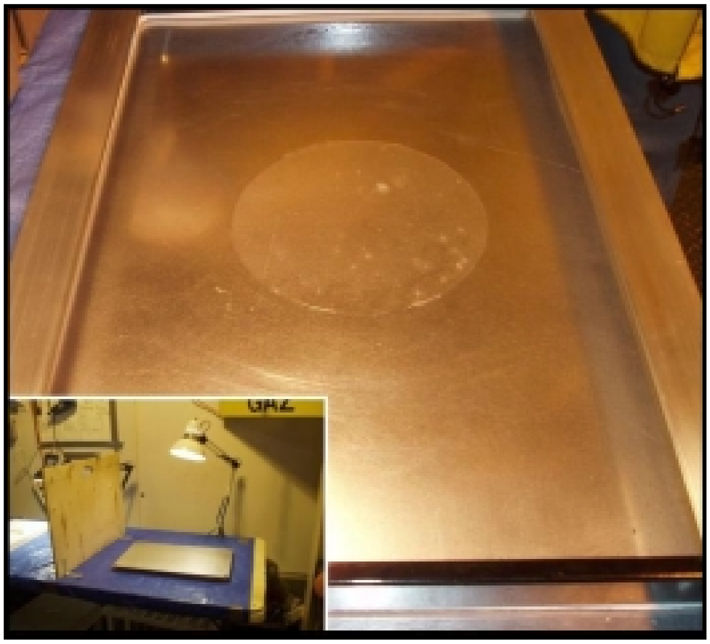
TP 14449E

Development of Ice Samples for Visual and Tactile Ice Detection Capability Tests



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Transportation Development Centre

In cooperation with

Civil Aviation
Transport Canada

And

The Federal Aviation Administration
William J. Hughes Technical Center

Prepared by

APS Aviation Inc.

September 2005
Final Version 1.0

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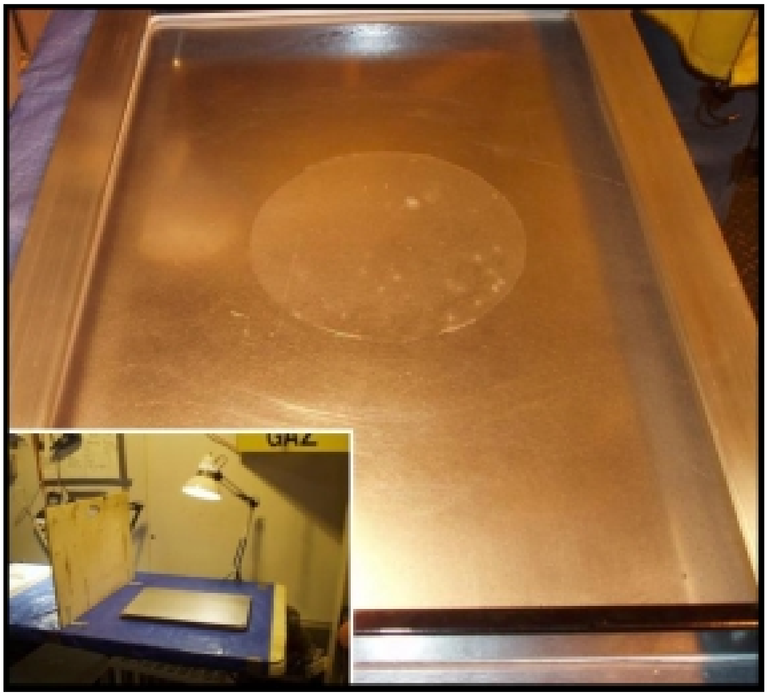

by

Nicoara Moc

APS Aviation Inc.

September 2005
Final Version 1.0

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

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

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Un sommaire français se trouve avant la table des matières.

PREFACE

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

- To develop holdover time data for all newly-qualified de/anti-icing fluids;
- To conduct endurance time tests in frost on various test surfaces;
- To assist with the operational evaluation of Type III fluids;
- To finalize the laboratory snow test protocol with Type II/III and IV fluids;
- To evaluate weather data from previous winters to establish a range of conditions suitable for the evaluation of holdover time limits;
- To assist the SAE G-12 Ground Equipment Subcommittee in evaluating forced air-assist systems;
- To evaluate the possibility of using a fluid failure sensor in holdover time testing;
- To conduct endurance time tests on non-aluminum plates;
- To examine the effect of heat on Type II/III/IV endurance times;
- To provide support for human factor tactile tests; and
- To conduct general and exploratory de/anti-icing research.

The research activities of the program conducted on behalf of Transport Canada during the winter of 2004-05 are documented in nine reports. The titles of the reports are as follows:

- TP 14443E Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2004-05 Winter;
- TP 14444E Winter Weather Impact on Holdover Time Table Format (1995-2005);
- TP 14445E Evaluation of Type IV Fluids Applied Using Forced Air Assist Equipment;
- TP 14446E A Sensor for Determining Anti-icing Fluid Failure: Phase II;
- TP 14447E Effect of Heat on Endurance Times of Anti-icing Fluids;
- TP 14448E Aircraft Ground Deicing Fluid Endurance Times on Composite Surfaces;
- TP 14449E Development of Ice Samples for Visual and Tactile Ice Detection Capability Tests;
- TP 14450E Development of Ice Samples for Comparison Study of Human and Sensor Capability to Detect Ice on Aircraft; and

- TP 14451E Aircraft Ground Icing Research General Activities During the 2004-05 Winter.

In addition, an interim report entitled *Substantiation of Aircraft Ground Deicing Holdover Times in Frost Conditions* will be written.

- The present report, TP 14449E, covers provision of support for testing regarding the human visual and tactile ice detection capability, as part of this program.

A series of tests were run in Montreal (Blainville), Quebec, by Transport Canada and the U.S. Federal Aviation Administration.

This research project has been funded by the Civil Aviation Group, Transport Canada with support from the U.S. Federal Aviation Administration, William J. Hughes Technical Center, Atlantic City, NJ.

PROGRAM ACKNOWLEDGEMENTS

This multi-year research program has been funded by the Civil Aviation Group, Transport Canada along with the U.S. Federal Aviation Administration Office of Aviation Research Flight Safety Branch and the Federal Aviation Administration William J. Hughes Technical Center Simulation and Analysis Group. This program could not have been accomplished without the participation of many organizations. APS would therefore like to thank the Transportation Development Centre of Transport Canada, the U.S. Federal Aviation Administration, National Research Council Canada, the Meteorological Service of Canada, MD Robotics, BF Goodrich, and several fluid manufacturers.

APS would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data. This includes the following people: Stephanie Bendickson, Nicolas Blais, Michael Chaput, Sami Chebil, John D'Avirro, Peter Dawson, Stéphane Gosselin, Mark Mayodon, Chris McCormack, Nicoara Moc, Filomeno Pepe, Marco Ruggi, Joey Tiano, Kim Vepsa, and David Youssef.

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

PROJECT ACKNOWLEDGEMENTS

The author would like to thank TDC and FAA personnel for their continuous support and guidance related to this project.

The author would like to acknowledge and thank: AéroMag 2000 personnel for assistance in the test work and for contribution of deicing fluid used in the project, and PMG Technologies Inc. (PMG) operators of the Cold Chamber facility. PMG facility staff was helpful in providing support for these tests.

Special thanks are extended to Edmundo A. Sierra, Jr., Kimberlea Bender and Edward Pugacz, who on behalf of the FAA, have participated, contributed and provided guidance in the preparation of this project.

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

Several research reports for testing of de/anti-icing technologies were produced for previous winters on behalf of Transport Canada. These are available from the Transportation Development Centre (TDC). Nine reports (including this one) were produced as part of 2004-2005 winter research program. The reported project was co-sponsored by the Federal Aviation Administration.

16. Abstract

Currently, after preflight deicing operations, the possible presence of residual ice on an aircraft's wing is determined by a human checker by visual or tactile inspection. A Ground Ice Detection System (GIDS) Regulatory Approval Working Group (RAWG), under the auspices of the SAE G-12 Ice Detection Sub committee, was formed to find an approach whereby regulators might be able to approve GIDS. Tests were designed by Federal Aviation Administration (FAA) Office of Aviation Research, Flight Safety Branch (William J. Hughes Technical Center) to assess the threshold of humans to detect ice, both visually and by tactile touch. The project comprised two phases. Phase I comprised tests of human visual and tactile capability to detect ice samples on small plates following application of deicing fluid. The second phase of the project, reported separately, included testing on an aircraft wing to compare the human performance with the performance of ice detection equipment. This report discusses only the first phase of the project.

Under contract to Transportation Canada (TC) and the FAA, APS Aviation Inc. (APS) has undertaken a research program to determine the feasibility of making ice samples at thicknesses down to 0.2mm, to develop a procedure for making reproducible ice samples of and to measure ice thickness change under fluid.

In January 2005, APS carried out feasibility tests in the laboratory, followed by a more extensive series of tests in a cold chamber. Based on these experiments, the initial procedure was extended to include the ideal fluid concentration, test temperature and ice dissolving calibration as a result of fluid application. In April 2005, additional confirmatory calibration tests were conducted in a cold chamber. The results were in line with the findings from the pre-test session. A series of demonstration tests were prepared with the FAA Human Factors group. Based upon the test sessions conducted in the cold chamber, APS developed a reliable ice making procedure that addressed all essential test requirements and produced reproducible results in terms of ice characteristics and stability under fluid for sample thicknesses of 0.2, 0.35, 0.5, 0.65, 0.8 and 1.0 mm over an area of 315cm2 and over a full plate, 30cm x 50cm.

Actual human visual and tactile capabilities tests were carried out in April 2005. APS personnel provided support throughout the testing session including chamber layout design, ice sample preparation, cleaning and replacing ice samples, communication with chamber facility personnel, and all aspects of logistics and test area management.

Analysis of the human factors tests is reported separately.

17. Key Words Visual inspection, Tactile inspection, Ice-making procedure, Ice patch, GIDS, Human capabilities, Human factors study, Ice creation methods, Deicing personnel	18. Distribution Statement Limited number of print copies available from the Transportation Development Centre. Also available online at www.tc.gc.ca/tdc/menu.htm

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

Plusieurs rapports de recherche sur les essais de technologies de dégivrage/antigivrage réalisés au cours des hivers antérieurs ont été produits au nom de Transports Canada. Ces rapports sont disponibles auprès du Centre de développement des transports (CDT). Neuf rapports (y compris celui-ci) ont été publiés dans le cadre du programme de recherche de 2004-2005. Le présent projet étati coparrainé par la Federal Aviation Administration.

16. Résumé

À l'heure actuelle, après les opérations de dégivrage avant le vol, un préposé fait une inspection visuelle ou tactile des ailes de l'avion pour vérifier s'il reste du givre. Un groupe de travail sur l'approbation réglementaire des systèmes de détection de givrage au sol (GIDS, *Ground Ice Detection System*) a été créé sous l'égide du sous-comité de détection du givrage G-12 de la Society of Automotive Engineers (SAE). Ce groupe a pour mandat de définir une démarche pour l'approbation des GIDS par les organismes de réglementation. La Direction de la sécurité en vol (William J. Hughes Technical Center) du Bureau de recherche en aéronautique de la Federal Aviation Administration (FAA) a conçu des essais pour déterminer le seuil de détection «humaine» du givre, par inspection visuelle et tactile. Le projet comportait deux phases. La première a consisté en des essais de la capacité visuelle et tactile d'un être humain à détecter des éprouvettes de givre sur de petites plaques, après l'application de liquide de dégivrage. La deuxième phase, qui fait l'objet d'un rapport distinct, a consisté en des essais sur une aile d'avion, qui visaient à comparer la performance de préposés et celle de systèmes de détection de givrage. Le présent rapport porte uniquement sur la première phase.

Aux termes d'un contrat avec Transports Canada (TC) et la FAA, APS Aviation Inc. (APS) a réalisé un programme de recherche qui visait à déterminer la possibilité de préparer des éprouvettes de givre de diverses épaisseurs (à partir d'aussi peu que 0,2 mm), à élaborer une procédure pour la préparation d'éprouvettes de givre reproductibles et à mesurer la dégradation du givre sous le liquide de dégivrage.

En janvier 2005, APS a réalisé des essais de faisabilité en laboratoire, avant de passer à une série d'essais en chambre froide. À la lumière de ces expériences, on a modifié la procédure initiale pour y inclure la concentration idéale du liquide, la température d'essai, et l'évaluation de la dissolution du givre par suite de l'application du liquide. En avril 2005, les essais en chambre froide ont été repris, et ont confirmé les résultats des essais préliminaires. Des essais de démonstration ont alors été organisés, de concert avec le groupe *Human Factors* de la FAA. Les essais en chambre froide ont démontré que la procédure de préparation des éprouvettes de givre élaborée par APS est fiable, qu'elle répond à tous les impératifs d'essai et qu'elle donne des résultats reproductibles en ce qui a trait aux caractéristiques du givre et à sa stabilité sous le liquide de dégivrage, pour des épaisseurs de 0,2, 035, 0,5, 0,65, 0,8 et 1,0 mm, sur une superficie de 315 cm^2 et sur une plaque complète de 30 cm sur 50 cm.

Les essais de capacité visuelle et tactile ont eu lieu en avril 2005. Le personnel d'APS a participé à toutes les étapes des essais, notamment à l'aménagement de la chambre froide, à la préparation des éprouvettes, au nettoyage de la surface et au remplacement des éprouvettes, aux communications avec le personnel de la chambre froide, et à tous les aspects de la logistique et de la gestion de la zone d'essai.

L'analyse des essais sur les facteurs humains fait l'objet d'un rapport distinct.

17. Mots clés Inspection visuelle, inspection tactile, méthode de fabrication de givre, éprouvette de givre, système de détection de givrage au sol, GIDS, capacités humaines, étude des facteurs humains, méthode de préparation de givre, personnel de dégivrage	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires imprimés. Disponible également en ligne à www.tc.gc.ca/cdt/menu.htm

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EXECUTIVE SUMMARY

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

Over the past several years, the Transportation Development Centre (TDC) has managed and conducted de/anti-icing related tests at various sites in Canada; it has also coordinated world-wide testing and evaluation of evolving technologies related to de/anti-icing operations with the co-operation of the US Federal Aviation Administration (FAA), National Research Council (NRC), Atmospheric Environment Services, Transport Canada (TC), several major airlines, and deicing fluid manufacturers. The TDC is continuing its research, development, testing and evaluation program.

Currently, after preflight deicing operations, the possible presence of residual ice on an aircraft's wing is determined by a human checker. The presence of ice on a wing is determined visually under most circumstances. Tactile inspections may be required following deicing of certain types of "hard wing" aircraft, or for aircraft where cold soaking may be a problem. Some problems have been identified with tactile inspections. Tactile inspections expose testers' hands to cold surfaces, require close proximity to an aircraft (at times with engines on), are slow, and can be limited by the checker's reach.

If visual and tactile inspections for the presence of ice on a wing are to be replaced with other methods, human visual and tactile capabilities must be assessed to serve as a measure against which other methods can be evaluated. A Ground Ice Detection System (GIDS) Regulatory Approval Working Group (RAWG), under the auspices of the Society of Automotive Engineers (SAE) G-12 Ice Detection Sub-committee, was formed to find ways to investigate this objective. The GIDS RAWG is composed of representatives from the FAA, TC, end users, aircraft and GIDS manufacturers. Tests were designed by FAA Office of Aviation Research, Flight Safety Branch (William J. Hughes Technical Center) to investigate the threshold of human ability to detect ice following deicing, both visually and by tactile touch. Under contract to the Transport Canada (TC) and FAA, APS Aviation Inc. (APS) undertook a research and development program to determine the feasibility of making ice of specified thicknesses, and to develop a procedure for making the ice and measure ice thickness change under fluid. The work statement for this project can be found in Appendix A.

