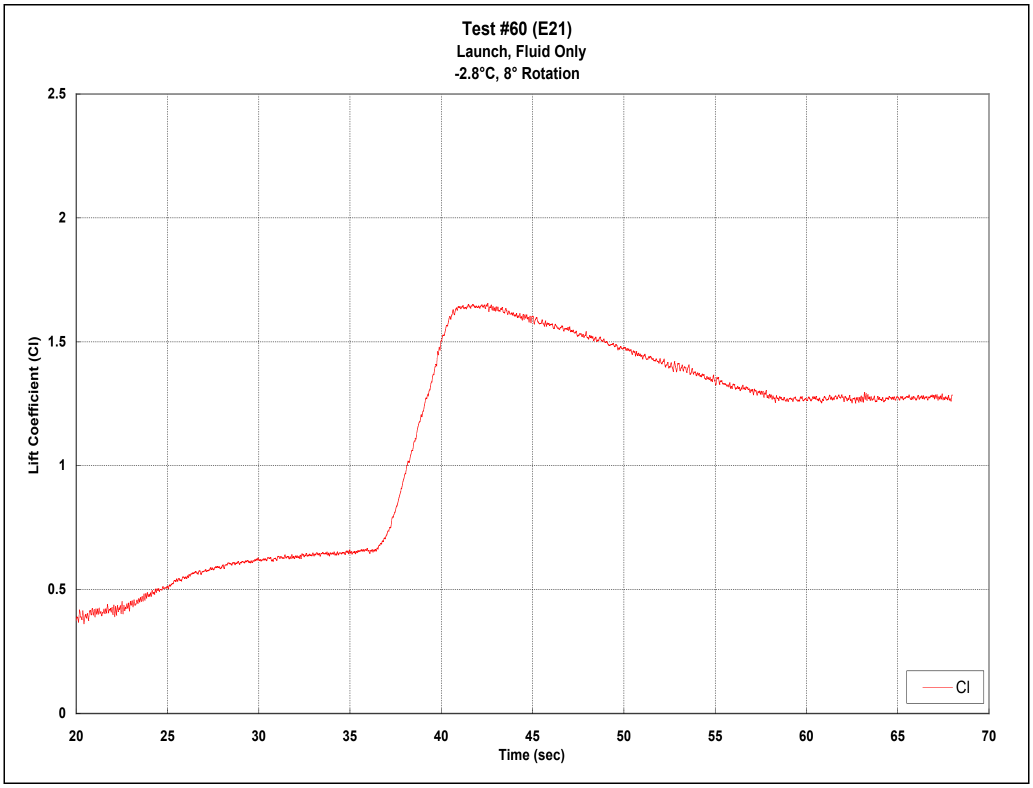

Figure D95: Run #60

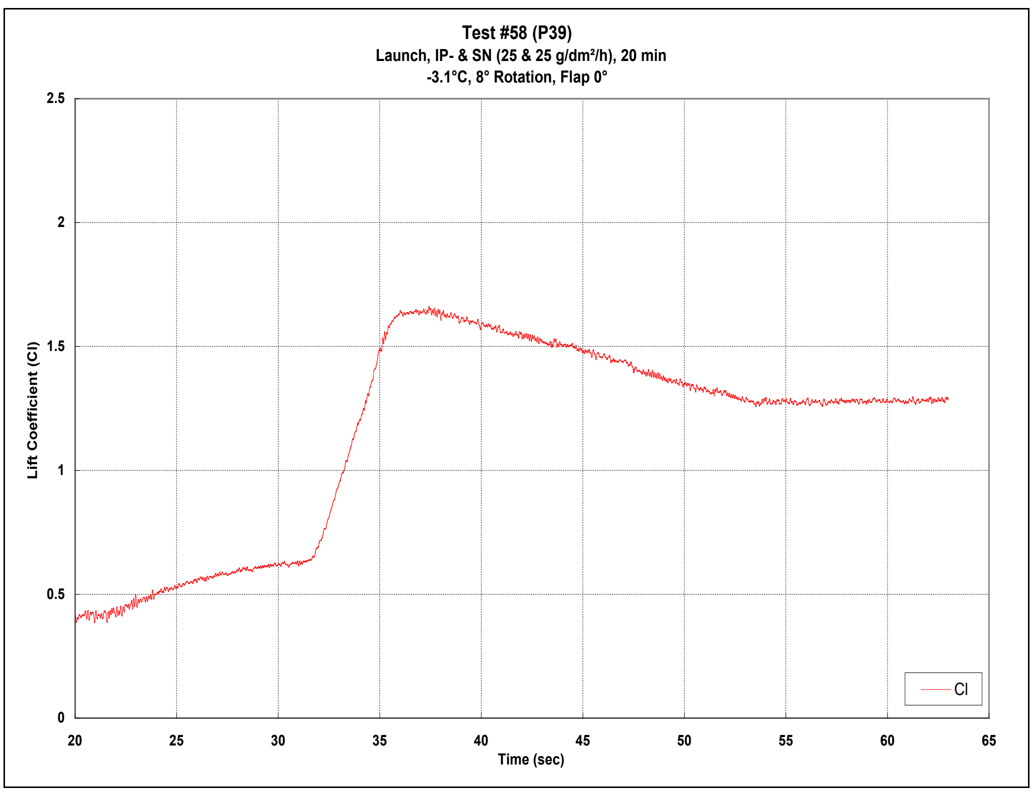

Figure D96: Run #58

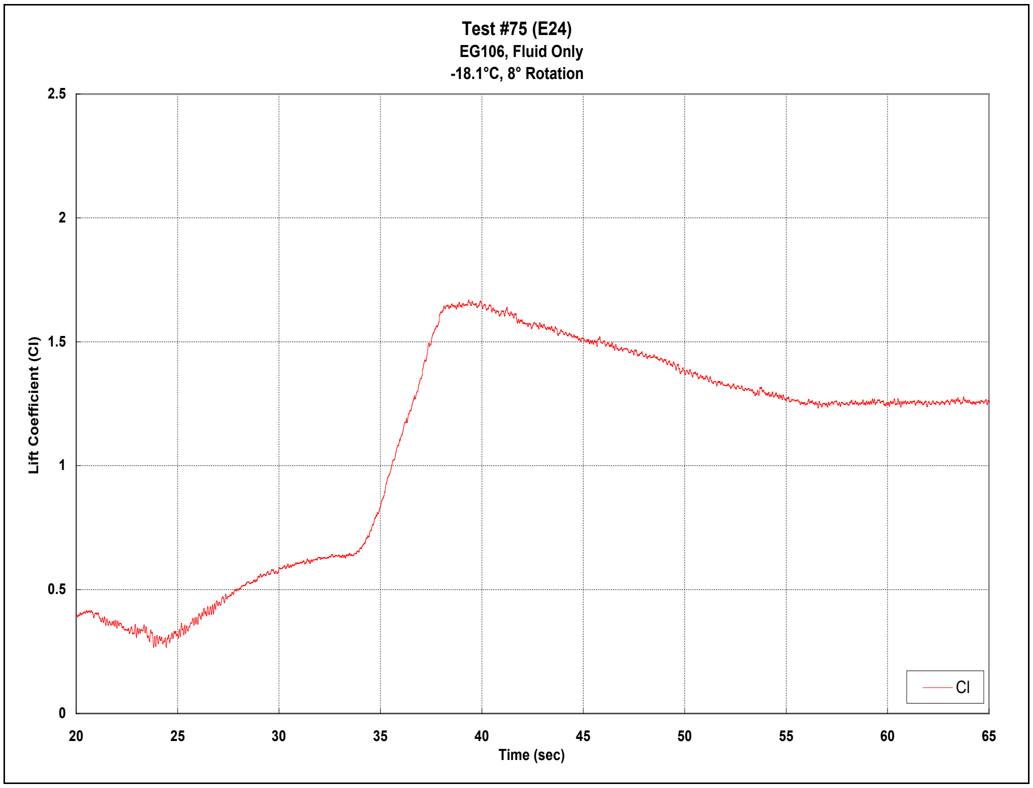

Figure D97: Run #75

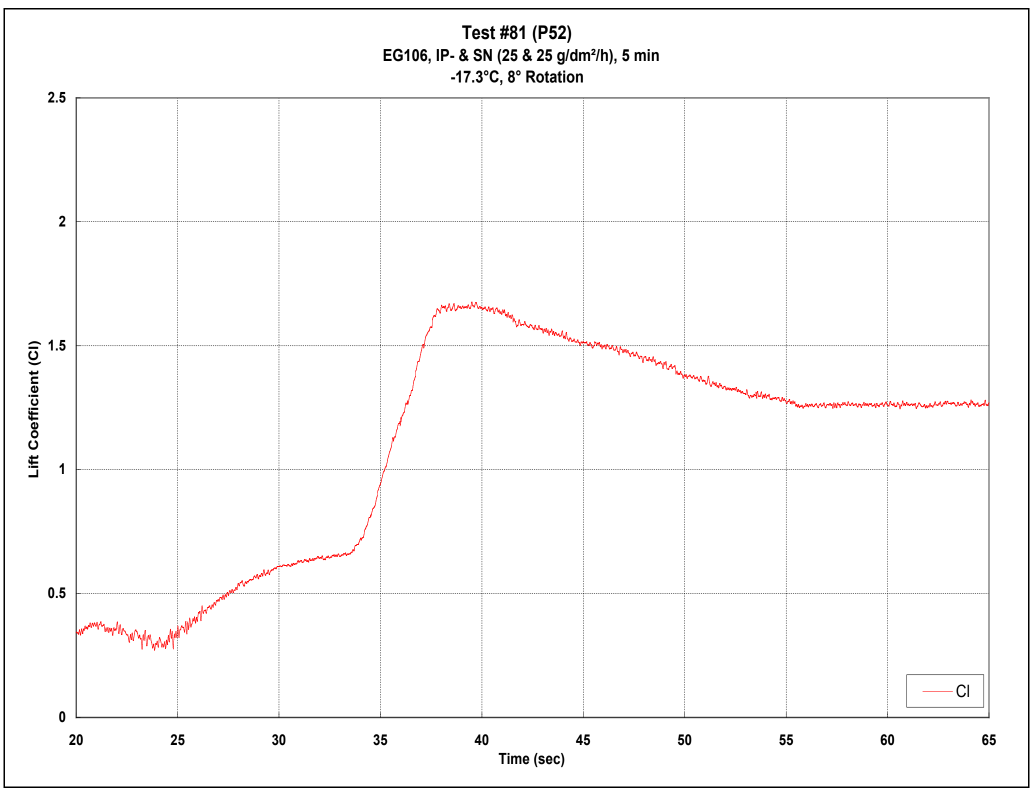

Figure D98: Run #81

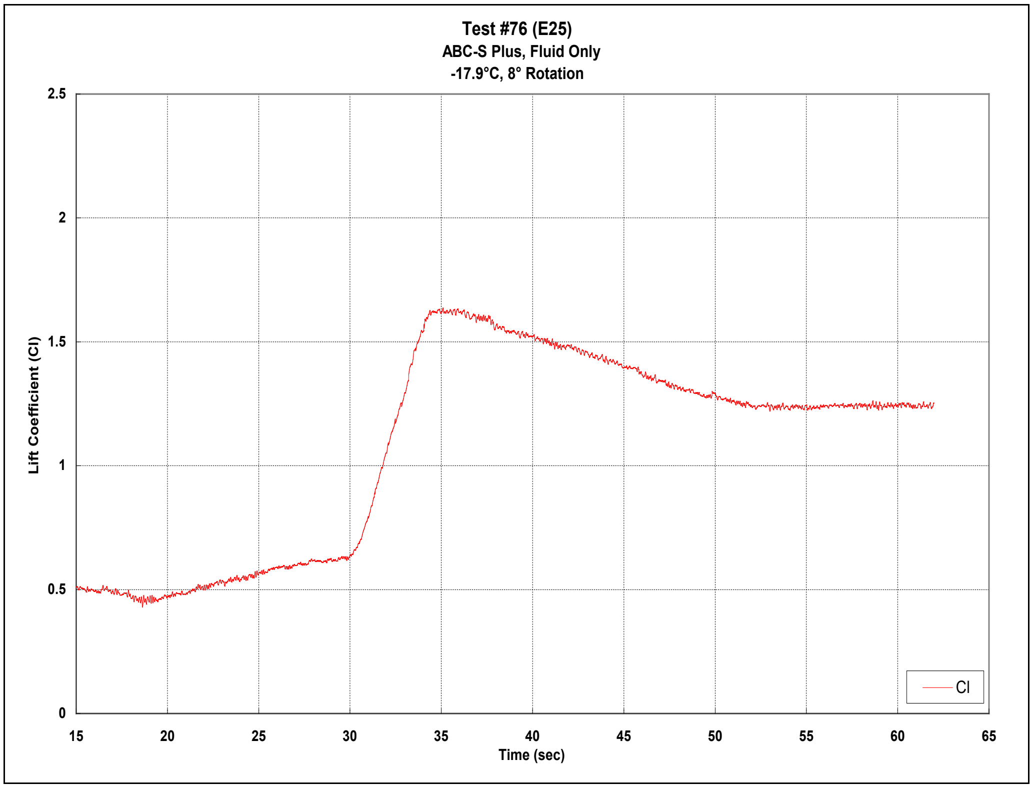

