TP 14450E

Development of Ice Samples for Comparison Study of Human and Sensor Capability to Detect Ice on Aircraft




Prepared for
Transportation Development Centre

In cooperation with

Civil Aviation
Transport Canada

And

The Federal Aviation Administration
William J. Hughes Technical Center

Prepared by

APS Aviation Inc.

January 2006
Final Version 1.0

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Development of Ice Samples for Comparison Study of Human and Sensor Capability to Detect Ice on Aircraft




by

Christina Narlis

APS Aviation Inc.

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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 Using FedEx 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 produced.

This report, TP 14450E, has the following objective:

- To provide support for comparison tests of human ice detection capabilities and ground ice detection system performance under post-deicing conditions on a wing.

This objective was met by providing support for a series of tests run in Montreal (Blainville), Quebec, by Transport Canada and the Federal Aviation Administration.

PROGRAM ACKNOWLEDGEMENTS

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

APS would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data. This includes the following people: Katrina Bell, Stephanie Bendickson, Nicolas Blais, Michael Chaput, Sami Chebil, John D'Avirro, Peter Dawson, Stéphane Gosselin, Marc Mayodon, Chris McCormack, Nicoara Moc, Christina Narlis, 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.

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The author would like to acknowledge and thank AéroMag 2000 and GlobeGround for the contribution of test subject personnel and for continuous support since the early stages of the project. The author would also like to acknowledge and thank the PMG facility staff who were very helpful in providing support for the conduct of these tests.

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

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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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 ways to replace or assist visual and tactile inspections by other methods. Tests were designed by Federal Aviation Administration (FAA) Office of Aviation Research, Flight Safety Branch (William J. Hughes Technical Center) to assess the threshold for humans to detect ice, both visually and by tactile touch. Phase 1 comprised tests of human visual and tactile capability to detect ice samples on small plates following application of deicing fluid. Phase 2, reported separately, involved testing on an aircraft wing to compare human performance with that of ice detection equipment.

This report documents the activities carried out by APS Aviation Inc. (APS) on behalf of Transport Canada in preparation and support of the Phase 2 tests. A separate report produced and issued by the FAA provides the analysis of the actual test results.

In July 2005, APS carried out tests to determine the feasibility of making ice samples on a wing using the ice-making procedure developed in Phase 1. In August 2005, APS carried out a setup session to finalize the chamber layout for the comparison tests. A series of dry runs was also completed. In August 2005, comparison tests of human ice detection capabilities and GIDS performance were completed. The conclusions from the tests comparing human ice detection capabilities and GIDS performance are provided separately in an FAA report.

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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 était 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 SAE. Ce groupe avait pour mandat de trouver des méthodes pouvant remplacer les inspections visuelles et tactiles. La Direction de la sécurité en vol (le William J. Hughes Technical Center) du Bureau de recherche en aéronautique de la FAA (Federal Aviation Administration) a conçu des essais pour déterminer le seuil de détection «humaine» du givre, par inspection visuelle et tactile. La phase 1 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 phase 2, qui a 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.

Ce rapport rend compte des activités menées par APS Aviation Inc. (APS) au nom de Transports Canada pour préparer et appuyer les essais de la phase 2. Un rapport distinct, préparé et publié par la FAA, fait l'analyse des résultats des essais comme tels.

En juillet 2005, APS a réalisé des essais pour déterminer la faisabilité de préparer des éprouvettes de givre sur une aile d'avion en utilisant la même procédure qui avait été élaborée pour la phase 1. En août 2005, APS a organisé une séance de mise au point, au cours de laquelle il a finalisé l'aménagement de la chambre froide en vue des essais comparatifs. Des répétitions ont aussi eu lieu. Toujours en août 2005, les essais de comparaison des capacités humaines de détection de givre et des performances des GIDS ont été réalisés. Les conclusions des essais de comparaison des capacités humaines de détection de givre et des performances des GIDS sont contenues dans un rapport distinct de la FAA.

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

Currently, individuals from ground deicing crews check for the presence of residual ice on aircraft wings following ground deicing. These checks are done visually in most circumstances, although tactile inspections may be required following deicing of certain types of “hard wing” aircraft, or aircraft where cold soaking may be an issue. Tactile inspections require close proximity to an aircraft (at times with engines on), are slow, and can be limited by the checker’s reach. For this reason, alternate solutions are being looked for.

In collaboration with the Federal Aviation Administration (FAA) Office of Aviation Research, Flight Safety Branch (William J. Hughes Technical Center), the Transport Development Centre (TDC) of Transport Canada (TC) conducted a study to compare human and ground ice detection systems (GIDS) capabilities under aircraft post-deicing conditions. GIDS are new technologies being developed to assist ice checkers in performing their duties. This was the second phase of a two-phase project conceived by the Society of Automotive Engineers G-12 Ice Detection Sub-Committee GIDS Regulatory Approval Working Group (RAWG).

The first phase of the project was to measure human visual and tactile capabilities, as they would serve as a standard against which other ice detection methods could be evaluated. Therefore, the primary objective of Phase 1 of the project was to evaluate the ability of human checkers to detect ice. Phase 1 was completed in April 2005 and is documented in separate TC and FAA reports.

The primary objective of Phase 2 was to evaluate GIDS ice detection capabilities by comparing them with human visual and tactile ice detection capabilities in identical post-deicing conditions. These tests were conducted in August 2005 with GIDS provided by MDA Robotics (MDA) and Goodrich Aerospace. This report documents the activities carried out by APS Aviation Inc. (APS) on behalf of TC in preparation and support of the Phase 2 tests. A separate report produced and issued by the FAA provides the analysis of the actual test results.

APS was given several objectives to meet in support of the Phase 2 tests, including:

- Create residual ice samples of required areas (315 cm^2 and 1295 cm^2), and required thicknesses (0.5 to 0.8 mm and 1.2 to 1.5 mm) at different locations on a JetStar wing;
- Develop a method for applying Type I fluid on an entire wing surface;

- Calibrate the degradation of ice thickness when Type I fluid is applied over the ice samples; and
- Provide support in the cold chamber during the conduct of human ice detection capability and GIDS performance comparison tests.

Preparation work and tests were conducted over three sessions to meet the objectives.

> **Pre-test Session**: In July 2005, APS carried out a series of tests to determine the feasibility of making ice samples on a wing using the ice-making procedure developed in Phase 1. Ice samples of different sizes and thicknesses were produced on different locations on the wing. APS also developed a fluid application method for the wing. Several modifications related to the thicknesses of the ice samples, the location of checkers and the location of the sensors were subsequently made to the procedure. During the pre-test session the ice sample preparation and fluid application methods were confirmed and a demonstration was prepared for the Human Factors group.
>
> **Setup Session**: In August 2005, APS carried out a setup session in order to finalize the chamber layout for the comparison tests. A series of dry runs was also completed in preparation for the comparison tests.
>
> **Comparison Tests Session**: In August 2005, comparison tests of human ice detection capabilities and GIDS performance were carried out. APS personnel provided support throughout the test session including chamber layout design, locating the wing in the chamber, ice-making on the wing, fluid application, wing decontamination, communication with chamber facility personnel, and all aspects of logistics and test area management.

APS supported Phase 2 of the study by meeting all of the project objectives.

The conclusions from the tests comparing human ice detection capabilities and GIDS performance are presented in a related report produced and issued by the FAA.

SOMMAIRE

À l'heure actuelle, après les opérations de dégivrage avant le vol, des membres de l'équipe de dégivrage vérifient la présence de givre résiduel sur les ailes de l'avion. La plupart du temps, ces vérifications sont faites visuellement, mais il arrive que des inspections tactiles soient nécessaires après le dégivrage de certains types d'avions au bord d'attaque fixe ou d'avions dont on soupçonne les ailes d'être imprégnées de froid. Les inspections tactiles 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. Pour toutes ces raisons, des solutions de rechange sont recherchées.

En collaboration avec la Direction de la sécurité en vol (le William J. Hughes Technical Center) du Bureau de recherche en aéronautique de la Federal Aviation Administration (FAA), le Centre de développement des transports (CDT) de Transports Canada (TC) a mené une étude qui visait à comparer les capacités de l'être humain et celles d'un système de détection du givrage au sol (GIDS, Ground Ice Detection System), après le dégivrage de l'avion. Les GIDS sont des nouvelles technologies conçues pour aider les vérificateurs de givre dans leurs tâches. Cette étude était la deuxième phase d'un projet en deux phases lancé par le groupe de travail sur l'approbation réglementaire (RAWG) des GIDS du sous-comité de détection du givrage G-12 de la Society of Automotive Engineers.

La première phase du projet a consisté à mesurer les capacités visuelles et tactiles humaines, pour avoir un critère en regard duquel évaluer d'autres méthodes de détection de givre. L'objectif principal de la phase 1 était donc d'évaluer la capacité des vérificateurs humains à détecter du givre. Cette phase a eu lieu en avril 2005 et elle est documentée dans des rapports distincts, produits par TC et la FAA.

L'objectif principal de la phase 2 était d'évaluer les capacités de détection de givre des GIDS par rapport aux capacités de détection visuelle et tactile, dans des conditions identiques, après les opérations de dégivrage. Ces essais ont eu lieu en août 2005 et mettaient en jeu des GIDS fournis par MDA Robotics (MDA) et Goodrich Aerospace. Le présent rapport rend compte des activités menées par APS Aviation Inc. (APS) au nom de Transports Canada pour préparer et appuyer les essais de la phase 2. Un rapport distinct, préparé et publié par la FAA, fait l'analyse des résultats des essais comme tels.

APS s'était vu fixer plusieurs objectifs pour appuyer les essais de la phase 2, dont les suivants :

- préparer des éprouvettes de givre résiduel répondant à des exigences précises quant à la superficie (315 cm² et 1295 cm²) et à l'épaisseur (0,5 à 0,8 mm et 1,2 à 1,5 mm), à différents endroits sur une aile de JetStar;
- élaborer une méthode pour appliquer un liquide de type I sur toute la surface de l'aile;
- mesurer l'amincissement de la couche de givre par suite de l'application du liquide de type I;
- être présent dans la chambre froide pour appuyer les essais de comparaison des capacités humaines de détection de givre et des performances des GIDS.

Les travaux préparatoires et les essais comme tels ont dû être étalés sur trois séances pour que les objectifs soient atteints.

Séance d'essais préliminaires : En juillet 2005, APS a mené une série d'essais pour déterminer s'il était possible de préparer des éprouvettes de givre sur une aile en recourant à la même procédure qui avait été élaborée pour la phase 1. Des éprouvettes de givre de différentes superficies et épaisseurs ont été produites à différents endroits sur l'aile. APS a aussi élaboré une méthode d'application du liquide sur l'aile. Plusieurs modifications relatives à l'épaisseur des éprouvettes de givre, au point d'observation des vérificateurs et à l'emplacement des capteurs ont ensuite été apportées à la procédure. Cette même séance a permis de valider les méthodes de préparation des éprouvettes de givre et d'application du liquide, et d'en faire une démonstration au groupe des facteurs humains du Hughes Technical Center.

Séance de mise au point : En août 2005, le personnel d'APS a organisé une séance de mise au point, au cours de laquelle il a finalisé l'aménagement de la chambre froide en vue des essais comparatifs. Des répétitions ont aussi eu lieu en prévision des essais.

Séance d'essais comparatifs : En août 2005, les essais de comparaison des capacités humaines de détection de givre et des performances des GIDS ont été réalisés. Le personnel d'APS a participé à toutes les étapes des essais, notamment à l'aménagement de la chambre froide, au positionnement de l'aile dans la chambre, à la fabrication de givre sur l'aile, à l'application du liquide de dégivrage, à la décontamination de l'aile, 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.

APS a appuyé la phase 2 de l'étude en atteignant tous les objectifs assignés au projet.

Les conclusions des essais de comparaison des capacités humaines de détection de givre et des performances des GIDS sont présentées dans un rapport connexe préparé et publié par la FAA.

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GLOSSARY

APS	APS Aviation Inc.
EG	Ethylene Glycol
FAA	Federal Aviation Administration
GIDS	Ground Ice Detection System
MDA	MDA Robotics
NRC	National Research Council Canada
PMG	PMG Technologies Inc.
RAWG	Regulatory Approval Working Group
SAE	Society of Automotive Engineers
TC	Transport Canada
TDC	Transportation Development Centre

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1. GENERAL

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

Over the past several years, the Transportation Development Centre (TDC) of Transport Canada (TC) has managed and conducted de/anti-icing related tests at various sites in Canada. It has also co-ordinated 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), the National Research Council (NRC), Atmospheric Environment Services, several major airlines, and deicing fluid manufacturers. The TDC is continuing its research, development, testing and evaluation program.

In collaboration with the FAA Office of Aviation Research, Flight Safety Branch (William J. Hughes Technical Center), TC is conducting a study to compare human ice detection capabilities and ground ice detection systems (GIDS) performance under aircraft post-deicing conditions. This study will help evaluate new systems and equipment used to detect ice, such as GIDS. GIDS are new technologies that are being developed to assist ice checkers in performing their duties. Under the auspices of the Society of Automotive Engineers (SAE) G-12 Ice Detection Sub-Committee, a GIDS Regulatory Approval Working Group (RAWG) was formed to find ways to meet this objective.

The RAWG conceived a project plan that was implemented in 2 phases. Phase 1 was completed in April 2005. Two reports, one written by APS Aviation Inc. (APS) for TC and one written by the FAA, cover the first phase of the program:

- APS: Development of Ice Samples for Visual and Tactile Ice Detection Capability Tests, TP 14449E (1)
- FAA: Human Visual and Tactile Ice Detection Capabilities Under Aircraft Post-Deicing Conditions, DOT/FAA/TC-06/21 (2)

Two reports have also been produced for Phase 2, which focussed on the comparison of human and sensor ice detection capabilities. This report, written by APS, documents the activities carried out by APS in preparation for and support of the tests. A second report, produced and issued by the FAA, gives actual conclusions from the comparison tests. That FAA report is entitled, Comparison of Human Ice Detection Capabilities and Ground Ice Detection System Performance Under Post Deicing Conditions, DOT/FAA/TC-06/20 (3).

1.1 Background

Currently, individuals from ground deicing crews check for the presence of residual ice on aircraft wings following ground deicing. The presence of ice on a wing is visually checked in most circumstances. Tactile inspections may be required following deicing of certain types of “hard wing” aircraft, or for aircraft where cold soaking may be an issue. Some cases 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 wings are to be replaced by other methods, human visual and tactile capabilities must be measured to serve as a standard against which other methods can be evaluated.

Phase 1 of this study was conducted in April 2005. The research method involved a procedure in which two samples were presented to test participants, who were then asked to indicate on which of the two samples ice was detectable. APS provided project support throughout the experimental sessions of Phase 1, including chamber layout design, making ice samples and placing them on a “Lazy Susan”, cleaning and replacing ice samples, communicating with chamber facility personnel, and general logistics and test area management. During these sessions, APS developed a reliable ice-making procedure that addressed all essential test variables and produced reproducible results in terms of ice characteristics.

The Phase 1 experimental session led to several conclusions. First, when visually inspecting white surfaces from a fixed position, post deicing, human checkers can fail to spot fluid covered ice if it is less than or equal to 0.8 mm thick. Second, checkers are likely to detect post-deicing fluid-covered ice that is greater than or equal to 0.5 mm thick with a tactile check when inspecting a precise area. Third, ice of any thickness can be visually detected on aluminum surfaces.

1.2 Objectives

The objective of Phase 2 was to compare human visual and tactile ice detection capabilities with GIDS performance in identical post-deicing conditions. The FAA and TC carried out these tests in August 2005.

In Phase 2, GIDS designers were able to benchmark their device capabilities against human performance. The Phase 2 experimental session was conducted by collecting data from both human checkers and GIDS under identical conditions and comparing their ice detection performance. MDA Robotics and Goodrich Aerospace each provided GIDS for testing.

The TC work statement for this project can be found in Appendix A. APS supported Phase 2 of the study by meeting the following objectives given in the work statement:

- Create ice samples of different sizes and thicknesses at different locations on a JetStar wing;
- Develop a method for applying Type I fluid on an entire wing surface;
- Calibrate the degradation of ice thickness when Type I fluid is applied over the ice samples; and
- Provide support in the cold chamber during the conduct of human ice detection capability and GIDS performance comparison tests.

1.3 Report Format

This report is divided into four sections. Section 2 describes the methodology followed during the conduct of the test sessions, presents the test schedule and describes the equipment used. Section 3 describes the process followed by APS in making ice samples on the wing, applying fluid and measuring ice sample thicknesses. It analyzes the findings of this work and also describes the tests conducted during the comparison tests session. Section 4 gives conclusions as to how the project objectives were met.

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2. METHODOLOGY

This section describes the test conditions and experimental methodologies followed during the conduct of the pre-test, setup and test sessions. It also describes the test schedules and the equipment and personnel requirements.

2.1 Test Schedules

Phase 2 activities were carried out at the PMG Technologies Inc. (PMG) cold chamber. Three chamber sessions were required:

- **Pre-test session** – July 2005
- **Setup session** – August 2005
- **Comparison tests session** – August 2005

These session designations will be used throughout this report to distinguish between the three sessions.

The pre-test session was scheduled for July 12-14 and 18-21, 2005. During this session APS determined the best technique for making ice samples on an aircraft wing. This included the manufacturing of a mask to make ice samples and practicing the development of circular (315 cm^2 and 1295 cm^2) and semi-circular ice samples at the required thicknesses (0.5 to 0.8 mm and 1.2 to 1.5 mm). In addition, the session involved timing each test process, recording the wing and chamber cooling time, measuring the wing's temperature, developing a method for fluid application, measuring the ice thickness before and after fluid application, and decontaminating the wing. The schedule for the pre-test session is shown in Figure 2.1.

In August, four days were scheduled for the setup session (August 23-25 and 29, 2005) and four days for the comparison tests session (August 30 – September 2, 2005), which included one day for dismantling (September 2). The schedule for the pre-test and comparison tests sessions is shown in Figure 2.2.

2.2 Description of Test Procedure

APS developed a method of making ice samples of various sizes and thicknesses on various locations on a JetStar wing. These ice samples were subsequently used in the comparison tests. After evaluating several methods of making ice samples on the wing, APS selected a final ice-making procedure, which was based on the ice-making procedure developed for Phase 1.