A preliminary literature search was conducted and no references to similar work done before was found. APS's role comprised two phases. Phase I of the project included developing a methodology to produce ice samples of uniform thickness from 0.2 mm to 1.2 mm over an area of 315 cm² with a smooth surface and a feathered edge on a flat plate, and then to assist with conduct of visual and tactile testing using the ice samples. A second phase of the project includes testing on an aircraft wing to compare the human performance with the performance of ice detection equipment. This present report covers only the first phase of the project.

In Phase I, different ways of making ice samples were investigated. Ice samples were created on white or polished standard aluminum flat plates similar to those used for standard SAE endurance time testing. The area of the panel covered by the ice samples was 315 cm². A primary concern was that the ice samples be of a desired thickness, clear, and that the edges of the ice samples be feathered. This task also involved the investigation of the combined ice and fluid to determine whether there would be a degradation of the ice thickness or evaporation (dryout) or hydration of the fluid over a 24-48 hour period.

In January 2005, feasibility tests were carried out in the laboratory. The plates were maintained at sub-zero temperatures in a freezer. Based on the results from these tests, a preliminary methodology for making ice samples was developed.

Subsequently, in February 2005, APS carried out a more extensive series of tests in a cold chamber to ensure that the ice samples would be reproducible. Six ice thicknesses were produced, ranging from 0.2 to 1.2 mm. Based on these experiments, the initial procedure was changed to address the ideal fluid concentration, the appropriate test temperature and the calibration of ice dissolving caused by fluid application. Also, the plan for conduct of Human Factors Visual and Tactile experiments was modified to incorporate ice samples covering the entire surface of a flat plate. During the pre-test session the ice-making procedure was firmed up and a series of demonstrations were prepared with the FAA William J. Hughes Technical Center Human Factors (HF) personnel. These demonstrations showed that, using the selected plates, clear ice samples could be produced having the required thickness, area and surface profile; that these samples could be stored under appropriate conditions for 24 hours for future use; and that the samples could be calibrated to achieve the desired thickness at the time of the experiment to allow for degradation due to deicing fluid application.

In April 2005, additional confirmatory calibration tests were conducted in a controlled temperature cold chamber. Six different ice thicknesses were produced, this time ranging from 0.2 to 1.0 mm. The results were consistent with the findings from the pre-test session. After completion of the confirmatory calibration tests, a series of demonstration tests were prepared with the FAA HF personnel for the Workgroup members.

In April 2005, FAA and TC conducted human visual and tactile capabilities experiments. APS personnel provided support throughout the testing session including chamber layout design, ice making, cleaning and replacing ice samples, communication with chamber facility personnel, and all aspects of logistics and test area management.

The validity of the ice samples provided by APS was confirmed – the thickness of ice samples was recorded prior to and after each experiment.

Based upon experience in the cold chamber experiments, APS demonstrated a reliable ice-making procedure that addressed all essential test requirements and produced reproducible results in terms of ice characteristics and thickness stability under fluid.

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SOMMAIRE

Dans des conditions de précipitations hivernales, on nettoie les surfaces en y pulvérisant un liquide cryoscopique (abaisseur du point de congélation), puis on les protège de toute autre accumulation de précipitations en faisant une application supplémentaire de liquide, parfois épaissi pour prolonger la durée de la protection. Ce n'est que récemment que l'on a commencé à étudier le dégivrage des avions au sol et il reste encore beaucoup à faire pour bien comprendre le risque que posent les opérations aériennes en conditions de précipitations hivernales, et les moyens que l'on peut prendre pour atténuer ce risque. Le présent programme de recherche sur les opérations hivernales et les avions contaminés au sol vise à combler ces lacunes.

Ces dernières années, le Centre de développement des transports (CDT) a dirigé et mené des essais de dégivrage/antigivrage à divers endroits au Canada; il a aussi coordonné la mise à l'essai et l'évaluation, en divers points du monde, de nouvelles technologies reliées aux opérations de dégivrage/antigivrage, en collaboration avec la Federal Aviation Administration (FAA) des États-Unis, le Conseil national de recherches du Canada (CNRC), le Service de l'environnement atmosphérique, Transports Canada (TC), de grandes sociétés aériennes et des fabricants de liquides de dégivrage. Le programme de recherche, de développement, d'essais et d'évaluation du CDT est toujours en cours.

À l'heure actuelle, après les opérations de dégivrage avant le vol, un préposé fait une inspection visuelle ou tactile des ailes de l'avion pour vérifier s'il reste du givre. La plupart du temps, une inspection visuelle suffit. Mais des inspections tactiles peuvent être nécessaires après le dégivrage de certains types d'avions dont les ailes présentent un bord d'attaque fixe, ou dans le cas d'aéronefs imprégnés de froid. Or, les inspections tactiles posent des problèmes. En effet, elles entraînent l'exposition des mains à des surfaces froides, elles obligent à s'approcher de très près de l'avion (parfois avec les moteurs en marche), elles prennent du temps et leur portée se limite à celle du bras de l'inspecteur.

Avant de pouvoir remplacer les inspections visuelles et tactiles par d'autres méthodes de détection de givrage, il faut d'abord évaluer les capacités visuelles et tactiles humaines, afin de disposer d'un repère en regard duquel évaluer les autres méthodes. Un groupe de travail sur l'approbation réglementaire (RAWG, Regulatory Approval Working Group) des systèmes de détection de givrage au sol (GIDS, Ground Ice Detection System) a été créé sous l'égide du sous-comité de détection du givrage G-12 de la Society of Automotive Engineers (SAE), pour trouver des moyens d'atteindre cet objectif. Ce RAWG est composé de représentants de la FAA, de TC, des utilisateurs finals, des avionneurs et des fabricants de GIDS. La Direction de la sécurité en vol (William J. Hughes Technical Center) du Bureau de recherche en aéronautique de la FAA a conçu des essais pour déterminer le seuil de détection «humaine» du givre, par

inspection visuelle et tactile. Aux termes d'un contrat avec Transports Canada (TC) et la FAA, APS Aviation Inc. (APS) a réalisé un programme de recherche qui visait à déterminer la possibilité de préparer des éprouvettes de givre d'une épaisseur précise, puis à élaborer une procédure pour la préparation des éprouvettes et à mesurer la dégradation du givre sous le liquide de dégivrage. L'énoncé des travaux de ce projet est présenté à l'annexe A.

Une recherche documentaire a d'abord été effectuée. Aucune référence à des travaux similaires n'a alors été repérée. Le mandat d'APS comportait deux phases. La première consistait à élaborer une méthode pour produire des éprouvettes de givre d'épaisseur uniforme de 0,2 mm à 1,2 mm, à surface lisse et aux bords amincis, couvrant 315 cm² sur une plaque plane, puis à appuyer la conduite d'essais d'inspection visuelle et tactile à l'aide de ces éprouvettes. La deuxième phase comportait des essais sur une aile d'avion, qui visaient à comparer la performance de préposés et celle de systèmes de détection de givrage. Le présent rapport porte uniquement sur la première phase du projet.

À la phase I, on a étudié différentes façons de préparer des éprouvettes de givre. On a utilisé à cette fin des plaques planes standard en aluminium blanc ou poli, semblables à celles qui servent aux essais d'endurance de la SAE. Les éprouvettes couvraient 315 cm² de la plaque. La préoccupation première était d'obtenir des éprouvettes de givre transparent de l'épaisseur voulue, aux bords en biseau. Cette tâche comprenait en outre l'examen du givre et du liquide combinés afin de déterminer si, pendant une période de 24 à 48 heures, l'épaisseur du givre diminuait, ou si le liquide s'évaporait (s'asséchait) ou s'hydratait.

En janvier 2005, des essais de faisabilité ont été menés en laboratoire. Les plaques étaient maintenues à des températures inférieures à zéro dans un congélateur. À partir des résultats de ces essais, une méthode préliminaire de préparation d'éprouvettes de givre a été développée.

Plus tard, en février 2005, APS a mené une série d'essais en chambre froide afin de vérifier si les éprouvettes de givre étaient reproductibles. Six épaisseurs de givre ont été produites, de 0,2 à 1,2 mm. À la lumière de ces expériences, on a modifié la procédure initiale pour y inclure la concentration idéale du liquide, la température d'essai appropriée, et l'évaluation de la dissolution du givre par suite de l'application du liquide. De plus, le plan des expériences sur les capacités visuelles et tactiles «humaines» a lui aussi été modifié : on allait utiliser des éprouvettes de givre couvrant toute la surface de la plaque plane. Au cours des essais préliminaires, la procédure de préparation des éprouvettes de givre a été validée et des démonstrations ont été organisées avec le personnel du groupe Human Factors du William J. Hughes Technical Center de la FAA. Ces démonstrations ont révélé qu'il était possible, en utilisant les plaques choisies, de produire des éprouvettes de givre transparent présentant l'épaisseur, la superficie et le profil de surface voulus; que, dans des conditions appropriées, ces éprouvettes pouvaient être entreposées pendant 24 heures pour une utilisation ultérieure; et que les conditions de givrage pouvaient être réglées pour obtenir l'épaisseur voulue au moment de l'expérience, pour permettre de mesurer l'amincissement de la couche de givre par suite de l'application du liquide de dégivrage.

En avril 2005, des essais supplémentaires en chambre froide à température contrôlée ont eu lieu, pour confirmer les premiers. Six différentes épaisseurs de givre ont été produites, allant cette fois de 0,2 à 1,0 mm. Les résultats ont effectivement confirmé ceux des essais préliminaires. Des essais de démonstration ont ensuite été organisés à l'intention des membres du groupe de travail, en collaboration avec le groupe Human Factors de la FAA.

Toujours en avril 2005, la FAA et TC ont mené des expériences de capacité visuelle et tactile humaine. Le personnel d'APS a participé à toutes les étapes des essais, notamment à l'aménagement de la chambre froide, à la préparation des éprouvettes de givre, au nettoyage de la surface et au remplacement des éprouvettes, aux communications avec le personnel de la chambre froide, et à tous les aspects de la logistique et de la gestion de la zone d'essai.

La validité des éprouvettes de givre fournies par APS a été confirmée – l'épaisseur des éprouvettes était notée avant et après chaque expérience.

Les expériences en chambre froide ont démontré que la procédure de préparation de givre élaborée par APS est fiable, qu'elle répond à tous les impératifs d'essai et qu'elle donne des résultats reproductibles en ce qui a trait aux caractéristiques du givre et à sa stabilité sous le liquide de dégivrage.

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GLOSSARY

APS	APS Aviation Inc.
EG	Ethylene Glycol
FAA	Federal Aviation Administration
GIDS	Ground Ice Detection System
H-F	Human Factors
PMG	PMG Technologies Inc.
RAWG	Regulatory Approval Working Group
SAE	Society of Automotive Engineers, Inc.
TC	Transport Canada
TDC	Transportation Development Centre
WJHTC	William J. Hughes Technical Center

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1. INTRODUCTION

Under contract to the Transportation Development Centre (TDC) of Transport Canada (TC), with support from the Federal Aviation Administration (FAA), APS Aviation Inc. (APS) has undertaken a research program to determine the feasibility of making ice of various thicknesses. Subsequently, the objective was to develop a reproducible procedure for making ice of a uniform, specified thickness under a layer of fluid. The ice sample would subsequently be used for human visual and tactile ice detection threshold capability experiments.

1.1 Background

Ice on an aircraft's wing, particularly at the leading edge can lead to a hazardous situation. Currently, after preflight deicing operations, the possible presence of residual ice on an aircraft's wing is determined by a human checker. The presence of ice on a wing is determined visually under most circumstances. Tactile inspections may be required following deicing of certain types of "hard wing" aircraft, or for aircraft where cold soaking may be a problem. Some problems have been identified with tactile inspections. Tactile inspections require close proximity to an aircraft (at times with engines on), are slow, and can be limited by the checker's reach.

If visual and tactile inspections for the presence of ice on a wing are to be replaced with other methods, human visual and tactile capabilities must be determined to serve as a measure against which other methods can be evaluated. A Ground Ice Detection System (GIDS) Regulatory Approval Working Group (RAWG), under the auspices of the Society of Automotive Engineers (SAE) G-12 Ice Detection Sub-Committee, was formed to find ways to meet this objective. The GIDS RAWG is composed of representatives from the FAA, TC, end users, aircraft and GIDS manufacturers. The GIDS RAWG met at the William J. Hughes Technical Center (WJHTC) in Atlantic City, New Jersey in September 2004 to determine the most meaningful variables to use in an experiment whose objective is to assess human visual and tactile ice detection capabilities. The work statement for this project can be found in Appendix A.

With a specified procedure, designers of new methods and devices for detection of ice can evaluate their device's detection ability as it compares to human capabilities. Approval agencies may then be able to use this objective data as part of submission to accept or reject new systems or procedures.

1.2 Objectives

1.2.1 Program Objective:

- To assess human visual and tactile ice detection capabilities.

In the first phase of the project, a two-alternative forced choice procedure was planned to asses human psycho-physical capabilities under a specified set of conditions in a cold chamber at -5°C.

1.2.2 APS Objectives

Under contract to the TC and FAA, APS has undertaken a research program that had the following objectives:

- Determine the feasibility of making ice at various thicknesses ranging from 0.2 to 1.2 mm, produce appropriate samples if this can be done. Establish if there is degradation in ice thickness when Type I fluid is applied over the ice, calibrate conditions to establish stable ice thicknesses if this can be done;

- Determine if ice samples with a uniform thickness over the entire area, with smooth surface and feathered edge on a flat plate can be produced. Produce samples in appropriate quantities if this can be done;

- Determine if ice samples of specified thickness can be preserved and stored for a period of 2-3 days for future use;

- Determine whether ice samples used for tactile checking can be reused for subsequent tests;

- Develop a reproducible procedure for making ice and conduct calibration tests to measure ice thickness change under fluid; and

- Provide support in a cold chamber during the human observer visual and tactile threshold evaluation experiments.

Before initiating the research program, a preliminary literature search was conducted and no references to similar work were found.

APS personnel also provided support throughout the experimental sessions including chamber layout design, production of ice samples on plates as required, cleaning and replacing ice samples, communication with chamber facility personnel, and all aspects of logistics and test area management. The results from the actual human capability experiments were analyzed by the FAA and are presented in a separate FAA report.

1.3 Report Format

The following section of this report (Section 2) describes the methodology followed during the conduct of the test sessions. It also presents the test schedule and the equipment used. The subsequent section (Section 3) presents the test logs from all calibration test sessions, analyzes the findings and describes the process followed by APS in developing the ice dissolving calibration. It also describes the tests conducted during the actual human visual and tactile capability tests, and includes an analysis to validate the ice samples produced by APS.

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2. METHODOLOGY

This section describes the conditions and methodologies followed during the ice sample pre-test and test sessions. It also describes the schedule as well as the equipment and personnel requirements.

2.1 Description of Test Procedure

The actual visual and tactile ice detection capability experiments were conducted in April 2005 at the PMG facility in Montreal (Blainville), Quebec. APS undertook the research program to determine the feasibility of making appropriate ice samples as required by the pertinent experimental plan. The objective was to develop a reproducible procedure for making ice of a uniform, specified thickness under a layer of fluid. The ice sample would subsequently be used for experiments directed to the visual and tactile ice detection capabilities of human observers. After analyzing the findings from a series of tests run in the laboratory as well as during a pre-test session in the cold chamber, APS developed a final ice making procedure that addressed all essential test requirements and produced reproducible results in terms of ice characteristics and thickness stability under fluid. This procedure is included in Appendix B.

