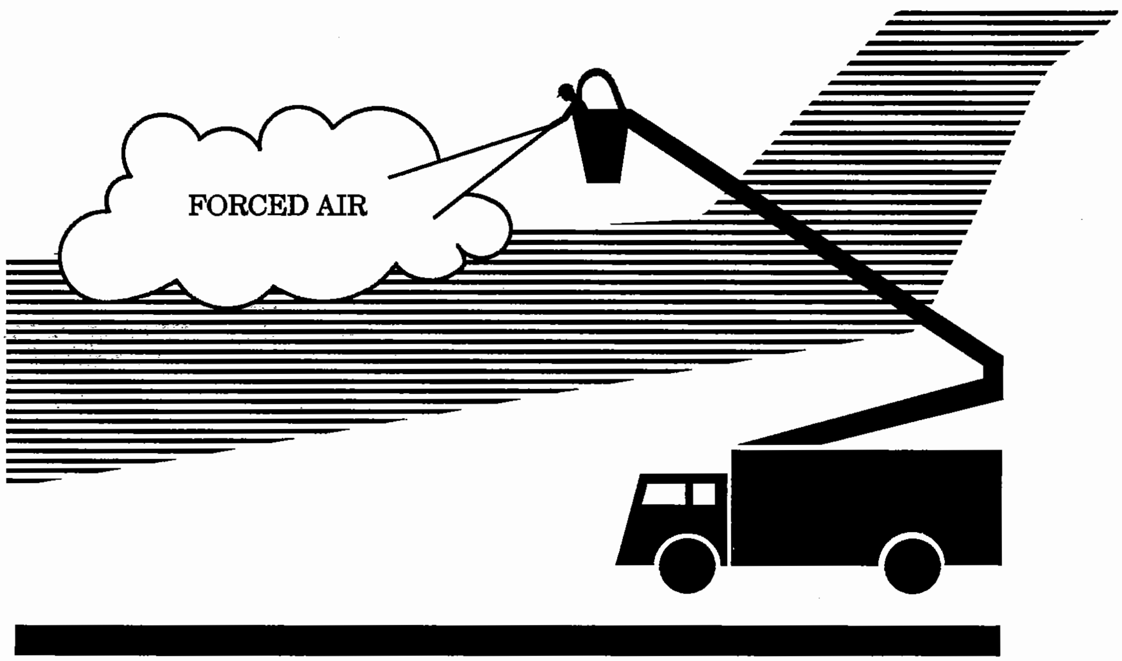
TP 12655E

Forced Air De-icing Trials for the 1994-1995 Winter



Prepared for

Dryden Commission Implementation Project
Transport Canada

by

APS AVIATION INC.

December 1995

TP 12655E
CM1222.001

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Peter Dawson, John D'Avirro

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The contents of this report reflect the views of APS Aviation Inc. and not necessarily the official view or opinions of the Dryden Commission Implementation Project of Transport Canada.

Un sommaire en français de ce rapport est inclus.

PREFACE

At the request of the Dryden Commission Implementation Program of Transport Canada, APS Aviation Inc. has undertaken a research program to further advance aircraft ground de-icing/anti-icing technology. Specific objectives of the program were:

- Substantiation of SAE/ISO Holdover Time Tables that define a de-icing fluid's ability to delay ice formation by conducting tests on flat plates under conditions of natural snow, simulated freezing drizzle, simulated light freezing rain, and simulated freezing fog for a range of fluid dilutions and temperature conditions;

- Development of data for "cold-soaked" wing conditions using cooled flat plates to simulate the conditions;

- Correlation of flat plate test data with the performance of various fluids on service aircraft by concurrent testing;

- Evaluation of the suitability of hot blown air equipment to remove frost at extreme low temperatures;

- Evaluation of the suitability of equipment which blows air to remove snow;

- Determination of the environmental limits for use of hot water as a de-icing fluid;

- Evaluation of a remote sensor to detect contamination on wing surfaces;

- Determination of the pattern of fluid run-off from the wing during take-off; and

- Determination of wing temperature profiles during and after the de-icing operation.

The research activities of the program conducted on behalf of Transport Canada during the 1994/95 winter season are documented in four separate reports. The titles of these reports are as follows:

- TP 12595E Aircraft Full-Scale Test Program for the 1994/95 Winter;
- TP 12653E Hot Water De-Icing Trials for the 1994/95 Winter;
- TP 12654E Aircraft Ground De/Anti-icing Fluid Holdover Time Field Testing Program for the 1994/95 Winter; and
- TP 12655E Forced Air De-Icing Trials for the 1994/95 Winter.

Three additional reports were produced as a part of this research program. The titles of these reports are as follows:

- TP 12676E Consolidated Fluid Holdover Time Test Data;
- TP 12677E Consolidated Research and Development Report; and
- TP 12678E Methodology for Simulating a Cold-Soaked Wing.

This report TP 12655E addresses the objective of determining the suitability of heated blown air to remove frost in cold ambient temperatures (Part I), and evaluating the use of forced ambient temperature air for snow removal (Part II).

The completion of this program could not have occurred without the assistance of many individuals and organizations. APS would therefore like to thank the Dryden Commission Implementation Project, Transportation Development Centre, the Federal Aviation Administration, the National Research Council, Atmospheric Environment Services, Transport Canada and the fluid manufacturers for their contribution and assistance in the project. Special thanks are extended to Aeromag 2000, Aerotech International Incorporated, Air Atlantic, Air Canada, Calm Air, Canadian Airlines International, CanAir Cargo and United Airlines for their cooperation, personnel and facilities.

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16. Abstract

Research reports produced on behalf of Transport Canada for testing during previous winters are available as follows: TP 11206E 1990/91; TP 11454E 1991/92; TP 11836E 1992/93; and 1993/94 Summary Report submitted to DCIP. Seven reports (including this report) were produced as part of the 1994/95 research program: TP 12595E Full-Scale Tests; TP 12653E Hot Water; TP 12655E Forced Air; TP 12654E Holdover Time Substantiation; TP 12676E Consolidated Holdover Time Data; TP 12678E Methodology for Simulating a Cold-Soaked Wing; and TP 12677E Consolidated Research and Development.

This study was composed of two separate projects, with the first (Part I) addressing the application of hot blown air to remove frost from wing surfaces in very cold temperatures, and the second (Part II) evaluating the effectiveness of developed equipment using blown air at high velocity to remove snow and ice.

Part I - Heated Air

Removal of frost deposits from wing surfaces in very low ambient temperatures in Northern operations is an unresolved problem. This research evaluates the suitability of hot blown air as a frost removal agent. Trials utilising a ground heater fitted with a test nozzle showed that a feasible solution could be developed based on existing ground heaters.

It is recommended that research and development be conducted:

- to determine the acceptability of removal of frost by sweeping;
- to determine the implication of defrosting only the forward part of the wing;
- to develop a fully engineered nozzle for defrosting with heated air.

Part II - Forced Air

The common practice of de-icing loose snow by spraying heated de-icing fluid has cost, environmental impact and operational characteristics that encourage a search for alternatives. United Airlines has developed a forced air de-icing process that plays an active role in their operations at Denver, Colorado. A commercial version of this equipment has been developed and Canadian Airlines International installed two units on de-icing vehicles for operational evaluation. The equipment has not yet been evaluated due to lack of snow conditions. Positive results of United Airlines experience and observations on the CAI installation are reported.

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Voir le résumé

16. Résumé

Transports Canada a fait produire les rapports de recherche suivants sur les essais menés durant les hivers précédents : TP 11206E pour 1990-1991; TP 11454E pour 1991-1992; TP 11836E pour 1992-1993 et le rapport sommaire pour l'année 1993-1994 présenté au Comité de mise en oeuvre de la Commission Dryden. Concernant le programme de recherche mené durant l'hiver de 1994-1995, les sept rapports suivants (y compris le présent) ont été produits : TP 12595E Full-Scale Tests; TP 12653E Hot Water; TP 12655E Forced Air; TP 12654E Holdover Time Substantiation; TP 12676E Consolidated Holdover Time Data; TP 12678E Methodology for Simulating a Cold-Soaked Wing et, enfin, TP 12677E Consolidated Research and Development.

La présente recherche est séparée en deux : la partie I concerne le soufflage d'air chaud pour le dégivrage des ailes par temps très froid et la partie II, l'évaluation de l'efficacité des équipements conçus pour souffler un courant d'air animé d'une grande vitesse sur les ailes d'un avion afin de les débarrasser de la neige et du givre les recouvrant.

Partie I - Soufflage d'un courant d'air chaud

Le dégivrage des ailes d'un avion par temps très froid a toujours été et demeure un problème aigu. La recherche visait à approfondir l'utilité du soufflage d'air chaud comme moyen de dégivrage. Les essais faits avec un générateur d'air chaud standard équipé d'une tuyère adéquate montre que la solution consisterait à tirer parti des appareils qui existent déjà.

Il est recommandé de poursuivre les recherches dans le but :

- de déterminer dans quelle mesure on pourrait se suffire d'une action de balayage;
- de déterminer les conséquences d'un dégivrage se limitant à la partie amont de l'aile;
- d'étudier une tuyère convenant à la technique de dégivrage par soufflage d'air chaud.

Partie II - Soufflage d'un courant d'air forcé

Enlever la neige non durcie à l'aide d'un liquide dégivrant chaud est une pratique courante, dont le coût, l'impact sur l'environnement et l'effet sur les opérations aéroportuaires sont tels qu'une solution de rechange est devenue nécessaire. United Airlines a mis au point un matériel de dégivrage par soufflage d'air forcé, que cette compagnie utilise à bon escient à l'aéroport de Denver (Colorado). Une version commerciale de ce matériel a été mis au point. Les Lignes aériennes Canadien International (CAI) en ont commandé deux qu'elle a fait monter sur des véhicules de dégivrage pour en faire l'évaluation en service. Cette évaluation ne s'est pas encore faite pour cause d'insuffisance de neige. Le rapport présente les résultats probants chez United Airlines ainsi que les observations concernant l'installation de ce matériel par CAI.

17. Mots clés Aéronefs, neige, fluide, durée d'efficacité, dégivrage, glace, givre, air forcé, air chaud	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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EXECUTIVE SUMMARY

This two–part report addresses the use of heated air to remove frost in cold ambient temperatures, and the use of forced ambient temperature air for snow removal.

PART I - HEATED AIR

Removal of frost deposits from wing surfaces in very cold ambient temperatures (–35°C and below) has remained an unresolved problem. At these temperature extremes, application of de–icing fluids is not practical and other approaches such as hangaring aircraft or applying wing covers are not always feasible. Partial removal of frost by sweeping does not satisfy regulatory requirements, but is practiced in the absence of any other solution.

Recognizing that a practical and economical solution would benefit a great number of operators, Transport Canada requested APS Aviation Inc. to evaluate the suitability of hot blown air as a frost removal agent. Ideally this would be based on modifications of available equipment to keep costs low.

Calm Air International volunteered to co–operate in an attempt to find a resolution to the problem, and Aerotech International Incorporated of Winnipeg, manufacturer of the Aerotech Herman Nelson heater, offered to assemble an air nozzle for trial purposes. The trials consisted of determining the most effective prototype nozzle outlet configuration, and thereafter evaluating the efficiency and operational acceptability of applying heated air. Trials were held at Thompson, Manitoba, on 9 February 1995 in an outside air temperature of –25°C.

Test Results

Initial trials showed the best approach to be to first remove as much as possible of the surface frost by sweeping, and then apply hot air with a small nozzle setting.

Sweeping of the entire wing outboard of the engine was accomplished in about two minutes. Subsequent removal of frost with heated air took 15 minutes. The result of the process was a clean wing surface.