Figure D99: Run #76

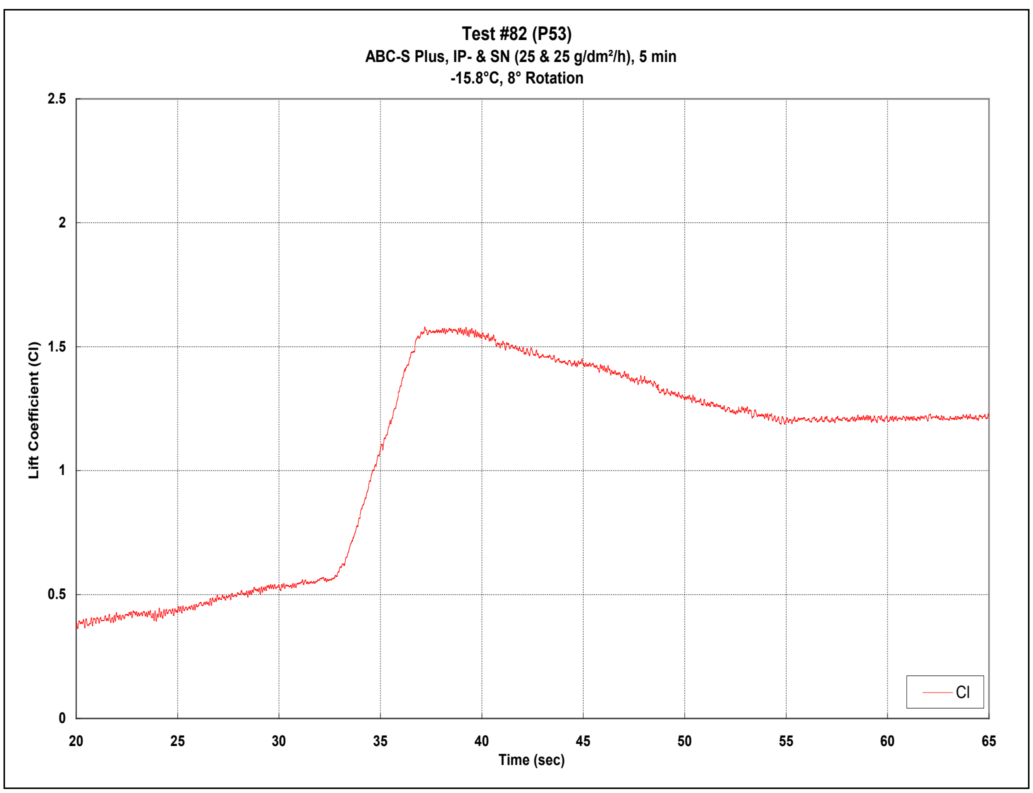

Figure D100: Run #82

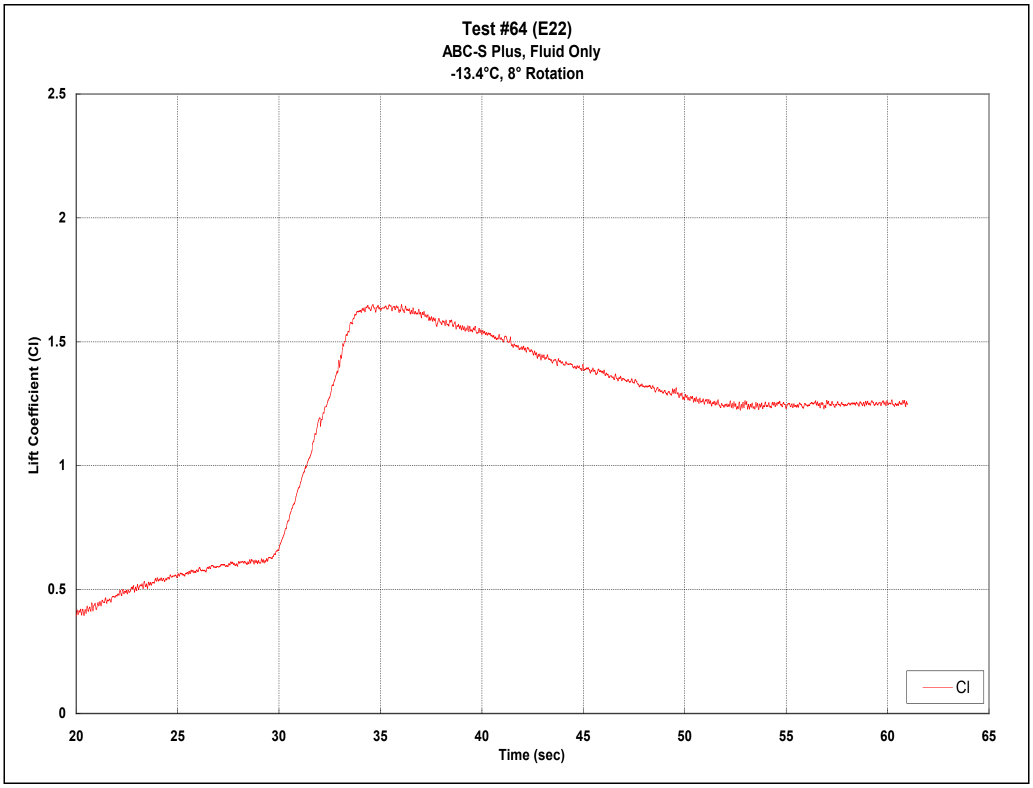

Figure D101: Run #64

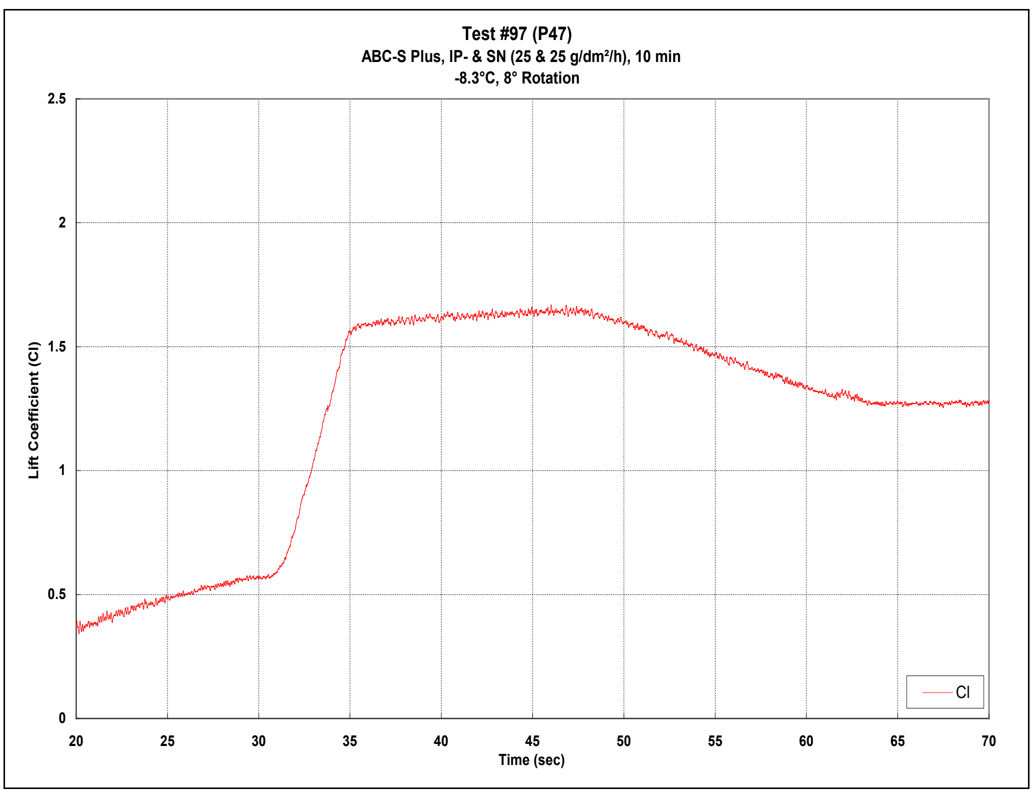

Figure D102: Run #97

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FLAP RETRACTED (UP) VERSUS FLAP EXTENDED (DOWN)