The ice making procedure developed by APS provides detailed information with respect to the initial preparations of the test plates, initial fluid preparation and the actual ice making procedure. It also specifies the equipment requirements for every step of the process.

2.2 Preparation and Test Schedule

In January 2005, thirty-five feasibility tests were carried out in the laboratory. The plates were maintained at a temperature of -20°C in a freezer. Ice thickness samples were produced and the ice thickness change under fluid was measured. Based on the results from these tests, a preliminary methodology for making ice samples was developed.

In February 2005, APS carried out a more extensive series of calibration tests in a cold chamber to ensure that the ice samples would be reproducible. Based on these tests, the initial procedure was changed to address new findings, including the ideal fluid concentration for minimal ice dissolving, test temperature and ice dissolving calibration as a result of fluid application. The human factors (H-F) experimental plan was modified to incorporate ice samples covering the entire surface of the flat plate. During the pre-test session the ice making procedure was firmed up and a series of demonstrations were prepared with the H-F group. In the post-experimental session, the FAA and TC conducted initial experiments with participation of AéroMag 2000 personnel. The schedule for this session is shown in Figure 2.1.

In April 2005, additional confirmatory calibration tests were conducted in the cold chamber. The results were in line with the findings from the initial experimental session. After the completion of the confirmatory calibration tests, a series of demonstrations were prepared for the FAA and TC H-F groups. In April 2005, FAA and TC carried out human visual and tactile capabilities experiments. APS personnel provided support throughout the testing session including chamber layout design, ice making, cleaning and replacing ice samples, communication with chamber facility personnel, and all aspects of logistics and test area management. The schedule for the confirmatory test session and for the actual human capabilities experiments is shown in Figure 2.2.

The testing and support activities carried out by APS on four distinct occasions comprised:

- **Feasibility study** – December 15, 2004 to mid January 2005;
- **Pre-test session** – February 2005;
- **Confirmatory tests session** – April 2005, and
- **Support for human visual and tactile capability tests** – April 2005.

The above-mentioned designations are used throughout this report to distinguish between the four different test sessions.

2.3 Equipment

The key equipment items used are described below.

2.3.1 Aluminum Plates

50x30 cm aluminum plates, with bare surface finish or painted white were used. The bare aluminum plates were sanded with 1 500 grit sand paper prior to use. Painting of the plates was done by NuTech Associates, aircraft-painting specialists. The painting was done with one coat of primer and two coats of paint. The paint used was Jet Glo Matterhorn white, manufactured by Sherwin-Williams. A typical bare surface finish aluminum plate is shown in Photo 2.1. Prior to each ice sample being made, the supporting test plate was cleaned with isopropyl alcohol.

February						2005
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
30 • Office work this week longevity of ice sample with tactile 1 day (.2 and 1.2 mm)	**31**	**1**	**2**	**3**	**4**	**5**
6	**7** • Set-up equipment in afternoon 2-4 pm • -3ºC tactile	**8** • -3ºC tactile • Confirm that ice alone is stable • Confirm scale operation	**9** • Validation of -15ºC • Confirm computer monitor	**10** • Confirm ice alone • Refinement for feathering smooth and opacity • Fluid application method refinement	**11** • Refinement for feathering smooth and opacity • Make ice samples for next day • Fluid application method refinement	**12**
13	**14** • Evaluate degradation of ice • Do preliminary correlation dry vs. wet	**15** • Correlation dry-fluid 10 ice samples thickness 0.35 mm • Make ice samples for next day	**16** • Correlation dry-fluid 10 ice samples thickness 0.5 mm • Make ice samples for next day	**17** • Correlation dry-out fluid 10 ice samples thickness 0.8 mm • Make ice samples for next day	**18** • Correlation dry-fluid 10 ice samples thickness 1.0 mm • Make ice samples for next day	**19**
20	**21** • Correlation dry-fluid 10 ice samples thickness 1.2 mm • Make ice samples for next week	**22** • Correlation dry-fluid 10 ice samples thickness 0.2 mm • Make ice samples for next day	**23** • Confirm ice alone • Refinement for feathering smooth and opacity • Lazy Susan effects	**24** • Determine maximum number of ice samples that could be made in day • Confirm Lazy Suzan additional dissolving	**25** • Determine maximum number of ice samples that could be made in day • Refinement for feathering	**26**
27	**28** • Setup for human factors dry run • Determine maximum number of ice samples that could be made in day	**1** • Demo to the FAA & Transport Canada • Setup for testing • Human factors dry run	**2** • Human factors dry run • (FAA & Transport Canada testing)	**3** • Human factors dry run • (AeroMag Testing)	**4** • Equipment transportation to test site • Test chamber cleanup	**5**

Figure 2.1: Actual Calendar of Procedure Checkout Tests at PMG Facility, February 2005

April						2005
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
					1	**2**
3	**4**	**5**	**6**	**7**	**8** • APS Spraying Set-up • Test fluid cooling speed • Cal. Dry Vs. Wet 0.20mm (1) 0.35mm (3) 0.50mm (2) 0.80mm (1)	**9**
10	**11** • Cal. Dry Vs. Wet • 0.65mm (3) • 1.00mm (3)	**12** • APS Full Setup • Monitor Hum & Temp • Prepare Ice for next day	**13** • APS Dry Run • Real time simulation with the buss boy	**14** • FAA Setup • Prepare Ice for next day	**15** • Working Group dry run • Prepare Ice for the next day	**16**
17	**18** • Visual Testing (7 thickness) • Prepare Ice for next day	**19** • Visual Testing (6 thickness) • Prepare Ice for next day	**20** • Visual Testing (8 thickness) • Prepare Ice for next day	**21** • Visual Testing (6 thickness) • Prepare Ice for next day	**22** • Tactile Testing (4 thickness) • Test chamber cleanup	**23**
24	**25**	**26**	**27**	**28**	**29**	**30**

Figure 2.2: Actual Calendar of Human Factors Data Gathering Tests at PMG Facility, April 2005

The roughness of the plates used for testing was measured at Sysprime after the tests were completed. The results were as follows:

- Bare Aluminum: 0.53 to 0.58 microns; and
- Painted Aluminum: 0.23 to 0.31 microns.

2.3.2 Plate Masks

Plate masks were developed to be applied to the plate so that water spray application resulted in the required form of ice on the plate. The masks were made of plastic and had the same outer dimensions as the plate. The masks had a 315 cm^2 circle carved out in the center to allow for spraying water onto the cold-soaked plate (Photo 2.2). The mask was centered on the plate using four bolts (one in each corner of the mask), matching four symmetrical reference holes in the test plate.

2.3.3 Thickness Gauge

A modified paint thickness gauge was used to measure the ice thickness of an ice sample on the plate (Photo 2.3). The gauge was modified to facilitate measurement in the ranges of interest and to reduce the number of reference markings made in the ice.

2.3.4 Test Fluid

The fluid used in the visual and tactile ice detection capability tests was Dow Chemical UCAR EG ADF, diluted to a Brix[1] of 11 (freezing point of approximately -7°C). The Brix of 11 was found to be the ideal fluid concentration because it provided minimal dissolving of the ice sample while preserving enough glycol in the solution to prevent freezing. The neat fluid provided by AéroMag 2000, was diluted and dispensed by APS personnel. At a Brix of 11, the freezing point of the fluid was some 2°C below the -5°C temperature of the cold chamber. The fluid Brix was measured with a Misco refractometer.

2.3.5 Fluid Containers and Cooler

The pre-mixed fluid was applied to the ice using calibrated fluid containers. The fluid container used by APS is shown in Photo 2.4. The fluid quantity in each

[1] Brix is a measure of the amount of glycol a solution contains.

container was 30 mL. Overnight the fluid containers, filled with 30 mL of pre-mixed fluid, were stored at a nominal temperature of +1°C in a cooler (Photo 2.5).

2.3.6 Fluid Retaining Lips

Plates were installed horizontally for test purposes to ensure a uniform fluid distribution. In order to contain the layer of fluid onto the ice throughout the experiment, fluid retaining lips were used. The fluid retaining lip will be referred to as 'lip' throughout the report. The lip consisted of a 30x46 cm metallic frame. A strip of rubber was applied to the bottom surface of the lip to block the fluid from seeping out. To ensure proper tightness at the lip-plate interface, the lip was secured to the plate with clamps as shown in Photo 2.6.

2.3.7 Spray Gun and Compressor

A high quality spray gun was thermally insulated and is shown in Photo 2.7. The compressor used during testing is shown in Photo 2.8.

2.3.8 Digital Scale

The accuracy of the ice sample thickness distribution was evaluated by measuring its thickness and, as a double check, its weight. The weight of the ice was measured by weighing the plate before and after the ice was made. To measure the weight, APS used a 0.1 g accuracy Ainsworth balance shown in Photo 2.9. The functionality of the balance at the test temperature was checked prior to the beginning of testing.

2.3.9 Freezers

As the PMG chamber was cooled only during testing hours, the ice samples made a day in advance were maintained at subzero temperatures overnight in a freezer. The freezer was set at -12°C. The plates were taken out on the second day and the temperature raised to the test temperature prior to use. A second freezer was also working in parallel and was used to maintain support equipment at experiment temperatures.

2.3.10 Lazy Susan Tables

Two rotary Lazy Susan tables were built. Once the plates were prepared and ready for testing, they were placed on a Lazy Susan table. This rotary table consisted of a fixed (table) section and a rotary part, as shown in Photo 2.10. As seen in Photo 2.10, the rotary part of the Lazy Susan table included a vertical divider so that test participants could only see one test plate at the time.

2.3.11 Other Items

Miscellaneous items provided comprised: racks, paintbrush, measuring cups, sand paper, spatula, cleaning fluid, fluid temperature probe, surface temperature probes, temperature and a relative humidity data logger.

2.4 Ice Sample Development

The controlled dimension ice samples were made by spaying water onto the cold-soaked surface of the aluminum plate (Photo 2.1). Water was applied to the plate using a spray gun, attached to a compressor. Parameters such as water temperature, spray distance, compressor output pressure and spray application rate were controlled throughout the spraying process. In order to limit the heat exchange with the cold chamber and to maintain the water temperature within assigned tolerances, the spray gun was thermally insulated.

2.5 Data Forms

The test sample data control form used by APS is presented in Figure 2.3. As observed in the data form, for each target thickness, two thickness measurements were taken, one prior to fluid application (dry thickness) and one at the end of each experiment (wet thickness). Also, the weight of ice was evaluated by measuring the weight of the bare plate as well as the weight of the plate with ice. This measurement was used to check the accuracy of the ice produced. An analysis of the initial and final thicknesses is presented in Section 3.

During the pre-test session, fluid dilution information was also recorded onto the data form. These measurements were used to determine the rate of ice dissolving under fluid as a function of initial glycol concentration.

2.6 Personnel

A minimum of two APS staff members was required for the conduct of H-F experiments. One for preparing ice samples, and one for providing new plates, cleaning the discarded plates, preparing plates for experiments, and placement of plates on the two Lazy Susan tables. One additional person was occasionally required to coordinate with the FAA personnel the placement of plates on the Lazy Susan tables.

During the pre-test session, representatives from TC and FAA provided direction for the experiments and participated as observers.

Date	Surface	Target Thickness (mm)	Weight of Bare Plate (g)	Weight of Ice and Bare Plate (g)	Dry Thickness (mm)	Wet Thickness (mm)	Comments

COMMENTS

Figure 2.3: Data Form

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Photo 2.1: Aluminum Plate and Ice Sample

