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TESTING AND EVALUATION OF MIXED PHASE ICING CONDITIONS: WINTER 2024-25



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**Transport Canada
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Innovation Centre**

In cooperation with:

**Federal Aviation Administration
William J. Hughes Technical Center for
Advanced Aerospace**

**Transport Canada
Civil Aviation**

**Federal Aviation Administration
Flight Standards – Air Carrier Operations**



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Prepared by:

Benjamin Bernier

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PREFACE

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

- To develop holdover time data for all new de/anti-icing fluids;
- To conduct testing to determine holdover times for Type II, III, and IV fluids in snow at temperatures below -14°C ;
- To evaluate and develop the use of artificial snow machines for holdover time development;
- To conduct wind tunnel testing with a thin high performance wing model to support the development of guidance material for operating in ice pellet conditions;
- To conduct comparative endurance time testing and evaluate endurance times in several mixed conditions;
- To conduct general and exploratory de/anti-icing research;
- To conduct analysis to support harmonization of the Transport Canada and the Federal Aviation Administration visibility table guidance;
- To finalize the publication and delivery of current and historical reports;
- To update the regression information report to reflect changes made to the holdover time guidelines; and
- To update the holdover time guidance materials for annual publication by Transport Canada and the Federal Aviation Administration.

The research activities of the program conducted on behalf of Transport Canada during the winter of 2024-25 are documented in five reports. The titles of the reports are as follows:

- TP 15692E Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2024-25 Winter;
- TP 15693E Regression Coefficients and Equations Used to Develop the Winter 2025-26 Aircraft Ground Deicing Holdover Time Tables;
- TP 15684E Aircraft Ground Icing General Research Activities During the 2024-25 Winter;
- TP 15685E Wind Tunnel Trials to Support Further Development of Ice Pellet Allowance Times: Winter 2024-25; and
- TP 15686E Testing and Evaluation of Mixed Phase Icing Conditions: Winter 2024-25.

In addition, the following interim report is being prepared:

- *Artificial Snow Research Activities for the 2024-25 Winter.*

This report, TP 15686E, has the following objective:

- To conduct comparative endurance time testing and evaluate endurance times in different mixed phase icing conditions.

This objective was met by conducting endurance time tests with fluids in simulated mixed icing conditions at the National Research Council Canada Climatic Engineering Facility in Ottawa.

PROGRAM ACKNOWLEDGEMENTS

This multi-year research program has been funded by the Transport Canada Programs Group Innovation Centre, with support from the Federal Aviation Administration William J. Hughes Technical Center for Advanced Aerospace, Transport Canada Civil Aviation, and Federal Aviation Administration Flight Standards – Air Carrier Operations. This program could not have been accomplished without the participation of many organizations. APS Aviation Inc. would therefore like to thank Transport Canada, the Federal Aviation Administration, National Research Council Canada, and supporting members of the SAE International G-12 Aircraft Ground Deicing Committees.

APS Aviation Inc. would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data, completion of data analysis, and preparation of reports. This includes the following people: Brandon Auclair, Steven D. Baker, David Beals, Benjamin Bernier, Chloë Bernier, Megane Brien, Sarah Chadzak, Kasandra Cook, Devin Costain, John D’Avirro, Peter Dawson, Sean Devine, Akvile Gigaite, Tyler Groleau, Cassidy Kinderman-McCormick, Kyra Kinderman-McCormick, Peter Kitchener, Francine De Ladurantaye, Shamim Nakhaei, Dany Posteraro, Marc Quesnel, Salvatore Rosato, Marco Ruggi, Javad Safari, James Smyth, Yi Tian, Jeffrey Wajsberg, and Ian Wittmeyer.

Special thanks are extended to Antoine Lacroix, Yvan Chabot, Carlos Carreiro, Warren Underwood, Timothy McClain, Timothy G. Smith, Stephanie Divito, and Thomas Natoli who on behalf of Transport Canada and the Federal Aviation Administration, have participated, contributed, and provided guidance in the preparation of these documents.

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15. Supplementary Notes (Funding programs, titles of related publications, etc.) Several research reports for testing of de/anti-icing technologies were produced for previous winters on behalf of Transport Canada (TC). These are available from the TC Programs Group Innovation Centre. Several reports were produced as part of this winter's research program. Their subject matter is outlined in the preface. This project was co-sponsored by the Federal Aviation Administration.				
16. Abstract APS Aviation Inc. (APS) carried out research in the winter of 2024-25 in support of the Transport Canada (TC) aircraft ground icing research program. This report documents the evaluation of fluid endurance times in mixed phase icing conditions. Endurance time test results suggest that Type I fluid endurance time performance in mixed snow and freezing fog at operationally relevant rates is equivalent to its snow-only endurance time performance in corresponding conditions. The holdover time (HOT) guidance for Type I fluids in Mixed Snow and Freezing Fog conditions is being modified to be equal to 100 percent of the corresponding Moderate Snow Generic Type I HOTs for the 2025-26 HOT Guidelines. The data collected over three years of testing indicates that Type II, Type III, and Type IV fluid endurance time performance in mixed rain and snow was 75 percent or more of the fluid endurance time performance in a high-rate rain on a cold-soaked wing (CSW) condition regardless of the specific ratio of rain and snow in combination. Following a review of the multi-year endurance time test data, it was determined by TC/Federal Aviation Administration (FAA) that HOT guidance for conditions of Moderate Snow mixed with Rain would be provided for all fluid types in the 2025-26 HOT Guidelines. For Type I fluids, the Moderate Snow mixed with Rain HOTs are equal to 100 percent of the corresponding (aluminum or composite) Type I HOT for the Rain on a CSW condition. These HOTs are provided as a single time value based on the shorter CSW HOT value. For Type II, Type III, and Type IV fluids, the Moderate Snow mixed with Rain HOTs are equal to 75 percent of the fluid-specific HOT for the Rain on a CSW condition. These HOTs are provided as a single time value based on the shorter CSW HOT value. Although the mixed snow and mist endurance time test data suggested that the presence of mist does not have a significant impact on fluid endurance times in snow, it was determined by TC and the FAA that concerns related to the reporting of mist and drizzle conditions could potentially result in drizzle conditions being misreported as mist. As such, it was determined that additional research would be necessary before conclusive HOT guidance could be issued for Mixed Snow and Mist conditions. For all fluids tested, the mixed light snow and rain endurance time results were equivalent to or superior to the corresponding light freezing rain endurance time results at -3°C. Given the results obtained, the historical indication to use Light Freezing Rain HOTs in conditions of very light or light snow mixed with rain or drizzle remains appropriate.				
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15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.) Plusieurs rapports de recherche sur des essais de technologies de dégivrage et d'antigivrage ont été produits au cours des hivers précédents pour le compte de Transports Canada (TC). Ils sont disponibles auprès du Centre d'innovation du groupe de programmes de TC. De nombreux rapports ont été rédigés dans le cadre du programme de recherche de cet hiver. Leur objet apparaît à l'avant-propos. Ce projet était coparrainé par la Federal Aviation Administration.				
16. Résumé APS Aviation Inc. (APS) a mené des essais au cours de l'hiver 2024-2025 dans le cadre d'un programme de recherche de Transports Canada (TC) sur le givrage d'aéronefs au sol. Le présent rapport fait état de l'évaluation des durées d'endurance des liquides dans des conditions de givrage en phase mixte. Les résultats des essais sur les durées d'endurance suggèrent que la performance des durées d'endurance des liquides de type I en conditions mixtes de neige et de brouillard verglaçant à des taux opérationnellement pertinents est équivalente à la performance des durées d'endurance de ces liquides sous neige seulement dans des conditions correspondantes. Les lignes directrices relatives aux durées d'efficacité des liquides de type I en conditions mixtes de neige et de brouillard verglaçant sont modifiées pour correspondre à 100 pour cent des durées d'efficacité génériques pour les liquides de type I correspondantes en conditions de neige modérée dans les lignes directrices relatives aux durées d'efficacité de 2025-2026. Les données recueillies dans le cadre des essais réalisés sur trois ans indiquent que la performance des durées d'endurance des liquides de type II, de type III et de type IV en conditions mixtes de pluie et de neige correspond à 75 pour cent ou plus de la performance des durées d'endurance des liquides en conditions de forte pluie sur une aile imprégnée de froid, quel que soit le rapport donné de pluie et de neige en association. À la suite d'une revue des données d'essais pluriannuels relatifs aux durées d'endurance, TC et la Federal Aviation Administration (FAA) ont déterminé que les lignes directrices relatives aux durées d'efficacité en conditions de neige modérée mêlée de pluie seraient fournies pour tous les types de liquides dans le cadre des lignes directrices relatives aux durées d'efficacité de 2025-2026. Les durées d'efficacité des liquides de type I en conditions de neige modérée mêlée de pluie correspondent à 100 pour cent des durées d'efficacité des liquides de type I correspondantes (surfaces en aluminium ou en matériaux composites) en conditions de pluie sur une aile imprégnée de froid. Ces durées d'efficacité sont fournies en tant que valeur temporelle unique fondée sur la valeur de durée d'efficacité sur une aile imprégnée de froid plus courte. Les durées d'efficacité des liquides de type II, de type III et de type IV en conditions de neige modérée mêlée de pluie correspondent à 75 pour cent des durées d'efficacité spécifiques aux liquides en conditions de pluie sur une aile imprégnée de froid. Ces durées d'efficacité sont fournies en tant que valeur temporelle unique fondée sur la valeur de durée d'efficacité sur une aile imprégnée de froid plus courte. Bien que les données des essais sur les durées d'endurance en conditions mixtes de neige et de brume suggèrent que la présence de brume n'a pas une incidence importante sur les durées d'endurance des liquides en conditions de neige, TC et la FAA ont exprimé des préoccupations quant au signallement des conditions de brume et de bruine (les conditions de bruine risquant d'être interprétées à tort comme de la brume). Par conséquent, il a été déterminé que des recherches supplémentaires seraient nécessaires avant de pouvoir formuler des lignes directrices concluantes quant aux durées d'efficacité en conditions mixtes de neige et de brume. Pour tous les liquides évalués, les résultats relatifs aux durées d'endurance en conditions mixtes de faible neige et de pluie étaient équivalents ou supérieurs à ceux relatifs aux durées d'endurance correspondantes en conditions de pluie verglaçante légère à -3 °C. Compte tenu des résultats obtenus, l'indication historique consistant à utiliser les durées d'efficacité en conditions de pluie verglaçante légère en présence de conditions de neige légère ou très légère mêlée de pluie ou de bruine demeure appropriée.				
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EXECUTIVE SUMMARY

Under contract to the Transport Canada (TC) Programs Group Innovation Centre, with support from the Federal Aviation Administration (FAA) William J. Hughes Technical Center for Advanced Aerospace, TC Civil Aviation, and FAA Flight Standards – Air Carrier Operations, APS Aviation Inc. (APS) carried out research in the winter of 2024-25 in support of the aircraft ground icing research program.

Each major project completed as part of the 2024-25 research is documented in a separate individual report. This report documents the evaluation of fluid endurance times in mixed phase icing conditions.

Background and Objective

Holdover time (HOT) guidance is currently provided to industry in the form of generic and fluid-specific guidance tables that provide operators with the time ranges for safe operation after anti-icing in various environmental conditions. Most of the HOT guidance that is currently published has been developed for conditions where only one precipitation type is present.

One of the primary goals of TC/FAA's ongoing HOT research and development is to maximize the operational capabilities for air operators in winter conditions. In recent years, mixed icing conditions has become a research priority to reduce the number of occurrences where operations are restricted by a lack of existing HOT guidance. In 2021-22, APS conducted mixed snow and freezing fog endurance time testing, which led to the development of a generic HOT table for use in those conditions. That work was documented in the TC report, TP 15540E, *Evaluation of Fluid Endurance Times in Mixed Snow and Freezing Fog Conditions* (1).

Since the initial testing session in 2021-22, work has continued annually to address outstanding concerns related to guidance development for mixed icing conditions. The 2023-24 testing session was documented in the TC report, TP 15610E, *Testing and Evaluation of Mixed Phase Icing Conditions: Winter 2023-24* (2). This report contained a series of recommendations for future research, including additional data collection in conditions including mixed snow and freezing fog, mixed snow and mist, and mixed rain and snow to support further development of the HOT guidance.

A workplan for the 2024-25 mixed icing research was developed in consultation with TC and the FAA, with the primary goal of addressing the data collection recommendations from TP 15610E (2).

Conclusions

The Type I fluid performance in the 2024-25 mixed condition tests (conducted with a reduced fog rate of 1 g/dm²h) was equivalent to or greater than the snow-only baseline performance in all cases on both aluminum and composite surfaces.

Endurance time test results suggest that Type I fluid endurance time performance in mixed snow and freezing fog at operationally relevant rates is equivalent to its snow-only endurance time performance in corresponding conditions.

The HOT guidance for Type I fluids in Mixed Snow and Freezing Fog conditions is being modified to be equal to 100 percent of the corresponding Moderate Snow Generic Type I HOTs for the 2025-26 HOT Guidelines.

The data collected over three years of testing indicates that Type II, Type III, and Type IV fluid endurance time performance in mixed rain and snow was 75 percent or more of the fluid endurance time performance in a high-rate rain on a cold-soaked wing (CSW) condition regardless of the specific ratio of rain and snow in combination. For many fluids, the mixed condition performance was equal to or better than the CSW condition performance.

Following a review of the multi-year endurance time test data, it was determined by TC/FAA that HOT guidance for conditions of Moderate Snow mixed with Rain would be provided for all fluid types in the 2025-26 HOT Guidelines.

For Type I fluids, the Moderate Snow mixed with Rain HOTs are equal to 100 percent of the corresponding (aluminum or composite) Type I HOT for the rain on a CSW condition. These HOTs are provided as a single time value based on the shorter CSW HOT value.

For Type II, Type III, and Type IV fluids, the Moderate Snow mixed with Rain HOTs are equal to 75 percent of the fluid-specific HOT for the rain on a CSW condition. These HOTs are provided as a single time value based on the shorter CSW HOT value.

The collected endurance time data demonstrated no reduction in fluid performance in mixed snow and mist as compared to the fluid performance in an equivalent snow-only condition for any of the fluids evaluated.

Although the mixed snow and mist endurance time test data suggested that the presence of mist does not have a significant impact on fluid endurance times in snow, it was determined by TC and the FAA that concerns related to the accurate identification of mist and drizzle conditions could potentially result in drizzle conditions being misreported as mist. As such, it was determined that additional research would be necessary before conclusive HOT guidance could be issued for mixed snow and mist conditions.

For all fluids tested, the mixed light snow and rain endurance time results were equivalent to or superior to the corresponding light freezing rain endurance time results at -3°C. Given the results obtained, the historical direction to use Light Freezing Rain HOTs in conditions of very light or light snow mixed with rain or drizzle remains appropriate.

Recommendations

It is recommended that additional mixed icing conditions research be conducted next year to address the outstanding testing and guidance development objectives from 2024-25.

The priorities for mixed icing conditions testing and development in winter 2025-26 have been identified in consultation with TC and the FAA and are listed below.

- Conduct natural conditions precipitation rate data collection to further characterize the following conditions:
 - Freezing Mist mixed with Freezing Drizzle; and
 - Freezing Fog mixed with Freezing Drizzle.
- Conduct simulated mixed icing condition endurance time testing in the following conditions:
 - Snow mixed with Freezing Drizzle; and
 - Snow mixed with Freezing Rain.

It is expected that the above data collection activities will be beneficial in better characterizing icing conditions containing mist and will in turn support guidance development activities.

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SOMMAIRE

En vertu d'un contrat avec le groupe des programmes du Centre d'innovation de Transports Canada (TC) et avec le soutien du William J. Hughes Technical Center for Advanced Aerospace de la Federal Aviation Administration (FAA), du département de l'aviation civile de TC, et de la FAA Flight Standards – Air Carrier Operations, APS Aviation Inc. (APS) a mené des essais au cours de l'hiver 2024-2025 dans le cadre d'un programme de recherche sur le givrage d'aéronefs au sol.

Tous les projets importants achevés dans le cadre du programme de recherche de 2024-2025 sont documentés par l'entremise de rapports individuels. Le présent rapport fait état de l'évaluation des durées d'endurance des liquides dans des conditions de givrage en phase mixte.

Contexte et objectifs

Les lignes directrices relatives aux durées d'efficacité sont actuellement soumises au secteur sous forme de tableaux génériques et de tableaux spécifiques aux liquides qui indiquent aux exploitants les plages d'activité sécuritaires suivant les opérations d'antigivrage dans diverses conditions environnementales. La plupart des lignes directrices sur les durées d'efficacité actuellement publiées ont été élaborées en fonction de conditions où n'intervient qu'un seul type de précipitations.

L'un des objectifs principaux du projet de recherche et développement continu de TC et de la FAA sur les durées d'efficacité est de maximiser les capacités opérationnelles des exploitants aériens dans des conditions hivernales. Ces dernières années, la recherche dans des conditions mixtes de givrage est devenue prioritaire pour réduire le nombre de cas où les opérations sont limitées par l'absence de lignes directrices adaptées à ce contexte. En 2021-2022, APS a mené des essais sur les durées d'endurance en conditions mixtes de neige et de brouillard verglaçant, lesquels ont mené à la mise au point d'un tableau des durées d'efficacité génériques aux fins d'utilisation dans ces conditions. Ces travaux ont été documentés dans le rapport TP 15540E de TC, intitulé *Evaluation of Fluid Endurance Times in Mixed Snow and Freezing Fog Conditions* (1).

Depuis la première séance d'essais ayant eu lieu en 2021-2022, des travaux ont eu lieu chaque année pour répondre aux questions persistantes concernant la mise au point de lignes directrices sur les conditions mixtes de givrage. La séance d'essais de 2023-2024 a été documentée dans le rapport TP 15610E de TC, intitulé *Testing and Evaluation of Mixed Phase Icing Conditions: Winter 2023-24* (2). Ce rapport contenait une série de recommandations pour la réalisation de recherches futures, y compris la collecte de données, notamment en conditions mixtes de neige et de brouillard verglaçant, en conditions mixtes de neige et de brume et en conditions

mixtes de pluie et de neige, afin d'appuyer l'élaboration plus poussée de lignes directrices relatives aux durées d'efficacité.

À la suite de consultations avec TC et la FAA, un plan de travail pour la réalisation de recherches en conditions mixtes de givrage a été mis au point pour 2024-2025. Son objectif principal consistait à répondre aux recommandations sur la collecte de données tirées du TP 15610E (2).

Conclusion

La performance des liquides de type I lors des essais en conditions mixtes menés en 2024-2025 (à des taux de brouillard moindres de 1 g/dm²h) était équivalente ou supérieure à la performance de référence sous neige seulement dans tous les cas sur des surfaces en aluminium et des surfaces en matériaux composites.

Les résultats des essais sur les durées d'endurance suggèrent que la performance des durées d'endurance des liquides de type I en conditions mixtes de neige et de brouillard verglaçant à des taux opérationnellement pertinents est équivalente à la performance des durées d'endurance de ces liquides sous neige seulement dans des conditions correspondantes.

Les lignes directrices relatives aux durées d'efficacité des liquides de type I en conditions mixtes de neige et de brouillard verglaçant sont modifiées pour correspondre à 100 pour cent des durées d'efficacité génériques pour les liquides de type I correspondantes en conditions de neige modérée dans les lignes directrices relatives aux durées d'efficacité de 2025-2026.

Les données recueillies dans le cadre des essais réalisés au cours d'une période de trois ans indiquent que la performance des durées d'endurance des liquides de type II, de type III et de type IV en conditions mixtes de pluie et de neige correspond à 75 pour cent ou plus de la performance des durées d'endurance des liquides en conditions de taux élevé de pluie sur une aile imprégnée de froid, quel que soit le rapport donné de pluie et de neige en association. Pour bon nombre de liquides, la performance en conditions mixtes était égale ou supérieure à la performance sur une aile imprégnée de froid.

À la suite d'une revue des données d'essais pluriannuels relatifs aux durées d'endurance, TC et la FAA ont déterminé que les lignes directrices relatives aux durées d'efficacité en conditions de neige modérée mêlée de pluie seraient fournies pour tous les types de liquides dans le cadre des lignes directrices relatives aux durées d'efficacité de 2025-2026.

Les durées d'efficacité des liquides de type I en conditions de neige modérée mêlée de pluie correspondent à 100 pour cent des durées d'efficacité des liquides de type I correspondantes (surfaces en aluminium ou en matériaux composites) en conditions de pluie sur une aile imprégnée de froid. Ces durées d'efficacité sont fournies en tant que valeur temporelle unique fondée sur la valeur de durée d'efficacité sur une aile imprégnée de froid plus courte.

Les durées d'efficacité des liquides de type II, de type III et de type IV en conditions de neige modérée mêlée de pluie correspondent à 75 pour cent des durées d'efficacité spécifiques aux liquides en conditions de pluie sur une aile imprégnée de froid. Ces durées d'efficacité sont fournies en tant que valeur temporelle unique fondée sur la valeur de durée d'efficacité sur une aile imprégnée de froid plus courte.

Les données recueillies sur les durées d'endurance n'ont révélé aucune réduction de la performance des liquides en conditions mixtes de neige et de brume par rapport à la performance des liquides en conditions équivalentes sous neige seulement, quel que soit le liquide évalué.

Bien que les données des essais sur les durées d'endurance en conditions mixtes de neige et de brume suggèrent que la présence de brume n'a pas une incidence importante sur les durées d'endurance des liquides en conditions de neige, TC et la FAA ont exprimé des préoccupations quant au signalement précis des conditions de brume et de bruine (les conditions de bruine risquant d'être interprétées à tort comme de la brume). Par conséquent, il a été déterminé que des recherches supplémentaires seraient nécessaires avant de pouvoir formuler des lignes directrices concluantes quant aux durées d'efficacité en conditions mixtes de neige et de brume.

Pour tous les liquides évalués, les résultats relatifs aux durées d'endurance en conditions mixtes de faible neige et de pluie étaient équivalents ou supérieurs à ceux relatifs aux durées d'endurance correspondantes en conditions de pluie verglaçante légère à -3 °C. Compte tenu des résultats obtenus, l'indication historique consistant à utiliser les durées d'efficacité en conditions de pluie verglaçante légère en présence de conditions de neige légère ou très légère mêlée de pluie ou de bruine demeure appropriée.

Recommandations

Il est recommandé d'effectuer d'autres recherches sur les conditions mixtes de givrage l'année prochaine afin d'atteindre les objectifs relatifs aux essais en suspens et à la mise au point de lignes directrices lancés en 2024-2025.

Les priorités en matière de recherche et de développement dans des conditions mixtes de givrage au cours de l'hiver 2025-2026 ont été définies de concert avec TC et la FAA, et sont énumérées ci-dessous :

- Procéder à la collecte de données sur les taux de précipitations dans des conditions naturelles afin de mieux caractériser les conditions suivantes :
 - Brume verglaçante mêlée de bruine verglaçante;
 - Brouillard verglaçant mêlé de bruine verglaçante.
- Mener des essais sur les durées d'endurance en conditions mixtes de givrage simulées dans les conditions suivantes :
 - Neige mêlée de bruine verglaçante;
 - Neige mêlée de pluie verglaçante.

On s'attend à ce que les activités de collecte de données mentionnées ci-dessus améliorent la caractérisation des conditions de givrage en présence de brume, ce qui permettra en retour de mieux appuyer les activités de mise au point de lignes directrices.

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GLOSSARY

APS	APS Aviation Inc.
ARP	Aerospace Recommended Practice
CEF	Climatic Engineering Facility
CSW	Cold-Soaked Wing
EG	Ethylene Glycol
ET	Endurance Time
FAA	Federal Aviation Administration
HOT	Holdover Time
LWE	Liquid Water Equivalent
METAR	Meteorological Aerodrome Report
MWG	METAR Working Group
NRC	National Research Council Canada
PG	Propylene Glycol
SAE	SAE International
TC	Transport Canada
YUL	Montréal–Pierre Elliott Trudeau International Airport

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1. INTRODUCTION

Under winter precipitation conditions, aircraft surfaces are cleaned prior to takeoff. This is typically done with aircraft ground deicing fluids, which are freezing point depressant fluids developed specifically for aircraft use. If required, aircraft are then protected against further accumulation of precipitation by the application of aircraft ground anti-icing fluids, which are also freezing point depressant fluids. Most anti-icing fluids contain thickeners to extend protection time.

Prior to the 1990s, aircraft ground de/anti-icing had not been extensively researched. However, following several ground icing related incidents in the late 1980s, an aircraft ground icing research program was initiated by Transport Canada (TC). The objective of the program is to improve knowledge, enhance safety, and advance operational capabilities of aircraft operating in winter precipitation conditions.

Since its inception in the early 1990s, the aircraft ground icing research program has been managed by TC, with the co-operation of the United States Federal Aviation Administration (FAA), the National Research Council Canada (NRC), several major airlines, and de/anti-icing fluid manufacturers.

There is still an incomplete understanding of some of the hazards related to aircraft ground icing. As a result, the aircraft ground icing research program continues, with the objective of further reducing the risks posed by the operation of aircraft in winter precipitation and other icing conditions.

Under contract to the TC Programs Group Innovation Centre, with support from the FAA William J. Hughes Technical Center for Advanced Aerospace, TC Civil Aviation, and FAA Flight Standards – Air Carrier Operations, APS Aviation Inc. (APS) carried out research in the winter of 2024-25 in support of the aircraft ground icing research program. Each major project completed as part of the 2024-25 research is documented in a separate individual report. This report documents the evaluation of fluid endurance times in mixed icing conditions to support guidance development.

1.1 Background

Holdover time (HOT) guidance is currently provided to industry in the form of generic and fluid-specific guidance tables that provide operators with time ranges for safe operation after anti-icing in various environmental conditions. Most of the HOT guidance that is currently published has been developed for conditions where only one precipitation type is present. Meteorological aerodrome report (METAR)-reported weather conditions may not always have a corresponding entry in the HOT guidance to allow for safe departure, and this is especially true for mixed conditions.

One of the primary goals of TC/FAA's ongoing HOT research and development is to maximize operational capabilities for air operators in winter conditions. In recent years, the development of guidance for mixed icing conditions has been a research priority to reduce the number of occurrences where operations are restricted by a lack of HOT guidance.

A METAR working group (MWG) consisting of TC/FAA representatives, university-affiliated meteorologists, and industry experts was formed in 2020-21 with the goal of assessing the occurrence of mixed icing conditions in North America and determining which combinations of icing conditions should be prioritized for guidance development. Based on a frequency analysis, Mixed Snow and Freezing Fog was identified by the group as the top priority for guidance development. This condition was the focus of a testing session conducted in 2021-22, which led to the development of a generic HOT table for use in mixed snow and freezing fog conditions. This work is documented in TP 15540E (1).

Since the initial testing session in 2021-22, work has continued annually to address outstanding concerns related to guidance development for mixed icing conditions. The most recent testing session occurred in 2023-24 and was documented in TP 15610E (2). This report contained a series of recommendations for future research, including additional data collection in conditions including Mixed Snow and Freezing Fog, Mixed Snow and Mist, and Mixed Rain and Snow to support further development of the HOT guidance.

A workplan for the 2024-25 mixed icing research was developed in consultation with TC and the FAA, with the primary goal of addressing the data collection recommendations from TP 15610E (2). This research is described in this report.

1.2 Project Objectives

The objectives of this project were as follows:

- 1) To conduct endurance time testing in the following mixed icing conditions:
 - a) Snow mixed with Rain;
 - b) Snow mixed with Mist;
 - c) Snow mixed with Freezing Fog; and
 - d) Very Light or Light Snow mixed with Rain or Drizzle.
- 2) To analyse the test data collected to evaluate the potential for the related HOT guidance.

The statement of work excerpt for this project is provided in Appendix A.

1.3 Report Format

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

- a) Section 2 describes the methodologies used to conduct the mixed icing endurance time tests;
- b) Section 3 describes data collected during the test session;
- c) Section 4 describes the results from the testing, as well as the related guidance development activities;
- d) Section 5 describes changes to holdover time guidance material;
- e) Section 6 provides a summary of the conclusions; and
- f) Section 7 provides a summary of the recommendations.

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2. METHODOLOGY

This section provides a brief description of the test methodologies and equipment used during the mixed icing endurance time testing conducted at the NRC Climatic Engineering Facility (CEF).

2.1 Test Location and Schedule

All 2024-25 mixed icing endurance time testing was conducted in simulated conditions at the NRC CEF. Photo 2.1 provides an outdoor view of the facility, giving a general indication of its size (30 m by 5.4 m, height 8 m). The facility was originally designed for the testing of locomotives; Photo 2.2 provides an interior view of the CEF setup for general endurance time testing. The facility is temperature-controlled and is equipped with a sprayer system capable of producing multiple types of simulated freezing precipitation.

Nine days of testing were conducted over a two-week period in February and March 2025 (the setup and tear-down days included a half-day of testing each). The test calendar summarizing the planned daily objectives is shown below in Figure 2.1.

Week of	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
23-Feb-25		Set-Up + Moderate Rain and Snow Testing	Moderate Rain and Snow Testing	Very Light or Light Snow and Rain Testing + Snow and Freezing Fog Testing	Snow and Freezing Mist Testing	Snow and Freezing Mist Testing	
02-Mar-25		Snow and Freezing Mist Testing	Snow and Freezing Mist Testing	Snow and Freezing Mist Testing + Snow and Freezing Fog Testing	Moderate Rain and Snow Testing	Very Light or Light Snow and Rain Testing + Tear-Down	

Figure 2.1: NRC CEF Mixed Icing Test Calendar

Due to the exploratory nature of the work performed, a daily review discussion was held at the conclusion of each day with TC, the FAA, and APS. During these discussions, the group reviewed the daily test results and discussed the test plan and any modifications required for the following day.

2.2 Test Procedure

To satisfy the project objectives, fluid endurance time tests were conducted in a variety of simulated precipitation conditions. Fluid thickness, fluid Brix, and plate temperature measurements were collected at regular intervals during the test runs.

The general test procedure is included in Appendix B. This procedure includes details regarding the test objectives, test plan, test setup, test methodologies, test equipment used, fluids used, and other pertinent information and documentation.

The general APS methodology for endurance time testing in simulated freezing precipitation conditions is included in Appendix C. The test setup used for this project deviated from the standard setup used in freezing precipitation HOT testing in the following ways:

- Canopy tents were installed beside the test stands to shield the snow dispenser equipment from the freezing fog, freezing mist, and rain spray; and
- The two test stands were oriented so that the higher edges of each plate were in the middle of the setup to ensure that the snow-dispensing process was equivalent on each stand.

The general testing setup is depicted in Photo 2.3. A view of the test stand during the application of contamination is depicted in Photo 2.4.

2.3 Simulated Precipitation and Rate Calibration

The following types of precipitation were simulated for the endurance time testing:

- Snow;
- Freezing Fog;
- Freezing Mist; and
- Rain.

2.3.1 Simulated Snow

Simulated snow consists of small ice crystals measuring less than 1.4 mm in diameter. Previous testing conducted by APS investigated the dissolving properties of the artificial snow versus natural snow. The artificial snow produced by this method was selected as an appropriate substitute for natural snow.

The snow was manufactured inside the cooled test chamber. Cubes of ice were crushed and passed through calibrated sieves (see Photo 2.5) to obtain the required ice crystal size range. Hand-held motorized dispensers (seen in Photo 2.3) were used to dispense the snow during testing.

2.3.2 Simulated Rain, Fog, and Mist

The conditions of freezing and non-freezing rain, fog, and mist were simulated using an NRC-developed sprayer assembly providing a large scan area and appropriate spray uniformity over the test area. The scanner consists of a horizontal main shaft supported by two bearings. The actual spray head assembly is shaft-mounted on a rotating scanner so that one scan covers a lateral running strip of the test area. A stepper motor is synchronized to index the relative angle of the spray head between scans along an axis perpendicular to the scan axis. This provides two axes of rotation, essentially an x-y plane, one along each axis. Each scan is consecutively indexed to complete the precipitation coverage of the test bed area. This defines one cycle of the spray unit. The scan rate, index angle, and the number of scans per cycle are adjusted, along with the fluid delivery pressures (water and compressed air), to obtain appropriate droplet sizes and precipitation rates through selected nozzles. The sprayer assembly is shown in Photo 2.6.

2.3.3 HOT Precipitation Rates

The rate limits defined for standard HOT testing were referenced to determine appropriate precipitation rates for the different mixed icing combinations evaluated during the test session. The relevant HOT testing precipitation rate limits for the precipitation types used in the testing are listed below:

- Freezing Fog: 2-5 g/dm²/h;
- Light Snow: 4-10 g/dm²/h;
- Moderate Snow: 10-25 g/dm²/h;
- Heavy Snow: > 25 g/dm²/h; and
- Rain (Cold-Soaked Wing): 5-75 g/dm²/h.

The limits are depicted in Figure 2.2. (For snow, only the moderate intensity range is shown.)

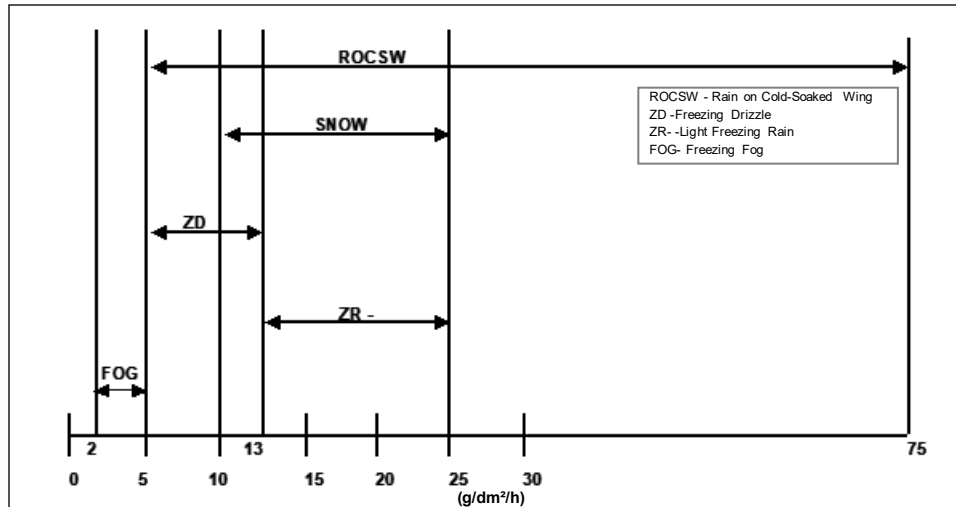


Figure 2.2: HOT Precipitation Rate Limits

It should be noted that the mixed snow and freezing fog tests conducted in 2024-25 used a reduced fog rate of 1 g/dm²/h, which is considered more representative of the fog encountered in a typical operational scenario. The rate limit employed for fog and mist was supported by additional research conducted to characterize the deposition rates of fog and mist in natural conditions. This work is documented in the TC report, TP 15684E, *Aircraft Ground Icing General Research Activities During the 2024-25 Winter* (3).

The condition of mist is not currently associated with a standard precipitation, as it is not typically evaluated during the HOT testing process. Mist is generally understood to be similar in nature to fog but with a reduced impact on visibility. As such, it was simulated during the testing by generating freezing fog at a targeted rate of 0.4 g/dm²/h.

2.3.4 Precipitation Rate Calibration and Rate Measurement

This subsection describes the precipitation rate calibration activities conducted prior to and during the test session at the NRC CEF, as well as the methods employed for determining test precipitation rates during the testing session.

2.3.4.1 Snow Rate Calibration

The simulated snow production and distribution methodology used in this comparative test methodology is not typical of standard HOT testing. As such, significant effort went into calibrating the application process to ensure the repeatability of the test results.

Snow rate calibration was achieved through dry runs (no fluid applied) where known snow masses were applied to the test surfaces over a fixed period. The resulting precipitation rates were subsequently calculated for each position on the test stand using the measured change in mass to confirm that the achieved rates were in line with the targeted rate for the tests being performed and that the rate variability from position to position was also acceptable.

Initial calibration testing for this application methodology was first performed in 2021-22 in a refrigerated trailer at the APS test site near the Montréal–Pierre Elliott Trudeau International Airport (YUL) in Montreal, Quebec, in the weeks leading up to the NRC CEF test session. These initial tests involved dispensing known snow masses onto test stands outfitted with collection pans and configured in the same manner as during the actual testing session. The collection pans were weighed before and after the application process, and the resulting test rates were recorded. The simulated snow was manufactured using the same process employed during the test session and was applied using the same snow-dispensing equipment and dispenser configuration as during the testing. The preliminary snow calibration trials are depicted in Photo 2.7.

The results of the preliminary trials were used to set the initial snow mass needed to achieve the target snow rates in the test plan. Prior to beginning the endurance time tests, snow calibration runs were performed in the test chamber at the NRC CEF to validate the targets established during the preliminary calibration trials. During these runs, it was determined that minor adjustments to the snow masses assigned to the snow dispensers were necessary to achieve the target snow rates evenly across both test stands within the CEF test chamber. Adjustments were made until a run with satisfactory rates across all positions was observed.