JULY						2005
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
					1	**2**
3	**4**	**5**	**6**	**7**	**8**	**9**
10	**11**	**12** APS (Pre-pre test) Wing setup Scaffold setup Platform setup 20°C	**13** APS (Pre- pre test) Ice sample practiced. Speed recorded. Wing and chamber cool time measured. Fluid application method developed. Mask for ice samples conceived. -5°C	**14** APS (Pre- pre test) Highly contaminated wing practiced. Wing and chamber cool time measured. Ice thickness measured. Test simulation with APS personnel was conducted. -5°C	**15**	**16**
17	**18** FAA (Pre-test) Sensor setup. Wing cleaned. Fluid prepared for next day. 20°C	**19** FAA (Pre-test) Sensor setup. AeroMag Sensor training. Dry run triple sample. Ice thickness measured. Lighting verified. -5°C	**20** FAA (Pre-test) Dry run multiple and triple sample. Ice thickness measured. Wing and chamber cool time measured. -5°C	**21** FAA (Pre-test) Spare day to change sensors position Equipment dismantle and stored at PMG -5°C	**22**	**23**
24	**25**	**26**	**27**	**28**	**29**	**30**

Figure 2.1: Pre-test Session Schedule (PMG, July 2005)

AUGUST						2005
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
31	**1**	**2**	**3**	**4**	**5**	**6**
7	**8**	**9**	**10**	**11**	**12**	**13**
14	**15**	**16**	**17**	**18**	**19**	**20**
21	**22**	**23** APS & FAA (Setup) Wing setup Scaffold setup GIDS setup Scissor lift positioned 20°C	**24** FAA (Setup) Sensor training and dry run (two ice samples). Wing and chamber cool time measured. Ice thickness measured. Lighting verified. -5°C	**25** FAA (Setup) Dry run (multiple and triple sample) full test day with WG & Globe Ground. Wing and chamber cool time measured. Ice thickness measured. -5°C	**26**	**27**
28	**29** FAA (Setup) Sensor training and dry run (four ice samples) with AeroMag and Globeground. Wing and chamber cool time measured. Ice thickness measured. -5°C	**30** FAA (Test) Test day 1 Multiple contamination, clear wing and low contamination test. Wing and chamber cool time measured. Ice thickness measured. -5°C	**31** FAA (Test) Test day 2 Multiple contamination, low contamination and clear wing test. Wing and chamber cool time measured. Ice thickness measured. -5°C	**1** FAA (Test) Test day 3 Multiple contamination, low contamination and clear wing test. Wing and chamber cool time measured. Ice thickness measured. -5°C	**2** APS Equipment dismantled, packed and stored at the test site. 20°C	**3**

Figure 2.2: Setup Session and Comparison Tests Session Schedule (PMG, August 2005)

The ice-making procedure developed by APS provides very detailed information with respect to the initial preparations of the test plates used in Phase 1, initial fluid preparation and the actual ice-making procedure (see TC report TP 14449E (1)). It also specifies the equipment required for each step of the process. The Phase 2 procedure is included in Appendix B.

2.3 Equipment

APS used various pieces of equipment for the tests. The main items employed are described below.

2.3.1 JetStar Wing

A Lockheed JetStar wing was used during testing (Photo 2.1). The design characteristics of the JetStar wing are as follows:

- Wing section NACA 63A112 at the wing root;
- Wing section NACA 63A309 (modified at the wing tip);
- Wing chord of 4.16 m at the wing root (13 ft. 7¾ in.);
- Wing chord of 1.55 m at the wing tip (5 ft. 1 in.);
- Incidence of 1° at the wing root and -1° at the wing tip;
- 2° dihedral;
- Sweepback 30° at quarter-chord;
- Conventional fail-safe stressed-skin structure of high-strength aluminum; and
- Aluminum alloy aileron, double-slotted all metal trailing edge flap, hinged leading edge slat, no spoilers.

All aerodynamic control surfaces were retracted.

Figure 2.3 illustrates the bare aluminum alloy surface of the wing. Different improvements have been made to the wing, as reported in the TC report TP 13829E, Modification of Test Wing to Accommodate Fuel Load Effects for Deicing Research 2001 (4).

Under normal test circumstances, the test wing is half filled with glycol (to represent a fuel load) so that the thermal characteristics of the wing are representative of normal operations. The glycol was removed from the wing for these tests since their objective was such that the upper surface temperature needed to be below 0°C.

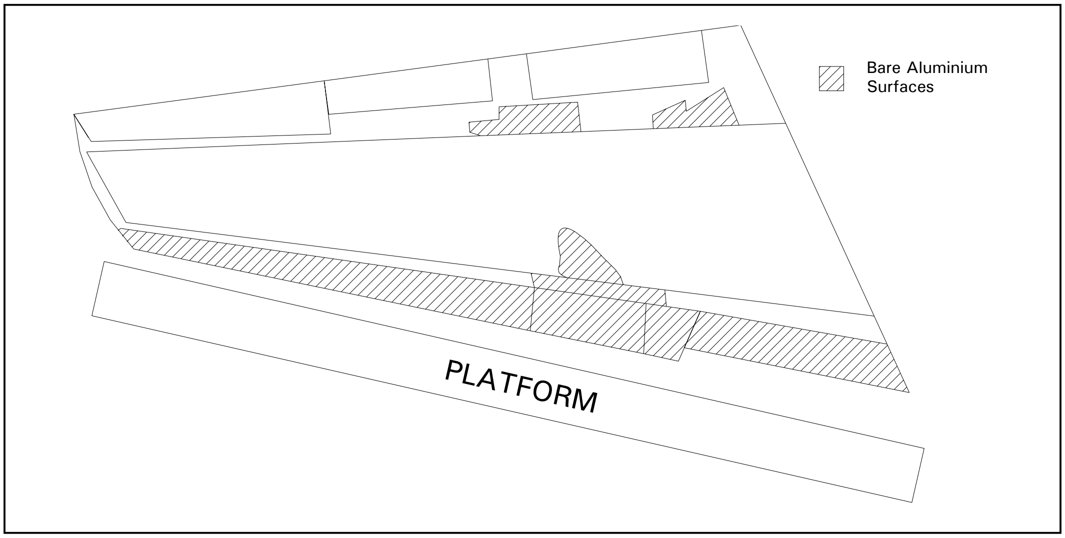

Figure 2.3: JetStar Wing with Bare Aluminum Alloy Surface

2.3.2 Mask

A mask was placed on the wing to develop ice at the specified areas. The mask was made out of a synthetic carpet (olefin fibre with woven polypropylene at the back) and cut to the same dimensions as the wing's surface. Circles of either 315 cm² or 1295 cm² were cut in the synthetic carpet to allow the making of ice samples on the wing (Photo 2.2).

2.3.3 Thickness Gauge

A thickness gauge was used to measure the thickness of the ice samples on the wing (Photo 2.3). The gauges used were modified to reduce the number of markings made in the ice. As per the instructions specified on the gauge, the true thickness measurement lies between the last tooth that leaves a mark on the ice and the following tooth. As a result, the values recorded by visual observation have to be corrected to determine the actual thickness measured. All of the thickness measurements taken by APS during the test sessions were corrected accordingly.

2.3.4 Test Fluid

The fluid used in the comparison of human ice detection and GIDS performance tests was UCAR Ethylene Glycol (EG) ADF, diluted to a Brix[1] of 11° (freezing point of approximately -7°C). The neat fluid was provided by AeroMag 2000 and was diluted and dispensed by APS personnel. At a Brix of 11°, the freezing point of the fluid was about 2°C below the -5°C temperature of the cold chamber. The fluid Brix was measured with a Misco refractometer.

2.3.5 Fluid Sprayers

The pre-mixed fluid was maintained at a temperature of -5°C and applied to the wing using a sprayer. The fluid sprayer used was a polyethylene tank with a plastic extension control valve with a brass flat nozzle cap, a wand and a brass nozzle. The sprayer was manually operated and is shown in Photo 2.4. The fluid quantity sprayed was 9 litres (2 gal.).

2.3.6 Spray Gun and Compressor

The ice samples were made by spraying water onto the cold-soaked surface of the wing. Water was sprayed onto the wing using a spray gun attached to a compressor.

Parameters such as water temperature, spray distance and compressor output pressure were controlled throughout the spraying process. In order to limit heat exchange with the cold chamber and to maintain the water temperature within assigned tolerances, the spray gun was insulated, as shown in Photo 2.5.

2.3.7 Freezer

As the chamber was cooled during testing hours only, the fluid was pre-mixed a day in advance and maintained at subzero temperatures by storing it in a freezer overnight. The freezer temperature was below -5°C. The fluid was taken out the following day and warmed up to the test temperature prior to being used for testing.

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

2.3.8 Other Items

Miscellaneous items used included racks, measuring cups, spatula, fluid temperature probe, surface temperature probe (Photo 2.6), and a temperature and relative humidity data logger.

2.4 Data Forms

The data form used by APS during the pre-test session is presented in Figure 2.4. As observed in the data form, two thickness measurements were taken for each target thickness: one prior to fluid application (dry thickness) and one at the end of testing (wet thickness). An analysis of the initial and final thicknesses measured during the pre-test session is presented in Section 3.2.

The data form used during the pre-test session was modified for the setup and comparison tests sessions. The data form used for the setup and comparison tests sessions is presented in Figure 2.5. As observed in the data form, six thickness measurements were taken for each target thickness – three per sample prior to fluid application (dry thickness) and three per sample at the end of testing (wet thickness). Analyses of the average initial and average final thicknesses measured during the setup and comparison tests sessions are presented in Sections 3.3 and 3.4, respectively.

2.5 Personnel

Four APS personnel were required to conduct these tests. One person managed the production of ice samples, one person assisted the ice-making manager, one person was in charge of logistics and the fourth person supported and coordinated the tests.

During the pre-test session, the Human Factors group and personnel from AeroMag 2000 provided direction in testing and participated as observers.

Ice Samples	Target Thickness (mm)	Dry Thickness (mm)	Wet Thickness (mm)	Comments

Comments: ____

____

____

____

____

Figure 2.4: Data Form for Pre-Test Sessions

Date:

Ice Samples	Target Thickness (mm)	Dry Thickness (mm)			Average Dry Thickness (mm)	Wet Thickness (mm)			Average Wet Thickness (mm)	Delta Average Dry & Average Wet (mm)
Average										
STDEV										

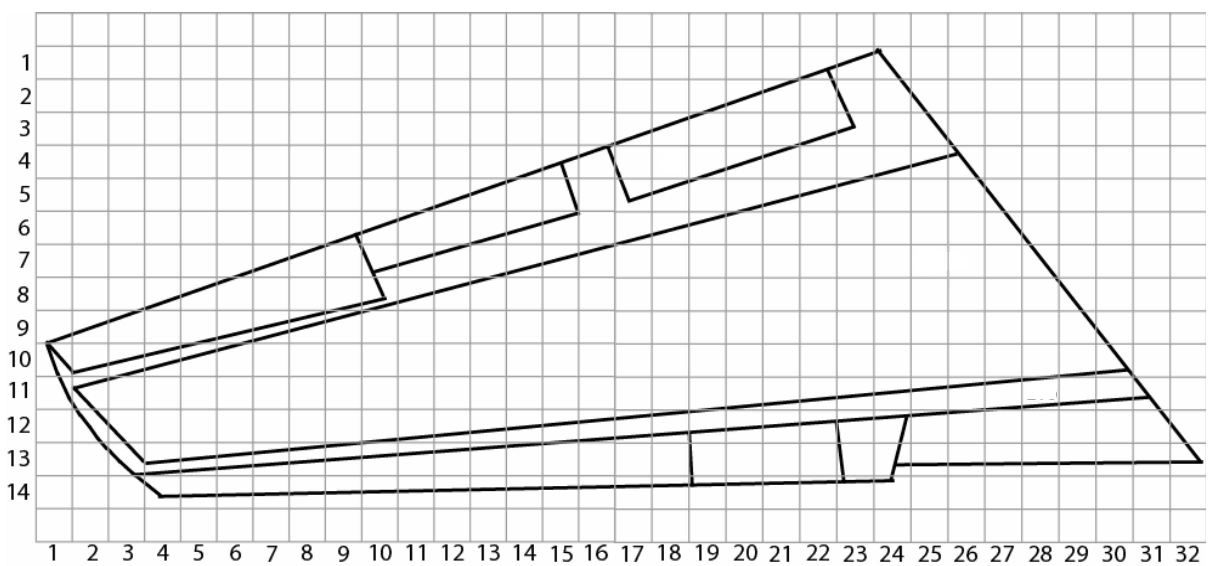

Figure 2.5: Data Form for Setup and Test Sessions

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Photo 2.1: JetStar Wing

Photo 2.2: Mask Placed on Wing for Ice Patch Making

Photo 2.3: Thickness Gauge

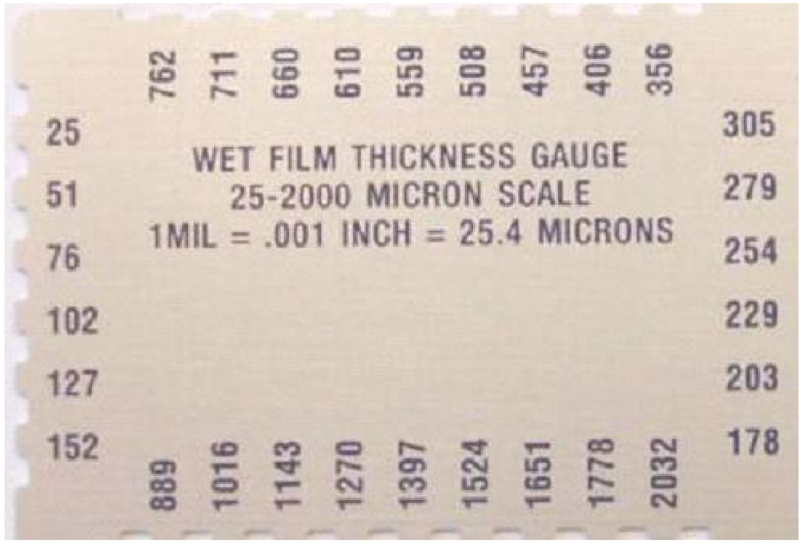

Photo 2.4: Fluid Sprayer

Photo 2.5: Insulated Spray Gun

Photo 2.6: Surface Temperature Probe

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3. DATA COLLECTED

3.1 Overview of Tests

In Phase 2, APS conducted tests in preparation for and in support of the comparison of human ice detection and GIDS performance tests. This work was carried out in each of the three sessions:

1. **Pre-test session**: In July 2005, APS carried out a series of tests to determine the feasibility of making ice samples on the JetStar wing using the ice-making procedure developed in Phase 1. Ice samples of different sizes and thicknesses were produced on different locations on the wing. APS also developed a fluid application method for the wing. Several modifications were subsequently made to the procedure. These related to the thicknesses of the ice samples, the location of checkers and the location of the sensors. During the pre-test session, the ice sample preparation and fluid application methods were confirmed and a demonstration was prepared for the Human Factors group;

2. **Setup session**: In August 2005, APS carried out a setup session in order to finalize the chamber layout for the comparison tests. The team also carried out dry runs in preparation for the comparison tests;

3. **Comparison tests session**: In August 2005, comparison tests of human ice detection capabilities and GIDS performance were carried out. APS personnel provided support throughout the test session including chamber layout design, locating the wing in the chamber, ice making on the wing, fluid application, wing decontamination, communication with chamber facility personnel, and all aspects of logistics and test area management.

Subsections 3.2, 3.3 and 3.4 describe the data collected during each of the sessions.

3.2 Pre-Test Session

In July 2005, APS conducted pre-tests in the PMG cold chamber. The pre-test session took place according to the schedule presented in Figure 2.1. During the pre-test session, APS personnel concentrated on making ice samples on the JetStar wing, developing a method to apply fluid, and decontaminating the wing in preparation for subsequent tests. The knowledge gained during the Phase 1 experimental session served as a starting point for the pre-test session of Phase 2.

3.2.1 Chamber Setup

The layout of the chamber during the pre-test session is presented in Figure 3.1. The cold chamber measurements were 16.5 m x 6.6 m x 4 m (l x w x h). The JetStar wing was mounted 1.2 m from the floor. The sensor displays were placed outside the chamber. A viewing platform was erected next to the wing (leading edge side), as shown in Photo 3.1. The viewing angle and distance for human visual checks were 45° and 2 m, respectively, looking at a point at mid-chord of the wing.

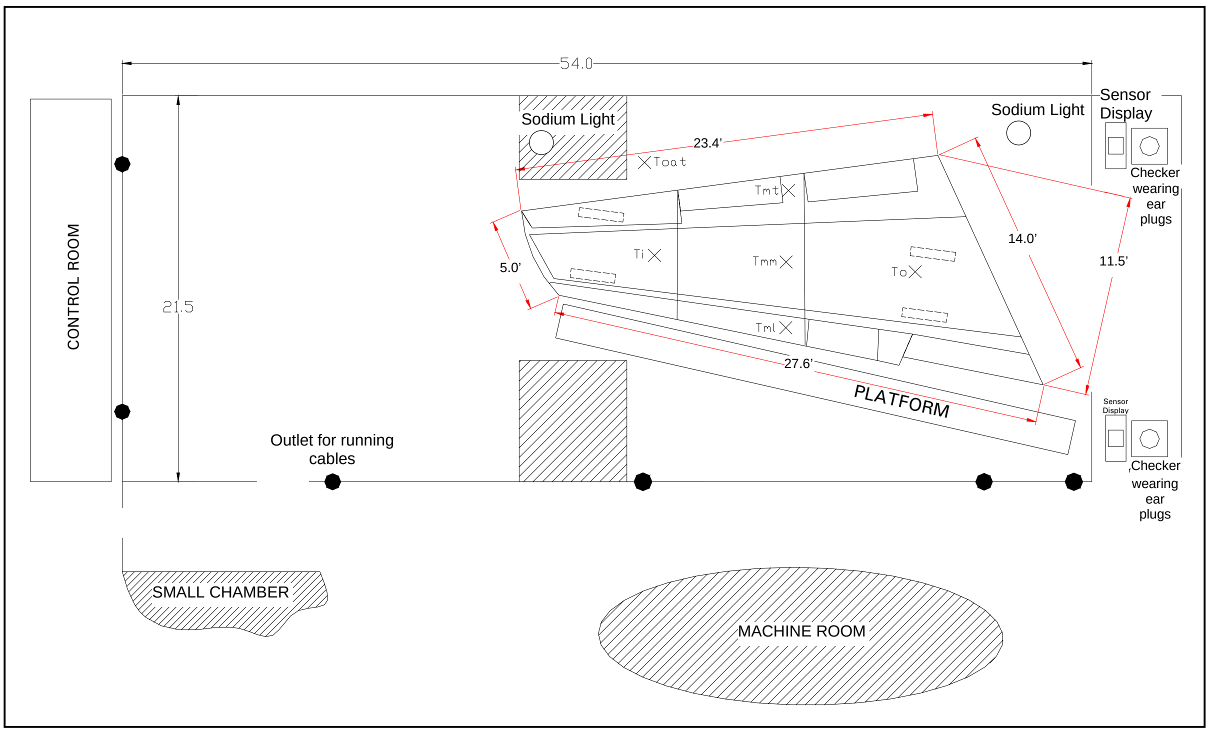


Figure 3.1: PMG Chamber Layout During Pre-Test Session

There were a total of eight sodium bulb lights in the chamber; four on each side. Of the eight sodium lights, only two diffused sodium bulbs (150 watt high pressure) were used to illuminate the chamber in order to reproduce the lighting used during the Phase 1 tests. AeroMag personnel felt that this illumination was representative of typical lighting conditions that can be found during normal deicing operations. The location of lights in the cold chamber is shown in Figure 3.1.

3.2.2 Chamber and Wing Cooling Times

The pricing for use of the cold chamber is mostly based upon whether the chamber is being cooled. In an attempt to minimize chamber changes, the cooling system was turned off after each day, and the temperature in the chamber was allowed to warm to the natural ambient temperatures.