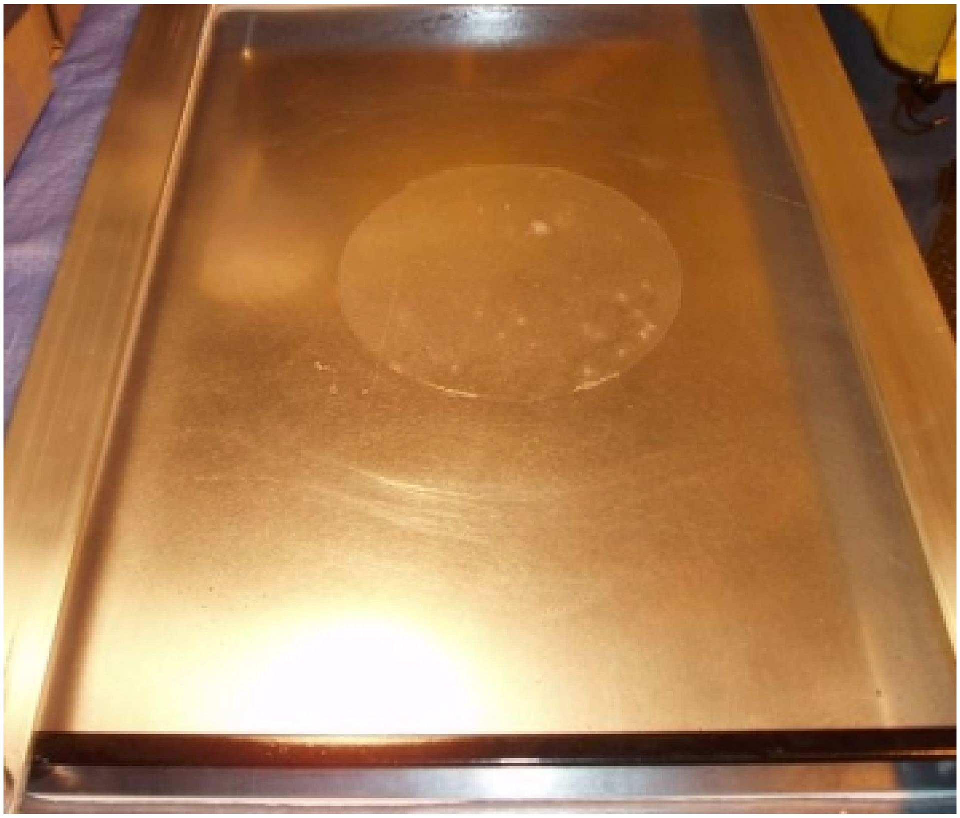


Photo 2.2: Mask

Photo 2.3: Thickness Gauge

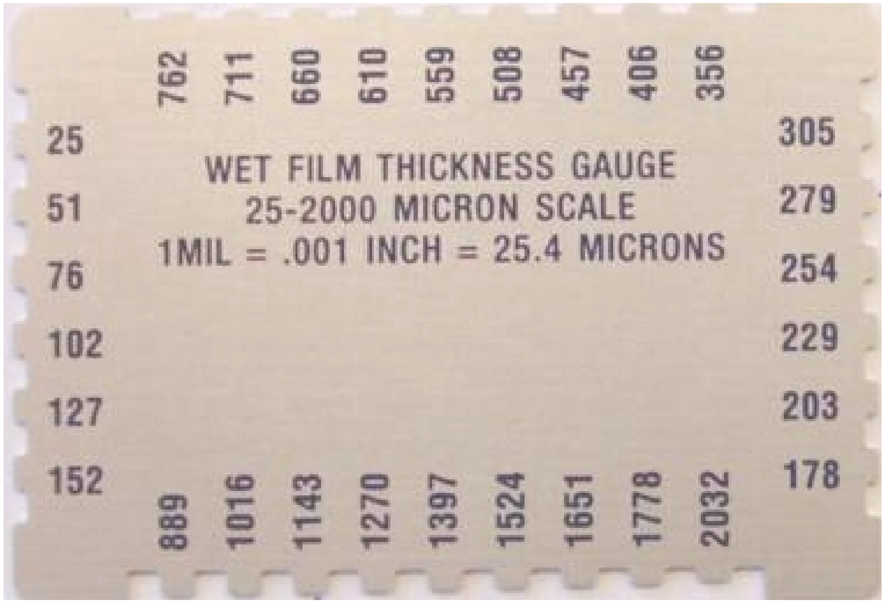


Photo 2.4: Application of Fluid from Fluid Container

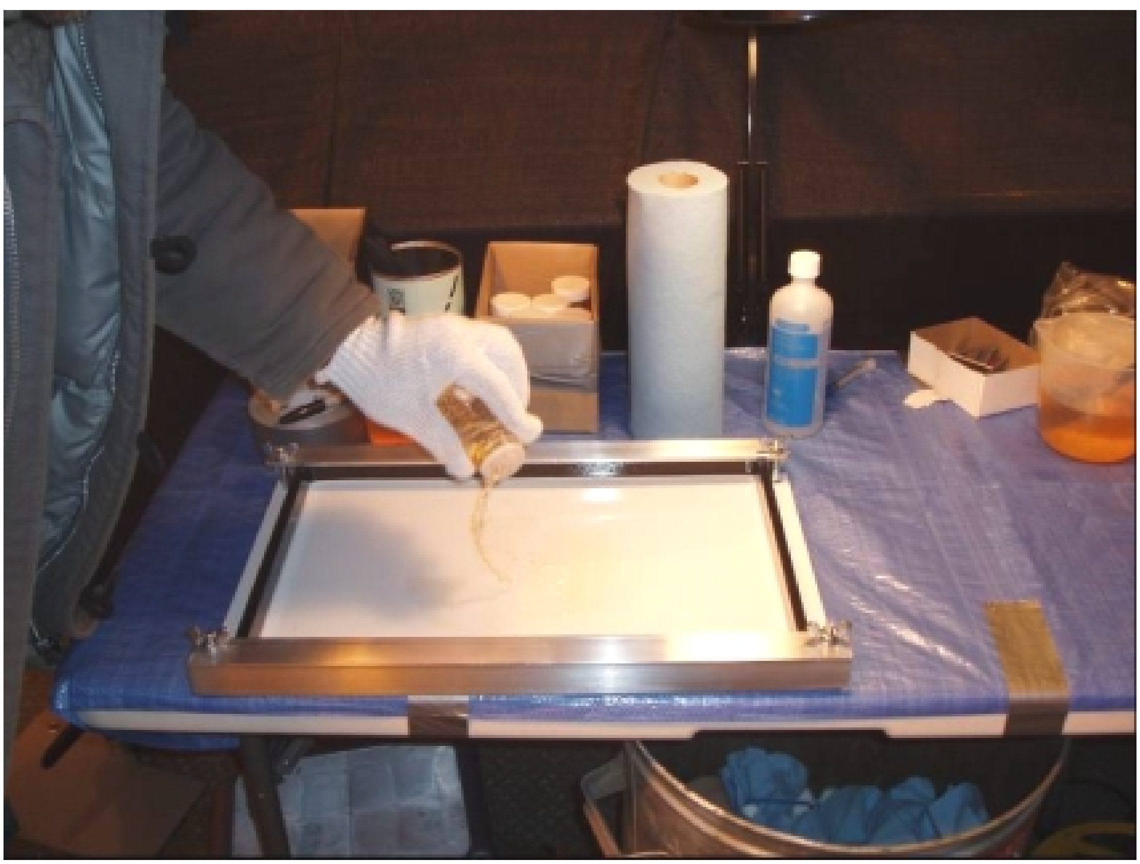


Photo 2.5: Cooler and Heater

Photo 2.6: Lip Secured to the Plate

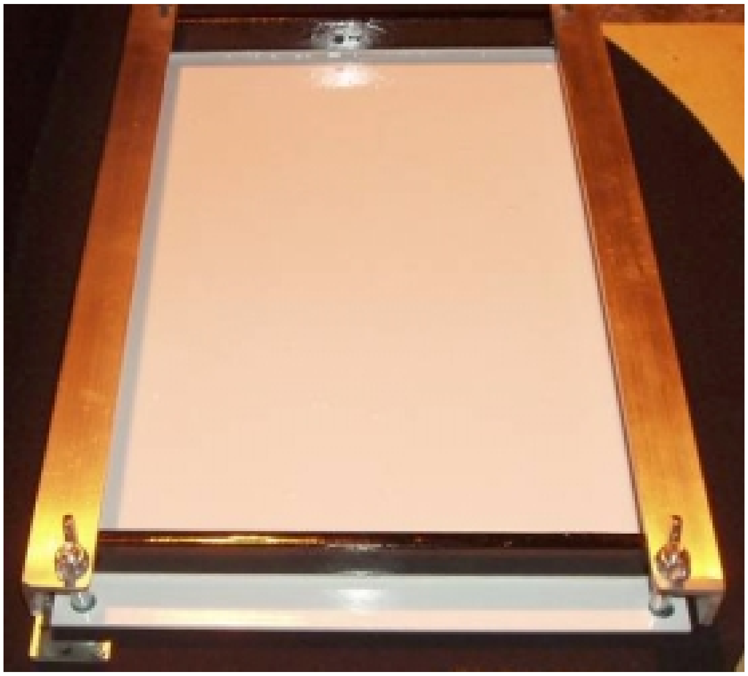
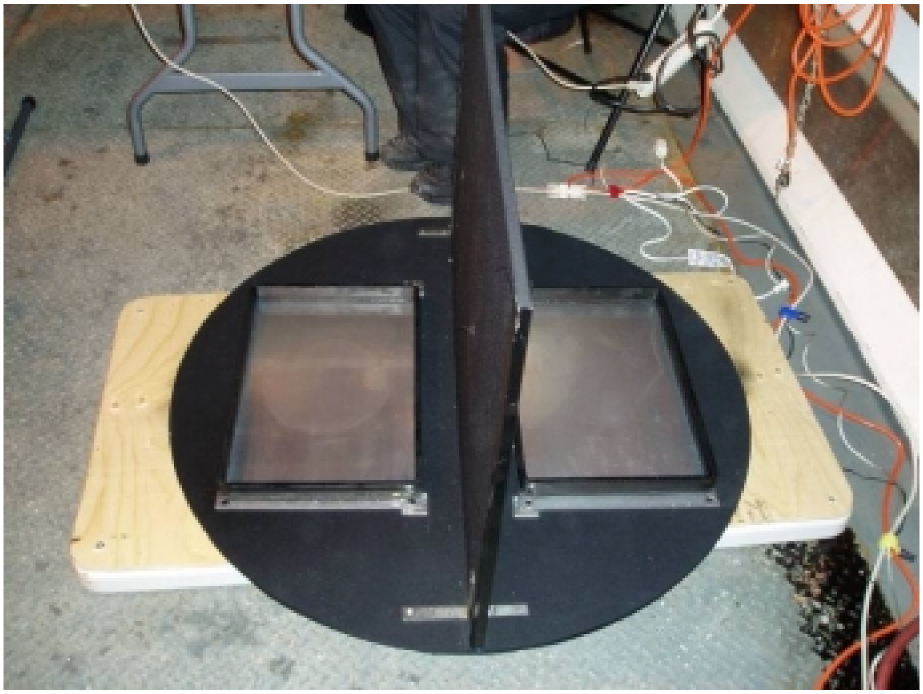


Photo 2.7: Insulated Spray Gun

Photo 2.8: Compressor

Photo 2.9: Digital Scale

Photo 2.10: Lazy Susan Table



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3. DATA COLLECTED

3.1 Overview of Ice Sample Preparation Tests

As mentioned in the previous section, in an attempt to develop an ice making procedure, APS conducted tests on several occasions:

- **Feasibility tests**: Between December 15, 2004 and mid January 2005, preliminary tests were carried out in the laboratory. The plates were maintained at subzero temperatures in a freezer. Based on the results from these tests, a preliminary methodology for making ice samples was developed;

- **Pre-tests**: In February 2005, APS carried out a more extensive series of tests in a cold chamber to ensure that the ice samples would be reproducible. Six ice thicknesses were produced, ranging from 0.2 to 1.2 mm. Based on these experiments, the initial procedure was changed to address new findings, including fluid concentration, test temperature and ice dissolving calibration as a result of fluid application. During the pre-test session the ice making procedure was confirmed and a series of demonstrations prepared for the H-F group;

- **Confirmatory tests**: In April 2005, additional confirmatory calibration tests were conducted in the cold chamber. Six different ice thicknesses were produced, this time ranging from 0.2 to 1.0 mm. The results were in line with the findings from the previous test session. After the completion of the confirmatory calibration tests, a series of demonstrations were prepared with the H-F group; and

- **Actual capability tests**: In April 2005, FAA and TC carried out actual human visual and tactile capabilities tests. APS personnel provided support throughout the testing session including chamber layout design, ice making and placing of plates on the Lazy Susan, cleaning and replacing ice samples, communication with chamber facility personnel, and all aspects of logistics and test area management.

3.2 Feasibility Tests in the Laboratory

Initially, feasibility tests were conducted to evaluate whether the ice would degrade after the application of fluid. APS carried out tests to:

- Determine the feasibility of making ice at the required thicknesses; and

- Develop a procedure for making ice and measuring ice thickness change under fluid.

The test program included 35 tests conducted with two Type I fluid types (ethylene and propylene-based) for a total of 350 hours. These tests were conducted using a freezer at -20°C nominal. For each test, the initial and final weight, temperature, fluid Brix and ice thickness were recorded. Because of the relatively low test temperature, both fluids were diluted to a standard mix (50/50) concentration.

Initially, preliminary calibration work was conducted by monitoring the weight variation over time for a dry pan, a pan with ice (with no fluid) and a pan with fluid (with no ice). It was found that, over a period of 24 hours, the final weight did not differ from the initial weight in all three cases, indicating that in the absence of fluid the ice is stable over the time span of the experiment.

Thirty-two tests were run with fluid applied over ice. Fluid was applied carefully to avoid significant foam and turbulence. The dilution of the fluid was recorded at the beginning of the experiment as well as at the end of the experiment. It was found that the reduction in the Brix (dilution of fluid) occurs within the first 30 minutes. Following fluid application and provided that the fluid does not move across the surface of the plate, its dilution remains constant to the end of the test. Based on these findings, sixteen detailed exploratory tests were run for 30 minutes, only. The results are presented in Figure 3.1. As it can be observed, fluid dilution occurred in all cases and appears to be more pronounced with the ethylene-based Type I fluids. Most of the ice thickness reduction takes place within the first 15 minutes, as there is no significant difference between the Brix values recorded after 15 minutes and those recorded at 30 minutes following fluid application. Photos 3.1 to 3.4 show the progression observed during a typical test.

The fluid dilution occurs as a result of the ice surface dissolving due to the presence of the deicing fluid at the beginning of the test. Consequently, the test results were analyzed in an attempt to determine how much the actual ice thickness diminishes under fluid. The findings are shown in Table 3.1. After analyzing the data from all these tests, it was decided to use the ethylene-based Type I fluid for the subsequent phases of the project.

In summary:

- Ice (with fluid) can be made at any selected thickness within the range of interest; and

- Ice thickness under fluid diminishes over time, with thickness stabilizing after 15 minutes following fluid application.

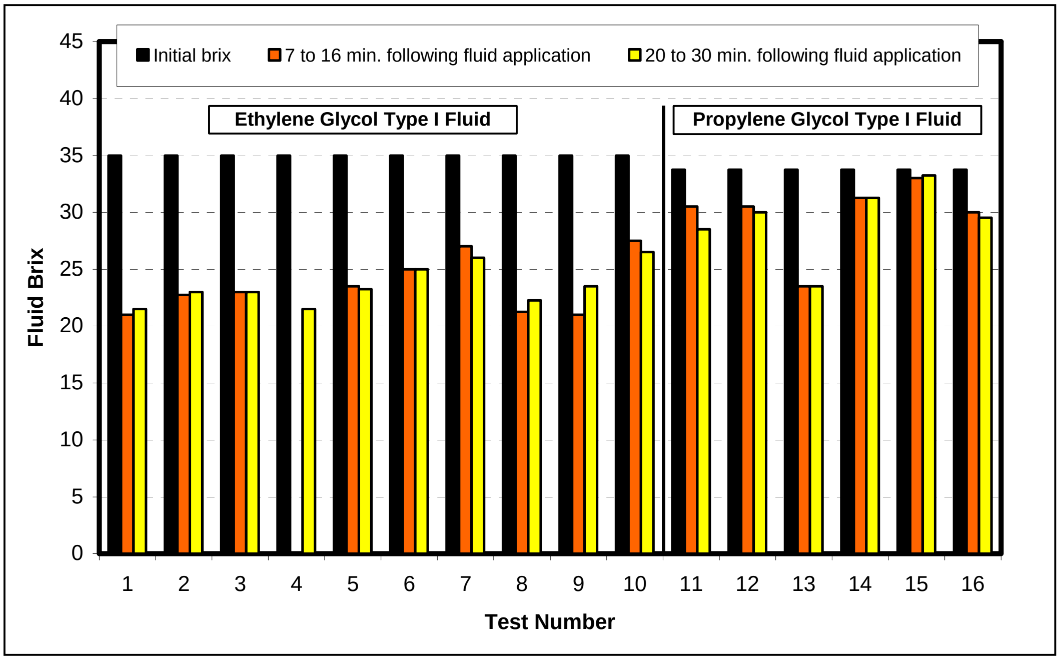

Figure 3.1: Fluid Dilution Profiles

Table 3.1: Ice Degradation Measurements – Preliminary Summary of Results

ETHYLENE GLYCOL			PROPYLENE GLYCOL		
Initial Ice Thickness (mm)	**Final Ice Thickness (mm)**	**Surface**	**Initial Ice Thickness (mm)**	**Final Ice Thickness (mm)**	**Surface**
0.20	0	bare Al.	0.25	0	bare Al.
0.41 0.41 0.46 0.46 0.46 0.44 ± 0.03	0.31 0.14 0.28 0.25 0.28 0.25 ± 0.06	bare Al. bare Al. bare Al. red Al. white Al.	0.41 0.41 0.51 0.44 ± 0.06	0.31 0.31 0.46 0.36 ± 0.09	bare Al. red Al. white Al.
0.60 0.61 0.61 0.61 ± 0.01	0.40 0.40 0.40 0.40 ± 0.0	bare Al. bare Al. bare Al.	0.66	0.51	bare Al.
1.27	0.89	bare Al.	1.27	1.02	bare Al.

Note: Average and standard deviation shown vertically.

For the subsequent phases of testing a series of recommendations were made, and are listed below:

- Further investigate the correlation between dry ice and ice with fluid;
- Determine an optimal temperature for running the tests;
- Refine ice smoothness and opacity; and
- Determine maximum number of ice samples that could be made in one day.

3.3 Pre-Test Session at PMG Chamber

In February 2005, APS carried out a more extensive series of tests in the PMG cold chamber to address the recommendations arising from initial H-F experiments and to finalize the ice making procedure. APS provided services to set up and operate the H-F tests in the cold chamber. The cold chamber dimensions are 7mx4m with the chamber divided into an ice preparation area and a test area, as shown in Figure 3.2.