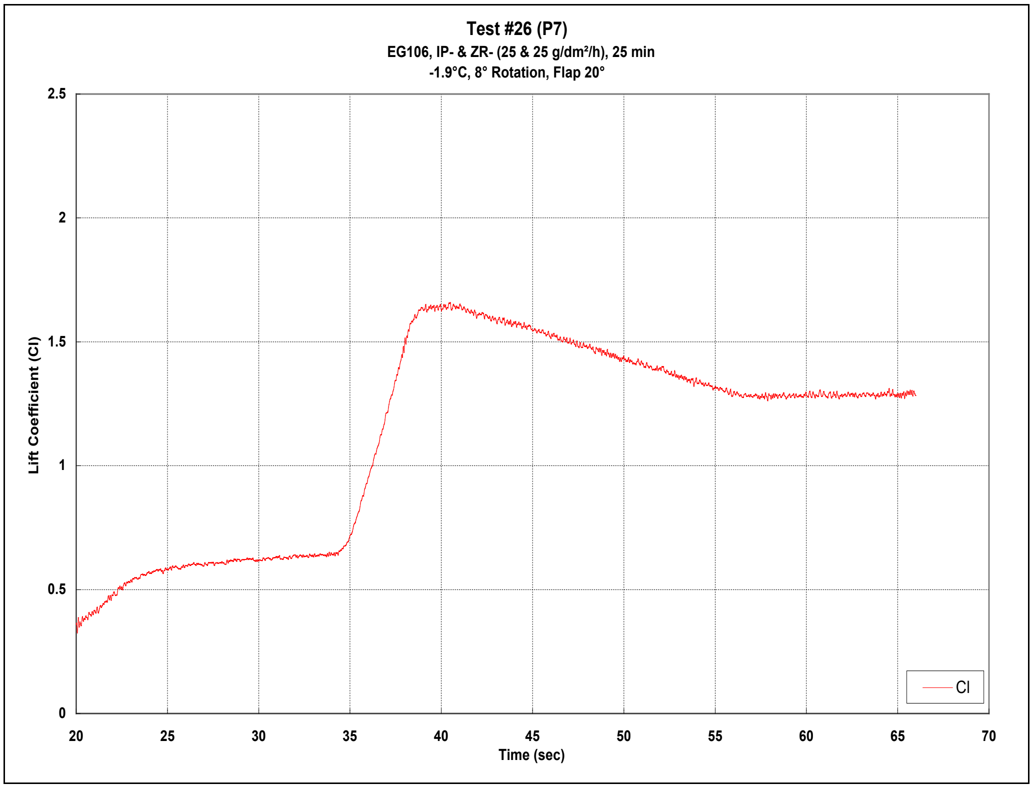

Figure D103: Run #26

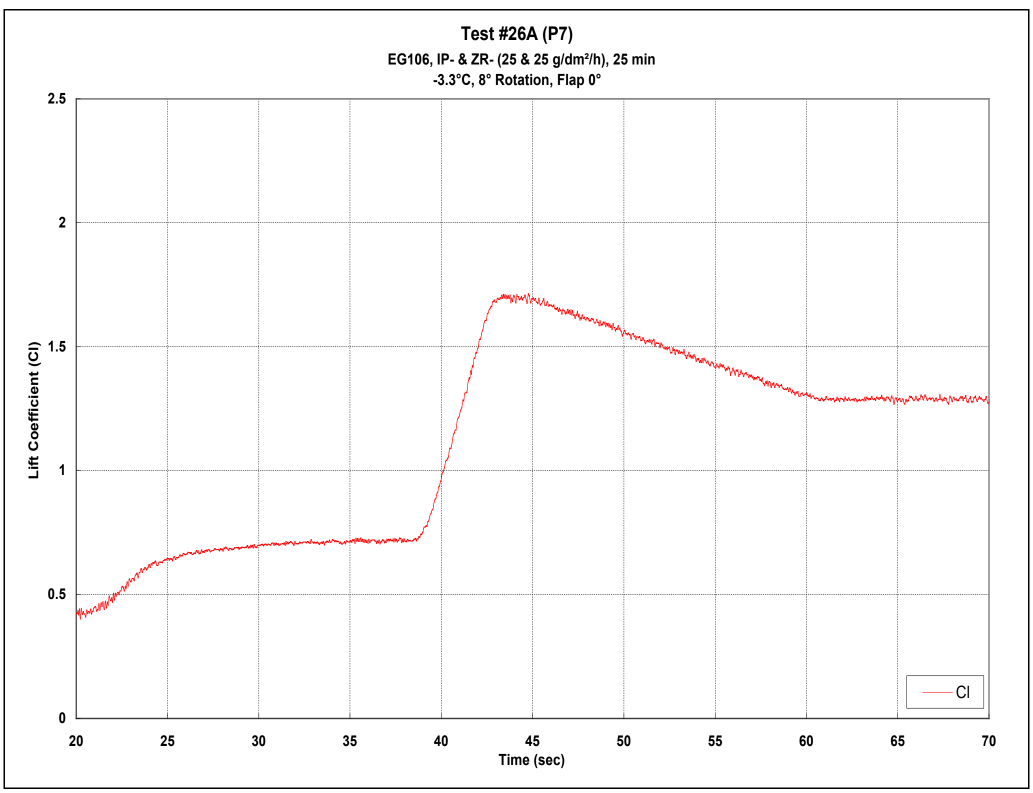

Figure D104: Run #26A

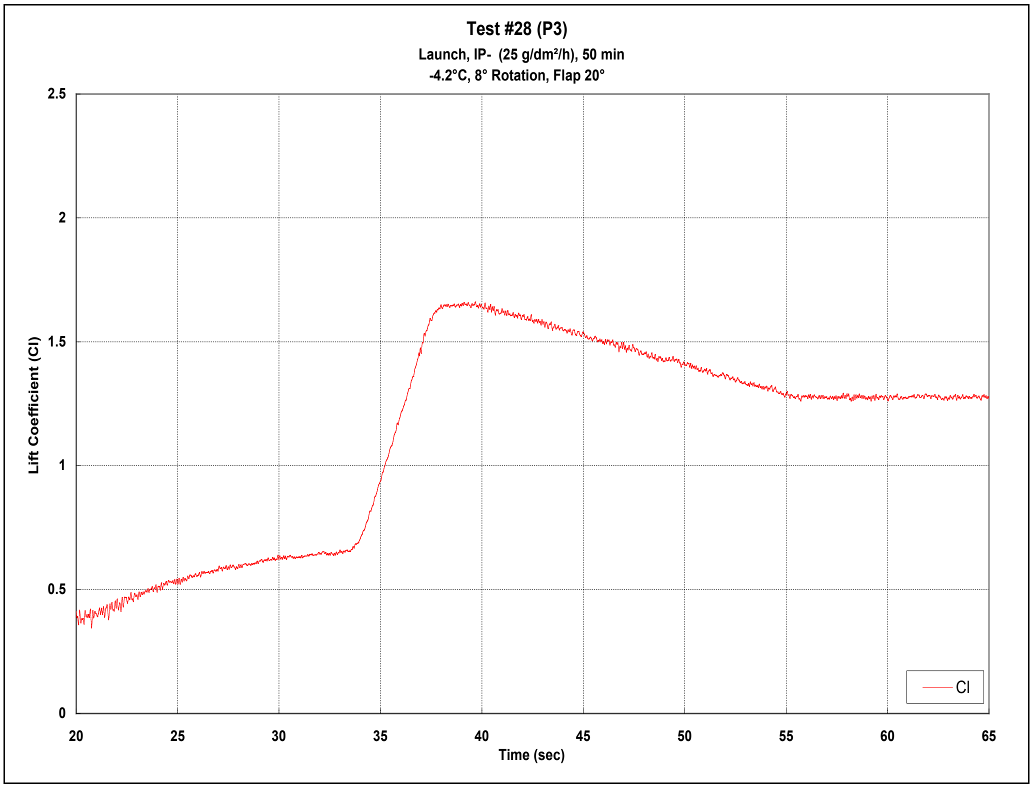

Figure D105: Run #28

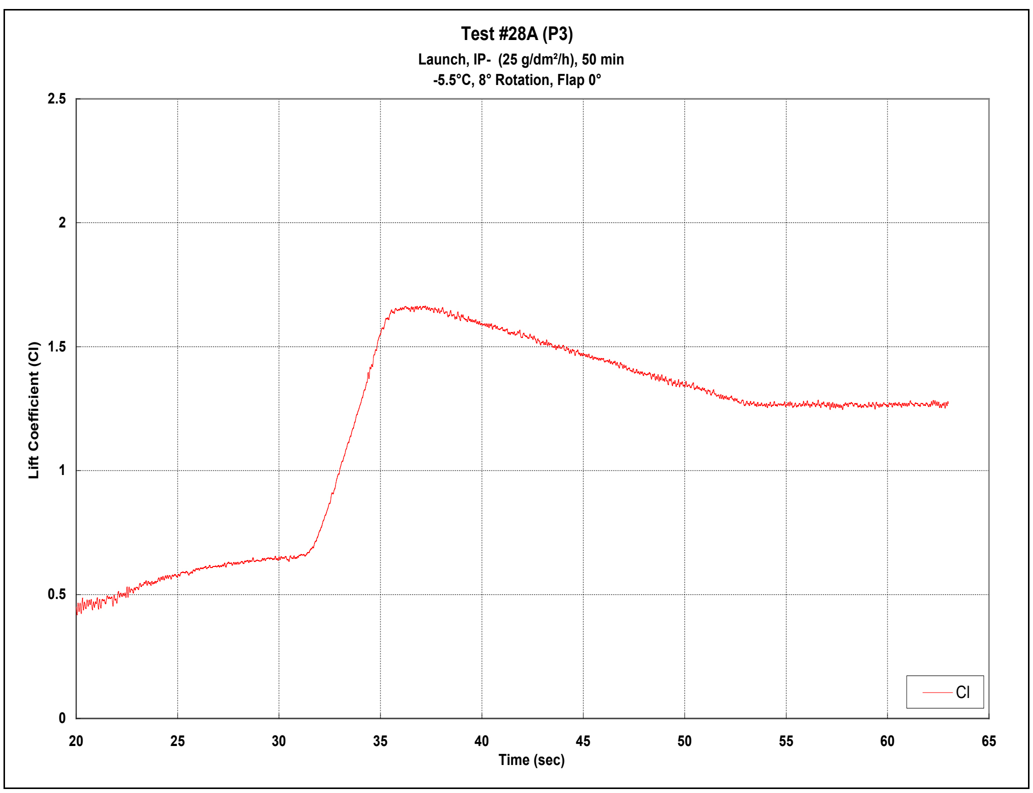

Figure D106: Run #28A

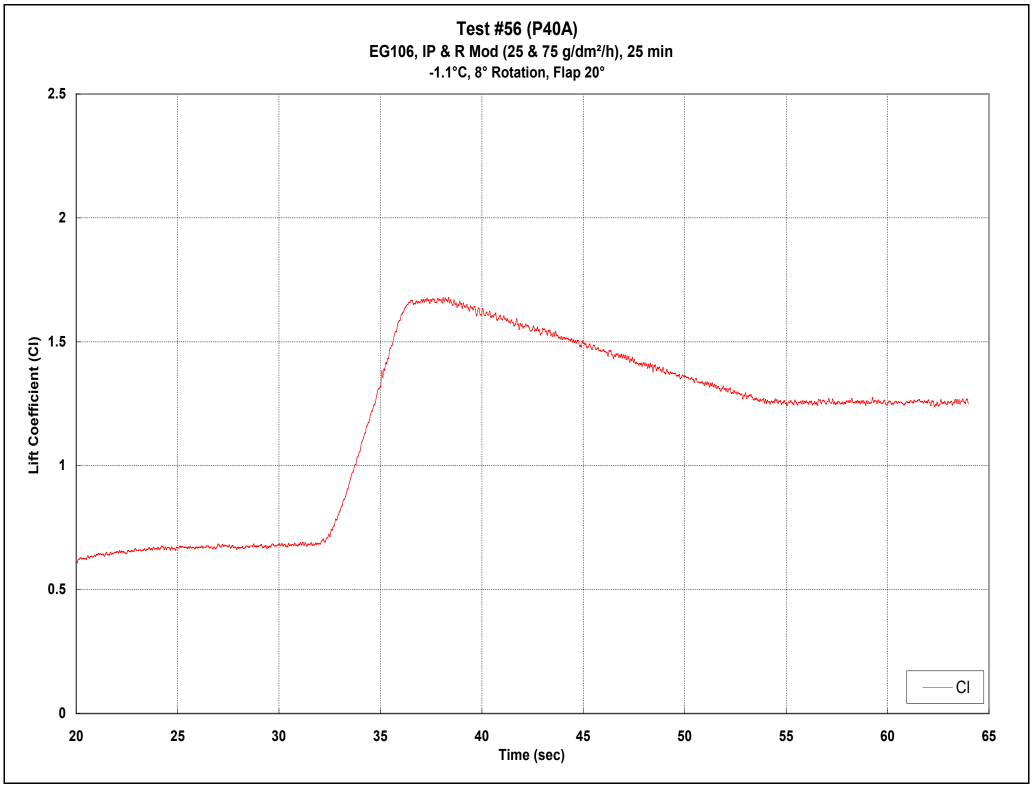

Figure D107: Run #56

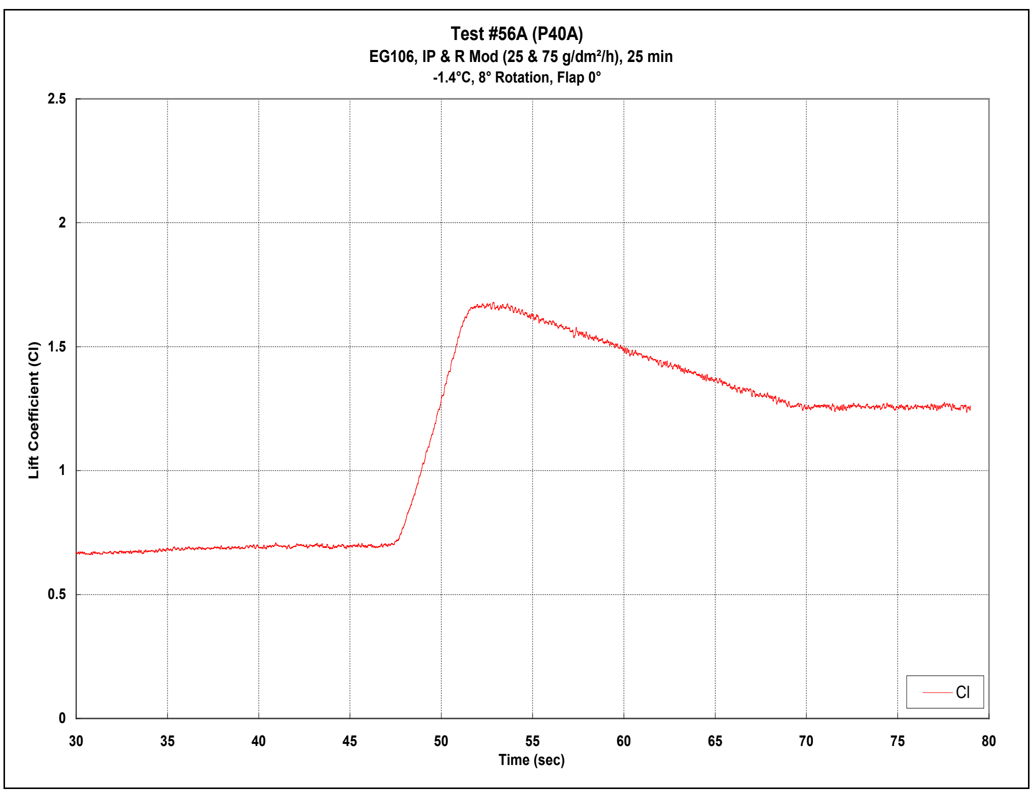

Figure D108: Run #56A

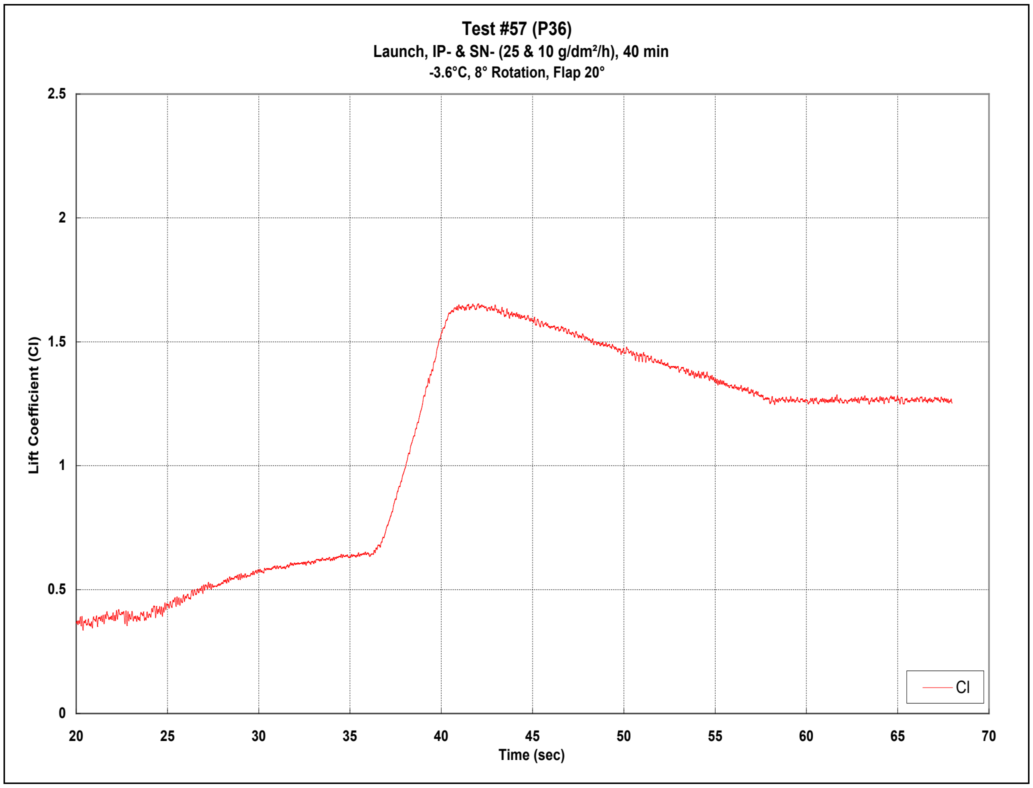

Figure D109: Run #57

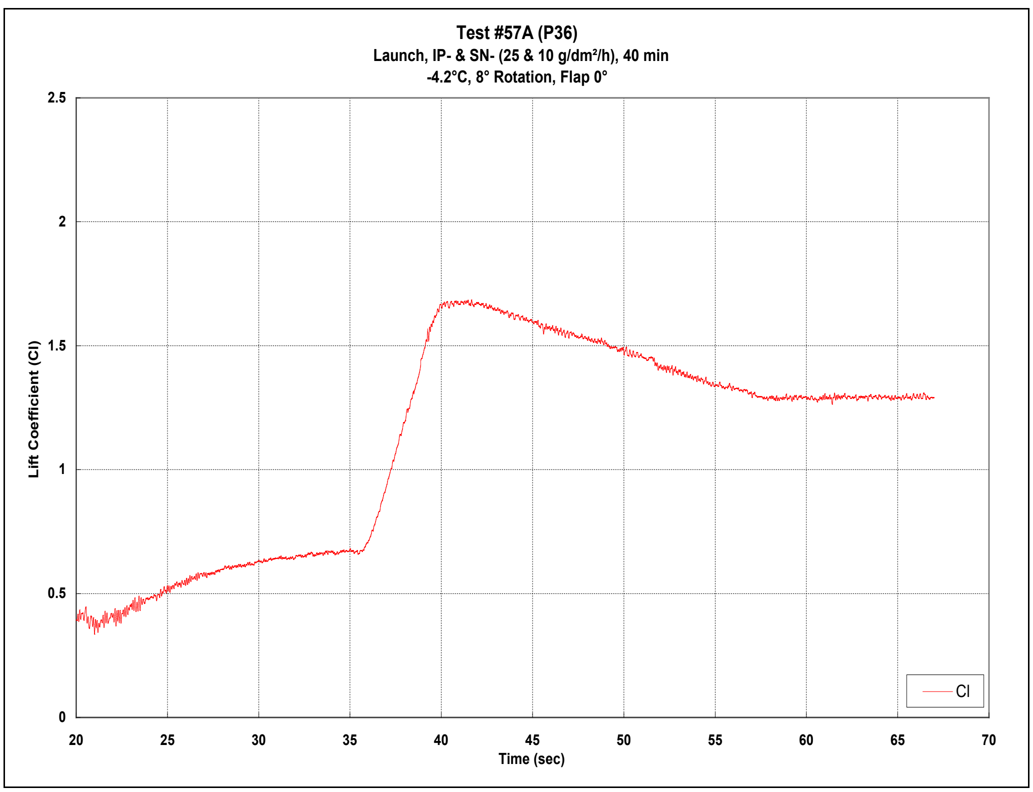

Figure D110: Run #57A

APPENDIX E

ICE PELLET ALLOWANCE TIMES SUMMARY SHEETS

LIST OF FIGURES

LIGHT ICE PELLETS

Light Ice Pellets
Wind Tunnel Summary Packages
CM2169.002

	OAT -5°C and above	OAT less than -5°C to -10°C	OAT less than -10°C
Light Ice Pellets	(A) 50 minutes 9 PG, 22 EG, 28 PG, 28A PG	(B) 30 minutes 67 EG, 96 PG, (9) PG	(C) 30 minutes 65 PG, 68 PG, 80 EG (67) EG
			20 mins 66 PG
			15 mins 69 PG

(A) EG: GOOD
PG: GOOD

(B) EG: GOOD. Could be higher
PG: OK. Further review required

(C) EG: GOOD
PG: BAD (0 mins)

GOOD
GOOD/REVIEW
BAD/REVIEW
BAD

Figure E1: Light Ice Pellets Allowance Table

Objective	IP VALIDATION	
Fluid	ABC-S + (PG)	
Test # / Test Plan #	RUN 9 (P2)	
OAT	TARGET: -5°C ACTUAL: -7°C GOOD	
Rate	IP = 25 GOOD	
Exposure Time	50 MINS GOOD	
Associated Fluid Only Case	RUN 1 (P8B): 5.01%	
Visual Contamination	START: 2/2/3 ROT: 1/1.8/1.8 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6° : 1.462 GOOD 8° : 1.641	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 ***** 8° Cl should be >=1.64 } **5%** ***** 6° Cl should be >=1.40 ***** 8° Cl should be >=1.59 } **8%**
Lift Loss At 8°	4.67% GOOD	
OVERALL STATUS (good, bad, or review)	GOOD	

Figure E2: Run #9

Objective	IP VALIDATION	
Fluid	EG106 (EG)	
Test # / Test Plan #	RUN 22 (P1)	
OAT	TARGET: -5° ACTUAL: -4.1 GOOD	
Rate	IP = 25 GOOD	
Exposure Time	50 MINS GOOD	
Associated Fluid Only Case	RUN 25 (E9): 1.99%	
Visual Contamination	START: 1.8/2/4 ROT: 1/1/1 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6° : 1.495 GOOD 8° : 1.707	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 ***** 8° Cl should be >=1.64 } **5%** ***** 6° Cl should be >=1.40 ***** 8° Cl should be >=1.59 } **8%**
Lift Loss At 8°	0.83% GOOD	
OVERALL STATUS (good, bad, or review)	GOOD	

Figure E3: Run #22

Objective	IP VALIDATION	
Fluid	LAUNCH (PG)	
Test # / Test Plan #	RUN 28(P3)	
OAT	TARGET: -5°C ACTUAL: -4.2°C GOOD	
Rate	IP=25 GOOD	
Exposure Time	50 MINS GOOD	
Associated Fluid Only Case	RUN 29 (E11): 4.96%	
Visual Contamination	START: 2/2/3.7 ROT: 1/1.7/2 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.449 8°: 1.648 GOOD	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } 5% ***** 8° Cl should be >=1.64 } 5% ***** 6° Cl should be >=1.40 } 8% ***** 8° Cl should be >=1.59 } 8%
Lift Loss At 8°	4.26% GOOD	
OVERALL STATUS (good, bad, or review)	GOOD	

Figure E4: Run #28

Objective	IP VALIDATION	
Fluid	LAUNCH (PG)	
Test # / Test Plan #	RUN 28A(P3)	
OAT	TARGET: -5°C ACTUAL: -5.5°C GOOD	
Rate	IP=25 GOOD	
Exposure Time	50 MINS GOOD	
Associated Fluid Only Case	RUN 29(E11): 4.96%	
Visual Contamination	START. 2/2/2.7 ACTUAL: 1/1.5/2 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.467 8°: 1.655 GOOD	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } 5% ***** 8° Cl should be >=1.64 } 5% ***** 6° Cl should be >=1.40 } 8% ***** 8° Cl should be >=1.59 } 8%