Conclusions

Utilizing existing ground heaters as a source of hot air and fitting them with well–designed nozzles to deliver this air to the wing surface appears to be a feasible and economical solution.

Operational concerns include the speed of frost removal, the size and physical handling characteristics of the air application equipment, and the need to operate from the top of the wing.

An initial sweeping of the frost surface makes the defrosting process more efficient, resulting in a faster overall operation and a cleaner surface.

Further elevation in delivered air temperature above 82°C (180°F) also enhances the result, in terms of both surface condition and speed of operation. Discussions with aircraft manufacturers identify the upper limit as 93°C (200°F).

Recommendations

The following further activities are recommended:

a) research to determine the implication on loss of lift caused by the frost film remaining after the "sweep to shine" procedure. If it can be shown that "sweep to shine" results in only a minimal loss of lift or if a procedure can be developed to accommodate any negative effects due to residual frost, then "sweep to shine" could become an approved procedure;

b) further experimental research to confirm the implication of defrosting only the forward part of the wing. Research results have predicted that frost coverage beginning well downstream of the suction peak can cause little performance degradation;

c) depending on the result of the foregoing research, development of a properly engineered nozzle to facilitate defrosting with heated air. This design should enable the operator to handle the nozzle from the ramp.

PART II - FORCED AIR

Removal of loose snow from aircraft surfaces through the application of heated de–icing fluid is standard practice throughout the industry. The associated cost, environmental impact, and influence on airline and airport operations encourage a search for alternatives.

United Airlines has developed forced air de–icing equipment to an operational state, and that equipment is currently used in their de–icing operations at Denver, Colorado.

Bleed air from an Auxiliary Power Unit (APU) mounted on the top of a standard de–icing vehicle is delivered to an operator–controlled nozzle mounted at the basket, where it is directed to remove accumulated snow. Type I fluid can be injected into the air stream on demand, allowing a thin layer of fluid to be dispensed over the wing to remove frost.

World Auxiliary Power Company (WAPCO) has developed a forced air equipment kit that may be mounted on customer's de–icing vehicles, and Canadian Airlines International (CAI) arranged for two of these kits to be installed on de–icing vehicles at Toronto's Pearson International Airport during the 1994/95 winter season for evaluation.

APS Aviation was requested to participate in this evaluation and developed an approach to gather data and record observations during actual operations.

Two forced air de–icing kits, without the fluid injection feature, were installed ready for operation in late February '95. The remainder of the winter season offered no snow, and the winter season terminated with the units not seeing service in CAI operations.

The equipment is being retained to gather operational experience during the 1995/96 winter season.

Conclusions

Observations and staff reports during a site visit to United Airlines at Denver indicate that forced air equipment can play a valuable role in removal of snow and frost.

The United Airlines procedure consists of a two–step operation: first removing accumulated snow from overnight aircraft at off–gate parking locations, and then directing the aircraft through fluid de–icing positions following dispatch from the gates. A single unit is adequate for their Denver operation.

Removal of frost with the Type I fluid injection feature appears to offer significant benefits and reduces the amounts of fluid dispensed.

Recommendations

It is recommended that the Canadian Airlines International evaluation program be supported in the 1995/96 winter season. Relocation of at least one unit to a more severe weather location, such as Dorval airport at Montreal, would increase opportunities for operational use and data gathering.

It is recommended that the two units be retrofitted with the fluid injection feature if possible, to evaluate effectiveness of frost removal.

SOMMAIRE

Ce rapport en deux parties décrit une technique de soufflage d'air chaud pour le dégivrage des avions par temps froid et une autre sur le soufflage d'air forcé à température ambiante pour débarrasser les ailes des avions de la neige accumulée.

PARTIE I - SOUFFLAGE D'UN COURANT D'AIRE CHAUD

Le dégivrage des ailes d'un avion par temps très froid (- 35 °C) a toujours été et demeure un problème aigu. À ces températures extrêmes, les agents dégivrants sont inopérants, alors que les autres techniques telles que la mise sous hangar de l'avion ou la protection des ailes de celui-ci par des couvertures ne sont pas toujours faciles à mettre en oeuvre. Le dégivrage partiel par balayage contrevient au règlement, mais on y a recours quand même faute d'autre moyen.

Devant la nécessité de trouver une solution à la fois pratique et économique qui profitera à nombre d'exploitants, Transports Canada a confié à APS Aviation Inc. le mandat d'approfondir l'utilité du soufflage d'air chaud comme moyen de dégivrage, en faisant appel, dans un but d'économie, à des matériels existants dûment modifiés.

Calm Air International s'est proposée de s'atteler à cette tâche tandis que Aerotech International Incorporated de Winnipeg, qui fabrique les générateurs d'air chaud Herman Nelson, a accepté de réaliser la tuyère nécessaire aux essais. Le but de ces essais était d'abord de trouver la meilleure configuration à donner au prototype de la tuyère et ensuite d'évaluer sur le plan pratique l'efficacité du soufflage d'air chaud comme moyen de dégivrage. Les essais ont eu lieu à Thompson (Manitoba) le 9 février 1995 par une température de - 25 °C.

Résultats des essais

Les essais préliminaires montrent que la meilleure façon de procéder est d'abord d'utiliser la technique de balayage pour enlever le maximum de givre et ensuite de souffler de l'air chaud par la tuyère ouverte au minimum.

Le balayage depuis le moteur jusqu'à l'extrémité de l'aile n'a pris que deux minutes et le dégivrage à l'air chaud, 15 minutes. Il en est résulté une surface d'aile bien nette.

Conclusions

La solution la plus pratique et la plus économique serait de recourir aux générateurs d'air chaud existants, équipés d'une tuyère conçue pour souffler de l'air chaud sur les ailes de l'avion.

Les contraintes à prendre en compte sont le temps pris par la manoeuvre, l'encombrement et la manutention du générateur d'air chaud et la nécessité de grimper sur l'aile pour effectuer la manoeuvre.

Il a été constaté qu'un balayage préalable favorise le dégivrage, qui se fait alors plus rapidement, laissant une surface plus nette.

Le dégivrage sera encore plus rapide, laissant une surface encore plus nette, si la température de l'air à la sortie de la tuyère dépasse 82 °C (180 °F). Des conversations avec des avionneurs ont fait ressortir qu'il ne fallait cependant pas dépasser 93 °C (200 °F).

Recommandations

Il est recommandé de lancer les actions complémentaires suivantes :

d) approfondir les conséquences de la perte de portance due au givre demeurant après l'opération «balayage jusqu'à faire briller». Si on parvient à montrer que ce givre résiduel n'entraîne qu'une faible perte de portance, ou si on trouve un moyen permettant de compenser tout effet négatif dû au givre résiduel, alors la procédure de «balayage jusqu'à faire briller» pourrait devenir réglementaire;

e) approfondir les conséquences d'un dégivrage se limitant à la partie amont de l'aile. Des recherches ont montré que, sur le plan théorique, la portance souffre peu de la présence de givre bien à l'arrière de la région de dépression maximale;

f) à la lumière des résultats des actions précédentes, étudier un tuyère optimisant la technique de soufflage d'air chaud et grâce à laquelle le dégivrage de l'aile pourrait se faire à partir du sol.

PARTIE II - SOUFFLAGE D'AIR FORCÉ

Enlever la neige non durcie à l'aide d'un liquide dégivrant chaud est une pratique courante, dont le coût, l'impact sur l'environnement et l'effet sur les opérations aéroportuaires sont tels qu'une solution de rechange est devenue nécessaire.

United Airlines a mis au point un matériel de dégivrage par soufflage d'air forcé, que cette compagnie utilise à bon escient à l'aéroport de Denver (Colorado).

De l'air prélevé d'un groupe auxiliaire de puissance placé au sommet d'un véhicule de dégivrage réglementaire est amené jusqu'à une tuyère qui, à partir d'une nacelle, sert à débarrasser les ailes de la neige accumulée. Il est possible aussi d'injecter dans le courant d'air forcé du liquide dégivrant de type I qui se déposera en couche mince sur l'aile pour la dégivrer.

La compagnie World Auxiliary Power Company (WAPCO) a mis au point un appareil de soufflage d'air forcé qui peut être monté sur les véhicules de dégivrage. Les Lignes aériennes Canadien International (CAI) en ont commandé deux dans le but de les mettre en service expérimental à l'aéroport international de Toronto durant l'hiver 1994-1995.

APS Aviation, invité à participer à cette évaluation, a organisé la collecte de données et l'enregistrement des opérations.

Deux véhicules de dégivrage équipés de l'appareil de soufflage d'air forcé sans injection de liquide dégivrant étaient prêts à fonctionner vers la fin de février 1995. Mais, comme la neige a fait défaut, CAI n'a pas eu l'occasion de s'en servir.

Ce matériel sera gardé en vue de son utilisation l'hiver suivant.

Conclusions

Les observations faites durant une visite aux installations de la United Airlines à Denver, ainsi que les rapports circonstanciels rédigés, montrent que l'enlèvement de la neige et du givre par soufflage d'air forcé pourrait devenir une technique valable.

La technique mise au point par United Airlines se fait en deux temps : d'abord enlèvement de la neige accumulée durant la nuit, dans l'aire de stationnement et à l'écart de l'aérogare; ensuite passage de l'avion chargé de ses passagers par un poste de dégivrage réglementaire. L'aéroport de Denver se suffit d'un seul de ces postes.

L'injection d'un liquide de dégivrage de type I dans le courant d'air soufflé semble porteuse d'avantages très intéressants, notamment la possibilité de réduire les quantités de liquide utilisées.

Recommandations

Il est recommandé que le programme d'évaluation lancé par les Lignes aériennes Canadien International soit reconduit pour l'hiver 1995-1996 et qu'au moins un des deux appareils soit déplacé vers un aéroport où l'enneigement est plus intense, celui de Dorval (Montréal), par exemple, afin d'augmenter les possibilités de le faire fonctionner en service et de recueillir des données suffisantes.

Il est recommandé aussi que, dans la mesure du possible, ces deux appareils soient munis en rééquipement de la fonction d'injection de liquide dégivrant, dans le but d'évaluer l'efficacité de ces appareils dans ce rôle.

SECTION NUMBER | **PAGE NUMBER**

APPENDICES

PHOTO NUMBER | **PAGE NUMBER**

LIST OF ACRONYMS

AES	Atmospheric Environment Services (Canada)
APS	APS Aviation Inc.
APU	Auxiliary Power Unit
BTU	British Thermal Units
CAI	Canadian Airlines International
CFM	Cubic Feet Per Minute
DCIP	Dryden Commission Implementation Program
DIA	Denver International Airport
KTS	Knots
NRC	National Research Council
OAT	Outside Air Temperature
TDC	Transportation Development Centre
UA	United Airlines
WAPCO	World Auxiliary Power Company
WX	Weather

PART I - HEATED AIR

1. INTRODUCTION

1. INTRODUCTION

A problem common to many operators in Northern operations is the removal of frost from wing surfaces in very cold ambient temperatures (-35°C and below). Characteristics of the operation along with extreme low temperatures combine to preclude frost removal/prevention procedures that are standard approaches elsewhere:

- at these temperature extremes, application of de-icing fluids is not practical as the fluid freeze points (with the required 10°C buffer) have been approached or surpassed;

- prevention of frost formation by hangaring aircraft is not always possible;

- wing covers have been extensively tested but do not offer a complete solution, being difficult and in some situations dangerous to install and remove. Frost sometimes forms underneath the wing cover;

- removal of frost crystals through sweeping (referred to as the "sweep to shine" method) results in a surface that is considerably smoother than the undisturbed frost, but does leave behind a thin film adhering to the wing.