To determine the test rates during snow-only tests, rate collection pans were left on the corner positions of each test stand during testing. At the conclusion of the test run (once all plates on the stands had failed), the rates accumulated in the four pans were calculated. The average rate of the four corner pan rates was then used as the test rate for each of the tests conducted on the stands.

The test stand setup (with rate pans installed on the corners) is depicted in Photo 2.8.

2.3.4.2 Rain and Freezing Precipitation Rate Calibration

Simulated freezing fog, freezing mist, and non-freezing rain were created using the same NRC sprayer assembly that is used to generate these conditions in standard HOT testing. As such, the rate calibration processes employed were the same as those employed during a standard HOT test session. These calibration processes are described in detail within the SAE International (SAE) Aerospace Recommended Practice (ARP) 5485B, *Endurance Time Test Procedures for SAE Type II/III/IV Aircraft Deicing/Anti-Icing Fluids* (4).

Briefly described, the process is as follows: The test stands were positioned in the test chamber, equipped with pre-weighed rate collection pans, and subsequently exposed to the simulated precipitation spray for a known period. The pans were then weighed again, and the precipitation rate was calculated for each testing position. Following this, adjustments to the flow rate of the precipitation were made until the targeted rates were accurately simulated.

2.3.4.3 Mixed Snow and Rain or Freezing Precipitation Rate Calibration

To determine the impact that the simulated rain or freezing precipitation had on the simulated snow application, additional mixed condition rate calibration runs were performed.

To calibrate the combined precipitation, the freezing precipitation/rain spray was first activated, and the freezing precipitation or rain rates were measured and calibrated to the desired target level. Once the desired rate was achieved, rate collection pans were installed on the test stands and known snow masses were applied for a fixed period. The resulting precipitation rates were subsequently calculated for each position on the test stand using the measured change in mass to confirm that the achieved rates were in line with the targeted rate for the tests being performed and that the rate variability from position to position was also acceptable.

Analysis of the early combined calibration run results indicated that further adjustments to the snow quantities dispensed would be necessary on a run-by-run basis to offset the impact of the downwash from the rain or fog precipitation spray (which frequently resulted in a top stand and bottom stand differential).

Due to the need to vary the snow quantities from the pre-calibration targets depending on the conditions of a given test, it was determined that all mixed precipitation test runs would be preceded by rate validation to ensure that the target rates were being achieved.

To determine the overall test rates for the mixed condition tests, rate collection pans were left on the corner positions of each test stand during the test. At the conclusion of the test run (once all plates on the stands had failed), the rates accumulated in the four pans were calculated. The average rate of the four corner pan rates was then used as the test rate for each of the tests conducted on the stands. The individual snow rates were determined (whenever possible) by subtracting the average rain/freezing precipitation rates measured prior to snow application from the overall test rate. Note that for the Type I freezing fog tests, no individual test rates are available due to the modified dispensing methodology employed. Additionally, only combined rates are available for the mixed snow and mist tests.

2.4 Mixed Icing Conditions, Subobjectives, and Test Groupings

Several different mixed icing conditions and testing objectives were evaluated during this test session. The conditions and objectives are described in the following subsections.

For each of the research objectives evaluated, the endurance time tests performed were grouped to allow for a comparative assessment of the effects of different precipitation type and rate combinations. The analytical groupings are also described in the following subsections.

2.4.1 Snow Mixed with Freezing Fog (Type I Fluid Testing)

APS previously conducted endurance time testing with Type I fluids in conditions of snow mixed with freezing fog in 2022-23 and 2023-24.

This testing led to the development of the generic Type I HOT guidance for Mixed Snow and Freezing Fog, equivalent to 80 percent of the Type I Moderate Snow HOTs. It was recommended following the previous test session that additional Type I tests be conducted at reduced fog rates more representative of a typical operational scenario to evaluate the fluid performance sensitivity to the freezing fog rate. As such, APS conducted endurance time testing in 2024-25 in mixed snow and freezing fog conditions using a freezing fog component rate of 1 g/dm²/h (down from 2 g/dm²/h in previous test years).

For the mixed snow and freezing fog research, snow-only tests are used as the baseline tests, as snow is typically the predominant precipitation in the mixed condition. Additionally, snow HOTs are a more conservative baseline, as they are generally shorter than freezing fog HOTs for a given fluid.

The test groupings for the 2024-25 mixed snow and freezing fog Type I test runs are shown in Figure 2.3.

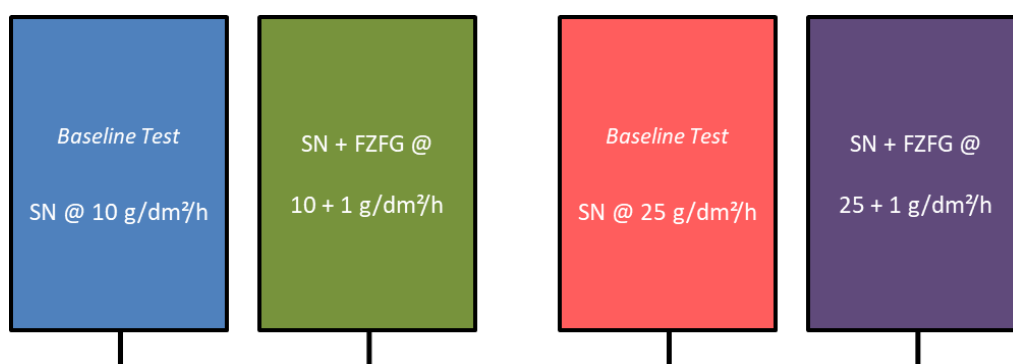


Figure 2.3: Test Groupings – Mixed Snow and Freezing Fog Type I Testing

The mixed snow and freezing fog tests conducted in 2024-25 used a reduced fog rate of 1 g/dm²/h, which is more representative of the fog encountered in a typical operational scenario. Additional research into the deposition rates of mist and freezing fog can be found in TP 15684E (3).

Testing was conducted at temperatures of -3°C only, as this was the only temperature where the Type I performance in the mixed condition was found to be reduced as compared to the baseline in previous years' tests (see TP 15610E [2]).

2.4.2 Snow Mixed with Rain

There is currently no HOT guidance available for conditions of Moderate Snow mixed with Rain (and Moderate Rain mixed with Snow). It was recommended that APS conduct endurance time testing in Mixed Snow and Rain conditions to support the development of HOT guidance for this mixed condition.

This research began in the winter of 2022-23 and included evaluation of both "Moderate Snow and Rain" and "Moderate Rain and Snow" conditions in different rate combinations, differentiated by which of the two precipitation types predominates. The research continued in 2023-24, with additional combinations of rain and snow being evaluated to fully characterize the condition.

After the 2023-24 test session, it was recommended by the TC/FAA-led MWG that future evaluations of snow mixed with rain target higher combined rates of rain and snow to determine the sensitivity of the fluid performance to additional liquid water equivalent (LWE). As such, APS conducted endurance time testing in 2024-25 in mixed snow and rain conditions with combined snow/rain rates of 100 g/dm²/h (up from 75 g/dm²/h in previous test years).

For the mixed snow and rain research, rain on a cold-soaked wing (CSW) conditions are used as the baseline due to similarities in the testing temperatures and target precipitation rates employed. The test groupings for the 2024-25 mixed rain and snow test runs are shown below in Figure 2.4.

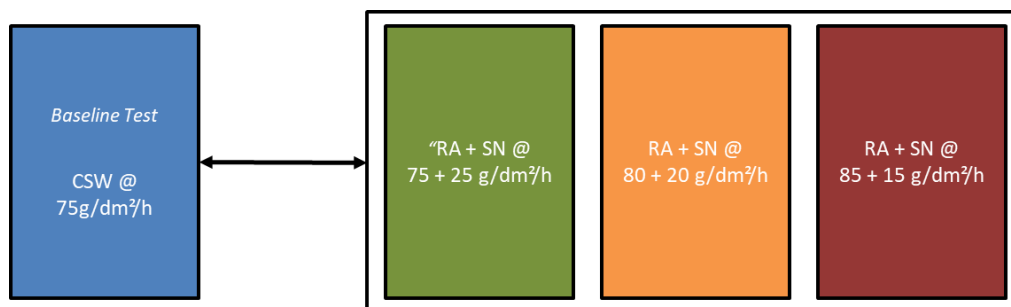


Figure 2.4: Test Groupings – Moderate Rain Mixed with Snow Testing

Multiple different combinations of rain and snow rates were evaluated to allow for better characterization of fluid performance in this mixed icing condition, with the goal of determining the combination that results in the most restrictive measured endurance times.

2.4.3 Snow Mixed with Mist

Mist, like fog, consists of small droplets of water suspended in cold air. The primary difference between mist and fog is the impact on visibility: mist results in less visibility reduction as compared to fog due to the lower density of suspended water droplets in the air. As no explicit HOT guidance exists for a mixed snow and mist condition, it was recommended that APS develop a test methodology to evaluate this precipitation combination, as it is believed that the lower intensity of mist should result in a reduced impact on the snow HOTs as compared to mixed snow and freezing fog conditions.

Preliminary research began in the winter of 2023-24. To simulate the mixed snow and mist condition, the previously developed methodologies for mixed snow and freezing fog testing were employed; however, a reduced precipitation rate of the fog component was used to represent the lighter droplet density associated with mist. Limited data was collected that year using the above methodology (see TP15610E [2]).

It was recommended that data collection be continued in 2024-25 in a broader range of test conditions to further characterize the impact of mist on fluid performance in the mixed condition. As such, APS conducted endurance time testing in a wider range of mixed snow and mist conditions in 2024-25.

For the mixed snow and mist research, snow-only tests are used as the baseline tests, as snow is typically the predominant precipitation in the mixed condition.

The test groupings for the 2024-25 mixed snow and mist tests are depicted in Figure 2.5.

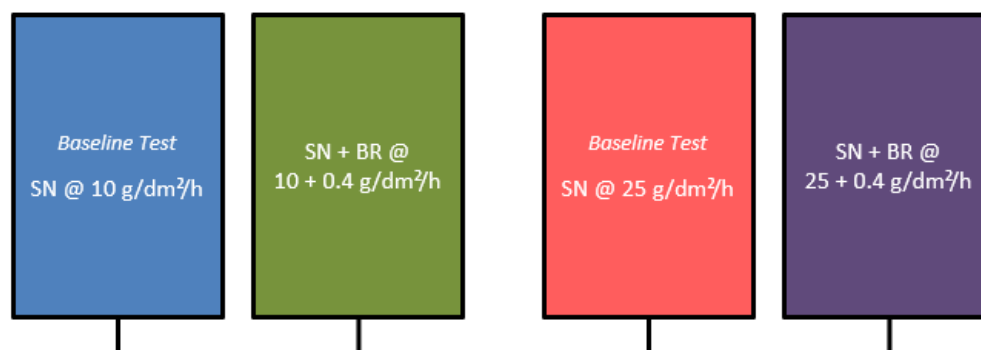


Figure 2.5: Test Groupings – Snow Mixed with Mist Testing

This testing is a continuation of a research objective begun in 2023-24. The previous year's testing targeted a rate of 0.5 g/dm²/h for the simulated mist component of the contamination; this target was adjusted to 0.4 g/dm²/h for the 2024-25 testing to reflect a more operationally relevant situation. Additional research into the deposition rates of mist and freezing fog can be found in TP 15684E (3).

2.4.4 Very Light or Light Snow Mixed with Rain or Drizzle

In the winter of 2008-09, APS conducted research to develop HOT guidance for conditions of Light Snow mixed with Rain. This was achieved by conducting tests in mixed light snow and rain conditions; the resulting endurance times were found to be comparable to light freezing rain endurance times, and guidance was issued allowing the use of Light Freezing Rain HOTs in conditions of light snow mixed with rain. This work is documented in the TC report, TP 14936E, *Aircraft Ground Icing General Research Activities During the 2008-09 Winter* (5).

It was recommended that data collection using the modern mixed icing condition testing methodologies be conducted to validate the historical findings related to the combination of light snow mixed with rain. As such, APS conducted limited data collection to determine whether the historical guidance remained appropriate.

For the light snow mixed with rain research, light freezing rain tests are used as the baseline test, as historical work in this condition established the Light Freezing Rain HOTs as suitable for the mixed condition.

The test groupings for the 2024-25 light snow mixed with rain tests are depicted in Figure 2.6.

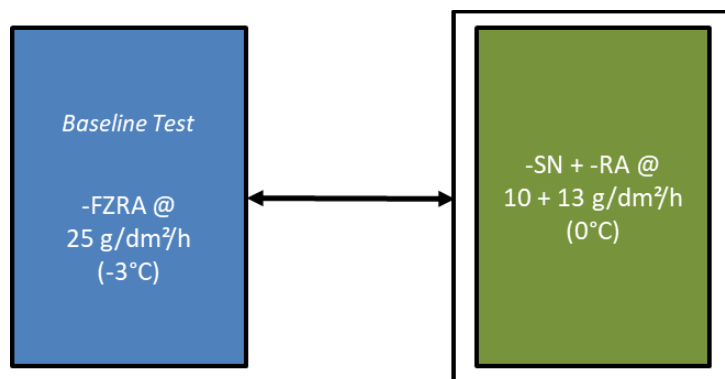


Figure 2.6: Test Groupings – Light Snow Mixed with Rain Testing

2.5 Photography and Videography

Videography of the test runs was captured using tripod-mounted video cameras. One camera was positioned on each side of the test stands, and each test run was recorded from fluid application through to fluid failure.

In addition to the videography, photographs documenting fluid failure were captured for each individual test pour. General testing and setup photographs were also taken throughout the test program.

Due to the large volume of data collected, photographs of the individual tests have not been included in this report. However, the high-resolution photographs and video files have been provided to TC in electronic format and can be made available upon request.

2.6 Personnel

Four APS staff members were required on-site to conduct the tests. In addition, five APS support staff members from Ottawa were retained to manufacture and dispense snow, as well as assist with general setup activities. A professional photographer was also retained to coordinate photography and videography of the test runs.

Representatives from TC and the FAA provided testing direction during daily conference meetings.

2.7 Data Forms

An endurance time testing data form was used to record the results of the endurance time tests. An additional data form was used to calculate and log the necessary snow quantities for each test run. Copies of these forms are provided in the test procedure, which is included in Appendix B.

2.8 Fluids

Seven fluids were used in the mixed icing testing conducted in 2024-25. The fluids used and the measured viscosity (using the manufacturer's method) are as follows:

- Dow Inc. UCAR™ PG Type I ADF Concentrate, a propylene glycol (PG)-based Type I fluid (viscosity not measured);
- ChemR EG Type I Concentrate, an ethylene glycol (EG)-based Type I fluid (viscosity not measured);

- ABAX ECOWING AD-2, a PG-based Type II fluid (measured viscosity: 12,500 cP);
- AllClear AeroClear MAX, an EG-based Type III fluid (measured viscosity: 15,200 cP);
- AllClear Clearwing EG, an EG-based Type IV fluid (measured viscosity: 50,000 cP);
- Cryotech Polar Guard® Advance, a PG-based Type IV fluid (measured viscosity: 15,200 cP); and
- Dow Inc. UCAR Endurance™ EG106 ADF/AAF, an EG-based Type IV fluid (measured viscosity: 37,800 cP).

These fluids were chosen to allow for a broad assessment of the mixed icing conditions evaluated across a range of different fluid types and fluid bases.

The Type I fluid was prepared in batches from concentrate, with each batch being diluted to the appropriate concentration to ensure a consistent 10°C buffer between the test temperature and the fluid freezing point.

The Type II, Type III, and Type IV fluids used were all undiluted, mid-production viscosity samples.

Photo 2.1: Outside View of the NRC CEF



Photo 2.2: Inside View of the NRC CEF Control Room



Photo 2.3: NRC CEF Cold Chamber and General Mixed Condition Testing Setup



Photo 2.4: Test Stand View During Contamination

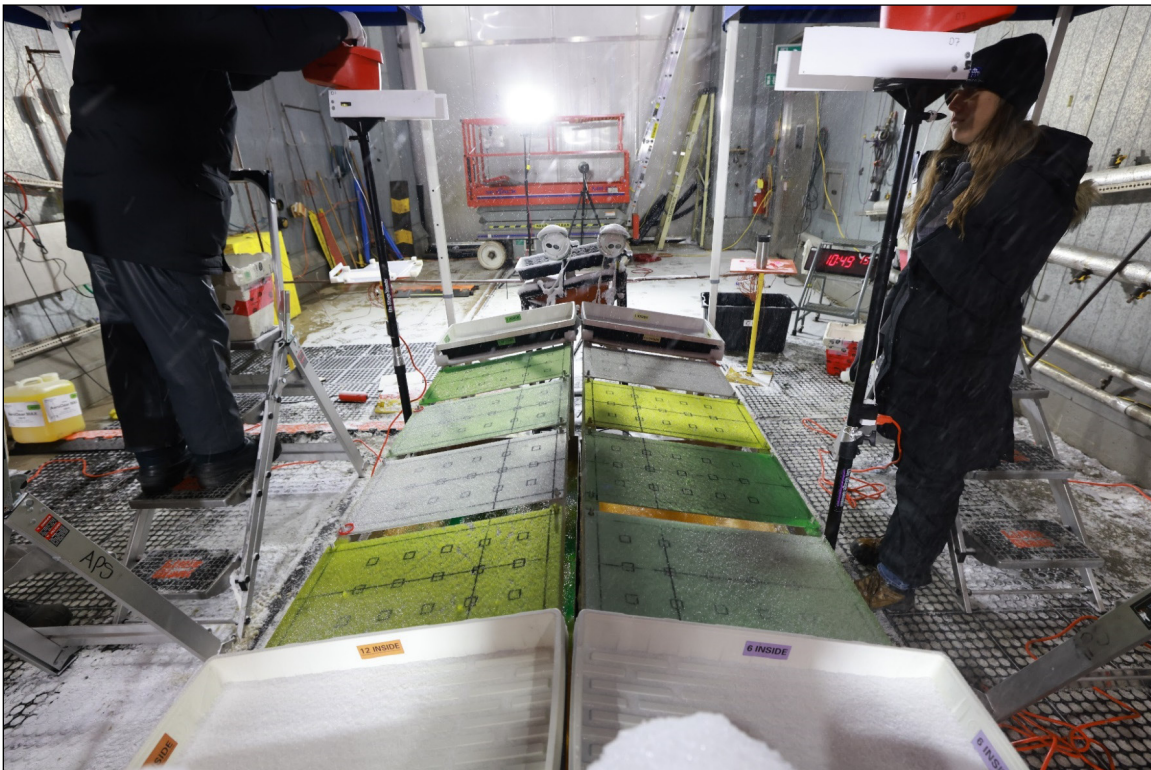


Photo 2.5: Calibrated Sieves Used to Obtain Desired Snow Size Distribution



Photo 2.6: NRC Sprayer Assembly

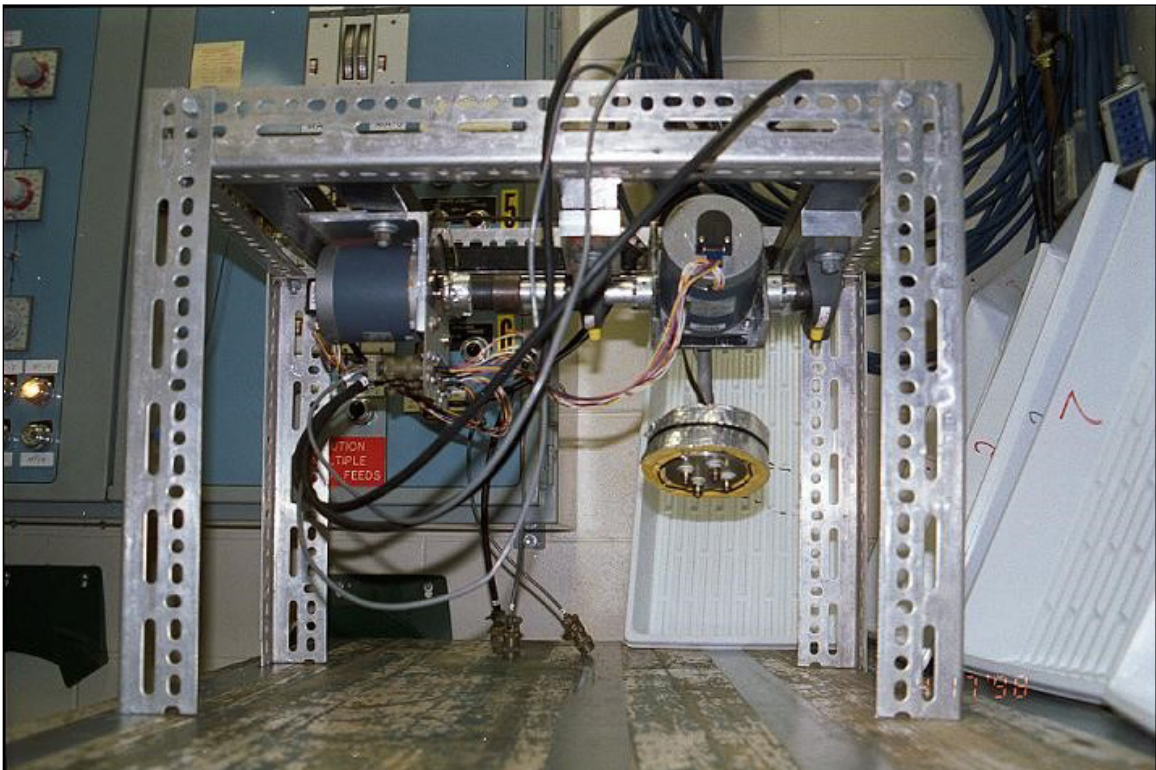


Photo 2.7: Developmental Snow Calibration Trials

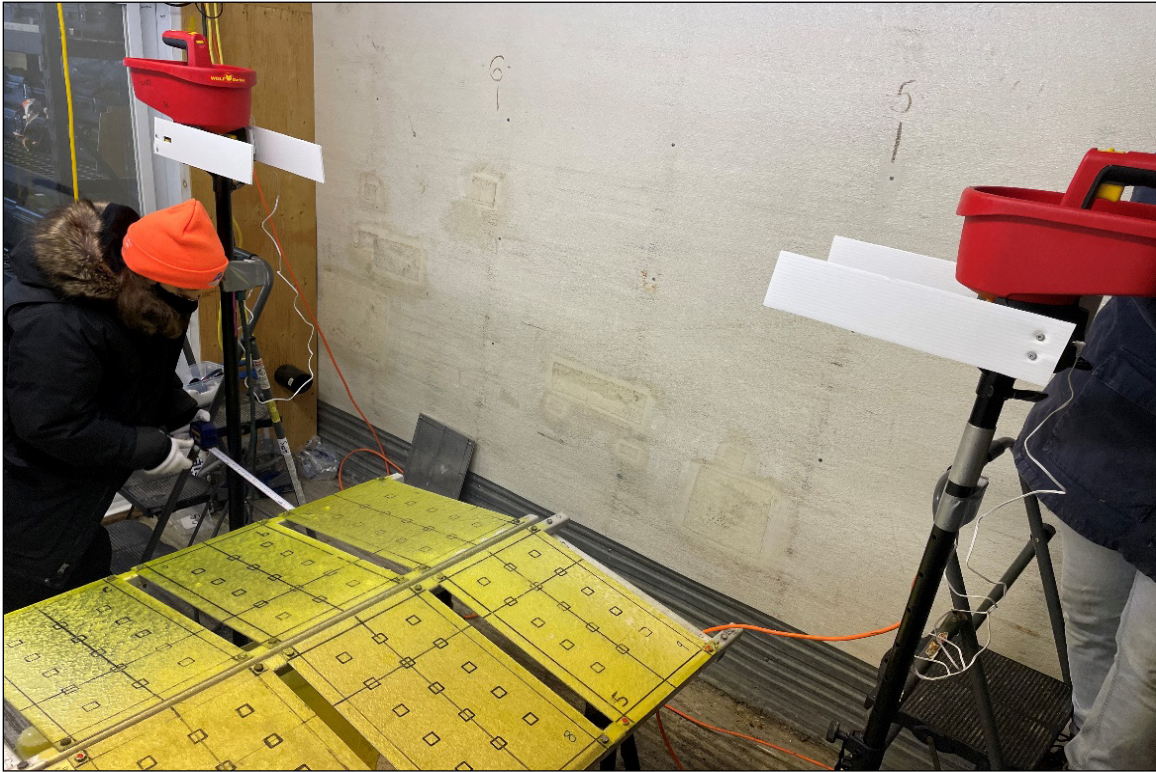
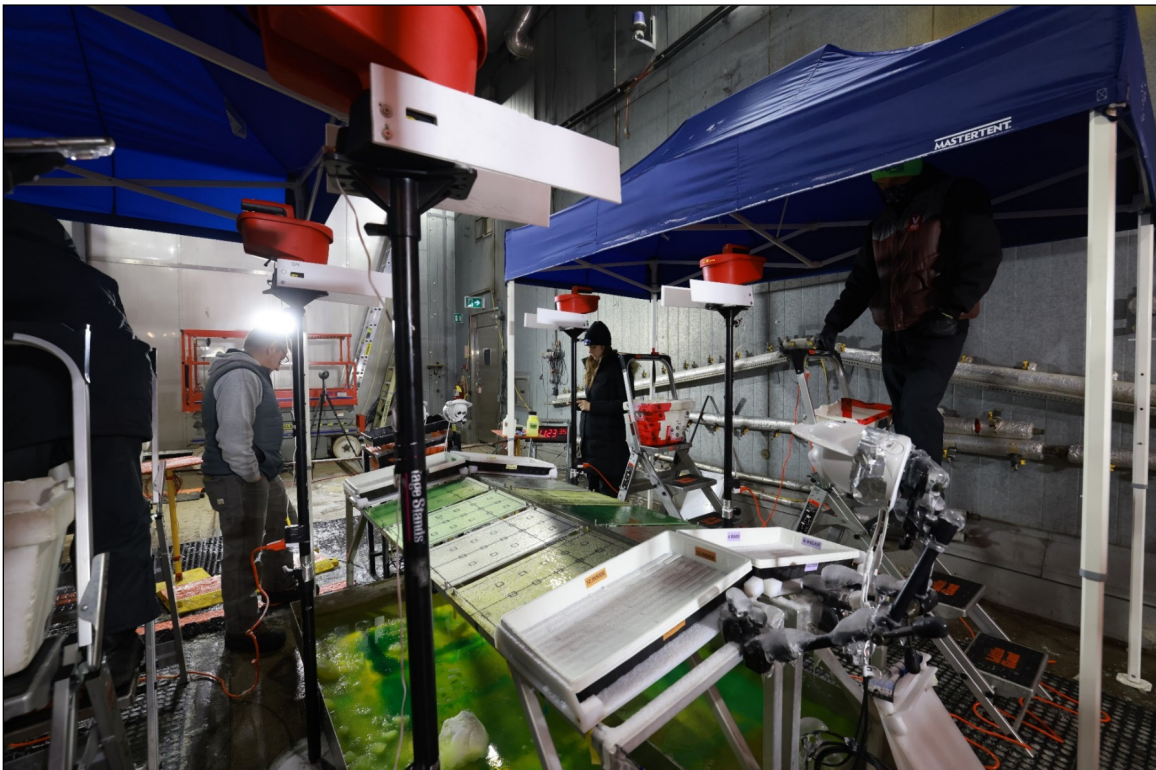


Photo 2.8: Mixed Conditions Test Stand with Rate Pans on Corner Positions



3. DATA – NRC CEF TESTING

This section contains the details on the testing data obtained during the mixed icing endurance time testing conducted at the NRC CEF in 2024-25.

3.1 Relevant Test Data from Previous Years

Several research subobjectives refer to test data collected in previous mixed icing endurance time testing sessions. The relevant test data from previous years' mixed icing endurance time testing has been included with this report in Appendix D.

3.2 Test Logs

A total of 128 mixed icing endurance time tests were conducted at the NRC CEF in 2024-25, broken down by condition as follows:

- 8 tests were conducted to evaluate conditions of snow mixed with freezing fog;
- 52 tests were conducted to evaluate conditions of snow mixed with rain (or rain mixed with snow);
- 60 tests were conducted to evaluate conditions of snow mixed with mist; and
- 8 tests were conducted to evaluate conditions of very light or light snow mixed with rain or drizzle.

Table 3.1 contains a brief description of each of the column headers found in the test logs. The tests conducted at the NRC CEF during the winter of 2024-25 have been included in four separate logs:

- Table 3.2 contains the details of all tests conducted in 2024-25 to evaluate conditions of snow mixed with freezing fog;
- Table 3.3 contains the details of all tests conducted in 2024-25 to evaluate conditions of snow mixed with rain (or rain mixed with snow);
- Table 3.4 contains the details of all tests conducted in 2024-25 to evaluate conditions of snow mixed with mist; and
- Table 3.5 contains the details of all tests conducted in 2024-25 to evaluate conditions of very light or light snow mixed with rain or drizzle.

These logs provide 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.

Table 3.1: Description of Column Headers in the NRC CEF Testing Logs

Column Headers	Description
Test #	The number assigned in the test plan to identify the test run.
Date	The date when the test was conducted.
Fluid Name	The name of the anti-icing fluid used during the test.
Fluid Type	The type of the anti-icing fluid used during the test.
Test Surface	The material of which the test surface is composed.
Condition	The precipitation type(s) being simulated during the test.
Testing Subobjective	The subobjective that the test was conducted to evaluate (snow and freezing fog tests only).
Temp. (°C)	The chamber temperature setting during the test.
Target Combined Rate (g/dm ² /h)	The targeted rate of all components of the precipitation combined.
Target Rate (Snow-Only – g/dm ² /h)	The targeted rate of the snow component of the precipitation alone. This column is replaced by the actual snow-only rate in the mixed snow and rain log (Table 3.3).
Target Rate (Other Precipitation Only – g/dm ² /h)	The targeted rate of the rain or freezing precipitation component of the precipitation. This column is replaced by the actual rain-only rate in the mixed snow and rain log (Table 3.3).
Actual Rate (Snow-Only – g/dm ² /h)	The measured rate of the snow component of the precipitation alone. This column is included only in the mixed snow and rain log (Table 3.3).
Actual Rate (Other Precipitation Only – g/dm ² /h)	The measured rate of the rain or freezing precipitation component of the precipitation. This column is included only in the mixed snow and rain log (Table 3.3).
Actual Rate (Combined – g/dm ² /h)	The measured rate of all components of the precipitation combined.
Endurance Time (min)	The measured endurance time of the test.
Adjusted Endurance Time (min)	The measured endurance time of the test after adjustment to account for rate variations relative to the target rate.

When conducting comparative tests, it is necessary to adjust the measured endurance times to compensate for variations in precipitation rates within the individual tests. For the tests in Table 3.2, Table 3.3, Table 3.4, and Table 3.5, this was done by adjusting the measured endurance time for each test by a linear ratio, which is determined by the average rate of precipitation (combined or individual) measured over the course of each individual test, as compared to the targeted rate of the baseline test. The endurance times were adjusted based on a linear relationship with the following formula:

$$\text{Adjusted Endurance Time} = \text{Actual Endurance Time} \times \frac{\text{Actual Rate of Precipitation}}{\text{Target Rate of Precipitation}}$$

These adjustments were made to allow for the direct comparison of tests with the same target combined rate of precipitation.

Table 3.2: Test Log – 2024-25 Snow Mixed with Freezing Fog Endurance Time Testing at the NRC CEF

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Testing Subobjective	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Target Rate (Snow-Only) (g/dm ² /h)	Target Freezing Fog Rate (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
13	26-Feb-25	PG ADF Concentrate	I-PG	Aluminum	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	11	10	1	12.3	7.5	8.4
14	26-Feb-25	PG ADF Concentrate	I-PG	Composite	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	11	10	1	11.2	4.4	4.5
15	26-Feb-25	CHEMR REG I	I-EG	Aluminum	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	11	10	1	11.4	7.4	7.6
16	26-Feb-25	CHEMR REG I	I-EG	Composite	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	11	10	1	11.1	5.1	5.1
17	05-Mar-25	PG ADF Concentrate	I-PG	Aluminum	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	26	25	1	26.2	5.3	5.4
18	05-Mar-25	PG ADF Concentrate	I-PG	Composite	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	26	25	1	26.2	3.5	3.6
19	05-Mar-25	CHEMR REG I	I-EG	Aluminum	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	26	25	1	26.2	5.4	5.4
20	05-Mar-25	CHEMR REG I	I-EG	Composite	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	26	25	1	26.2	3.3	3.3

Table 3.3: Test Log – 2024-25 Snow Mixed with Rain Endurance Time Testing at the NRC CEF

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Actual Rate (Snow-Only) (g/dm ² /h)	Actual Rate (Rain-Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
1	24-Feb-25	Ecowing AD-2	II	Aluminum	Moderate Rain mixed with Snow	0	100	30.8	78.8	109.6	11.4	12.5
2	24-Feb-25	Ecowing AD-2	II	Aluminum	Moderate Rain mixed with Snow	0	100	30.8	78.8	109.6	12.3	13.5
3	24-Feb-25	AeroClear MAX	III	Aluminum	Moderate Rain mixed with Snow	0	100	30.8	78.8	109.6	8.5	9.3
4	24-Feb-25	AeroClear MAX	III	Aluminum	Moderate Rain mixed with Snow	0	100	30.8	78.8	109.6	11.4	12.5
5	24-Feb-25	Polar Guard® Advance	IV-PG	Aluminum	Moderate Rain mixed with Snow	0	100	30.8	78.8	109.6	16.6	18.2
6	24-Feb-25	Polar Guard® Advance	IV-PG	Aluminum	Moderate Rain mixed with Snow	0	100	30.8	78.8	109.6	15.6	17.1
7	24-Feb-25	Clearwing EG	IV-EG	Aluminum	Moderate Rain mixed with Snow	0	100	30.8	78.8	109.6	11.2	12.2
8	24-Feb-25	Clearwing EG	IV-EG	Aluminum	Moderate Rain mixed with Snow	0	100	30.8	78.8	109.6	11.3	12.4
9	25-Feb-25	Ecowing AD-2	II	Aluminum	Moderate Rain mixed with Snow	0	100	19.8	79.8	99.6	12.4	12.4
10	25-Feb-25	Ecowing AD-2	II	Aluminum	Moderate Rain mixed with Snow	0	100	19.8	79.8	99.6	12.3	12.3
11	25-Feb-25	AeroClear MAX	III	Aluminum	Moderate Rain mixed with Snow	0	100	19.8	79.8	99.6	9.1	9.1
12	25-Feb-25	AeroClear MAX	III	Aluminum	Moderate Rain mixed with Snow	0	100	19.8	79.8	99.6	11.4	11.3
13	25-Feb-25	Polar Guard® Advance	IV-PG	Aluminum	Moderate Rain mixed with Snow	0	100	19.8	79.8	99.6	16.5	16.5
14	25-Feb-25	Polar Guard® Advance	IV-PG	Aluminum	Moderate Rain mixed with Snow	0	100	19.8	79.8	99.6	16.2	16.1
15	25-Feb-25	Clearwing EG	IV-EG	Aluminum	Moderate Rain mixed with Snow	0	100	19.8	79.8	99.6	10.8	10.8
16	25-Feb-25	Clearwing EG	IV-EG	Aluminum	Moderate Rain mixed with Snow	0	100	19.8	79.8	99.6	11.3	11.2
25	27-Mar-25	Ecowing AD-2	II	Aluminum	Rain on a Cold-Soaked Wing	1	75	-	-	75	15.7	15.7
26	27-Mar-25	Ecowing AD-2	II	Aluminum	Rain on a Cold-Soaked Wing	1	75	-	-	75	17.4	17.4
27	27-Mar-25	AeroClear MAX	III	Aluminum	Rain on a Cold-Soaked Wing	1	75	-	-	75	10.8	10.8
28	27-Mar-25	AeroClear MAX	III	Aluminum	Rain on a Cold-Soaked Wing	1	75	-	-	75	11.5	11.5
29	27-Mar-25	Clearwing EG	IV-EG	Aluminum	Rain on a Cold-Soaked Wing	1	75	-	-	75	11.8	11.8
30	27-Mar-25	Clearwing EG	IV-EG	Aluminum	Rain on a Cold-Soaked Wing	1	75	-	-	75	12.0	12.0

Table 3.3: Test Log – 2024-25 Mixed Snow and Rain Endurance Time Testing at the NRC CEF (cont'd)