Lift Loss At 8°	3.85% GOOD	
OVERALL STATUS (good, bad, or review)	GOOD	

Figure E5: Run #28A

Objective	IP VALIDATION
Fluid	ABC-S+ (PG)
Test # / Test Plan #	RUN 65 (P17)
OAT	TARGET: -10°C ACTUAL: -13.7°C GOOD
Rate	IP=25 GOOD
Exposure Time	30 MINS GOOD
Associated Fluid Only Case	RUN 64 (E22): 5.07%
Visual Contamination	START: 2.8/2.8/4 ROT: 1.2/2/2.2 OK/REVIEW
Lift Coefficient	6°: 1.353 8°: 1.563 BAD/REVIEW
Lift Loss At 8°	9.20% BAD
OVERALL STATUS (good, bad, or review)	BAD/REVIEW

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing
(Less than 5% loss accepatble)
***** 6° Cl should be >=1.44 } 5%
***** 8° Cl should be >=1.64 } 5%
***** 6° Cl should be >=1.40 } 8%
***** 8° Cl should be >=1.59 } 8%

Figure E6: Run #65

Objective	IP VALIDATION
Fluid	ABC-S+ (PG)
Test # / Test Plan #	RUN 66 (P17A)
OAT	TARGET: -10°C ACTUAL: -13.6° GOOD
Rate	IP=25 GOOD
Exposure Time	20 MINS OK
Associated Fluid Only Case	RUN 64 (E22): 5.07%
Visual Contamination	START: 2.2/2/3.2 ROT: 1.2/2/2.5 OK
Lift Coefficient	6°: 1.349 8°: 1.573 BAD/REVIEW
Lift Loss At 8°	8.62% BAD
OVERALL STATUS (good, bad, or review)	BAD/REVIEW

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing
(Less than 5% loss accepatble)
***** 6° Cl should be >=1.44 } 5%
***** 8° Cl should be >=1.64 } 5%
***** 6° Cl should be >=1.40 } 8%
***** 8° Cl should be >=1.59 } 8%

Figure E7: Run #66

Objective	IP VALIDATION	
Fluid	EG106 (EG)	
Test # / Test Plan #	RUN 67 (P16)	
OAT	TARGET: -10°C ACTUAL: -12.6°C GOOD	
Rate	IP = 25 GOOD	
Exposure Time	30 MINS GOOD	
Associated Fluid Only Case	RUN 100 (E26): 2.28%	
Visual Contamination	START: 2.2/2.2/3.2 ROT: 1/1.5/1.8 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.463 8°: 1.683 GOOD	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 ***** 8° Cl should be >=1.64 } **5%** ***** 6° Cl should be >=1.40 ***** 8° Cl should be >=1.59 } **8%**
Lift Loss At 8°	2.23% GOOD	
OVERALL STATUS (good, bad, or review)	GOOD	

Figure E8: Run #67

Objective	IP VALIDATION	
Fluid	LAUNCH (PG)	
Test # / Test Plan #	RUN 68 (P18)	
OAT	TARGET: -10°C GOOD/ ACTUAL: -16.6°C REVIEW	
Rate	IP = 25 GOOD	
Exposure Time	30 MINS GOOD	
Associated Fluid Only Case	RUN 70 (E23): 5.59%	
Visual Contamination	START: 3/2.5/3.7 OK/ ROT: 1.3/2/2.2 REVIEW	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.331 BAD/ 8°: 1.56 REVIEW	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 ***** 8° Cl should be >=1.64 } **5%** ***** 6° Cl should be >=1.40 ***** 8° Cl should be >=1.59 } **8%**
Lift Loss At 8°	9.60% BAD	
OVERALL STATUS (good, bad, or review)	BAD / REVIEW	

Figure E9: Run #68

Objective	IP VALIDATION	
Fluid	LAUNCH (PG)	
Test # / Test Plan #	RUN 69 (P18A)	
OAT	TARGET: -10°C ACTUAL: -17.8°C OK	
Rate	IP: 25 GOOD	
Exposure Time	15 MINS OK	
Associated Fluid Only Case	RUN 70(E23): 5.59%	
Visual Contamination	START: 2.8/2.5/3.5 ROT: 1.3/2/2.7 OK	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.331 BAD/ 8°: 1.556 REVIEW	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } 5% ***** 8° Cl should be >=1.64 ***** 6° Cl should be >=1.40 } 8% ***** 8° Cl should be >=1.59
Lift Loss At 8°	9.60% BAD	
OVERALL STATUS (good, bad, or review)	BAD / REVIEW	