Early in the morning the temperature in the chamber was set at -5°C (±0.5°C), consistent with the first phase of the project. The chamber and the wing cooling times were recorded. A surface temperature probe was used to measure the wing temperature. Three locations on the wing were measured: outboard, middle and inboard of the wing. The average wing temperature was then recorded. This made it possible to determine the time it took for the wing to cool below the water freezing point in order to start the process of making ice samples.

The wing and chamber cooling times were recorded on July 13, 14 and 19, 2005. The time recorded for the wing and chamber cooling times differed each day depending on the initial temperature of the chamber. Figures 3.2, 3.3 and 3.4 illustrate the wing and chamber cooling times for July 13, 14 and 19, 2005 respectively. For July 13 and July 19, 2005, Figure 3.2 and Figure 3.4 show that it took about 2 hours to reach 0°C; for July 14, 2005, it took less than 1 hour to reach 0°C, as the chamber had been cooled the day before.

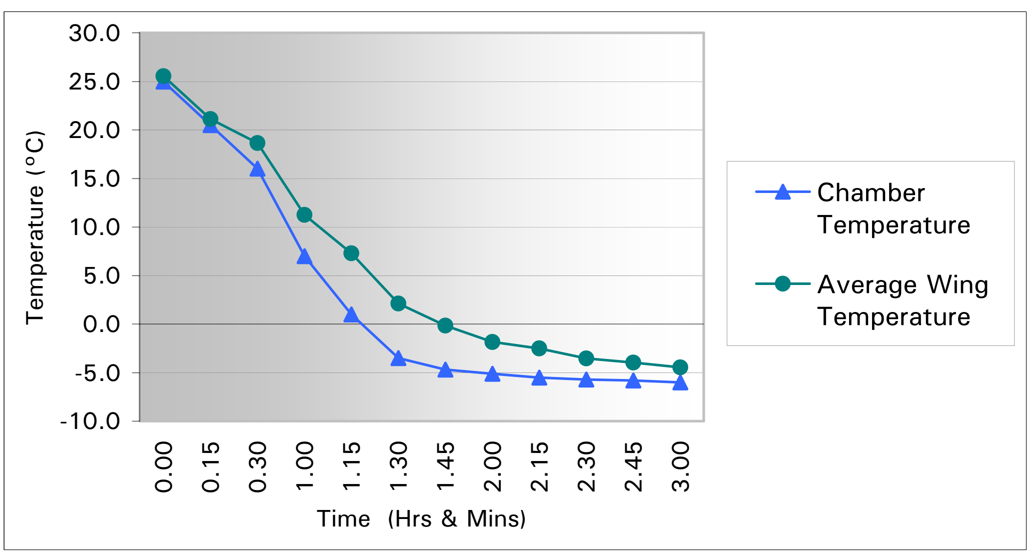


Figure 3.2: Wing and Chamber Cooling Times, July 13, 2005

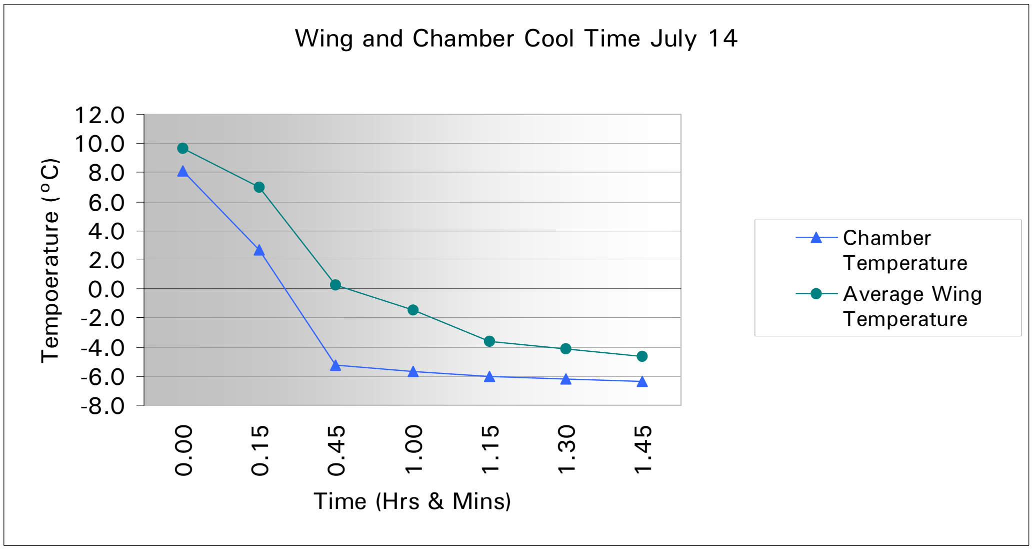


Figure 3.3: Wing and Chamber Cooling Times, July 14, 2005

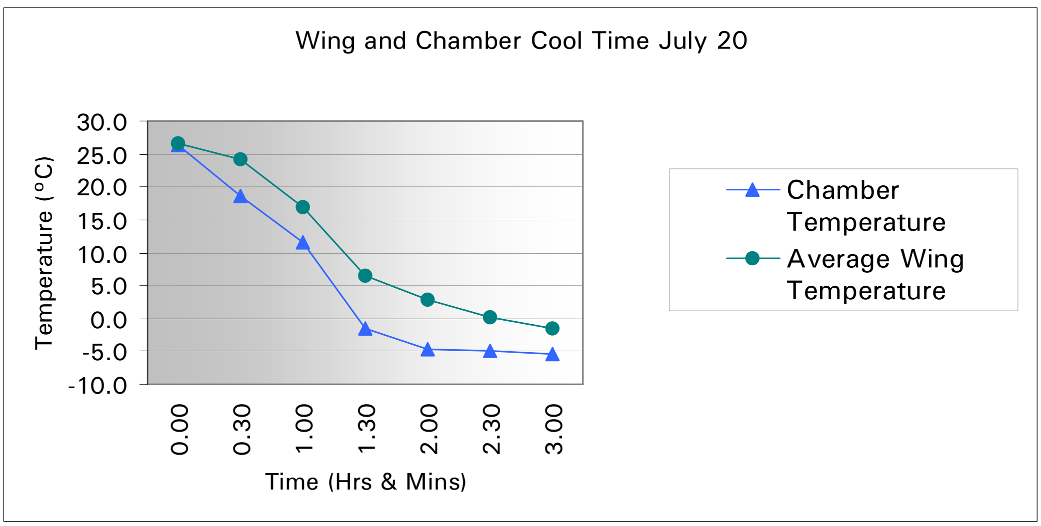


Figure 3.4: Wing and Chamber Cooling Times, July 19, 2005

3.2.3 Calibration

To satisfy human factor requirements for low and highly contaminated samples, calibration was carried out using two different ice sample thickness groups: 0.5 to 0.8 mm and 1.2 to 1.5 mm.

The synthetic carpet mask was cut into 3 sections (outboard, middle and inboard sections) and used to cover the wing. It was made of synthetic carpet to minimize the slipping hazard for test personnel. The mask covered the whole surface of the wing in order to prevent footprints on the wing and overspray when spraying distilled water onto the cold-soaked surface of the wing.

For the purpose of making ice samples, circles were cut in the mask in the appropriate location and size according to the FAA test plan. The circle sizes varied from 315 cm² (8'' in diameter) to 1295 cm² (16'' in diameter). The ice samples were created on the JetStar wing (Photo 3.2) by using the ice-making procedure. The wing area was cleaned with isopropyl alcohol prior to each ice sample being made.

After the ice samples were made, approximately 8 litres of fluid were applied to the entire wing surface using a sprayer (Photo 3.3). This method provided a quick and even fluid distribution, as the pressure was easily adjustable. A fluid retainer (polypropylene tarpaulin) was placed under the wing to prevent outflows.

As was established in the Phase 1 session and evaluated in the Phase 2 pre-test session, the glycol concentration gradient in the fluid melted the ice somewhat over time. A more concentrated fluid produced more ice melting when compared to a fluid that had a freeze point just below the test temperature. The calibration process finalized in Phase 1 indicated that the ideal fluid concentration was a Brix of 11° (freezing point of -7°C). As a result, the tests were conducted using a fluid with a Brix of 11°.

As discussed previously, the thickness of the ice samples varied from 0.5 to 0.8 mm and 1.2 to 1.5 mm. Once the ice samples were made, fluid was applied to simulate post-deicing conditions. After fluid application, the thickness of the ice samples was reduced. Therefore, to obtain the correct thickness value, the ice sample thickness had to be greater then the target thickness.

A rectangular thickness gauge was used to measure thickness. The thickness was measured before and after fluid application. The required dry thickness was calculated using a formula developed in Phase 1. Each calculated thickness (dry thickness) was then associated with the thickness gauge tooth closest to the calculated value, as shown in Table 3.1.

Table 3.1: Target and Dry Ice Sample Thicknesses

Target Thickness (mm)	Dry Thickness (mm)	Thickness Gauge Teeth (mm)
0.5 to 0.8	0.59 to 0.90	0.559 to 1.016
1.2 to 1.5	1.32 to 1.63	1.397 to 1.651

Twelve ice samples representing a highly contaminated wing were produced on July 13 and 20, 2005. Three ice samples representing a low contaminated wing were developed on July 13, 19 and 20, 2005. Dry ice thicknesses were measured prior to fluid application and wet ice thicknesses were measured 30 minutes after fluid application on July 13 and 19, 2005. On July 20, 2005 wet ice thicknesses were measured 30 minutes after fluid application for several of the low contamination samples and 160 minutes after fluid application for all of the ice samples. The thicknesses measured with the thickness gauge were corrected accordingly.

Table 3.2 presents the ice sample thickness measurements taken before and after fluid application during the pre-test session.

Table 3.2: Dry and Wet Ice Thickness Measurements during Pre-Test Session

Date	Ice Sample #*	Target Thickness (mm)	Dry Thickness (mm)	Wet Thickness (mm)	Delta Average Ice Thickness (mm)	Measurement Time After Fluid Application (minutes)
July 13, 05	1	0.5 - 0.8	0.6	0.5	0.1	30
July 13, 05	2	0.5 - 0.8	0.8	0.7	0.1	30
July 13, 05	3	0.5 - 0.8	0.6	0.6	0.0	30
July 13, 05	4	0.5 - 0.8	1.0	0.7	0.3	30
July 13, 05	5	0.5 - 0.8	0.7	0.7	0.0	30
July 13, 05	6	1.2 - 1.5	1.5	1.5	0.0	30
July 13, 05	7	1.2 - 1.5	1.7	1.5	0.2	30
July 13, 05	8	1.2 - 1.5	1.5	1.5	0.0	30
July 13, 05	9	1.2 - 1.5	1.5	1.3	0.2	30
July 13, 05	10	1.2 - 1.5	1.3	1.3	0.0	30
July 13, 05	11	1.2 - 1.5	1.3	1.3	0.0	30
July 13, 05	12	1.2 - 1.5	1.5	1.5	0.0	30
July 19,05	1	0.5 - 0.8	0.7	0.7	0.0	30
July 19,05	2	0.5 - 0.8	0.7	0.6	0.1	30
July 19,05	3	0.5 - 0.8	0.8	0.7	0.1	30
July 20,05	1	0.5 - 0.8	0.7	0.6	0.1	160
July 20,05	2	0.5 - 0.8	0.7	0.7	0.0	160
July 20,05	3	0.5 - 0.8	0.8	0.7	0.1	160
July 20,05	4	0.5 - 0.8	0.6	0.6	0.0	160
July 20,05	5	0.5 - 0.8	0.6	0.6	0.0	160
July 20,05	6	0.5 - 0.8	0.6	0.5	0.1	160
July 20,05	7	1.2 - 1.5	1.7	1.5	0.2	160
July 20,05	8	1.2 - 1.5	1.6	1.5	0.1	160
July 20,05	9	1.2 - 1.5	1.6	1.5	0.1	160
July 20,05	10	1.2 - 1.5	1.6	1.2	0.4	160
July 20,05	11	1.2 - 1.5	1.7	1.5	0.2	160
July 20,05	12	1.2 - 1.5	1.7	1.3	0.4	160
July 20,05	1	0.5 - 0.8	0.8	0.7	0.1	30
July 20,05	2	0.5 - 0.8	0.7	0.6	0.1	30
July 20,05	3	0.5 - 0.8	0.6	0.6	0.0	30
					Average: 0.10	
					STDEV: 0.11	

*In order of preparation

While some of the ice sample thicknesses remained unchanged 30 minutes after fluid application, most thicknesses were reduced; this thickness reduction was between 0.0 and 0.4 mm. The expectation from Phase 1 was that the reduction would be about 0.1 mm. The greater reduction was likely caused by an elevated amount of fluid accruing on the ice samples due to the inclination angles of the wing and to the location of the ice samples. There was a slightly higher degradation of ice thickness 160 minutes after fluid application; however, the ice thickness remained in target range. Figure 3.5 illustrates dry ice thickness vs. wet ice thickness 30 minutes after fluid application. Figure 3.6 illustrates dry ice thickness vs. wet ice thickness 160 minutes after fluid application.

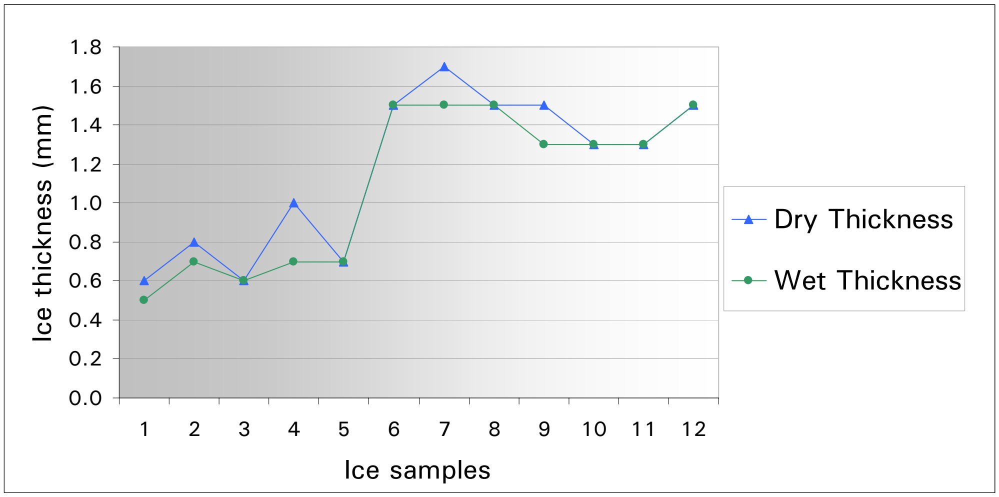


Figure 3.5: Dry Ice Thickness vs. Wet Ice Thickness 30 Minutes after Fluid Application, July 13, 2005

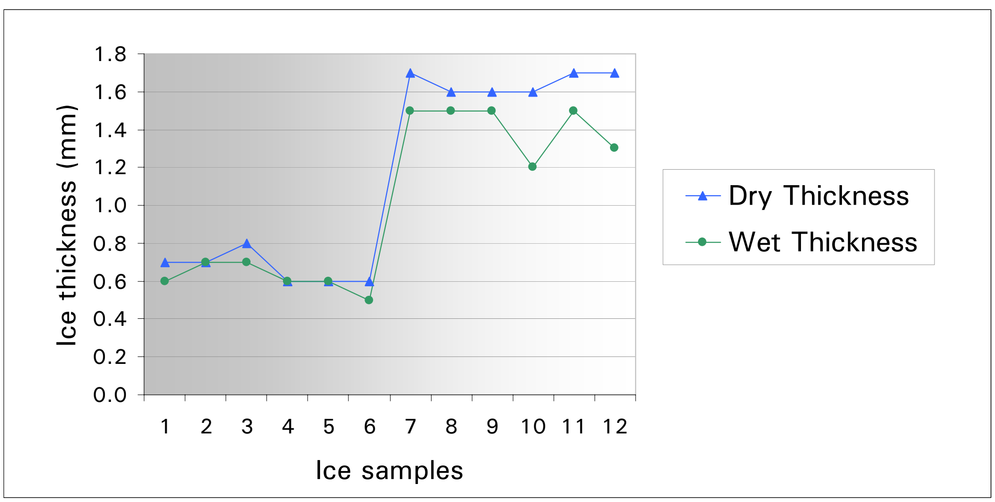


Figure 3.6: Dry Ice Thickness vs. Wet Ice Thickness 160 Minutes after Fluid Application, July 20, 2005

3.2.4 Decontamination

Decontamination of the wing was completed in several steps. First, the wing was cleared of ice by heating each ice sample with a heat gun. Next, the ice was scraped from the wing with an ice scraper. Then, the fluid and ice residue were cleared from the wing by using a squeegee. Finally, the remaining fluid was absorbed with paper towels (Photo 3.4).

3.2.5 Results

After analyzing the findings from the pre-test session, several minor adjustments were made to the original test procedure including modifying the ice sample thicknesses and changing the checker and sensor positions. The changes are discussed in detail in Subsection 3.3.1.

3.3 Setup Session

The setup session was carried out August 23, 24, 25 and 29, 2005. The first day was used for setting up the chamber and the three remaining days were used to conduct "dry runs" of ice sample production.

3.3.1 Procedure Changes

The ice-making procedure presented in Appendix B was used for the pre-test session. Changes were made to the initial procedure for the actual test session. All recommendations with respect to the chamber and test design made during the pre-test session were addressed during the actual test session:

- Similar to the pre-test session, the wing was placed in the cold chamber with two sensors mounted at approximately ceiling height (4 m). However, this time the wing was moved forward in the cold chamber and the test area for the ice checker was situated at a fixed position. The viewing platform for the ice checker was changed for a scissor lift placed next to the wing on the leading edge side (Photo 3.5). The distance for human visual checks was 2.1 m from the leading edge, placed near the outboard side of the wing.

- The sensors were also moved to different locations in the chamber to enhance their viewing angle (Photo 3.6). The sensor displays were placed outside of the chamber as shown in Photo 3.7 for the MDA GIDS display and Photo 3.8 for the Goodrich GIDS display.

The layout of the chamber during the test session is presented in Figure 3.7.