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Actual Rate (Snow-Only) (g/dm ² /h)	Actual Rate (Rain-Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
31	27-Mar-25	EG106	IV-EG	Aluminum	Rain on a Cold-Soaked Wing	1	75	-	-	75	18.8	18.8
32	27-Mar-25	EG106	IV-EG	Aluminum	Rain on a Cold-Soaked Wing	1	75	-	-	75	19.4	19.4
E1	25-Feb-25	Ecowing AD-2	II	Aluminum	Moderate Rain mixed with Snow	0	75	9.7	64.6	74.3	13.2	13.1
E2	25-Feb-25	Ecowing AD-2	II	Aluminum	Moderate Rain mixed with Snow	0	75	9.7	64.6	74.3	13.7	13.6
E3	25-Feb-25	AeroClear MAX	III	Aluminum	Moderate Rain mixed with Snow	0	75	9.7	64.6	74.3	10.1	10.0
E4	25-Feb-25	AeroClear MAX	III	Aluminum	Moderate Rain mixed with Snow	0	75	9.7	64.6	74.3	11.7	11.5
E5	25-Feb-25	Polar Guard® Advance	IV-PG	Aluminum	Moderate Rain mixed with Snow	0	75	9.7	64.6	74.3	17.8	17.7
E6	25-Feb-25	Polar Guard® Advance	IV-PG	Aluminum	Moderate Rain mixed with Snow	0	75	9.7	64.6	74.3	18.8	18.6
E7	25-Feb-25	Clearwing EG	IV-EG	Aluminum	Moderate Rain mixed with Snow	0	75	9.7	64.6	74.3	10.5	10.4
E8	25-Feb-25	Clearwing EG	IV-EG	Aluminum	Moderate Rain mixed with Snow	0	75	9.7	64.6	74.3	12.4	12.3
E9	06-Mar-25	EG106	IV-EG	Aluminum	Moderate Rain mixed with Snow	0	75	-	-	76.5	15.2	15.5
E10	06-Mar-25	EG106	IV-EG	Aluminum	Moderate Rain mixed with Snow	0	75	-	-	76.5	17.5	17.8
E11	06-Mar-25	EG106	IV-EG	Aluminum	Moderate Rain mixed with Snow	0	75	-	-	76.5	15.5	15.8
E12	06-Mar-25	EG106	IV-EG	Aluminum	Moderate Rain mixed with Snow	0	75	-	-	76.5	14.3	14.6
E13	06-Mar-25	Polar Guard® Advance	IV-PG	Aluminum	Moderate Rain mixed with Snow	0	75	-	-	76.5	19.6	20.0
E14	06-Mar-25	Polar Guard® Advance	IV-PG	Aluminum	Moderate Rain mixed with Snow	0	75	-	-	76.5	17.5	17.9
E15	06-Mar-25	Polar Guard® Advance	IV-EG	Aluminum	Moderate Rain mixed with Snow	0	75	-	-	76.5	17.9	18.2
E16	06-Mar-25	Polar Guard® Advance	IV-EG	Aluminum	Moderate Rain mixed with Snow	0	75	-	-	76.5	19.0	19.4
E17	06-Mar-25	Ecowing AD-2	II	Aluminum	Moderate Rain mixed with Snow	0	75	-	-	76.4	14.2	14.4
E18	06-Mar-25	AeroClear MAX	III	Aluminum	Moderate Rain mixed with Snow	0	75	-	-	76.4	9.6	9.8
E19	06-Mar-25	Polar Guard® Advance	IV-PG	Aluminum	Moderate Rain mixed with Snow	0	75	-	-	76.4	17.7	18.0
E20	06-Mar-25	EG106	IV-EG	Aluminum	Moderate Rain mixed with Snow	0	75	-	-	76.4	15.7	16.0

Table 3.3: Test Log – 2024-25 Mixed Snow and Rain Endurance Time Testing at the NRC CEF (cont’d)

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Actual Rate (Snow-Only) (g/dm ² /h)	Actual Rate (Rain-Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
E21	06-Mar-25	Ecowing AD-2	II	Aluminum	Moderate Rain mixed with Snow	0	75	14.1	64.6	78.7	13.1	13.8
E22	06-Mar-25	Ecowing AD-2	II	Aluminum	Moderate Rain mixed with Snow	0	75	14.1	64.6	78.7	14.3	15.0
E23	06-Mar-25	AeroClear MAX	III	Aluminum	Moderate Rain mixed with Snow	0	75	14.1	64.6	78.7	8.6	9.1
E24	06-Mar-25	AeroClear MAX	III	Aluminum	Moderate Rain mixed with Snow	0	75	14.1	64.6	78.7	8.7	9.1
E25	06-Mar-25	Polar Guard® Advance	IV-PG	Aluminum	Moderate Rain mixed with Snow	0	75	14.1	64.6	78.7	17.6	18.5
E26	06-Mar-25	Polar Guard® Advance	IV-PG	Aluminum	Moderate Rain mixed with Snow	0	75	14.1	64.6	78.7	18.8	19.7
E27	06-Mar-25	EG106	IV-EG	Aluminum	Moderate Rain mixed with Snow	0	75	14.1	64.6	78.7	14.8	15.5
E28	06-Mar-25	EG106	IV-EG	Aluminum	Moderate Rain mixed with Snow	0	75	14.1	64.6	78.7	14.8	15.6

Table 3.4: Test Log – 2024-25 Snow Mixed with Mist Endurance Time Testing at the NRC CEF

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Target Rate (Snow-Only) (g/dm ² /h)	Target Rate (Mist-Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
17	5-Mar-25	Ecowing AD-2	II	Aluminum	Snow Mixed with Mist	-3	25.4	25	0.4	27	49.0	52.1
18	5-Mar-25	Ecowing AD-2	II	Aluminum	Snow Mixed with Mist	-3	25.4	25	0.4	27	59.3	63.1
19	5-Mar-25	AeroClear MAX	III	Aluminum	Snow Mixed with Mist	-3	25.4	25	0.4	27	28.8	30.6
20	5-Mar-25	AeroClear MAX	III	Aluminum	Snow Mixed with Mist	-3	25.4	25	0.4	27	26.5	28.2
21	5-Mar-25	Polar Guard® Advance	IV-PG	Aluminum	Snow Mixed with Mist	-3	25.4	25	0.4	27	63.6	67.6
22	5-Mar-25	Polar Guard® Advance	IV-PG	Aluminum	Snow Mixed with Mist	-3	25.4	25	0.4	27	65.9	70.0
23	5-Mar-25	Clearwing EG	IV-EG	Aluminum	Snow Mixed with Mist	-3	25.4	25	0.4	27	54.6	58.1
24	5-Mar-25	Clearwing EG	IV-EG	Aluminum	Snow Mixed with Mist	-3	25.4	25	0.4	27	48.2	51.2
29	4-Mar-25	Ecowing AD-2	II	Aluminum	Snow Mixed with Mist	-14	10.4	10	0.4	11.5	38.3	42.4
30	4-Mar-25	Ecowing AD-2	II	Aluminum	Snow Mixed with Mist	-14	10.4	10	0.4	11.5	38.3	42.4
31	4-Mar-25	AeroClear MAX	III	Aluminum	Snow Mixed with Mist	-14	10.4	10	0.4	11.5	74.2	82.0
32	4-Mar-25	AeroClear MAX	III	Aluminum	Snow Mixed with Mist	-14	10.4	10	0.4	11.5	77.5	85.7
33	4-Mar-25	Polar Guard® Advance	IV-PG	Aluminum	Snow Mixed with Mist	-14	10.4	10	0.4	11.5	58.6	64.8
34	4-Mar-25	Polar Guard® Advance	IV-PG	Aluminum	Snow Mixed with Mist	-14	10.4	10	0.4	11.5	59.1	65.4
35	4-Mar-25	Clearwing EG	IV-EG	Aluminum	Snow Mixed with Mist	-14	10.4	10	0.4	11.5	70.3	77.7
36	4-Mar-25	Clearwing EG	IV-EG	Aluminum	Snow Mixed with Mist	-14	10.4	10	0.4	11.5	76.7	84.8
53	3-Mar-25	Ecowing AD-2	II	Aluminum	Snow Mixed with Mist	-25	10.4	10	0.4	11.1	28.9	30.8
54	3-Mar-25	Ecowing AD-2	II	Aluminum	Snow Mixed with Mist	-25	10.4	10	0.4	11.1	28.9	30.9
55	3-Mar-25	AeroClear MAX	III	Aluminum	Snow Mixed with Mist	-25	10.4	10	0.4	11.1	84.9	90.6
56	3-Mar-25	AeroClear MAX	III	Aluminum	Snow Mixed with Mist	-25	10.4	10	0.4	11.1	78.1	83.3
57	3-Mar-25	Polar Guard® Advance	IV-PG	Aluminum	Snow Mixed with Mist	-25	10.4	10	0.4	11.1	38.8	41.4
58	3-Mar-25	Polar Guard® Advance	IV-PG	Aluminum	Snow Mixed with Mist	-25	10.4	10	0.4	11.1	38.9	41.6

Table 3.4: Test Log – 2024-25 Mixed Snow and Mist Endurance Time Testing at the NRC CEF (cont'd)

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Target Rate (Snow-Only) (g/dm ² /h)	Target Rate (Mist-Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
59	3-Mar-25	Clearwing EG	IV-EG	Aluminum	Snow Mixed with Mist	-25	10.4	10	0.4	11.1	66.3	70.7
60	3-Mar-25	Clearwing EG	IV-EG	Aluminum	Snow Mixed with Mist	-25	10.4	10	0.4	11.1	64.4	68.7
73	28-Feb-25	Ecowing AD-2	II	Aluminum	Snow	-3	10	10	0	10.5	102.2	107.3
75	28-Feb-25	AeroClear MAX	III	Aluminum	Snow	-3	10	10	0	10.5	44.9	47.2
77	28-Feb-25	Polar Guard® Advance	IV-PG	Aluminum	Snow	-3	10	10	0	10.5	121.9	128.0
79	28-Feb-25	Clearwing EG	IV-EG	Aluminum	Snow	-3	10	10	0	10.5	100.0	105.0
81	4-Mar-25	Ecowing AD-2	II	Aluminum	Snow	-14	10	10	0	10.8	32.1	34.7
82	4-Mar-25	Ecowing AD-2	II	Aluminum	Snow	-14	10	10	0	10.8	32.2	34.8
83	4-Mar-25	AeroClear MAX	III	Aluminum	Snow	-14	10	10	0	10.8	73.9	79.8
84	4-Mar-25	AeroClear MAX	III	Aluminum	Snow	-14	10	10	0	10.8	75.0	81.0
85	4-Mar-25	Polar Guard® Advance	IV-PG	Aluminum	Snow	-14	10	10	0	10.8	41.5	44.8
86	4-Mar-25	Polar Guard® Advance	IV-PG	Aluminum	Snow	-14	10	10	0	10.8	46.1	49.7
87	4-Mar-25	Clearwing EG	IV-EG	Aluminum	Snow	-14	10	10	0	10.8	66.7	72.0
88	4-Mar-25	Clearwing EG	IV-EG	Aluminum	Snow	-14	10	10	0	10.8	75.0	81.0
89	3-Mar-25	Ecowing AD-2	II	Aluminum	Snow	-25	10	10	0	10.1	21.6	21.8
90	3-Mar-25	Ecowing AD-2	II	Aluminum	Snow	-25	10	10	0	10.1	22.2	22.4
91	3-Mar-25	AeroClear MAX	III	Aluminum	Snow	-25	10	10	0	10.1	77.6	78.4
92	3-Mar-25	AeroClear MAX	III	Aluminum	Snow	-25	10	10	0	10.1	71.5	72.2
93	3-Mar-25	Polar Guard® Advance	IV-PG	Aluminum	Snow	-25	10	10	0	10.1	26.8	27.0
94	3-Mar-25	Polar Guard® Advance	IV-PG	Aluminum	Snow	-25	10	10	0	10.1	27.2	27.5
95	3-Mar-25	Clearwing EG	IV-EG	Aluminum	Snow	-25	10	10	0	10.1	64.0	64.7
96	3-Mar-25	Clearwing EG	IV-EG	Aluminum	Snow	-25	10	10	0	10.1	60.8	61.4

Table 3.4: Test Log – 2024-25 Mixed Snow and Mist Endurance Time Testing at the NRC CEF (cont'd)

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Target Rate (Snow-Only) (g/dm ² /h)	Target Rate (Mist-Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
R5	28-Feb-25	Ecowing AD-2	II	Aluminum	Snow Mixed with Mist	-3	10.4	10	0.4	12	110.9	128.0
R6	28-Feb-25	Ecowing AD-2	II	Aluminum	Snow Mixed with Mist	-3	10.4	10	0.4	12	141.1	162.8
R7	28-Feb-25	AeroClear MAX	III	Aluminum	Snow Mixed with Mist	-3	10.4	10	0.4	12	47.1	54.4
R8	28-Feb-25	AeroClear MAX	III	Aluminum	Snow Mixed with Mist	-3	10.4	10	0.4	12	50.5	58.2
R9	28-Feb-25	Polar Guard® Advance	IV-PG	Aluminum	Snow Mixed with Mist	-3	10.4	10	0.4	12	140.3	161.9
R10	28-Feb-25	Polar Guard® Advance	IV-PG	Aluminum	Snow Mixed with Mist	-3	10.4	10	0.4	12	140.7	162.3
R11	28-Feb-25	Clearwing EG	IV-EG	Aluminum	Snow Mixed with Mist	-3	10.4	10	0.4	12	96.9	111.8
R12	28-Feb-25	Clearwing EG	IV-EG	Aluminum	Snow Mixed with Mist	-3	10.4	10	0.4	12	97.0	111.9
E1	5-Mar-25	Ecowing AD-2	II	Aluminum	Snow	-3	25	25	0	25.4	31.1	31.6
E2	5-Mar-25	Ecowing AD-2	II	Aluminum	Snow	-3	25	25	0	25.4	43.0	43.7
E3	5-Mar-25	AeroClear MAX	III	Aluminum	Snow	-3	25	25	0	25.4	26.1	26.6
E4	5-Mar-25	AeroClear MAX	III	Aluminum	Snow	-3	25	25	0	25.4	27.9	28.4
E5	5-Mar-25	Polar Guard® Advance	IV-PG	Aluminum	Snow	-3	25	25	0	25.4	42.2	42.9
E6	5-Mar-25	Polar Guard® Advance	IV-PG	Aluminum	Snow	-3	25	25	0	25.4	41.5	42.1
E7	5-Mar-25	Clearwing EG	IV-EG	Aluminum	Snow	-3	25	25	0	25.4	51.5	52.3
E8	5-Mar-25	Clearwing EG	IV-EG	Aluminum	Snow	-3	25	25	0	25.4	47.8	48.6

Table 3.5: Test Log – 2024-25 Very Light or Light Snow Mixed with Rain or Drizzle Endurance Time Testing at the NRC CEF

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Target Rate (Snow-Only) (g/dm ² /h)	Target Rate (Rain/Freezing Rain-Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
1	07-Mar-25	Ecowing AD-2	II	Aluminum	Light Snow mixed with Light Rain	0	23	10	13	22.8	58.3	57.8
2	07-Mar-25	Ecowing AD-2	II	Aluminum	Light Snow mixed with Light Rain	0	23	10	13	22.8	54.9	54.4
3	07-Mar-25	AeroClear MAX	III	Aluminum	Light Snow mixed with Light Rain	0	23	10	13	22.8	24.4	24.2
4	07-Mar-25	AeroClear MAX	III	Aluminum	Light Snow mixed with Light Rain	0	23	10	13	22.8	23.7	23.5
5	07-Mar-25	Polar Guard® Advance	IV-PG	Aluminum	Light Snow mixed with Light Rain	0	23	10	13	22.8	57.7	57.2
6	07-Mar-25	Polar Guard® Advance	IV-PG	Aluminum	Light Snow mixed with Light Rain	0	23	10	13	22.8	55.8	55.3
7	07-Mar-25	Clearwing EG	IV-EG	Aluminum	Light Snow mixed with Light Rain	0	23	10	13	22.8	30.8	30.5
8	07-Mar-25	Clearwing EG	IV-EG	Aluminum	Light Snow mixed with Light Rain	0	23	10	13	22.8	31.7	31.5
17	26-Feb-25	Ecowing AD-2	II	Aluminum	Light Freezing Rain	-3	25	0	25	24.3	32.0	31.1
18	26-Feb-25	Ecowing AD-2	II	Aluminum	Light Freezing Rain	-3	25	0	25	24.7	42.3	41.8
19	26-Feb-25	AeroClear MAX	III	Aluminum	Light Freezing Rain	-3	25	0	25	24.6	23.3	22.9
20	26-Feb-25	AeroClear MAX	III	Aluminum	Light Freezing Rain	-3	25	0	25	24.7	25.0	24.7
21	26-Feb-25	Polar Guard® Advance	IV-PG	Aluminum	Light Freezing Rain	-3	25	0	25	25.2	45.9	46.3
22	26-Feb-25	Polar Guard® Advance	IV-PG	Aluminum	Light Freezing Rain	-3	25	0	25	24.5	35.5	34.7
23	26-Feb-25	Clearwing EG	IV-EG	Aluminum	Light Freezing Rain	-3	25	0	25	24.7	29.5	29.2
24	26-Feb-25	Clearwing EG	IV-EG	Aluminum	Light Freezing Rain	-3	25	0	25	24.9	27.9	27.8

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4. ANALYSIS

This section contains the analytical findings related to the mixed icing conditions testing conducted at the NRC CEF in 2024-25.

For each condition evaluated, the endurance time performance of the test fluids in the mixed icing conditions was compared to their performance in related single icing conditions that served as baseline. The relative fluid performance in the mixed icing condition was expressed as a ratio to assess the condition impact.

The ratio calculation is as follows:

$$\text{Relative Performance Ratio (\%)} = \frac{\text{Adjusted Mixed Condition Test Endurance Time}}{\text{Adjusted Baseline Condition Test Endurance Time}}$$

The relative performance ratio is referred to as the “ratio” in the subsequent analysis subsections.

4.1 Mixed Snow and Freezing Fog – Type I Testing

The Type I endurance times recorded in the mixed snow and freezing fog tests were compared to the baseline snow-only endurance times to assess the impact of the added freezing fog precipitation on the fluid performance.

The Type I fluid performance was evaluated by counting the number of snow application cycles, or “snow bursts,” required to bring the plate to failure. Expressing the results in this manner still accurately captures the performance of the Type I fluid in the mixed condition while reducing the potential impact of test process variance due to the shorter endurance times being evaluated.

For each row, the ratio represents the relative performance of the Type I fluid in the mixed snow and freezing fog condition as compared to the corresponding snow-only baseline (see Figure 2.3). This activity was a continuation of a research objective begun in 2022-23; the snow-only baseline values used for analysis are from the historical data. The previous mixed snow and freezing fog Type I test results are documented in TP 15610E (2).

The test results for the Type I fluid mixed snow and freezing fog tests are summarized in Table 4.1.

Table 4.1: 2024-25 Type I Mixed Snow and Freezing Fog Results

Test Surface	Temperature (°C)	Target Snow Rate (g/dm²/h)	Target Freezing Fog Rate (g/dm²/h)	Test Count	Average Application Cycle Ratio	Minimum Application Cycle Ratio
Aluminum	-3	10	1	2	108%	100%
		25	1	2	100%	100%
All Aluminum Tests				4	104%	100%
Composite	-3	10	1	2	100%	100%
		25	1	2	100%	100%
All Composite Tests				4	100%	100%
All Tests (All Surfaces)				8	102%	100%

The current guidance for use of Type I fluids in mixed snow and freezing fog conditions is to use a HOT equal to 80 percent of the snow-only baseline. This value was based on the worst-case results observed in the 2022-23 and 2023-24 testing (which was conducted with a target rate of 2 g/dm²/h for the freezing fog component of the mixed condition).

The Type I fluid performance in the 2024-25 mixed condition tests (conducted with a reduced fog rate of 1 g/dm²/h) was equivalent to or greater than the snow-only baseline performance in all cases on both aluminum and composite surfaces.

The test results suggest that Type I fluid endurance time performance in mixed snow and freezing fog at operationally relevant rates is equivalent to its snow-only endurance time performance in corresponding conditions. As such, it was recommended that TC/FAA consider increasing the guidance ratio for Type I fluids in mixed snow and freezing fog from 80 percent of the corresponding Moderate Snow HOT to 100 percent of the Snow HOT for future publications of the HOT Guidelines.

4.2 Mixed Moderate Rain and Snow Testing

Endurance time tests were conducted in mixed snow and rain at a series of different rate combinations to support the development of HOT guidance for the mixed conditions of Moderate Snow mixed with Rain and Moderate Rain mixed with Snow.

The results of the mixed condition tests were compared to rain on a CSW baseline tests to produce relative performance ratios. All mixed condition tests were conducted at a temperature of 0°C (to maintain a conservative test setup while ensuring the rain remained non-freezing).

This work was a continuation of a research objective begun in 2022-23. Testing in previous years evaluated a series of different combinations of mixed rain and snow conditions with a total combined precipitation rate of 75 g/dm²/h (but with differing constituent rain/snow rates) to determine which produces the worst-case endurance times.

Data collection in 2024-25 was performed to evaluate new rate combinations with a total combined precipitation rate of 100 g/dm²/h to the analysis to ensure the worst-case scenario has been evaluated. The newly tested rate combinations are as follows:

- 20 g/dm²/h snow + 80 g/dm²/h rain; and
- 25 g/dm²/h snow + 75 g/dm²/h rain.

Tests were also conducted using the capped rate combinations that produced the worst-case results in previous years:

- 15 g/dm²/h snow + 60 g/dm²/h rain; and
- 10 g/dm²/h snow + 65 g/dm²/h rain.

The test results for the Type II, Type III, and Type IV fluid mixed rain and snow tests are summarized below in Table 4.2.

Table 4.2: 2024-25 Type II, Type III, and Type IV Mixed Snow and Rain Results

Fluid Base	Temp. (°C)	Target Snow Rate (g/dm²/h)	Target Rain Rate (g/dm²/h)	Target Combined Rate (g/dm²/h)	Test Count	Average ET Ratio	Minimum ET Ratio
PG-based	0	25	75	100	4	94%	75%
		20	80	100	4	88%	74%
		15	60	75	4	103%	83%
		10	65	75	10	105%	79%
EG-based	0	25	75	100	4	101%	84%
		20	80	100	4	92%	82%
		15	60	75	4	82%	81%
		10	65	75	10	89%	76%
All Tests					44	95%	74%

The minimum ratios for all rate combinations tested (including tests conducted in 2022-23 and 2023-24) are shown in Figure 4.1, providing a visual representation of the trend in the thickened fluid performance as the rates of the constituent precipitation types change.

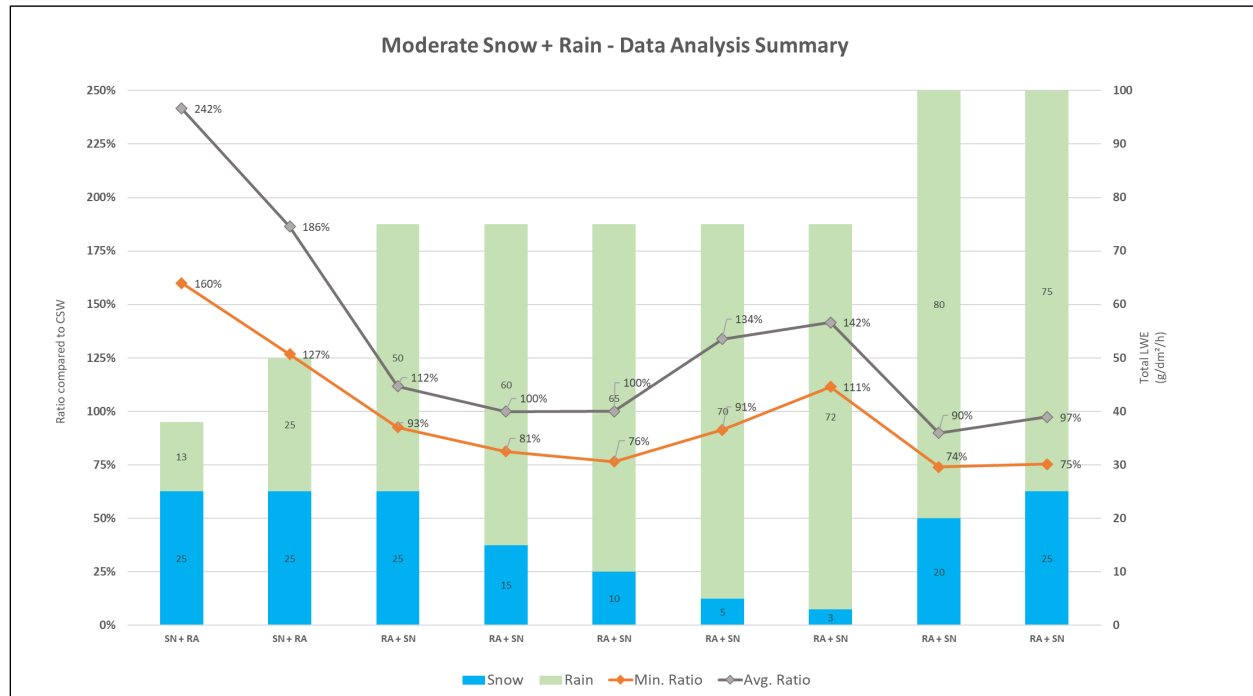


Figure 4.1: Worst-Case Type II/III/IV Performance Ratio at Different Rain and Snow Rate Combinations

When considering those tests capped at a combined rate of 75 g/dm²/h, Type II/III/IV fluids show a decreasing trend in fluid performance in the mixed condition compared to the CSW baseline tests as the rain rate was increased, with the worst-observed performance occurring during the “Rain 65 + Snow 10” combination. Fluid performance improved as the rain rate was increased beyond 65 g/dm²/h (with the snow rate being decreased accordingly).

The tests conducted in 2024-25 using the “Rain 65 + Snow 10” show results that were similar to those conducted in previous years, with a minimum performance ratio of 76 percent observed.

The Type II/III/IV fluid performance in the additive rate combinations (conducted with a combined rate of 100 g/dm²/h) was generally slightly worse, with observed performance ratios of 74 percent and 75 percent in the two combinations evaluated. For reference, the worst-observed performance ratio across all combined rate 75 g/dm²/h conditions tests was 76 percent at the Moderate Rain mixed with Snow combination of “Rain 65 + Snow 10.”

The total data collected indicated that fluid endurance time performance in mixed rain and snow was 75 percent or more of the fluid endurance time performance in a high-rate rain on a CSW condition regardless of the specific ratio of rain and snow in combination. For many fluids, the mixed condition performance was equivalent to or better than the CSW condition performance.

The combined test rate of 100 g/dm²/h at which the most restrictive tests were conducted represents the maximum liquid water equivalency of a potential moderate rain and snow scenario. Given the conservative nature of the rate combinations used to evaluate the mixed condition, it is believed that the test results could be used as a benchmark to establish safe HOT guidance for conditions of Moderate Rain mixed with Snow.

4.3 Mixed Snow and Mist Testing

Endurance time tests were conducted with Type II, III, and IV fluids in mixed snow and mist conditions. The results of the mixed condition tests were compared to snow-only baseline tests to produce relative performance ratios.

This work was a continuation of a research objective begun in 2023-24. Testing in 2024-25 used a different precipitation rate for mist; therefore, the 2024-25 data has been analysed alone. The test results are summarized below in Table 4.3.

Table 4.3: 2024-25 Type II, Type III, and Type IV Mixed Snow and Mist Results

Fluid	Temp. (°C)	Target Snow Rate (g/dm ² /h)	Target Mist Rate (g/dm ² /h)	Test Count	Average ET Ratio	Minimum ET Ratio
All Fluids (Type II, III, and IV)	-3	10	0.4	16	125%	100%
	-3	25	0.4	8	129%	100%
	-14	10	0.4	8	115%	100%
	-25	10	0.4	8	124%	105%
All Tests				40	124%	100%

The endurance times measured in the mixed snow and mist tests typically exceeded their corresponding snow-only baseline test. The worst-observed performance ratio in all the mixed conditions tests was 100 percent of the snow-only baseline.

It was previously noted during mixed icing testing conducted in 2021-22 that, in some cases, a fluid's performance in a mixed snow and freezing fog condition could surpass its performance in a corresponding snow-only condition. This phenomenon was described in TP 15540E (1). In that report, it was observed that the cases where the mixed condition performance was superior were due to a change in the fluid failure mechanism observed in the mixed condition. This interaction is demonstrated in Figure 4.2.

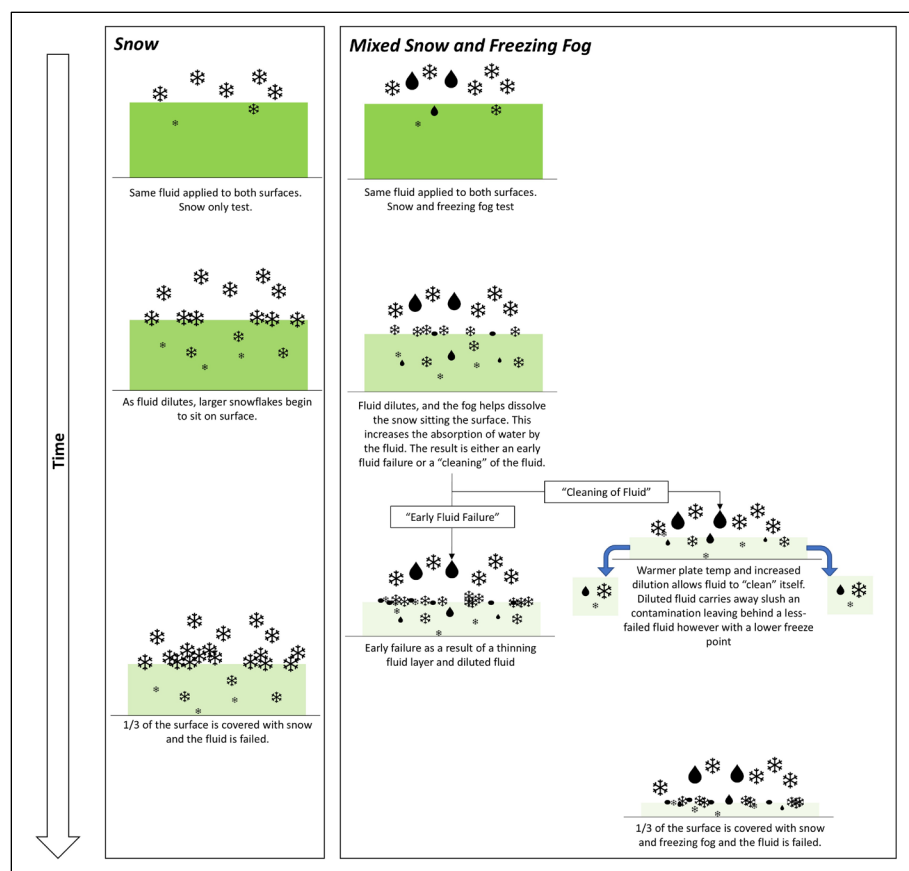


Figure 4.2: Fluid Failure Mechanism in Snow vs. Mixed Snow and Freezing Fog (from TP 15540E [1])

The improvement in the fluid performance observed in the mixed snow and mist condition is believed to be driven by the same change in the fluid failure mechanism. Additionally, the reduced LWE component of mist as compared to freezing fog is thought to explain why no instances where the mixed condition performance was inferior to the snow-only performance were observed.

Overall, the endurance times recorded in the mixed snow and mist endurance time tests suggest that the presence of mist does not have a significant impact on fluid endurance times in snow.

4.4 Light Snow Mixed with Rain Testing

Endurance time tests were conducted in mixed light snow and rain with Type II, Type III, and Type IV fluids to validate the historical guidance indicating that Light Freezing Rain HOTs can safely be applied in this mixed condition.

The results of the mixed condition tests were compared to light freezing rain baseline tests to produce relative performance ratios. All mixed condition tests were conducted at a temperature of 0°C (to maintain conservatism and to ensure the rain remained non-freezing).

The test results are summarized below in Table 4.4.

Table 4.4: 2024-25 Type II, Type III, and Type IV Light Snow Mixed with Rain Results

Temp	Fluid	Target Snow Rate (g/dm ² /h)	Target Rain Rate (g/dm ² /h)	Test Count	Average ET Ratio	Minimum ET Ratio
0°C	Type II PG	10	13	2	154%	149%
	Type III EG	10	13	2	100%	99%
	Type IV EG	10	13	2	109%	107%
	Type IV PG	10	13	2	139%	137%
All Tests				8	126%	99%

For all fluids tested, the mixed light snow and rain endurance time results were equivalent to or superior to the corresponding light freezing rain endurance time results at -3°C.

Given the results obtained and the conservative testing temperature used (0°C is the coldest temperature possible before rain becomes freezing rain), it is believed that the historical indication to use light freezing rain HOTs in conditions of very light or light snow mixed with rain or drizzle remains appropriate.

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5. CHANGES TO HOLDOVER TIME GUIDANCE MATERIAL FOR 2025-26

The results of the mixed icing tests were reviewed and discussed with TC and the FAA to determine the best path forward for further mixed icing HOT guidance development.

The discussions and decisions related to each icing condition evaluated are described within this section.

5.1 Mixed Snow and Freezing Fog

Following a review of the 2024-25 Type I mixed snow and freezing fog test data, it was determined by TC/FAA that the Type I HOT guidance for conditions of snow mixed with freezing fog would be increased from 80 percent of the corresponding Moderate Snow HOT to 100 percent of the Snow HOT for future publications of the HOT Guidelines.

The Type I aluminum HOT table from the 2025-26 TC HOT Guidelines including the new HOT values for Snow mixed with Freezing Fog is shown below in Figure 5.1 (the FAA version of the guidance is equivalent).

Outside Air Temperature ^{2,3}	Freezing Fog, Freezing Mist ⁴ , or Ice Crystals ⁵	Snow mixed with Freezing Fog ⁶	Very Light Snow, Snow Grains or Snow Pellets ^{7,8}	Light Snow, Snow Grains or Snow Pellets ^{7,8}	Moderate Snow, Snow Grains or Snow Pellets ^{7,8}	Freezing Drizzle ⁹	Light Freezing Rain	Moderate Snow mixed with Rain ^{10,11}	Rain on Cold-Soaked Wing ¹¹	Other ¹²
-3°C and above (27°F and above)	0:11 - 0:17	0:06 - 0:11	0:18 - 0:22	0:11 - 0:18	0:06 - 0:11	0:09 - 0:13	0:04 - 0:06	0:02 - 0:02	0:02 - 0:05	
below -3 to -6°C (below 27 to 21°F)	0:08 - 0:13	0:05 - 0:08	0:14 - 0:17	0:08 - 0:14	0:05 - 0:08	0:05 - 0:09	0:04 - 0:06	CAUTION: No holdover time guidelines exist		
below -6 to -10°C (below 21 to 14°F)	0:06 - 0:10	0:04 - 0:06	0:11 - 0:13	0:06 - 0:11	0:04 - 0:06	0:04 - 0:07	0:02 - 0:05			
below -10°C (below 14°F)	0:05 - 0:09	0:02 - 0:04	0:07 - 0:08	0:04 - 0:07	0:02 - 0:04					

NOTES

- These holdover times apply to aircraft with critical surfaces constructed predominantly or entirely of aluminum materials that have demonstrated satisfactory use of these holdover times. Takeoff after the longest applicable holdover time has been exceeded is not permitted for Type I fluids.
- Type I fluid / water mixture must be selected so that the freezing point of the mixture is at least 10°C (18°F) below outside air temperature.
- Ensure that the lowest operational use temperature (LOUT) is respected.
- Freezing mist is best confirmed by observation. It is never reported by METAR; however, it can occur when mist is present at 0°C (32°F) and below.
- Use freezing fog holdover times in conditions of ice crystals mixed with freezing fog or freezing mist.
- The Snowfall Intensities as a Function of Prevailing Visibility table (Table 54) is required to confirm that the precipitation intensity is no greater than "moderate". No holdover times exist if the reported visibility correlates to a "heavy" precipitation intensity.
- To determine snowfall intensity, the Snowfall Intensities as a Function of Prevailing Visibility table (Table 54) is required.
- Use snow holdover times in conditions of very light, light, or moderate snow mixed with ice crystals.
- Includes light, moderate and heavy freezing drizzle. Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
- These holdover times apply to conditions of "moderate" precipitation intensity. In cases of very light or light snow mixed with light rain or drizzle, use light freezing rain holdover times. The Snowfall Intensities as a Function of Prevailing Visibility table (Table 54) is required to confirm the precipitation intensity. No holdover times exist if the reported visibility correlates to a "heavy" precipitation intensity.
- No holdover time guidelines exist for this condition for 0°C (32°F) and below.
- Heavy snow, ice pellets, moderate and heavy freezing rain, small hail and hail.

CAUTIONS

- The cautions that apply to the holdover times in the table above can be found on page 11.

Figure 5.1: TC Type I Aluminum HOT Guidance from the 2025-26 HOT Guidelines

5.2 Mixed Snow and Rain

Following a review of the multi-year endurance time test data, it was determined by TC/FAA that HOT guidance for conditions of moderate snow mixed with rain would be provided for all fluid types in the 2025-26 HOT Guidelines.

For Type I fluids, the Moderate Snow mixed with Rain HOTs are equal to 100 percent of the corresponding (aluminum or composite) Type I HOT for the rain on a CSW condition. These HOTs are provided as a single time value based on the shorter CSW HOT value.