Figure E10: Run #69

Objective	IP VALIDATION	
Fluid	EG106 (EG)	
Test # / Test Plan #	RUN 80 (P28)	
OAT	TARGET: -25°C ACTUAL: -17°C OK	
Rate	IP = 25 GOOD	
Exposure Time	30 MINS GOOD	
Associated Fluid Only Case	RUN 75(E24): 4.08%	
Visual Contamination	START: 2.5/2.2/3 ROT: 1/1.25/1.7 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.463 GOOD 8°: 1.670	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } 5% ***** 8° Cl should be >=1.64 ***** 6° Cl should be >=1.40 } 8% ***** 8° Cl should be >=1.59
Lift Loss At 8°	2.98% GOOD	
OVERALL STATUS (good, bad, or review)	GOOD	

Figure E11: Run #80

Objective	IP VALIDATION	
Fluid	ABC-S+ (PG)	
Test # / Test Plan #	RUN 96 (P17)	
OAT	TARGET: -10°C ACTUAL: -7.6°C OK	
Rate	IP=25 GOOD	
Exposure Time	30 MINS GOOD	
Associated Fluid Only Case	RUN 64 (E22): 5.07%	
Visual Contamination	START: 2.3/2/3 ROT: 1/2/2 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.400 GOOD/ 8°: 1.608 REVIEW	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } **5%** ***** 8° Cl should be >=1.64 ***** 6° Cl should be >=1.40 } **8%** ***** 8° Cl should be >=1.59
Lift Loss At 8°	6.58% GOOD/ REVIEW	
OVERALL STATUS (good, bad, or review)	GOOD / REVIEW	

Figure E12: Run #96

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MODERATE ICE PELLETS

Moderate Ice Pellets
Wind Tunnel Summary Packages
CM2169.002

	OAT -5°C and above	OAT less than -5°C to -10°C	OAT less than -10°C
Moderate Ice Pellets	Ⓐ 25 minutes 10 (PG), 10A (PG) NA, 10B (PG), 21 (EG), 47 (PG)	Ⓑ 10 minutes 95 (PG), (10) (PG), (71) (EG)	Ⓒ 10 minutes 71 (EG), 72 (PG)
	15 mins 48 (PG), 49 (PG)		5 mins ~~73~~ NA (PG), 74 (PG)

Ⓐ EG: GOOD. Need colder data
PG: OK @15mins. Further review required

Ⓑ EG: GOOD
PG: GOOD/REVIEW

Ⓒ EG: GOOD
PG: BAD

GOOD
GOOD/REVIEW
BAD/REVIEW
BAD

Figure E13: Moderate Ice Pellets Allowance Table

Objective	IP VALIDATION	
Fluid	ABC-S+ (PG)	
Test # / Test Plan #	RUN 10 (P5)	
OAT	TARGET: -5°C GOOD ACTUAL: -7.4°C	
Rate	IP: 75 GOOD	
Exposure Time	25 MINS GOOD	
Associated Fluid Only Case	RUN 1 (P8B): 5.01%	
Visual Contamination	START: 2/3/4 ROT: 1/2/2 GOOD/	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.438 GOOD/ 8°: 1.616 REVIEW	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 ***** 8° Cl should be >=1.64 } 5% ***** 6° Cl should be >=1.40 ***** 8° Cl should be >=1.59 } 8%
Lift Loss At 8°	6.12% GOOD/ REVIEW	
OVERALL STATUS (good, bad, or review)	GOOD/REVIEW	

Figure E14: Run #10

Objective	IP VALIDATION	
Fluid	ABC-S+ (PG)	
Test # / Test Plan #	RUN 10A (P5)	
OAT	TARGET: -5°C GOOD ACTUAL: -5.6°C	
Rate	IP: 75 GOOD	
Exposure Time	25 MIN GOOD	
Associated Fluid Only Case	RUN 1 (P8B): 5.01%	
Visual Contamination	START: 2/2.8/2.7 ROT: 1/1.8/2 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.525 8°: 1.709 GOOD	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 ***** 8° Cl should be >=1.64 } 5% ***** 6° Cl should be >=1.40 ***** 8° Cl should be >=1.59 } 8%
Lift Loss At 8°	0.71% GOOD	
OVERALL STATUS (good, bad, or review)	GOOD	

Figure E15: Run #10A

Objective	IP VALIDATION	
Fluid	ABC-S+ (PG)	
Test # / Test Plan #	RUN 10B (P5)	
OAT	TARGET: -5°C ACTUAL: -6.2°C GOOD	
Rate	IP=75 GOOD	
Exposure Time	25 MINS GOOD	
Associated Fluid Only Case	RUN 1 (P8B): 5.01%	
Visual Contamination	START: 2.2/3/3 ROT: 1/2/2 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.405 8°: 1.587 BAD	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } **5%** ***** 8° Cl should be >=1.64 ***** 6° Cl should be >=1.40 } **8%** ***** 8° Cl should be >=1.59
Lift Loss At 8°	7.80% BAD	
OVERALL STATUS (good, bad, or review)	BAD / REVIEW	

Figure E16: Run #10B

Objective	IP VALIDATION	
Fluid	EG106 (EG)	
Test # / Test Plan #	RUN 21 (P4)	
OAT	TARGET: -5°C ACTUAL: -3.6°C OK	
Rate	IP=75 GOOD	
Exposure Time	25 MINS GOOD	
Associated Fluid Only Case	RUN 55 (E20): 1.88%	
Visual Contamination	START: 2/2.2/4 ROT: 1/1/1.2 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.515 8°: 1.712 GOOD	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } **5%** ***** 8° Cl should be >=1.64 ***** 6° Cl should be >=1.40 } **8%** ***** 8° Cl should be >=1.59
Lift Loss At 8°	0.54% GOOD	
OVERALL STATUS (good, bad, or review)	GOOD	

Figure E17: Run #21

Objective	IP VALIDATION	
Fluid	LAUNCH (PG)	
Test # / Test Plan #	RUN 47 (P6)	
OAT	TARGET: -5°C ACTUAL: -4.9°C GOOD	
Rate	IP=75 GOOD	
Exposure Time	25 MINS GOOD	
Associated Fluid Only Case	RUN 29 (E11): 4.96%	
Visual Contamination	START: 3.7/3.8/4 ROT: 1/1.7/2.5 BAD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.383 BAD/ 8°: 1.58 REVIEW	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 ***** 8° Cl should be >=1.64 } **5%** ***** 6° Cl should be >=1.40 ***** 8° Cl should be >=1.59 } **8%**
Lift Loss At 8°	8.21% BAD/ REVIEW	
OVERALL STATUS (good, bad, or review)	BAD	

Figure E18: Run #47

Objective	IP VALIDATION	
Fluid	LAUNCH (PG)	
Test # / Test Plan #	RUN 48 (P6A)	
OAT	TARGET: -5°C ACTUAL: -2.7°C GOOD	
Rate	IP=75 GOOD	
Exposure Time	15 MINS BAD	
Associated Fluid Only Case	RUN 54 (E19): 3.56%	
Visual Contamination	START: 2/2.8/4 ROT: 1/1.7/1.8 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.429 GOOD/ 8° 1.609 REVIEW	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 ***** 8° Cl should be >=1.64 } **5%** ***** 6° Cl should be >=1.40 ***** 8° Cl should be >=1.59 } **8%**
Lift Loss At 8°	6.52% GOOD/ REVIEW	
OVERALL STATUS (good, bad, or review)	GOOD/REVIEW	

Figure E19: Run #48

Objective	IP VALIDATION	
Fluid	LAUNCH	
Test # / Test Plan #	RUN 49 (P6B)	
OAT	TARGET: -5°C ACTUAL: -3.1°C GOOD	
Rate	IP = 75 GOOD	
Exposure Time	15 MINS BAD	
Associated Fluid Only Case	RUN 60 (E21): 4.61%	
Visual Contamination	START: 2.7/2.8/3 ROT: 1/1.5/1.8 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.414 GOOD/ 8°: 1.606 REVIEW	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } 5% ***** 8° Cl should be >=1.64 } 5% ***** 6° Cl should be >=1.40 } 8% ***** 8° Cl should be >=1.59 } 8%
Lift Loss At 8°	6.70% GOOD/ REVIEW	
OVERALL STATUS (good, bad, or review)	GOOD/REVIEW	

Figure E20: Run #49

Objective	IP VALIDATION	
Fluid	EG106 (EG)	
Test # / Test Plan #	RUN 71 (P19)	
OAT	TARGET: -10°C ACTUAL: -17.7°C GOOD	
Rate	IP = 75 GOOD	
Exposure Time	10 MINS GOOD	
Associated Fluid Only Case	RUN 75 (E24): 4.08%	
Visual Contamination	START: 2.3/2.3/2.8 ROT: 1/1.3/1.8 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.475 GOOD 8°: 1.671	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } 5% ***** 8° Cl should be >=1.64 } 5% ***** 6° Cl should be >=1.40 } 8% ***** 8° Cl should be >=1.59 } 8%
Lift Loss At 8°	2.92% GOOD	
OVERALL STATUS (good, bad, or review)	GOOD	

Figure E21: Run #71

Objective	IP VALIDATION
Fluid	ABC-S+ (PG)
Test # / Test Plan #	RUN 72 (P20)
OAT	TARGET: -10°C ACTUAL: -18°C OK
Rate	IP=75 GOOD
Exposure Time	10 MINS GOOD
Associated Fluid Only Case	RUN 76 (E25): 5.89%
Visual Contamination	START: 2.8/2.5/3.8 ROT: 1.2/2/2.8 OK
Lift Coefficient	6°: 1.381 8°: 1.561 BAD
Lift Loss At 8°	9.31% BAD
OVERALL STATUS (good, bad, or review)	BAD

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing (Less than 5% loss accepatble)
***** 6° Cl should be >=1.44 } 5%
***** 8° Cl should be >=1.64 } 5%
***** 6° Cl should be >=1.40 } 8%
***** 8° Cl should be >=1.59 } 8%

Figure E22: Run #72

Objective	IP VALIDATION
Fluid	ABC-S+ (PG)
Test # / Test Plan #	RUN 73 (P20A)
OAT	TARGET: -10°C ACTUAL: -18.2°C GOOD
Rate	IP=75 GOOD
Exposure Time	5 MINS BAD
Associated Fluid Only Case	RUN 76 (E25): 5.89%
Visual Contamination	START: 2.2/2.2/3.4 ROT: 1.2/2/2.5 OK
Lift Coefficient	6°: 1.45 8°: 1.635 GOOD
Lift Loss At 8°	5.01% GOOD
OVERALL STATUS (good, bad, or review)	GOOD

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing (Less than 5% loss accepatble)
***** 6° Cl should be >=1.44 } 5%
***** 8° Cl should be >=1.64 } 5%
***** 6° Cl should be >=1.40 } 8%
***** 8° Cl should be >=1.59 } 8%

Figure E23: Run #73

Objective	IP VALIDATION	
Fluid	LAUNCH (PG)	
Test # / Test Plan #	RUN 74 (P21A)	
OAT	TARGET: -10°C ACTUAL: -18.5°C GOOD	
Rate	IP=75 GOOD	
Exposure Time	5 MINS BAD	
Associated Fluid Only Case	RUN 70 (E23): 5.59 %	
Visual Contamination	START: 2.7/2.3/3.2 ROT: 1.5/2/2.8 BAD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.359 8°: 1.544 BAD	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } **5%** ***** 8° Cl should be >=1.64 ***** 6° Cl should be >=1.40 } **8%** ***** 8° Cl should be >=1.59
Lift Loss At 8°	10.30% BAD	
OVERALL STATUS (good, bad, or review)	BAD	

Figure E24: Run #74

Objective	IP VALIDATION	
Fluid	ABC-S+ (PG)	
Test # / Test Plan #	RUN 95 (P20)	
OAT	TARGET: -10°C ACTUAL: -8.1°C GOOD	
Rate	IP=75 GOOD	
Exposure Time	10 MINS GOOD	
Associated Fluid Only Case	RUN 64 (E22): 5.07%	
Visual Contamination	START: 2.2/2/2.8 ROT: 1/1.7/2 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.401 GOOD/ 8°: 1.602 REVIEW	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } **5%** ***** 8° Cl should be >=1.64 ***** 6° Cl should be >=1.40 } **8%** ***** 8° Cl should be >=1.59
Lift Loss At 8°	6.93% GOOD/ REVIEW	
OVERALL STATUS (good, bad, or review)	GOOD/REVIEW	

Figure E25: Run #95

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LIGHT ICE PELLETS MIXED WITH LIGHT FREEZING RAIN

Light Ice Pellets Mixed with Light Freezing Rain
Wind Tunnel Summary Packages
CM2169.002