Recognizing this unresolved common problem and the benefit that a practicable and economical solution would bring to a great number of operators, Transport Canada requested APS Aviation Inc. to evaluate the suitability of hot blown air as a frost removal agent at these very cold temperatures.

A search of technical literature was undertaken to locate any documentation on any previous related research or on actual application in service, but met with no success.

In searching for a practical solution to the problem, the economic impact of introducing new equipment was recognized and priority was given to finding a solution based on existing equipment. This search narrowed itself down to ground heaters that are available at many airports throughout the North and to a method of delivering air to the wing surface from such a source.

Calm Air International, a Canadian passenger airline with much experience in Northern operations, volunteered to cooperate in an attempt to find a solution to the problem, and provided staff assistance, aircraft and ground equipment at their base at Thompson, Manitoba to evaluate effectiveness of applying hot blown air.

The problem was discussed with Aerotech International Incorporated based in Winnipeg, Manitoba who manufacture the Aerotech Herman Nelson heater, a ground heater that is well known in Arctic and Antarctic establishments throughout the globe. Subsequently Aerotech offered to assemble a nozzle for trial purposes.

During a preliminary site visit, an attempt was made to remove frost from an aircraft surface that had accumulated a heavy coating of hoar frost overnight, using a Calm Air owned Herman Nelson heater.

From these preliminary trials, desired characteristics of an air nozzle were given to Aerotech Herman Nelson who then manufactured and provided a prototype nozzle for evaluation trials.

The objective of the trials was to evaluate the suitability of hot blown air as a frost removal agent at very cold temperatures (see Appendix F for the work statement). The first phase of the trial consisted of determining the most effective nozzle outlet configuration of the variable air nozzle. The second phase evaluated the effectiveness of the hot air nozzle in removing frost, giving attention to the resultant condition of the wing surface, the time required for defrosting and equipment handling characteristics.

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2. METHODOLOGY

2.1 Site

2.2 Equipment

2.3 Trial Procedures and Data Forms

2.4 Participants

2.5 Evaluation Methodology

2. METHODOLOGY

The methodology description deals with the site, equipment, trial procedures and data forms, participants, and evaluation methodology. The test procedure used during the Calm Air trials is included as Appendix A.

2.1 Site

The trial was performed on the ramp of the Calm Air maintenance hangar at Thompson airport in northern Manitoba on February 09, 1995. Thompson typically experiences low temperatures in the range of concern throughout January and February. Because of the dependable nature of Thompson's climate and because it is accessible by road, it is frequently used by North American car manufacturers as a cold weather test site.

Meteorological data was obtained from the local flight services office.

The aircraft was parked close by the hangar enabling running of electrical power extension cords for the video camera operator. This was required as the camera batteries would quickly run down in the cold temperature which was the experience of the battery powered scissor lift used by the camera operator.

2.2 Equipment

Calm Air International, arranged to park a HS-748 aircraft outdoors overnight to accumulate frost. The low overnight temperature was -29°C (-20°F).

An Aerotech Herman Nelson BT400 heater owned by Calm Air was used as the source for heated blown air for the trial. Specifications for this heater include heat output of 400,000 British Thermal Units (BTU) per hour at -54°C (-64°F), air delivery rate maximum 1500 cubic feet per minute (CFM)/minimum 600 CFM, and hand selected temperature control 65°C (150°F) to 138°C (280°F). Photos 1 through 4 on the following pages reflect the type of heater used in the trial.

A preliminary trial to remove frost from an aircraft surface had been conducted using both the 30 cm (12") and 15 cm (6") ducts that are standard to the heater. That trial had identified that the larger heater duct provided the best results, giving a more vigorous flow of heated air. The ducts were used without nozzles and both had to be held against the wing surface to achieve results. Nozzle specifications resultant from this trial included an interface to the 30 cm (12") duct, a nozzle cross-sectional area reflecting that of the duct to avoid back-pressure and support a strong flow of air, and a variable outlet to enable evaluation of accelerating the air flow via a constriction at the nozzle exit. Photos of the prototype nozzle developed for the trial follow (Photos 1 and 2).

The final variable nozzle sizes on the delivered prototype were; 43 cm x 9 cm (17" x 3.5"), 43 cm x 7 cm (17" x 2.75"), 43 cm x 4.5 cm (17" x 1.75") and 43 cm x 2.5 cm (17" x 1.0").

A Calm Air HS-748 aircraft was made available for the trial along with sufficient stands to enable observation of the process and the wing surface conditions. A battery powered scissor lift was made available to the video camera operator to enable a clear view of the process and the wing surfaces.