Note that no additional testing was conducted with Type I fluids in 2024-25; this guidance was established based on the test results obtained in 2022-23 and 2023-24 (see TP15610E [2]).

For Type II, Type III, and Type IV fluids, the Moderate Snow mixed with Rain HOTs are equal to or greater than 75 percent of the fluid-specific HOT for the rain on a CSW condition. These HOTs are provided as a single time value based on the shorter CSW HOT value.

A sample Type IV HOT table from the 2025-26 TC HOT Guidelines including the newly added column containing the Moderate Snow mixed with Rain guidance is shown below in Figure 5.2.

Outside Air Temperature ¹	Fluid Concentration Fluid/Water By % Volume	Freezing Fog, Freezing Mist ² , or Ice Crystals ³	Snow mixed with Freezing Fog ⁴	Very Light Snow, Snow Grains or Snow Pellets ^{5,6}	Light Snow, Snow Grains or Snow Pellets ^{5,6}	Moderate Snow, Snow Grains or Snow Pellets ^{5,6}	Freezing Drizzle ⁷	Light Freezing Rain	Moderate Snow mixed with Rain ^{8,9}	Rain on Cold-Soaked Wing ⁹	Other ¹⁰
-3°C and above (27°F and above)	100/0	2:50 - 4:00	0:50 - 1:25	2:00 - 2:00	1:55 - 2:00	1:05 - 1:55	1:35 - 2:00	1:15 - 1:30	0:10 - 0:10	0:15 - 2:00	CAUTION: No holdover time guidelines exist
	75/25	2:30 - 4:00	0:30 - 1:05	2:00 - 2:00	1:25 - 2:00	0:40 - 1:25	1:40 - 2:00	0:40 - 1:10	0:07 - 0:07	0:09 - 1:40	
	50/50	0:50 - 1:25	0:07 - 0:20	1:10 - 1:35	0:25 - 1:10	0:10 - 0:25	0:20 - 0:45	0:09 - 0:20			
below -3 to -8°C (below 27 to 18°F)	100/0	0:55 - 2:30	0:35 - 1:05	2:00 - 2:00	1:25 - 2:00	0:50 - 1:25	0:35 - 1:35	0:35 - 0:45			
	75/25	0:40 - 1:30	0:25 - 0:50	2:00 - 2:00	1:05 - 2:00	0:30 - 1:05	0:25 - 1:05	0:35 - 0:45			
below -8 to -14°C (below 18 to 7°F)	100/0	0:55 - 2:30	0:30 - 0:50	2:00 - 2:00	1:10 - 2:00	0:40 - 1:10	0:35 - 1:35 ¹¹	0:35 - 0:45 ¹¹			
	75/25	0:40 - 1:30	0:20 - 0:45	2:00 - 2:00	0:55 - 2:00	0:25 - 0:55	0:25 - 1:05 ¹¹	0:35 - 0:45 ¹¹			
below -14 to -18°C (below 7 to 0°F)	100/0	0:25 - 0:50	0:08 - 0:25	1:35 - 2:00	0:35 - 1:35	0:10 - 0:35					
below -18 to -25°C (below 0 to -13°F)	100/0	0:25 - 0:50	0:03 - 0:10	0:40 - 0:55	0:15 - 0:40	0:04 - 0:15					
below -25 to -30.5°C (below -13 to -23°F)	100/0	0:25 - 0:50	0:02 - 0:05	0:25 - 0:30	0:07 - 0:25	0:02 - 0:07					

NOTES

- 1 Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I fluid when Type IV fluid cannot be used.
- 2 Freezing mist is best confirmed by observation. It is never reported by METAR; however, it can occur when mist is present at 0°C (32°F) and below.
- 3 Use freezing fog holdover times in conditions of ice crystals mixed with freezing fog or freezing mist.
- 4 The Snowfall Intensities as a Function of Prevailing Visibility table (Table 54) is required to confirm that the precipitation intensity is no greater than "moderate". No holdover times exist if the reported visibility correlates to a "heavy" precipitation intensity.
- 5 To determine snowfall intensity, the Snowfall Intensities as a Function of Prevailing Visibility table (Table 54) is required.
- 6 Use snow holdover times in conditions of very light, light, or moderate snow mixed with ice crystals.
- 7 Includes light, moderate and heavy freezing drizzle. Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
- 8 These holdover times apply to conditions of "moderate" precipitation intensity. In cases of very light or light snow mixed with light rain or drizzle, use light freezing rain holdover times. The Snowfall Intensities as a Function of Prevailing Visibility table (Table 54) is required to confirm the precipitation intensity. No holdover times exist if the reported visibility correlates to a "heavy" precipitation intensity.
- 9 No holdover time guidelines exist for this condition for 0°C (32°F) and below.
- 10 Heavy snow, ice pellets, moderate and heavy freezing rain, small hail and hail (Table 53 provides allowance times for Type IV PG fluids in ice pellets and small hail).
- 11 No holdover time guidelines exist for this condition below -10°C (14°F).

CAUTIONS

- The cautions that apply to the holdover times in the table above can be found on page 31.

Figure 5.2: Type IV HOT Table from the 2025-26 TC HOT Guidelines

5.3 Mixed Snow and Mist

Currently, no specific HOT guidance for mixed snow and mist conditions exists within the TC/FAA HOT Guidelines. Operators are currently allowed to use the Snow HOTs in conditions of mixed snow and mist, owing to an allowance written into the TC/FAA visibility tables relating to an obscuration to visibility.

The mixed snow and mist endurance time test data suggests that the presence of mist does not have a significant impact on fluid endurance times in snow and that the existing Snow HOTs are likely safe for use in cases of snow mixed with mist.

However, members of the MWG provided feedback during a technical review of the mixed icing research, indicating that issues with the reporting of mist and drizzle conditions in Canada and the US could potentially result in light drizzle conditions being misreported as mist. There was concern that in these cases, the actual LWE of the non-snow component of the mixed condition could be greater than the test rates used to simulate mist during the testing session.

Due to these concerns, TC and the FAA concluded that additional research and investigation into the METAR reporting environment would be required before conclusive HOT guidance could be issued for mixed snow and mist conditions. This remains an active area of ongoing research.

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6. CONCLUSIONS

The following conclusions were derived from the mixed icing conditions research conducted in the winter of 2024-25.

6.1 Snow Mixed with Freezing Fog Testing

The Type I fluid performance in the 2024-25 mixed condition tests (conducted with a reduced fog rate of 1 g/dm²/h) was equivalent to or greater than the snow-only baseline performance in all cases on both aluminum and composite surfaces.

The test results suggest that Type I fluid endurance time performance in mixed snow and freezing fog at operationally relevant rates is equivalent to its snow-only endurance time performance in corresponding conditions. As such, it was recommended that TC/FAA consider increasing the guidance ratio for Type I fluids in mixed snow and freezing fog from 80 percent of the corresponding Moderate Snow HOT to 100 percent of the Moderate Snow HOT for future publications of the HOT Guidelines.

6.2 Moderate Rain Mixed with Snow Testing

The data collected over three years of testing indicates that Type II, Type III, and Type IV fluid endurance time performance in mixed rain and snow was 75 percent or more of the fluid endurance time performance in a high-rate rain on a CSW condition regardless of the specific ratio of rain and snow in the mixed combination. For many fluids, the mixed condition performance was equal to or better than the CSW condition performance.

The combined test rate of 100 g/dm²/h at which the most restrictive tests were conducted represents the maximum liquid water equivalency of a potential moderate rain and snow scenario. Given the conservative nature of the rate combinations used to evaluate the mixed condition, it is believed that the test results could be used as a benchmark to establish safe HOT guidance for conditions of Moderate Rain mixed with Snow.

6.3 Snow Mixed with Mist Testing

The endurance time data collected demonstrated no reduction in fluid performance in mixed snow and mist as compared to the fluid performance in an equivalent snow-only condition for any of the fluids evaluated.

Although the mixed snow and mist endurance time test data suggested that the presence of mist does not have a significant impact on fluid endurance times in snow, it was determined by TC and the FAA that concerns related to the reporting of mist and drizzle conditions could potentially result in drizzle conditions being misreported as mist.

As such, it was determined that additional research would be necessary before conclusive HOT guidance could be issued for mixed snow and mist conditions.

6.4 Light Snow Mixed with Rain Testing

For all fluids tested, the mixed light snow and rain endurance time results were equivalent to or superior to the corresponding light freezing rain endurance time results at -3°C.

Given the results obtained and the conservative testing temperature used (0°C is the coldest temperature possible before rain becomes freezing rain), it is believed that the historical advice to use Light Freezing Rain HOTs in conditions of very light or light snow mixed with rain or drizzle remains appropriate.

6.5 Changes to Mixed Icing Guidance in the HOT Guidelines

Following a review of the test data and subsequent technical discussions with TC and the FAA, several mixed icing guidance changes were made for the 2025-26 HOT Guidelines publication, outlined below.

6.5.1 Changes to Type I Mixed Snow and Freezing Fog Guidance

The guidance for Type I fluids in Mixed Snow and Freezing Fog conditions is being modified to be equal to 100 percent of the corresponding Moderate Snow generic Type I HOTs.

6.5.2 Changes to Mixed Snow and Rain Guidance

Following a review of the multi-year endurance time test data, it was determined by TC/FAA that HOT guidance for conditions of Moderate Snow mixed with Rain would be provided for all fluid types in the 2025-26 HOT Guidelines.

For Type I fluids, the Moderate Snow mixed with Rain HOTs are equal to 100 percent of the corresponding (aluminum or composite) Type I HOT for the rain on a CSW condition. These HOTs are provided as a single time value based on the shorter CSW HOT value.

For Type II, Type III, and Type IV fluids, the Moderate Snow mixed with Rain HOTs are equal to 75 percent of the fluid-specific HOT for the rain on a CSW condition. These HOTs are provided as a single time value based on the shorter CSW HOT value.

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7. RECOMMENDATIONS

It is recommended that additional mixed icing conditions research be conducted next year to address the outstanding testing and guidance development objectives identified during the 2024-25 program.

The priorities for mixed icing conditions testing and development in Winter 2025-26 have been identified in consultation with TC and the FAA and are listed below.

- Conduct natural conditions precipitation rate data collection to further characterize the following conditions:
 - Freezing Mist mixed with Freezing Drizzle; and
 - Freezing Fog mixed with Freezing Drizzle.
- Conduct simulated mixed icing condition endurance time testing in the following conditions:
 - Snow mixed with Freezing Drizzle; and
 - Snow mixed with Freezing Rain.

It is expected that the above data collection activities will improve the characterization of icing conditions involving mist and, in turn, support future guidance development activities.

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REFERENCES

1. Bernier, B., Posteraro, D., *Evaluation of Fluid Endurance Times in Mixed Snow and Freezing Fog Conditions*, APS Aviation Inc., Transport Canada, Montreal, March 2023, TP 15540E, 74.
2. Bernier, B., *Testing and Evaluation of Mixed Phase Icing Conditions: Winter 2023-24*, APS Aviation Inc., Transport Canada, Montreal, December 2024, TP 15610E, 62.
3. APS Aviation Inc., *Aircraft Ground Icing General Research Activities During the 2024-25 Winter*, APS Aviation Inc., Transport Canada, Montreal, December 2025, TP 15684E, XX (to be published).
4. SAE International Aerospace Recommended Practice 5485B, *Endurance Time Test Procedures for SAE Type II/III/IV Aircraft Deicing/Anti-Icing Fluids*, October 2017.
5. APS Aviation Inc., *Aircraft Ground Icing General Research Activities During the 2008-09 Winter*, APS Aviation Inc., Transportation Development Centre, Montreal, December 2009, TP 14936E, 68.

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APPENDIX A

**TRANSPORT CANADA
STATEMENT OF WORK EXCERPT –
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2024-25**

**TRANSPORT CANADA
STATEMENT OF WORK EXCERPT –
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2024-25**

1. Mixed Icing Analysis, Research, and Testing to Support METAR Working Group and Guidance Development

- a) Review and update the list of mixed icing conditions identified by the METAR working group (MWG) and categorize the identified conditions by level-of-effort required for HOT guidance development;
- b) Review and refine existing test methodologies and procedures for simulating mixed icing precipitation conditions including:
 - i. Snow mixed with Freezing Fog;
 - ii. Snow mixed with Rain;
 - iii. Snow mixed with Freezing Mist; and
 - iv. Any other priority mixed icing conditions identified by the MWG.
- c) Conduct comparative endurance time testing at the NRC-CEF in the above-listed conditions (expected 10 days testing at climatic facility);
- d) Analyze comparative test results;
- e) Hold technical discussions with TC/FAA and develop necessary guidance material;
- f) Prepare presentation for SAE G-12; and
- g) Prepare a report.

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APPENDIX B

PROCEDURE:

**EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS
WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS**

301351

PROCEDURE:

**EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS
WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS**

Winter 2024-25

Prepared for:

**Transport Canada
Programs Group Innovation Centre**

In cooperation with:

**Federal Aviation Administration
William J. Hughes Technical Center**

**Transport Canada
Civil Aviation**

**Federal Aviation Administration
Flight Standards – Air Carrier Operations**

Prepared by: Peter Kitchener 

Reviewed by: Benjamin Bernier 

Approved by: Marco Ruggi 



February 19, 2025
Final Version 1.0

EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

Winter 2024-25

1. BACKGROUND

Holdover time (HOT) guidance is currently provided to industry in the form of generic and fluid-specific guidance tables that provide operators time ranges for safe operation after anti-icing in various environmental conditions. Most of the HOT guidance that is currently published has been developed for conditions where only one precipitation type is present.

One of the primary goals of Transport Canada (TC) and the Federal Aviation Administration (FAA)'s ongoing HOT research and development is to maximize operational capabilities for air operators in winter conditions. In recent years, there have been calls from industry to make mixed icing conditions a research priority and to reduce the number of occurrences where operations are restricted by a lack of existing HOT guidance.

To provide continuous improvement to the existing mixed icing conditions guidance, APS Aviation Inc. (APS) provides support to the METAR Working Group (MWG), which includes technical experts and meteorologists from TC, the FAA, APS, and the National Center for Atmospheric Research (NCAR). This support includes participation in meetings, development of project objectives, discussions of technical content, and direction of research efforts.

TC and the FAA tasked APS with developing testing methodologies suitable for evaluating anti-icing fluid performance in mixed icing conditions identified as priorities by the MWG, with the intent to obtain the data necessary to develop HOT guidance for these conditions. These testing methodologies are detailed out in Section 4.

2. OBJECTIVE

The objective of this testing is to conduct endurance time testing in simulated mixed icing conditions.

To satisfy this objective, a series of flat plate fluid endurance time tests will be conducted at the National Research Council Canada (NRC) Climatic Engineering Facility (CEF) in a variety of conditions including Snow and Freezing Mist, Moderate Rain and Snow, Moderate Snow and Rain, Snow and Freezing Fog, Light Rain and Snow, and Light Snow and Rain.

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The data collected will be used to support the development of HOT guidance material for operations in mixed icing conditions and support the research into precipitation rate sensitivity in mixed conditions.

3. TIMING AND TEST PLAN

A total of ten days of testing are expected. The following four main testing objectives will be targeted:

- Snow + Freezing Mist;
- Moderate Rain/Snow + Snow/Rain;
- Snow + Freezing Fog; and
- Light Rain/Snow + Snow/Rain.

Testing will be conducted at the NRC during regular daytime hours of 8:00 am to 4:00 pm. Extra hours after 4 pm will be considered on a day-by-day basis as required. A test calendar is included in Table 3.1.

Table 3.1: Test Calendar

Monday	Tuesday	Wednesday	Thursday	Friday
Feb. 24	Feb. 25	Feb. 26	Feb. 27	Feb. 28
SETUP DAY/ CALIBRATION - DAY 1	TESTING - DAY 2	TESTING - DAY 3	TESTING - DAY 4	TESTING - DAY 5
NO TESTING	Moderate Snow + Rain	Moderate Snow + Rain	Moderate Snow + Rain	Snow + Freezing Fog Light Snow + Rain
	Guidance Development / Rate Sensitivity Research	Guidance Development / Rate Sensitivity Research	Guidance Development / Rate Sensitivity Research	Research
Mar. 3	Mar. 4	Mar. 5	Mar. 6	Mar. 7
TESTING - DAY 6	TESTING - DAY 7	TESTING - DAY 8	TESTING - DAY 9	TESTING - DAY 10
Snow + Freezing Mist Guidance Development	Snow + Freezing Mist Guidance Development	Snow + Freezing Mist Guidance Development	Snow + Freezing Mist Guidance Development	Snow + Freezing Mist Guidance Development

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EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

4. TESTING METHODOLOGY

The NRC CEF is a temperature-controlled facility. Prior to testing, the desired temperature will be set by NRC staff and allowed to stabilize.

Representative Type I/II/III/IV propylene glycol (PG) and ethylene glycol (EG)-based fluids in the 100/0 dilution (10-degree buffer for Type I) shall be evaluated in a variety of mixed icing conditions.

The required fluids are shown in Table 4.1. Fluids that will be used the first day of testing should be placed inside the chamber overnight at the NRC. Fluids should be stored at their test temperature, either inside the chamber or in coolers, a minimum of 12 hours prior to testing.

Table 4.1: Fluids Available for Mixed Icing Tests

Fluid	Type	EG or PG	APS Fluid Code	Dilution	Jugs (L)	Pour Containers (1 L)	Total Fluids (L)
DOW PG ADF Concentrate	I	PG	097A	Conc.	3 x 20 L	8 (empty)	60
CHEMR REG I	I	EG	104A	Conc.	3 x 20 L	8 (empty)	60
Ecowing AD-2	II	PG	083A	100/0	5 x 20 L	8 (empty)	100
AeroClear MAX	III	EG	150A	100/0	5 x 20 L	8 (empty)	100
Polar Guard Advance	IV	PG	068A	100/0	5 x 20 L	8 (empty)	100
EG106	IV	EG	117A	100/0	5 x 20 L	8 (empty)	100
ABC-S Plus	IV	PG	123A	100/0	4 x 20 L	8 (empty)	80
Clearwing EG	IV	EG	093A	100/0	4 x 20 L	8 (empty)	80
ChemR EG IV	IV	EG	075A	100/0	4 x 20 L	8 (empty)	80
Total Fluids							760

Subsections 4.1 to 4.4 describe the basic test parameters for the different test sets that will be simulated.

A detailed test matrix (subject to change) is included in Attachment 3, Attachment 4, Attachment 5, and Attachment 6. As this testing is exploratory, changes to the test plan may be proposed and made by APS at the time of testing and will be confirmed by TC/FAA.

4.1 Mixed Snow and Freezing Mist

Mist and fog are commonly reported weather phenomena. Both are considered an obscuration rather than a type of precipitation and can be reported alone or in conjunction with other weather conditions such as snow, freezing rain, et cetera. Mist is defined as a lower-density form of fog rather than as a distinct type of obscuration; mist can reduce visibility to between 0.6 and 1.2 statute miles (~1 to 2 km), whereas fog reduces it to less than 0.6 statute miles (~1 km).

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As part of the continuous effort for guidance development and support of separate concurrent research projects, TC/FAA has decided to conduct preliminary tests in conditions involving mixed snow and mist (below 0°C). For these tests, mist will be simulated by producing fog at a lower-than-typical rate.

Figure 4.1 demonstrates the basic test parameters for the mixed condition of mixed snow and freezing mist. When testing freezing mist, a rate of between 0.3 g/dm²/h to 0.4 g/dm²/h should be used at all temperatures. Different sets of test parameters may also be evaluated, based on the initial results obtained.

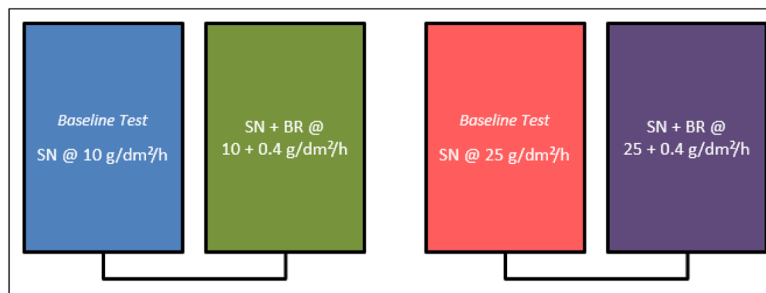


Figure 4.1: Comparative Test Sets (Snow & Freezing Mist)

4.2 Mixed Moderate Rain and Snow, and Moderate Snow and Rain

Rain (RA) consists of liquid water particles either in the form of drops of more than 0.5 mm diameter, or of smaller widely scattered drops. The precipitation rate limits for endurance time testing in moderate rain are 25 and 75 g/dm²/h. The precipitation rate limits for endurance time testing in moderate snow are 10 and 25 g/dm²/h.

During the 2022-23 testing in this mixed condition, an analysis of potential baseline conditions for comparison was conducted. It was determined that the "Rain on a Cold-Soaked Wing" condition was the most suitable baseline for comparison. This determination was based on the similarity in the rate limits used in testing (particularly the upper rate limit of 75 g/dm²/h used in cold-soaked wing conditions).

Figure 4.2 demonstrates the basic test parameters for the mixed condition moderate rain/snow and snow/rain, as conducted, and analysed in the winter of 2024-25. Additional different sets of test parameters may also be evaluated, based on the initial results obtained.

EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

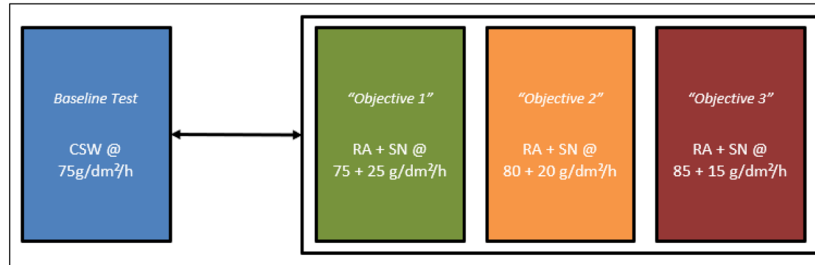


Figure 4.2: Comparative Test Sets (Moderate Snow & Rain)

4.3 Mixed Snow and Freezing Fog – Type I Testing

On behalf of the FAA and TC, APS conducted a series of mixed snow and freezing fog tests in the winter of 2021-22, 2022-23, and 2023-24, which led to the publication of fluid-specific HOTs for this mixed condition. Following the publication of the guidance, the industry continues to express concerns relating to limited operational usability and the duration of some of the shorter HOTs provided for Type I fluids. Testing in this condition has undergone improvements to the snow dispensing cycles to provide better minute-by-minute resolution for the shorter expected endurance times. Continuing the research from 2023-24, the objective is to conduct additional tests at lower freezing fog rates to determine whether a longer protection times for Type I fluids are possible in mixed snow and freezing fog.

Figure 4.3 demonstrates the basic test parameters for the mixed condition of snow mixed with freezing fog. When testing freezing fog, a rate of 1.0 g/dm²/h will be used for warmer temperatures, while a lower rate of 0.7 g/dm²/h will be used for colder temperatures. Different sets of test parameters may also be evaluated, based on the initial results obtained.

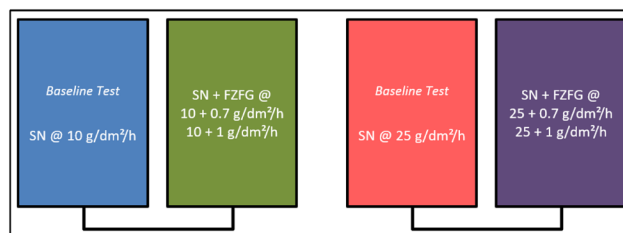


Figure 4.3: Comparative Test Sets (Snow & Freezing Fog)

EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

4.4 Mixed Light Rain and Snow, and Light Snow and Rain

Light Rain (-RA) consists of liquid water particles either in the form of drops of more than 0.5 mm diameter, or of smaller widely scattered drops. The precipitation rate limits for endurance time testing in light rain are 13 and 25 g/dm²/h. The precipitation rate limits for endurance time testing in light snow are 4 and 10 g/dm²/h.

During the winter of 2008-09, testing was conducted to evaluate operations in mixed conditions, with a liquid water equivalent (LWE) rate of 25 g/dm²/h, combining 13 g/dm²/h of rain and 12 g/dm²/h of snow at +1°C. The analysis concluded that light freezing rain HOTs could be applied to light snow and rain conditions. Since then, the MWG has emphasized that testing should consider the additive effect of maximum rates for mixed conditions. The current testing aims for this winter is to validate the 2008-09 findings and improve the understanding of rate sensitivity in mixed conditions.

Figure 4.4 demonstrates the basic test parameters for the mixed condition light rain/snow and light snow/rain. Different sets of test parameters may also be evaluated, based on the initial results obtained.

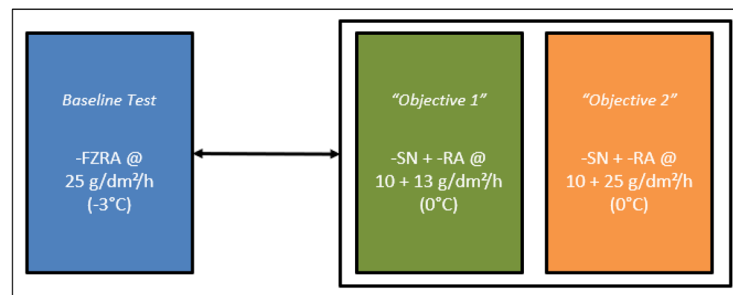


Figure 4.4: Comparative Test Sets (Light Snow & Rain)

EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

5. TESTING PROCEDURE

The following subsections describe the tasks to be performed during each test conducted. The standard HOT testing procedures will be followed and modified as required to accommodate the mixed precipitation testing setup.

5.1 Fluid Application

The steps listed below should be followed for fluid application.

- Hand-pour 1 L of Type II, III, or IV fluid at outside air temperature (OAT) or 1 L of Type I fluid at 20°C over the test plate. The type of fluid poured on the designated test plate will be decided prior to the beginning of the test.
- Record fluid application time and fluid failure time.
- Measure the fluid Brix prior to pouring, the fluid thickness 5 minutes after application, and the Brix at time of fluid failure.
- Photograph the fluid as the test continues until fluid failure and 5 minutes after fluid failure.

5.2 Application of Precipitation

The simulated precipitation that can be generated include the following:

- Freezing Fog at rates of 0.7 or 1 g/dm²/h*;
- Freezing Mist at rates of 0.3 to 0.4 g/dm²/h;
- Snow at rates of 10 or 25 g/dm²/h;
- Rain at rates of 13, 25, 75, 80, or 85 g/dm²/h; and
- Freezing Rain at rates of 25 g/dm²/h.

*These rates were reduced from the usual 2-5 g/dm²/h for HOT testing based on the more recent data collected, which is included in Subsection 5.2.2.

A rate management program will be used to assist in managing the measurement of precipitation rates. When measuring precipitation rates in mixed conditions, a process is followed to ensure both precipitation types are measured correctly.

Firstly, freezing or non-freezing precipitation (e.g., freezing fog, rain) is measured using plastic rate pans across the test stand. Once a consistent and repeatable rate is established across the test stand, frozen precipitation (e.g., snow) is added to the test, using the dispensing method shown in Subsection 5.2.3 for a set period

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(typically 10 minutes). The frozen precipitation rate is determined by subtracting the freezing condition rate from the total measured rate.

In addition, precipitation rates are continuously measured at the four corner locations of the test stand, with the average recorded rates serving as the final test rate applicable to the nearby tests (i.e., rate of plate 1 is associated to plates 2 and 3). Adjustments to the recorded endurance times can be made according to the ratio difference in rate to the baseline.

5.2.1 NRC Sprayer Assembly

Simulated precipitation is created using an NRC-developed sprayer assembly, providing a large scan area and appropriate spray uniformity over the test area. The scanner consists of a horizontal main shaft supported by two bearings. The actual spray head assembly is shaft-mounted on a rotating scanner, so that one scan covers a lateral running strip of the testing area. A stepper motor is synchronised to index the relative angle of the spray head between scans along an axis perpendicular to the scan axis. This provides two axes of rotation, essentially an x-y plane, one along each axis. Each scan is consecutively indexed to complete the precipitation coverage of the test bed area. This defines one cycle of the spray unit. The scan rate, index angle, and the number of scans per cycle are adjusted, along with the fluid delivery pressures (water and air) to obtain appropriate droplet sizes and precipitation rates. The sprayer system uses compressed air and distilled water. The sprayer assembly is shown in Photo 5.1.

Photo 5.1: Sprayer Assembly



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5.2.2 Simulated Freezing Fog & Mist Rates

Deposition rates for mist were initially quantified during 2020-21. In 2021-22, the research scope expanded to include freezing fog. Previously, freezing fog deposition rates had been quantified in the early 2000s. For more information concerning this study, see Subsection 3 of the TC report, TP 15608E, *Aircraft Ground Icing General Research Activities During the 2023-24 Winter* (1).

The recommended deposition rates for mixed conditions based on the research conducted including simulated freezing fog and mist are provided in the Table 5.1.

Table 5.1: Summary of Simulated Freezing Fog & Mist Deposition Rates

Precipitation Condition	Temperature	Determined Deposition Rates (g/dm ² /h)		Deposition Rates to be used for Simulated Testing (g/dm ² /h)	
		Min. Rate	Max. Rate	Min. Rate	Max. Rate
Freezing Fog	-3°C and above	0.5	1	0.5	1
	-10°C	0.2	0.7	0.2	0.7
	-14°C	0.1	0.7		
	-25°C	0.1	0.6		
Mist	-3°C and above	0.2	0.4	0.2	0.4
	-10°C	0.1	0.3	0.1	0.3
	-14°C	0.1	0.3		
	-25°C	0.1	0.3		

5.2.3 Simulated Snow (Type II/III/IV Fluids)

Calibration work was completed during the winter of 2021-22 with the purpose of obtaining the dispenser's distribution footprint over two test stands based on the historical data used to support the wind tunnel tests. A series of tests was performed in low-wind conditions using rate pans. Pre-measured amounts of snow were dispersed over the area, and the amount collected by each pan was recorded.

5.2.3.1 Dispensing Snow for NRC Tests

Using the results from these calibration tests, a decision was made to use two dispensers on each side of the two test stands; each of the four dispensers are moved to four different positions along each edge during the dispensing process. Figure 5.1, Figure 5.2, and Figure 5.3 demonstrate the setup of the dispensers in relation to the

EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

stand. Attachment 1 displays 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 snow needed, effective rates, and dispenser positions. The precipitation rates will be confirmed using the rate pan method at the time of testing.

5.2.4 Simulated Snow (Type I Fluids)

During the testing of the mixed condition of snow and freezing fog at the NRC CEF in the winter of 2021-22, it was determined that the original snow dispensing methodology was inappropriate for Type I fluids, as the shorter endurance times yielded by Type I fluids were found to be disproportionately impacted by the timing of the five-minute snow application cycle. This was revised to adapt a minute-by-minute resolution of endurance times.

Calibration work was completed prior to changing the methodology at the NRC CEF in a series of tests in low wind conditions using rate pans. Pre-measured amounts of snow were dispersed over the area, and the amount collected by each pan was recorded.

5.2.4.1 Dispensing Snow for NRC Tests

Using the results from these calibration tests, a decision was made to use two dispensers on each side of the two test stands, each dispenser covering one plate; each of the four dispensers are moved to two different positions along each edge during the dispensing process. Figure 5.1, Figure 5.2, and Figure 5.3, demonstrate the setup of the dispensers in relation to the stand. Attachment 1 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 snow needed, effective rates, and dispenser positions. The precipitation rates will be confirmed using the rate pan method at the time of testing.

EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

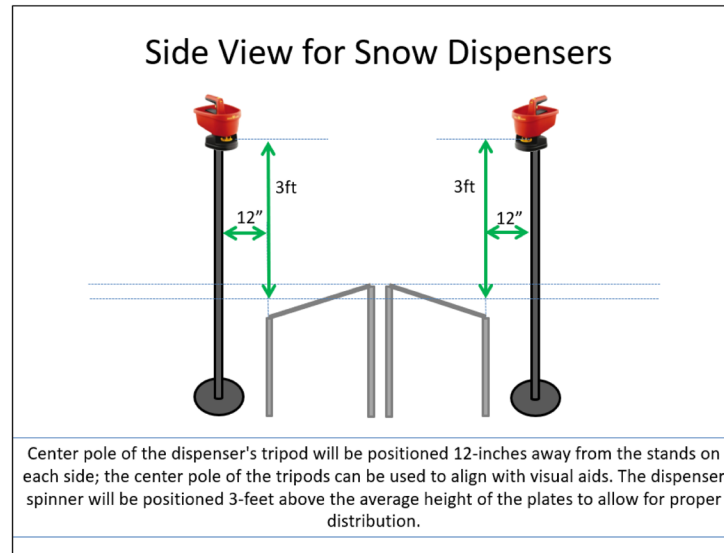


Figure 5.1: Side View of Positioning of Dispenser Relative to the Wing – Snow

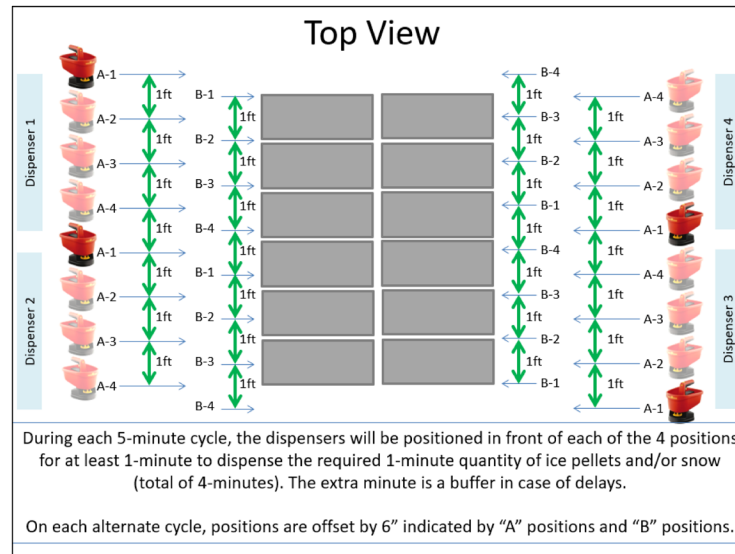


Figure 5.2: Top View of Positioning of Dispenser Relative to the Test Stands

EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

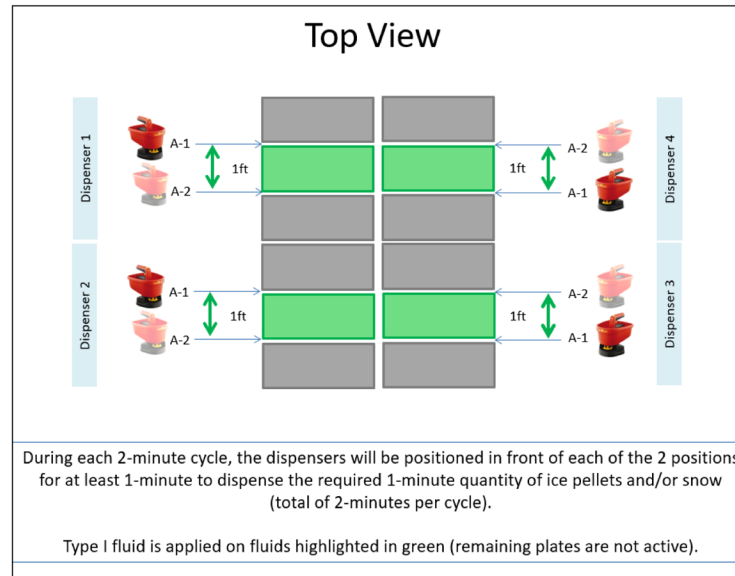


Figure 5.3: Top View of Positioning of Dispenser Relative to the Test Stands

5.3 At the End of Each Test Day

At the end of the testing day, the following tasks must be completed:

- Fluid clean-up and disposal (APS/YOW);
- Download plate temperature data (BB/MQ);
- Update the log of completed tests (PK); and
- Testing debrief meeting with TC and the FAA (MR).

EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

6. PERSONNEL

Six APS staff members are required for the tests at the NRC cold chamber. Six additional persons from Ottawa will be required for making and dispensing the snow. An APS photographer will be required to photograph the testing and to support the remote camera viewing. Table 6.1 demonstrates the personnel required and their associated tasks.

Fluid and snow applications will be performed by APS/YOW personnel at the NRC cold chamber. NRC personnel will operate the NRC cold chamber and operate the sprayer (if requested).

Table 6.1: Personnel List

APS Personnel List	
Person	Responsibility
Marco Ruggi (MR)	Project Manager / TC FAA Liaison
John D'Avirro (JD)	SME and Remote Support
Benjamin Bernier (BB)	Rate Manager / Fluid Manager (inventory and application) / YOW Pers. Manager
Marc Quesnel (MQ)	Data Collection / Rate Support / Snow Dispensing and Production Manager
Peter Kitchener (PK)	Testing Manager / Data Documentation (Forms, logs, etc.)
Salvatore Rosato (SR)	Remote Camera Setup
APS YOW Personnel List	
Person	Responsibility
Photographer (SN)	Photography / Remote Camera Maintenance
Steve Baker (STB)	General Support Lead
YOW 1	Fluids / Snow Manufacturing / Dispensing
YOW 2	Fluids / Snow Manufacturing / Dispensing
YOW 3	Fluids / Snow Manufacturing / Dispensing
YOW 4	Fluids / Snow Manufacturing / Dispensing
YOW 5	Snow Manufacturing

EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

7. EQUIPMENT

Table 7.1 provides a list of required equipment.