	OAT -5°C and above	OAT less than -5°C to -10°C	OAT less than -10°C
Light Ice Pellets Mixed with Light Freezing Rain	(A) 25 minutes 0 (PG), 26 (EG), 26A (EG), 59 (PG)	(B) 10 minutes 63 (PG), 98 (EG)	

(A) EG: GOOD @ 25 mins
PG: OK @ 25 mins

(B) EG: GOOD
PG: OK - REVIEW

GOOD
GOOD / REVIEW
BAD / REVIEW
BAD

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Figure E26: Light Ice Pellets Mixed with Light Freezing Rain Allowance Table

Objective	IP VALIDATION	
Fluid	ABC-S+ (PG)	
Test # / Test Plan #	RUN 0 (P8)	
OAT	TARGET: -5°C ACTUAL: -6.1°C GOOD	
Rate	IP = 25 ZR = 25 GOOD	
Exposure Time	25 MINS GOOD	
Associated Fluid Only Case	RUN 1 (P8B): 5.01%	
Visual Contamination	START: 2/2/4 ROT: 1/1/3.7 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.423 GOOD/ 8°: 1.609 REVIEW	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } 5% ***** 8° Cl should be >=1.64 ***** 6° Cl should be >=1.40 } 8% ***** 8° Cl should be >=1.59
Lift Loss At 8°	6.52% GOOD/ REVIEW	
OVERALL STATUS (good, bad, or review)	GOOD/REVIEW	

Figure E27: Run #0

Objective	IP VALIDATION	
Fluid	EG106 (EG)	
Test # / Test Plan #	RUN 26 (P7)	
OAT	TARGET: -5 GOOD/ ACTUAL: -1.9 REVIEW	
Rate	IP = 25 ZR = 25 GOOD	
Exposure Time	25 MINS GOOD	
Associated Fluid Only Case	RUN 55 (E20): 1.88%	
Visual Contamination	START: 2.2/1.7/4.7 ROT: 1/1/4 BAD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.441 GOOD 8°: 1.639	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } 5% ***** 8° Cl should be >=1.64 ***** 6° Cl should be >=1.40 } 8% ***** 8° Cl should be >=1.59
Lift Loss At 8°	4.78% GOOD	
OVERALL STATUS (good, bad, or review)	GOOD	

Figure E28: Run #26

Objective	IP VALIDATION
Fluid	EG106 (EG)
Test # / Test Plan #	RUN 26A (P7)
OAT	TARGET: -5°C ACTUAL: -3.3°C GOOD
Rate	IP = 25 ZR = 25 GOOD
Exposure Time	25 MINS GOOD
Associated Fluid Only Case	RUN 25(E9): 1.99%
Visual Contamination	START: 1.8/2/1.9 ROT: 1/1/1 GOOD
Lift Coefficient	6°: 1.499 8°: 1.697 GOOD
Lift Loss At 8°	1.41 % GOOD
OVERALL STATUS (good, bad, or review)	GOOD

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing
(Less than 5% loss accepatble)
***** 6° Cl should be >=1.44 } **5%**
***** 8° Cl should be >=1.64 } **5%**
***** 6° Cl should be >=1.40 } **8%**
***** 8° Cl should be >=1.59 } **8%**

Figure E29: Run #26A

Objective	IP VALIDATION
Fluid	LAUNCH (PG)
Test # / Test Plan #	RUN 59 (P9)
OAT	TARGET: -5°C ACTUAL: -3.3°C GOOD
Rate	IP = 25 ZR = 25 GOOD
Exposure Time	25 MINS GOOD
Associated Fluid Only Case	RUN 60(E21): 4.61%
Visual Contamination	START: 2/2/2.2 ROT: 1/1.3/1.5 GOOD
Lift Coefficient	6°: 1.449 8°: 1.651 GOOD
Lift Loss At 8°	4.08 % GOOD
OVERALL STATUS (good, bad, or review)	GOOD

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing
(Less than 5% loss accepatble)
***** 6° Cl should be >=1.44 } **5%**
***** 8° Cl should be >=1.64 } **5%**
***** 6° Cl should be >=1.40 } **8%**
***** 8° Cl should be >=1.59 } **8%**

Figure E30: Run #59

Objective	IP VALIDATION
Fluid	ABC-S + (PG)
Test # / Test Plan #	RUN 63(P23)
OAT	TARGET: -10°C ACTUAL: -12.3°C GOOD
Rate	IP= 25 ZR: 25 GOOD
Exposure Time	10 MINS GOOD
Associated Fluid Only Case	RUN 64(E22): 5.07%
Visual Contamination	START: 2.3/2.3/3.2 ROT: 1.2/1.2/2.3 OK
Lift Coefficient	6°: 1.363 GOOD/ 8°: 1.59 REVIEW
Lift Loss At 8°	7.69% GOOD/ REVIEW
OVERALL STATUS (good, bad, or review)	GOOD/REVIEW

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing
(Less than 5% loss accepatble)
***** 6° Cl should be >=1.44
***** 8° Cl should be >=1.64 } **5%**
***** 6° Cl should be >=1.40
***** 8° Cl should be >=1.59 } **8%**

Figure E31: Run #63

Objective	IP VALIDATION
Fluid	EG106 (EG)
Test # / Test Plan #	RUN 98(P22)
OAT	TARGET: -10°C ACTUAL: -6.7°C GOOD
Rate	IP= 25 ZR: 25 GOOD
Exposure Time	10 MINS GOOD
Associated Fluid Only Case	RUN 100(E26): 2.28%
Visual Contamination	START: 2/2/2.5 ROT: 1/1/1.3 GOOD
Lift Coefficient	6°: 1.501 8°: 1.691 GOOD
Lift Loss At 8°	1.76% GOOD
OVERALL STATUS (good, bad, or review)	GOOD

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing
(Less than 5% loss accepatble)
***** 6° Cl should be >=1.44
***** 8° Cl should be >=1.64 } **5%**
***** 6° Cl should be >=1.40
***** 8° Cl should be >=1.59 } **8%**

Figure E32: Run #93

LIGHT ICE PELLETS MIXED WITH MODERATE RAIN

Light Ice Pellets Mixed with Moderate Rain

Wind Tunnel Summary Packages

CM2169.002

	OAT -5°C and above	OAT less than -5°C to -10°C	OAT less than -10°C
Light Ice Pellets Mixed with Moderate Rain	(A) 25 minutes 56 EG, 56A EG		
	40mins 20 PG, 44 EG		

(A) EG: Borderline @ 25 mins
Colder temp. data needed

PG: GOOD @ 25 mins. More data needed

GOOD

GOOD/REVIEW

BAD/REVIEW

BAD

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Figure E33: Light Ice Pellets Mixed with Moderate Rain Allowance Table

Objective	IP EXPANSION
Fluid	ABC-S+ (PG)
Test # / Test Plan #	RUN 20 (P41)
OAT	TARGET: 0°C BAD ACTUAL: +2.9°C
Rate	IP=25 R=75 GOOD
Exposure Time	40 MINS GOOD
Associated Fluid Only Case	RUN 53 (E18): 39.1%
Visual Contamination	START: 1/1/1 GOOD ROT: 1/1/1
Lift Coefficient	DATA LOSS
Lift Loss At 8°	DATA LOSS
OVERALL STATUS (good, bad, or review)	GOOD / REVIEW

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing (Less than 5% loss accepatble)
***** 6° Cl should be >=1.44
***** 8° Cl should be >=1.64 } 5%
***** 6° Cl should be >=1.40
***** 8° Cl should be >=1.59 } 8%

Figure E34: Run #20

Objective	IP EXPANSION
Fluid	EG106 (EG)
Test # / Test Plan #	RUN 44 (P40)
OAT	TARGET: 0°C GOOD ACTUAL: -0.8°C
Rate	IP=25 R=75 GOOD
Exposure Time	40 MINS GOOD
Associated Fluid Only Case	RUN 55 (E20): 18.8%
Visual Contamination	START: 5/4.5/5 ROT: 5/5/5 BAD
Lift Coefficient	6°: 1.079 8°: 1.231 BAD
Lift Loss At 8°	28.48 % BAD
OVERALL STATUS (good, bad, or review)	BAD

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing (Less than 5% loss accepatble)
***** 6° Cl should be >=1.44
***** 8° Cl should be >=1.64 } 5%
***** 6° Cl should be >=1.40
***** 8° Cl should be >=1.59 } 8%

Figure E35: Run #44

Objective	IP VALIDATION/ EXPANSION
Fluid	EG106 (EG)
Test # / Test Plan #	RUN 56 (PH01A)
OAT	TARGET: 0°C ACTUAL: -1.1°C GOOD
Rate	IP= 25 R= 75 GOOD
Exposure Time	25 MINS GOOD
Associated Fluid Only Case	RUN 55 (E20): 1.88%
Visual Contamination	START: 1.8/2/4.7 ROT: 1/1/5 BAD
Lift Coefficient	6°: 1.478 8°: 1.666 GOOD
Lift Loss At 8°	3.21% GOOD
OVERALL STATUS (good, bad, or review)	GOOD/REVIEW

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing
(Less than 5% loss accepatble)
***** 6° Cl should be >=1.44 } **5%**
***** 8° Cl should be >=1.64
***** 6° Cl should be >=1.40 } **8%**
***** 8° Cl should be >=1.59

Figure E36: Run #56

Objective	IP EXPANSION
Fluid	EG106 (EG)
Test # / Test Plan #	RUN 56A (PH0A)
OAT	TARGET: 0°C ACTUAL: -1.4°C GOOD
Rate	IP= 25 R= 75 GOOD
Exposure Time	25 MINS GOOD
Associated Fluid Only Case	RUN 55 (E20): 1.88%
Visual Contamination	START: 1.8/2.2/3 ROT: 1/1/4.3 GOOD
Lift Coefficient	6°: 1.473 8°: 1.663 GOOD
Lift Loss At 8°	3.39% GOOD
OVERALL STATUS (good, bad, or review)	GOOD/REVIEW *

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing
(Less than 5% loss accepatble)
***** 6° Cl should be >=1.44 } **5%**
***** 8° Cl should be >=1.64
***** 6° Cl should be >=1.40 } **8%**
***** 8° Cl should be >=1.59

Figure E37: Run #56A

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LIGHT ICE PELLETS MIXED WITH LIGHT SNOW

Light Ice Pellets Mixed with Light Snow
Wind Tunnel Summary Packages
CM2169.002

	OAT -5°C and above	OAT less than -5°C to -10°C	OAT less than -10°C
Light Ice Pellets Mixed with Light Snow	Ⓐ 25 minutes 5 PG	Ⓑ 15 minutes 94 PG	Ⓒ 10 mins 77 PG, 79 EG
	40 mins 11 PG, 23 EG, 57 PG, 57A PG		5 mins 78 PG

Ⓐ EG: GOOD @ 40 mins
PG: GOOD @ 40 mins (higher if flap up)

Ⓑ EG: No tests in cell, remain @ 15 mins. Data needed
PG: GOOD @ 15 mins

Ⓒ EG: GOOD @ 10 mins (could expand)
PG: BAD. 0 mins

GOOD
GOOD/REVIEW
BAD/REVIEW
BAD

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Figure E38: Light Ice Pellets Mixed with Light Snow Allowance Table

Objective	IP VALIDATION	
Fluid	ABC-S+ (PG)	
Test # / Test Plan #	RUN 5 (P11)	
OAT	TARGET: -5°C ACTUAL: -4.8°C GOOD	
Rate	IP= 25 SN: 10 GOOD	
Exposure Time	25 MINS GOOD	
Associated Fluid Only Case	RUN 4 (E4): 4.03%	
Visual Contamination	START: 2/2/3 ROT: 1/1.5/1.8 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.448 8°: 1.658 GOOD	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } 5% ***** 8° Cl should be >=1.64 } 5% ***** 6° Cl should be >=1.40 } 8% ***** 8° Cl should be >=1.59 } 8%
Lift Loss At 8°	3.68% GOOD	
OVERALL STATUS (good, bad, or review)	GOOD	

Figure E39: Run #5

Objective	IP EXPANSION	
Fluid	ABC-S+ (PG)	
Test # / Test Plan #	RUN 11 (P35)	
OAT	TARGET: -5°C ACTUAL: -5.9°C GOOD	
Rate	IP=25 SN: 10 GOOD	
Exposure Time	40 MINS GOOD	
Associated Fluid Only Case	RUN 1 (P8B): 5.01%	
Visual Contamination	START: 3/2.3/4 ROT: 1/1.8/2.5 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.459 8°: 1.646 GOOD	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } 5% ***** 8° Cl should be >=1.64 } 5% ***** 6° Cl should be >=1.40 } 8% ***** 8° Cl should be >=1.59 } 8%
Lift Loss At 8°	4.37% GOOD	
OVERALL STATUS (good, bad, or review)	GOOD	