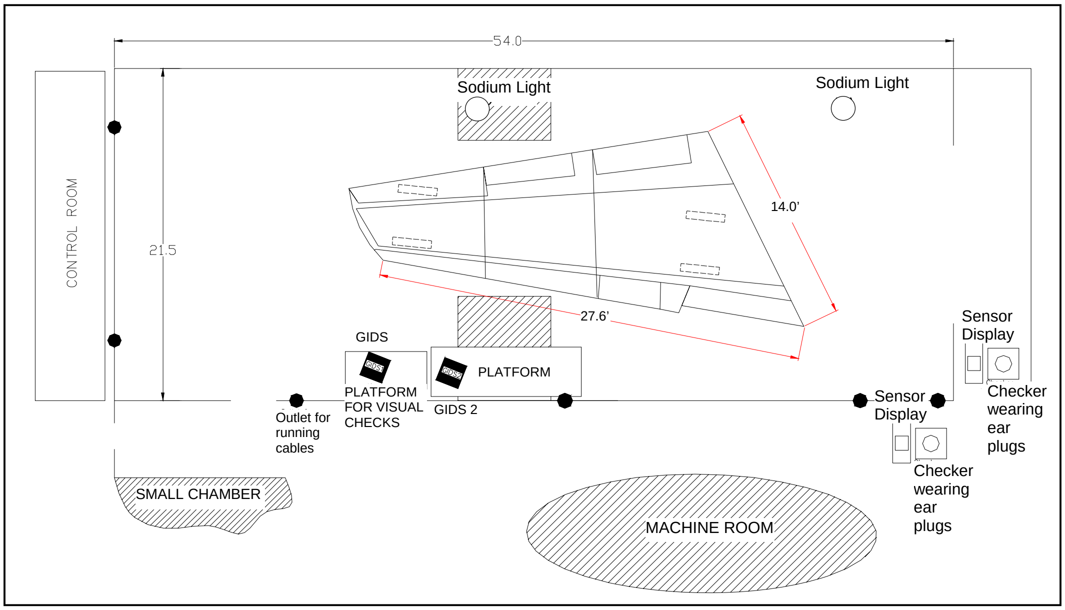


Figure 3.7: PMG Chamber Layout during Test Session

3.3.2 Chamber Conditions

The temperature in the chamber was -5°C (±0.5°C), the relative humidity was 90 percent (±5%) and the wind speed throughout the chamber was less than one metre per second. The wing and chamber cooling times were recorded each day.

As per the test schedule, the chamber was cooled to -5°C (±0.5°C) at 7 am during the setup sessions and at 6 am during the test sessions. If the chamber had been cooled the previous day, it would take approximately an hour to an hour and a half to cool the wing to 0°C. The appropriate wing temperature to start production of ice samples on the JetStar wing was -3°C.

3.3.3 Validation/Verification of Setup by AeroMag and Sensor Manufacturers

Based on the pre-test session in July 2005, AeroMag personnel were satisfied with the light intensity and position, as it was felt that it operationally represented dusk/dawn. The description of light intensity can be found in the

FAA report. AeroMag was also in agreement with the fixed position viewing platform located at the wing tip. Moreover, it was confirmed by AeroMag that the ice samples on the wing with fluid represented post-deicing conditions.

Despite chamber size restrictions, the GIDS personnel were satisfied with the positioning of the sensors and the setup of the sensor displays.

3.3.4 Dry Runs

Dry runs were conducted on August 24, 25 and 29, 2005. The following ice samples were produced:

- August 24: low contamination samples (2)
- August 25: high contamination samples (12)
- August 25: low contamination samples (3)
- August 29: contamination samples (4 ONLY) – Done from high contamination day

The average wet ice thickness was measured one hour after fluid application on each ice sample. The thickness measurements taken with the thickness gauge were corrected accordingly. Tables 3.3 to 3.6 present the ice sample thickness measurements taken before and after fluid application on August 24, 25 and 29, 2005.

Table 3.3: Low Contamination Ice Sample Thicknesses (August 24)

Ice Samples	Target Thickness (mm)	Dry Thickness (mm)		Average Dry Thickness (mm)	Wet Thickness (mm)		Average Wet Thickness (mm)	Delta Average Dry & Average Wet (mm)
1	0.6-0.8	0.686	0.686	**0.686**	0.533	0.686	**0.610**	0.077
2	0.3-0.5	0.533	0.584	**0.559**	0.483	0.533	**0.508**	0.051
Average								**0.064**
STDEV								**0.018**

Low Contamination Test Day 1 Diagram

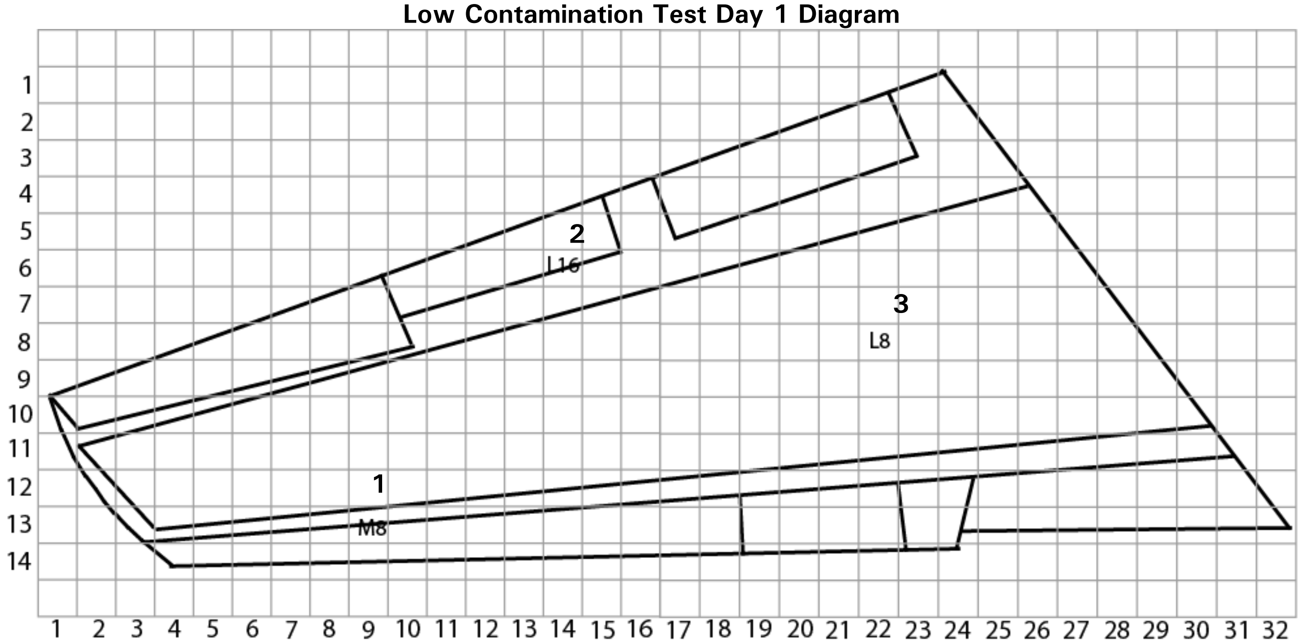


Table 3.4: High Contamination Ice Sample Thicknesses (August 25)

Ice Samples	Target Thick. (mm)	Dry Thickness (mm)			Average Dry Thick. (mm)	Wet Thickness (mm)			Average Wet Thick. (mm)	Delta Average Dry & Average Wet (mm)
1	0.6-0.8	0.737	0.686	0.737	**0.720**	0.737	0.686	0.737	**0.720**	0.000
2	0.3-0.5	0.533	0.584	0.584	**0.567**	0.445	0.533	0.533	**0.504**	0.063
3	0.3-0.5	0.584	0.635	0.533	**0.584**	0.483	0.533	0.483	**0.500**	0.084
4	0.3-0.5	0.584	0.483	0.533	**0.533**	0.483	0.533	0.483	**0.500**	0.034
5	0.6-0.8	0.737	0.737	0.737	**0.737**	0.737	0.737	0.737	**0.737**	0.000
6	0.6-0.8	0.826	0.737	0.826	**0.796**	0.826	0.826	0.711	**0.788**	0.009
7	0.6-0.8	0.737	0.737	0.737	**0.737**	0.686	0.686	0.635	**0.669**	0.068
8	0.3-0.5	0.533	0.533	0.483	**0.516**	0.533	0.483	0.381	**0.466**	0.051
9	0.6-0.8	0.826	0.826	0.826	**0.826**	0.635	0.686	0.737	**0.686**	0.140
10	0.3-0.5	0.533	0.533	0.635	**0.567**	0.483	0.483	0.533	**0.500**	0.067
11	0.3-0.5	0.533	0.635	0.483	**0.550**	0.533	0.483	0.483	**0.500**	0.051
12	0.6-0.8	0.737	0.826	0.826	**0.796**	0.737	0.826	0.737	**0.767**	0.030
Average										**0.050**
STDEV										**0.040**

High Contamination Test Day 2 Diagram

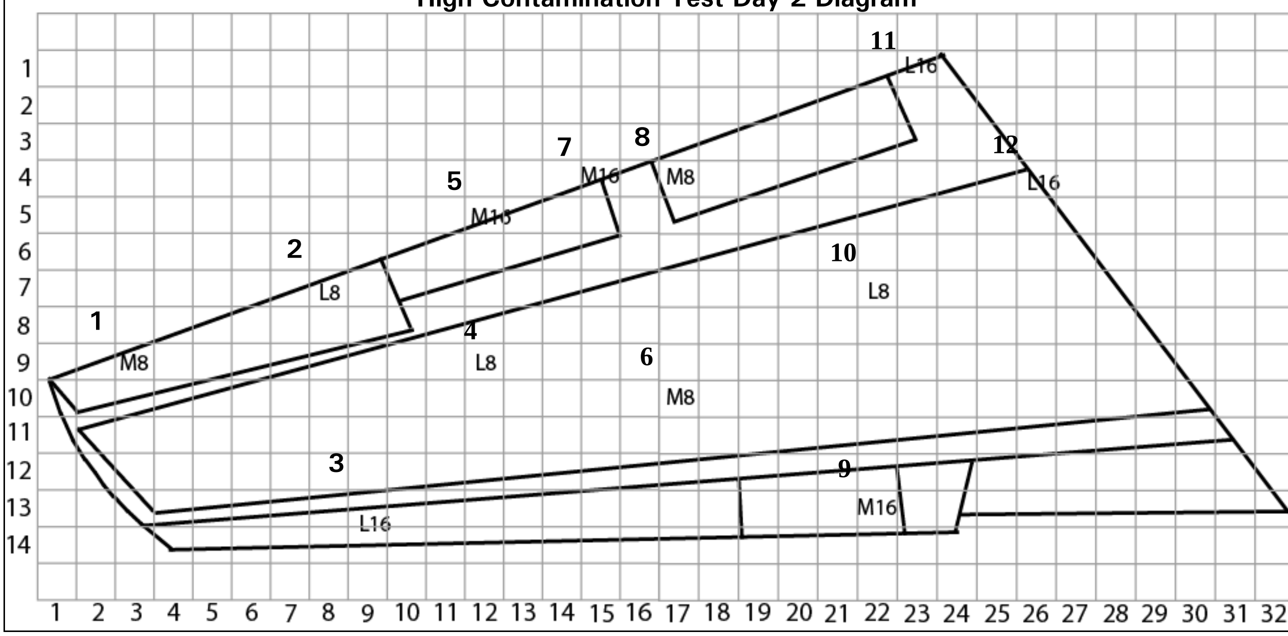
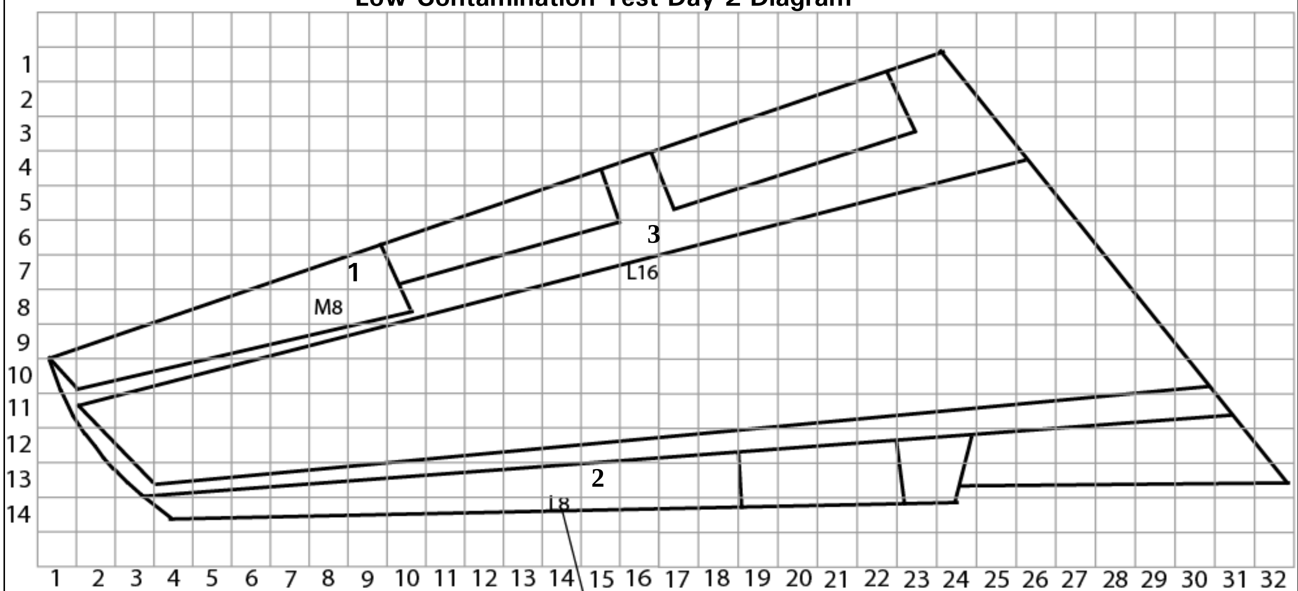


Table 3.5: Low Contamination Ice Sample Thicknesses (August 25)

Ice Samples	Target Thick. (mm)	Dry Thickness (mm)			Average Dry Thick. (mm)	Wet Thickness (mm)			Average Wet Thick. (mm)	Delta Average Dry & Average Wet (mm)
1	0.6-0.8	0.826	0.826	0.826	**0.826**	0.737	0.826	0.826	**0.796**	0.030
2	0.3-0.5	0.584	0.635	0.445	**0.555**	0.533	0.533	0.445	**0.504**	0.051
3	0.3-0.5	0.584	0.584	0.584	**0.584**	0.445	0.533	0.533	**0.504**	0.080
Average										**0.054**
STDEV										**0.025**

Low Contamination Test Day 2 Diagram

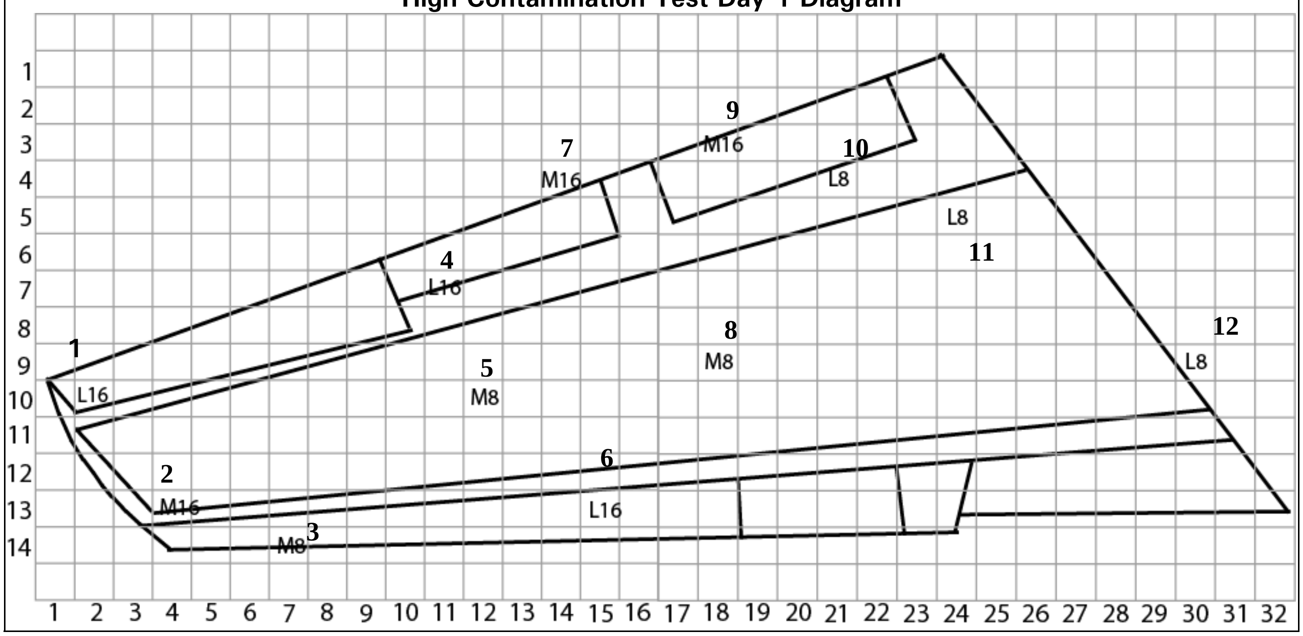


Half moon on edge & spill

Table 3.6: High Contamination Ice Sample Thicknesses (August 29)

Ice Samples	Target Thick. (mm)	Dry Thickness (mm)			Average Dry Thick. (mm)	Wet Thickness (mm)			Average Wet Thick. (mm)	Delta Average Dry & Average Wet (mm)
2	0.6-0.8	0.737	0.737	0.737	**0.737**	0.686	0.686	0.737	**0.703**	0.034
5	0.6-0.8	0.826	0.826	0.826	**0.826**	0.826	0.584	0.483	**0.631**	0.195
8	0.6-0.8	0.826	0.686	0.686	**0.733**	0.737	0.584	0.584	**0.635**	0.098
11	0.3-0.5	0.584	0.686	0.533	**0.601**	0.445	0.533	0.533	**0.504**	0.097
Average										**0.106**
STDEV										**0.066**

High Contamination Test Day 1 Diagram



Note: Four contamination samples done from high contamination day

3.3.5 Analysis of Ice Sample Thickness During Setup Session

The average ice thickness reduction obtained on August 24, 2005 was 0.064 mm (±0.018 mm) for the low contamination wing (see Table 3.3). On August 25 the average ice thickness reduction was 0.050 mm (±0.040 mm) for the high contamination wing and 0.049 mm (±0.019 mm) for the low contamination wing (see Tables 3.4 and 3.5). Finally, on August 29, the average ice thickness reduction reached 0.106 mm (±0.066 mm) for the low contamination wing (see Table 3.6).

The ice thickness reduction observed during the setup session was less than that obtained during the pre-test session. The precision of ice sample measurements was greater during the setup session in comparison with the pre-test session, as three ice measurements were taken during the setup session compared to only one during the pre-test session. This could explain the difference in ice thickness reduction between the pre-test and setup sessions.

3.4 Comparison Tests Session

The comparison tests session took place August 30 to September 2, 2005 according to the schedule presented in Figure 2.2.

3.4.1 Ice Samples

The ice thickness ranges were modified following the pre-test session. The ice thicknesses were either low (L): 0.3 to 0.5 mm, or moderate (M): 0.6 to 0.8 mm. The sizes of ice samples remained unchanged; they were 315 cm² and 1295 cm². Table 3.7 illustrates the four ice sample combinations.

Table 3.7: Ice Sample Combinations

Type of Ice Sample	Thickness (mm)	Size (cm²)
1 (L8)	0.3 to 0.5	315
2 (M8)	0.6 to 0.8	315
3 (L16)	0.3 to 0.5	1295
4 (M16)	0.6 to 0.8	1295

As discussed previously, after the application of fluid, the ice sample thickness was reduced. During the pre-test session, this average thickness reduction was 0.10 mm (±0.11 mm). Therefore, to obtain the right thickness value, the ice sample thickness had to be greater than the target thickness by 0.10 mm. The average ice thickness was measured before and after fluid application. Each calculated thickness (dry thickness) was then associated with the thickness gauge tooth closest to the calculated value, as shown in Table 3.8.