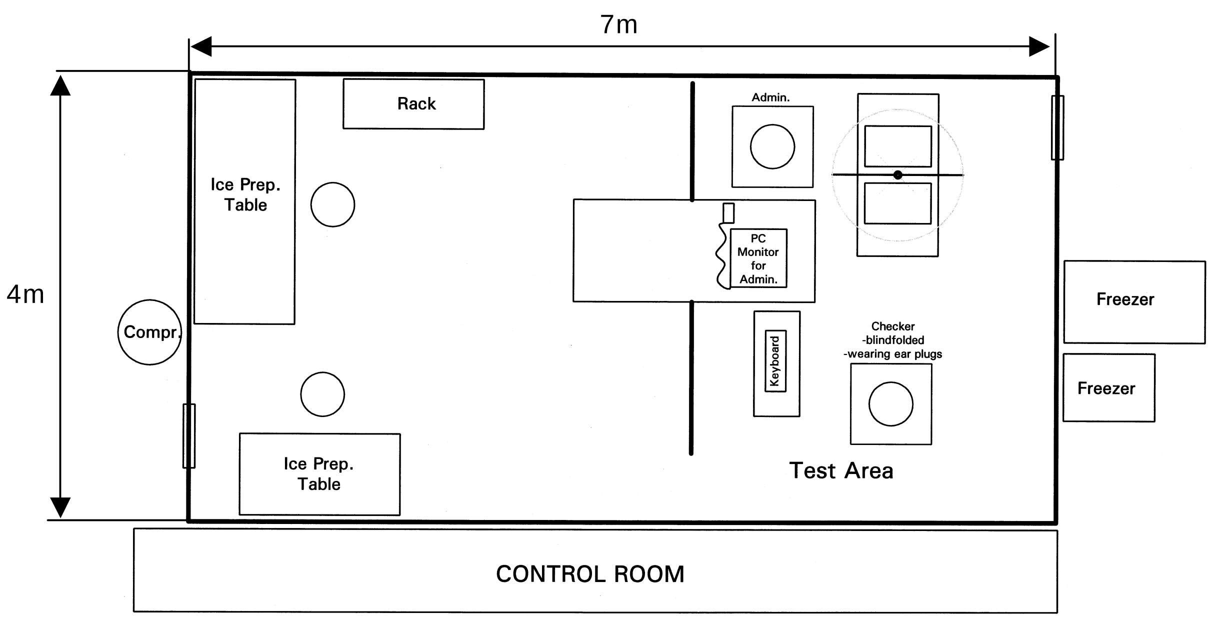

Figure 3.2: PMG Chamber Layout During Pre-Test Session

The ice preparation area is presented in Photo 3.5. In the last week of the pre-test session a series of demonstrations were prepared with the H-F group. The test area was adjusted for each of the two specific situations pertaining to the visual (Photo 3.6) or tactile (Photo 3.7) ice detection capability experiments.

The pre-test session took place according to the schedule presented in Figure 2.1.

The temperature in the chamber was -5°C (±0.5°C), 92 percent (± 2%) relative humidity, and wind speed of one meter per second.

During the pre-test session APS personnel concentrated on developing a reliable procedure to produce acceptable ice samples at a rate consistent with conduct of the experiments. The knowledge gained during the previous tests in the laboratory served as a starting point for this pre-test session.

It was found that a series of adjustments were necessary in order to improve the general appearance of the ice sample. Initially, the chamber temperature was set to -15°C. At this temperature personnel had to leave the chamber at 20-minute intervals in order to warm up, since the conditions were relatively uncomfortable even with proper clothing. The possibility of making ice at a warmer temperature was examined. The ice making procedure was replicated at -15°C, -10°C and -5°C. It was found that not only the ice was still stable at -5°C but also the ice samples produced at this temperature had a higher quality. After consultation with TC and FAA personnel, it was decided to continue making ice and perfecting the procedure at -5°C.

According to the H-F plan, the calibration was carried out using six ice sample thicknesses: 0.2, 0.35, 0.5, 0.8, 1.0 and 1.2 mm. The ice samples were created on white or polished standard aluminum flat plates similar to those used in deicing fluid holdover time testing. The area of the panel covered by the ice was a circle of 315 cm^2. A primary concern was that the ice samples be of a desired thickness, clear, and that the edges of the ice samples be "feathered". A constant quantity of fluid of 30 mL was applied to every plate and spread across the surface of the test plate to form an even thickness fluid film. During the calibration process test parameters were evaluated and adjusted to produce ice samples of the desired quality and aspect.

Dissolving of ice at the fluid/ice interface is driven by the glycol concentration gradient in the fluid. A more concentrated fluid produced more ice dissolving when compared to a fluid that had a freeze point just below the test temperature. Data was collected using a fluid with a Brix of 15 (freezing point of -11°C). As the ice dissolving is directly proportional to the amount of glycol in the applied fluid, it was decided to further dilute the fluid to a level just below freezing point for -5°C, so that the fluid would not freeze and at the same time yield minimal ice dissolving. The ideal fluid concentration was found to be at a Brix of 11, equivalent to a nominal freezing point of -7°C.

If the fluid remains stationary on the plate for 15 minutes following fluid application, a state of equilibrium is reached and from that point on further ice dissolving occurs at an insignificant rate for the purpose of the experiments.

However, according to FAA and TC procedure, the test plates are placed on a Lazy Susan table and subjected to a number of rotations. This motion caused fluid flow and additional dissolving occurred. This effect was factored into the calibration.

After analyzing the findings from the tests, critical aspects of the procedure were established: ideal fluid concentration, test temperature and ice dissolving calibration as a result of fluid application. A final ice making procedure was developed that addressed all essential test variables and produced reproducible results in terms of ice characteristics and thickness stability under fluid. This procedure is included in Appendix B.

During the pre-test session, the H-F experimental procedure was changed to accommodate preliminary findings, and as a result, the calibration process using regular 315 cm^2 ice samples as well as ice samples covering the entire surface of the flat plate was developed. The ice samples covering the entire surface of the plate were checked for thicknesses ranging between 0.2 and 1.2 mm.

A summary of the calibration tests conducted during the pre-test session is presented in Table 3.2. As can be observed, the calibration conducted addressed both visual and tactile ice detection capability tests. The calibration tests carried out with ice samples designed for tactile inspection also factored in the combined dissolving effects of glycol and human contact with the ice sample.

Even though extensive calibration testing has been carried out with fluid applied at a Brix of 15, Table 3.2 presents only the tests conducted with fluid at a Brix of 11 as this data was used in the final ice thickness calibration analysis.

Based on the information provided in Table 3.2, using regression analysis, an equation was developed to describe the relationship between the initial ice thickness (dry ice) and the thickness of the ice sample at the end of the experiment (wet ice). The equation along with the regression line for a coefficient of determination (R^2) of 99 percent, are shown in Figure 3.3, indicating a very strong linear relationship between the initial and final thickness values. The 95-percent prediction interval is also indicated on the graph. The prediction interval represents the estimation interval for an individual y (dry ice) observation, for any given value of x (wet ice). The 95-percent prediction interval indicates that there is 95 percent probability that the individual y observation will fall within the bounds described by the prediction interval. Using the equation developed based upon the data collected in the pre-test session, a target (dry) thickness was calculated for each of the five thicknesses assigned for visual detection and both thicknesses assigned for tactile inspection. Each calculated ice thickness (dry) was then associated with the thickness gauge tooth closest to the calculated value, as shown in Table 3.3 and Photo 3.8.

Table 3.2: Log of Calibration Tests During Pre-Test Session

Test Type	Plate Type	Target Thickness (mm)	Starting Thickness Dry (mm)	Final Thickness Wet (mm)	Degradation (mm)	Weight of Bare Plate (g)	Weight of Bare Plate and Ice (g)	Net Ice Weight (g)	Initial Brix	Final Brix
Visual	GC	0.2	0.24	0.19	0.05	1378.2	1384.8	6.6	11	9.75
	GC	0.2	0.38	0.22	0.16	1376.2	1390.5	14.3	11	8.75
	GF	0.2	0.44	0.38	0.06	N/A	N/A	N/A	11	8.75
	GF	0.2	0.33	0.29	0.04	1377.8	1422.3	44.5	11	9.00
	WC	0.2	0.33	0.19	0.14	1387.9	1400.6	12.7	11	8.75
	WC	0.2	0.33	0.24	0.09	1387.4	N/A	N/A	11	9.00
	WC	0.2	0.33	0.22	0.11	1383.5	1395.5	12.0	11	8.50
	WF	0.2	0.33	0.27	0.06	N/A	N/A	N/A	11	9.50
	WF	0.2	0.33	0.22	0.11	1389.9	1433.3	43.4	11	8.50
	WC	0.5	0.48	0.44	0.04	1387.6	1403.6	16.0	11	10.00
	WC	0.5	0.64	0.58	0.06	1387.8	1410.5	22.7	11	7.75
	GF	0.8	0.95	0.83	0.12	N/A	1440.5	N/A	11	9.00
	WC	0.8	0.95	0.83	0.12	N/A	N/A	N/A	11	8.25
	GC	1.0	1.09	1.09	0.00	N/A	1419.4	N/A	11	9.50
	WC	1.0	1.09	0.95	0.14	1405.5	1422.6	17.1	11	9.25
	GC	1.2	1.20	1.20	0.0	1380.5	1421.4	40.9	11	10.25
	WF	1.2	1.33	1.21	0.12	1381.6	N/A	N/A	11	N/A
	WF	1.2	1.33	1.21	0.12	1384.9	1551.0	166.1	11	9.50
Tactile	GC	0.2	0.33	0.29	0.04	1377.7	1384.2	6.5	11	9.75
	WF	0.2	0.33	0.24	0.09	N/A	N/A	N/A	11	9.75
	GF	1.2	1.33	1.21	0.12	1378.3	1531.0	152.7	11	9.25

Legend:
GC – Circular ice sample on polished AL plate
GF – Full ice sample on polished AL plate
WC – Circular ice sample on white AL plate
WF – Full ice sample on white AL plate

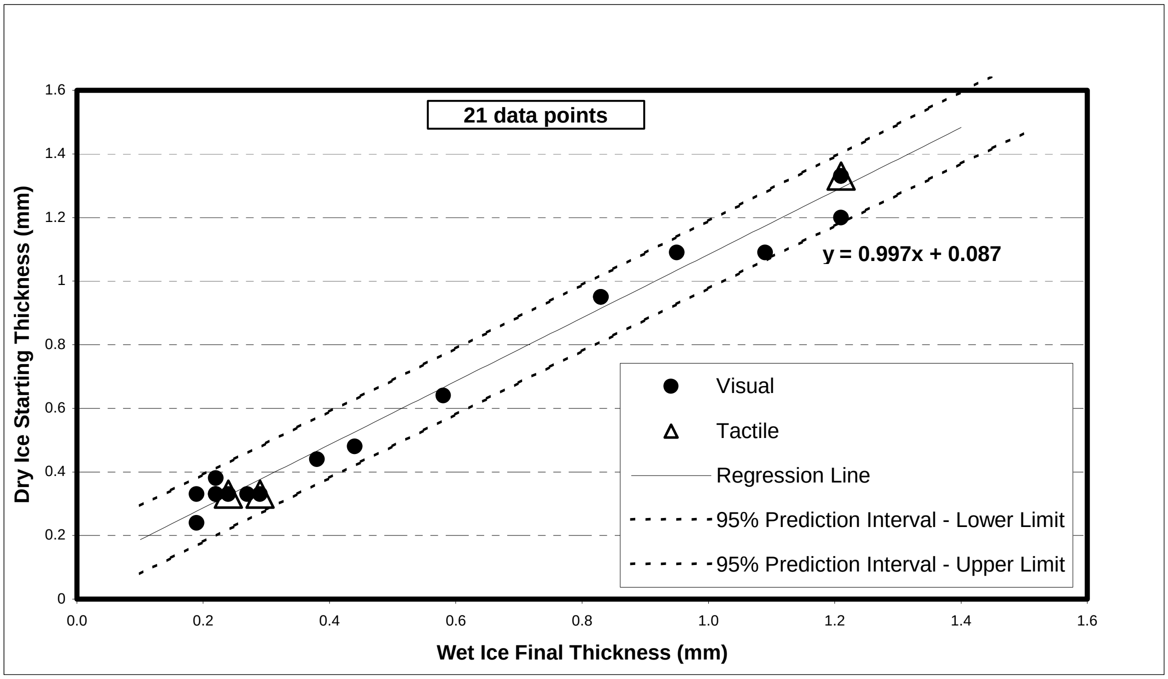

Figure 3.3: Dry Ice Thickness vs. Wet Ice Thickness – Pre-Test Session

Table 3.3: Pre-Test Session Results

	Target Thickness (mm)	Thickness Gauge Tooth (mm)	Weight of Ice (g)
White AL. Plate (Circular Ice Sample)	0.20	0.279	7 ± 3
	0.35	0.406	12 ± 3
	0.50	0.559	17 ± 3
	0.65	0.711	22 ± 3
	0.80	0.889	27 ± 3
Polished AL. Plate (Fully covered with Ice)	0.50	0.559	81 ± 14
	1.00	1.143	157 ± 14

As mentioned in Section 2, the weight of ice was evaluated by measuring the weight of the bare plate compared to the weight of the plate with ice. This measurement was used to check the accuracy of the ice produced. As shown in Table 3.2, most of the data was collected on 0.2 mm thick ice samples. However, for this analysis all ice samples produced were considered, including those used for calibration test carried out with a fluid with an initial Brix of 15. Based on 47 data points collected using circular ice samples on flat plates, an equation describing the correlation between the initial (dry) thickness and the weight of the ice sample was developed:

$W = 33.3 * T$, where

W - weight of ice, in grams

T - Initial ice thickness (dry), in mm

The weight of the ice samples covering the entire surface of the plate was similarly calculated.

3.4 Human Factors Test Experiments in the PMG Chamber

In April 2005, FAA and TC carried out human visual and tactile capability experiments at the PMG Test and Research Centre cold chamber. Similar to the pre-test session, the cold chamber was divided into an ice preparation area and a test area. However, this time the human participant test area was subdivided into two fully independent work stations, as shown in Figure 3.4. All recommendations with respect to the chamber and test design made during the H-F pre-test session were addressed during the visual and tactile experiments.

3.4.1 Confirmatory Tests

The test session took place according to the schedule presented in Figure 2.2. Initially, additional confirmatory calibration tests were conducted in the cold chamber. APS carried out the calibration process using regular 315 cm^2 ice samples as well as ice samples covering the entire surface of the flat plate. The ice samples were created on white or polished standard aluminum flat plates. Six different ice thicknesses were produced, this time ranging from 0.2 to 1.0 mm. These new thicknesses were selected by the human factor group based on the pre-test results.

The methodology used to carry out the experiments in April 2005 was similar to that used during the pre-test session. However, in addition to the procedure developed during the pre-test session, in this case the flat plate fluid retention frame lips were secured onto the test plate by using two angle iron sections along the long side of the plate.