Figure E40: Run #11

Objective	IP EXPANSION	
Fluid	EG106 (EG)	
Test # / Test Plan #	RUN 23 (P34)	
OAT	TARGET: -5°C ACTUAL: -3.2°C GOOD	
Rate	IP = 25 SN = 10 GOOD	
Exposure Time	40 MINS GOOD	
Associated Fluid Only Case	RUN 25 (E9): 1.99%	
Visual Contamination	START: 2.3/2.2/4 ROT: 1/1.2/1.5 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.491 GOOD 8°: 1.702	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } **5%** ***** 8° Cl should be >=1.64 ***** 6° Cl should be >=1.40 } **8%** ***** 8° Cl should be >=1.59
Lift Loss At 8°	1.12 % GOOD	
OVERALL STATUS (good, bad, or review)	GOOD	

Figure E41: Run #23

Objective	IP EXPANSION	
Fluid	LAUNCH (PG)	
Test # / Test Plan #	RUN 57 (P36)	
OAT	TARGET: -5°C ACTUAL: -3.6°C GOOD	
Rate	IP = 25 SN = 10 GOOD	
Exposure Time	40 MINS GOOD	
Associated Fluid Only Case	RUN 29 (E11): 4.96%	
Visual Contamination	START: 2.7/2.6/4 ROT: 1/1.7/2.8 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.43 GOOD 8°: 1.64	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } **5%** ***** 8° Cl should be >=1.64 ***** 6° Cl should be >=1.40 } **8%** ***** 8° Cl should be >=1.59
Lift Loss At 8°	4.72 % GOOD	
OVERALL STATUS (good, bad, or review)	GOOD	

Figure E42: Run #57

Objective	IP EXPANSION	
Fluid	LAUNCH (PG)	
Test # / Test Plan #	RUN 57A (P36)	
OAT	TARGET: -5°C ACTUAL: -4.2°C GOOD	
Rate	IP= 25 SN = 10 GOOD	
Exposure Time	40 MINS GOOD	
Associated Fluid Only Case	RUN 29 (E11): 4.96%	
Visual Contamination	START: 2.6/2.6/3 ROT: 1/1.3/1.7 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.49 8°: 1.67 GOOD	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } 5% ***** 8° Cl should be >=1.64 } 5% ***** 6° Cl should be >=1.40 } 8% ***** 8° Cl should be >=1.59 } 8%
Lift Loss At 8°	2.92% GOOD	
OVERALL STATUS (good, bad, or review)	GOOD	

Figure E43: Run #57A

Objective	IP EXPANSION	
Fluid	ABC-S+ (PG)	
Test # / Test Plan #	RUN 77 (P50)	
OAT	TARGET: -25°C ACTUAL: -14.1°C BAD	
Rate	IP= 25 SN = 10 GOOD	
Exposure Time	10 MINS GOOD	
Associated Fluid Only Case	RUN 64 (E22): 5.07%	
Visual Contamination	START: 2.8/2.7/3.7 ROT: 1.7/2/2.8 BAD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.338 BAD/ 8°: 1.551 REVIEW	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } 5% ***** 8° Cl should be >=1.64 } 5% ***** 6° Cl should be >=1.40 } 8% ***** 8° Cl should be >=1.59 } 8%
Lift Loss At 8°	9.89 % BAD	
OVERALL STATUS (good, bad, or review)	BAD	

Figure E44: Run #77

Objective	IP EXPANSION
Fluid	ABC-S + (PG)
Test # / Test Plan #	RUN 78(P50A)
OAT	TARGET: -25°C ACTUAL: -16°C REVIEW
Rate	IP: 25 SN: 10 GOOD
Exposure Time	5 MINS GOOD
Associated Fluid Only Case	RUN 76(E25): 5.89%
Visual Contamination	START: 2.3/2.2/3 ROT: 1.4/2/2.7 BAD
Lift Coefficient	6°: 1.381 BAD/ 8°: 1.573 REVIEW
Lift Loss At 8°	8.62% BAD/ REVIEW
OVERALL STATUS (good, bad, or review)	BAD/REVIEW

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing
(Less than 5% loss accepatble)
***** 6° Cl should be >=1.44
***** 8° Cl should be >=1.64 } 5%
***** 6° Cl should be >=1.40
***** 8° Cl should be >=1.59 } 8%

Figure E45: Run #78

Objective	IP EXPANSION
Fluid	EG106 (EG)
Test # / Test Plan #	RUN 79 (P49)
OAT	TARGET: -25°C ACTUAL: -14.8°C REVIEW
Rate	IP: 25 SN: 10 GOOD
Exposure Time	10 MINS GOOD
Associated Fluid Only Case	RUN 75(E24): 4.08%
Visual Contamination	START: 2.2/2/2.5 ROT: 1/1.5/2 GOOD
Lift Coefficient	6°: 1.46 GOOD 8°: 1.66
Lift Loss At 8°	3.56% GOOD
OVERALL STATUS (good, bad, or review)	GOOD

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing
(Less than 5% loss accepatble)
***** 6° Cl should be >=1.44
***** 8° Cl should be >=1.64 } 5%
***** 6° Cl should be >=1.40
***** 8° Cl should be >=1.59 } 8%

Figure E46: Run #79

Objective	IP VALIDATION	
Fluid	ABC-S+ (PG)	
Test # / Test Plan #	RUN 94 (P26)	
OAT	TARGET: -10°C ACTUAL: -6.3°C GOOD	
Rate	IP = 25 SN = 10 GOOD	
Exposure Time	15 MINS GOOD	
Associated Fluid Only Case	RUN 1 (P8B): 5.01%	
Visual Contamination	START: 2.5/2/2.8 ROT: 1/1.8/2 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.420 GOOD/ 8°: 1.626 REVIEW	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } 5% ***** 8° Cl should be >=1.64 } 5% ***** 6° Cl should be >=1.40 } 8% ***** 8° Cl should be >=1.59 } 8%
Lift Loss At 8°	5.54% GOOD/ REVIEW	
OVERALL STATUS (good, bad, or review)	GOOD / REVIEW	

Figure E47: Run #94

LIGHT ICE PELLETS MIXED WITH MODERATE SNOW

Light Ice Pellets Mixed with Moderate Snow
Wind Tunnel Summary Packages
CM2169.002

	OAT -5°C and above	OAT less than -5°C to -10°C	OAT less than -10°C
Light Ice Pellets Mixed with Moderate Snow	(A) 10 minutes 15 PG	(B) 10 mins 97 PG	(C) 5 mins 81 EG, 82 PG
	5 mins 16 PG		
	15 mins 14 PG		
	20mins 13 PG, 24 EG, 58 PG		

(A) EG: GOOD @ 20mins. Could be higher
PG: GOOD @ 20mins. Review

(B) EG: GOOD @ 5 mins. Data Needed
PG: GOOD/REVIEW. 0 mins

(C) EG: GOOD @ 5 mins. Data needed
PG: REVIEW. 0 mins

GOOD
GOOD/REVIEW
BAD/REVIEW
BAD

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Figure E48: Light Ice Pellets Mixed with Moderate Snow Allowance Table

Objective	IP EXPANSION
Fluid	ABC-S+ (PG)
Test # / Test Plan #	RUN 13 (P38)
OAT	TARGET: -5°C ACTUAL: -4.6°C GOOD
Rate	IP= 25 SN: 25 GOOD
Exposure Time	20 MIN GOOD
Associated Fluid Only Case	RUN 17(E8): 4.96%
Visual Contamination	START: 3/2/3.5 ROT: 1/1.8/2.7 GOOD
Lift Coefficient	6°: 1.422 GOOD/ 8°: 1.617 REVIEW
Lift Loss At 8°	6.06% GOOD/ REVIEW
OVERALL STATUS (good, bad, or review)	GOOD/REVIEW

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing
(Less than 5% loss accepatble)
***** 6° Cl should be >=1.44 } 5%
***** 8° Cl should be >=1.64 } 5%
***** 6° Cl should be >=1.40 } 8%
***** 8° Cl should be >=1.59 } 8%

Figure E49: Run #13

Objective	IP EXPANSION
Fluid	ABC-S + (PG)
Test # / Test Plan #	RUN 14 (P38)
OAT	TARGET: -5°C ACTUAL: -4.4°C GOOD
Rate	IP= 25 SN= 25 GOOD
Exposure Time	15 MIN GOOD
Associated Fluid Only Case	RUN 17(E8): 4.96%
Visual Contamination	START: 2.2/2/2.8 ROT: 1/1.5/1.5 GOOD
Lift Coefficient	6°: 1.414 GOOD/ 8°: 1.633 REVIEW
Lift Loss At 8°	5.54% GOOD/ REVIEW
OVERALL STATUS (good, bad, or review)	GOOD/REVIEW

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing
(Less than 5% loss accepatble)
***** 6° Cl should be >=1.44 } 5%
***** 8° Cl should be >=1.64 } 5%
***** 6° Cl should be >=1.40 } 8%
***** 8° Cl should be >=1.59 } 8%

Figure E50: Run #14

Objective	IP VALIDATION	
Fluid	ABC-S + (PG)	
Test # / Test Plan #	RUN 15 (P14)	
OAT	TARGET: -5°C ACTUAL: -4.3°C GOOD	
Rate	IP= 25 SN: 25 GOOD	
Exposure Time	10 MIN GOOD	
Associated Fluid Only Case	RUN 17 (E8): 4.96%	
Visual Contamination	START: 1.8/2/2.7 ROT: 1/1.3/1.7 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.433 GOOD/ 8°: 1.633 REVIEW	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 ***** 8° Cl should be >=1.64 } 5% ***** 6° Cl should be >=1.40 ***** 8° Cl should be >=1.59 } 8%
Lift Loss At 8°	5.13% GOOD/ REVIEW	
OVERALL STATUS (good, bad, or review)	GOOD/REVIEW	

Figure E51: Run #15

Objective	IP VALIDATION	
Fluid	ABC-S + (PG)	
Test # / Test Plan #	RUN 16 (P14)	
OAT	TARGET: -5°C ACTUAL: -4.2°C GOOD	
Rate	IP=25 SN = 25 GOOD	
Exposure Time	5 MIN BAD	
Associated Fluid Only Case	RUN 17 (E8): 4.96%	
Visual Contamination	START: 1.4/1.7/1.8 ROT: 1/1/1.3 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.414 GOOD/ 8°: 1.622 REVIEW	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 ***** 8° Cl should be >=1.64 } 5% ***** 6° Cl should be >=1.40 ***** 8° Cl should be >=1.59 } 8%
Lift Loss At 8°	5.77% GOOD/ REVIEW	
OVERALL STATUS (good, bad, or review)	GOOD/REVIEW	

Figure E52: Run #16

Objective	IP EXPANSION	
Fluid	EG106 (EG)	
Test # / Test Plan #	RUN 24 (P37)	
OAT	TARGET: -5°C ACTUAL: -3.7°C GOOD	
Rate	IP = 25 SN = 25 GOOD	
Exposure Time	20 MIN GOOD	
Associated Fluid Only Case	RUN 25 (E9): 1.99%	
Visual Contamination	START: 2.5/1.8/4 ROT: 1/1.2/1 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.517 8°: 1.699 GOOD	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } 5% ***** 8° Cl should be >=1.64 } 5% ***** 6° Cl should be >=1.40 } 8% ***** 8° Cl should be >=1.59 } 8%
Lift Loss At 8°	1.30% GOOD	
OVERALL STATUS (good, bad, or review)	GOOD	

Figure E53: Run #24

Objective	IP EXPANSION	
Fluid	LAUNCH (PG)	
Test # / Test Plan #	RUN 58 (P39)	
OAT	TARGET: -5°C ACTUAL: -3.1°C GOOD	
Rate	IP: 25 SN: 25 GOOD	
Exposure Time	20 MIN GOOD	
Associated Fluid Only Case	RUN 60 (E21): 4.61%	
Visual Contamination	START: 2.8/2.6/3 ROT: 1/1.5/2 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.439 8°: 1.638 GOOD	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } 5% ***** 8° Cl should be >=1.64 } 5% ***** 6° Cl should be >=1.40 } 8% ***** 8° Cl should be >=1.59 } 8%
Lift Loss At 8°	4.84% GOOD	
OVERALL STATUS (good, bad, or review)	GOOD	