Table 3.8: Target and Dry Ice Sample Thicknesses

Target Thickness (mm)	Dry Thickness (mm)	Thickness Gauge Teeth (mm)
0.3 to 0.5	0.4 to 0.6	0.406 to 0.559
0.6 to 0.8	0.7 to 0.9	0.660 to 0.762

3.4.2 Tests

The comparison tests took place over three test days. For each test day, three different wing contamination patterns were designed. The multiple contaminated tests required 12 ice samples, the low contaminated tests required three ice samples, and the clear wing test required no ice samples. For the high and low wing contamination tests, the ice samples were placed on the wing in various locations at the same time (Photo 3.9), according to the FAA test diagram. Fluid was then applied to the entire wing to create post deicing conditions (Photo 3.10).

On each day of testing, three tests were conducted: high contamination, low contamination and clean wing. The order of the tests changed, as per the schedule presented in Table 3.9.

The average wet ice thicknesses were measured forty-five minutes after fluid application for each ice sample (Photo 3.11). Tables 3.10 to 3.15 present the ice sample thickness measurements taken before and after fluid application during the comparison tests session.

Table 3.9: Comparison Tests Schedule

TEST DAY 1 (August 30th)

Time	**Task**
6^{00}	Cooling to -5ºC
7^{00}	Make ice patches x 12
10^{00}	Apply fluid
10^{30}	**High Contamination Test**
11^{00}	Decontamination of wing
12^{PM}	Dummy Period / Lunch
1^{30}	Apply fluid
2^{00}	**Clean Wing Test**
2^{30}	Decontamination of wing
2^{00}	Make ice patches x 3
4^{00}	Apply fluid
4^{30}	**Low Contamination Test**
5^{30}	Decontamination of wing

TEST DAY 2 (August 31st)

Time	**Task**
6^{00}	Cooling to -5ºC
7^{00}	Make ice patches x 12
10^{00}	Apply fluid
10^{30}	**High Contamination Test**
11^{00}	Decontamination of wing
12^{PM}	Make ice patches x 3 / Lunch
1^{00}	Apply fluid
1^{30}	**Low Contamination Test**
2^{30}	Decontamination of wing
3^{00}	Dummy Period
3^{30}	Apply fluid
4^{00}	**Clean Wing Test**
5^{30}	Decontamination of wing

TEST DAY 3 (September 1st)

Time	**Task**
6^{00}	Cooling to -5ºC
7^{00}	Make ice patches x 12
10^{00}	Apply fluid
10^{30}	**High Contamination Test**
11^{00}	Decontamination of wing
12^{PM}	Make ice patches x 3 / Lunch
1^{00}	Apply fluid
1^{30}	**Low Contamination Test**
2^{30}	Decontamination of wing
3^{00}	Apply fluid
3^{30}	**Clean Wing Test**
5^{00}	Decontamination of wing

Table 3.10: High Contamination Ice Sample Thicknesses (August 30)

Ice Samples	Target Thick. (mm)	Dry Thickness (mm)			Average Dry Thick. (mm)	Wet Thickness (mm)			Average Wet Thick. (mm)	Delta Average Dry & Average Wet (mm)
1	0.3-0.5	0.584	0.533	0.584	**0.567**	0.533	0.445	0.533	**0.504**	0.063
2	0.6-0.8	0.737	0.826	0.826	**0.796**	0.533	0.826	0.737	**0.699**	0.098
3	0.6-0.8	0.737	0.826	0.737	**0.767**	0.737	0.737	0.737	**0.737**	0.030
4	0.3-0.5	0.584	0.483	0.533	**0.533**	0.533	0.483	0.483	**0.500**	0.034
5	0.6-0.8	0.826	0.826	0.826	**0.826**	0.826	0.737	0.826	**0.796**	0.030
6	0.3-0.5	0.584	0.584	0.533	**0.567**	0.483	0.483	0.445	**0.470**	0.097
7	0.6-0.8	0.686	0.826	0.826	**0.779**	0.686	0.826	0.826	**0.779**	0.000
8	0.6-0.8	0.737	0.826	0.737	**0.767**	0.737	0.826	0.737	**0.767**	0.000
9	0.6-0.8	0.737	0.737	0.686	**0.720**	0.686	0.686	0.686	**0.686**	0.034
10	0.3-0.5	0.584	0.483	0.733	**0.600**	0.533	0.445	0.533	**0.504**	0.096
11	0.3-0.5	0.483	0.584	0.584	**0.550**	0.445	0.533	0.533	**0.504**	0.047
12	0.3-0.5	0.483	0.533	0.483	**0.500**	0.483	0.533	0.483	**0.500**	0.000
Average										**0.044**
STDEV										**0.037**

High Contamination Test Day 1 Diagram

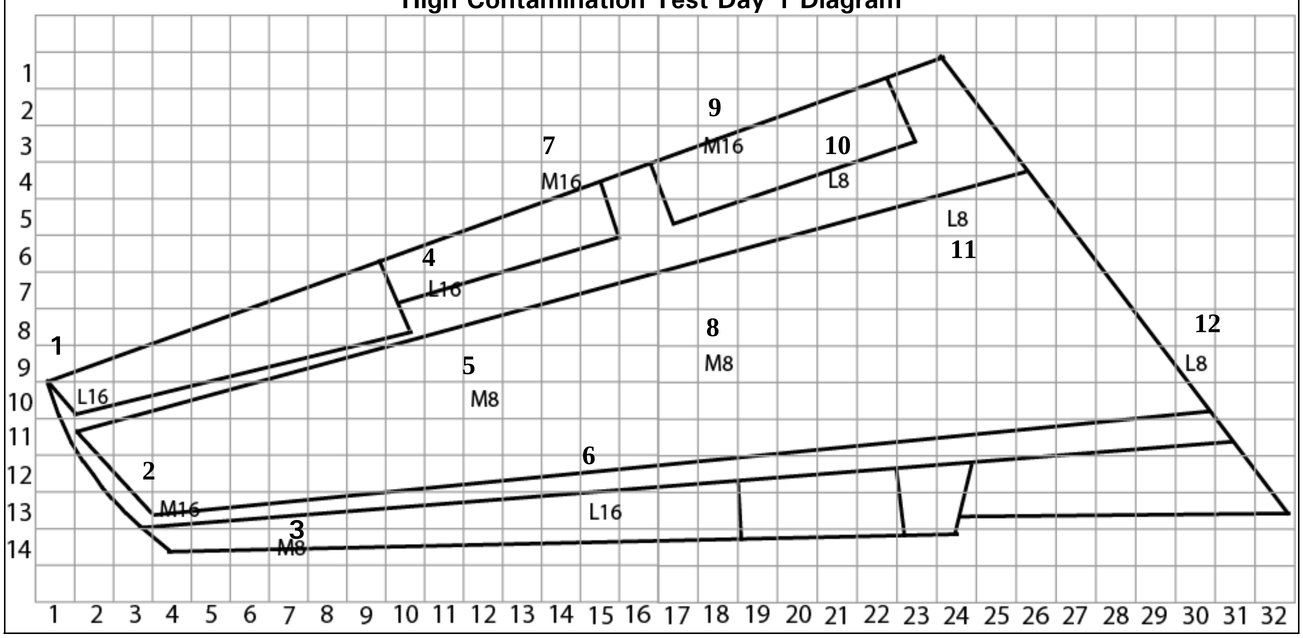


Table 3.11: Low Contamination Ice Sample Thicknesses (August 30)

Ice Samples	Target Thick. (mm)	Dry Thickness (mm)			Average Dry Thick. (mm)	Wet Thickness (mm)			Average Wet Thick. (mm)	Delta Average Dry & Average Wet (mm)
1	0.6-0.8	0.826	0.826	0.826	**0.826**	0.686	0.737	0.737	**0.720**	0.106
2	0.3-0.5	0.584	0.584	0.584	**0.584**	0.483	0.483	0.533	**0.500**	0.084
3	0.3-0.5	0.533	0.533	0.533	**0.533**	0.533	0.483	0.445	**0.487**	0.046
Average										**0.079**
STDEV										**0.030**

Low Contamination Test Day 1 Diagram

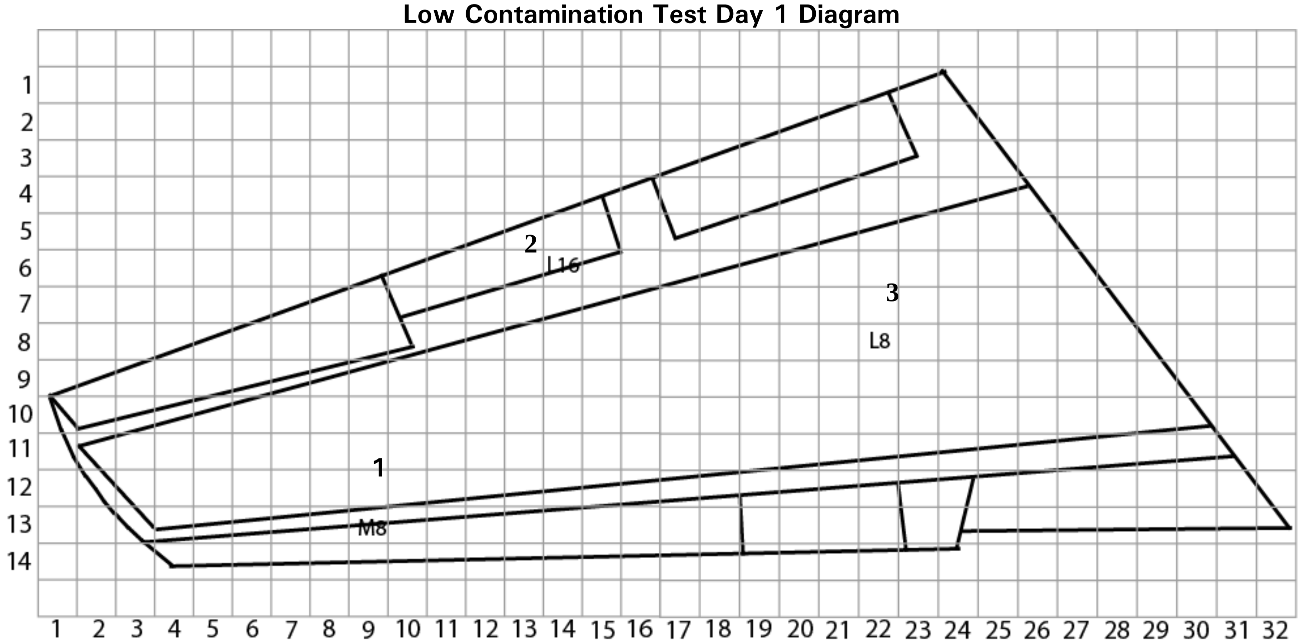
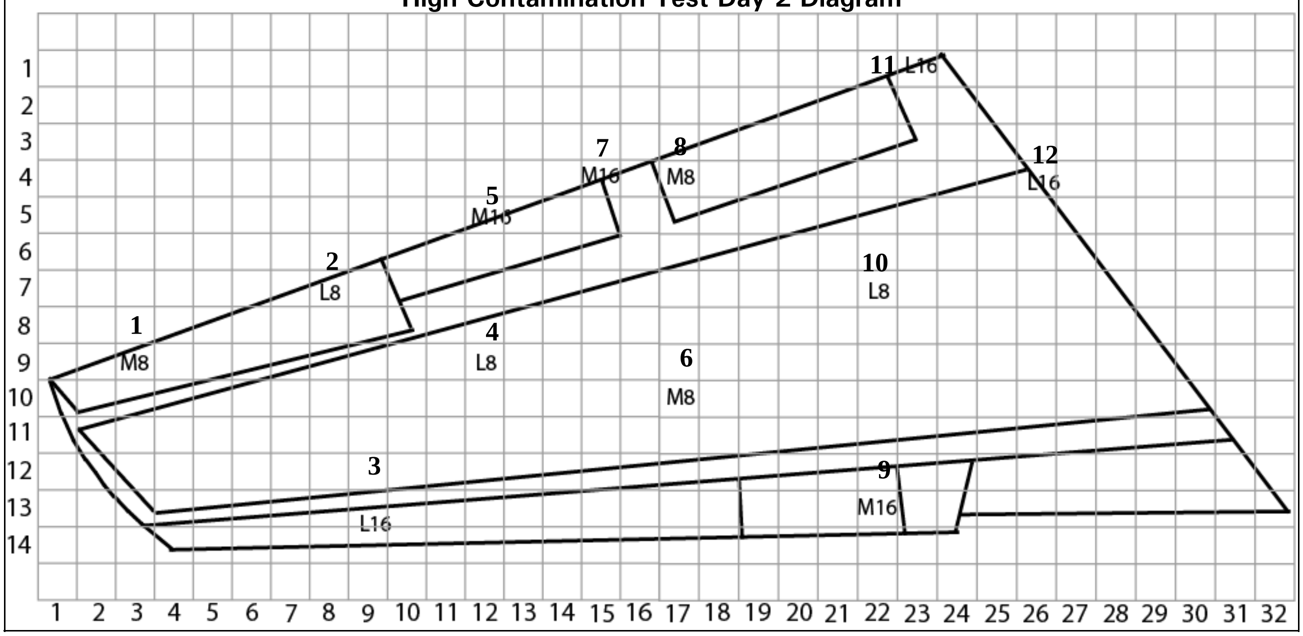


Table 3.12: High Contamination Ice Sample Thicknesses (August 31)

Ice Samples	Target Thick. (mm)	Dry Thickness (mm)			Average Dry Thick. (mm)	Wet Thickness (mm)			Average Wet Thick. (mm)	Delta Average Dry & Average Wet (mm)
1	0.6-0.8	0.826	0.737	0.737	**0.767**	0.686	0.737	0.737	**0.720**	0.047
2	0.3-0.5	0.533	0.533	0.533	**0.533**	0.483	0.483	0.533	**0.500**	0.033
3	0.3-0.5	0.584	0.584	0.533	**0.567**	0.533	0.533	0.445	**0.504**	0.063
4	0.3-0.5	0.533	0.533	0.483	**0.516**	x	x	x	**x**	x
5	0.6-0.8	0.737	0.737	0.826	**0.767**	0.686	0.635	0.737	**0.686**	0.081
6	0.6-0.8	0.737	0.737	0.737	**0.737**	0.737	0.737	0.737	**0.737**	0.000
7	0.6-0.8	0.737	0.826	0.737	**0.767**	0.737	0.737	0.737	**0.737**	0.030
8	0.6-0.8	0.737	0.826	0.826	**0.796**	0.686	0.584	0.686	**0.652**	0.144
9	0.6-0.8	0.826	0.826	0.826	**0.826**	0.635	0.826	0.826	**0.762**	0.064
10	0.3-0.5	0.533	0.584	0.635	**0.584**	0.483	0.445	0.483	**0.470**	0.114
11	0.3-0.5	0.635	0.533	0.584	**0.584**	0.483	0.445	0.584	**0.504**	0.080
12	0.3-0.5	0.584	0.533	0.584	**0.567**	0.533	0.483	0.483	**0.500**	0.067
Average										**0.066**
STDEV										**0.040**

High Contamination Test Day 2 Diagram

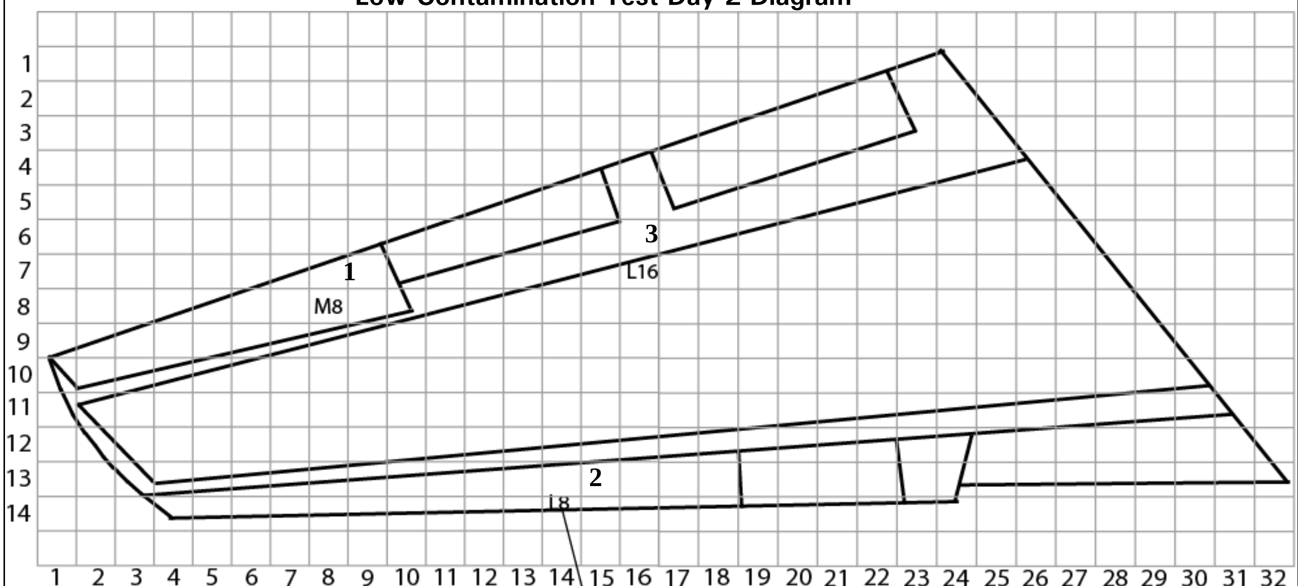


X: Ice sample damaged when decontaminating the wing

Table 3.13: Low Contamination Ice Sample Thicknesses (August 31)

Ice Samples	Target Thick. (mm)	Dry Thickness (mm)			Average Dry Thick. (mm)	Wet Thickness (mm)			Average Wet Thick. (mm)	Delta Average Dry & Average Wet (mm)
1	0.6-0.8	0.826	0.737	0.826	**0.796**	0.635	0.686	0.737	**0.686**	0.110
2	0.3-0.5	0.584	0.584	0.533	**0.567**	0.533	0.533	0.445	**0.504**	0.063
3	0.3-0.5	0.584	0.533	0.584	**0.567**	0.533	0.445	0.533	**0.504**	0.063
Average										**0.079**
STDEV										**0.027**