PHOTO 1
HOT AIR NOZZLE

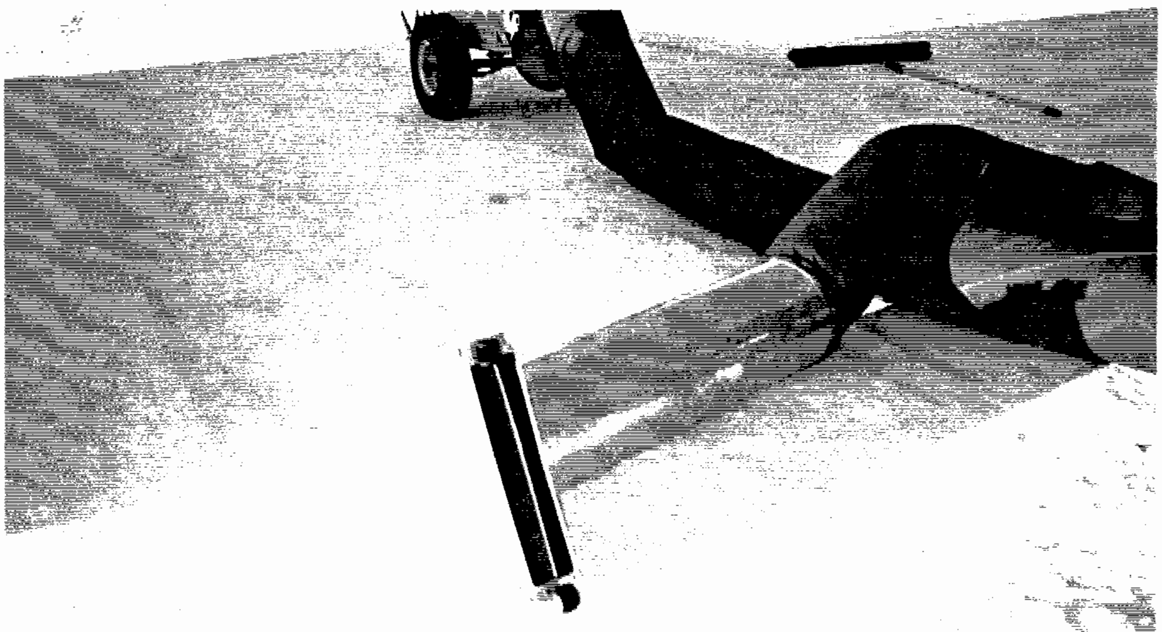


PHOTO 2
HOT AIR APPLICATION EQUIPMENT

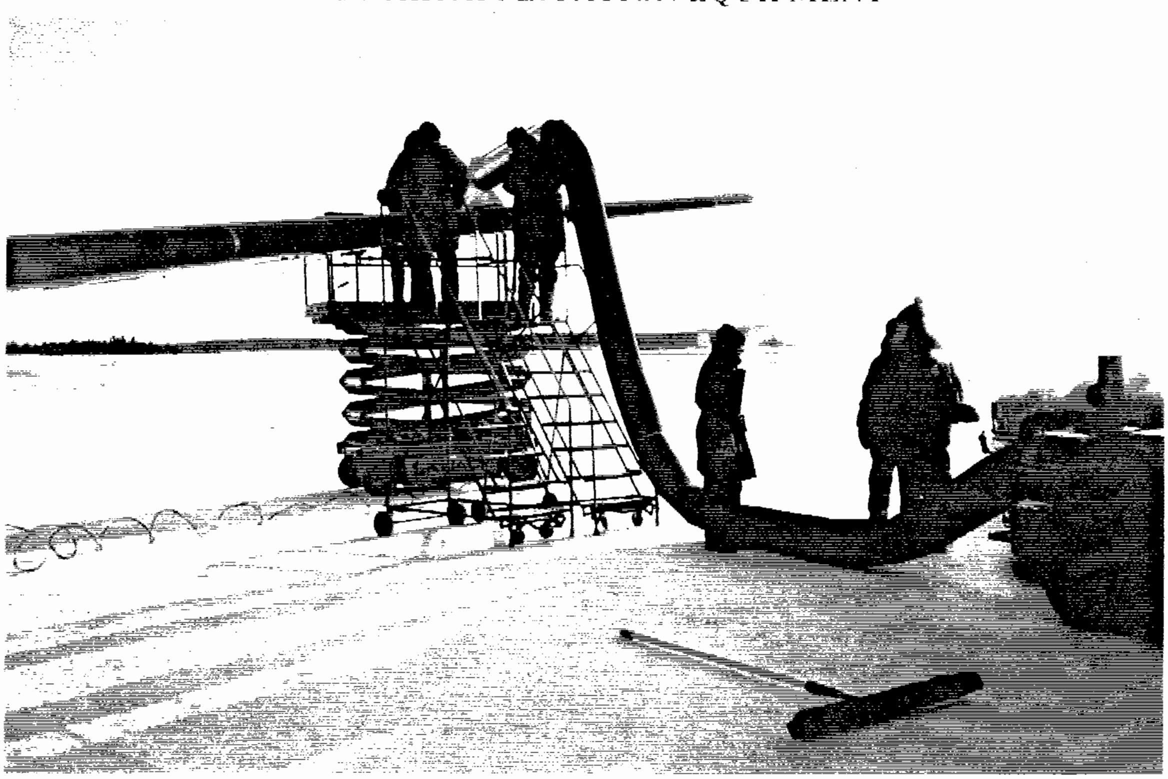


PHOTO 3
FROST REMOVAL WITH HOT AIR

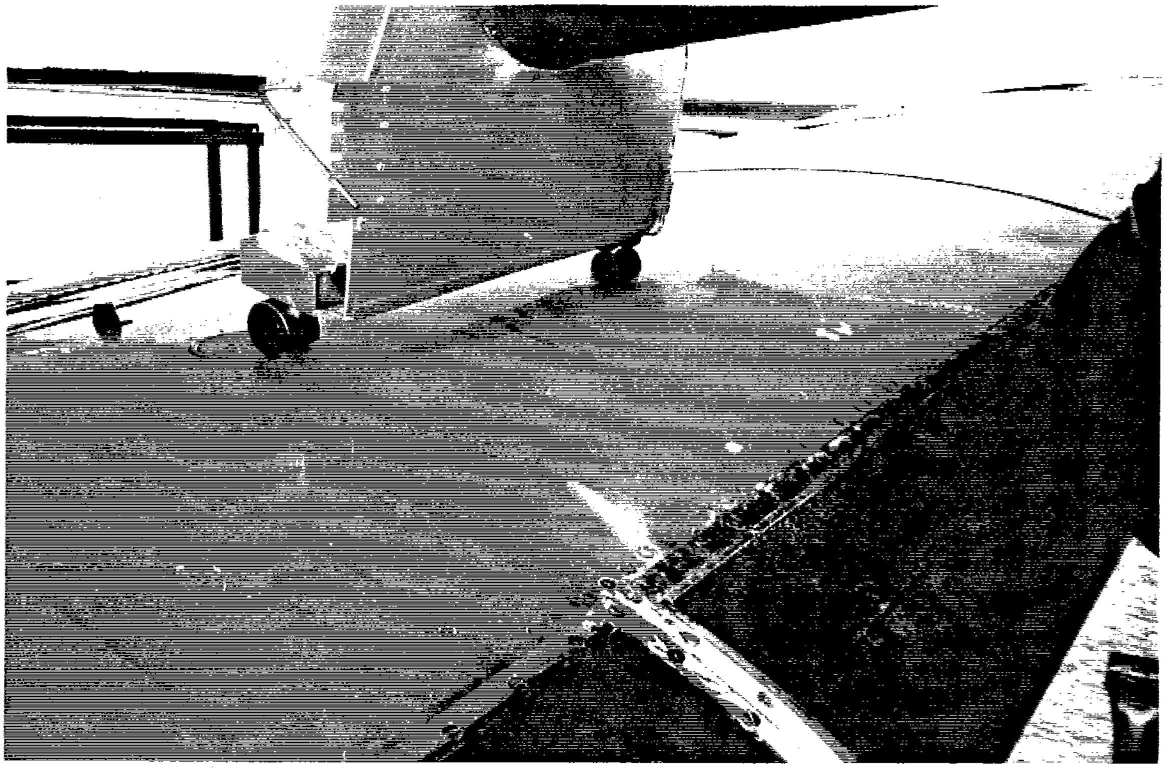
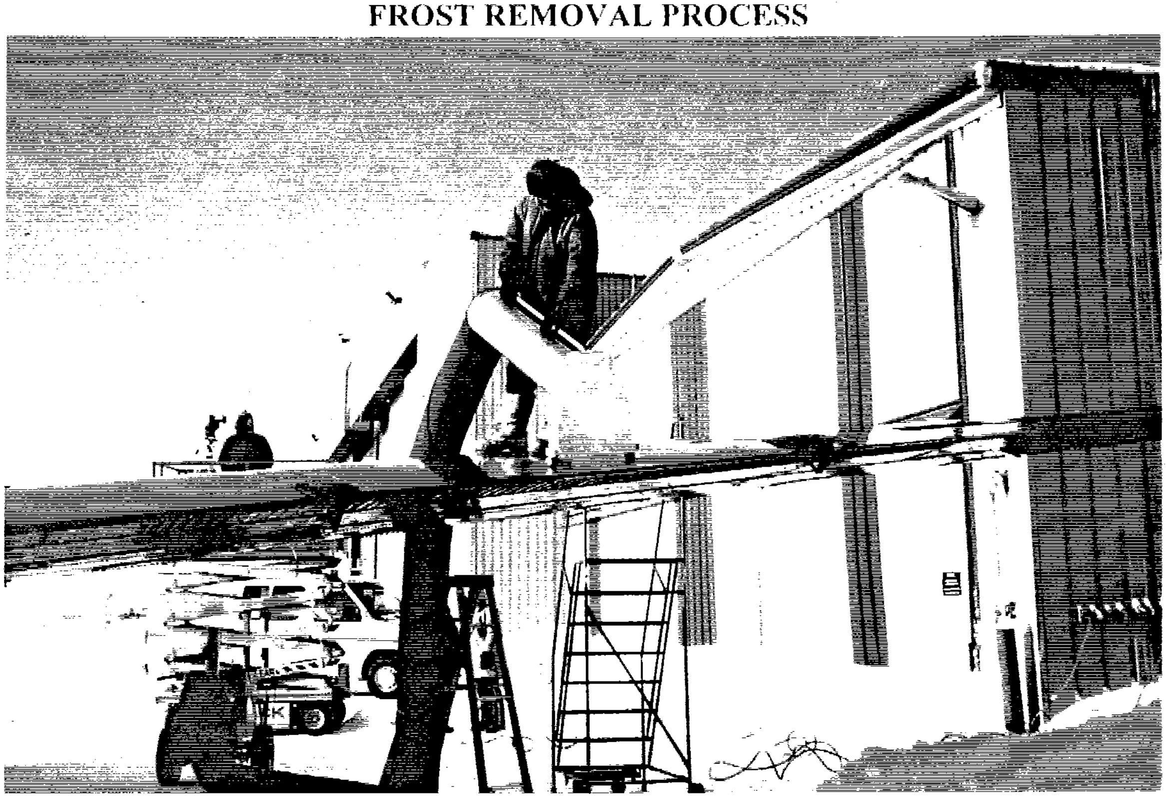


PHOTO 4
FROST REMOVAL PROCESS



A Cole-Parmer thermocouple thermometer was used to measure temperature of the forced air at the nozzle outlet. While this instrument performed well in measurement of the blown air temperature, it was not possible to obtain readings of wing skin temperature during the hot air application due to the rapid drop as the hot air flow was moved away.

2.3 Trial Procedures and Data Forms

The trials consisted of first determining the most effective nozzle outlet configuration of the prototype air nozzle provided, and there after evaluating its effectiveness in removing frost, and its operational acceptability.

Blown air temperature was controlled to deliver a nozzle outlet temperature as close as possible to, but not exceeding, 82°C (180°F). This limit had been established as a test parameter to protect against any risk of wing skin damage.

The variables in the trial were:

- setting the air nozzle to each of the variable nozzle positions to determine which produces the most desired effect;
- conducting the trial on both undisturbed frost deposits and on frost which had been swept, to evaluate the difference in resultant wing surface and operational impact.

Data forms were used to record results of each attempt, as well as current weather conditions.

In conducting these trials, the operator was positioned on an aircraft stand at the leading edge of the wing, from where he controlled the application of hot blown air from the rear of the wing forward (Photos 2 and 3).

Sweeping of the frost surface prior to application of hot air was conducted with a push broom from the stand position. The broom was stated to be typical of the type of broom commonly used for this type of procedure.

The video camera operator was positioned at the rear of the wing from where a clear view of wing surface conditions could be captured as well as the application process.

Temperature of the ejected air at the nozzle was initially measured with each trial until it was established that no significant change was being experienced. Measurement of wing skin temperature during the application process was attempted but much difficulty was experienced in obtaining reliable measures.

The wing surface was observed during each trial, watching for any formation of water droplets or rivulets, or for any movement of melt water into cavities.

The trials in the first phase were confined to the port wing of the test aircraft thereby leaving the entire frosted wing available for the second phase of the test. This second phase with the starboard wing was to evaluate operational times to clear entire wing surfaces and identify any physical handling limitations of such a process.

In the second phase the operators followed procedures as close as possible to those that would be experienced in an actual operation. This phase was conducted with a swept surface using that portion of the wing outboard of the engine. The sweeping activity involved the operator getting up on top of the wing via a ladder, and then sweeping the frost moving outward toward the wing tip (Photo 4).

The heater and ducting were positioned by a second man and the nozzle passed up to the operator on the wing who then proceeded to remove the remaining frost while working outwards toward the wing tip.

This process was timed in its entirety to capture set-up elements as well as the actual defrosting activity. The entire process was also captured on video.

As a final trial, the portion of the wing inboard of the engine was defrosted from an undisturbed state of frost using an elevated nozzle air temperature of 110°C (230°F). The intent of this trial was to assess the impact of the higher temperature both on the time taken and on the resultant wing surface condition, as well as to observe the wing surface for any evidence of bulging between rivet lines. The nozzle was kept in constant motion for this trial to avoid concentration of heat on the wing skin.

2.4 Participants

Two Calm Air maintenance employees participated as operators in the trials. Observers included staff from APS and DCIP, as well as a video camera operator contracted for the project.

2.5 Evaluation Methodology

These trials took the form of a demonstration of effectiveness of different air nozzle configurations to remove frost. The results of each attempt were assessed by visual observations of the wing surface condition and hand touching following de-frosting and observations of the physical procedure, as well as by noting the time taken. Operator comments was a very important element in the overall evaluation.

3. OBSERVATIONS AND DISCUSSION

3.1 Relative Effectiveness of Nozzle Settings

3.2 Relative Impact of Swept versus Unswept Frost Surface

3.3 Evaluation of Operational Suitability

3.4 General Observations on Nozzle Design

3.5 General Discussion on Suitability of Approach

3. OBSERVATIONS AND DISCUSSION

Weather conditions during the trials were:

OAT	-25°C
Wind	5 kts gradually increasing to 12 kts with gusts to 18 kts
Relative Humidity	62% dropping to 52%

The degree of frost accumulated on the wing at the start of the test was assessed as light frost. Frost formations were scattered with areas of bare wing between deposits. There was very little frost on the outer 20% of the wing.

3.1 Relative Effectiveness of Nozzle Settings

The four nozzle settings produced the following results:

Setting	Observation
43 cm x 9 cm (17" x 3.5")	Produced a dry surface; very slow operation
43 cm x 7 cm (17" x 2.75")	Dry surface but a few water rivulets
43 cm x 4.5 cm (17" x 1.75")	Dry surface but a few water rivulets; somewhat faster operation
43 cm x 2.5 cm (17" x 1.0")	A few more water droplets and rivulets but still generally a dry surface; fastest operation

None of the settings resulted in melted frost running into wing cavities and re-freezing.

3.2 Relative Impact of Swept versus Unswept Frost Surface

The surface condition following sweeping was smoother than the unswept condition. Passing the bare hand on the wing could identify presence of a thin layer of frost with some roughness remaining.

With all nozzle settings the defrosting process of the swept surface was consistently faster than that of the unswept, and left behind fewer water droplets.

3.3 Evaluation of Operational Suitability

The approach selected for testing in this phase involved first removing as much as possible of the surface frost by sweeping, and then applying hot air with the smallest nozzle setting.

Sweeping of the entire wing outboard of the engine was accomplished in about two minutes. The sweeping action could be seen to remove frost crystals which were brushed off the edge of the wing. The remaining frost layer was quite thin (visually estimated at less than one millimetre), but was still quite visually apparent and its presence identifiable by a touch test. A video of the test process is available which indicates the condition of frost on the wing surface before and after sweeping.

Removal of frost on a major portion (about 80%) of the wing outboard of the engine took 15 minutes. The result of the process was a dry wing surface, with no problem of melted frost re-freezing in wing cavities.

Extending the time for the test area to an entire wing, and including time allowance to reposition equipment, indicates that the prototype trial equipment would require about 27 minutes per wing on the HS-748 aircraft for the test conditions.

After adjusting the heater temperature control and stabilizing the delivered air temperature at 110°C (230°F), the wing area inboard of the engine was defrosted from an undisturbed frost condition. The additional heat resulted in a dry surface with no rivulets but occasional water droplets left behind. Time taken was 7 minutes.

The physical handling of the equipment was awkward, primarily due to the size and bulkiness of the 30 cm (12") ducting involved and to the need to operate from on top of the wing. The operation required two men; one on the wing performing the defrosting, and the other on the ground to hand up the nozzle and to reposition the heater and ducting as the operation progressed.

3.4 General Observations on Nozzle Design

The 30 cm (12") ducting tended to develop kinks resulting in pinched air flow. This was particularly true directly behind the interface with the nozzle where the ducting drooped immediately and caused significant pinching of air flow.

When held at an operating angle, the front edge of the nozzle was further than the back edge from the wing surface. This gap was further exaggerated by the caster wheels that were installed on the side lips of the nozzle to support it off the wing (see Photo 3). The result was that some of the air flow escaped laterally instead of being directed vertically downwards onto the wing surface.

3.5 General Discussion on Suitability of Approach

While the trial showed that heated air can be used to achieve a clean wing by removing frost from wing surfaces during very cold temperatures, it also pointed out the importance of properly engineering the air application equipment to satisfy user needs.