Figure E54: Run #58

Objective	IP EXPANSION	
Fluid	EG106 (EG)	
Test # / Test Plan #	RUN 81 (P52)	
OAT	TARGET: -25°C ACTUAL: -17.3°C OK	
Rate	IP = 25 SN = 25 GOOD	
Exposure Time	5 MIN GOOD	
Associated Fluid Only Case	RUN 75(E24): 4.08%	
Visual Contamination	START: 1.8/2/2.3 ROT: 1/1.5/2 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.445 8°: 1.656 GOOD	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } **5%** ***** 8° Cl should be >=1.64 ***** 6° Cl should be >=1.40 } **8%** ***** 8° Cl should be >=1.59
Lift Loss At 8°	3.79% GOOD	
OVERALL STATUS (good, bad, or review)	GOOD	

Figure E55: Run #81

Objective	IP EXPANSION	
Fluid	ABC-S+ (PG)	
Test # / Test Plan #	RUN 82 (P53)	
OAT	TARGET: -25°C ACTUAL: -15.8°C BAD	
Rate	IP = 25 SN = 25 GOOD	
Exposure Time	5 MIN GOOD	
Associated Fluid Only Case	RUN 76(E25): 5.89%	
Visual Contamination	START: 2.5/2.2/3.2 ROT: 1.5/1.5/1.8 BAD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.354 8°: 1.563 BAD	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } **5%** ***** 8° Cl should be >=1.64 ***** 6° Cl should be >=1.40 } **8%** ***** 8° Cl should be >=1.59
Lift Loss At 8°	9.20% BAD	
OVERALL STATUS (good, bad, or review)	BAD/REVIEW	

Figure E56: Run #82

Objective	1P EXPANSION	
Fluid	ABC-S + (PG)	
Test # / Test Plan #	RUN 97 (P47)	
OAT	TARGET: -10°C ACTUAL: -8.3°C GOOD	
Rate	1P = 25 SN = 25 GOOD	
Exposure Time	10 MIN GOOD	
Associated Fluid Only Case	RUN 64 (E22): 5.07%	
Visual Contamination	START: 2.9/2.3/3 ROT: 1.3/1.8/2.5 BAD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.402 GOOD/ 8°: 1.59 REVIEW	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } 5% ***** 8° Cl should be >=1.64 } 5% ***** 6° Cl should be >=1.40 } 8% ***** 8° Cl should be >=1.59 } 8%
Lift Loss At 8°	7.63% GOOD/ REVIEW	
OVERALL STATUS (good, bad, or review)	GOOD / REVIEW	

Figure E57: Run #97

FLAP RETRACTED (UP) VERSON FLAP EXTENDED (DOWN)

Objective	IP VALIDATION
Fluid	EG106 (EG)
Test # / Test Plan #	RUN 26 (P7)
OAT	TARGET: -5 GOOD/ ACTUAL: -1.9 REVIEW
Rate	IP= 25 GOOD ZR: 25
Exposure Time	25 MINS GOOD
Associated Fluid Only Case	RUN 55 (E20): 1.88%
Visual Contamination	START: 2.2/1.7/4.7 ROT: 1/1/4 BAD
Lift Coefficient	6°: 1.441 GOOD 8°: 1.639
Lift Loss At 8°	4.78 % GOOD
OVERALL STATUS (good, bad, or review)	GOOD

****** Not Based on photos
****** Visual at Start should be <=3, Flap<=4
****** Visual at Rot LE should be 1

****** Compared to Dry Wing
(Less than 5% loss accepatble)
****** 6° Cl should be >=1.44
****** 8° Cl should be >=1.64 } 5%
****** 6° Cl should be >=1.40
****** 8° Cl should be >=1.59 } 8%

Figure E58: Run #26

Objective	IP VALIDATION
Fluid	EG106 (EG)
Test # / Test Plan #	RUN 26A (P7)
OAT	TARGET: -5°C GOOD ACTUAL: -3.3°C
Rate	IP= 25 GOOD ZR: 25
Exposure Time	25 MINS GOOD
Associated Fluid Only Case	RUN 25 (E9): 1.99%
Visual Contamination	START: 1.8/2/1.9 ROT: 1/1/1 GOOD
Lift Coefficient	6°: 1.499 GOOD 8°: 1.697
Lift Loss At 8°	1.41 % GOOD
OVERALL STATUS (good, bad, or review)	GOOD

****** Not Based on photos
****** Visual at Start should be <=3, Flap<=4
****** Visual at Rot LE should be 1

****** Compared to Dry Wing
(Less than 5% loss accepatble)
****** 6° Cl should be >=1.44
****** 8° Cl should be >=1.64 } 5%
****** 6° Cl should be >=1.40
****** 8° Cl should be >=1.59 } 8%

Figure E59: Run #26A

Objective	IP VALIDATION
Fluid	LAUNCH (PG)
Test # / Test Plan #	RUN 28(P3)
OAT	TARGET: -5°C ACTUAL: -4.2°C GOOD
Rate	IP= 25 GOOD
Exposure Time	50 MINS GOOD
Associated Fluid Only Case	RUN 29 (E11): 4.96%
Visual Contamination	START: 2/2/3.7 ROT: 1/1.7/2 GOOD
Lift Coefficient	6°: 1.449 8°: 1.648 GOOD
Lift Loss At 8°	4.26% GOOD
OVERALL STATUS (good, bad, or review)	GOOD

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing
(Less than 5% loss accepatble)
***** 6° Cl should be >=1.44 } **5%**
***** 8° Cl should be >=1.64
***** 6° Cl should be >=1.40 } **8%**
***** 8° Cl should be >=1.59

Figure E60: Run #28

Objective	IP VALIDATION
Fluid	LAUNCH (PG)
Test # / Test Plan #	RUN 28A(P3)
OAT	TARGET: -5°C ACTUAL: -5.5°C GOOD
Rate	IP= 25 GOOD
Exposure Time	50 MINS GOOD
Associated Fluid Only Case	RUN 29(E11): 4.96%
Visual Contamination	START. 2/2/2.7 ACTUAL: 1/1.5/2 GOOD
Lift Coefficient	6°: 1.467 8°: 1.655 GOOD
Lift Loss At 8°	3.85% GOOD
OVERALL STATUS (good, bad, or review)	GOOD

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing
(Less than 5% loss accepatble)
***** 6° Cl should be >=1.44 } **5%**
***** 8° Cl should be >=1.64
***** 6° Cl should be >=1.40 } **8%**
***** 8° Cl should be >=1.59

Figure E61: Run #28A

Objective	IP VALIDATION/ EXPANSION	
Fluid	EG106 (EG)	
Test # / Test Plan #	RUN 56 (PH01A)	
OAT	TARGET: 0°C ACTUAL: -1.1°C GOOD	
Rate	IP=25 R=75 GOOD	
Exposure Time	25 MINS GOOD	
Associated Fluid Only Case	RUN 55 (E20): 1.88%	
Visual Contamination	START: 1.8/2/4.7 ROT: 1/1/5 BAD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.478 8°: 1.666 GOOD	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } 5% ***** 8° Cl should be >=1.64 ***** 6° Cl should be >=1.40 } 8% ***** 8° Cl should be >=1.59
Lift Loss At 8°	3.21% GOOD	
OVERALL STATUS (good, bad, or review)	GOOD/REVIEW	

Figure E62: Run #56

Objective	IP EXPANSION	
Fluid	EG106 (EG)	
Test # / Test Plan #	RUN 56A (PH01A)	
OAT	TARGET: 0°C ACTUAL: -1.4°C GOOD	
Rate	IP=25 R=75 GOOD	
Exposure Time	25 MINS GOOD	
Associated Fluid Only Case	RUN 55 (E20): 1.88%	
Visual Contamination	START: 1.8/2.2/3 ROT: 1/1/4.3 GOOD	***** Not Based on photos ***** Visual at Start should be <=3, Flap<=4 ***** Visual at Rot LE should be 1
Lift Coefficient	6°: 1.473 8°: 1.663 GOOD	***** Compared to Dry Wing (Less than 5% loss accepatble) ***** 6° Cl should be >=1.44 } 5% ***** 8° Cl should be >=1.64 ***** 6° Cl should be >=1.40 } 8% ***** 8° Cl should be >=1.59
Lift Loss At 8°	3.39% GOOD	
OVERALL STATUS (good, bad, or review)	GOOD/REVIEW *	

Figure E63: Run #56A

Objective	IP EXPANSION
Fluid	LAUNCH (PG)
Test # / Test Plan #	RUN 57 (P36)
OAT	TARGET: -5°C ACTUAL: -3.6°C GOOD
Rate	IP=25 SN=10 GOOD
Exposure Time	40 MINS GOOD
Associated Fluid Only Case	RUN 29 (E11): 4.96%
Visual Contamination	START: 2/7/2.6/4 ROT: 1/1.7/2.8 GOOD
Lift Coefficient	6°: 1.43 8°: 1.64 GOOD
Lift Loss At 8°	4.72% GOOD
OVERALL STATUS (good, bad, or review)	GOOD

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing
(Less than 5% loss accepatble)
***** 6° Cl should be >=1.44
***** 8° Cl should be >=1.64 } 5%
***** 6° Cl should be >=1.40
***** 8° Cl should be >=1.59 } 8%

Figure E64: Run #57

Objective	IP EXPANSION
Fluid	LAUNCH (PG)
Test # / Test Plan #	RUN 57A (P36)
OAT	TARGET: -5°C ACTUAL: -4.2°C GOOD
Rate	IP=25 SN=10 GOOD
Exposure Time	40 MINS GOOD
Associated Fluid Only Case	RUN 29 (E11): 4.96%
Visual Contamination	START: 2.6/2.6/3 ROT: 1/1.3/1.7 GOOD
Lift Coefficient	6°: 1.49 8°: 1.67 GOOD
Lift Loss At 8°	2.92% GOOD
OVERALL STATUS (good, bad, or review)	GOOD

***** Not Based on photos
***** Visual at Start should be <=3, Flap<=4
***** Visual at Rot LE should be 1

***** Compared to Dry Wing
(Less than 5% loss accepatble)
***** 6° Cl should be >=1.44
***** 8° Cl should be >=1.64 } 5%
***** 6° Cl should be >=1.40
***** 8° Cl should be >=1.59 } 8%

Figure E65: Run #57A

APPENDIX F

ADDITIONAL NOTES AND OBSERVATIONS AT NRC WIND TUNNEL

Form 5

CAMERA LOCATIONS FORM

(Fill in only once unless camera locations are changed)

Date: February 2, 2010

Time: 23:30

Run Numbers: ______

Camera ~~1~~ 2: Wide Angle ☑ 18-50 Zoom ☐

Distance from window edge (C1): 50.5" (5.25')

Height from window base: 13"

window to lens: 2.75"

Flash ~~1~~ 2: Distance from window edge (F1): 33"

45° angle Height from window base: 29"

Actual window to Mount 15.75"

Camera ~~2~~ 1: Sony Prime Wide Angle ☐ Zoom ☐

Distance from window edge (C2): 3"

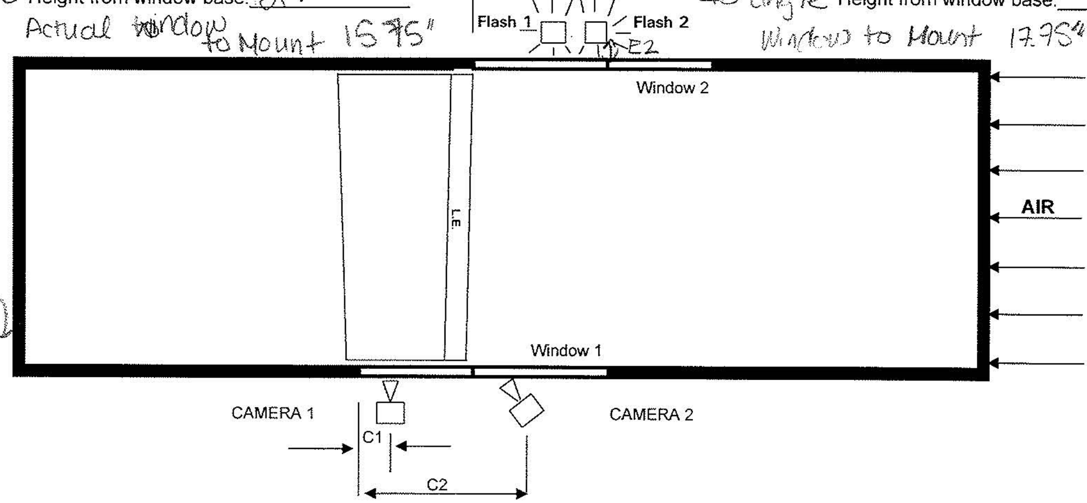
Height from window base: 10"

window to lens 6.75"

Flash ~~2~~ 1: Distance from window edge (F2): 29" *

45° angle Height from window base: 39°

Window to Mount 17.75"



* 99.5" from edge of window FLASH 2

OBSERVER: Ben

ASSISTED BY: VICTORIA

Observations: ______

M:/Groups/PM2020(TC-Deicing 05-06)/Procedures/Data Forms/WT VZ docs

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