Low Contamination Test Day 2 Diagram

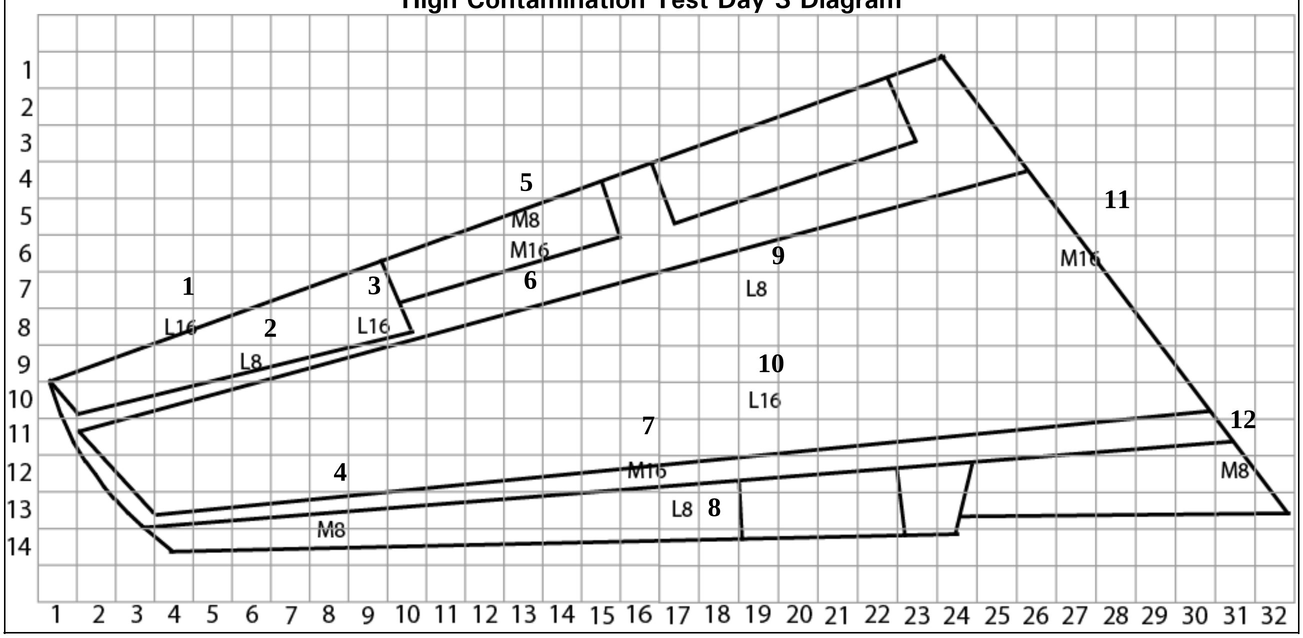


Half moon on edge & spill

Table 3.14: High Contamination Ice Sample Thicknesses (September 1)

Ice Samples	Target Thick. (mm)	Dry Thickness (mm)			Average Dry Thick. (mm)	Wet Thickness (mm)			Average Wet Thick. (mm)	Delta Average Dry & Average Wet (mm)
1	0.3-0.5	0.533	0.584	0.584	**0.567**	0.483	0.533	0.483	**0.500**	0.067
2	0.3-0.5	0.533	0.533	0.584	**0.550**	0.483	0.483	0.533	**0.500**	0.050
3	0.3-0.5	0.584	0.483	0.584	**0.550**	0.483	0.445	0.533	**0.487**	0.063
4	0.6-0.8	0.737	0.737	0.737	**0.737**	0.686	0.737	0.737	**0.720**	0.017
5	0.6-0.8	0.737	0.737	0.737	**0.737**	0.686	0.737	0.737	**0.720**	0.017
6	0.6-0.8	0.737	0.826	0.737	**0.767**	0.686	0.686	0.737	**0.703**	0.064
7	0.6-0.8	0.826	0.826	0.826	**0.826**	0.737	0.826	0.737	**0.767**	0.059
8	0.3-0.5	0.533	0.533	0.533	**0.533**	x	x	x	**x**	x
9	0.3-0.5	0.584	0.533	0.584	**0.567**	0.533	0.445	0.533	**0.504**	0.063
10	0.3-0.5	0.533	0.533	0.533	**0.533**	0.483	0.483	0.533	**0.500**	0.033
11	0.6-0.8	0.737	0.737	0.826	**0.767**	0.686	0.737	0.826	**0.750**	0.017
12	0.6-0.8	0.826	0.826	0.826	**0.826**	0.826	0.737	0.826	**0.796**	0.030
Average										**0.044**
STDEV										**0.021**

High Contamination Test Day 3 Diagram

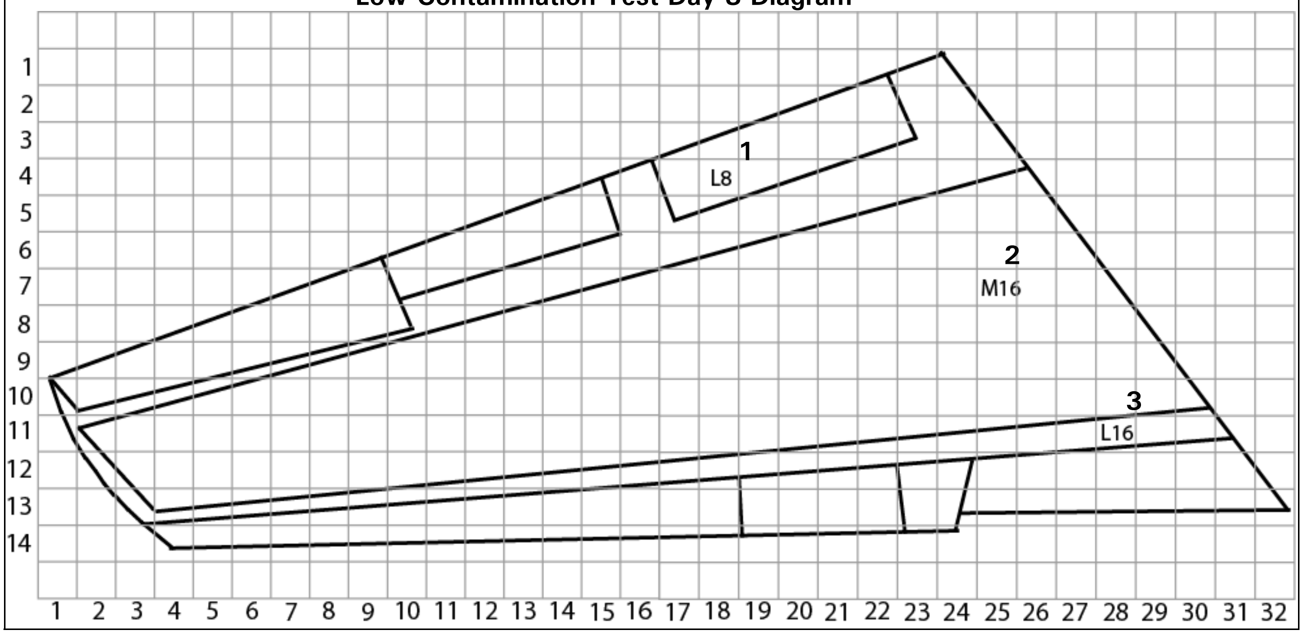


X: Ice sample damaged when decontaminating the wing

Table 3.15: Low Contamination Ice Sample Thicknesses (September 1)

Ice Samples	Target Thick. (mm)	Dry Thickness (mm)			Average Dry Thick. (mm)	Wet Thickness (mm)			Average Wet Thick. (mm)	Delta Average Dry & Average Wet (mm)
1	0.3-0.5	0.584	0.533	0.533	**0.550**	0.483	0.445	0.483	**0.470**	0.080
2	0.6-0.8	0.737	0.826	0.737	**0.767**	0.635	0.635	0.686	**0.652**	0.115
3	0.3-0.5	0.584	0.584	0.584	**0.584**	0.445	0.533	0.533	**0.504**	0.080
Average										**0.092**
STDEV										**0.020**

Low Contamination Test Day 3 Diagram



3.4.3 Analysis of Ice Sample Thickness During Comparison Tests Session

The average ice thickness reduction obtained on August 30, 2005 was 0.044 mm (±0.037 mm) for the high contamination wing test and 0.079 mm (±0.030 mm) for the low contamination wing test (see Tables 3.10 and 3.11). On August 31, the average ice thickness reduction was 0.066 mm (±0.040 mm) for the high contamination wing test and 0.079 mm (±0.0127 mm) for the low contamination wing test (see Tables 3.12 and 3.13). Finally on September 1, the average ice thickness reduction reached 0.044 mm (±0.021 mm) for the high contamination wing test and 0.092 mm (±0.020 mm) for the low contamination wing test (see Tables 3.14 and 3.15). The ice thickness reduction during the test session was similar to the setup session.

Further analysis of the ice thickness data shows that for the combination of ice sample thickness range of 0.3 to 0.5 mm and size of 315 cm² (L8), most of the ice samples were in the upper end of the range, with ten ice samples between 0.45 and 0.5 mm. In contrast, for the combination of ice sample thickness range of 0.6 to 0.8 mm and size of 315 cm² (M8), the ice samples were spread in several ice thickness ranges: two ice samples between 0.65 and 0.7 mm, six ice samples between 0.7 and 0.75 mm, and three ice samples between 0.75 and 0.8 mm. Figure 3.8 illustrates the number of ice samples per ice thickness range for the 315 cm² size ice samples.

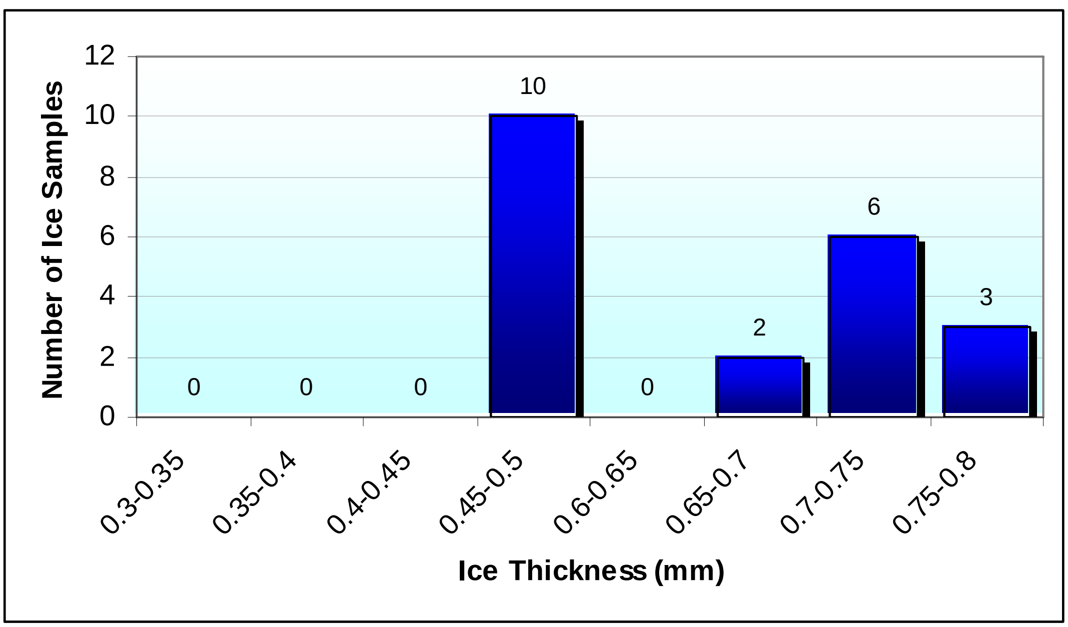


Figure 3.8: Number of Ice Samples per Ice Thickness Range (315 cm² size)

For the combination of ice thickness range of 0.3 to 0.5 mm and size of 1295 cm² (L16), most of the ice samples were in the upper end of the range (similar to L8), including twelve ice samples between 0.45 and 0.5 mm. For the combination of ice thickness range of 0.6 to 0.8 mm and size of 1295 cm² (M16), samples were spread in several ice thickness ranges, including four ice samples between 0.65 and 0.7 mm, three ice samples between 0.7 and 0.75 mm and three ice samples between 0.75 and 0.8 mm. Figure 3.9 illustrates the number of ice samples per ice thickness range for the 1295 cm² size ice samples.

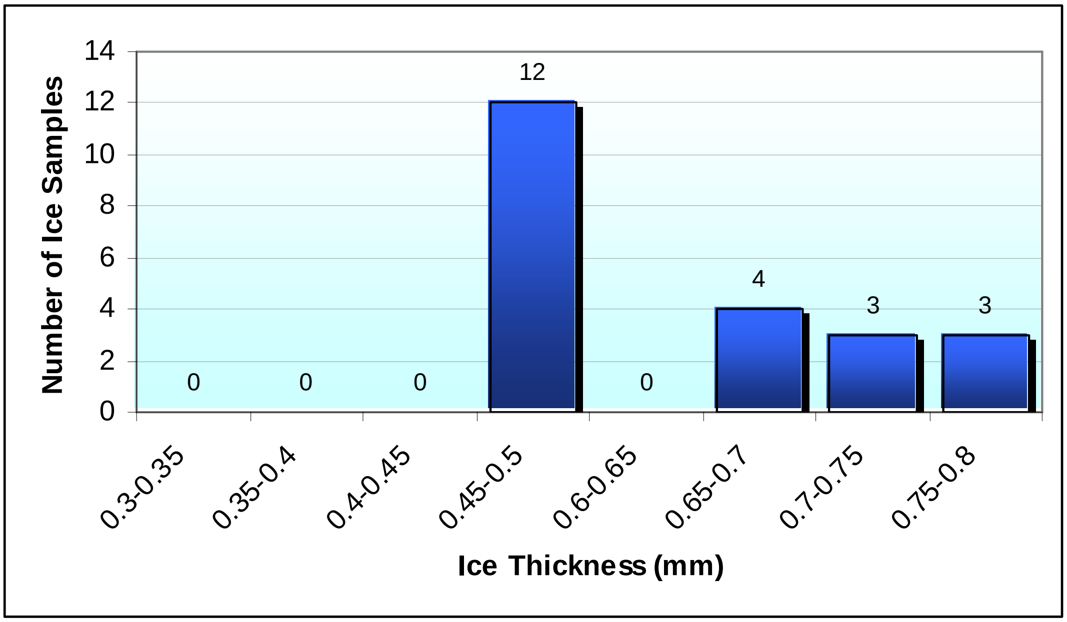


Figure 3.9: Number of Ice Samples per Ice Thickness Range (1295 cm² size)

In summary, after analyzing the ice thickness data from the setup and test sessions, the ice sample thicknesses were in target range (0.3 to 0.5 mm and 0.6 to 0.8 mm) after fluid application.

Photo 3.1: Test Area (Pre-Test Session)

Photo 3.2: Dry Ice Samples on Wing (Pre-Test Session)

Photo 3.3: Fluid Application

Photo 3.4: Decontamination of Wing

Photo 3.5: Test Area (Test Session)

Photo 3.6: MDA GIDS and Goodrich GIDS (Test Session)

Photo 3.7: MDA GIDS Display

Photo 3.8: Goodrich GIDS Display

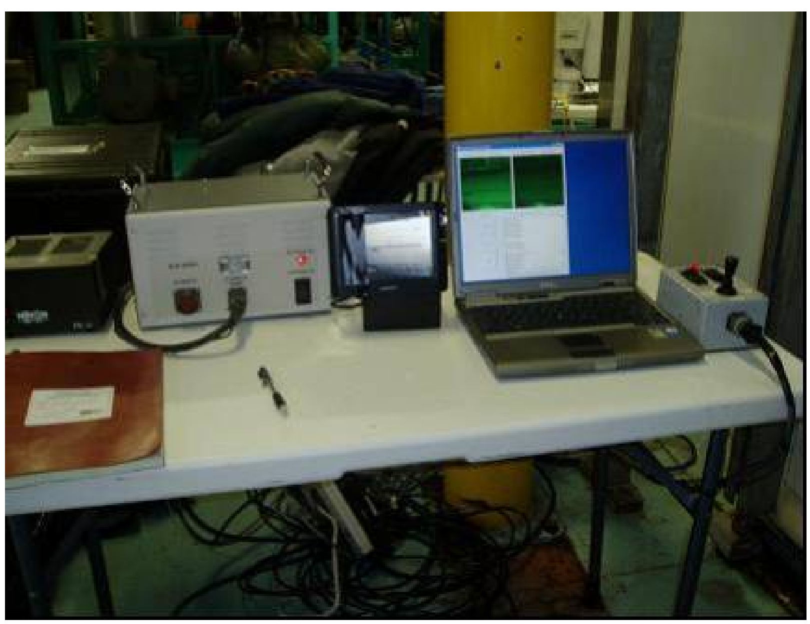
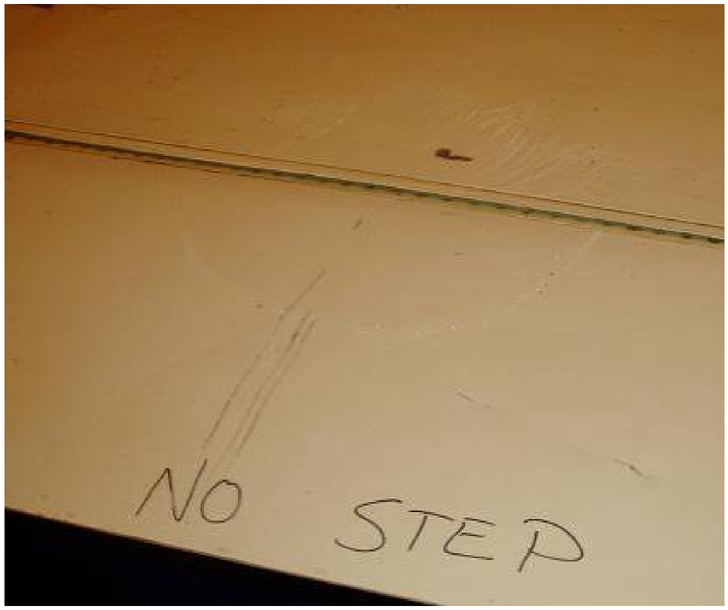


Photo 3.9: Dry Ice Samples on Wing (Test Session)

Photo 3.10: Wet Ice Samples on Wing (Test Session)

Photo 3.11: Wet Ice Samples on Wing 45 min after Fluid Application (Test Session)



4. CONCLUSIONS

The report objectives were met as presented below.

4.1 Feasibility of Making Ice Samples on a Wing

In July 2005, preliminary tests were carried out in the cold chamber during the pre-test session. The wing was highly contaminated with ice samples and Type I fluid was applied. Based on the results from these tests, it was concluded that making ice samples to a required thickness and area on a wing after fluid application by using the previously developed ice-making procedure was feasible.

The RAWG Working Group, and more specifically the experts in deicing operations, indicated that the resulting deiced wing with residual ice patches accurately simulated a possible service condition. It should be noted that the presence of residual ice is not a common occurrence. Many large patches would not likely occur in the field but were required for statistical evaluation purposes.

4.2 Development of a Fluid Application Method

The application of fluid on the entire wing using the fluid application procedure was confirmed to be feasible. The fluid coverage of the entire wing surface was comparable to post-deicing conditions.

4.3 Calibrate Ice Thickness Degradation

To obtain the desired thickness value, the ice sample thicknesses had to be greater then the target thickness. By applying fluid, the thickness of the ice samples was reduced but remained in the required test target range.

4.4 Support for Comparison Tests

APS personnel provided support throughout the comparison tests session which included: chamber layout design, moving the wing to the chamber, making ice samples on the wing, fluid application, wing decontamination, communication with chamber facility personnel, and all aspects of logistics and test area management.