Table 7.1: Equipment List

EQUIPMENT	STATUS	EQUIPMENT	STATUS
General Support and Testing Equipment		Camera Equipment	
Brixometer x 3		4K IP Camera with tripod mounts x 4	
Clock (Large digital) x 2		Ethernet Cable (150 ft) x 5	
Extension cords (power bars x 6 + reels x 4)		Manfrotto® arms and mounts suitcase	
Flashlights x 2		Monitor with VGA cable	
Fluids (separate table)		NVR Receiver	
Folding Shelves x2		Osmo®/GoPro® Cameras + accessories	
Freezers x 3		Power Cables for monitor and receiver x 2	
Gloves: black (thermal layer) x12		Remote camera system	
Gloves: cotton (a lot)		Photography laptop with mouse/charger	
Gloves: latex (a lot)		SpaceX Starlink® System	
Hard water chemicals x 5 premixes			
Inclinometer (yellow level) x 2		Snow Fabrication Equipment	
Isopropyl x 12		Adherence Probes Kit	
Ladders x 4		Blenders x 12 in good condition	
Lock for truck		Folding tables (3 large, 2 small)	
Marker for Waste x 2		Ice bags	
Measuring Cups x 3		Snow control wires and boxes	
Paper towel (blue shop towel) x 40		Snow dispersers x 12	
Personnel clothing (testing coats/boots)		Sieves (solid base, 1.4 mm, 4 mm) x 2 each	
Pour containers: (1-litre) - 8 empty		Stands for Snow dispensing devices x 6	
Pour containers: (1-litre) - see list of fluids		Snow Styrofoam containers x40	
Printer & Ink Cartridge		Measuring cups (1 L + 1 cup/smaller)	
Rain Suits x 5		Ohaus 30KG scale	
Rate Pan (aluminum HOT) x1		Steel Frame Canopy x2 (10x5)	
Rate Pans (white plastic) x all		Rubber Mats x 4	
Sample bottles x 6		Wooden Spoons	
Ohaus weigh scales x 2			
Scrapers x 14		Office Equipment	
Shop Vac + 2x18 L open top pails		Blank Waterproof labels (1 page)	
SmartButton kits x 2 + extension wire		Calculators x 3	
Squeegees x 4 (small)		Clip boards x 5	
Tape: Duct tape x 2		Data Forms (on water phobic paper)	
Tape: Electrical tape x 5		Dry eraser markers	
Tape: Speed tape x 1		Envelopes (9x12) x box	
Tape measurer (large yellow + small)		Falling Ball Viscometer + Syringes	
Temperature probes: immersion x 3		File box x 2	
Temperature probes: surface x 3		Hard drive (if necessary)	
Test plate covers (white plastic) x 12		iPad® x 1	
Test plate covers (wooden boards) x 12		Laptop for Rate Station and SmartButtons	
Test Plates: Composite Full Plates x 4		Mouse for Rate Station and keypad	
Test Plates: Full plates x 12 w/buttons		Paper for printer x 1 pack	
Test Stand Collection Pans (one per stand)		Pencils + pens + markers	
Test Stand Shims (poker chips) x 1 box		Scissors	
Test Stands: 2 x Short 6-position		Test Procedures x 5	
Thickness Gauges: 4 rectangles		Walkie Talkies and Accessories x 12	
Thickness Gauges: 4 octagons		Waterproof paper (40 sheets)	
Type I Mixing Jug		Plastic Failure Rings (a lot)	
Vise grip (large) + rubber opener		Tuques x 10	
Water (4 x 18 L) for hard water			
Whatman paper kit + dye			
White poster board panels for water run-off			

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8. PRE-TESTING AND TESTING ACTIVITIES

Table 8.1 demonstrates the activities that will be completed prior to arriving at the NRC.

Table 8.1: Task List for Setup and Actual Tests

No.	Task	Person	Status
Planning and Preparation			
1	Coordinate with NRC personnel and check status of chamber	MR	
2	Ensure fluid is received and ready to be transported to NRC	PK/BA	
3	Arrange for hotel accommodations for APS personnel	JS	
4	Arrange truck rental	JS	
5	Arrange for ice delivery	JS	
6	Order walkie talkies	JS	
7	Organize personnel travel to Ottawa;	MR	
8	Hire YOW personnel	MR/FDL	
9	Complete contract for YOW personnel	FDL	
10	Coordinate with APS photographer	MR	
11	Prepare and arrange office materials for YOW	PK	
12	Prepare data forms and procedure	PK	
13	Prepare Test Log	PK	
14	Update (as necessary) fluid viscosity log, and have available viscosity of fluids	PK	
15	Finalize and complete list of equipment/materials required	PK/ALL	
16	Prepare and arrange site equipment for YOW	PK/BA	
17	Ensure proper functioning of snow dispenser equipment;	MR	
18	Prepare fluid pouring containers	BA//TGPK	
19	Review SN dispersal techniques and location	BB/MR/PK	
20	Update SN order form (if necessary)	BB/MR/PK	
21	Complete purchase list and shopping	PK	
22	Pack and leave YUL for YOW	APS	
23	Mark plates with plate numbers on back and front – marking should be at bottom	BA	
24	Calibrate snow dispensers for the NRC set-up	MQ/BA	
25	Conduct fluid variability calibration for simulated snow	MQ/BA	
26	Rate pans: check quantity, check properly labelled, and verify spares available	PK/BA	
27	Equip plates with operational and verified thermistors or SmartButtons	BA/BB	
28	Prepare coded labels for pour containers as per fluids list	AG	
29	Check laptops (2) work for rate station	BB	
30	Review "NRC Rate Station 101"	BB	
31	Confirm NRC availability of camera system + black shelving unit	MR	
32	Confirm NRC Setup Waste tote + floor mats in chamber for setup day	STB	
33	Confirm NRC availability of rate monitoring system	BB	
34	Confirm NRC that the freezer works and is on the day before testing	BB	
35	Confirm NRC will set up test area temperature sensors for morning of test	MR	
36	Confirm NRC will have hallways and chamber are free of clutter	MR	
37	Arrange special video camera equipment for monitoring and recording tests	BA	
Setup Day			
38	General safety briefing and update on testing	APS/NRC/YOW	
39	Unload Truck and organize equipment	APS	
40	Verify and organize fluid	PK/STB	
41	Confirm ice delivery	BB	
42	Setup general office and testing equipment, confirm printer and projector available	PK	
43	Setup SN manufacturing material in cold chamber	STB	
44	Test and prepare SN dispensing equipment	STB	
45	Coordinate fabrication of snow	MQ/STB	
46	Setup still and video cameras	SR/SN	
47	Verify photo and video requirements	SN/MR	
Testing Day 1			
48	Train SN making personnel (ongoing) and continue SN manufacturing	STB/YOW	
49	Start Testing	APS/NRC	

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Table 8.1: Task List for Setup and Actual Tests (cont'd)

No.	Task	Person	Status
Each Testing Day			
50	Decide personnel requirements for following day for 24 hour notice	MR	
51	Prepare equipment and fluid to be used for test	BB	
52	Manufacture snow	MQ/YOW	
53	Prepare photography equipment	SN	
54	Prepare data forms for test	PK	
55	Conduct tests based on test plan	APS	
56	Modify test plan based on results obtained	TC/FAA/JD/MR	
57	Update snow, raw ice, and fluid inventory (end of day)	MQ/YOW	
58	Update fluid inventory (2 container left warning)	BB/STB	
59	Update test log and test plan (ongoing and end of day)	PK/MR	

9. SAFETY

Managers of the project must ensure that personnel involved in the setup and conduct of their respective projects are aware of the below.

- A safety briefing will be done on the first day of testing.
- Personnel should be familiar with NRC emergency procedures, i.e., DO NOT CALL 9-1-1, instead, call the NRC Emergency Center as they will contact and direct the necessary services.
- Fluid SDS sheets are available for review.
- Canadian Standards Association (CSA) approved footwear and appropriate clothing for frigid temperatures are to be worn by all personnel.
- Waterproof clothing and gloves are available.
- Fluid(s) should only be handled with protective gloves. If any fluid gets onto the skin, wash the affected area thoroughly.
- Rubber mats must be properly placed in and around the test area and cleaned as necessary.
- Care should be taken when circulating near the test stand due to slipperiness.
- If fluid comes into contact with skin, rinse hands under running water.
- If fluid comes into contact with eyes, flush with the portable eye wash station.
- First aid kit, water and fire extinguisher are available.
- All NRC safety guidelines must be followed.

A separate safety training may be required by NRC that staff will be required to complete prior to the start of testing.

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Personnel must operate in accordance with the "Testing Safety Recommendations" and must follow the protocols for "Extended Work Hours Protocol for APS Personnel." These documents are included in the "APS Office Policies & Procedures," which is made available to all APS staff.

10. DATA FORMS

A snow dispensing form for calculating snow quantities required for each test is included in the data form used to record the endurance time for any of the conditions being completed is shown in Attachment 1. An additional endurance time testing form to be used for all tests is included in Attachment 2.

11. REFERENCES

1. APS Aviation Inc., *Aircraft Ground Icing General Research Activities During the 2023-24 Winter*, APS Aviation Inc., Transport Canada, Montreal, December 2024, TP 15608, XX (to be published).

EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

Attachment 1: Example of Snow Dispensing Form

Top View

Side View for Snow Dispensers

Precipitation Type: Date: Run #:

* Fields to be manipulated are highlighted

Target Rate	10	g/dm ² /h
Duration	90	minutes
Adjustment Factor	100%	%

Snow needed per 5 minutes cycle

In each position	18	g
In each Dispenser per cycle	72	g

Snow needed for entire test

Total Amount Per Dispenser	720	g
Total Amount for Entire Test	2880	g

1. Enter "Date" and "Run #".
2. Manipulate desired "Target Rate" for test event.
3. Manipulate desired "Duration" for test event.
4. Manipulate desired "Adjustment Factor" if applicable.
5. Prepare "Total Amount for Entire Test" in grams.
6. Prepare 4 boxes for "Total Amount Per Dispenser" in grams. (Each Dispenser must be emptied at 5-minute intervals.)
7. Dictate amount of Snow needed "In each Position" in grams. (Each Position must be emptied at approximately 1-minute intervals.)
8. Starting with Cycle "A" Position 1, move to next position at 1-minute intervals (1-foot to the right)
9. Once a Dispenser has completed its cycle at Position #4, start next cycle at Position #1 of Cycle "B"
10. Continue alternating between Cycle "A" and Cycle "B" for each 5-minute cycle

NOTE:

- Centre pole of the dispenser stands must be 1-foot (12 inches) from the bottom of the plate
- Height of the Stand must be 3-feet from bottom of the dispenser
- Amounts are calibrated for "red" snow dispensers

Attachment 2: Example of Endurance Time Data Form

LOCATION: NYC (J-488) PRECIP. CONDITION: DATE: RUN NUMBER:

Time of Fluid Application: _____

Time of Fluid Failure: _____

Fluid Name: _____

Test #: _____

Thickness (@ 5 minutes): _____

Final Fluid Bin: _____

PLATE 1 **PLATE 2** **PLATE 3** **PLATE 4** **PLATE 5** **PLATE 6**

ICRY I **ICRY II** **ICRY III** **ICRY IV** **ICRY V** **ICRY VI**

Time of Fluid Application: _____

Time of Fluid Failure: _____

Fluid Name: _____

Test #: _____

Thickness (@ 5 minutes): _____

Final Fluid Bin: _____

AMBIENT TEMPERATURE: _____ °C LEADER / MANAGER: _____ MET FAILURES CALLED BY: _____

COMMENTS: _____

NOTE:

Please ensure correct functioning of plate temperature logging system at the start of the test and at the end of the session.

CYCLE TRACKING

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100																																																																																																				
5 mins	10 mins	15 mins	20 mins	25 mins	30 mins	35 mins	40 mins	45 mins	50 mins	55 mins	60 mins	65 mins	70 mins	75 mins	80 mins	85 mins	90 mins	95 mins	100 mins	105 mins	110 mins	115 mins	120 mins	125 mins	130 mins	135 mins	140 mins	145 mins	150 mins	155 mins	160 mins	165 mins	170 mins	175 mins	180 mins	185 mins	190 mins	195 mins	200 mins	205 mins	210 mins	215 mins	220 mins	225 mins	230 mins	235 mins	240 mins	245 mins	250 mins	255 mins	260 mins	265 mins	270 mins	275 mins	280 mins	285 mins	290 mins	295 mins	300 mins	305 mins	310 mins	315 mins	320 mins	325 mins	330 mins	335 mins	340 mins	345 mins	350 mins	355 mins	360 mins	365 mins	370 mins	375 mins	380 mins	385 mins	390 mins	395 mins	400 mins	405 mins	410 mins	415 mins	420 mins	425 mins	430 mins	435 mins	440 mins	445 mins	450 mins	455 mins	460 mins	465 mins	470 mins	475 mins	480 mins	485 mins	490 mins	495 mins	500 mins	505 mins	510 mins	515 mins	520 mins	525 mins	530 mins	535 mins	540 mins	545 mins	550 mins	555 mins	560 mins	565 mins	570 mins	575 mins	580 mins	585 mins	590 mins	595 mins	600 mins	605 mins	610 mins	615 mins	620 mins	625 mins	630 mins	635 mins	640 mins	645 mins	650 mins	655 mins	660 mins	665 mins	670 mins	675 mins	680 mins	685 mins	690 mins	695 mins	700 mins	705 mins	710 mins	715 mins	720 mins	725 mins	730 mins	735 mins	740 mins	745 mins	750 mins	755 mins	760 mins	765 mins	770 mins	775 mins	780 mins	785 mins	790 mins	795 mins	800 mins	805 mins	810 mins	815 mins	820 mins	825 mins	830 mins	835 mins	840 mins	845 mins	850 mins	855 mins	860 mins	865 mins	870 mins	875 mins	880 mins	885 mins	890 mins	895 mins	900 mins	905 mins	910 mins	915 mins	920 mins	925 mins	930 mins	935 mins	940 mins	945 mins	950 mins	955 mins	960 mins	965 mins	970 mins	975 mins	980 mins	985 mins	990 mins	995 mins	1000 mins

EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

Attachment 3: Proposed Test Plan for Testing Snow and Freezing Mist

Test No.	Priority	Precip. Cond.	Fluid Name	Dilution	APS Fluid Code	Fluid Type	Precipitation	Test Surface	Test Temp. (°C)	Fluid Temp. (°C)	SN Rate (g/dm ² /h)	BR Rate (g/dm ² /h)
1	1	SNBR	PG ADF Concentrate	33/67	097A	I-PG	Snow + Freezing Mist, -3, 10 + 0.4	Aluminum	-3	20°C	10	0.4
2	1	SNBR	PG ADF Concentrate	33/67	097A	I-PG	Snow + Freezing Mist, -3, 10 + 0.4	Composite	-3	20°C	10	0.4
3	1	SNBR	CHEMR REG I	28/73	104A	I-EG	Snow + Freezing Mist, -3, 10 + 0.4	Aluminum	-3	20°C	10	0.4
4	1	SNBR	CHEMR REG I	28/73	104A	I-EG	Snow + Freezing Mist, -3, 10 + 0.4	Composite	-3	20°C	10	0.4
5	1	SNBR	Ecowing AD-2	100/0	083A	II	Snow + Freezing Mist, -3, 10 + 0.4	Aluminum	-3	OAT	10	0.4
6	1	SNBR	Ecowing AD-2	100/0	083A	II	Snow + Freezing Mist, -3, 10 + 0.4	Aluminum	-3	OAT	10	0.4
7	1	SNBR	AeroClear MAX	100/0	150A	III	Snow + Freezing Mist, -3, 10 + 0.4	Aluminum	-3	OAT	10	0.4
8	1	SNBR	AeroClear MAX	100/0	150A	III	Snow + Freezing Mist, -3, 10 + 0.4	Aluminum	-3	OAT	10	0.4
9	1	SNBR	Polar Guard Advance	100/0	068A	IV-PG	Snow + Freezing Mist, -3, 10 + 0.4	Aluminum	-3	OAT	10	0.4
10	1	SNBR	Polar Guard Advance	100/0	068A	IV-PG	Snow + Freezing Mist, -3, 10 + 0.4	Aluminum	-3	OAT	10	0.4
11	1	SNBR	EG106	100/0	117A	IV-EG	Snow + Freezing Mist, -3, 10 + 0.4	Aluminum	-3	OAT	10	0.4
12	1	SNBR	EG106	100/0	117A	IV-EG	Snow + Freezing Mist, -3, 10 + 0.4	Aluminum	-3	OAT	10	0.4
13	2	SNBR	PG ADF Concentrate	33/67	097A	I-PG	Snow + Freezing Mist, -3, 25 + 0.4	Aluminum	-3	20°C	25	0.4
14	2	SNBR	PG ADF Concentrate	33/67	097A	I-PG	Snow + Freezing Mist, -3, 25 + 0.4	Composite	-3	20°C	25	0.4
15	2	SNBR	CHEMR REG I	28/73	104A	I-EG	Snow + Freezing Mist, -3, 25 + 0.4	Aluminum	-3	20°C	25	0.4
16	2	SNBR	CHEMR REG I	28/73	104A	I-EG	Snow + Freezing Mist, -3, 25 + 0.4	Composite	-3	20°C	25	0.4
17	2	SNBR	Ecowing AD-2	100/0	083A	II	Snow + Freezing Mist, -3, 25 + 0.4	Aluminum	-3	OAT	25	0.4
18	2	SNBR	Ecowing AD-2	100/0	083A	II	Snow + Freezing Mist, -3, 25 + 0.4	Aluminum	-3	OAT	25	0.4
19	2	SNBR	AeroClear MAX	100/0	150A	III	Snow + Freezing Mist, -3, 25 + 0.4	Aluminum	-3	OAT	25	0.4
20	2	SNBR	AeroClear MAX	100/0	150A	III	Snow + Freezing Mist, -3, 25 + 0.4	Aluminum	-3	OAT	25	0.4
21	2	SNBR	Polar Guard Advance	100/0	068A	IV-PG	Snow + Freezing Mist, -3, 25 + 0.4	Aluminum	-3	OAT	25	0.4
22	2	SNBR	Polar Guard Advance	100/0	068A	IV-PG	Snow + Freezing Mist, -3, 25 + 0.4	Aluminum	-3	OAT	25	0.4
23	2	SNBR	EG106	100/0	117A	IV-EG	Snow + Freezing Mist, -3, 25 + 0.4	Aluminum	-3	OAT	25	0.4
24	2	SNBR	EG106	100/0	117A	IV-EG	Snow + Freezing Mist, -3, 25 + 0.4	Aluminum	-3	OAT	25	0.4
25	3	SNBR	PG ADF Concentrate	33/67	097A	I-PG	Snow + Freezing Mist, -14, 10 + 0.4	Aluminum	-3	20°C	10	0.4
26	3	SNBR	PG ADF Concentrate	33/67	097A	I-PG	Snow + Freezing Mist, -14, 10 + 0.4	Composite	-3	20°C	10	0.4
27	3	SNBR	CHEMR REG I	28/73	104A	I-EG	Snow + Freezing Mist, -14, 10 + 0.4	Aluminum	-3	20°C	10	0.4

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Attachment 3: Proposed Test Plan for Testing Snow and Freezing Mist (Cont'd)

Test No.	Priority	Precip. Cond.	Fluid Name	Dilution	APS Fluid Code	Fluid Type	Precipitation	Test Surface	Test Temp. (°C)	Fluid Temp. (°C)	SN Rate (g/dm ² /h)	BR Rate (g/dm ² /h)
28	3	SNBR	CHEMR REG I	28/73	104A	I-EG	Snow + Freezing Mist, -14, 10 + 0.4	Composite	-3	20°C	10	0.4
29	1	SNBR	Ecowing AD-2	100/0	083A	II	Snow + Freezing Mist, -14, 10 + 0.4	Aluminum	-3	OAT	10	0.4
30	1	SNBR	Ecowing AD-2	100/0	083A	II	Snow + Freezing Mist, -14, 10 + 0.4	Aluminum	-3	OAT	10	0.4
31	1	SNBR	AeroClear MAX	100/0	150A	III	Snow + Freezing Mist, -14, 10 + 0.4	Aluminum	-3	OAT	10	0.4
32	1	SNBR	AeroClear MAX	100/0	150A	III	Snow + Freezing Mist, -14, 10 + 0.4	Aluminum	-14	OAT	10	0.4
33	1	SNBR	Polar Guard Advance	100/0	068A	IV-PG	Snow + Freezing Mist, -14, 10 + 0.4	Aluminum	-14	OAT	10	0.4
34	1	SNBR	Polar Guard Advance	100/0	068A	IV-PG	Snow + Freezing Mist, -14, 10 + 0.4	Aluminum	-14	OAT	10	0.4
35	1	SNBR	EG106	100/0	117A	IV-EG	Snow + Freezing Mist, -14, 10 + 0.4	Aluminum	-14	OAT	10	0.4
36	1	SNBR	EG106	100/0	117A	IV-EG	Snow + Freezing Mist, -14, 10 + 0.4	Aluminum	-14	OAT	10	0.4
37	3	SNBR	PG ADF Concentrate	46/54	097A	I-PG	Snow + Freezing Mist, -14, 25 + 0.4	Aluminum	-14	20°C	25	0.4
38	3	SNBR	PG ADF Concentrate	46/54	097A	I-PG	Snow + Freezing Mist, -14, 25 + 0.4	Composite	-14	20°C	25	0.4
39	3	SNBR	CHEMR REG I	43/57	104A	I-EG	Snow + Freezing Mist, -14, 25 + 0.4	Aluminum	-14	20°C	25	0.4
40	3	SNBR	CHEMR REG I	43/57	104A	I-EG	Snow + Freezing Mist, -14, 25 + 0.4	Composite	-14	20°C	25	0.4
41	2	SNBR	Ecowing AD-2	100/0	083A	II	Snow + Freezing Mist, -14, 25 + 0.4	Aluminum	-14	OAT	25	0.4
42	2	SNBR	Ecowing AD-2	100/0	083A	II	Snow + Freezing Mist, -14, 25 + 0.4	Aluminum	-14	OAT	25	0.4
43	2	SNBR	AeroClear MAX	100/0	150A	III	Snow + Freezing Mist, -14, 25 + 0.4	Aluminum	-14	OAT	25	0.4
44	2	SNBR	AeroClear MAX	100/0	150A	III	Snow + Freezing Mist, -14, 25 + 0.4	Aluminum	-14	OAT	25	0.4
45	2	SNBR	Polar Guard Advance	100/0	068A	IV-PG	Snow + Freezing Mist, -14, 25 + 0.4	Aluminum	-14	OAT	25	0.4
46	2	SNBR	Polar Guard Advance	100/0	068A	IV-PG	Snow + Freezing Mist, -14, 25 + 0.4	Aluminum	-14	OAT	25	0.4
47	2	SNBR	EG106	100/0	117A	IV-EG	Snow + Freezing Mist, -14, 25 + 0.4	Aluminum	-14	OAT	25	0.4
48	2	SNBR	EG106	100/0	117A	IV-EG	Snow + Freezing Mist, -14, 25 + 0.4	Aluminum	-14	OAT	25	0.4
49	3	SNBR	PG ADF Concentrate	55/45	097A	I-PG	Snow + Freezing Mist, -25, 10 + 0.4	Aluminum	-25	20°C	10	0.4
50	2	SNBR	PG ADF Concentrate	55/45	097A	I-PG	Snow + Freezing Mist, -25, 10 + 0.4	Composite	-25	20°C	10	0.4
51	3	SNBR	CHEMR REG I	53/47	104A	I-EG	Snow + Freezing Mist, -25, 10 + 0.4	Aluminum	-25	20°C	10	0.4
52	3	SNBR	CHEMR REG I	53/47	104A	I-EG	Snow + Freezing Mist, -25, 10 + 0.4	Composite	-25	20°C	10	0.4
53	1	SNBR	Ecowing AD-2	100/0	083A	II	Snow + Freezing Mist, -25, 10 + 0.4	Aluminum	-25	OAT	10	0.4
54	1	SNBR	Ecowing AD-2	100/0	083A	II	Snow + Freezing Mist, -25, 10 + 0.4	Aluminum	-25	OAT	10	0.4
55	1	SNBR	AeroClear MAX	100/0	150A	III	Snow + Freezing Mist, -25, 10 + 0.4	Aluminum	-25	OAT	10	0.4

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Attachment 3: Proposed Test Plan for Testing Snow and Freezing Mist (Cont'd)

Test No.	Priority	Precip. Cond.	Fluid Name	Dilution	APS Fluid Code	Fluid Type	Precipitation	Test Surface	Test Temp. (°C)	Fluid Temp. (°C)	SN Rate (g/dm ² /h)	BR Rate (g/dm ² /h)
56	1	SNBR	AeroClear MAX	100/0	150A	III	Snow + Freezing Mist, -25, 10 + 0.4	Aluminum	-25	OAT	10	0.4
57	1	SNBR	Polar Guard Advance	100/0	068A	IV-PG	Snow + Freezing Mist, -25, 10 + 0.4	Aluminum	-25	OAT	10	0.4
58	1	SNBR	Polar Guard Advance	100/0	068A	IV-PG	Snow + Freezing Mist, -25, 10 + 0.4	Aluminum	-25	OAT	10	0.4
59	1	SNBR	EG106	100/0	117A	IV-EG	Snow + Freezing Mist, -25, 10 + 0.4	Aluminum	-25	OAT	10	0.4
60	1	SNBR	EG106	100/0	117A	IV-EG	Snow + Freezing Mist, -25, 10 + 0.4	Aluminum	-25	OAT	10	0.4
61	3	SNBR	PG ADF Concentrate	55/45	097A	I-PG	Snow + Freezing Mist, -25, 25 + 0.4	Aluminum	-25	20°C	25	0.4
62	3	SNBR	PG ADF Concentrate	55/45	097A	I-PG	Snow + Freezing Mist, -25, 25 + 0.4	Composite	-25	20°C	25	0.4
63	3	SNBR	CHEMR REG I	53/47	104A	I-EG	Snow + Freezing Mist, -25, 25 + 0.4	Aluminum	-25	20°C	25	0.4
64	3	SNBR	CHEMR REG I	53/47	104A	I-EG	Snow + Freezing Mist, -25, 25 + 0.4	Composite	-25	20°C	25	0.4
65	2	SNBR	Ecowing AD-2	100/0	083A	II	Snow + Freezing Mist, -25, 25 + 0.4	Aluminum	-25	OAT	25	0.4
66	2	SNBR	Ecowing AD-2	100/0	083A	II	Snow + Freezing Mist, -25, 25 + 0.4	Aluminum	-25	OAT	25	0.4
67	2	SNBR	AeroClear MAX	100/0	150A	III	Snow + Freezing Mist, -25, 25 + 0.4	Aluminum	-25	OAT	25	0.4
68	2	SNBR	AeroClear MAX	100/0	150A	III	Snow + Freezing Mist, -25, 25 + 0.4	Aluminum	-25	OAT	25	0.4
69	2	SNBR	Polar Guard Advance	100/0	068A	IV-PG	Snow + Freezing Mist, -25, 25 + 0.4	Aluminum	-25	OAT	25	0.4
70	2	SNBR	Polar Guard Advance	100/0	068A	IV-PG	Snow + Freezing Mist, -25, 25 + 0.4	Aluminum	-25	OAT	25	0.4
71	2	SNBR	EG106	100/0	117A	IV-EG	Snow + Freezing Mist, -25, 25 + 0.4	Aluminum	-25	OAT	25	0.4
72	2	SNBR	EG106	100/0	117A	IV-EG	Snow + Freezing Mist, -25, 25 + 0.4	Aluminum	-25	OAT	25	0.4
73	1	SN	AeroClear MAX	100/0	150A	III	Snow, -3, 10	Aluminum	-3	OAT	10	0
74	1	SN	AeroClear MAX	100/0	150A	III	Snow, -3, 10	Aluminum	-3	OAT	10	0
75	1	SN	EG106	100/0	117A	IV-EG	Snow, -3, 10	Aluminum	-3	OAT	10	0
76	1	SN	EG106	100/0	117A	IV-EG	Snow, -3, 10	Aluminum	-3	OAT	10	0
77	2	SN	AeroClear MAX	100/0	150A	III	Snow, -3, 25	Aluminum	-3	OAT	25	0
78	2	SN	AeroClear MAX	100/0	150A	III	Snow, -3, 25	Aluminum	-3	OAT	25	0
79	2	SN	EG106	100/0	117A	IV-EG	Snow, -3, 25	Aluminum	-3	OAT	25	0
80	2	SN	EG106	100/0	117A	IV-EG	Snow, -3, 25	Aluminum	-3	OAT	25	0
81	1	SN	AeroClear MAX	100/0	150A	III	Snow, -14, 10	Aluminum	-14	OAT	10	0
82	1	SN	AeroClear MAX	100/0	150A	III	Snow, -14, 10	Aluminum	-14	OAT	10	0
83	1	SN	EG106	100/0	117A	IV-EG	Snow, -14, 10	Aluminum	-14	OAT	10	0

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EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

Attachment 3: Proposed Test Plan for Testing Snow and Freezing Mist (Cont'd)

Test No.	Priority	Precip. Cond.	Fluid Name	Dilution	APS Fluid Code	Fluid Type	Precipitation	Test Surface	Test Temp. (°C)	Fluid Temp. (°C)	SN Rate (g/dm ² /h)	BR Rate (g/dm ² /h)
84	1	SN	EG106	100/0	117A	IV-EG	Snow, -14, 10	Aluminum	-14	OAT	10	0
85	2	SN	AeroClear MAX	100/0	150A	III	Snow, -14, 25	Aluminum	-14	OAT	25	0
86	2	SN	AeroClear MAX	100/0	150A	III	Snow, -14, 25	Aluminum	-14	OAT	25	0
87	2	SN	EG106	100/0	117A	IV-EG	Snow, -14, 25	Aluminum	-14	OAT	25	0
88	2	SN	EG106	100/0	117A	IV-EG	Snow, -14, 25	Aluminum	-14	OAT	25	0
89	1	SN	AeroClear MAX	100/0	150A	III	Snow, -25, 10	Aluminum	-25	OAT	10	0
90	1	SN	AeroClear MAX	100/0	150A	III	Snow, -25, 10	Aluminum	-25	OAT	10	0
91	1	SN	EG106	100/0	117A	IV-EG	Snow, -25, 10	Aluminum	-25	OAT	10	0
92	1	SN	EG106	100/0	117A	IV-EG	Snow, -25, 10	Aluminum	-25	OAT	10	0
93	2	SN	AeroClear MAX	100/0	150A	III	Snow, -25, 25	Aluminum	-25	OAT	25	0
94	2	SN	AeroClear MAX	100/0	150A	III	Snow, -25, 25	Aluminum	-25	OAT	25	0
95	2	SN	EG106	100/0	117A	IV-EG	Snow, -25, 25	Aluminum	-25	OAT	25	0
96	2	SN	EG106	100/0	117A	IV-EG	Snow, -25, 25	Aluminum	-25	OAT	25	0

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EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

Attachment 4: Proposed Test Plan for Testing Moderate Rain Mixed with Snow

Test No.	Priority	Precip. Cond.	Fluid Name	Dilution	APS Fluid Code	Fluid Type	Precipitation	Test Surface	Test Temp. (°C)	Fluid Temp. (°C)	SN Rate (g/dm ² /h)	RA Rate (g/dm ² /h)
1	1	RASN	Ecowing AD-2	100/0	083A	II	Moderate Rain + Snow, 0, 75 + 25	Aluminum	0	OAT	25	75
2	1	RASN	Ecowing AD-2	100/0	083A	II	Moderate Rain + Snow, 0, 75 + 25	Aluminum	0	OAT	25	75
3	1	RASN	AeroClear MAX	100/0	150A	III	Moderate Rain + Snow, 0, 75 + 25	Aluminum	0	OAT	25	75
4	1	RASN	AeroClear MAX	100/0	150A	III	Moderate Rain + Snow, 0, 75 + 25	Aluminum	0	OAT	25	75
5	1	RASN	Polar Guard Advance	100/0	068A	IV-PG	Moderate Rain + Snow, 0, 75 + 25	Aluminum	0	OAT	25	75
6	1	RASN	Polar Guard Advance	100/0	068A	IV-PG	Moderate Rain + Snow, 0, 75 + 25	Aluminum	0	OAT	25	75
7	1	RASN	EG106	100/0	117A	IV-EG	Moderate Rain + Snow, 0, 75 + 25	Aluminum	0	OAT	25	75
8	1	RASN	EG106	100/0	117A	IV-EG	Moderate Rain + Snow, 0, 75 + 25	Aluminum	0	OAT	25	75
9	1	RASN	Ecowing AD-2	100/0	083A	II	Moderate Rain + Snow, 0, 80 + 20	Aluminum	0	OAT	20	80
10	1	RASN	Ecowing AD-2	100/0	083A	II	Moderate Rain + Snow, 0, 80 + 20	Aluminum	0	OAT	20	80
11	1	RASN	AeroClear MAX	100/0	150A	III	Moderate Rain + Snow, 0, 80 + 20	Aluminum	0	OAT	20	80
12	1	RASN	AeroClear MAX	100/0	150A	III	Moderate Rain + Snow, 0, 80 + 20	Aluminum	0	OAT	20	80
13	1	RASN	Polar Guard Advance	100/0	068A	IV-PG	Moderate Rain + Snow, 0, 80 + 20	Aluminum	0	OAT	20	80
14	1	RASN	Polar Guard Advance	100/0	068A	IV-PG	Moderate Rain + Snow, 0, 80 + 20	Aluminum	0	OAT	20	80
15	1	RASN	EG106	100/0	117A	IV-EG	Moderate Rain + Snow, 0, 80 + 20	Aluminum	0	OAT	20	80
16	1	RASN	EG106	100/0	117A	IV-EG	Moderate Rain + Snow, 0, 80 + 20	Aluminum	0	OAT	20	80
17	1	RASN	Ecowing AD-2	100/0	083A	II	Moderate Rain + Snow, 0, 85 + 15	Aluminum	0	OAT	15	85
18	1	RASN	Ecowing AD-2	100/0	083A	II	Moderate Rain + Snow, 0, 85 + 15	Aluminum	0	OAT	15	85
19	1	RASN	AeroClear MAX	100/0	150A	III	Moderate Rain + Snow, 0, 85 + 15	Aluminum	0	OAT	15	85
20	1	RASN	AeroClear MAX	100/0	150A	III	Moderate Rain + Snow, 0, 85 + 15	Aluminum	0	OAT	15	85
21	1	RASN	Polar Guard Advance	100/0	068A	IV-PG	Moderate Rain + Snow, 0, 85 + 15	Aluminum	0	OAT	15	85
22	1	RASN	Polar Guard Advance	100/0	068A	IV-PG	Moderate Rain + Snow, 0, 85 + 15	Aluminum	0	OAT	15	85
23	1	RASN	EG106	100/0	117A	IV-EG	Moderate Rain + Snow, 0, 85 + 15	Aluminum	0	OAT	15	85
24	1	RASN	EG106	100/0	117A	IV-EG	Moderate Rain + Snow, 0, 85 + 15	Aluminum	0	OAT	15	85
25	1	RA	Ecowing AD-2	100/0	083A	II	Rain on Cold-Soaked Wing, 1, 75	Aluminum	1	OAT	0	75
26	1	RA	Ecowing AD-2	100/0	083A	II	Rain on Cold-Soaked Wing, 1, 75	Aluminum	1	OAT	0	75
27	1	RA	AeroClear MAX	100/0	150A	III	Rain on Cold-Soaked Wing, 1, 75	Aluminum	1	OAT	0	75

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EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

Attachment 4: Proposed Test Plan for Testing Moderate Rain Mixed with Snow (Cont'd)

Test No.	Priority	Precip. Cond.	Fluid Name	Dilution	APS Fluid Code	Fluid Type	Precipitation	Test Surface	Test Temp. (°C)	Fluid Temp. (°C)	SN Rate (g/dm ² /h)	RA Rate (g/dm ² /h)
28	1	RA	AeroClear MAX	100/0	150A	III	Rain on Cold-Soaked Wing, 1, 75	Aluminum	1	OAT	0	75
29	1	RA	EG106	100/0	117A	IV-EG	Rain on Cold-Soaked Wing, 1, 75	Aluminum	1	OAT	0	75
30	1	RA	EG106	100/0	117A	IV-EG	Rain on Cold-Soaked Wing, 1, 75	Aluminum	1	OAT	0	75

EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

Attachment 5: Proposed Test Plan for Testing Snow Mixed with Freezing Fog (Type I)