The nozzle developed for the trial was not intended to represent a final design but it did identify particular areas of operational, technical and ergonomic concern that would need to be addressed in a final solution; specifically:

- reducing the time required to perform the operation; considerations include air outlet temperature; plus elimination of constrictions and other sources of weakened air flow;

- reducing awkwardness of handling of equipment; primarily due to the size of nozzle resultant from linking with a 30 cm (12") duct and the mass of the duct itself;

- eliminating the requirement for the operator to be positioned on top of the wing to perform the defrosting process.

While it is well known that naturally occurring frost significantly degrades take-off performance, the roughness of the frost layer remaining after following the "sweep to shine" procedure was observed to be considerably reduced. Whether it has been reduced sufficiently to avoid serious degradation of performance for the various kinds of aircraft flown in Northern operations, remains to be established. Providing the results are acceptable from an aerodynamic and safety perspective, the simplest solution to defrosting in very cold temperatures would appear to be the "sweep to shine" approach.

Kind and Lawrysyn [(1)] research results predicted that frost coverage beginning at or near the suction peak causes serious degradation of airfoil, wing and take-off performance, while frost formation beginning well downstream of the suction peak, say at one-quarter chord, causes little performance degradation.

1 Kind, R.J. and Lawrysyn, M.A. - *Performance Degradation due to Hoar Frost on Lifting Surfaces* Canadian Aeronautics and Space Journal June 1992 pp. 62-70

4. CONCLUSIONS

4. CONCLUSIONS

Trials showed that heated forced air as provided by a ground heater is a suitable agent to remove frost from a wing surface, producing dry wing surfaces without problems of melted frost refreezing in wing cavities. Utilizing existing ground heaters as a source of hot air, fitted with well designed nozzles to deliver air to the wing surface, appears to be a feasible and economical approach to the problem.

Two operators using a prototype unit would have taken 27 minutes to clean one wing.

Concerns to be addressed in the development of an operationally acceptable system include the speed of frost removal, the size and physical handling characteristics of the air application equipment, and the need to operate from the top of the wing.

The efficiency of the defrosting process may be enhanced by an initial sweeping of the frosted surface, resulting in a faster overall operation and a cleaner surface.

Further elevation in air temperature above 82°C (180°F) may also enhance the result, leaving fewer water droplets on the wing surface. Discussions with aircraft manufacturers identify the upper temperature limit to be 93°C (200°F).

Considerations in design of an air delivery nozzle design include:

- a maximum concentrated air flow;
- a streamlined air delivery system ducting with smooth and gradual transitions to minimize loss of pressure;
- support to prevent kinking and drooping of the ducting;
- a nozzle support that brings all air nozzle edges close to and equidistant from the wing surface;
- a fringe or curtain around the nozzle edges to prevent lateral escape of blown air.

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5. RECOMMENDATIONS FOR FURTHER DEVELOPMENT

5. RECOMMENDATIONS FOR FURTHER DEVELOPMENT

A resolution to the problem could take the shape of:

a) Research to determine the implication on loss of performance caused by the frost film remaining after following the "sweep to shine" procedure. If the loss of lift is acceptable or can be offset by aircraft operating procedures, then "sweep to shine" could become an approved procedure. Research to determine the type of broom that gives best results might be in order.

If research determines that the surface roughness of the remaining frost layer after sweeping may be variable, to the degree that some variations in roughness are acceptable while others result in unacceptable loss of lift, then a means of estimating the actual degree of roughness with a definition of critical levels could be developed and provided to operators.

b) Further experimental research to confirm the implication of defrosting only the forward part of the wing.

c) Dependent on results of the foregoing research, develop a properly engineered nozzle to facilitate defrosting with heated air. This design should have an objective of enabling the operator to handle the nozzle and apply heated air to the critical area from the ground, if possible.

Development should incorporate the highest acceptable temperature of delivered air at the nozzle, with a view to enhancing the efficiency of the frost removal process.

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PART II - FORCED AIR

1. INTRODUCTION

1. INTRODUCTION

Removal of loose snow from aircraft surfaces through the application of heated de-icing fluid is standard practice throughout the industry. Although effective in accomplishing its ultimate purpose of producing a clean surface, this process has particular attributes that encourage search for alternatives. These considerations include cost, environmental impact and influence on the airline and airport operation.

Over a number of seasons United Airlines has actively investigated the application of forced air to remove loose snow from aircraft, and has evolved equipment and procedures to a commendable operational state. One forced air de-icing unit is currently in use in the United Airlines de-icing operations at Denver, Colorado.

The Forced-Air de-icing system involves the application of a large mass of air directed at high velocity toward snow and frost on the aircraft surfaces. Bleed air from an Auxiliary Power Unit (APU) mounted on the top of a standard de-icing vehicle is delivered through ducting and tubing to a hydraulically controlled nozzle mounted at the operators basket, where it is directed by the operator to remove the accumulated snow. The delivery nozzle was designed by World Auxiliary Power Company (WAPCO) of Alameda, California. Type I fluid can be injected into the air stream on demand, enabling a thin layer of fluid to be dispersed over the wing. This has been found to be a very cost effective approach to removing residual frost, requiring much less fluid than the standard spraying approach.

The evolution in United Airlines operation has led to commercial development by WAPCO of a forced air equipment kit that may be mounted on customer's current de-icing vehicles.

Canadian Airlines International (CAI) arranged for two of these kits to be installed on their de-icing vehicles at Toronto International Airport during the 1994/95 winter season with the intent of evaluating the operational and economic impact on their de-icing operation.

APS Aviation was requested to participate in this evaluation. An approach was developed in conjunction with Canadian Airlines International to gather data and record observations from actual operations to support an objective analysis.

The forced air de-icing kits were delayed in delivery and finally were installed ready for operation in late February 1995. The equipment delivered was similar to that at Denver with the exception that de-icing fluid injection was not included, thereby excluding the opportunity to test the equipment on frost removal.

The remainder of the winter season following delivery failed to offer any significant snow conditions, and the winter season terminated with the units not seeing service in CAI operations.

The equipment is being retained to gather operational experience during the forthcoming winter 1995/96 season.

A technical literature search for information on previous attempts to apply forced air as a de-icing agent yielded few tangible results. Hand-held leaf blowers have been in use at some Canadian airports for several years. Operators report that they are slow and in general offer no advantage over snow removal by sweeping.

Reports of currently competing forced air delivery systems have been noted and two of these are included in Appendix B.

2. METHODOLOGY

2.1 United Airlines Site Visit

2.2 Introduction to Canadian Airlines Service

2.3 Trial Procedures and Data Forms

2.4 Equipment

2.5 Participants

2.6 Evaluation Methodology

2. METHODOLOGY

The methodology description deals with site visit to United Airlines at Denver airport, trial procedures and data forms, equipment, participants, and evaluation methodology.

2.1 United Airlines Site Visit

In preparation for introduction of the forced air equipment to the CAI de-icing operation and to assist in the development of trial procedures, the United Airlines operation at Denver was visited to review their experience to date.

That visit offered an opportunity to observe the equipment first hand as well as to operate it on a non-operational aircraft. Observations as follows on experience of the equipment in actual operation were offered by United Airlines staff.

Operation of the APU appears to be straight forward with no problems known to date. Air nozzle controls are on a joy stick at the basket, and include switches for air delivery and glycol injection as well as directional control of the air delivery boom. Control of the air delivery boom is sensitive and needs the finesse which is developed with practice. The air stream can be directed over the full wing chord from leading to trailing edge by a good operator with good technique.

An experienced de-icing operator will develop adequate skills on using forced air within two to three hours. United Airlines concentrates use of the forced air equipment to the midnight shift which automatically limits its use to fewer operators and maintains skill levels.

Noise levels are typical of an APU. United Airlines reports that noise levels have been measured and found to be within acceptable limits for ramp operations.

The air nozzle boom projects about 1.2 metres in front of the basket. Proximity to wing must constantly be kept in mind by the operator, and the de-icing truck path is maintained correspondingly further back from the wing profile.

Dry snow is removed in large clumps which fall to the ramp, and otherwise loose snow is blown vigorously about the aircraft which interferes with simultaneous work on the ramp.

The equipment works well for overnight operations where snow has accumulated on aircraft surfaces. The majority of snow is blown off at off-gate parking positions prior to towing the aircraft to the gate. At departure the aircraft is directed to a de-icing position where it undergoes the standard fluid de-icing operation but involves a much lower quantity of fluid and a decreased delay.

Similarly, overnight frost can be removed with fluid injection in the air stream using considerably less fluid than standard hose application.

The air blower is not used during operational arrivals and departures due to limited snow accumulation during ground times, and time pressures during connection banks. There are no plans for more than one forced air unit at Denver where about twenty-three United Airlines aircraft currently overnight.

A copy of the trip report is included (Appendix C).

2.2 Introduction to Canadian Airlines Service

As the forced air equipment was entirely new to the CAI operation, development of operating procedures and training was required. It was planned that a limited number of operators would be involved in order to accelerate the introduction to service and to take best advantage of the limited de-icing opportunities remaining to concentrate operator experience.

2.3 Trial Procedures and Data Forms

It was observed from the review with United Airlines that a period of operational experience would be required during which operator techniques and operating procedures might solidify, before meaningful observations and valid data gathering could take place.

As a result, data collection was divided into two phases:

Phase I was planned to collect operational data by the operators during the initial period while they developed expertise and knowledge of how best to use the equipment in the operation on different kinds of snow. Data sheets were developed for operator use, with the objective of being simple and user friendly. Sample forms are included in (Appendix D).

After some experience was gained, Phase II was planned to collect further data to enable valid evaluation of all parameters. In addition to cost factors, considerations included safety implications, effectiveness in removing snow, operational flexibility and impact on the operation, ease of use and ease of integrating into the de-icing operation. A comparison to a standard de-icing operation utilizing de-icing fluid was to be developed.

It was planned to video tape actual operations to capture equipment handling techniques as well as resultant condition of aircraft surfaces.

2.4 Equipment

The forced air de-icing kit delivered by WAPCO was similar to the installation observed at United Airlines operation in Denver, with the exception that fluid injection was not included thereby eliminating its potential for frost removal.

Comments on the installed equipment kits from a trip report March 21, 1995 (Appendix E) are summarized here.

The APU fuel tank is in an exposed location suspended under the truck chassis behind a rear wheel where it is vulnerable to damage when reversing the truck. This risk is recognized by CAI who are discussing with the manufacturer a proposal to relocate it. A post-installation modification has been installed by CAI to protect fluid lines from APU exhaust heat.

Start up of the APU is as simple as that witnessed in the United Airlines installation.

The air nozzle control joy stick used by the operator in the basket is quite sensitive giving large and rapid nozzle movements with slight pressure. CAI is confident that operators will quickly become adept at control. The distance the nozzle extends beyond the basket offers some risk of striking aircraft surface during operation and will require constant attention.

Temperature of the nozzle tubing was measured at 120°C. Temperature of the blown air about 6 inches beyond the nozzle was 55°C. CAI stated that the air temperature when it reaches the wing is close to ambient.

CAI believe the manufacturer is examining the installation of Type I fluid injection into the nozzle, as has been done with the United Airlines unit at Denver.

CAI staff present were enthusiastic about the potential of the unit and are looking forward to an opportunity to see it in action although lateness in the season may not accommodate this.

The installation is still very much of a prototype. It is not clear that the equipment could be installed on all makes and models of de-icing trucks. Candid and explicit feedback from actual de-icing operations is needed to optimize the design from an airline operators perspective.

Canadian Airlines have had no snow to practice on, and refinement of operational procedures based on actual use has still to take place.

A typical installation of the forced air de-icing equipment on a de-icing vehicle is shown in Photo 5. The photo shows the APU installation beside the boom pedestal, the ducting run along the boom, and the air nozzle located under the operator basket.