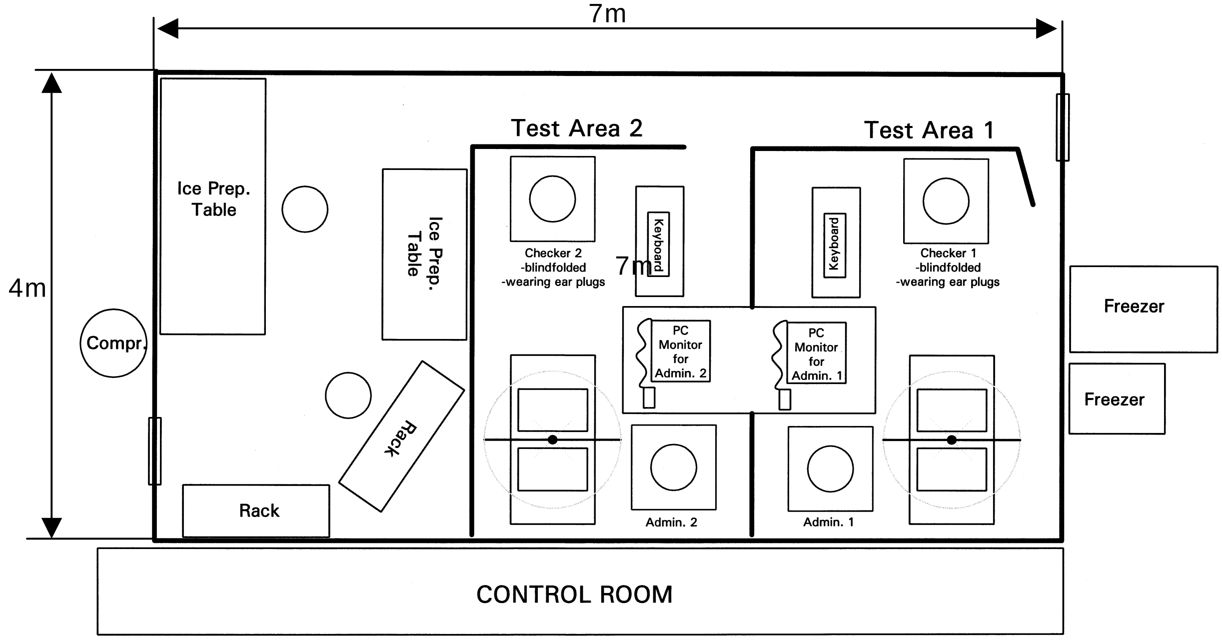

Figure 3.4: PMG Chamber Layout during Test Session

By adjusting the screws at both ends of the angle iron, the lip exerted sufficient pressure on the test plate to prevent the fluid from escaping the test plate area. The modified system is shown in Photo 3.9.

The purpose of the confirmatory calibration experiments was to verify whether the results were in line with the findings from the previous test session and to confirm that the procedure developed during the pre-test session generated reproducible results.

A summary of the tests conducted by APS during the confirmatory session is presented in Table 3.4. The tests presented in Table 3.4 were conducted exclusively with fluid mixed at a Brix of 11 (freezing point of approximately -7°C).

In order to confirm the validity of the ice making procedure developed by APS, the additional data points presented in Table 3.4, were superimposed on the chart shown in Figure 3.3. The result is presented in Figure 3.5.

As can be seen on the graph, the confirmatory test results lay in close proximity to the regression line and within the range described by the 95-percent prediction interval. Therefore, it was concluded that the equation developed based upon the tests conducted during the pre-test session was valid, and consequently the values presented in Table 3.3, were accurate and gave reproducible results.

Table 3.4: Log of Confirmatory Tests

Test Type	Plate Type	Target Thickness (mm)	Starting Thickness Dry (mm)	Final Thickness Wet (mm)	Degradation (mm)	Weight of Bare Plate (g)	Weight of Bare Plate and Ice (g)	Net Ice Weight (g)
Visual	WC	0.20	0.33	0.24	0.090	1390.6	1402.6	12.0
	WC	0.35	0.44	0.33	0.110	1390.7	1411.2	20.5
	WC	0.35	0.44	0.27	0.170	1392.0	1397.2	5.2
	WC	0.35	0.48	0.38	0.100	1385.1	1406.4	21.3
	GF	0.50	0.69	0.64	0.050	1376.3	1455.0	78.7
	GF	0.50	0.58	0.53	0.050	1374.6	1448.8	74.2
	WC	0.50	0.64	0.58	0.060	N/A	1418.7	N/A
	WC	0.50	0.58	0.53	0.050	1389.5	1411.4	21.9
	WC	0.65	0.83	0.74	0.090	1392.3	1419.5	27.2
	WC	0.65	0.83	0.69	0.140	1390.5	1422.2	31.7
	WC	0.65	0.83	0.74	0.090	1389.0	1419.4	30.4
	WC	0.80	1.09	0.95	0.140	1396.0	1435.1	39.1
	GF	1.00	1.09	1.09	0.000	1371.8	1525.8	154.0
	GF	1.00	1.09	1.09	0.000	1376.6	1518.2	141.6
	WC	1.00	1.09	0.95	0.140	1401.6	1444.9	43.3
	WC	1.00	1.21	1.09	0.120	1387.7	1432.2	44.5

Legend:
GF – Full ice sample on polished AL plate
WC – Circular ice sample on white AL plate
N/A – Data not available

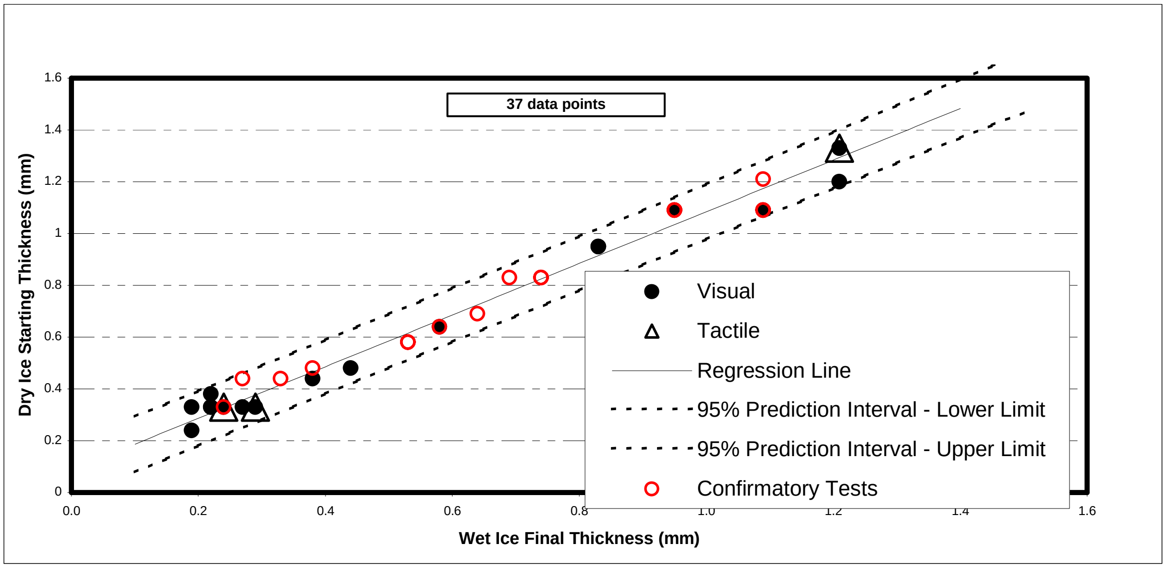

Figure 3.5: Dry Ice Thickness vs. Wet Ice Thickness – Confirmatory Tests

3.4.2 Human Visual and Tactile Capability Experiments

In the second week of the test session, actual human visual and tactile capabilities experiments were carried out. Six different ice thicknesses were produced:

- 0.2, 0.35, 0.5, 0.65, 0.8, 1.0 mm – for visual tests; and
- 0.5, 1.0 mm – for tactile tests.

For each ice thickness, photographs were taken from the participant's seat (see Figure 3.4) as well as from a side view to the plate. For each ice thickness, photographs were taken for the plate with ice and also the plate with no ice, as shown in Table 3.5 and in Appendix C. The actual photos have not been included in Appendix C, but may be available upon request.

A summary of the ice samples used during the actual test sessions is presented in Table 3.6 for both the visual and the tactile ice detection experiments. These demonstrate the consistency and reproducibility of the ice samples produced. The validity of the ice samples provided by APS was confirmed by measuring the ice thickness. The thicknesses of ice samples were recorded prior to application of the fluid as well as after the tests were completed. The values presented in Table 3.6 were plotted on a 1:1 chart, and the results are shown in Figure 3.6.

A summary of the data in Table 3.6, is also given in Table 3.7 by grouping the tests by ice thickness value.

Table 3.5: Matrix of Documentation Photos Taken During Actual Tests

Test Type	Plate Type	Target Thickness (mm)	Test Area No. 1	Test Area No. 2
Visual	White Circle	0.2	X	X
	White Circle	0.35	X	X
	White Circle	0.5	X	X
	White Circle	0.65	X	X
	White Circle	0.8	X	X
	Grey Full	0.5	X	X
	Grey Full	1.0	X	X
Tactile	White Full	0.5	X	X
	White Full	1.0	X	X

X – each set consisted of 4 photographs

Table 3.6: Log of Thicknesses Measured During Test Session

Test Type	Plate Type	Target Thickness (mm)	Starting Thickness (mm)	Final Thickness (mm)	Degradation (mm)
Visual	WC	0.20	0.33	N/A	N/A
	WC	0.20	0.33	0.22	0.110
	WC	0.20	0.33	0.29	0.040
	WC	0.20	0.29	0.24	0.050
	WC	0.20	0.33	0.22	0.110
	WC	0.20	0.33	0.24	0.090
	WC	0.35	0.44	0.29	0.150
	WC	0.35	0.44	0.33	0.110
	WC	0.35	0.44	0.27	0.170
	WC	0.35	0.48	0.38	0.100
	GF	0.50	0.58	0.53	0.050
	GF	0.50	0.58	0.53	0.050
	GF	0.50	0.58	0.58	0.000
	WC	0.50	0.53	N/A	N/A
	WC	0.50	0.58	0.53	0.050
	WC	0.50	0.58	0.48	0.100
	WC	0.50	0.58	0.53	0.050
	WC	0.50	0.64	0.58	0.060
	WC	0.65	0.83	0.69	0.140
	WC	0.65	0.74	0.58	0.160
	WC	0.65	0.74	0.69	0.050
	WC	0.65	0.74	0.69	0.050
	WC	0.80	0.95	N/A	N/A
	WC	0.80	0.95	0.83	0.120
	WC	0.80	1.09	0.83	0.260
	WC	0.80	0.95	0.95	0.000
	GF	1.00	1.21	1.09	0.120
	GF	1.00	1.21	1.09	0.120
	GF	1.00	1.21	1.09	0.120
Tactile	WF	0.50	0.58	0.53	0.050
	WF	0.50	0.53	0.48	0.050
	WF	1.00	1.09	0.95	0.140
	WF	1.00	1.21	0.95	0.260

Legend:

GF – Full ice sample on polished AL plate
WC – Circular ice sample on white AL plate
N/A – Data not available

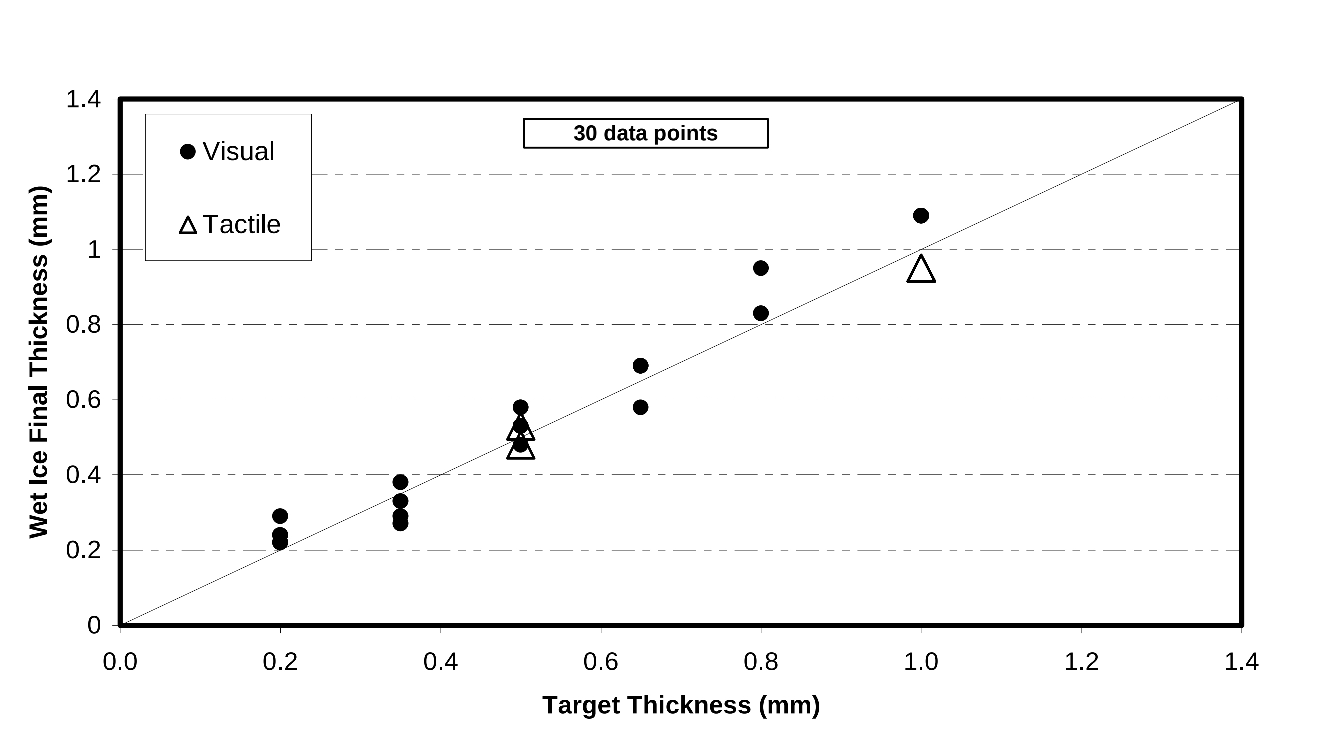

Figure 3.6: Target Thickness vs. Final Thickness for Actual Tests

Table 3.7: Summary of Ice Thicknesses – Actual Test Session

Test Type	Target Thickness (mm)	Number of Tests	Average Final Thickness (mm)	Final Thickness Std. Deviation (mm)
Visual	0.20	5	0.24	0.029
	0.35	4	0.32	0.049
	0.50	7	0.54	0.035
	0.65	4	0.66	0.055
	0.80	3	0.87	0.069
	1.00	3	1.09	0.000
Tactile	0.50	2	0.51	0.035
	1.00	2	0.95	0.000

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Photo 3.1: Ice Sample on Flat Plate (Feasibility Study)

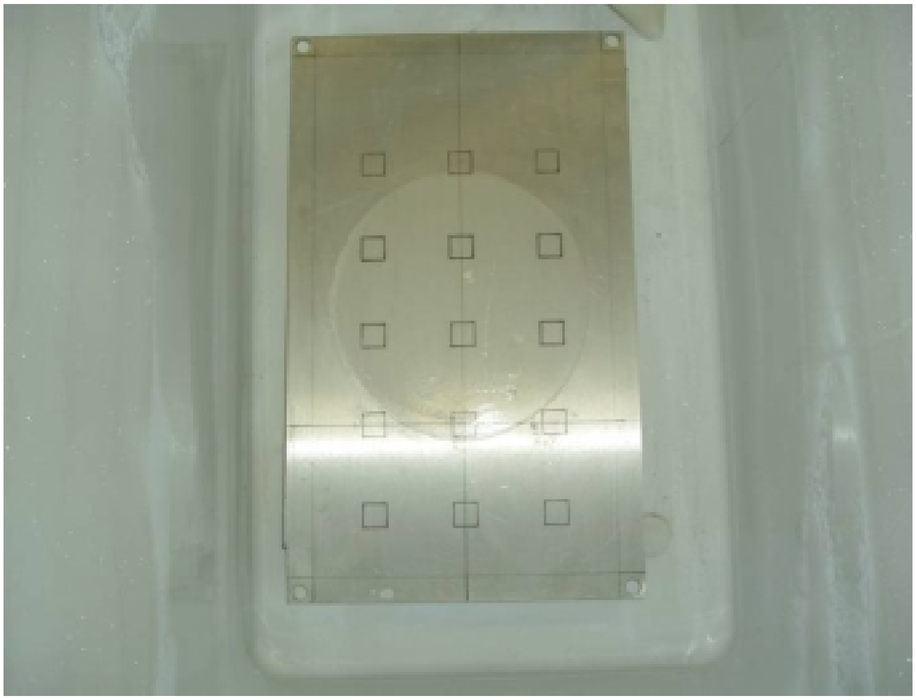


Photo 3.2: Fluid Application (Feasibility Study)