Test No.	Priority	Precip. Cond.	Fluid Name	Dilution	APS Fluid Code	Fluid Type	Precipitation	Test Surface	Test Temp. (°C)	Fluid Temp. (°C)	SN Rate (g/dm ² /h)	FZFG Rate (g/dm ² /h)
1	2	SNFZFG	PG ADF Concentrate	46/54	097A	I-PG	Snow + Freezing Fog, -14, 10 + 2	Aluminum	-14	20°C	10	2
2	2	SNFZFG	PG ADF Concentrate	46/54	097A	I-PG	Snow + Freezing Fog, -14, 10 + 2	Composite	-14	20°C	10	2
3	2	SNFZFG	CHEMR REG I	43/57	104A	I-EG	Snow + Freezing Fog, -14, 10 + 2	Aluminum	-14	20°C	10	2
4	2	SNFZFG	CHEMR REG I	43/57	104A	I-EG	Snow + Freezing Fog, -14, 10 + 2	Composite	-14	20°C	10	2
5	3	SNFZFG	PG ADF Concentrate	55/45	097A	I-PG	Snow + Freezing Fog, -25, 10 + 2	Aluminum	-25	20°C	10	2
6	3	SNFZFG	PG ADF Concentrate	55/45	097A	I-PG	Snow + Freezing Fog, -25, 10 + 2	Composite	-25	20°C	10	2
7	3	SNFZFG	CHEMR REG I	53/47	104A	I-EG	Snow + Freezing Fog, -25, 10 + 2	Aluminum	-25	20°C	10	2
8	3	SNFZFG	CHEMR REG I	53/47	104A	I-EG	Snow + Freezing Fog, -25, 10 + 2	Composite	-25	20°C	10	2
9	3	SNFZFG	PG ADF Concentrate	55/45	097A	I-PG	Snow + Freezing Fog, -25, 25 + 2	Aluminum	-25	20°C	25	2
10	3	SNFZFG	PG ADF Concentrate	55/45	097A	I-PG	Snow + Freezing Fog, -25, 25 + 2	Composite	-25	20°C	25	2
11	3	SNFZFG	CHEMR REG I	53/47	104A	I-EG	Snow + Freezing Fog, -25, 25 + 2	Aluminum	-25	20°C	25	2
12	3	SNFZFG	CHEMR REG I	53/47	104A	I-EG	Snow + Freezing Fog, -25, 25 + 2	Composite	-25	20°C	25	2
13	1	SNFZFG	PG ADF Concentrate	33/67	097A	I-PG	Snow + Freezing Fog, -3, 10 + 1	Aluminum	-3	20°C	10	1
14	1	SNFZFG	PG ADF Concentrate	33/67	097A	I-PG	Snow + Freezing Fog, -3, 10 + 1	Composite	-3	20°C	10	1
15	1	SNFZFG	CHEMR REG I	28/73	104A	I-EG	Snow + Freezing Fog, -3, 10 + 1	Aluminum	-3	20°C	10	1
16	1	SNFZFG	CHEMR REG I	28/73	104A	I-EG	Snow + Freezing Fog, -3, 10 + 1	Composite	-3	20°C	10	1
17	1	SNFZFG	PG ADF Concentrate	33/67	097A	I-PG	Snow + Freezing Fog, -3, 25 + 1	Aluminum	-3	20°C	25	1
18	1	SNFZFG	PG ADF Concentrate	33/67	097A	I-PG	Snow + Freezing Fog, -3, 25 + 1	Composite	-3	20°C	25	1
19	1	SNFZFG	CHEMR REG I	28/73	104A	I-EG	Snow + Freezing Fog, -3, 25 + 1	Aluminum	-3	20°C	25	1
20	1	SNFZFG	CHEMR REG I	28/73	104A	I-EG	Snow + Freezing Fog, -3, 25 + 1	Composite	-3	20°C	25	1
21	2	SNFZFG	PG ADF Concentrate	46/54	097A	I-PG	Snow + Freezing Fog, -14, 10 + 0.7	Aluminum	-14	20°C	10	0.7
22	2	SNFZFG	PG ADF Concentrate	46/54	097A	I-PG	Snow + Freezing Fog, -14, 10 + 0.7	Composite	-14	20°C	10	0.7
23	2	SNFZFG	CHEMR REG I	43/57	104A	I-EG	Snow + Freezing Fog, -14, 10 + 0.7	Aluminum	-14	20°C	10	0.7
24	2	SNFZFG	CHEMR REG I	43/57	104A	I-EG	Snow + Freezing Fog, -14, 10 + 0.7	Composite	-14	20°C	10	0.7
25	3	SNFZFG	PG ADF Concentrate	46/54	097A	I-PG	Snow + Freezing Fog, -14, 25 + 0.7	Aluminum	-14	20°C	25	0.7
26	3	SNFZFG	PG ADF Concentrate	46/54	097A	I-PG	Snow + Freezing Fog, -14, 25 + 0.7	Composite	-14	20°C	25	0.7
27	3	SNFZFG	CHEMR REG I	43/57	104A	I-EG	Snow + Freezing Fog, -14, 25 + 0.7	Aluminum	-14	20°C	25	0.7

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EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

Attachment 5: Proposed Test Plan for Testing Snow Mixed with Freezing Fog (Type I) (cont'd)

Test No.	Priority	Precip. Cond.	Fluid Name	Dilution	APS Fluid Code	Fluid Type	Precipitation	Test Surface	Test Temp. (°C)	Fluid Temp. (°C)	SN Rate (g/dm ² /h)	FZFG Rate (g/dm ² /h)
28	3	SNFZFG	CHEMR REG I	43/57	104A	I-EG	Snow + Freezing Fog, -14, 25 + 0.7	Composite	-14	20°C	25	0.7
29	3	SNFZFG	PG ADF Concentrate	55/45	097A	I-PG	Snow + Freezing Fog, -25, 10 + 0.7	Aluminum	-25	20°C	10	0.7
30	3	SNFZFG	PG ADF Concentrate	55/45	097A	I-PG	Snow + Freezing Fog, -25, 10 + 0.7	Composite	-25	20°C	10	0.7
31	3	SNFZFG	CHEMR REG I	53/47	104A	I-EG	Snow + Freezing Fog, -25, 10 + 0.7	Aluminum	-25	20°C	10	0.7
32	3	SNFZFG	CHEMR REG I	53/47	104A	I-EG	Snow + Freezing Fog, -25, 10 + 0.7	Composite	-25	20°C	10	0.7
33	3	SNFZFG	PG ADF Concentrate	55/45	097A	I-PG	Snow + Freezing Fog, -25, 25 + 0.7	Aluminum	-25	20°C	25	0.7
34	3	SNFZFG	PG ADF Concentrate	55/45	097A	I-PG	Snow + Freezing Fog, -25, 25 + 0.7	Composite	-25	20°C	25	0.7
35	3	SNFZFG	CHEMR REG I	53/47	104A	I-EG	Snow + Freezing Fog, -25, 25 + 0.7	Aluminum	-25	20°C	25	0.7
36	3	SNFZFG	CHEMR REG I	53/47	104A	I-EG	Snow + Freezing Fog, -25, 25 + 0.7	Composite	-25	20°C	25	0.7

EVALUATION OF ENDURANCE TIMES IN MIXED ICING CONDITIONS WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

Attachment 6: Proposed Test Plan for Testing Light Rain Mixed with Snow

Test No.	Priority	Precip. Cond.	Fluid Name	Dilution	APS Fluid Code	Fluid Type	Precipitation	Test Surface	Test Temp. (°C)	Fluid Temp. (°C)	SN Rate (g/dm ² /h)	RA Rate (g/dm ² /h)
1	1	-SNRA	Ecowing AD-2	100/0	083A	II	Light Snow + Rain, 0, 10 + 13	Aluminum	0	OAT	10	13
2	1	-SNRA	Ecowing AD-2	100/0	083A	II	Light Snow + Rain, 0, 10 + 13	Aluminum	0	OAT	10	13
3	1	-SNRA	AeroClear MAX	100/0	150A	III	Light Snow + Rain, 0, 10 + 13	Aluminum	0	OAT	10	13
4	1	-SNRA	AeroClear MAX	100/0	150A	III	Light Snow + Rain, 0, 10 + 13	Aluminum	0	OAT	10	13
5	1	-SNRA	Polar Guard Advance	100/0	068A	IV-PG	Light Snow + Rain, 0, 10 + 13	Aluminum	0	OAT	10	13
6	1	-SNRA	Polar Guard Advance	100/0	068A	IV-PG	Light Snow + Rain, 0, 10 + 13	Aluminum	0	OAT	10	13
7	1	-SNRA	EG106	100/0	117A	IV-EG	Light Snow + Rain, 0, 10 + 13	Aluminum	0	OAT	10	13
8	1	-SNRA	EG106	100/0	117A	IV-EG	Light Snow + Rain, 0, 10 + 13	Aluminum	0	OAT	10	13
9	1	-SNRA	Ecowing AD-2	100/0	083A	II	Light Snow + Rain, 0, 10 + 25	Aluminum	0	OAT	10	25
10	1	-SNRA	Ecowing AD-2	100/0	083A	II	Light Snow + Rain, 0, 10 + 25	Aluminum	0	OAT	10	25
11	1	-SNRA	AeroClear MAX	100/0	150A	III	Light Snow + Rain, 0, 10 + 25	Aluminum	0	OAT	10	25
12	1	-SNRA	AeroClear MAX	100/0	150A	III	Light Snow + Rain, 0, 10 + 25	Aluminum	0	OAT	10	25
13	1	-SNRA	Polar Guard Advance	100/0	068A	IV-PG	Light Snow + Rain, 0, 10 + 25	Aluminum	0	OAT	10	25
14	1	-SNRA	Polar Guard Advance	100/0	068A	IV-PG	Light Snow + Rain, 0, 10 + 25	Aluminum	0	OAT	10	25
15	1	-SNRA	EG106	100/0	117A	IV-EG	Light Snow + Rain, 0, 10 + 25	Aluminum	0	OAT	10	25
16	1	-SNRA	EG106	100/0	117A	IV-EG	Light Snow + Rain, 0, 10 + 25	Aluminum	0	OAT	10	25
17	1	-FZRA	Ecowing AD-2	100/0	083A	II	Light Freezing Rain, -3, 25	Aluminum	-3	OAT	0	25
18	1	-FZRA	Ecowing AD-2	100/0	083A	II	Light Freezing Rain, -3, 25	Aluminum	-3	OAT	0	25
19	1	-FZRA	AeroClear MAX	100/0	150A	III	Light Freezing Rain, -3, 25	Aluminum	-3	OAT	0	25
20	1	-FZRA	AeroClear MAX	100/0	150A	III	Light Freezing Rain, -3, 25	Aluminum	-3	OAT	0	25
21	1	-FZRA	Polar Guard Advance	100/0	068A	IV-PG	Light Freezing Rain, -3, 25	Aluminum	-3	OAT	0	25
22	1	-FZRA	Polar Guard Advance	100/0	068A	IV-PG	Light Freezing Rain, -3, 25	Aluminum	-3	OAT	0	25
23	1	-FZRA	EG106	100/0	117A	IV-EG	Light Freezing Rain, -3, 25	Aluminum	-3	OAT	0	25
24	1	-FZRA	EG106	100/0	117A	IV-EG	Light Freezing Rain, -3, 25	Aluminum	-3	OAT	0	25

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APPENDIX C

PROCEDURE:

**ENDURANCE TIME TESTING IN SIMULATED FREEZING PRECIPITATION
WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS**

301351

PROCEDURE:

**ENDURANCE TIME TESTING IN SIMULATED FREEZING PRECIPITATION
WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS**

Prepared for:

**Transport Canada
Programs Group Innovation Centre**

In cooperation with:

**Federal Aviation Administration
William J. Hughes Technical Center**

**Transport Canada
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**Federal Aviation Administration
Flight Standards – Air Carrier Operations**

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Reviewed by: John D'Avirro 



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PROCEDURE:
ENDURANCE TIME TESTING IN SIMULATED FREEZING PRECIPITATION
WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

1. BACKGROUND

SAE International (SAE) has published standards detailing acceptable practices for endurance time testing in simulated freezing precipitation conditions. The Aerospace Recommended Practice (ARP) documents ARP5945 and ARP5485 outline these practices for Type I and Type II/III/IV de/anti-icing fluids, respectively. These documents set the requirements for fluid samples, testing materials, test conditions, and test practices for anti-icing fluid endurance time testing. These standards are continually reviewed and updated at the discretion of the SAE Holdover Time committee.

APS Aviation Inc. (APS) has been conducting outdoor simulated freezing precipitation endurance time testing with the goal of measuring the effectiveness of new holdover time fluids since the early 1990s. All testing is conducted in accordance with the established SAE standards, ARP5945, and ARP5485.

This procedure serves as an update to the previous APS procedure, *Endurance Time Testing in Simulated Freezing Precipitation with SAE Type I, II, III, and IV De/Anti-icing Fluids*, which was issued in November 2018. This new document serves to incorporate refinements to the procedure that have been made in the intervening years, as well as to provide additional information relating to event planning and APS specific processes.

2. OBJECTIVE

This procedure describes the testing procedures used to evaluate the endurance time performance of Type I, II, III, and IV fluids in simulated freezing precipitation conditions.

This procedure also describes the testing procedure used to measure fluid thickness profiles of Type I, II, III, and IV fluids.

A related procedure is produced annually containing year-specific test plans, equipment needs, as well as details on other projects being undertaken during the annual simulated freezing precipitation holdover time test session.

3. PRE-TESTING ACTIVITIES

This section describes activities that need to be performed prior to commencing a simulated freezing precipitation testing session.

3.1. Event Coordination and Scheduling

Simulated freezing precipitation testing is a highly coordinated activity requiring the use of advanced testing facilities, numerous personnel (from both APS and the National Research Council Canada [NRC]), and significant resources. To that end, a significant effort must be put into planning these activities in order to keep testing running as smoothly, with as few costly disruptions as possible.

A typical test session will require that all fluids being qualified are tested in every simulated freezing precipitation condition found within a typical fluid holdover time table. This results in testing being done in discrete blocks (referred to as “conditions”) which are defined by the following:

- Precipitation Type;
- Test Temperature; and
- Target Precipitation Rate.

These parameters of each condition are designed to replicate the boundary conditions governing each freezing precipitation holdover time table cell.

Given that each fluid being tested must be tested in all boundary conditions, each simulated freezing precipitation test session will consist of a known amount of conditions, each of whose length can be estimated with the following information:

- Number of tests to be run (determined by the number of fluids to be tested); and
- Expected endurance time of each test (estimated based on fluid performance in natural snow).

Additionally, each fluid being qualified must also undergo fluid film thickness testing. This is generally performed concurrently with the standard endurance time testing, but must also be accounted for when scheduling a test session. As fluid film thickness testing is conducted at a chamber temperature of -3°C , the testing should be scheduled to be done during the -3°C condition blocks.

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It is the responsibility of the event coordinator to arrange the schedule of conditions in such a way as to ensure that each testing day will conclude at an appropriate time, and that time between conditions is minimized. To this end, like precipitation types/temperatures should be grouped as much as possible to avoid unnecessary temperature and spray equipment changes.

3.2. Data Requirements and Test Planning

Unlike natural snow testing, where data is gathered at a range of rates and temperatures, simulated freezing precipitation testing is conducted at a specific set of rates and temperatures representing the boundary conditions for each precipitation type. Table 3.1 lists all of the test conditions that comprise a standard simulated freezing precipitation holdover time test session.

Table 3.1: Standard Holdover Time Freezing Precipitation Test Conditions

Condition Abbreviation	Precipitation Type	OAT (°C)	Test Rate (g/dm ² /h)	Notes
ZF, -3, 2	Freezing Fog	-3	2	
ZF, -3, 5	Freezing Fog	-3	5	
ZF, -10, 2	Freezing Fog	-10	2	Type III only
ZF, -10, 5	Freezing Fog	-10	5	Type III only
ZF, -14, 2	Freezing Fog	-14	2	
ZF, -14, 5	Freezing Fog	-14	5	
ZF, -25, 2	Freezing Fog	-25	2	
ZF, -25, 5	Freezing Fog	-25	5	
ZF, -35, 2	Freezing Fog	-35	2	LOUT ≤ -29.5°C
ZF, -35, 5	Freezing Fog	-35	5	LOUT ≤ -29.5°C
ZD, -3, 5	Freezing Drizzle	-3	5	
ZD, -3, 13	Freezing Drizzle	-3	13	
ZD, -6, 5	Freezing Drizzle	-6	5	Type I only
ZD, -6, 13	Freezing Drizzle	-6	13	Type I only
ZD, -10, 5	Freezing Drizzle	-10	5	
ZD, -10, 13	Freezing Drizzle	-10	13	
ZR, -3, 13	Freezing Rain	-3	13	
ZR, -3, 25	Freezing Rain	-3	25	
ZR, -6, 13	Freezing Rain	-6	13	Type I only
ZR, -6, 25	Freezing Rain	-6	25	Type I only
ZR, -10, 13	Freezing Rain	-10	13	
ZR, -10, 25	Freezing Rain	-10	25	
CS, 1, 5	Rain on Cold-Soaked Wing	-1	5	
CS, 1, 75	Rain on Cold-Soaked Wing	-1	75	

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As the test conditions are standardized and finite in number, the amount of tests required for a given fluid in a typical holdover time test session is always known. For thickened fluids, this number is determined by how many dilutions are to be tested, as well as the fluid lowest operational use temperature (LOUT). For Type I fluids, data must be obtained using both aluminum and composite test surfaces for all conditions. Table 3.2 lists the data requirements in simulated freezing precipitation for all fluid types.

Table 3.2: Freezing Precipitation Data Requirements

Fluid Type, Dilution(s)	Fluid LOUT	Number of Tests Required
Type I	Any	56
Type II/IV, Neat Only	Above -29.5°C	32
	-29.5°C or Below	36
Type II/IV, All Dilutions	Above -29.5°C	72
	-29.5°C or Below	76
Type III, Neat Only	Above -29.5°C	32
	-29.5°C or Below	36
Type III, All Dilutions	Above -29.5°C	72
	-29.5°C or Below	76

Note that the totals in the above table do not include any tests which must be repeated (see Subsection 5.4.3 for details relating to repeated tests).

Refer to the above tables when planning an upcoming freezing precipitation test event; tests must be planned for each appropriate condition, and the number of tests for a given fluid should be equivalent to the appropriate number from the table above.

As a reminder, test plans for a given simulated freezing precipitation testing session are included in a related procedure that is prepared annually prior to that year's testing session.

3.3. Equipment Preparation

As all simulated freezing precipitation testing takes place at the NRC Climatic Engineering Facility (CEF) in Ottawa, there are several equipment preparation activities that must be completed prior to arrival at the NRC facility. These activities are listed below.

- 1) Mark all test surfaces with gridlines and with plate numbers on the back and front (note that markings should be at the bottom of the test surfaces).
- 2) Ensure all test plates are equipped with an operational SmartButton, and ensure that all temperature loggers have been properly configured. Loggers must be able to log a full week's worth of data as data will only be exported at the end of each testing week.
- 3) Locate the rate pans: check the quantity, confirm that all pans properly labelled and fully intact (no holes/cracks), and verify that spare pans are available.
- 4) Prepare labels for pour containers, as needed.
- 5) Confirm that the primary and backup rate station laptops are working normally, confirm that the rate station software runs on both laptops.
- 6) Confirm that the primary and backup rate station weigh scales are working normally and calibrated, confirm that both weigh scales are communicating properly with both the primary and backup rate station laptops.
- 7) Confirm that the APS closed-circuit television (CCTV) camera system is properly functioning, including all supporting equipment.
- 8) Ensure that sufficient copies of all data forms, procedures and condition sheets have been printed in advance.

3.4. Fluid Preparation Management

This subsection describes the steps necessary to ensure that the fluids to be tested are properly prepared for testing.

3.4.1. Type I Fluid Preparation

Type I fluids will generally be sent to APS by the manufacturer in concentrate form. Prior to commencing a test session, appropriately buffered mixtures of the fluid must be prepared for each test temperature that is planned for the session. As per ARP5945A, Type I fluids must be tested at dilutions where the freezing point of the solution is 10°C colder than the outside air temperature (OAT) at which testing is taking place.

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To prepare the buffered solution, you must first identify the temperatures at which the testing will take place. Separate solutions must be prepared for each discrete testing temperature, and each prepared solution must be stored at the correct temperature. For example, if the daily schedule calls for tests at both -3°C and -10°C, two separate batches of Type I fluid must be prepared (with freezing points of -13°C and -20°C respectively). Each batch must be stored at ambient room temperature (20°C).

The Type I concentrate must be diluted with hard water, which is prepared by dissolving 400 mg of calcium acetate dehydrate and 280 mg of magnesium sulfate heptahydrate into 1 L of water (the quantities can be scaled up proportionally if preparing a larger batch). Consult the dilution chart associated with the Type I fluid being tested in order to determine the appropriate glycol/hard water ratio necessary to achieve the desired freeze point. Dilution charts are generally available on the fluid manufacturer's website or provided directly from the manufacturer upon fluid receipt.

Confirm that the glycol concentration in your prepared solution is appropriate by measuring the Brix (generally Type I dilution charts will indicate the target Brix for the desired fluid freeze point). Ensure that the container in which the solution is mixed is clearly marked with the freeze point and Brix of the fluid. Pour container labels listing the fluid name, Brix and freeze point should also be created and affixed to all pour containers to be used during the test session.

Note that although ARP5945A stipulates that Type I fluid samples be sheared in a laboratory blender prior to testing, previous work has indicated that the effects of this shearing process on resulting Type I fluid endurance times are negligible. The Type I fluid shearing process is generally not performed with fluid samples as part of the typical simulated freezing precipitation testing process.

3.4.2. Type II/III/IV Fluid Management

In order to ensure that a testing session runs smoothly with minimal disruptions, it is critical that a sufficient number of filled 1 L pour containers for each fluid to be tested are prepared and tempered prior to the start of a given test condition. The required amount of each fluid for each condition will be known in advance; it is good practice to have additional fluid ready for testing in the event of unexpected circumstances.

Used pour containers should be periodically refilled when time permits to prevent delays in the fluid application process. At a minimum, empty pour containers should be refilled at the conclusion of each testing day. All pour containers must be affixed with labels listing the fluid name, batch number and dilution and special care must be taken when refilling to ensure that the proper fluid, batch, and dilution are used.

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At the testing manager's discretion, the fluid names on the pour container labels may need to be coded to preserve fluid anonymity in the presence of visitors.

All fluids to be used in simulated freezing precipitation endurance time testing must be properly stored in order to ensure that they are at the correct temperature when a test session begins. Given that simulated freezing precipitation testing takes place at several discrete testing temperatures, a series of programmable chest freezers set to the various testing temperatures should be available at the NRC such that a sufficient quantity of fluid can be kept at each temperature being tested.

Fluid can also be stored within the test chamber itself, provided that the temperature of the chamber is the desired storage temperature for the fluid in question.

As stated in ARP5485B, the temperature of Type II, III (unheated) or IV fluid being applied to a test surface in a simulated freezing precipitation endurance time test must be within 3°C (ideally 1°C) of the OAT. Valuable testing time can be lost waiting for fluids to temper if the proper storage procedures have not been followed.

4. TEST SITE

All testing in simulated freezing precipitation is conducted indoors at the NRC CEF located in Ottawa Canada, where precipitation is artificially produced using a specialized spray assembly capable of producing droplets of precisely calibrated size. This spray assembly (and the nozzles it contains) were developed by the NRC in conjunction with APS over the course of several years of research.

Photo 4.1 provides an outdoor view of the facility (U-88) giving a general indication of its size (30 m by 5.4 m, height 8 m). The facility was originally designed for the testing of locomotives; Photo 4.2 provides an interior view of the CEF set up for endurance time testing. The lowest temperature achievable in the CEF is -46°C.

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Photo 4.1: Outdoor View of NRC Climatic Engineering Facility



Photo 4.2: Inside View of NRC Climatic Engineering Facility



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5. TESTING PROCEDURES

This section describes the procedures to be followed during a simulated freezing precipitation test event.

The procedures conform to the requirements for simulated freezing precipitation testing outlined in Section 11 of ARP5485B – *Endurance Time Tests for Aircraft Deicing/Anti-icing Fluids, SAE Type II, III and IV*.

The procedures also conform to the requirements for simulated freezing precipitation testing outlined in Section 11 of ARP5945A – *Endurance Time Tests for Aircraft Deicing/Anti-icing Fluids, SAE Type I*.

5.1. Set-Up

The set-up steps to be performed once upon initial arrival at the CEF for a freezing precipitation endurance time testing session are listed below.

- 1) Unload all equipment from the truck upon arriving at the CEF. General equipment boxes should be stored in the women's washroom off of the client area. Office equipment is to be kept in the client area.
- 2) Set up the fluid storage freezers within the hallway off of the client area. Ensure that there is a freezer set to each of the target test temperatures at which testing will take place during the test session.
- 3) Set up the rate station within the client area: ensure that the scale being used is properly leveled and test that the scale and chosen rate station computer are functioning normally together.
- 4) Store the cold-soaked box fluid jugs (brought from the test site) inside the cold NRC freezer and confirm that the freezer is set to $< -30^{\circ}\text{C}$.
- 5) Set up two full six-position test stands within the spray area inside the testing chamber. The initial position of the test stands is dependent upon the first condition being tested; refer to the NRC Continuous Rate form to determine the appropriate starting position for the test stands. Ensure the stands are levelled such that the test surfaces lie at a 10° angle (within 9.8° and 10.2° is acceptable, check each test surface). The angle of the test stand can be adjusted as needed by placing poker chips under the stand legs. Whenever the configuration is adjusted by adding or removing chips, ensure that the stand is reasonably stable and that all test surfaces are at the proper angle. Ensure the fluid collection pans are placed beneath the test stands to collect fluid runoff, however equip the collection pans with white covers to prevent their filling with sprayed precipitation.

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- 6) Equip the two six-position test stands with aluminum test plates. Half plates may be used for one test in each duplicate pair of tests in order to increase the number of available test positions. Note that Type I fluids need to be tested on both composite and aluminum test surfaces, test surfaces can be adjusted on the test stands as needed. Note also that a special test surface is used for rain on cold-soaked wing condition testing with all fluid types. See Subsection 5.6 for additional details. All test plates used must be equipped with SmartButtons that are actively logging temperature data. Figure 5.1 depicts the proper plate set-up for the two test stands.
- 7) Install four of the five CCTV cameras (2.8 mm focal length) on the back corners of both test stands. Adjust the Manfrotto® arms accordingly so that optimal plate coverage is obtained for the complete stand. Install the fifth CCTV camera (2.8 mm focal length) in the climate chamber so that an overall view of the testing is obtained. Figure 5.2 illustrates the position of the five CCTV cameras.
- 8) Sync all digital clocks and install them in the large end of the test chamber (near spray area), and in the small end of the test chamber.
- 9) Confirm that the NRC personnel have properly set-up the CCTV camera system. It is critical that the camera system provides a good view of the testing area; the rate station manager must be able to have a clear view of the test stands while seated at the rate station. Ensure that the digital clocks are visible on the camera screens.
- 10) Post copies of the condition testing schedules and rate tolerance guidelines inside the client area.
- 11) Fill out the General Session Conformance Checklist (Attachment 1)
- 12) Prior to departing the facility on setup day, confirm that all personnel (NRC/APS) are aware of the starting time and initial test condition for the first testing day.

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Figure 5.1: Test Stand Set-Up

NRC Cold Chamber 2022-23

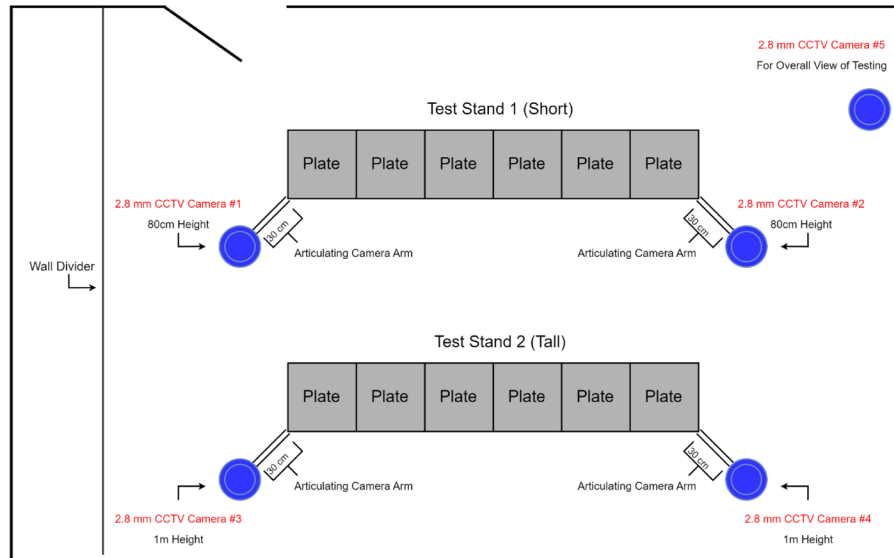


Figure 5.2: Camera Location During Holdover Time Testing

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5.2. Testing Process for a Typical Condition

A simulated freezing precipitation endurance time testing session is comprised of discrete blocks of tests known as conditions. Different conditions will vary in terms of precipitation type, precipitation rate, and test chamber temperature.

The general flow of work for each condition is very similar; the steps in the testing process are listed below.

- 1) Confirm the condition being tested with NRC personnel. NRC personnel will install the proper spraying equipment/needles and set the flow rate specific to the condition precipitation type and will set the testing chamber temperature to the appropriate target test temperature.
- 2) While NRC personnel are configuring the chamber and spray equipment, APS personnel must confirm that the test stands are in the proper starting position relative to the condition being tested (refer to the NRC Continuous Rate Form for proper stand position coordinates). Ensure that the test stands are equipped with the appropriate test surfaces, APS CCTV cameras are properly positioned, and confirm that all fluids to be tested in the upcoming condition are at the appropriate temperature.
- 3) Once the chamber has reached the appropriate temperature, NRC personnel will activate the spraying equipment and begin precipitation.
- 4) Once precipitation has begun, pre-test rate collection and calibration takes place. This process continues until stable, in-tolerance rates have been achieved on a sufficient number of test stand positions to allow testing. In order for a position to be used for testing, two consecutive in-tolerance rates must have been recorded on that position.
- 5) All required endurance time tests are conducted and the results are validated. Note that for a given condition, the number of tests to be conducted will be known beforehand and all tests to be run will be listed on a condition-specific test plan known as a "Condition Sheet". Two data points must be collected with each dilution of each fluid being tested in a given condition. Note that if the endurance time results obtained failed to satisfy preliminary data validation checks, supplemental test runs may be required.
- 6) As endurance time tests are completed, post-testing rate collection cycles are performed. Two rate collection cycles are required for a given position after an endurance time test is completed.
- 7) After the final post-test rate collection cycle is complete, the condition is considered complete. Rate and endurance time data processing takes place, and APS/NRC personnel can begin their set-up steps for the following condition.

5.3. Rate Collection

The rate collection process for simulated freezing precipitation differs significantly from the process employed during natural snow. Unlike natural snow rate collection, where one rate pan in one position is used to collect rates for the entire test stand, rate collection in simulated freezing precipitation is performed on each position of the test stand that is used for testing, resulting in unique rates being obtained for each position.

Additionally, while natural snow rate collection is a continuous process (occurring before, during and after a test), simulated freezing precipitation rate collection is performed only immediately prior and immediately following an endurance time test. The test rate for a given freezing precipitation endurance time test is determined by taking the average of four recorded rates; two rates taken immediately prior to the test, and two rates taken immediately following the test. All rates associated with a test must be collected from the same position on which the test is conducted. Similar to natural snow rate collection, the target time period for a recorded rate is ten minutes.

Test rates for simulated freezing precipitation endurance time tests must fall within a set of tolerances stipulated within ARP5945A and ARP5485B (for Type I and Type II/III/IV fluids, respectively). These tolerances dictate allowable ranges for the average rate of a test, as well as the allowable standard deviation of the individual rate measurements comprising a test rate. These tolerances are condition specific; they vary depending on precipitation type and target test rate. It is the responsibility of the rate station manager to ensure that test rates are falling within these tolerances; out-of-tolerance rates can result in the invalidation of an endurance time test. Table 5.1 lists the average test rate tolerances for the various simulated freezing precipitation conditions.

Table 5.1: Simulated Freezing Precipitation Average Test Rate Tolerances

Precipitation Type	Target Test Rate (g/dm ² /h)	Tolerance for Average Test Rate (g/dm ² /h)
Freezing Fog	2	± 0.3
	5	± 0.4
Freezing Drizzle	5	± 0.4
	13	± 0.5
Freezing Rain	13	± 0.5
	25	± 1.0
Rain on Cold-Soaked Wing	5	± 0.4
	75	± 3.0

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5.3.1. Procedure for Rate Collection

The rate collection process is generally performed by the rate station manager with two Ottawa personnel assisting. The steps for rate collection in simulated freezing precipitation are summarized below.

- 1) Open the rate station software (RateStation.WinForms). Complete initial configuration of the rate station software by selecting your test condition and specifying the temperature. If any positions on the test stand are not being used for testing in a given condition, retire them immediately in the software by clicking the "Retire" button under the unused positions.
- 2) Open a copy of the Excel sheet used to record the rates (RateStationTemplate). Rename the Excel sheet with a name that describes the condition being (ex. "ZD -10 5 - 2023-24" for low rate freezing drizzle at -10°C) and close the file.
- 3) Confirm that the test stands are in the correct starting position for the condition being tested (refer to the NRC Continuous Rate Form which lists the stand starting positions for each condition).
- 4) Ensure that the rate station scale is level, and pre-weigh dry "Inside" rate pans for all unretired positions. To record the pre-weight of the pans in the rate station software, click "Start Rate" under the appropriate position and input the weight from the scale in the "Weight" dialog box. Do not click "Start" after recording the pre-weight – this will signal to the software that the rate collection period has begun for that position.
- 5) Note that each numbered rate pan set corresponds to a specific numbered position on the test stand (see Figure 5.1) and consists of an "Inside" and an "Outside" plastic pan; whenever a pan is being weighed, only the "Inside" pans are to be placed on the scale. After weighing an "Inside" pan, place it back inside its corresponding "Outside" pan. Once all pans are pre-weighed, arrange them in numerical order on the shelves adjacent to the rate station. Figure 5.3 depicts the rate station software window after all pre-weights have been recorded (but before any rate cycles have begun).
- 6) Once the NRC personnel have started the precipitation for the condition, begin collecting initial rates for all available positions. In a typical two test stand set up, positions 2 through 12 should all be initially available. Bring the empty pans (Inside + Outside together) into the test chamber, and carefully place them on their respective positions one at a time, taking care to avoid covering other positions with the rate pan as it is placed on the stand. The rate station manager is to monitor this process closely on the NRC cameras; as each pan is placed on the stand, the rate station manager must click the "Start" button for the position in question to indicate the start of the rate collection period.

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- 7) As the ten-minute mark of the initial rate cycle approaches, begin collecting the rates pans from the test stand and returning them to the rate station, again in numerical order. Ensure that no precipitation is lost from inside each pan as they are transported – any lost precipitation will cause inaccuracies in the measured rate for that collection period. The rate station manager must once again monitor the process closely, and click the appropriate “Stop Rate” button at the moment that each pan is collected, signalling the end of the rate collection period. A dialog box will appear prompting the user for the final weight of the collection pan.
- 8) Weigh the “Inside” pans, record the weight in the dialog box and click “Save Rate”. Repeat this process for each of the pans collected.
- 9) As the final weights are entered, the program will automatically calculate the measured rate of precipitation over the collection period for each position. The program will show the calculated rate on the screen, highlighted either green (for an in-tolerance rate) or red (for an out-of-tolerance rate). Figure 5.4 depicts the rate station software window after one cycle of rates have been collected for each available position in a standard two stand set-up, with both in and out of tolerance rates being shown.
- 10) After the initial rate cycle is complete (and prior to starting the second rate cycle), review the measured rates shown on-screen. If most or all positions are out-of-tolerance and a consistent trend is noted in the rates (i.e. all too high or all too low), consider asking the NRC personnel to adjust the back pressure (lower if rates are too high, higher if rates are too low).
- 11) If changing the back pressure does not bring the rates back in tolerance, or if there is no discernable trend in the rates across the positions, consider adjusting the position of the test stands. If making any adjustments, allow time for the adjustment to be made and come into effect before bringing pans back out to start a new rate cycle.
- 12) Begin a second rate cycle with all pans, repeating the same process as was completed for the first cycle.
- 13) After the second cycle is complete, the rate station manager can begin allocating positions to the testing team provided that both measured rates on the position in question are within tolerance. Tests can only be run on positions that have had two consecutive valid rates collected. Making further changes to the back-pressure settings or stand position after testing has begun is discouraged – it is generally advisable to adjust early in the process with the goal of bringing as many positions in tolerance as possible.