Data gathering support equipment included video equipment suited to operation in weather and temperature conditions typical to de-icing temperatures.

PHOTO 5
FORCED AIR SYSTEM INSTALLED ON CAI DE-ICER

2.5 Participants

A small body of experienced CAI de-icing operators were to be trained and assigned to the forced air de-icing units. The intent was to build up a good level of operational and equipment experience in a few operators to provide good operator techniques during data gathering events.

An alert process was put in place to contact APS Aviation and TC Project Officer for forecasted snow events to enable travel to the site in time to participate in data gathering and video taping.

2.6 Evaluation Methodology

Evaluation of equipment and process effectiveness was to be based on data gathered during actual operations, designed to enable an objective comparison to standard fluid de-icing operations. Historic data gathered from previous years operations would form part of the analysis.

Observations including video records of operations and resultant aircraft surface condition would form part of the analysis, as would feedback from de-icing operators.

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3. OBSERVATIONS AND DISCUSSION

3. OBSERVATIONS AND DISCUSSION

Due to the late delivery of the installed units along with mild weather conditions during the remainder of the winter season, the forced air de-icing equipment has not yet been used in operation.

Observations on United Airlines installation, and United Airlines user comments are recorded in Section 2.1 United Airlines Site Visit and Appendix C. Observations on the Canadian Airlines installation is reported in Section 2.4 Equipment and Appendix E.

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4. CONCLUSIONS

4. CONCLUSIONS

The experience of United Airlines as reported by their staff indicate that forced air equipment can play a definite and valuable role in removal of snow and frost from aircraft surfaces.

Observations and experience to date support the Canadian Airlines International evaluation program, which will require another winter to complete.

Utilization of the equipment at off-gate de-icing operations as practised by United Airlines appears to be the most effective application due to the constraints on manoeuvrability at gates, the resultant large amounts of snow deposited onto the ramp during aircraft loading and servicing operations, and the blowing snow conditions resulting from the operation.

A two step operation, first removing accumulated snow from over-nighting aircraft at off-gate parking locations, and then directing the aircraft through fluid de-icing locations following dispatch from gates works well for United. They have found that a single unit adequately serves this purpose for their Denver operation.

Removal of frost with the Type I fluid injection feature is reported by United Airlines to offer significant benefits associated with reduced fluid dispensed.

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5. RECOMMENDATIONS FOR FURTHER DEVELOPMENT

5. RECOMMENDATIONS FOR FURTHER DEVELOPMENT

It is recommended that support be offered to Canadian Airlines International as they continue the evaluation in the 1995/96 winter season. Potential for use of the two forced air de-icing units may be increased by relocating at least one unit to a more severe weather location such as Dorval Airport at Montreal.

It is recommended that the two units be retrofitted with the fluid injection feature if possible, to evaluate effectiveness of the unit to remove frost accumulation.

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APPENDIX A

HOT AIR TEST PROCEDURE

EXPERIMENTAL PROGRAM
TO DETERMINE SUITABILITY OF HOT BLOWN AIR
AS A FROST REMOVAL AGENT AT VERY COLD TEMPERATURES
1994 - 1995

1. OBJECTIVE

To evaluate the suitability of hot blown air as a frost removal agent at very cold ambient temperatures.

2. TEST REQUIREMENTS

In cooperation with Calm Air Intl at Thompson, Manitoba, test the effectiveness and practicability of removing frost with heated blown air at very cold temperatures (- 35° and below).

Blown air temperature will be controlled to deliver an outlet temperature as near as possible to, but not exceeding, 180 °F.

The variables in the trial will be:

- air nozzle at different outlet dimensions to vary the air speed and flow to determine which is most effective;

- conducting the trial both on undisturbed frost deposits, and separately on deposits remaining after sweeping.

The most effective combination of the above will then be subjected to time trials to establish representative times to clear complete wing surfaces.

Conditions of wing surfaces prior to trials and after each step will be noted and filmed. The entire process will be captured on video tape for future reference.

Test procedures as defined in Attachment A will apply. Data sheets Attachment C and D apply.

3. EQUIPMENT

A locally available Herman Nelson heater will be used as a source of heated forced air, producing a flow of air at controllable temperatures. Characteristics of a nozzle to deliver the air flow to the wing surface have been discussed with Calm Air and with Aerotech Herman Nelson of Winnipeg. Aerotech have committed to manufacture a prototype nozzle and forward it to Thompson for trial.

Additional equipment to be employed is described in Attachment B.

ATTACHMENT A - TEST PROCEDURE
FROST AT VERY COLD TEMPERATURES
IN CONJUNCTION WITH CALM AIR INTERNATIONAL
THOMPSON, MANITOBA

1. Preparation

Training for the trials will consist of familiarization with the test process and objective, measurements and observations to be taken, and data collection sheets. Individual tasks will be assigned.

The video camera man will be briefed on the objective and elements of the trial process, and will be provided with a stable platform giving a view of the entire process.

2. Pre-Test Set-Up

1. Park aircraft on ramp overnight to accumulate frost.
2. Position access stands to support process and to enable observation of wing surface.
3. Set up scissor-lift and support to video camera man.
4. Check cameras and recording devices for proper functioning.
5. Assemble Herman Nelson ducting and air nozzle, and position at aircraft.
6. Start Herman Nelson heater and allow to stabilize; set controls to produce constant temperature air at delivery, as close as possible to, but not exceeding 180°F.
7. Recording personnel in place with necessary data sheets.

3. Test Procedure

A) Record Conditions

1. Complete data forms recording aircraft and weather conditions.
2. Record ambient air temperature. Obtain measures on other conditions from local weather office.
3. Visually note and record severity of frost condition. Capture condition on a film close-up using a ruler placed on the wing to provide perspective.

B) Test to Establish Optimum Operational Procedure

4. Proceed with trials of each nozzle setting, initially in unswept conditions and then in swept conditions to evaluate relative effectiveness in terms of delivering a dry surface. Identify fastest nozzle by measuring area cleared by contending nozzle settings in a fixed span of time.
5. Record forced air temperature at delivery nozzle during each trial.
6. Record wing skin temperature at locations being cleared during trials on each area.
7. Observe carefully and note observations, giving attention to whether any dampness or water rivulets form and if so, their final state, ie. do they refreeze or evaporate, or are they dispersed by the air blast.
8. Note degree of ease or difficulty of managing air application device and of achieving a clean surface.
9. APS team coordinator and Calm Air representative to observe and note wing condition following completion. Touch wing to ascertain whether a film remains or whether the wing is dry. Examine cavities and recesses to ascertain whether any melt fluid has entered and re-frozen.

C) Establish Time to Achieve Clean Wing with Selected Process

10. Apply selected procedure to an entire wing or to a large wing area representative of the entire wing, including full wing chord from leading to trailing edge, and record time taken to complete area. Measure area involved with tape measure and note.
11. Observe for further 30 minutes to determine if frost re-forms. Record time taken if event occurs.
12. Video tape entire air application exercise. Close-up of frost condition on wing prior to start, and close-up of wing surface following completion. Video tape any significant events that occur during the exercise such as fluid formation, re-freezing of melt fluid, or reformation of frost.

4. End of Test

APS team coordinator will confirm end of each test. This will occur when test parameters have been completed, or when it becomes evident that further activity within a test is futile. Ensure all data collection is completed.

5. Number of Tests

As results are expected to be readily apparent after trials of each variable, a long series of tests are not expected and it is planned to conduct these tests on a single aircraft. Provisions are made to extend the trials if necessary.

Should the procedure not be wholly acceptable but show definite promise subject to modifications, modifications will be made and further trials re-planned.

ATTACHMENT B

TEST EQUIPMENT - FROST AT VERY COLD TEMPERATURES IN CONJUNCTION WITH CALM AIR INTERNATIONAL THOMPSON, MANITOBA

Frost removal equipment

Herman Nelson heater with ducting
Air delivery nozzle to mate with ducting

Test equipment

Aircraft overnighted on ramp
Access stands
Scissor lift for video camera man
Data collection forms
Tape Measure
Stop Watches
Temperature probe
Video camera with spare batteries and charger
Still camera

Staff

Calm Air, management and technical staff
APS
Video camera man
DCIP representative

Administrative Logistics

Hotel accommodation
Car rental

ATTACHMENT C

FROST REMOVAL WITH HOT FORCED AIR

Assessment of nozzle configuration and procedure

Location ____________________ Date ____________ Aircraft type _______________

Wing selected (Port or Stbd) ____ Fuel in wing ____________
WX Office: Temp ______ Rel Hum ______ Wind Speed ______ Wind Dir'n ______
Measured OAT ______
Note wing surface condition at start ____

Duct Size / Nozzle Area	Swept / Unswept	Air Temp at Nozzle	Skin Temp during Air	Comments on Final Wing Condition and Effectiveness of Procedure

ATTACHMENT D

TEST DATA

FROST REMOVAL WITH HOT FORCED AIR
ELAPSED TIME TO DEFROST WITH SELECTED PROCEDURE AND NOZZLE

Location ____________________ Date ____________________
Aircraft type _______________

Conditions at start/end of test

Wing selected (Port or Stbd) ____ Fuel in wing ____________
Measured Ambient Air Temp. ____/____
WX cond. from WX Office: Temp ____/____ Rel Hum ____/____
Wind Speed ____/____ Wind Dir'n ____/____
Temp. of blown air ____/____
Note surface condition at start __________________________________

==

Wing Surface Conditions at end of test
Note surface condition __________________________________
Note cavities for ice __________________________________
Surface touch test __________________________________
Notes on frost removal effectiveness __________________________________

____
Notes on application process __________________________________

____
Other comments

____

==

Surface Condition at end of test + 30 minutes
Note surface condition __________________________________

==

TIME TO DEFROST

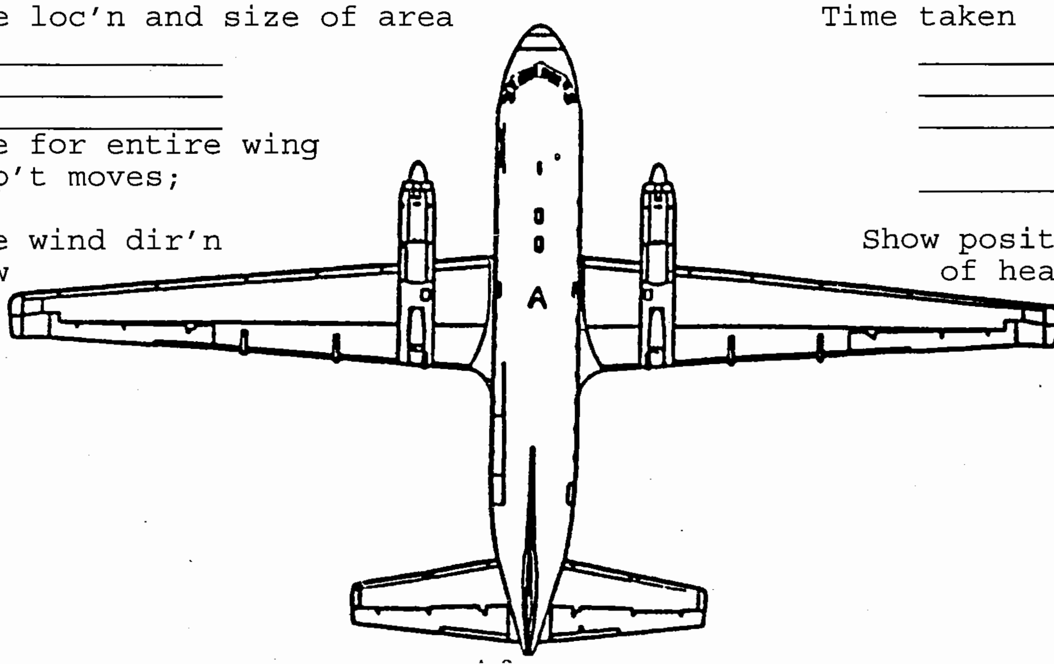
Describe loc'n and size of area | Time taken

________________ ____________
________________ ____________
________________ ____________

Est time for entire wing with eqp't moves; ____________

Indicate wind dir'n by arrow

Show position of heater



APPENDIX B
OTHER FORCED AIR DE-ICING SYSTEMS

STATE OF MARYLAND
OFFICE OF THE GOVERNOR

FOR IMMEDIATE RELEASE

FOR MORE INFORMATION:
Dale Baxter
Maryland Energy Administration
1-(800)-72-ENERGY

Dianna Rosborough
Marilyn Corbett
Governor's Press Office
(410) 974-2316

GOVERNOR'S PRESS OFFICE

MARYLAND FIRM WINS MAJOR ENERGY GRANT

Annapolis, MD (July 13, 1995) -- A Harford County company which developed technology to save energy and promote flight safety has received a major grant from the U.S. Department of Energy and the Environmental Protection Agency. Catalyst and Chemical Services, Incorporated (CCSI), in partnership with the State of Maryland, was granted $405,000 for commercialization of *Whisper Wash*™, an innovative aircraft deicing technology.