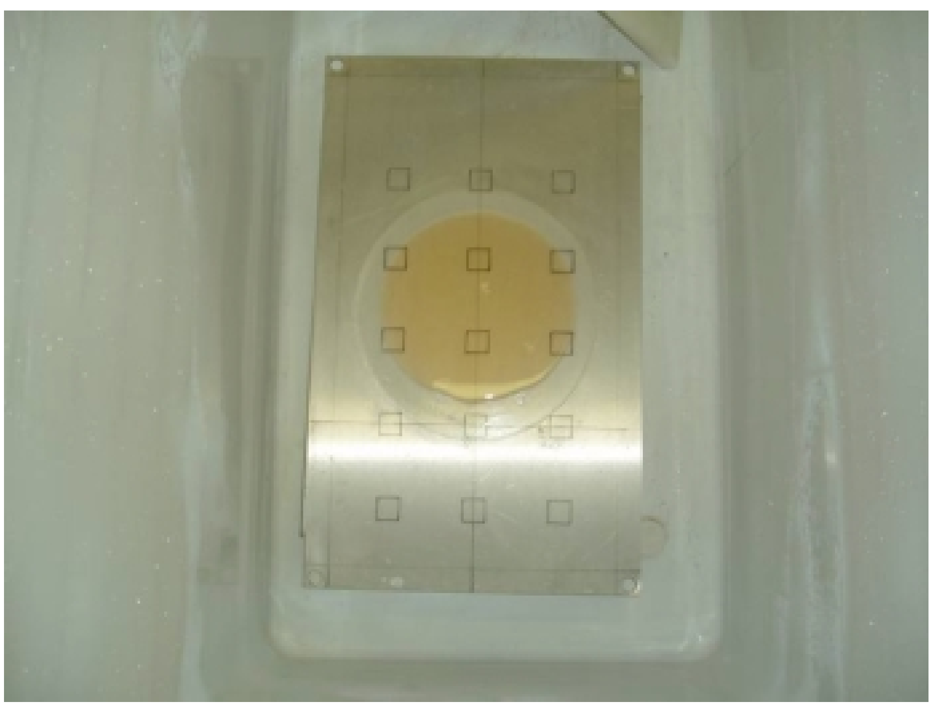


Photo 3.3: Fifteen Minutes Following Fluid Application (Feasibility Study)

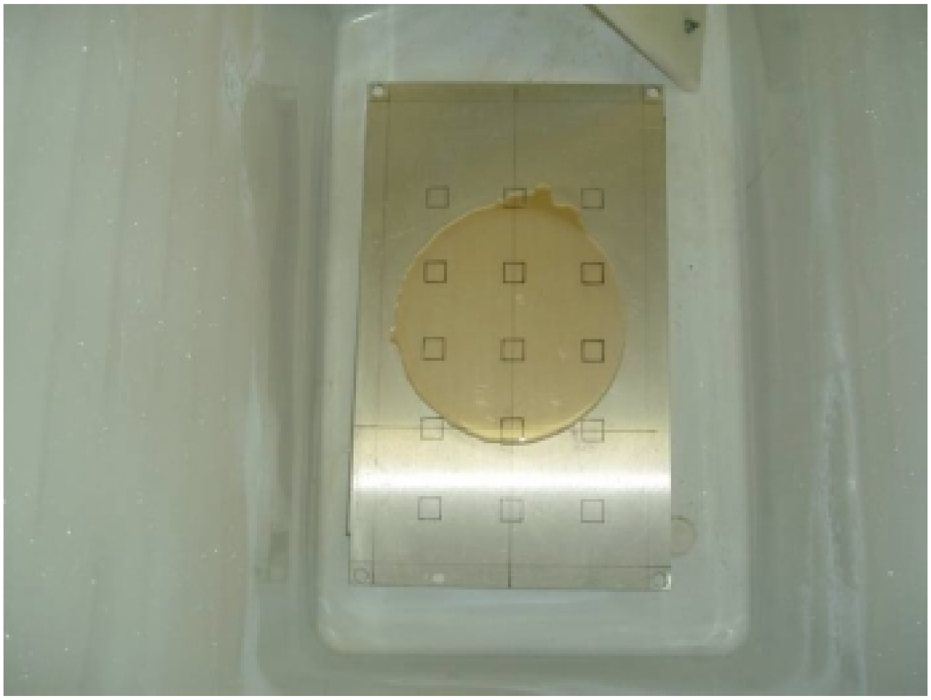


Photo 3.4: Thirty Minutes Following Fluid Application (Feasibility Study)

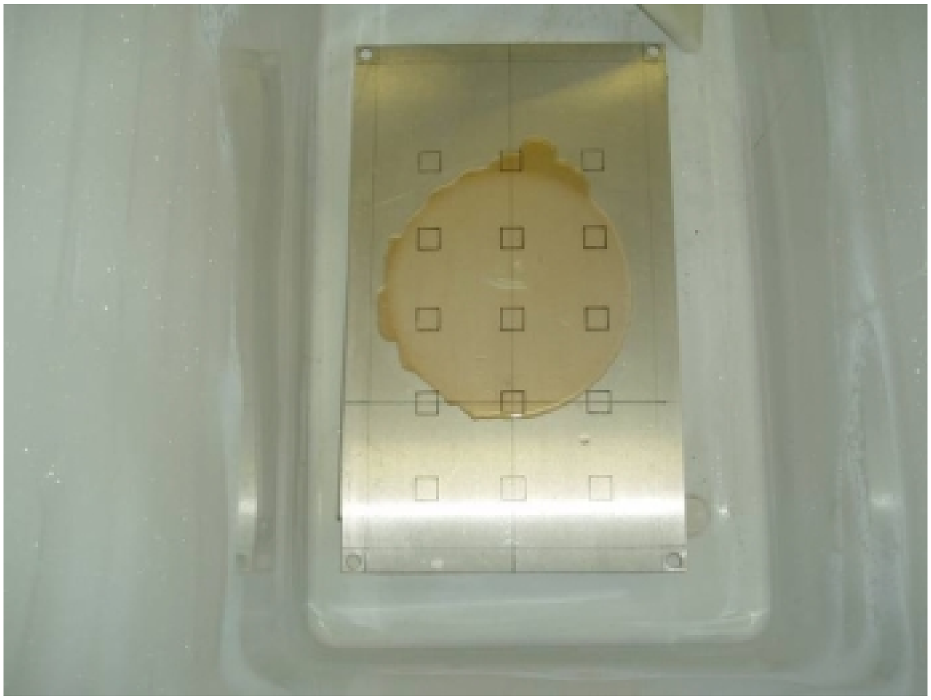


Photo 3.5: Ice Preparation Area During Pre-Test Session

Photo 3.6: Test Area During Pre-Test Session – Visual Tests

Photo 3.7: Test Area During Pre-Test Session – Tactile Tests

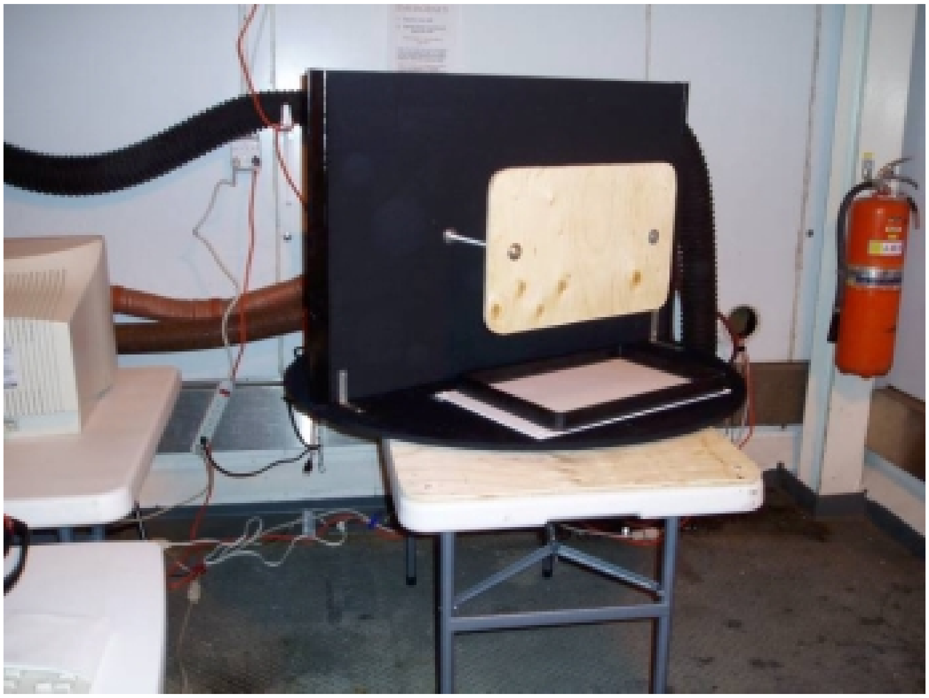


Photo 3.8: Selected Teeth on the Thickness Gauge

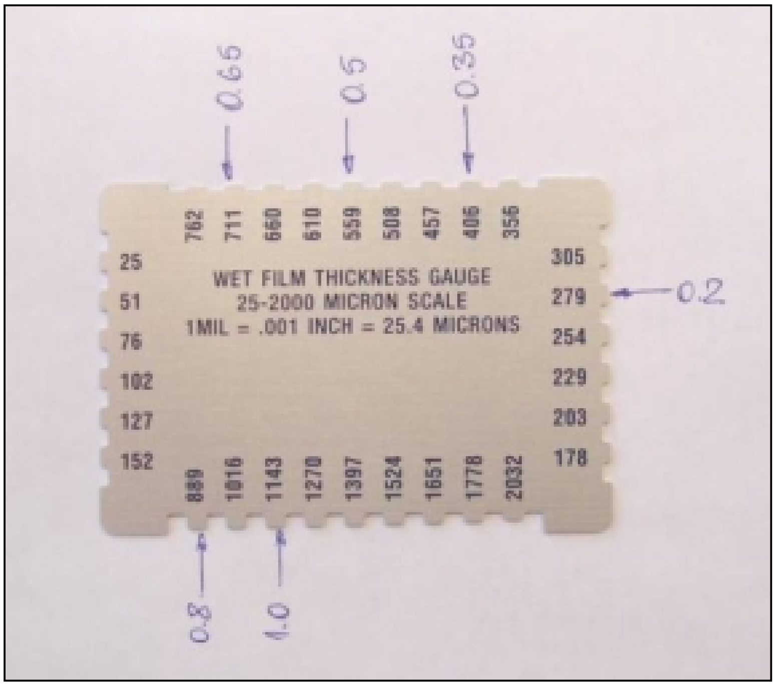
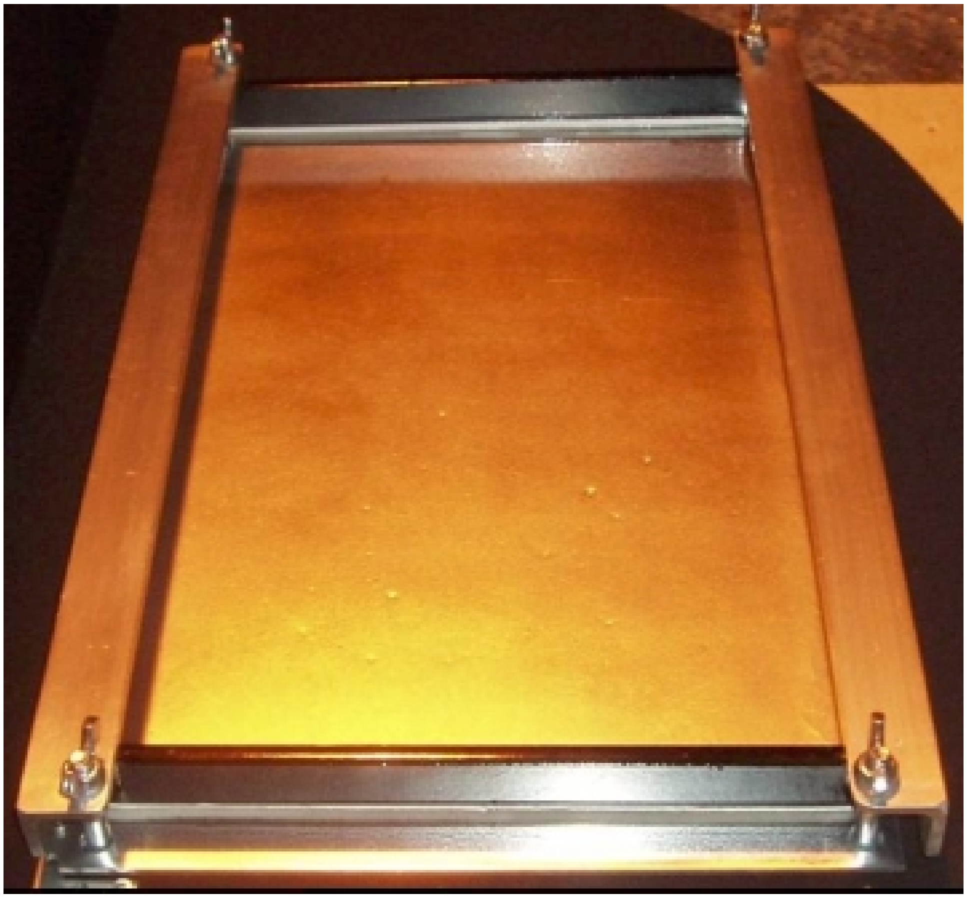


Photo 3.9: Fluid Retaining Lip



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4. CONCLUSIONS

This report's objectives were met as presented below.

4.1 Feasibility of Ice-Making

In January 2005 preliminary tests were carried out in the laboratory. The plates were maintained at subzero temperatures in a freezer. Based on the results from these tests, it was concluded that making ice samples of the required thickness and form under laboratory conditions was feasible.

4.2 Development of an Ice-Making Procedure

Upon running several test sessions in the cold chamber, APS met the following objectives:

- Ice samples with uniform thicknesses from 0.2 to 1.2 mm over the required 315 sq cm. and full plate areas, with smooth surfaces and feathered edge, where required, were produced;

The dissolving of ice due to fluid application for various thicknesses ranging from 0.2 to 1.2 mm was calibrated, and ice samples with these thicknesses at time of experiment were produced;

- It was demonstrated that ice samples of specified thickness could be preserved; and

- Critical aspects of the ice making procedure were established: ideal fluid concentration and test temperature. APS developed a reliable ice making procedure that addressed all essential test requirements and produced reproducible results in terms of ice characteristics and thickness stability under fluid.

4.3 Support for Human Visual and Tactile Capability Experiments

APS personnel provided support throughout the testing session including chamber layout design, ice sample production, cleaning and replacing ice samples, communication with chamber facility personnel, and all aspects of logistics and test area management.

4.4 Visual and Tactile Human Capability

The conclusions from the human visual and tactile capability experiments are presented in a report produced and issued by the FAA (1). This report and other relevant publications can be downloaded from the Simulation and Analysis Group section of the FAA website (2).

REFERENCES

1. Sierra Jr., E. A., Bender, K., Marcil, I., D'Avirro, J., Pugacz, E., Eyre, F., *Human Visual and Tactile Ice Detection Capabilities under Aircraft Post Deicing Conditions*, FAA, November 2005, DOT/FAA/CT (unpublished).