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- 14) Once a given position has been allocated for use to the testing team, click "Start Test" in the rate station software window. The display for this position will change colour, and will indicate that a test is running. At this point, rate pans will no longer need to be placed on this position until the testing team has completed their test(s). Figure 5.5 depicts the rate station software window with several active tests running (test numbers have been added).
- 15) After the testing team pours a test on an allocated position, input the test number in the "Test #" section in the software.
- 16) If two tests are poured simultaneously on a position equipped with half-plates, input both test numbers separated by a slash (ex. 6/7, with test 6 being poured on the left-hand half plate and test 7 being poured on the right-hand half-plate).
- 17) If two tests are poured consecutively on a position (known as a "test-test"), input both test numbers separated by a plus sign (ex. 6 + 7, with test 6 being poured first and test 7 being poured on the same position after test 6 is complete).
- 18) Continue rate collection cycles on all positions that are not currently allocated for testing. Positions can be allocated to the testing team whenever two consecutive in-tolerance rates are obtained. Ensure that at all times rate cycles are continuously run on a minimum of one position – unexpected changes in the measured rates on this position will highlight changes in precipitation that may be difficult to detect otherwise.
- 19) When the testing team has completed their tests on a given position, they will communicate to the rate station manager that the position in question is now ready for post-test rates. Click "End Test" in the rate station software window for the position in question, and resume rate collection cycles on this position. A minimum of two post-test rate collection cycles must be completed in order to generate the final test rate for all tests run on that position. If the two post test rate cycles generate in-tolerance rates, the position can immediately be allocated back to the testing team (if more tests are to be run).
- 20) Once all tests and post-test rate cycles have been completed for a given condition, the rate data must be exported from the rate station software. To do so, click "Fill Excel Sheet" in the rate station software and locate the previously created Excel file.
- 21) Once the Excel sheet is populated, open the "Output" tab in the Excel file. Click "Update All" – the sheet will now process all of the imported rate data. Once complete, the rates for all tests run in the condition should be shown in this tab.

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- 22) Double check that test numbers for all tests run in the condition appear in Column D (refer to the condition sheet to confirm nothing was missed), and click "Status Calculator". The sheet will now verify that the rates for each test are conforming to the tolerances stipulated. Results of the checks are shown in columns P, Q, and R. If any of the tests fail any of the tolerance checks, advise the testing manager – they will make the decision whether to re-run the affected tests.
- 23) Once confirmed that all tests are present in the Excel sheet with in-tolerance rates, print out a copy of the details in the Output tab (columns D through S) and provide the printout to the testing assistant for filing.
- 24) Finally, at the conclusion of each condition, assess the overall difficulty of the rate process for that condition on a scale from 1-5 and note this difficulty on the NRC Continuous Rate Form.

The screenshot displays the 'Rate Station v1.0.23' software interface. On the left is a sidebar with the following elements: a 'Select Test Condition' button, the date and temperature 'Jul 19, 2018 ZDL, -10°C', a 'Fill Excel Sheet' button, a red 'Delete All' button, a 'Due Next (refreshes every 5 sec)' label, a 'TTT' button, and an 'Options' button. The main area is a 3x6 grid of test plates. The top row contains Plates 1 through 6; Plate 1 is black with 'RETIRED' text, while Plates 2-6 are yellow with weight input fields and 'Start' buttons. The middle row contains Plates 7 through 12, all yellow with weight inputs and 'Start' buttons. The bottom row contains Plates 1S through 6S, all black with 'RETIRED' text. Each active plate also shows 'Last' and '2nd Last' weight readings. At the bottom of the grid are 'TTT' and 'Options' buttons.

Figure 5.3: Rate Station Software Window after Pre-Weighing of Pans

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Figure 5.4: Rate Station Software Window after One Rate Cycle



Figure 5.5: Rate Station Software Window with Active Tests Running

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5.3.2. Challenges and Additional Information Concerning Rate Collection

Note that managing the rate station is a challenging role which requires a large amount of focus. The rate station manager should work closely with both the testing manager and NRC personnel in order to obtain valid, in-tolerance rates on as many positions as possible. Obtaining in-tolerance rates is not always straight-forward, and the challenge varies from condition to condition. Frequently, the rate station manager will need to make a decision between allocating fewer in-tolerance plates to the testing team (thus reducing the amount of tests that can be run concurrently) or attempting to tweak the water flow back pressure settings / stand positioning further (which delays the start of testing, with the goal of freeing up more usable positions).

The rate station manager should refer to the "Continuous Rate Form" in order to obtain an understanding of the relative difficulties of rate collection in the different conditions. This knowledge is helpful when attempting to make the "tweak or test" decisions alluded to in the previous paragraph. Finally, an internal companion document has been developed detailing common issues encountered during rate collection and troubleshooting suggestions. This document is available on the APS SharePoint.

5.4. Fluid Endurance Time Tests

The steps for conducting simulated freezing precipitation fluid endurance time tests are summarized below.

5.4.1. Procedure for Testing Unheated Fluids (Type II, III-Unheated, and IV)

- 1) Prepare the data form / data form app by recording the fluids to be poured in their respective positions.
- 2) Measure the initial fluid temperature of all fluids that are to be poured during the test session. Confirm that all fluids are within 3°C (ideally 1°C) of the current target test temperature. If fluids are not at the correct temperature, warm them in the client area or cool them in a chest freezer as needed.
- 3) Coordinate with the rate station manager to determine which positions on the test stand have rates suitable for testing.
- 4) Once test stand positions have been allocated to the testing team by the rate station manager, clear the test surfaces to be used of existing contamination using a scraper. To ensure that each position is properly cleaned, apply a small quantity of the fluid being tested to the test surface and use a squeegee to spread it across the full test surface.

ENDURANCE TIME TESTING IN SIMULATED FREEZING PRECIPITATION WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

- 5) Confirm that the data form manager is ready to begin the fluid application process. At each position, remove the plate cover and pour 1 L of the selected fluid onto the test surface from the top of the plate, ensuring that the entire surface of the plate is coated with an even fluid layer. During the pouring process, use the removed plate cover to shield the test surface from the falling precipitation. Record the time of fluid application on the chosen data form.
- 6) After fluid application is complete, each plate must be inspected periodically in order to assess the condition of the fluid layer. A section of the plate is considered failed when it is covered with frozen contamination.
- 7) If more than one-third of a given plate is determined to be “failed” (or if fluid failure is noted at any five of the crosshair marks on the plate), the plate as a whole is considered to be failed. Announce the fluid failure and ensure the failure time is recorded by the data form manager. Take a photo of the failed fluid from the back side, slightly above the plate, to capture full coverage. Place a “poker chip” on the plate once failure has been declared to indicate that the plate is no longer running an active test.
- 8) Alternately, if a test reaches the maximum run time (representing the maximum allowable holdover time for the freezing precipitation condition being tested), the test can be stopped immediately. For freezing fog, the maximum run time is four hours. For all other simulated freezing precipitation conditions, that maximum run time is two hours. The data form manager must note that the test did not fail (typically by noting “Did Not Fail (DNF)” on the data form).
- 9) If there are no other tests currently running or immediately to be run on the position, reinstall the plate cover and signal the rate station manager to begin post-test rate collection cycles. Note that a given position can be used for no more than two consecutive tests; post-test rate collection cycles must be performed after the second consecutive test.
- 10) Ensure fluid for the next condition is available and tempered to the correct temperature.

5.4.2. Procedure for Testing Heated Fluids (Type I and III-Heated)

- 1) Prepare the data form / data form app by recording the fluids to be poured in their respective positions.
- 2) Measure the initial fluid temperature of all fluids that are to be poured during the test session. Confirm that all fluids are within 5 °C (ideally 1 °C) of 20 °C. If fluids are not at the correct temperature, warm them in the client area or cool them in a chest freezer as needed.

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- 3) Coordinate with the rate station manager to determine which positions on the test stand have rates suitable for testing.
- 4) Once test stand positions have been allocated to the testing team by the rate station manager, clear the test surfaces to be used of existing contamination using a scraper. To ensure that each position is properly cleaned, apply a small quantity of the fluid being tested to the test surface and use a squeegee to spread it across the full test surface.
- 5) Confirm that the data form manager is ready to begin the fluid application process. At each position, remove the plate cover and pour 1 L of the selected fluid onto the test surface from the top of the plate, ensuring that the entire surface of the plate is coated with an even fluid layer. During the pouring process, use the removed plate cover to shield the test surface from the falling precipitation. Record the time of fluid application on the chosen data form.
- 6) After fluid application is complete, each test surface must be inspected periodically in order to assess the condition of the fluid layer. A section of the plate is considered failed when it is covered with frozen contamination. For Type I fluids, failure may occur quickly after fluid application.
- 7) If more than one-third of a given plate is determined to be "failed" (or if fluid failure is noted at any five of the crosshair marks on the plate), the plate as a whole is considered to be failed. Announce the fluid failure and ensure the failure time is recorded by the data form manager. Place a "poker chip" once failure has been declared to indicate that the plate is no longer running an active test.
- 8) Alternately, if a test reaches the maximum run time (representing the maximum allowable holdover time for the freezing precipitation condition being tested), the test can be stopped immediately. For freezing fog, the maximum run time is four hours. For all other simulated freezing precipitation conditions, that maximum run time is two hours. The data form manager must note that the test did not fail (typically by noting "Did Not Fail (DNF)" on the data form).
- 9) If there are no other tests currently running or immediately to be run on the position, reinstall the plate cover and signal the rate station manager to begin post-test rate collection cycles.
- 10) Prepare for the next condition.

5.4.3. Criteria for Validation of Fluid Endurance Time Test Results

Two data points must be collected with each dilution of each fluid being tested in a given condition. After both tests are complete, the endurance time results of the two tests must be compared to confirm that they conform to the reproducibility criteria outlined in ARP5945A / ARP5845B.

The standard states that if the endurance time of one of the two tests lies outside ± 10 percent from the average, then two additional data points must be collected with the fluid in question. In cases where additional data must be gathered, no data is to be discarded. All four data points will ultimately be used when analysing the test results and determining fluid holdover times.

It is the responsibility of the testing manager to ensure that all results obtained conform to the reproducibility criteria, and that additional data is collected when the reproducibility criteria is not met. A spreadsheet was developed for quick verification of the reproducibility criteria; as matched pairs of tests are completed, their results should be entered into the spreadsheet for verification of conformance.

5.5. Fluid Film Thickness Testing

In addition to fluid endurance time testing, a standard simulated freezing precipitation endurance time test session will also include fluid film thickness testing for each dilution of each fluid being tested. This testing performed in the “small end” of the test chamber (away from the spray area) as no precipitation is required. The testing is performed at -3°C , and is generally run concurrently to fluid endurance time tests.

The steps for conducting fluid film thickness tests are summarized below.

- 1) Set up a full six-position test stand in the “small end” of the testing chamber (away from the spray area). The exact position of the test stand is not important, but ensure that the stand is levelled such that the test surfaces lie at a 10° angle (within 9.8° and 10.2° is acceptable, check each test surface). Equip the test stand with aluminum test plates.
- 2) Prepare the data form by recording the fluids to be poured in their respective positions.
- 3) Measure the initial fluid temperature of the fluids that are undergoing thickness testing. Unheated fluids (Types II, III-Unheated and IV) must be within 3°C (ideally 1°C) of -3°C . Heated fluids (Types I and III-Heated) must be within 5°C (ideally 1°C) of 20°C . If fluids are not at the correct temperature, warm them in the client area or cool them in a chest freezer as needed.

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- 4) Pour 1 L of each fluid onto the test surface from the top of the plate, ensuring that the entire surface of the plate is coated with an even fluid layer. Start recording time on a stopwatch after the first fluid is poured. Stagger each pour in order to ensure that all thickness measurements can be captured at the appropriate times. Record the time of fluid application on the data form for each pour.
- 5) At the five minute mark (as noted on the stopwatch), measure the thickness of the first poured fluid layer along the six-inch line of the plate with a film thickness gauge. Confirm the measured value by taking a second reading at a different point along the six-inch line of the plate. If there is disagreement between the first and second thickness values, take a third measurement at another point along the six-inch line. If all three values are different, record all three values obtained. Otherwise, discard the non-conforming value.
- 6) Repeat the thickness measurement process for the other fluid layers, staggering the measurements in the same manner as the fluid application process, to ensure that each fluid film thickness is measured at its respective five minute mark. Record the measured fluid film thicknesses on the data form.
- 7) Repeat the thickness measurement process at the 15 minute mark, and again at the 30 minute mark. Ensure that all measurements are recorded for each fluid being tested.

5.6. Procedure for Cold-Soaked Box Preparation

For rain on a cold-soaked wing endurance time testing, the test surface to be used is a leading edge thermal equivalent box filled with cold Type I fluid (known as a cold-soaked box). As per ARP5945A and ARP5485B, the boxes must be prepared such that the surface temperature of the plate at the start time of an endurance time test is $-10 \pm 1^{\circ}\text{C}$.

The cold-soaked box preparation should begin during the initial rate collection cycles of the cold-soaked wing condition in order to ensure that the surfaces are ready for testing as soon as the rate collection process is complete.

The steps for preparing cold-soaked boxes for testing are listed below.

- 1) Close the large door in the test chamber, dividing the chamber into the large end (containing the spray area and the test stands) and the small end. Have the NRC personnel set the temperature of the small end of the chamber to -10°C .

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- 2) Retrieve the containers of cold Type I fluid from the cold (-30°C) freezers and place in the small end of the chamber.
- 3) Using a combination of the cold Type I fluid jugs removed from the freezers and the warmer Type I fluid found in the barrel at the small end of the chamber, prepare a large batch of Type I fluid with a fluid temperature of $-12 \pm 1^{\circ}\text{C}$. The Brix of the fluid mixture should fall between 26.00 and 29.00. Note that a very large volume of cold fluid is required to fill the boxes; the batch should be prepared in the largest container available on-hand. Mix the fluid frequently while preparing the batch and monitor the fluid temperature at all times during the box preparation process.
- 4) Place the empty cold-soaked boxes and cold-soaked box filling stand on the large metal table found in the small end of the testing chamber.
- 5) Place a box in the filling stand and fill with the prepared Type I fluid mixture. Once full, agitate the box within the stand to free any trapped air within. Refill the box and agitate once again, repeating the process until the box is completely full with no trapped air.
- 6) Close the box and verify that the surface temperature of the box is $-11 \pm 1^{\circ}$. Remove the box from the filling stand and place on a dolly to await transfer to the testing team for use.
- 7) Repeat the process with the remaining empty boxes. Note that the filled boxes are heavy – avoid placing too many on the dolly at one time.
- 8) As positions on the test stand become available for testing, the testing team will advise the box preparation team that filled boxes are needed. Transfer prepared boxes to the testing team as needed by raising the doors dividing the testing chamber and passing the dolly underneath. Avoid transferring boxes too early or transferring unneeded boxes, as the surface temperature of the filled boxes will change rapidly in the warmer end of the testing chamber.
- 9) As tests are completed, filled boxes that have been used by the testing team will be returned to the box preparation team. Empty the used boxes back into the prepared fluid mixture, ensuring that the temperature of the mixture remains at $-12 \pm 1^{\circ}\text{C}$.
- 10) Continue preparing boxes until a sufficient quantity has been prepared to complete all planned tests (as well as any supplemental tests required, as determined by the testing team).
- 11) At the end of the cold-soaked wing condition, return all Type I fluid to the barrel for future use.

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5.7. End of Testing Day Activities

The steps for concluding a freezing precipitation endurance time testing day are summarized as below.

- 1) Ensure all test surfaces are properly cleaned after testing and that all fluid within the collection pans is disposed of appropriately (all glycol waste must be vacuumed up and disposed of in the waste fluid tote).
- 2) Ensure that all fluids to be tested during the first condition planned for the following day are available and are stored at the proper temperature. Refill empty pour containers as needed.
- 3) Ensure copies of the rate station Excel outputs for each condition tested have been saved in the Data and Rates folder of the APS SharePoint.
- 4) If using the HOT Data Form app to record endurance times, export the data files for each condition tested and save copies in the Data and Rates folder of the APS SharePoint.
- 5) If using paper data forms, place the completed forms in an envelope and mark the envelope with the date and number of forms.
- 6) If it is the final testing day of the week, ensure that the CCTV video camera footage has been downloaded and saved in the appropriate location on the APS SharePoint or external hard drive.
- 7) If it is the final testing day of the week, ensure that all SmartButton data from all test surfaces used is downloaded from the buttons and saved to the APS SharePoint.
- 8) If it is the final testing day of the session, ensure that the chamber temperature, relative humidity and video data is obtained from the NRC personnel.
- 9) Ensure that the SharePoint is synced and that all saved files have been uploaded.
- 10) Confirm starting time for the next testing day with all APS/NRC personnel prior to leaving for the day.

6. EQUIPMENT

The equipment required for endurance time testing in simulated freezing precipitation is listed in Attachment 2. The specific equipment needed for each session is listed in the annual NRC procedure.

7. PERSONNEL

Generally, five to six people are required for simulated freezing precipitation endurance time testing.

- 1) Testing Manager – responsible for overseeing the test event, determining which tests are to be run, applying fluids and calling all failures.
- 2) Rate Station Manager – responsible for overseeing the rate collection process and coordinating the testing assistants assigned to the rate station.
- 3) Data Form Manager – responsible for managing all data forms (paper and electronic) and ensuring all information is properly transcribed and captured.
- 4) Videographer – responsible for setting up and managing the CCTV camera system and ensuring all data is downloaded and saved in the proper location.
- 5) Testing Assistants (2 or 3) – responsible for set-up activities, rate collection, clean-up and assisting with any other tasks as determined by the testing manager.

Note that for simulated freezing precipitation testing, the testing assistants are generally part-time personnel who are based in the Ottawa area.

8. SAFETY

Testing in cold temperatures can pose significant safety issues. Jackets, gloves, and boots should be rated to very low temperatures and must be worn at all times when inside the testing chamber. Employees should be mindful of dangers associated with hypothermia and frostbite.

Additionally, as all simulated freezing precipitation testing takes place at an NRC controlled facility, all employees must adhere to any and all safety guidelines imposed by the NRC or its personnel.

Personnel must operate in accordance with the “Testing Safety Recommendations” and must follow the protocols for “Extended Work Hours Protocol for APS Personnel.” These documents are included in the “APS Office Policies & Procedures,” which is made available to all APS staff.

9. DATA FORMS AND SOFTWARE

The following data forms and software are typically used for simulated freezing precipitation endurance time testing:

- 1) Rate Station Software;
- 2) General Session Conformance Checklist (Attachment 1);
- 3) NRC Continuous Rate Form (Attachment 3);
- 4) End Condition Data Form for Endurance Time Tests – used as backup for app data form (Attachment 4);
- 5) App Data Form for Fluid Endurance Time Tests (Attachment 5); and
- 6) Fluid Film Thickness Testing Data Form (Attachment 6).

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Attachment 1: General Session Conformance Checklist

LOCATION: CEF (Ottawa)	DATE:
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Safety Issues Discussed		☐
Test Plate Material: (check the box if material used is Aluminum alloy AMS 4037)		☐
Test Plate Dimensions: (check the box if the dimensions are 500mm long x 300mm wide x 3.2mm thick)		☐
Test Box Dimensions: (only for CSW, check the box if the dimensions are 500mm long x 300mm wide x 75mm thick)		☐
Surface Finish: (check the box if the average surface roughness is $\leq 0.5 \mu\text{m}$)		☐
Ice-catch Pan Dimensions: (check the box if the dimensions are 406mm long x 279mm wide with a 64mm height)		☐
Water Supply to Nozzle: (check the box if the water supplied to the nozzles conforms to is ASTM D1193 Type IV water or a hardness of less than 300 ppm reported as CaCO_3)		☐
Weigh Scale Verification (check the box if calibration was performed in the previous summer)		☐
Distance between Nozzle and Test Plates (check the box if distance is 7 ± 0.5 , for ZD, ZR and CSW)		☐
Distance between Temperature Sensor and Test Plates (check the box if distance is within 1.5m)		☐

COMMENTS:

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LEADER:

ENDURANCE TIME TESTING IN SIMULATED FREEZING PRECIPITATION WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

Attachment 2: Equipment List for Simulated Freezing Precipitation Testing

SIMULATED FREEZING PRECIPITATION TESTING	
LOCATION: TEST SITE	
Barrel Opener to open CSW fluids	Rate Pan (aluminum HOT) x1
Bins for mixing CSW fluid x 5 (60L rubbermaids)	Rate Pans(white plastic) x all
Brixometer x 3	Sample bottles x 6
Camera x2 (small Canon) with accessories	Sartorius Scales x 2
Cart (IKEA) x 2	Scrapers x 14
Clear plastic clipboards x 5	Shop Vac + 2x18L open top pails
Clock (Large digital) x 2	SmartButton kits x 2 + extension wire
Cold-soak boxes (aluminum) x 16	Squeegees x 4 (small)
Empty 20L fluid container x 5 (for -30C CSW fluid)	Tape: Duct tape x 1
Extension Cords x 4	Tape: Electrical tape x 5
Flashlights x 2	Tape: Speed tape x 1
Fluids (separate table)	Tape measurer (large yellow + small)
Fluid carrying cases x 4	Temperature probes: immersion x 3
Folding table x 1 (small)	Temperature probes: surface x 3
Freezers x 3	Tents for Fog x 4
Funnels x 4 (very big, big, medium and small)	Test plate covers (white plastic) x 15
Gloves: rubber/winter x 4 pairs	Test plate covers (wooden boards) x 12
Gloves: cotton (1 large box)	Test Plates: Half plates x 12 (24 halves) w/buttons
Gloves: latex (2 boxes)	Test Plates: Full plates x 12 w/buttons
Ice Pic	Test Plates: Full plates x 8 no buttons
Inclinometer (yellow level) x 2	Test Stand Collection Pans (one per stand)
Isopropyl x 6	Test Stand Shims (poker chips) x 1 box
Lock for truck	Test Stands: 2 x 6-position (main stand)
Marker for Waste x 2	Test Stands: 1 x 6-position (thickness stand)
Measuring Cups x 3	Test Stands: 1 x 1-position (automated rate)
Paper Towels (4 packs)	Test Stands: 1 x 2-position (side stand)
Personnel clothing (testing coats/boots)	Thickness Gauges: 4 rectangle
Pour containers: (1-litre) - 6 empty	Thickness Gauges: 4 octagon
Pour containers: (1-litre) - see list of fluids	Tuques x 10
Power bars x 4	Vise grip (large) + rubber opener
Printer & Ink Cartridge	Whatman paper kit + dye
Rain Suits (all)	White poster board panels for water run-off
	EXTRA: Glycol for CSW boxes
LOCATION: OFFICE	
Blank Waterproof labels (1 page)	Laptop for Rate Station and SmartButtons
Condition Sheets x 6	Mouse for Rate Station and keypad
Data Forms (on water phobic paper)	Paper for printer x 1 pack
Envelopes (9x12) x box	Pencils + pens + markers
Falling Ball Viscometer + Syringes	Test Procedures x 5
File box x 2	Walkie Talkies and Accessories x 4
Hard Drive (if necessary)	Waterproof paper (40 sheets)
iPads x 2	

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Equipment List for Simulated Freezing Precipitation Testing (cont'd)

SIMULATED FREEZING PRECIPITATION TESTING	
REMOTE VIEWING CAMERA EQUIPMENT: TEST SITE	
4K IP Camera with tripod mounts x 2	NVR Receiver
4K IP Camera Zoomed Lens with tripod mounts x 2	Power Cables for monitor and receiver x 2
Ethernet Cable (150ft) x 5	ZTE with large internet plan
Monitor with VGA cable	CCTV Camera x 5
REMOTE VIEWING CAMERA EQUIPMENT: OFFICE	
Camera Cover x 4	Manfrotto Arms with clamp inserts x 4
External HDD	
LOCATION: NRC	
Cold-soak box filling stand	Rubber Mats
Cold-soak fluid pump	Shelving unit x 1 (black one)
Copper tubing insulation (for passing wires)	Tie wraps
Fluid for cold-soak boxes (barrel)	Tools
NRC Auto Rate Form with Historical #'s	Tote for Waste Fluid

ENDURANCE TIME TESTING IN SIMULATED FREEZING PRECIPITATION WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

Attachment 3: NRC Continuous Rate Form

Condition	Historical Average Calculated Rate – Position 1	Standard Deviation of Historical Average Calculated Rate (Pos. 1)	Historical Average of Session Standard Deviation	Suggested Start Position	Previous Condition Difficulty Rating (1-5, 1 is easiest)	Historical Condition Difficulty Rating (1-5, 1 is easiest)	Comments
ZF, -3, 2	1.8	0.3	0.7	Pos. 10 (2'',0'')	1.0	1.3	In 2020, stand was at (23' 11'', 6' 7''), (24', 9')
ZF, -3, 5	4.9	0.6	2.1	Pos. 4 (0'', 18'')	3.0	2.3	In 2020, stand was at (23' 11'', 5' 10''), (24', 9')
ZF, -10, 2	1.9	0.3	0.6	Pos. 10 (2'',0'')	n/a	1.0	
ZF, -10, 5	4.9	1.0	0.9	Pos. 10 (2'',0'')	n/a	1.5	
ZF, -14, 2	2.1	0.2	0.7	Pos. 10 (2'',0'')	1.0	1.3	In 2020, stand was at (23' 11'', 5' 10''), (24', 9')
ZF, -14, 5	4.8	0.3	1.1	Pos. 10 (2'',0'')	1.0	1.3	In 2020, stand was at (23' 11'', 5' 10''), (24', 9')
ZF, -25, 2	2.0	0.4	1.0	Pos. 10 (2'',0'')	1.0	1.0	In 2020, stand was at (23' 11'', 6' 7''), (24', 9')
ZF, -25, 5	4.8	0.4	1.2	Pos. 10 (2'',0'')	5.0	2.8	In 2020, we had to move stand to (23' 11'', 5' 10''), (24', 9')
ZF, -35, 2	2.1	0.1	1.0	Pos. 10 (2'',0'')	1.0	2.7	In 2020, stand was at (23' 11'', 6' 7''), (24', 9')
ZF, -35, 5	5.1	0.0	1.5	Pos. 10 (2'',0'')	2.0	3.0	In 2020, stand was at (23' 11'', 6' 7''), (24', 9')
ZD, -3, 5	5.5	0.2	0.9	(23' 11'', 6' 7''), (24', 9')	1.0	2.5	
ZD, -3, 13	13.0	1.8	1.7	(23' 11'', 6' 7''), (24', 9')	1.0	3.5	
ZD, -6, 5	n/a	n/a	n/a	n/a	n/a	n/a	
ZD, -6, 13	n/a	n/a	n/a	n/a	n/a	n/a	
ZD, -10, 5	5.9	0.4	0.8	(23' 11'', 6' 7''), (24', 9')	4.0	1.5	
ZD, -10, 13	14.0	0.5	1.7	(23' 11'', 6' 7''), (24', 9')	1.0	2.3	
ZR, -3, 13	13.6	0.5	1.2	(23' 11'', 6' 7''), (24', 9')	1.0	2.0	
ZR, -3, 25	25.7	0.6	1.5	(23' 11'', 6' 7''), (24', 9')	1.0	1.0	
ZR, -6, 13	n/a	n/a	n/a	n/a	n/a	n/a	
ZR, -6, 25	n/a	n/a	n/a	n/a	n/a	n/a	
ZR, -10, 13	13.9	0.7	1.0	(23' 11'', 6' 7''), (24', 9')	1.0	4.0	
ZR, -10, 25	26.1	0.5	1.2	(23' 11'', 6' 7''), (24', 9')	1.0	1.0	
CS, 1, 5	4.9	0.2	4.0	(23' 11', Closest to Bottom), (24', 9')	4.0	3.0	
CS, 1, 75	75.6	3.4	13.1	(Closest to Bottom), (24', 9')	2.0	2.5	

*Initial position to be set to (24', 7'), (24', 9') for (x, y) & (x', y') based on the schedule.

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Attachment 4: End Condition Data Form for Endurance Time Tests

REMEMBER TO SYNCHRONIZE TIME

LOCATION:	PRECIP. CONDITION:	DATE:	RUN NUMBER:	STAND #:
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Time of Fluid Application: _____

Time of Fluid Failure: _____

Fluid Name/Dilutor: _____

PLATE 1	PLATE 2	PLATE 3	PLATE 4	PLATE 5	PLATE 6

Failure Call: (describe) _____

Time of Fluid Application: _____

Time of Fluid Failure: _____

Fluid Name/Dilutor: _____

PLATE 7	PLATE 8	PLATE 9	PLATE 10	PLATE 11	PLATE 12

Failure Call: (describe) _____

AMBIENT TEMPERATURE: _____ °C

LEADER / MANAGER: _____

FAILURE S CALLED BY: _____

COMMENTS: _____

NOTE: Please ensure correct functioning of plate temperature logging system at the start of the test and at the end of the session

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Attachment 5: Screenshot of Holdover Time Data Form App

The screenshot shows the 'APS Aviation Inc - END CONDITION FORM' interface. The top bar includes 'Clear All', 'Add New', 'Precipitation Condition', and 'Logout' buttons. The main area contains 12 test slots, each with a number and specific test data. Slots 1 and 6 are inactive, while others are active. The bottom navigation bar includes: Home, Locations, Users, Fluid Name, Fluid Dilution, Stand, Precipitation Condition, Fluid Temp, Summary, and Export.

Slot	Fluid Type	Amount	Start Time	ET	GT	Buttons
1	-	-	-	-	-	New Test, Split
2	Type IV	100/0	14:30:28	00:06:38	-	Stop, DNF
3	Type II	75/25	14:32:27	00:01:41	-	Undo, Refresh
4	Type IV	50/50	00:00:00	-	-	Start, Refresh
5	Type III	100/0	14:36:24	00:00:42	-	Stop, DNF
6	-	-	-	-	-	New Test, Split
7	Type III	50/50	14:37:00	00:00:01	-	Undo, Refresh
8	Type II	75/25	14:36:21	00:00:45	-	Stop, DNF
9	Type IV	75/25	14:33:39	00:01:13	-	Undo, Refresh
10	Type III	100/0	14:32:27	00:04:39	-	Stop, DNF
11	Type IV	75/25	14:35:54	00:00:02	-	Undo, Refresh
12	Type II	50/50	14:34:59	00:02:07	-	Stop, DNF

APS/Library/Projects/301351 (TC Deicing 2023-24)/Procedures/Simulated FP ET Testing/Final Version 1.0/Simulated Freezing Precip ET Testing Final Version 1.0.docx
Final Version 1.0, December 23

ENDURANCE TIME TESTING IN SIMULATED FREEZING PRECIPITATION WITH SAE TYPE I, II, III, AND IV DE/ANTI-ICING FLUIDS

Attachment 6: Fluid Film Thickness Testing Data Form

REMEMBER TO SYNCHRONIZE TIME																																										
LOCATION:	DATE:	TEMPERATURE °C:	RUN NUMBER(S):	TEST # :	to																																					
Time of Fluid Application: _____																																										
Fluid Name/Dilution: _____																																										
RUN #:	PLATE 1 <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <th style="width: 50%;">TIME (min)</th> <th style="width: 50%;">THICKNESS 6" LINE</th> </tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> </table>		TIME (min)	THICKNESS 6" LINE											PLATE 2 <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <th style="width: 50%;">TIME (min)</th> <th style="width: 50%;">THICKNESS 6" LINE</th> </tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> </table>		TIME (min)	THICKNESS 6" LINE											PLATE 3 <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <th style="width: 50%;">TIME (min)</th> <th style="width: 50%;">THICKNESS 6" LINE</th> </tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> </table>		TIME (min)	THICKNESS 6" LINE										
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Fluid Name/Dilution: _____																																										
PERFORMED BY: _____ WRITTEN BY: _____																																										
COMMENTS: _____ _____ _____ _____																																										

NOTES:

- The quantity of fluid that will be poured for each test is 1.0 L on a full plate or 0.5L on a half plate
- Measurements should be made at the 6-inch line at the time of fluid application, and after 5 minutes, 15 minutes, and 30 minutes.
- If the results for one fluid vary by more than 10% repeat the two tests and disregard the highest and lowest values

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APPENDIX D

MIXED ICING RESEARCH – RELEVANT TEST DATA FROM PREVIOUS YEARS

MIXED ICING RESEARCH – RELEVANT TEST DATA FROM PREVIOUS YEARS

This appendix contains the test data from previous mixed icing testing sessions that are relevant to the analyses referred to within the report.

Table 1 contains the relevant mixed snow and freezing fog test data from 2022-23 and 2023-24.

Table 2 contains the relevant mixed snow and rain test data from 2022-23 and 2023-24.

Table 3 contains the relevant mixed snow and mist test data from 2023-24.