"This is a tremendous partnership between state government and a Maryland industry, which has led to a lead role in commercializing a new energy efficient technology," remarked Governor Parris N. Glendening. "The project with CCSI is a win for everyone. It will ultimately mean safer air travel, lowered use of polluting chemicals and energy, and new business development...and that is exciting," the Governor continued.

CCSI and the State received one of only 14 NICE^3 grants awarded nationally in 1995. Nice^3 is a joint U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA) cost-sharing grant program designed to improve competitiveness, foster energy efficiency, and reduce waste through the development of energy saving and pollution prevention industrial projects. The Maryland Energy Administration (MEA) will administer the grant for the State and

(more)

will assist CCSI in the commercialization of *Whisper Wash*™.

MEA Director Frederick Hoover remarked, "As Marylanders we are proud that the CCSI aircraft deicing project was one of a select few chosen from the hundreds submitted nationwide for funding under the NICE^3 program. The MEA looks forward with great anticipation to working with CCSI to field test a product which could revolutionize air flight safety while improving energy efficiency and protecting our air and water at the same time."

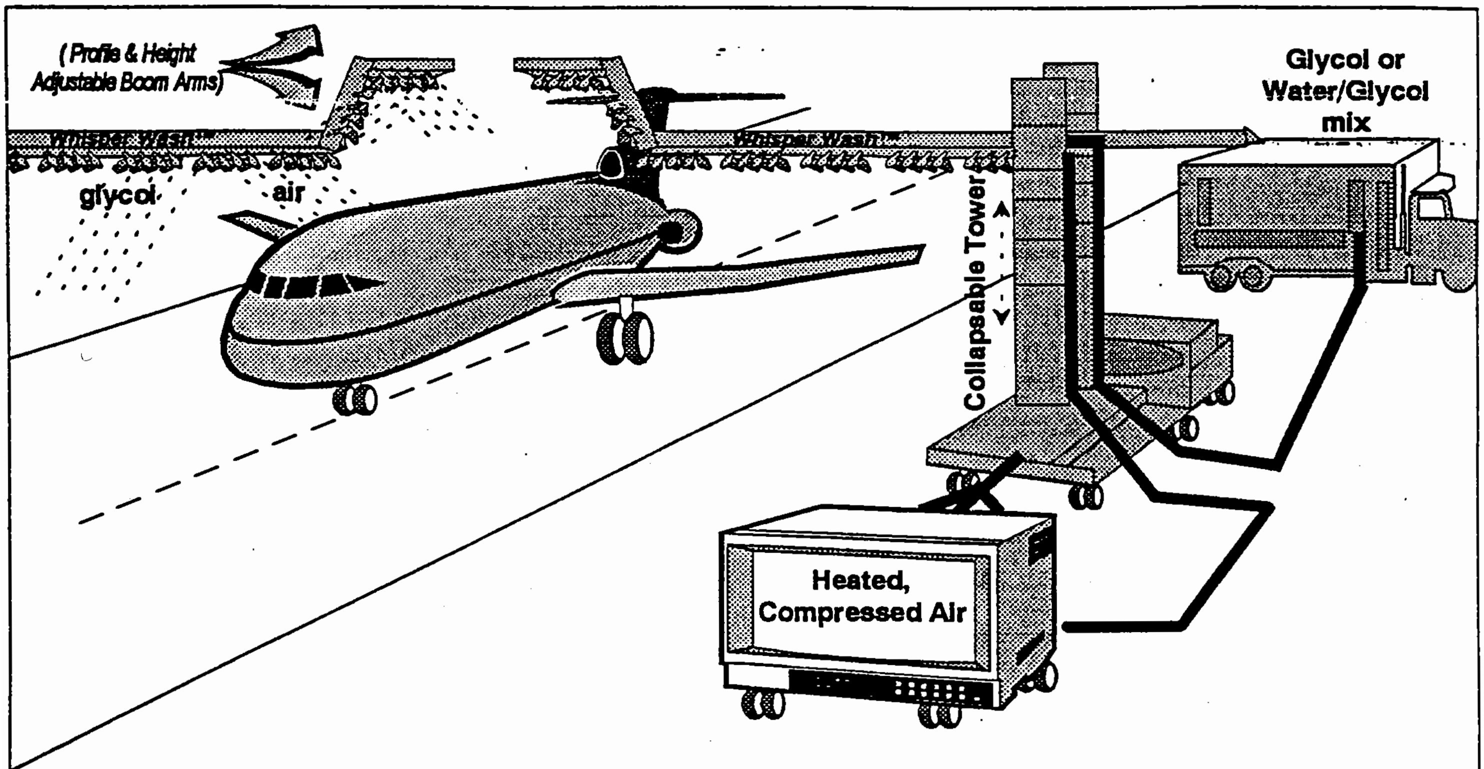
Mr. John Gaughan, President of CCSI and the inventor of *Whisper Wash*™, will utilize the DOE/EPA grant to construct and test a full-size commercial *Whisper Wash*™ unit. In a cooperative effort with the Maryland Aviation Administration, CCSI will install and test the *Whisper Wash*™ system at Baltimore/Washington International (BWI) Airport. Full scale testing of the system is scheduled for the Fall of 1995. As designed, *Whisper Wash*™ exceeds all applicable Federal Aviation Administration regulations governing aircraft deicing and successful operation atBWI will enable this new technology to be incorporated directly into current airport improvement plans. Pending a successful demonstration of the *Whisper Wash*™ technology, both Delta and Northwest Airlines have agreed to use the *Whisper Wash*™ system in their deicing programs.

The *Whisper Wash*™ deicing process utilizes a patented technology to improve the effectiveness of aircraft deicing while reducing the use of glycol-based deicing chemicals by up to two-thirds through improved technologies and recycling. As an energy and cost-effective process, *Whisper Wash*™ achieves the objectives of the NICE^3 program while improving aircraft safety. Additionally, *Whisper Wash*™ provides significant environmental benefits by meeting stringent Clean Water Act requirements to reduce potential pollutants at their source.

# # #

Whisper Wash™

Aircraft
Deicing / Anti-icing System



Whisper Wash™ Typical Layout
Perspective View

A joint venture project from:

CCSI

Catalyst & Chemical Services, Inc.
2100 Muir Way, Bel Air, MD 21015
Phone: 410-569-1200
FAX: 410-569-1202

USAF works with forced air de-icing

An auxiliary power unit is mounted at the rear of the boom as part of the Forced Air De-ice System (photo: AEC).

The United States Air Force (USAF) has signed a co-operative research agreement with Aviation Environmental Compliance (AEC) to work on the Forced Air De-ice System (FADS). AEC will develop FADS with the USAF at the Dayton Air Force base, and this agreement has already seen the nozzle being modified, said Williams.

The system uses an auxiliary power unit (in this case a Garrett T85 from a Boeing 727) to deliver forced air through a specialised nozzle at exit speeds of over 350mph to remove ice from aircraft surfaces. According to AEC president Lee Williams, results from testing by United at Denver Stapleton showed a 70-90% reduction in glycol fluid usage, and time-savings of up to 30% to de-ice a 727, compared to conventional methods.

FADS can be mounted on existing mobile units. United has used FADS on a Trump unit at Denver for two winters, and Federal Express converted a unit with FADS for trial at Denver last winter.

Express parcel carriers have shown a lot of interest in FADS, said Williams. It will have civil and military applications, he added.

APPENDIX C
FORCED AIR DE-ICING TRIP REPORT
United Airlines, Denver

FORCED AIR DE-ICING TRIP REPORT

United Airlines, Denver

United Airlines Visit 17/18 January 1995

Paul Ritchi, Canadian Airlines International

Peter Dawson, APS Aviation

Review of experience with air blower

PM 17 January - Met with Bob Irwin

Bob has been involved with the development within UA along with Chuck Chance since the project beginning.

Bob took Paul and I out to the vehicle, explained it's operation, and took each of us up in the basket on a parked DC10 to operate the air boom and get a feel for it.

Ease of Use

- Operation of the APU appears very straight forward. UA have had no problem with their unit throughout the project. The APU burns about a tank of fuel per snow storm event.

- Controls for the air delivery are on a joy stick on the front of the basket. Includes a switch for glycol injection as well as control for directing the boom and turning air on and off.

- Bob feels 2-3 hours of use by a previously skilled de-icing operator will develop adequate skills at using.

- Control of boom is sensitive - needs finesse developed with practice.

- The UA air operation is concentrated to the midnight shift which automatically limits its use to fewer operators and maintains their skill levels.

- The full wing chord from leading to trailing edge can be reached by a good operator with good technique.

Safety

- The APU produces normal APU levels of noise which UA have measured and state to be within acceptable limits for ramp operations.

- The boom sticks out in front of the basket about 4' - proximity to wing must constantly be kept in mind by operator. Truck track is correspondingly further back from wing profile. Will need constant attention to avoid a/c strikes - consider painting the tip to reinforce this.

- Bob reports that dry snow is removed in large clumps which fall to the ramp, and otherwise loose snow is blown vigorously about the aircraft which makes work on the ramp impossible. It doesn't fit well with simultaneous aircraft loading.

Operational flexibility

- Good for overnight operations where snow has accumulated on aircraft. The air blower can remove the major amounts of snow from surfaces and the aircraft can then undergo the normal de-icing operation at which point a much lower quantity of fluid is needed, and in a much decreased period of time.

- Similarly for overnight frost, frost can be removed with fluid injection in the air stream which uses considerably less fluid than standard hose application. Bob demonstrated this with very little fluid coming off wing. The process takes a little longer than with a hose.

- UA do not use the blower in day operations. Reasoning is that aircraft do not accumulate snow to same degree during ground times so same benefit is not available, in addition to time pressures during connection banks.

- No plans for more than one unit at Denver. About 23 aircraft currently overnight at DIA.

APPENDIX D
FORCED AIR DE-ICING
DATA COLLECTION REPORT

CANADIAN AIRLINES

FORCED AIR DE-ICING DATA COLLECTION REPORT

Date _____________ De-icing Operator ______________________ Driver _________________________

CONDITIONS

TEMPERATURE _____ °C

(Circle best description below)

SNOW ON A/C: Depth _____ "	powdery	dry	medium	wet	very wet
FALLING SNOW	none	light	medium	heavy	
WIND	none	mild	medium	high	

TEST DATA

A/C Type	A/C Tail	-- AIR DE-ICING TIMES --			COMMENTS
		Start Time	Finish Time	Time Taken	- condition of surface after blown air, comments on any difficulty or on best way to use nozzle, etc.