4.5 Comparison of Human Ice Detection Capabilities and GIDS Performance.

The conclusions from the tests comparing human ice detection capabilities and GIDS performance are presented in a related report produced and issued by the FAA (see FAA report DOT/FAA/TC-06/20 (3)).

REFERENCES

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2. 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/TC-06/21.

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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 Preparation and 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 for developing standard "ice coupons" of 315cm^2 area, circular in planform and with thicknesses from 0.2mm to 1.2mm having smooth surface and 'feather' edges;

c) Develop the methodology for making the required ice coupons, ensuring 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

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 using the developed standard coupons.

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 and test participant equipment.

k) Provide support services for conduct of check-out tests over a period of three days.

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

EXPERIMENTAL PROCEDURE: HUMAN FACTOR VISUAL AND TACTILE TESTS ON WING AT PMG – PHASE 2

CM1892.001 (04-05)

EXPERIMENTAL PROCEDURE:
HUMAN FACTOR VISUAL AND TACTILE TESTS ON WING AT PMG – PHASE 2

Winter 2004-05

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Christina Narlis

Reviewed by: John D'Avirro

July 11, 2005
Version 1.0

EXPERIMENTAL PROCEDURE: HUMAN FACTOR VISUAL AND TACTILE TESTS ON WING AT PMG – PHASE 2

Winter 2004-05

1. INTRODUCTION

1.1 Background

Transport Canada (TC), in collaboration with the Federal Aviation Administration (FAA), is studying human visual and tactile ice detection capabilities under aircraft post-deicing conditions. This will help evaluate new systems and devices used to detect ice. Ground ice detection systems (GIDS) are new technologies that are being developed to assist ice checkers perform their duties. A Ground Ice Detection System Regulatory Approval Working Group (GIDS RAWG), under the auspices of the SAE G-12 Ice Detection Sub-Committee, was formed to find ways to meet this objective.

Phase 1 of the experiment took place in April 2005 and was conducted in a cold chamber (-5°C) at PMG Technologies. The research method involved a procedure, in which a sample was presented to a group of participants, then another sample was presented to that same group and finally they were asked to indicate on which of the two samples ice was detectable. APS Aviation Inc. provided project support throughout the experimental sessions of Phase 1 including chamber layout design, ice making and placing of samples on a 'lady Susan', cleaning and replacing ice samples, communication with chamber facility personnel, as well as general logistics and test area management. During test sessions conducted in the cold chamber, APS developed a reliable ice-making procedure that addressed all essentials test variables and produced reproducible results in terms of ice characteristics.

The Phase 1 experimental session led to several conclusions. First of all, deicers can miss post-deicing, fluid covered ice, ≤0.8mm thick on white surfaces with a visual inspection in a fixed position. Secondly, deicers are likely to detect post-deicing, fluid covered ice, ≥0.5mm thick with a tactile check when inspecting a precise area. A third conclusion is that the ice of any thickness can be detected on aluminium surfaces. Furthermore, aluminium patches can be seen visually. Finally, a useful estimate has been obtained of visual and tactile post-deicing detection capabilities. Taking into account human capabilities, the GIDS RAWG should think beyond the ability of a device that can detect a certain thickness of ice. It may be more advantageous to evaluate GIDS in terms of how it will allow deicers to mitigate the tactile check limitations.

1.2 Objectives

Designers can benchmark their devices capabilities with regard to human performance. The objective of the Phase 2 experiment is to compare human ice detection capabilities and ground ice detection system performance under post-deicing conditions. Phase 2 will be accomplished by collecting ice detection data for both human checkers and GIDS under identical conditions and comparing their detection performance. MD Robotics and Goodrich Aerospace each developed GIDS, which will be used during testing. APS is supporting Phase 2 of the experimental session by providing ice patches of different location, sizes and thickness formed on a JetStar wing. APS will also provide the same logistics and test area management that it did during Phase 1 of the experiment.

2. TEST PLAN

2.1 Pre-Test

The pre-test is scheduled from 12 – 22 July. On 11 July the JetStar wing and scaffolds will be delivered to PMG. The setup of the equipment will be scheduled for 12 July. Two days (13 and 14 July) are scheduled for practicing the creation of ice patches, speed, time constant, measuring the wing temperature, developing a procedure for fluid application and also practicing half moon ice patches. The FAA setup preparation and dry runs are scheduled from 18 – 22 July.

2.2 Test

In August, five days will be scheduled for the setup and dry runs (23 – 26 & 29 August), three days for testing and one day for dismantling (30 – 31 August and 1 – 2 September). A detailed schedule is presented in Appendix A.

Each test day consists of a multiple patch test, a triple patch test and a clean wing test. A plan for each test day is presented in Appendix B.

The multiple patch test requires 12 to 16 ice patches, placed on the wing in various locations (to be determined during pre-test) at the same time. Figure 2.1 illustrates the potential spots on the wing.

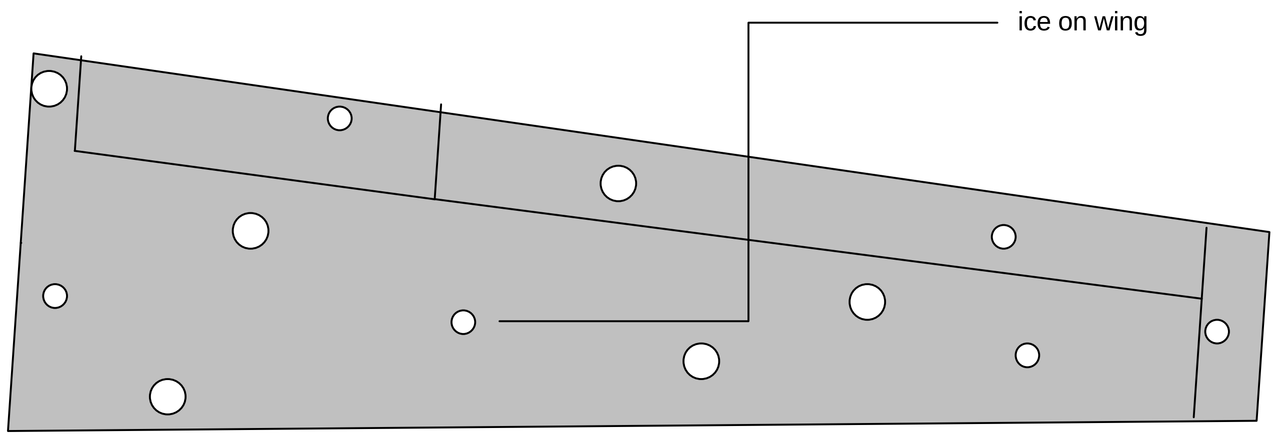


Figure 2.1: Potential Spots on Wing for Multiple Patch Test

Ice sample size will vary from 315 cm² and 1200 to 1500 cm² and thickness will vary from low (L): .5 to .8 mm and moderate (M): 1.2 to 1.5 mm. Table 2.1 illustrates the 4 different possible ice patch combinations.

Table 2.1: Different Ice Patch Combinations

Types of Ice Patch	Thickness (mm)	Size (cm²)
1 (L4)	.5 to .8	315
2 (M4)	1.2 to 1.5	315
3 (L8)	.5 to .8	1200 to 1500
4 (M8)	1.2 to 1.5	1200 to 1500

For the tripled patch test, three ice patches will be placed on the wing at the same time. For each trial, the three patches placed on the wing will be the same size and thickness. The size of the ice patch will vary from 315 cm² and 1200 to 1500 cm² and the ice thickness will vary from low (L): .5 to .8 mm and moderate (M): 1.2 to 1.5 mm. There are four potential spots for the trailing edge, five potential spots for the center and five potential spots for the leading edge. Figure 2.2 illustrates the potential spots on the wing.

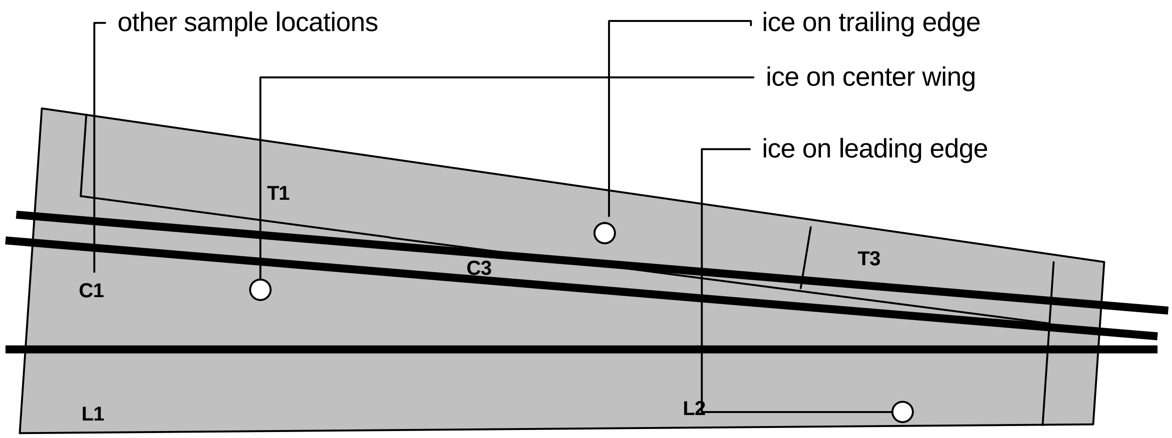


Figure 2.2: Potential Spots on Wing for the Triple Patch Test

2.3 Ice Patch Making

As discussed previously, the thicknesses of the ice patches vary from 0.5 to 0.8 mm and 1.2 to 1.5 mm. Once the ice patch is made, fluid is applied to simulate post-deicing conditions. By applying the fluid, the thickness of the ice patch is reduced. Therefore, to obtain the right thickness value, the ice patches thicknesses have to be greater then the final thickness. A gauge is used to measure the ice patches thickness. Based on ice making tests carried out on the previous project, and based on the final ice thickness tolerances that we are aiming, the initial thickness tolerances and the correspondent gauge teeth are summarized in Table 2.2.

Table 2.2: Initial and Final Ice Patches Thicknesses

Final Thickness Tolerance (mm)	Initial Thickness Tolerance (mm)	Thickness Gauge Teeth Accepted
0.5 to 0.8	0.59 to 0.90	0.559 to 1.016
1.2 to 1.5	1.32 to 1.63	1.397 to 1.651

3. TEST SITE

3.1 Chamber and Wing Plan

The experiment will be conducted at PMG Technologies in Blainville, Quebec. The cold chamber measures (in feet) 54 L x 21.5 W x 13 H. The cold chamber will be set at a constant temperature of -5°C. Two diffused; 150 watt high pressure sodium bulbs will be used to illuminate the chamber. A JetStar wing will be mounted three to four feet from the floor. The layout of the test site is presented in Appendix C and the drawing of the wing is presented in Appendix D.

3.2 Thermistor Plan

The thermistor probe location for the JetStar wing is presented in Appendix C.

3.3 Platform Plan

A viewing platform will be erected next to the wing. The viewing angle and distance for human visual checks will be 45° and 7 feet, respectively, looking at a point at mid-cord of the wing. The layout of the platform is presented in Appendix E.

3.4 Sensor Layout and Sensor Display Layout

The GIDS displays will be mounted at two selected locations in the chamber during the test. The GIDS will be mounted on scaffolds in the chamber at ceiling height (at approximately 13 feet). The layout of the two sensors in the chamber is presented in Appendix F.

The MD Robotics GIDS will be located at 4 feet distance from the leading edge at mid cord of the wing and the height of vantage point, above the wing will be of 10 feet. The Goodrich GIDS will be located at 25 feet distance from the wing and the height of vantage point, above the wing will be of 10 feet (ref Appendix F). Five viewing angles have been calculated from the view point of each sensor, these five positions are:

- Outboard leading edge of the wing;
- Outboard trailing edge of the wing;
- Inboard leading edge of the wing;

- Inboard trailing edge of the wing; and
- Middle and mid cord of the wing.

Tables 3.1 and 3.2 presents the viewing angles for MD Robotics and Goodrich GIDS, respectively.

Table 3.1: Five Viewing Angles of the MD Robotics GIDS Located in the Chamber

		Outboard	Middle	Inboard
Trailing Edge	Horizontal D (feet)	19.4		15.4
	Hypotenuse (feet)	21.8		18.4
	View Angle (°):	27.3		33.0
Mid Cord	Horizontal D (feet)		7.7	
	Hypotenuse (feet)		12.6	
	View Angle (°):		52.4	
Leading Edge	Horizontal D (feet)	16.0		13.3
	Hypotenuse (feet)	18.9		16.6
	View Angle (°):	32.0		36.9

Table 3.2: Five Viewing Angles of the Goodrich GIDS Located in the Chamber

		Outboard	Middle	Inboard
Trailing Edge	Horizontal D (feet)	25.1		47.3
	Hypotenuse (feet)	27.0		48.3
	View Angle (°):	21.7		11.9
Mid Cord	Horizontal D (feet)		38.5	
	Hypotenuse (feet)		39.8	
	View Angle (°):		14.6	
Leading Edge	Horizontal D (feet)	24.5		49.8
	Hypotenuse (feet)	26.5		50.8
	View Angle (°):	22.2		11.4

The sensors display will be placed on a table in the chamber. Two areas have been designated in the chamber for the sensors display. The disposition of the sensors' display is presented in Appendix C.

3.5 Safety

Fall protection equipment (harness) will be provided for personnel that will be climbing the scaffolds and at risk of falling three meters or more in the chamber. Also, it will be important to alert personnel to the hazards of walking and working on slippery surfaces due to fluid application. It will be essential to control these hazards during the experiment.

As a safety reference, Material Safety Data Sheets (MSDS) for the fluid will be available on site. Moreover, the FAA will provide safety procedures for the experimental sessions. These safety procedures will have to be followed throughout the experiment. Also, for safety assistance PMG has a safety department that can be reached on location.

4. TEST EQUIPMENT

The main equipment consists of a JetStar wing, thermistors, scaffolds, stairs and covering mats. The equipment will be coordinated by Marc Mayodon. The list of equipment is presented in Appendix G.

5. FLUIDS AND APPLICATION

The fluid used in the test session will be EG ADG, diluted to a Brix of 11 (freezing point of approximately -7°C). The fluid to be dispensed will be:

- 3 days @ 3 sprays per day = 9 sprays;
- 7 days (dry run) @ 3 sprays = 21 sprays; and
- Total: 30 sprays @ 3L = 90 L of Brix of 11.

The application of the fluid will be done by spraying it on the wing with a spray can. This method provides a quick and even fluid distribution, given that the pressure is easily adjustable.

6. LOGISTICS, COORDINATION & PREPARATION

The following are different tasks in preparation of wing testing at PMG for July:

1. Early June – Dispose of all waste fluid on the site/remove fluid from wing;
2. Mid-June – Transport and work on the wing; and

3. July 11th – Transport wing to PMG.

Preparation requirements for testing at PMG have been established; the task assignment is presented in Appendix H.

7. ICE-MAKING PROCEDURE

The ice-making procedure developed by APS provides detailed information with respect to the initial preparations of the test plates, fluid preparation and actual ice-making procedure. It also specifies equipment requirements for every step of the process. A similar procedure will be used to make ice on the wing. The ice-making procedure is presented in Appendix I.

8. PERSONNEL

Four APS staff members will be required to conduct these tests. One technician will be in charge of making the ice patches, two others will be responsible for assisting the ice-making manager, and the fourth person will support and coordinate. The task description is presented in Appendix J.

9. APPENDICES

This procedure includes the following appendices:

- Appendix A: Schedule
- Appendix B: Test Day Plan
- Appendix C: Plan of Test Site
- Appendix D: Wing Drawing
- Appendix E: Plan of platform
- Appendix F: Plan of Sensors Layout
- Appendix G: List of Equipment
- Appendix H: Task Distribution
- Appendix I: Ice-Making Procedure
- Appendix J: Task Description

APPENDIX A: SCHEDULE

JULY						2005
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
					1	**2**
3	**4**	**5**	**6**	**7**	**8**	**9**
10	**11**	**12** APS (Pre-pre test) – Wing setup – Scaffold setup 7am-3h30pm 20°C	**13 JD/NM** APS (Pre-pre test) – Practice patches – Speed – Time constant – Fluid application 7am-3h30pm -5°C	**14** APS (Pre-pre test) – Practice patches – Speed – Time constant – Fluid application 7am-3h30pm -5°C	**15**	**16**
17	**18 JD** FAA (Pre-test) – FAA setup – Sensor setup 7am-3h30pm 20°C	**19 NM** FAA (Pre-test) – Dry run – Sensor training (AeroMag) 7am-3h30pm -5°C	**20 JD** FAA (Pre-test) – AeroMag – Dry run 7am-6pm -5°C	**21 NM** FAA (Pre-test) – Spare day to test procedural changes from AeroMag commentary 7am-3h30pm -5°C	**22** Pre-test – Dismantle – Pack-up 7am-3h30pm 20°C	**23**
24	**25**	**26**	**27**	**28**	**29**	**30**

APPENDIX A: SCHEDULE (continued)

AUGUST						2005
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
31	**1**	**2**	**3**	**4**	**5**	**6**
7	**8**	**9**	**10**	**11**	**12**	**13**
14	**15**	**16**	**17**	**18**	**19**	**20**
21	**22**	**23** APS – Wing – Scaffold – Sensors 7am-3h30pm 20°C	**24** **JD** FAA – Setup 7am-3h30pm -5° or 20°C	**25** **NM** FAA – Setup and dry run 7am-3h30pm -5°C	**26** **JD** – WG dry run 7am-6pm -5°C	**27**
28	**29** **NM** – Sensor Training and dry run 7am-3h30pm -5°C	**30** **JD** – Test day 1 7am-6pm -5°C	**31** **NM** – Test day 2 7am-6pm -5°C	**1** **JD** – Test day 3 7am-6pm -5°C	**2** – Spare day and Pack-up 7am-3h30pm 20°C	**3**

APPENDIX B: TEST DAY PLAN

TEST DAY 1 (August 30th)

Time	Task
6^{00}	Cooling to -5ºC
7^{00}	Make patches x 12
10^{00}	Apply fluid
10^{30}	**Multiple Patch Test**
11^{00}	Decontamination of wing
12^{pm}	Apply fluid / Lunch
12^{30}	**Clean Wing Test**
1^{00}	Decontamination of wing
2^{00}	Make patches x 3
3^{30}	Apply fluid
4^{00}	**Triple Patch Test**
4^{30}	Decontamination of wing
5^{00}	Buffer