2. Simulation and Analysis Group Published Documents, FAA website, http://www.tc.faa.gov/acb300/330_documents.asp.

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APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT
AIRCRAFT & ANTI-ICING FLUID
WINTER TESTING 2003-05

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT
AIRCRAFT & ANTI-ICING FLUID
WINTER TESTING 2003-05

6.22 Support for Human Factor Tactile Tests

a) Provide support to TC/FAA for the conduct of tests

   (i) To assess the human psychophysical capability to detect the presence of ice on a simulated aircraft surface by visual observation, and by tactile means under a specific set of conditions.

   (ii) To compare human and Ground Ice Detection System (GIDS) capability to detect the presence of ice on an aircraft wing under a specific set of conditions.

b) Determine the feasibility, and develop the methodology for development of "ice coupons" for testing. Coupons to be circular of 315cm^2 area, to have a smooth surface, 'feather' edge, and to have thicknesses from 0.2mm to 1.2mm as required.

c) Further refine the "ice coupon" technology to ensure that the process is reproducible, that the coupons can be produced in 'batch' lots for multiple test sessions, and can be stored for re-use over a period up to three days.

d) Conduct a demonstration of the "ice coupon" production technology for TDC, and subsequently for other industry and government representatives (the SAE G-12 Ice Detection Subcommittee RA Working Group).

e) Arrange for use of a 'Cold chamber' suitable for conduct of Human Factor ice detection tests, and production of ice coupons on a regular basis for use in the tests, in accordance with the test plan developed by the SAE G-12 Ice Detection Subcommittee RA Working Group (copy to be supplied by TDC).

f) Prepare the Cold Chamber for Human Factor psychophysical tests, including provision of ice coupon production equipment, test participant equipment (tables, seats, test sample mounting equipment, computer recording equipment, and ancillary equipment, as necessary for satisfactory conduct of tests).

g) Provide support services for conduct of check-out tests over a period of three days, and human participant evaluation tests over a period of five days, including production of ice coupons as required.

h) Prepare and submit interim reports describing the services and facilities provided, and work performed.

i) Extend the "ice coupon" production technology for application of multiple 'patches' to an aircraft wing. Coupons to be circular of 315cm2 area (or as determined by TDC), to have a smooth surface, 'feather' edge, to have thicknesses from 0.2mm to 1.2mm, and to be distributed randomly with up to nine patches/wing, as required by TDC. The process to be reproducible, produced in 'batch' lots for multiple test sessions, and storeable for re-use over a period up to three days.

j) Arrange for use of a 'Cold chamber' suitable for conduct of Human Factor/GIDS comparative tests based on use of the TDC 'Jetstar' wing. Prepare the Cold Chamber for the comparative tests, including provision of ice coupon production equipment, test participant equipment (tables, seats, platforms, wing mounting equipment, sensor mounting equipment, computer recording equipment, and ancillary equipment, as necessary for satisfactory conduct of tests).

k) Provide support services for conduct of check-out tests over a period of three days. Check-out tests to include initial demonstration of the "ice coupon" production technology for TDC and other industry and government representatives (the SAE G-12 Ice Detection Subcommittee RA Working Group).

l) Provide support services for conduct of human/sensor comparative tests over a period of four days. Tests to be conducted in accordance with the test plan developed by the SAE G-12 Ice Detection Subcommittee RA Working Group (copy to be supplied by TDC).

m) Provide additional support services for conduct of tests including production of ice coupons/wing preparation as required.

n) Maintain liaison with the agencies involved (TC, TDC, FAA, Titan Corporation, Aeromag, GlobeGround (Toronto), MD Robotics Inc., BF Goodrich) to ensure timely coordination of work performed.

o) Prepare and submit interim reports describing the services and facilities provided, and work performed.

APPENDIX B

ICE-MAKING PROCEDURE

PROCEDURE FOR ICE DISK MAKING

1. INITIAL PREPARATION

1.1 Lightly sand the aluminum plates with a sander. Do not apply pressure to the sander and sand evenly. Use 1500 grain sand paper. Use one sand paper per plate; replace after every use.

1.2 Masks used to make a patch of ice (circular 315 cm^2): to ensure that masks are aligned to the plates, 1.3 cm (1/2 inch) diameter holes must be cut into each corner of the mask. The center of the holes should be 30 cm (11 inches) apart along the width and 48.3 cm (19 inches) apart along the length. Screw a bolt through the holes until they penetrate 1.3 cm through the bottom of the mask.

1.3 Thickness gauges are modified to reduce the number of markings left in the ice. Each target thickness has its own thickness gauge: all but three “teeth” are shaved off (the remaining “teeth” are the target “tooth”, one above, one below).

1.4 Painting of the plates was done by Nutech Associates, an aircraft-painting company located in Montreal. The painting was done with one coat of primer and two coats of paint. The paint used was Jet Glo Matterhorn white, manufactured by Sherwin-Williams.

1.5 After initial white painting of the aluminum plates use 600 and 1500 grain to sand plates respectively.

2. INITIAL FLUID PREPARATION

2.1 At 07:15 (for testing not earlier than 8:30), remove the containers containing 30 mL of glycol (Brix 11) from the cooler at 1ºC and store them in the chamber and allow them to cool to -5ºC. Use the colder freezer to assist, if necessary, to achieve -5ºC.

3. ACTUAL ICE MAKING PROCEDURE

3.1 The surface (plate or wing) to be sprayed with ice must first be:

- Cleaned of any grease or surface contaminants, using a highly volatile solvent such as isopropyl. Ensure complete evaporation of the solvent.

- Manipulated with nitrile gloves to prevent any contamination with finger grease.

- Stored in the chamber prior to spraying in order to cool down to -5°C.

3.2 The plate to be sprayed with ice must be:

- Cold soaked in the chamber to -5ºC for about 1 hour.

- Weighed using the digital scale.

Note 1: A 3.175 mm (1/8 inch) thick aluminum plate needs approximately 30 minutes of cold soaking at -12ºC for it to cool to a temperature of -5ºC.

Note 2: The ice mask must be cold soaked the same way to prevent icicles from forming.

3.3 Adjust the following:

- Spray gun air pressure at 2.72 atm. (40 psi).

  – Open fluid knob 2 full turns.

  – Open air knob 66% of its full range in order to have an adequate spray from 10 cm above the mask.

- Use distilled water at a temperature of 35ºC ± 5ºC.

  Note: The temperature of the water within the insulated spray gun container decreases about 7ºC in 40 minutes when in the chamber. Water at 17.5ºC will heat up to approximately 20ºC ± 1ºC in 30 minutes to 1 hour when placed in the heater. Water will continue to heat up 2ºC every 40 minutes.

3.4 Spraying the first coats (primer):

- Place the ice mask over the plates that require a circular shape.

- From a distance of 20 cm with rapid hand movement spray 6 fine coats (0.025 mm). The ice will appear opaque. Make sure the surface in question (circle or full plate) is evenly covered.

  Note: Since the ice layers are so fine they will freeze on contact.

3.5 Making the ice clear:

- ***Plain aluminum:*** adjust the heat gun in the High Position (2) and slowly heat the ice until the crystals melt and the ice becomes clear. Allow 2 minutes for the ice to cool before applying other coats.
- ***White aluminum:*** heat the tip of the fingers with the heat gun and then slowly rub the ice until it becomes clear.

3.6 Application of subsequent layers (0.15 mm):

- From a 10 cm distance, at an angle of approximately 90 degrees with respect to the horizontal plates, spray even layers by moving the hand at a constant speed.
- Measure the thickness of the ice. Heat up the gauge before measuring to avoid cracking of ice.
- Fill the holes left by the gauge using a small screwdriver dipped in water at ambient temperature (approximately 20ºC).
- Remove icicles with the scraper.
- Reuse the heat gun to homogenize the surface.
- Allow the surface to cool.

  Note 1: Every time before spraying, wait 5 seconds for the pressure to drop to 2.72 atm. (40 psi) ensuring a constant spray. If the spray is not constant the holes of the gun or the air hose might be frozen. Use screwdriver and hot water to unfreeze.

  Note 2: If ice looks opaque, repeat Step 3.5.

3.7 Feathering (circle shaped plates only):

- Use fingers on layer of ice to remove excess splash.

- Using a fine brush, apply small amount of glycol (ambient temperature at 20ºC, Brix 20) to the circumference of the ice patch.

3.8 Weight of Coupon:

- Ice coupons shall be then weighted with the digital scale and the weight should be verified against the expected weight.

Note: In order to apply glycol fluid stoppers must be fabricated from steel (45.7 x 30.5 cm). A strand of EPDM Rubber from Reno Depot (part number: 5949422002) is applied on the bottom surface to block fluid from dripping.

3.9 Fluid Application (20 min):

- ***Whole plate:*** Apply 30 mL of glycol and spread it evenly over the whole surface using a small brush.
- ***Circle plate*:** Apply 8 mL of glycol (Brix 11) over the ice patch and 22 mL over the rest of the plate.

APPENDIX C

PHOTO DOCUMENTATION OF VISUAL AND TACTILE TEST SESSION

PHOTO DOCUMENTATION OF VISUAL AND TACTILE TEST SESSION

Photo 1	Visual 0.2 mm	White Circle	Station 1	Ice (Front Profile)
Photo 2	Visual 0.2 mm	White Circle	Station 1	No Ice (Front Profile)
Photo 3	Visual 0.2 mm	White Circle	Station 1	Ice (Side Profile)
Photo 4	Visual 0.2 mm	White Circle	Station 1	No Ice (Side Profile)
Photo 5	Visual 0.2 mm	White Circle	Station 2	Ice (Front Profile)
Photo 6	Visual 0.2 mm	White Circle	Station 2	No Ice (Front Profile)
Photo 7	Visual 0.2 mm	White Circle	Station 2	Ice (Side Profile)
Photo 8	Visual 0.2 mm	White Circle	Station 2	No Ice (Side Profile)
Photo 9	Visual 0.35 mm	White Circle	Station 1	Ice (Front Profile)
Photo 10	Visual 0.35 mm	White Circle	Station 1	No Ice (Front Profile)
Photo 11	Visual 0.35 mm	White Circle	Station 1	Ice (Side Profile)
Photo 12	Visual 0.35 mm	White Circle	Station 1	No Ice (Side Profile)
Photo 13	Visual 0.35 mm	White Circle	Station 2	Ice (Front Profile)
Photo 14	Visual 0.35 mm	White Circle	Station 2	No Ice (Front Profile)
Photo 15	Visual 0.35 mm	White Circle	Station 2	Ice (Side Profile)
Photo 16	Visual 0.35 mm	White Circle	Station 2	No Ice (Side Profile)
Photo 17	Visual 0.50 mm	Grey Full	Station 1	Ice (Front Profile)
Photo 18	Visual 0.50 mm	Grey Full	Station 1	No Ice (Front Profile)
Photo 19	Visual 0.50 mm	Grey Full	Station 1	Ice (Side Profile)
Photo 20	Visual 0.50 mm	Grey Full	Station 1	No Ice (Side Profile)
Photo 21	Visual 0.50 mm	Grey Full	Station 2	Ice (Front Profile)
Photo 22	Visual 0.50 mm	Grey Full	Station 2	No Ice (Front Profile)
Photo 23	Visual 0.50 mm	Grey Full	Station 2	Ice (Side Profile)
Photo 24	Visual 0.50 mm	Grey Full	Station 2	No Ice (Side Profile)
Photo 25	Visual 0.50 mm	White Circle	Station 1	Ice (Front Profile)
Photo 26	Visual 0.50 mm	White Circle	Station 1	No Ice (Front Profile)
Photo 27	Visual 0.50 mm	White Circle	Station 1	Ice (Side Profile)
Photo 28	Visual 0.50 mm	White Circle	Station 1	No Ice (Side Profile)
Photo 29	Visual 0.50 mm	White Circle	Station 2	Ice (Front Profile)
Photo 30	Visual 0.50 mm	White Circle	Station 2	No Ice (Front Profile)
Photo 31	Visual 0.50 mm	White Circle	Station 2	Ice (Side Profile)
Photo 32	Visual 0.50 mm	White Circle	Station 2	No Ice (Side Profile)

Photo 33	Visual 0.65 mm	White Circle	Station 1	Ice (Front Profile)
Photo 34	Visual 0.65 mm	White Circle	Station 1	No Ice (Front Profile)
Photo 35	Visual 0.65 mm	White Circle	Station 1	Ice (Side Profile)
Photo 36	Visual 0.65 mm	White Circle	Station 1	No Ice (Side Profile)
Photo 37	Visual 0.65 mm	White Circle	Station 2	Ice (Front Profile)
Photo 38	Visual 0.65 mm	White Circle	Station 2	No Ice (Front Profile)
Photo 39	Visual 0.65 mm	White Circle	Station 2	Ice (Side Profile)
Photo 40	Visual 0.65 mm	White Circle	Station 2	No Ice (Side Profile)
Photo 41	Visual 0.80 mm	White Circle	Station 1	Ice (Front Profile)
Photo 42	Visual 0.80 mm	White Circle	Station 1	No Ice (Front Profile)
Photo 43	Visual 0.80 mm	White Circle	Station 1	Ice (Side Profile)
Photo 44	Visual 0.80 mm	White Circle	Station 1	No Ice (Side Profile)
Photo 45	Visual 0.80 mm	White Circle	Station 2	Ice (Front Profile)
Photo 46	Visual 0.80 mm	White Circle	Station 2	No Ice (Front Profile)
Photo 47	Visual 0.80 mm	White Circle	Station 2	Ice (Side Profile)
Photo 48	Visual 0.80 mm	White Circle	Station 2	No Ice (Side Profile)
Photo 49	Visual 1.0 mm	Grey Full	Station 1	Ice (Front Profile)
Photo 50	Visual 1.0 mm	Grey Full	Station 1	No Ice (Front Profile)
Photo 51	Visual 1.0 mm	Grey Full	Station 1	Ice (Side Profile)
Photo 52	Visual 1.0 mm	Grey Full	Station 1	No Ice (Side Profile)
Photo 53	Visual 1.0 mm	Grey Full	Station 2	Ice (Front Profile)
Photo 54	Visual 1.0 mm	Grey Full	Station 2	No Ice (Front Profile)
Photo 55	Visual 1.0 mm	Grey Full	Station 2	Ice (Side Profile)
Photo 56	Visual 1.0 mm	Grey Full	Station 2	No Ice (Side Profile)
Photo 57	Tactile 0.50 mm	White Full	Station 1	Ice (Front Profile)
Photo 58	Tactile 0.50 mm	White Full	Station 1	No Ice (Front Profile)
Photo 59	Tactile 0.50 mm	White Full	Station 1	Ice (Side Profile)
Photo 60	Tactile 0.50 mm	White Full	Station 1	No Ice (Side Profile)
Photo 61	Tactile 0.50 mm	White Full	Station 2	Ice (Front Profile)
Photo 62	Tactile 0.50 mm	White Full	Station 2	No Ice (Front Profile)
Photo 63	Tactile 0.50 mm	White Full	Station 2	Ice (Side Profile)
Photo 64	Tactile 0.50 mm	White Full	Station 2	No Ice (Side Profile)

Photo 65	Tactile 1.0 mm	White Full	Station 1	Ice (Front Profile)
Photo 66	Tactile 1.0 mm	White Full	Station 1	No Ice (Front Profile)
Photo 67	Tactile 1.0 mm	White Full	Station 1	Ice (Side Profile)
Photo 68	Tactile 1.0 mm	White Full	Station 1	No Ice (Side Profile)
Photo 69	Tactile 1.0 mm	White Full	Station 2	Ice (Front Profile)
Photo 70	Tactile 1.0 mm	White Full	Station 2	No Ice (Front Profile)
Photo 71	Tactile 1.0 mm	White Full	Station 2	Ice (Side Profile)
Photo 72	Tactile 1.0 mm	White Full	Station 2	No Ice (Side Profile)

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