Table 1: Mixed Snow and Freezing Fog Endurance Time Testing Data from 2022-23 and 2023-24

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Testing Sub-Objective	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Actual Rate (Snow Only) (g/dm ² /h)	Actual Rate (Freezing Fog Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
0-151A	08-Mar-22	Dow PG ADF Concentrate	I	Aluminum	Light Snow	Type I Testing (Improved Methodology)	-3	10	10.5	-	-	8.5	8.9
0-152A	08-Mar-22	Dow PG ADF Concentrate	I	Aluminum	Light Snow	Type I Testing (Improved Methodology)	-3	10	10.5	-	-	8.5	8.9
0-159A	08-Mar-22	Dow PG ADF Concentrate	I	Composite	Light Snow	Type I Testing (Improved Methodology)	-3	10	10.5	-	-	4.4	4.6
0-160A	08-Mar-22	Dow PG ADF Concentrate	I	Composite	Light Snow	Type I Testing (Improved Methodology)	-3	10	10.5	-	-	4.4	4.6
0-269A	11-Mar-22	Dow PG ADF Concentrate	I	Aluminum	Light Snow	Type I Testing (Improved Methodology)	-14	10	11.3	-	-	5.9	6.7
0-270A	11-Mar-22	Dow PG ADF Concentrate	I	Aluminum	Light Snow	Type I Testing (Improved Methodology)	-14	10	11.3	-	-	6.2	7.1
0-277A	11-Mar-22	Dow PG ADF Concentrate	I	Composite	Light Snow	Type I Testing (Improved Methodology)	-14	10	11.3	-	-	3.5	4.0
0-278A	11-Mar-22	Dow PG ADF Concentrate	I	Composite	Light Snow	Type I Testing (Improved Methodology)	-14	10	11.3	-	-	4.8	5.4
0-1115A	08-Mar-22	Dow PG ADF Concentrate	I	Aluminum	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	12	-	-	12.5	8.3	8.6
0-1116A	08-Mar-22	Dow PG ADF Concentrate	I	Aluminum	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	12	-	-	12.5	8.0	8.3
0-1117A	08-Mar-22	Dow PG ADF Concentrate	I	Composite	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	12	-	-	12.5	4.8	5.0
0-1118A	08-Mar-22	Dow PG ADF Concentrate	I	Composite	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	12	-	-	12.5	4.5	4.6
1	15-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Light Snow	Type I Testing (Improved Methodology)	-3	10	10.3	0	10.3	5.5	5.6
3	15-Mar-23	Dow PG ADF Concentrate	I	Composite	Light Snow	Type I Testing (Improved Methodology)	-3	10	10	0	10	3.8	3.8
5	15-Mar-23	CHEMR REG I	I	Aluminum	Light Snow	Type I Testing (Improved Methodology)	-3	10	9.3	0	9.3	6.4	6.0
7	15-Mar-23	CHEMR REG I	I	Composite	Light Snow	Type I Testing (Improved Methodology)	-3	10	9.9	0	9.9	4.3	4.3
9	15-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Snow	Type I Testing (Improved Methodology)	-3	25	26.3	0	26.3	4.1	4.3

Table 1: Mixed Snow and Freezing Fog Endurance Time Testing Data from 2022-23 and 2023-24 (cont'd)

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Testing Sub-Objective	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Actual Rate (Snow Only) (g/dm ² /h)	Actual Rate (Freezing Fog Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
11	15-Mar-23	Dow PG ADF Concentrate	I	Composite	Moderate Snow	Type I Testing (Improved Methodology)	-3	25	28.3	0	28.3	2.2	2.5
13	15-Mar-23	CHEMR REG I	I	Aluminum	Moderate Snow	Type I Testing (Improved Methodology)	-3	25	23	0	23	4.2	3.9
15	15-Mar-23	CHEMR REG I	I	Composite	Moderate Snow	Type I Testing (Improved Methodology)	-3	25	25.3	0	25.3	2.3	2.4
17	14-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Light Snow	Type I Testing (Improved Methodology)	-14	10	8.6	0	8.6	3.3	2.8
19	14-Mar-23	Dow PG ADF Concentrate	I	Composite	Light Snow	Type I Testing (Improved Methodology)	-14	10	9.2	0	9.2	2.2	2.0
21	14-Mar-23	CHEMR REG I	I	Aluminum	Light Snow	Type I Testing (Improved Methodology)	-14	10	8.9	0	8.9	3.1	2.7
23	14-Mar-23	CHEMR REG I	I	Composite	Light Snow	Type I Testing (Improved Methodology)	-14	10	10.2	0	10.2	2.2	2.2
25	14-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Snow	Type I Testing (Improved Methodology)	-14	25	26.1	0	26.1	2.1	2.1
27	14-Mar-23	Dow PG ADF Concentrate	I	Composite	Moderate Snow	Type I Testing (Improved Methodology)	-14	25	23.9	0	23.9	1.3	1.2
29	14-Mar-23	CHEMR REG I	I	Aluminum	Moderate Snow	Type I Testing (Improved Methodology)	-14	25	22.2	0	22.2	3.2	2.8
31	14-Mar-23	CHEMR REG I	I	Composite	Moderate Snow	Type I Testing (Improved Methodology)	-14	25	23.7	0	23.7	1.3	1.2
33	13-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Light Snow	Type I Testing (Improved Methodology)	-25	10	10.2	0	10.2	1.3	1.3
35	13-Mar-23	Dow PG ADF Concentrate	I	Composite	Light Snow	Type I Testing (Improved Methodology)	-25	10	10.2	0	10.2	1.1	1.1
37	13-Mar-23	CHEMR REG I	I	Aluminum	Light Snow	Type I Testing (Improved Methodology)	-25	10	10.2	0	10.2	1.8	1.9
39	13-Mar-23	CHEMR REG I	I	Composite	Light Snow	Type I Testing (Improved Methodology)	-25	10	10.2	0	10.2	1.3	1.3
41	13-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Snow	Type I Testing (Improved Methodology)	-25	25	25.7	0	25.7	0.9	0.9
43	13-Mar-23	Dow PG ADF Concentrate	I	Composite	Moderate Snow	Type I Testing (Improved Methodology)	-25	25	25.7	0	25.7	1.3	1.3

Table 1: Mixed Snow and Freezing Fog Endurance Time Testing Data from 2022-23 and 2023-24 (cont'd)

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Testing Sub-Objective	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Actual Rate (Snow Only) (g/dm ² /h)	Actual Rate (Freezing Fog Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
45	13-Mar-23	CHEMR REG I	I	Aluminum	Moderate Snow	Type I Testing (Improved Methodology)	-25	25	25.7	0	25.7	1.1	1.1
47	13-Mar-23	CHEMR REG I	I	Composite	Moderate Snow	Type I Testing (Improved Methodology)	-25	25	25.7	0	25.7	0.8	0.9
49	16-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	12	8.9	2.3	10.6	6.2	5.5
51	16-Mar-23	Dow PG ADF Concentrate	I	Composite	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	12	9.4	2.2	11.4	3.9	3.7
53	16-Mar-23	CHEMR REG I	I	Aluminum	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	12	10.1	2	12.2	6.4	6.5
55	16-Mar-23	CHEMR REG I	I	Composite	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	12	10.5	2.1	12.2	4.7	4.8
57	16-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	27	27	2.3	29.3	3.7	4.0
59	16-Mar-23	Dow PG ADF Concentrate	I	Composite	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	27	28.5	2.2	30.7	2.4	2.7
61	16-Mar-23	CHEMR REG I	I	Aluminum	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	27	27.2	2	29.2	5.2	5.6
63	16-Mar-23	CHEMR REG I	I	Composite	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	27	24.6	2.1	26.7	3.2	3.1
65	14-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-14	12	9	2.1	11.1	3.0	2.8
67	14-Mar-23	Dow PG ADF Concentrate	I	Composite	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-14	12	8.7	2.5	11.2	2.2	2.1
69	14-Mar-23	CHEMR REG I	I	Aluminum	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-14	12	8.6	2.4	11	3.0	2.8
71	14-Mar-23	CHEMR REG I	I	Composite	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-14	12	9.5	2.1	11.6	2.1	2.0
73	14-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-14	27	27	2.3	29.3	2.1	2.3
75	14-Mar-23	Dow PG ADF Concentrate	I	Composite	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-14	27	28.5	2.2	30.7	1.1	1.3
77	14-Mar-23	CHEMR REG I	I	Aluminum	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-14	27	27.2	2	29.2	2.2	2.3

Table 1: Mixed Snow and Freezing Fog Endurance Time Testing Data from 2022-23 and 2023-24 (cont'd)

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Testing Sub-Objective	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Actual Rate (Snow Only) (g/dm ² /h)	Actual Rate (Freezing Fog Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
79	14-Mar-23	CHEMR REG I	I	Composite	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-14	27	24.6	2.1	26.7	1.5	1.5
81	13-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-25	12	9.6	2.3	11.9	1.4	1.4
83	13-Mar-23	Dow PG ADF Concentrate	I	Composite	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-25	12	9.8	2.2	12	1.1	1.1
85	13-Mar-23	CHEMR REG I	I	Aluminum	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-25	12	9.9	1.9	11.8	1.2	1.2
87	13-Mar-23	CHEMR REG I	I	Composite	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-25	12	10	2.1	12.1	1.4	1.4
89	13-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-25	27	24.1	2.3	26.4	1.1	1.1
91	13-Mar-23	Dow PG ADF Concentrate	I	Composite	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-25	27	27.5	2.2	29.7	1.0	1.2
93	13-Mar-23	CHEMR REG I	I	Aluminum	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-25	27	22.9	2	24.9	1.1	1.0
95	13-Mar-23	CHEMR REG I	I	Composite	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-25	27	27.1	2.1	29.2	1.0	1.0
1	29-Feb-24	PG ADF Concentrate	I-PG	Aluminum	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	12	-	-	12.3	6.4	6.6
2	29-Feb-24	PG ADF Concentrate	I-PG	Composite	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	12	-	-	13.8	3.5	4.1
3	29-Feb-24	CHEMR REG I	I-EG	Aluminum	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	12	-	-	14.1	6.2	7.3
4	29-Feb-24	CHEMR REG I	I-EG	Composite	Light Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	12	-	-	12.3	3.5	3.5
5	29-Feb-24	PG ADF Concentrate	I-PG	Aluminum	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	27	-	-	26.3	4.6	4.5
6	29-Feb-24	PG ADF Concentrate	I-PG	Composite	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	27	-	-	26.1	2.3	2.2
7	29-Feb-24	CHEMR REG I	I-EG	Aluminum	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	27	-	-	26.5	4.3	4.2
8	29-Feb-24	CHEMR REG I	I-EG	Composite	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-3	27	-	-	26.3	2.3	2.2

Table 1: Mixed Snow and Freezing Fog Endurance Time Testing Data from 2022-23 and 2023-24 (cont'd)

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Testing Sub-Objective	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Actual Rate (Snow Only) (g/dm ² /h)	Actual Rate (Freezing Fog Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
17	05-Mar-24	PG ADF Concentrate	I-PG	Aluminum	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-14	27	-	-	29.6	3.2	3.5
18	05-Mar-24	PG ADF Concentrate	I-PG	Composite	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-14	27	-	-	29.6	2.3	2.5
19	05-Mar-24	CHEMR REG I	I-EG	Aluminum	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-14	27	-	-	29.6	3.2	3.5
20	05-Mar-24	CHEMR REG I	I-EG	Composite	Moderate Snow and Freezing Fog	Type I Testing (Improved Methodology)	-14	27	-	-	29.6	2.4	2.6

Table 2: Mixed Snow and Rain Endurance Time Testing Data from 2022-23 and 2023-24

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Actual Rate (Snow Only) (g/dm ² /h)	Actual Rate (Rain/Freezing Rain Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
1	28-Feb-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Rain mixed with Snow	-3	25	0	24.6	24.6	23.9	23.6
2	28-Feb-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Rain mixed with Snow	-3	25	0	24.6	24.6	19.6	19.3
3	28-Feb-23	Dow PG ADF Concentrate	I	Composite	Moderate Rain mixed with Snow	-3	25	0	24.9	24.9	23.4	23.3
4	28-Feb-23	Dow PG ADF Concentrate	I	Composite	Moderate Rain mixed with Snow	-3	25	0	24.9	24.9	21.1	21.0
5	28-Feb-23	CHEMR REG I	I	Aluminum	Moderate Rain mixed with Snow	-3	25	0	25.1	25.1	19.5	19.6
6	28-Feb-23	CHEMR REG I	I	Aluminum	Moderate Rain mixed with Snow	-3	25	0	25.1	25.1	17.0	17.0
7	28-Feb-23	CHEMR REG I	I	Composite	Moderate Rain mixed with Snow	-3	25	0	24.6	24.6	13.6	13.4
8	28-Feb-23	CHEMR REG I	I	Composite	Moderate Rain mixed with Snow	-3	25	0	24.6	24.6	14.7	14.5
9	28-Feb-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Rain mixed with Snow	-3	25	0	24.7	24.7	43.0	42.5
10	28-Feb-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Rain mixed with Snow	-3	25	0	25.3	25.3	43.3	43.8
11	28-Feb-23	AllClear AeroClear MAX	III	Aluminum	Moderate Rain mixed with Snow	-3	25	0	24.7	24.7	17.5	17.3
12	28-Feb-23	AllClear AeroClear MAX	III	Aluminum	Moderate Rain mixed with Snow	-3	25	0	25	25	18.0	18.0
13	28-Feb-23	Cryotech Polar Guard Advance	IV	Aluminum	Moderate Rain mixed with Snow	-3	25	0	25.5	25.5	48.9	49.9
14	28-Feb-23	Cryotech Polar Guard Advance	IV	Aluminum	Moderate Rain mixed with Snow	-3	25	0	25.5	25.5	49.2	50.2
15	28-Feb-23	Dow EG106	IV	Aluminum	Moderate Rain mixed with Snow	-3	25	0	25.5	25.5	50.9	51.9
16	28-Feb-23	Dow EG106	IV	Aluminum	Moderate Rain mixed with Snow	-3	25	0	25.1	25.1	52.4	52.6
17	01-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Rain mixed with Snow	0	75	22.4	54.3	76.7	6.5	6.6

Table 2: Mixed Snow and Rain Endurance Time Testing Data from 2022-23 and 2023-24 (cont'd)

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Actual Rate (Snow Only) (g/dm ² /h)	Actual Rate (Rain/Freezing Rain Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
18	01-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Rain mixed with Snow	0	75	22.4	54.3	76.7	6.6	6.7
19	01-Mar-23	Dow PG ADF Concentrate	I	Composite	Moderate Rain mixed with Snow	0	75	25.1	52.6	77.7	4.8	5.0
20	01-Mar-23	Dow PG ADF Concentrate	I	Composite	Moderate Rain mixed with Snow	0	75	25.1	52.6	77.7	5.9	6.2
21	01-Mar-23	CHEMR REG I	I	Aluminum	Moderate Rain mixed with Snow	0	75	22.2	50.7	72.9	6.5	6.3
22	01-Mar-23	CHEMR REG I	I	Aluminum	Moderate Rain mixed with Snow	0	75	22.2	50.7	72.9	6.4	6.2
23	01-Mar-23	CHEMR REG I	I	Composite	Moderate Rain mixed with Snow	0	75	23.5	49.9	73.4	4.9	4.8
24	01-Mar-23	CHEMR REG I	I	Composite	Moderate Rain mixed with Snow	0	75	23.5	49.9	73.4	5.8	5.7
25	01-Mar-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Rain mixed with Snow	0	75	24.9	51.2	76.1	16.0	16.3
26	01-Mar-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Rain mixed with Snow	0	75	24.9	51.2	76.1	13.9	14.1
27	01-Mar-23	AllClear AeroClear MAX	III	Aluminum	Moderate Rain mixed with Snow	0	75	24.9	51.2	76.1	9.4	9.5
28	01-Mar-23	AllClear AeroClear MAX	III	Aluminum	Moderate Rain mixed with Snow	0	75	24.9	51.2	76.1	10.0	10.2
29	01-Mar-23	Cryotech Polar Guard Advance	IV	Aluminum	Moderate Rain mixed with Snow	0	75	24.9	51.2	76.1	17.9	18.1
30	01-Mar-23	Cryotech Polar Guard Advance	IV	Aluminum	Moderate Rain mixed with Snow	0	75	24.9	51.2	76.1	18.7	19.0
31	01-Mar-23	Dow EG106	IV	Aluminum	Moderate Rain mixed with Snow	0	75	24.9	51.2	76.1	15.8	16.0
32	01-Mar-23	Dow EG106	IV	Aluminum	Moderate Rain mixed with Snow	0	75	24.9	51.2	76.1	15.8	16.0
33	03-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Rain mixed with Snow	0	75	10.1	67.1	77.2	10.0	10.3
35	03-Mar-23	Dow PG ADF Concentrate	I	Composite	Moderate Rain mixed with Snow	0	75	10.5	67.3	77.8	3.4	3.5

Table 2: Mixed Snow and Rain Endurance Time Testing Data from 2022-23 and 2023-24 (cont'd)

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Actual Rate (Snow Only) (g/dm ² /h)	Actual Rate (Rain/Freezing Rain Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
37	03-Mar-23	CHEMR REG I	I	Aluminum	Moderate Rain mixed with Snow	0	75	10.7	64.7	75.4	9.0	9.1
39	03-Mar-23	CHEMR REG I	I	Composite	Moderate Rain mixed with Snow	0	75	10	65.4	75.4	3.1	3.1
41	03-Mar-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Rain mixed with Snow	0	75	8.2	64.3	72.5	16.4	15.8
42	03-Mar-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Rain mixed with Snow	0	75	8.2	64.3	72.5	15.4	14.9
43	03-Mar-23	AllClear AeroClear MAX	III	Aluminum	Moderate Rain mixed with Snow	0	75	8.2	64.3	72.5	11.1	10.7
44	03-Mar-23	AllClear AeroClear MAX	III	Aluminum	Moderate Rain mixed with Snow	0	75	8.2	64.3	72.5	11.2	10.8
45	03-Mar-23	Cryotech Polar Guard Advance	IV	Aluminum	Moderate Rain mixed with Snow	0	75	8.2	64.3	72.5	17.1	16.5
46	03-Mar-23	Cryotech Polar Guard Advance	IV	Aluminum	Moderate Rain mixed with Snow	0	75	8.2	64.3	72.5	14.9	14.4
47	03-Mar-23	Dow EG106	IV	Aluminum	Moderate Rain mixed with Snow	0	75	8.2	64.3	72.5	15.4	14.9
48	03-Mar-23	Dow EG106	IV	Aluminum	Moderate Rain mixed with Snow	0	75	8.2	64.3	72.5	13.8	13.4
49	15-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Snow mixed with Rain	-3	10	10.3	0	10.3	5.5	5.6
51	15-Mar-23	Dow PG ADF Concentrate	I	Composite	Moderate Snow mixed with Rain	-3	10	10	0	10	3.8	3.8
53	15-Mar-23	CHEMR REG I	I	Aluminum	Moderate Snow mixed with Rain	-3	10	9.3	0	9.3	6.4	6.0
55	15-Mar-23	CHEMR REG I	I	Composite	Moderate Snow mixed with Rain	-3	10	9.9	0	9.9	4.3	4.3
57	17-Mar-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Snow mixed with Rain	-3	10	10.1	0	10.1	93.9	94.8
58	17-Mar-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Snow mixed with Rain	-3	10	10.1	0	10.1	108.4	109.4
59	17-Mar-23	AllClear AeroClear MAX	III	Aluminum	Moderate Snow mixed with Rain	-3	10	10.1	0	10.1	43.1	43.6

Table 2: Mixed Snow and Rain Endurance Time Testing Data from 2022-23 and 2023-24 (cont'd)

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Actual Rate (Snow Only) (g/dm ² /h)	Actual Rate (Rain/Freezing Rain Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
60	17-Mar-23	AllClear AeroClear MAX	III	Aluminum	Moderate Snow mixed with Rain	-3	10	10.1	0	10.1	41.7	42.1
61	17-Mar-23	Cryotech Polar Guard Advance	IV	Aluminum	Moderate Snow mixed with Rain	-3	10	10.1	0	10.1	142.4	143.8
62	17-Mar-23	Cryotech Polar Guard Advance	IV	Aluminum	Moderate Snow mixed with Rain	-3	10	10.1	0	10.1	116.9	118.1
63	17-Mar-23	Dow EG106	IV	Aluminum	Moderate Snow mixed with Rain	-3	10	10.1	0	10.1	95.5	96.5
64	17-Mar-23	Dow EG106	IV	Aluminum	Moderate Snow mixed with Rain	-3	10	10.1	0	10.1	83.2	84.0
65	15-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Snow mixed with Rain	-3	25	30.6	0	30.6	4.1	5.0
67	15-Mar-23	Dow PG ADF Concentrate	I	Composite	Moderate Snow mixed with Rain	-3	25	26.4	0	26.4	2.2	2.3
69	15-Mar-23	CHEMR REG I	I	Aluminum	Moderate Snow mixed with Rain	-3	25	26.7	0	26.7	4.2	4.5
71	15-Mar-23	CHEMR REG I	I	Composite	Moderate Snow mixed with Rain	-3	25	23.8	0	23.8	2.3	2.2
73	15-Mar-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Snow mixed with Rain	-3	25	28.1	0	28.1	29.4	33.1
74	15-Mar-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Snow mixed with Rain	-3	25	28.1	0	28.1	33.1	37.2
75	15-Mar-23	AllClear AeroClear MAX	III	Aluminum	Moderate Snow mixed with Rain	-3	25	28.1	0	28.1	28.8	32.4
76	15-Mar-23	AllClear AeroClear MAX	III	Aluminum	Moderate Snow mixed with Rain	-3	25	28.1	0	28.1	22.7	25.5
77	15-Mar-23	Cryotech Polar Guard Advance	IV	Aluminum	Moderate Snow mixed with Rain	-3	25	28.1	0	28.1	32.3	36.3
78	15-Mar-23	Cryotech Polar Guard Advance	IV	Aluminum	Moderate Snow mixed with Rain	-3	25	28.1	0	28.1	35.0	39.3
79	15-Mar-23	Dow EG106	IV	Aluminum	Moderate Snow mixed with Rain	-3	25	28.1	0	28.1	51.2	57.6
80	15-Mar-23	Dow EG106	IV	Aluminum	Moderate Snow mixed with Rain	-3	25	28.1	0	28.1	47.7	53.6

Table 2: Mixed Snow and Rain Endurance Time Testing Data from 2022-23 and 2023-24 (cont'd)

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Actual Rate (Snow Only) (g/dm ² /h)	Actual Rate (Rain/Freezing Rain Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
R1	28-Feb-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Snow mixed with Rain	-3	25	0	24.6	24.6	23.9	23.6
R2	28-Feb-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Snow mixed with Rain	-3	25	0	24.6	24.6	19.6	19.3
R3	28-Feb-23	Dow PG ADF Concentrate	I	Composite	Moderate Snow mixed with Rain	-3	25	0	24.9	24.9	23.4	23.3
R4	28-Feb-23	Dow PG ADF Concentrate	I	Composite	Moderate Snow mixed with Rain	-3	25	0	24.9	24.9	21.1	21.0
R5	28-Feb-23	CHEMR REG I	I	Aluminum	Moderate Snow mixed with Rain	-3	25	0	25.1	25.1	19.5	19.6
R6	28-Feb-23	CHEMR REG I	I	Aluminum	Moderate Snow mixed with Rain	-3	25	0	25.1	25.1	17.0	17.0
R7	28-Feb-23	CHEMR REG I	I	Composite	Moderate Snow mixed with Rain	-3	25	0	24.6	24.6	13.6	13.4
R8	28-Feb-23	CHEMR REG I	I	Composite	Moderate Snow mixed with Rain	-3	25	0	24.6	24.6	14.7	14.5
R9	28-Feb-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Snow mixed with Rain	-3	25	0	24.7	24.7	43.0	42.5
R10	28-Feb-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Snow mixed with Rain	-3	25	0	25.3	25.3	43.3	43.8
R11	28-Feb-23	AllClear AeroClear MAX	III	Aluminum	Moderate Snow mixed with Rain	-3	25	0	24.7	24.7	17.5	17.3
R12	28-Feb-23	AllClear AeroClear MAX	III	Aluminum	Moderate Snow mixed with Rain	-3	25	0	25	25	18.0	18.0
R13	28-Feb-23	Cryotech Polar Guard Advance	IV	Aluminum	Moderate Snow mixed with Rain	-3	25	0	25.5	25.5	48.9	49.9
R14	28-Feb-23	Cryotech Polar Guard Advance	IV	Aluminum	Moderate Snow mixed with Rain	-3	25	0	25.5	25.5	49.2	50.2
R15	28-Feb-23	Dow EG106	IV	Aluminum	Moderate Snow mixed with Rain	-3	25	0	25.5	25.5	50.9	51.9
R16	28-Feb-23	Dow EG106	IV	Aluminum	Moderate Snow mixed with Rain	-3	25	0	25.1	25.1	52.4	52.6
225	07-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Snow mixed with Rain	0	35	26.6	12.8	39.4	4.0	4.5

Table 2: Mixed Snow and Rain Endurance Time Testing Data from 2022-23 and 2023-24 (cont'd)

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Actual Rate (Snow Only) (g/dm ² /h)	Actual Rate (Rain/Freezing Rain Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
227	07-Mar-23	Dow PG ADF Concentrate	I	Composite	Moderate Snow mixed with Rain	0	35	24.6	12	36.6	2.0	2.1
229	07-Mar-23	CHEMR REG I	I	Aluminum	Moderate Snow mixed with Rain	0	35	27.3	12.2	39.5	4.0	4.5
231	07-Mar-23	CHEMR REG I	I	Composite	Moderate Snow mixed with Rain	0	35	25.7	12.4	38.1	2.2	2.4
233	07-Mar-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Snow mixed with Rain	0	35	25.4	12.2	37.6	33.1	35.6
234	07-Mar-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Snow mixed with Rain	0	35	25.4	12.2	37.6	34.9	37.5
235	07-Mar-23	AllClear AeroClear MAX	III	Aluminum	Moderate Snow mixed with Rain	0	35	25.4	12.2	37.6	13.4	14.4
236	07-Mar-23	AllClear AeroClear MAX	III	Aluminum	Moderate Snow mixed with Rain	0	35	25.4	12.2	37.6	15.7	16.8
237	07-Mar-23	Cryotech Polar Guard Advance	IV	Aluminum	Moderate Snow mixed with Rain	0	35	25.4	12.2	37.6	35.2	37.9
238	07-Mar-23	Cryotech Polar Guard Advance	IV	Aluminum	Moderate Snow mixed with Rain	0	35	25.4	12.2	37.6	31.6	34.0
239	07-Mar-23	Dow EG106	IV	Aluminum	Moderate Snow mixed with Rain	0	35	25.4	12.2	37.6	40.6	43.6
240	07-Mar-23	Dow EG106	IV	Aluminum	Moderate Snow mixed with Rain	0	35	25.4	12.2	37.6	42.3	45.4
241	02-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Snow mixed with Rain	0	50	23.5	25.3	48.8	5.5	5.4
243	02-Mar-23	Dow PG ADF Concentrate	I	Composite	Moderate Snow mixed with Rain	0	50	28.6	25	53.6	2.2	2.4
245	02-Mar-23	CHEMR REG I	I	Aluminum	Moderate Snow mixed with Rain	0	50	25.8	25.5	51.3	4.5	4.6
247	02-Mar-23	CHEMR REG I	I	Composite	Moderate Snow mixed with Rain	0	50	22.3	25.6	47.9	2.4	2.3
249	02-Mar-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Snow mixed with Rain	0	50	23.9	24.7	48.6	25.5	24.8
250	02-Mar-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Snow mixed with Rain	0	50	23.9	24.7	48.6	27.6	26.8

Table 2: Mixed Snow and Rain Endurance Time Testing Data from 2022-23 and 2023-24 (cont'd)

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Actual Rate (Snow Only) (g/dm ² /h)	Actual Rate (Rain/Freezing Rain Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
251	02-Mar-23	AllClear AeroClear MAX	III	Aluminum	Moderate Snow mixed with Rain	0	50	23.9	24.7	48.6	13.4	13.0
252	02-Mar-23	AllClear AeroClear MAX	III	Aluminum	Moderate Snow mixed with Rain	0	50	23.9	24.7	48.6	11.7	11.4
253	02-Mar-23	Cryotech Polar Guard Advance	IV-PG	Aluminum	Moderate Snow mixed with Rain	0	50	23.9	24.7	48.6	30.8	29.9
254	02-Mar-23	Cryotech Polar Guard Advance	IV-PG	Aluminum	Moderate Snow mixed with Rain	0	50	23.9	24.7	48.6	30.2	29.4
255	02-Mar-23	Dow EG106	IV-EG	Aluminum	Moderate Snow mixed with Rain	0	50	23.9	24.7	48.6	39.7	38.5
256	02-Mar-23	Dow EG106	IV-EG	Aluminum	Moderate Snow mixed with Rain	0	50	23.9	24.7	48.6	33.4	32.5
R17	01-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Snow mixed with Rain	0	75	22.4	54.3	76.7	6.5	6.6
R18	01-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Snow mixed with Rain	0	75	22.4	54.3	76.7	6.6	6.7
R19	01-Mar-23	Dow PG ADF Concentrate	I	Composite	Moderate Snow mixed with Rain	0	75	25.1	52.6	77.7	4.8	5.0
R20	01-Mar-23	Dow PG ADF Concentrate	I	Composite	Moderate Snow mixed with Rain	0	75	25.1	52.6	77.7	5.9	6.2
R21	01-Mar-23	CHEMR REG I	I	Aluminum	Moderate Snow mixed with Rain	0	75	22.2	50.7	72.9	6.5	6.3
R22	01-Mar-23	CHEMR REG I	I	Aluminum	Moderate Snow mixed with Rain	0	75	22.2	50.7	72.9	6.4	6.2
R23	01-Mar-23	CHEMR REG I	I	Composite	Moderate Snow mixed with Rain	0	75	23.5	49.9	73.4	4.9	4.8
R24	01-Mar-23	CHEMR REG I	I	Composite	Moderate Snow mixed with Rain	0	75	23.5	49.9	73.4	5.8	5.7
R25	01-Mar-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Snow mixed with Rain	0	75	24.9	51.2	76.1	16.0	16.3
R26	01-Mar-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Snow mixed with Rain	0	75	24.9	51.2	76.1	13.9	14.1
R27	01-Mar-23	AllClear AeroClear MAX	III	Aluminum	Moderate Snow mixed with Rain	0	75	24.9	51.2	76.1	9.4	9.5

Table 2: Mixed Snow and Rain Endurance Time Testing Data from 2022-23 and 2023-24 (cont'd)

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Actual Rate (Snow Only) (g/dm ² /h)	Actual Rate (Rain/Freezing Rain Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
R28	01-Mar-23	AllClear AeroClear MAX	III	Aluminum	Moderate Snow mixed with Rain	0	75	24.9	51.2	76.1	10.0	10.2
R29	01-Mar-23	Cryotech Polar Guard Advance	IV-PG	Aluminum	Moderate Snow mixed with Rain	0	75	24.9	51.2	76.1	17.9	18.1
R30	01-Mar-23	Cryotech Polar Guard Advance	IV-PG	Aluminum	Moderate Snow mixed with Rain	0	75	24.9	51.2	76.1	18.7	19.0
R31	01-Mar-23	Dow EG106	IV-EG	Aluminum	Moderate Snow mixed with Rain	0	75	24.9	51.2	76.1	15.8	16.0
R32	01-Mar-23	Dow EG106	IV-EG	Aluminum	Moderate Snow mixed with Rain	0	75	24.9	51.2	76.1	15.8	16.0
E5	06-Mar-23	Dow PG ADF Concentrate	I	Aluminum	Moderate Snow mixed with Rain	0	75	4.5	71.5	76	27.6	28.0
E6	06-Mar-23	Dow PG ADF Concentrate	I	Composite	Moderate Snow mixed with Rain	0	75	5.2	71.8	77	39.2	40.2
E7	06-Mar-23	CHEMR REG I	I	Aluminum	Moderate Snow mixed with Rain	0	75	2.7	72.6	75.3	27.7	27.8
E8	06-Mar-23	CHEMR REG I	I	Composite	Moderate Snow mixed with Rain	0	75	4.6	70.4	75	39.2	39.2
E9	03-Mar-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Snow mixed with Rain	0	75	-	-	72.5	21.5	20.8
E10	03-Mar-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Snow mixed with Rain	0	75	-	-	72.5	20.6	20.0
E11	03-Mar-23	AllClear AeroClear MAX	III	Aluminum	Moderate Snow mixed with Rain	0	75	-	-	72.5	12.2	11.8
E12	03-Mar-23	AllClear AeroClear MAX	III	Aluminum	Moderate Snow mixed with Rain	0	75	-	-	72.5	11.9	11.5
E13	03-Mar-23	Cryotech Polar Guard Advance	IV-PG	Aluminum	Moderate Snow mixed with Rain	0	75	-	-	72.5	21.1	20.4
E14	03-Mar-23	Cryotech Polar Guard Advance	IV-PG	Aluminum	Moderate Snow mixed with Rain	0	75	-	-	72.5	28.6	27.7
E15	03-Mar-23	Dow EG106	IV-EG	Aluminum	Moderate Snow mixed with Rain	0	75	-	-	72.5	20.0	19.3
E16	03-Mar-23	Dow EG106	IV-EG	Aluminum	Moderate Snow mixed with Rain	0	75	-	-	72.5	20.6	19.9

Table 2: Mixed Snow and Rain Endurance Time Testing Data from 2022-23 and 2023-24 (cont'd)

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Actual Rate (Snow Only) (g/dm ² /h)	Actual Rate (Rain/Freezing Rain Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
E17	28-Mar-23	Dow PG ADF Concentrate	I-PG	Aluminum	Moderate Snow mixed with Rain	1	75	-	-	75.4	1.9	1.9
E18	28-Mar-23	Dow PG ADF Concentrate	I-PG	Composite	Moderate Snow mixed with Rain	1	75	-	-	76.1	2.4	2.4
E19	28-Mar-23	CHEMR REG I	I-EG	Aluminum	Moderate Snow mixed with Rain	1	75	-	-	75.4	2.0	2.0
E20	28-Mar-23	CHEMR REG I	I-EG	Composite	Moderate Snow mixed with Rain	1	75	-	-	76.1	1.5	1.5
E21	28-Mar-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Snow mixed with Rain	1	75	-	-	74.3	10.6	10.5
E22	28-Mar-23	Clariant Safewing MP II FLIGHT	II	Aluminum	Moderate Snow mixed with Rain	1	75	-	-	74.4	13.0	12.9
E23	28-Mar-23	AllClear AeroClear MAX	III	Aluminum	Moderate Snow mixed with Rain	1	75	-	-	75.5	9.4	9.5
E24	28-Mar-23	AllClear AeroClear MAX	III	Aluminum	Moderate Snow mixed with Rain	1	75	-	-	75.9	8.4	8.5
E25	28-Mar-23	Cryotech Polar Guard Advance	IV-PG	Aluminum	Moderate Snow mixed with Rain	1	75	-	-	78	15.2	15.8
E26	28-Mar-23	Cryotech Polar Guard Advance	IV-PG	Aluminum	Moderate Snow mixed with Rain	1	75	-	-	77.7	15.7	16.3
E27	28-Mar-23	Dow EG106	IV-EG	Aluminum	Moderate Snow mixed with Rain	1	75	-	-	74.3	17.3	17.1
E28	28-Mar-23	Dow EG106	IV-EG	Aluminum	Moderate Snow mixed with Rain	1	75	-	-	74.4	17.6	17.5
41	06-Mar-24	Safewing MP II FLIGHT	II	Aluminum	Moderate Rain Mixed with Snow	0	75	-	-	77.4	16.2	16.7
42	06-Mar-24	Safewing MP II FLIGHT	II	Aluminum	Moderate Rain Mixed with Snow	0	75	-	-	77.4	17.0	17.5
43	06-Mar-24	AllClear AeroClear MAX	III	Aluminum	Moderate Rain Mixed with Snow	0	75	-	-	77.4	8.5	8.7
44	06-Mar-24	AllClear AeroClear MAX	III	Aluminum	Moderate Rain Mixed with Snow	0	75	-	-	77.4	8.3	8.5
45	06-Mar-24	Cryotech Polar Guard Advance	IV-PG	Aluminum	Moderate Rain Mixed with Snow	0	75	-	-	77.4	15.9	16.4

Table 2: Mixed Snow and Rain Endurance Time Testing Data from 2022-23 and 2023-24 (cont'd)

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Actual Rate (Snow Only) (g/dm ² /h)	Actual Rate (Rain/Freezing Rain Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
46	06-Mar-24	Cryotech Polar Guard Advance	IV-PG	Aluminum	Moderate Rain Mixed with Snow	0	75	-	-	77.4	16.3	16.8
47	06-Mar-24	Dow EG106	IV-EG	Aluminum	Moderate Rain Mixed with Snow	0	75	-	-	77.4	14.8	15.3
48	06-Mar-24	Dow EG106	IV-EG	Aluminum	Moderate Rain Mixed with Snow	0	75	-	-	77.4	13.8	14.2
53	06-Mar-24	Safewing MP II FLIGHT	II	Aluminum	Moderate Rain Mixed with Snow	0	75	-	-	73.9	16.6	16.4
54	06-Mar-24	Safewing MP II FLIGHT	II	Aluminum	Moderate Rain Mixed with Snow	0	75	-	-	73.9	19.0	18.7
55	06-Mar-24	AllClear AeroClear MAX	III	Aluminum	Moderate Rain Mixed with Snow	0	75	-	-	73.9	15.0	14.8
56	06-Mar-24	AllClear AeroClear MAX	III	Aluminum	Moderate Rain Mixed with Snow	0	75	-	-	73.9	17.0	16.7
57	06-Mar-24	Cryotech Polar Guard Advance	IV-PG	Aluminum	Moderate Rain Mixed with Snow	0	75	-	-	73.9	17.8	17.6
58	06-Mar-24	Cryotech Polar Guard Advance	IV-PG	Aluminum	Moderate Rain Mixed with Snow	0	75	-	-	73.9	18.6	18.3
59	06-Mar-24	Dow EG106	IV-EG	Aluminum	Moderate Rain Mixed with Snow	0	75	-	-	73.9	18.7	18.4
60	06-Mar-24	Dow EG106	IV-EG	Aluminum	Moderate Rain Mixed with Snow	0	75	-	-	73.9	16.0	15.8

Table 3: Mixed Snow and Mist Endurance Time Testing Data from 2023-24

Test #	Date	Fluid Name	Fluid Type	Test Surface	Condition	Temp. (°C)	Target Combined Rate (g/dm ² /h)	Actual Rate (Snow Only) (g/dm ² /h)	Actual Rate (Rain/Freezing Rain Only) (g/dm ² /h)	Actual Rate (Combined) (g/dm ² /h)	Endurance Time (min)	Adjusted Endurance Time (min)
29	29-Feb-24	Safewing MP II FLIGHT	II	Aluminum	Light Snow and Mist	-3	10.5	-	-	12.2	127.5	148.1
30	29-Feb-24	Safewing MP II FLIGHT	II	Aluminum	Light Snow and Mist	-3	10.5	-	-	12.2	140.0	162.7
31	29-Feb-24	AeroClear MAX	III	Aluminum	Light Snow and Mist	-3	10.5	-	-	12.2	43.4	50.5
32	29-Feb-24	AeroClear MAX	III	Aluminum	Light Snow and Mist	-3	10.5	-	-	12.2	51.3	59.6
33	29-Feb-24	Polar Guard Advance	IV-PG	Aluminum	Light Snow and Mist	-3	10.5	-	-	12.2	140.2	162.9
34	29-Feb-24	Polar Guard Advance	IV-PG	Aluminum	Light Snow and Mist	-3	10.5	-	-	12.2	140.1	162.8
35	29-Feb-24	Dow EG106	IV-EG	Aluminum	Light Snow and Mist	-3	10.5	-	-	12.2	110.9	128.8
36	29-Feb-24	Dow EG106	IV-EG	Aluminum	Light Snow and Mist	-3	10.5	-	-	12.2	110.9	128.8
E1	07-Mar-24	Safewing MP II FLIGHT	II	Aluminum	Light Snow and Mist	-14	10.5	-	-	12.2	32.8	38.1
E2	07-Mar-24	Safewing MP II FLIGHT	II	Aluminum	Light Snow and Mist	-14	10.5	-	-	12.2	38.6	44.8
E3	07-Mar-24	AeroClear MAX	III	Aluminum	Light Snow and Mist	-14	10.5	-	-	12.2	63.9	74.3
E4	07-Mar-24	AeroClear MAX	III	Aluminum	Light Snow and Mist	-14	10.5	-	-	12.2	72.9	84.7
E5	07-Mar-24	Polar Guard Advance	IV-PG	Aluminum	Light Snow and Mist	-14	10.5	-	-	12.2	52.0	60.4
E6	07-Mar-24	Polar Guard Advance	IV-PG	Aluminum	Light Snow and Mist	-14	10.5	-	-	12.2	51.1	59.4
E7	07-Mar-24	Dow EG106	IV-EG	Aluminum	Light Snow and Mist	-14	10.5	-	-	12.2	109.0	126.6
E8	07-Mar-24	Dow EG106	IV-EG	Aluminum	Light Snow and Mist	-14	10.5	-	-	12.2	109.0	126.6

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