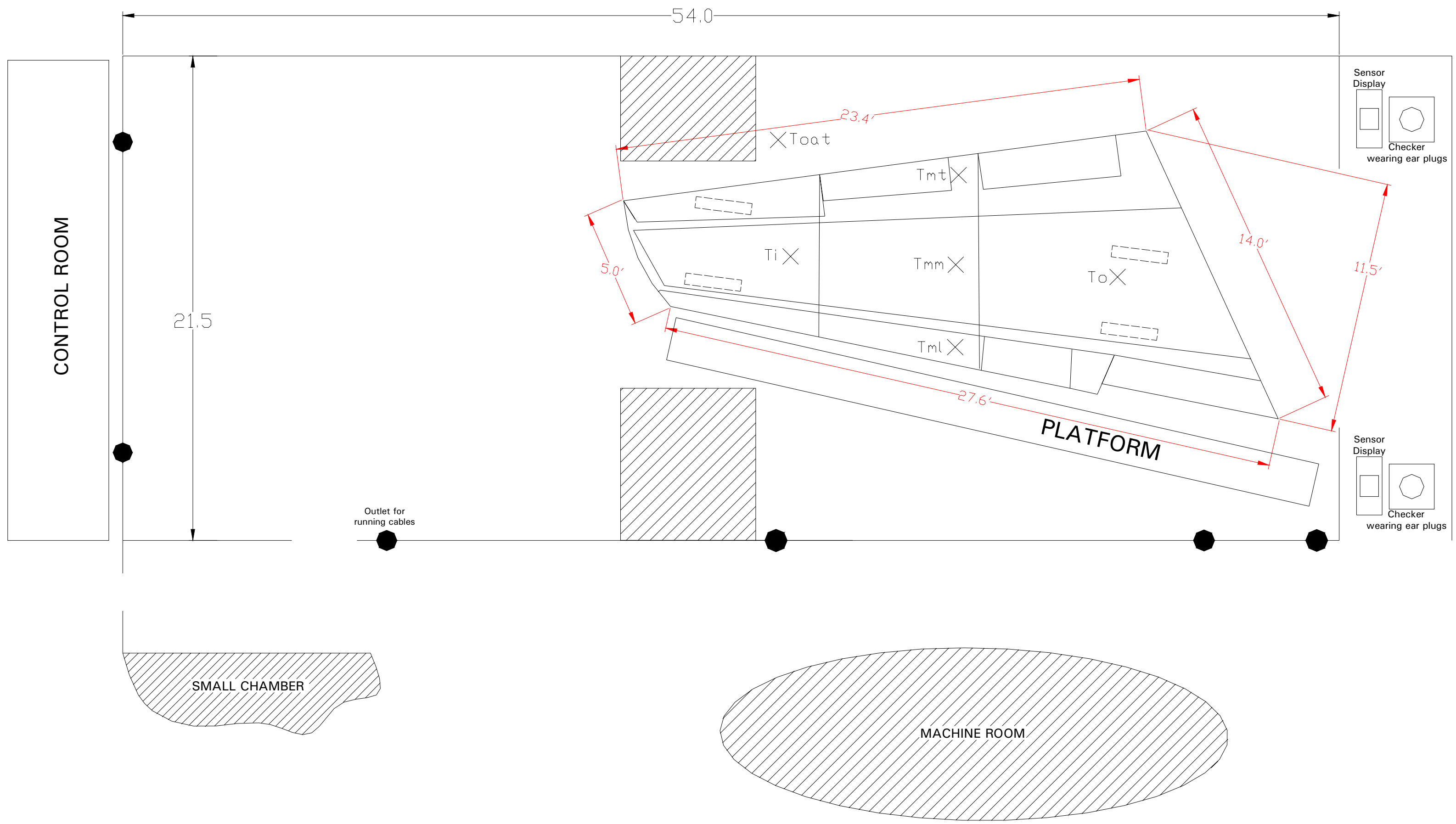
TEST DAY 2 (August 31st)

Time	Task
6^{00}	Cooling to -5ºC
7^{00}	Make patches x 12
10^{00}	Apply fluid
10^{30}	**Multiple Patch Test**
11^{00}	Decontamination of wing
12^{pm}	Make patches x 3 / Lunch
1^{30}	Apply fluid
2^{00}	**Triple Patch Test**
2^{30}	Decontamination of wing
3^{30}	Apply fluid
4^{00}	**Clean Wing Test**
4^{30}	Decontamination of wing
5^{00}	Buffer

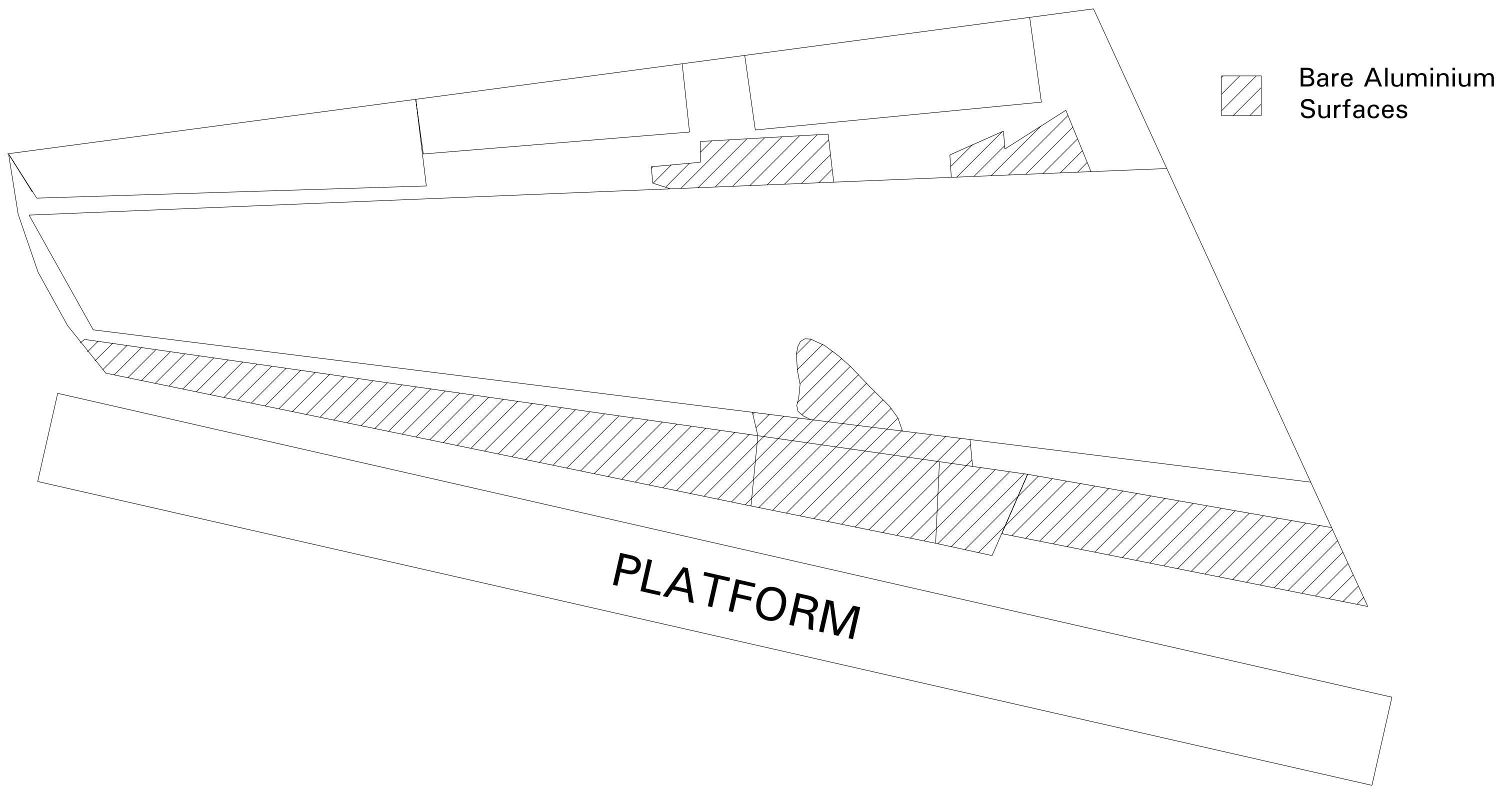
TEST DAY 3 (September 1st)

Time	Task
6^{00}	Cooling to -5ºC
7^{00}	Make patches x 12
10^{00}	Apply fluid
10^{30}	**Multiple Patch Test**
11^{00}	Decontamination of wing
12^{pm}	Apply fluid / Lunch
12^{30}	**Clean Wing Test**
1^{00}	Decontamination of wing
2^{00}	Make patches x 3
3^{30}	Apply fluid
4^{00}	**Triple Patch Test**
4^{30}	Decontamination of wing
5^{00}	Buffer

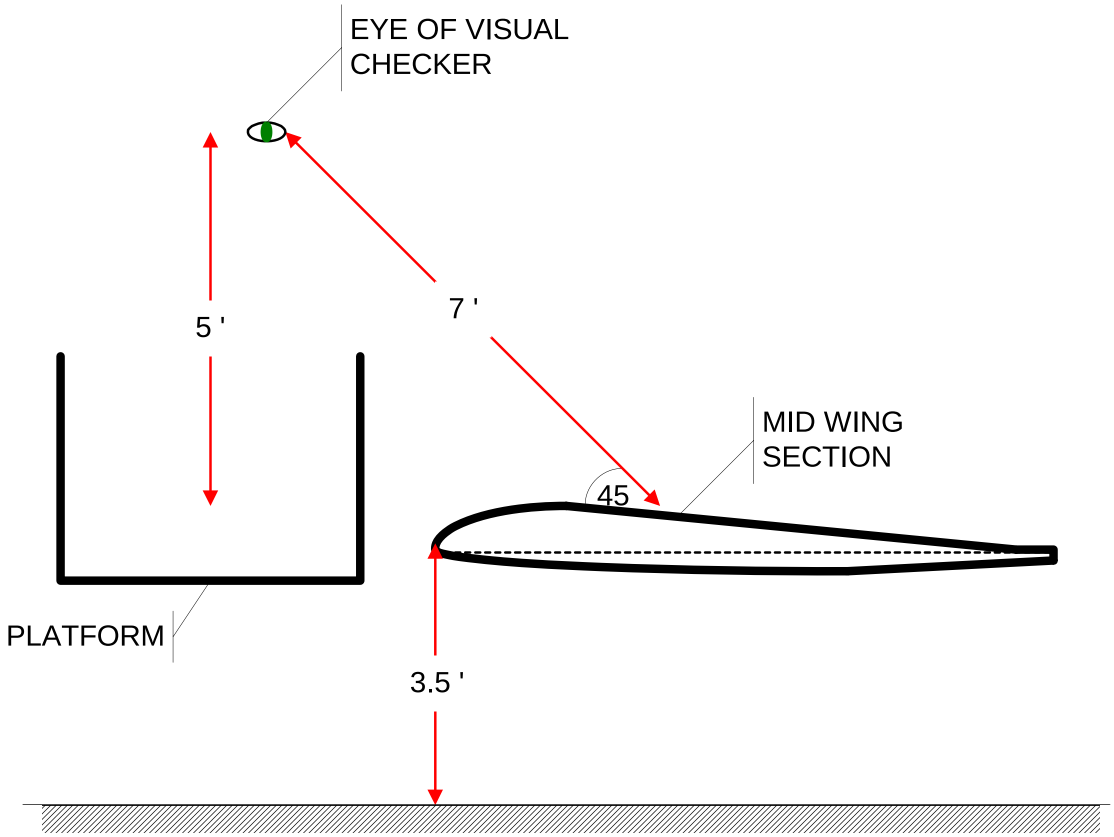
APPENDIX C: PLAN OF TEST SITE



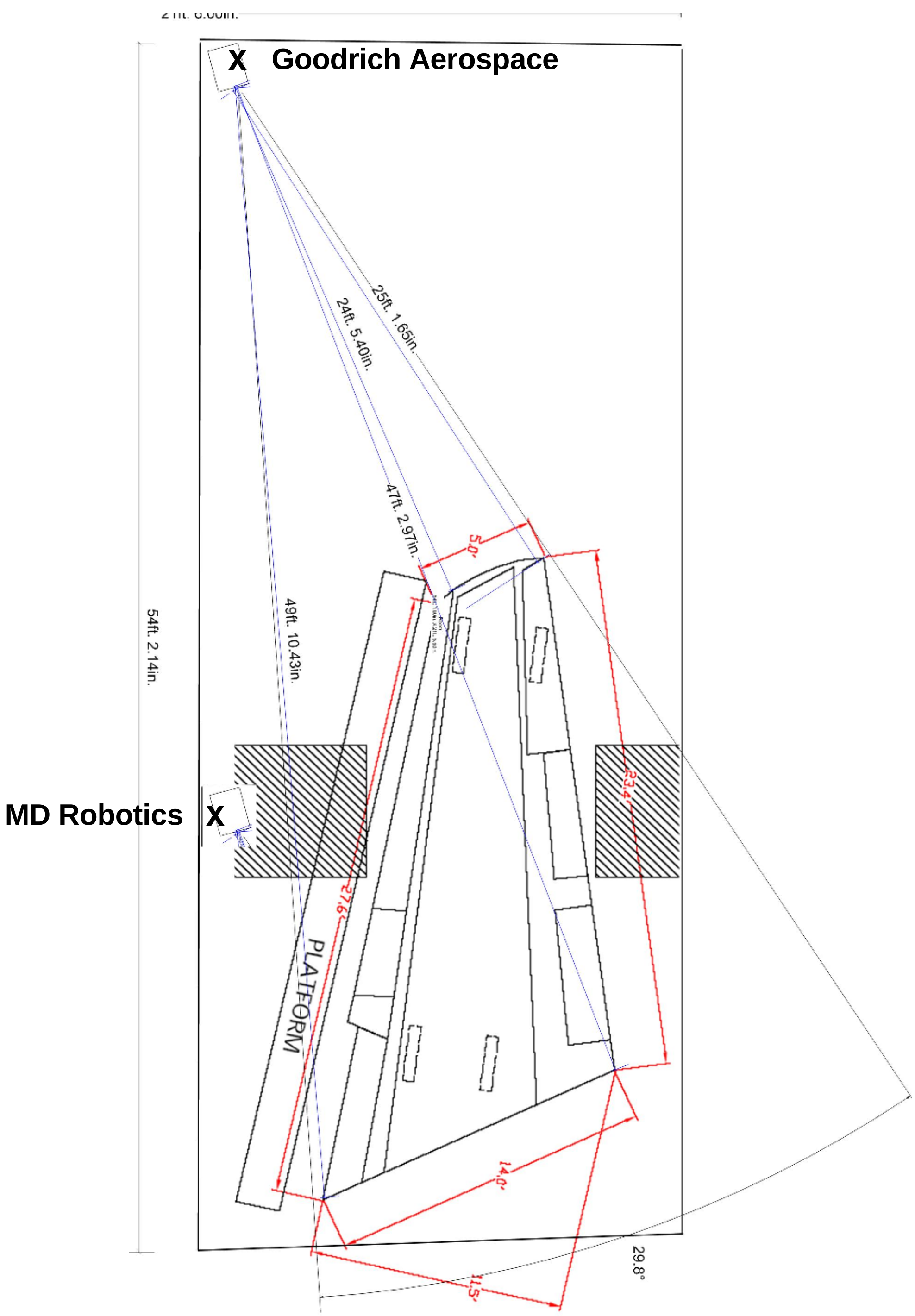
APPENDIX D: WING DRAWING



APPENDIX E: PLAN OF PLATFORM



APPENDIX F: PLAN OF SENSORS LAYOUT



APPENDIX G: LIST OF EQUIPMENT

Equipment at APS:

1. Thickness gage
2. Test fluid - Diluted Brix 11
3. Spray gun x 2
4. Hose x 2
5. Digital scale
6. Racks- Shelves
7. Measuring cups
8. Fluid temperature probe
9. Surface temperature probe
10. Relative humidity data logger
11. Shop vac x 1
12. Fluid container
13. Thermistors x 10
14. Logger x 2
15. Laptop x 1
16. Tables x 2
17. Chairs x 2
18. Digital camera x 1
19. Small ladder or stairs x 1
20. Headphones x 2
21. Gloves
22. Scrappers x 2

Equipment to purchase:

1. Masks x 3
2. Spray can x 2
3. Hose x 1
4. Compressors x 2 (or Y)
5. Freezer – Adjustable from -10 C to -28 C x 1
6. 18 L Water bottles
7. Scaffolds x 3
8. Harness x 2
9. Floor mats
10. Squeegee x 3
11. Isopropyl
12. Latex nitrile gloves
13. Carpet

APPENDIX H: TASK DISTRIBUTION

Assignments	Person in Charge
Wing issues (to fit into chamber)	NB
Fluid collection (tarp)	MM
Fluid disposal at PMG (absorbent pads)	MM
Equipment list (need to make one)	CN
Floor mats (rubber grid for non-slip)	MM
Masks for making patches	MM
Sensor coordination (height, positioning)	JD
Scaffolding	MM
Raising of wing?	JD
Fluid application (sprayer or mop or pour) – do tests at site on small wing	MM
Screening on walls (determine in pre-test)	
Lighting (determine in pre-test)	
Wing demarcation	NB
Lift for sensors (rolling stairs)	JD
Storage for wing between 2 sessions	NB
Order fluid (4 concentrate EG ADG 20 L containers – see Attachment 4)	JD
Compressor, water sprayers, freezer to store fluid	CN
Positioning of thermistors	NB
Write up profile roles (in bullet form)	JD
Other equipment needs?	CN
Renting truck	CN
Spray covering	MM
Safety concerns	CN
Tables and chairs for display	MM
Write a brief procedure	CN
Details of a typical test day	CN

APPENDIX I: ICE MAKING PROCEDURE

1. INITIAL PREPARATION

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

Masks used to make a patch of ice (circular 315 cm²): to ensure that masks are aligned to the plates, 1/2 inch diameter holes must be cut into each corner of the mask. The center of the holes should be 11 inches apart along the width and 19 inches apart along the length. Screw a bolt through the holes until they penetrate 1.3 cm through the bottom of the mask.

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).

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

2. INITIAL FLUID PREPARATION

At 07:15, 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.
- Weighted using the digital scale.

APPENDIX I: ICE MAKING PROCEDURE (continued)

Note 1: A 1/8 inch (3.175 mm) 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 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.

APPENDIX I: ICE MAKING PROCEDURE (continued)

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 plate. 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.
- Re-use 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 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 5.

3.7 Feathering (circle shaped plates only):

- Use fingers on layer of ice to remove excess splash.
- Using a fine brush, apply 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 (18″ x 12″). A strand of EPDM Rubber from Reno (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 J: TASK DESCRIPTION

1) Ice Making Manager (Nicolas Blais)

   - Communicate with FAA HF on plan of ice required
   - Manages ice making
   - Makes ice
   - Responsible of equipment

2) Ice Making Assistant (Marc Mayodon and Sami Chebil)

   - For tests, needed for half day?
   - Assists support/coordination
   - Assists ice making manager
   - Assists with equipment

3) Support/Coordination (Christina Narlis)

   - Support for ice making
   - Preparation of fluids
   - Clean-up fluid
   - Apply fluid
   - Clean wing
   - Communicate daily with project leader
   - Communicate with FAA HF regarding timing during day
   - Assists with equipment
   - Draft report preparation
   - Daily pre-test reports
   - Daily pre-test planning

4) Project Leader (John D'Avirro and Nicoara Moc)

   - Communicates with FAA
   - Communicates with PMG regarding daily plan and requirements
   - Makes arrangements for lunch
   - Prepare procedure/plan for tests
   - Communicates with ice detection companies and deicer
   - Ensure that data loggers are functional

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