APU FUEL GAUGE at start of operation ________ Litres; RE-FUELLING during operation ________ L
APU FUEL GAUGE at end of operation ________ Litres; TOTAL APU FUEL BURNED ________ L

APPENDIX E

FORCED AIR DE-ICING TRIP REPORT

Canadian Airlines, Toronto

FORCED AIR DE-ICING TRIP REPORT

Canadian Airlines, Toronto

Visit Report: 21 March 1995

Canadian Airlines International
Pearson Airport, Toronto

F. Eyre, DCIP Transport Canada
P. Dawson, APS Aviation
P. Stalker, Zephyr North
P. Dibranou, Chief, Ramp Equipment Maintenance, CAI Toronto

Purpose: To gain familiarity with the forced air de-icing kits installed on CAI de-icing vehicles.

Forced Air Unit

The forced air units have been mounted and checked out by manufacturer and CAI. During the visit, the unit was started and operated by a CAI staff. Both Eyre and Dawson operated the air blower nozzle controls to develop a feel for their operation.

The unit in operation was captured in still photos and video tape, illustrating the installation, and the reach of the air blast using grit on the ramp as a visual guide.

Comments on the installation and operation include:

- APU fuel tank is still in an exposed location. Being suspended under the truck chassis behind a rear wheel leaves it vulnerable to damage when reversing the truck. This risk has been recognized by CAI who are discussing with the manufacturer a proposal to relocate it ahead of the rear wheels.

- A post-installation modification has been installed by CAI to protect fluid lines from APU exhaust heat.

- Start up of the APU which provides the forced air is as simple as that witnessed in the United Airlines installation.

- The air nozzle control joy stick used by the operator in the basket is quite sensitive giving large and rapid nozzle movements with slight pressure. CAI is confident that operators will quickly become adept at control. The distance the nozzle extends beyond the basket offers some risk of striking aircraft surface during operation and will require constant attention.

- Temperature of the nozzle tubing was measured at 120°C. Temperature of the blown air about 6 inches beyond the nozzle was 55°C. CAI stated that the air temperature when it reaches the wing is close to ambient.

- CAI believe the manufacturer is examining the installation of Type I fluid injection into the nozzle, as has been done with the United Airlines unit at Denver.

- CAI staff present were enthusiastic about the potential of the unit and are looking forward to an opportunity to see it in action although lateness in the season may not accommodate this.

APPENDIX F

TERMS OF REFERENCE - WORK STATEMENT

APPENDIX F

WORK STATEMENT

AIRCRAFT AND FLUID HOLDOVER TIME TESTS FOR WINTER 94/95
(Short Title: Winter Tests 94/95)

1 INTRODUCTION

The recommendations of the Dryden Inquiry in March 1992 and the setting up of the Dryden Commission Implementation Project Office (DCIP), were followed almost immediately by the La Guardia crash of a F-28, also in March 1992. This accident also had clear implications that ice on take-off was involved. As a result the FAA introduced Holdover Time regulations and requested that the SAE Committee on Aircraft Ground Deicing spearhead work on establishing holdover guidelines. This led to the formation of the holdover time working group, co-chaired by DCIP and FAA/ARC. A major test program was initiated building on an existing program which had been initiated by the Transport Development Centre (TDC) for the 90/91 winter season.

Transport Canada (DCIP) agreed to coordinate the expanded test program, and provide several Instrumar Clean Wing Detection Systems (CWDS) sensor units to be used at selected sites as a measure to better define fluid failure criteria.

Times given in Holdover Time Tables were established by European Airlines based on assumptions of fluid properties, and anecdotal data. The extensive testing conducted by DCIP has been to determine the performance of fluids on standard flat plates in order to substantiate the times, or if warranted, to recommend changes. The original DCIP program has been largely completed, however as a result of the program findings DCIP has agreed with the SAE to extend the Table coverage to the low temperatures encountered in North American operations, to substantiate Table values for 'rain on a cold soaked wing', and to consider a new class of 'longer life' fluids. These latter fluids presently qualify as Type II, but preliminary data suggests that their very long times to failure, under certain circumstances, might warrant a new classification to permit the Airlines to benefit accordingly. Finally the flat plate data has not, to date, been correlated with fluid performance on service aircraft on a systematic basis.

Canadian Airlines International Ltd. (CAI), and Air Canada have offered to cooperate with DCIP in order to promote winter operational safety by making aircraft and limited ground support staff available to facilitate the correlation of flat plate data with performance of fluids on aircraft.

DCIP plans to take advantage of these offers to undertake the outstanding Holdover Time work, and with crew and equipment mobilized, to 'piggy-back' additional tests:
To evaluate the suitability of hot air for de-icing as an alternative to heated de-icing fluids at low (e.g. -30°C and below) ambient temperatures. The hot air temperature must not exceed 85°C; time to de-ice, avoidance of re-freezing, and operational economics are factors to be considered. Similarly forced air will also be considered for removal of cold dry snow, and for 'warm' wet snow.

Use of hot water is presently permitted for de-icing down to -3°C. Past experience suggests that this could be extended to -7°C, or lower, though no quantitative data is available. The economic and environmental advantages are self-evident. Pertinent tests will therefore be conducted to address the effectiveness of hot (up to 85°C) water with consideration given not only to the de-icing operation proper, but also to the problem of ice formation on the ground.

Since instrumentation will be used to determine fluid failure on the aircraft the role and application of such instrumentation within the regulatory environment will be studied.

2 PROGRAM OBJECTIVE (MCR 16)

Take an active and participatory role to advance aircraft ground de-icing/anti-icing technology. Develop international standards, guidance material for remote and runway-end de-icing facilities, and more reliable methods of predicting de-icing/anti-icing hold-over times.

3 PROGRAM SUB-OBJECTIVES

Perform tests to record data which will subsequently be used to establish relationships between laboratory testing and real world experience in protecting aircraft surfaces. Develop reliable holdover time (HOT) guideline material based on test information for a wide range of winter weather operating conditions. Substantiate values in existing holdover time tables for type 1,type 2, and possibly type 3 fluids.

4 PROJECT OBJECTIVES

4.1 To complete the substantiation of the existing SAE HoldOver Time Tables and proposed Table extensions by conduct of tests on modified 'standard' flat plates, adapted to provide reference conditions for 'cold soaked' wings, for Type I and Type II fluids subjected to a controlled environment of rain.

4.2 To complete the substantiation of the existing SAE holdover time Tables and proposed table extensions by conduct of tests on standard flat plates as follows:

Type I and Type II fluids under conditions of natural snow, freezing drizzle and simulated freezing fog and freezing drizzle at the lowest temperature ranges for each condition of precipitation.

Type I fluids at dilutions for which a buffer of 10^0 C from the fluid freeze point is maintained.

At least two samples of a new family of 'long-life' fluids will be tested to establish the holdover times over the full range of HOT table conditions for this potential new fluids category.

4.3 To correlate the flat plate test data used to substantiate the SAE HoldOver Time Tables with the performance of fluids on service aircraft, by concurrently testing de/anti-icing fluids on standard flat plates and service aircraft under conditions of natural freezing precipitation for Type I and Type II fluids during the 94/95 winter season.

4.4 To evaluate the suitability of hot air de-icing at low ambient temperatures as an alternative to heated de-icing fluids, and to evaluate the suitability of heated or unheated forced air for removal of cold dry snow, and/or wet snow.

4.5 To ascertain the evironmental limits for the use of hot water as a de-icing fluid.

4.6 To evaluate a remote sensor as an inspection device to detect contamination, under field conditions.

4.7 To determine the pattern of fluid run-off from the wing during take-off.

5. DETAILED STATEMENT OF WORK

The work shall be broken down into 7 distinct areas of activity consistent with the project objectives, together with activities for presentations and reporting at the completion of work. A detailed workplan, activity schedule, cash flow projection, project management control and documentation procedure shall be developed and delivered to the DCIP R&D Task Group project officer for approval within one week of effective start date.

5.1 "Cold soak' Test Program

5.1.1 Develop an experimental plan, prepare experiments, conduct tests, analyse results and prepare report for a program to substantiate the values given in the SAE HoldOver Time Tables for diluted and undiluted Type I and Type II fluids for "Rain on a Cold Soaked Wing".

5.1.2 Conduct tests at the Climatic Engineering Facility (CEF), of the National Research Council, Ottawa.

5.1.3 Supply all necessary equipment and fluids for conduct of the tests. This shall include a cooling system to maintain the test plate at constant temperature during the tests.

5.1.4 Schedule an array of tests, for review and approval by the DCIP project officer, covering a range of environmental temperatures from 0°C to +7°C, a range of plate temperatures from 0°C to -15°C, and a range of precipitation rates to be determined in consultation with personnel from AES and NRC. Coordinate the range of plate temperatures with data to be made available by DCIP from field measurements of wing temperatures on service aircraft.

5.1.5 Coordinate scheduling of tests with NRC. Give advance notice of all intended tests to DCIP project officer. Duration of tests shall be 5 working days, incuding set-up time. Complete tests no later than 31 March 1995.

5.2 Substantiation of HOT Tables

5.2.1 Develop experimental programs, for review and approval by the DCIP project officer, for testing of Type I fluids over the entire range of conditions covered by the HOT Tables. Test fluids at dilutions for which a buffer of 10° C from the fluid freeze point is maintained. These programs shall include outside testing under conditions of natural precipitation, and laboratory testing in the NRC CEF for tests involving freezing fog and freezing drizzle.

5.2.2 Develop test programs for each applicable condition of precipitation, as specified by the SAE HOT Tables, for review and approval by the DCIP project officer:
(a) For testing of undiluted Type II fluids under conditions of natural snow and freezing drizzle at the lowest temperature ranges (i.e. below -14°C).
(b) For testing of Type II fluids under conditions of simulated freezing fog and freezing drizzle at the lowest temperature ranges.

5.2.3 Develop a test program to test undiluted samples representative of the new 'long-life' fluids to establish holdover times over the full range of HOT table conditions for this potential new fluids category. Obtain samples from fluids producers. Conduct tests during periods of freezing precipitation concurrent with HOT Table substantiation tests of conventional fluids.

5.2.4 Establish a test site at Montreal, Dorval Airport for conduct of outside tests. Provide support services and appropriate facilities. Recruit and train local personnel. Repair and replace, as necessary, DCIP supplied equipment used for previous years' testing.

5.2.5 Conduct tests with simulated freezing fog and freezing drizzle in the NRC CEF facility, Ottawa. Provide materials and equipment necessary for tests, conduct tests, analyse results and report. Coordinate scheduling of tests with NRC. Give advance notice of all intended tests to DCIP R&D project officer. Duration of tests shall be 5 working days, incuding set-up time, and tests shall be completed no later than 31 March 1995.

5.2.6 Determine fluid failure by use of Instrumar C-FIMS instrument installed in at least one plate, by RVSI remote sensor set up to view a 'stand' of six standard test plates, and by visual observation.

5.2.7 Conduct ancilliary tests during outside tests at Dorval to collect visibility data during periods of freezing precipitation, and correlate measurements with concurrent meteorological data: precipitation rate, precipitation type, temperature, wind velocity and direction; and background lighting condition as appropriate. An NRC 'WIVIS' Visibility meter shall be obtained from AES in Toronto, where it will be calibrated, during early January 1995.

5.2.8 Program results and plans for completion shall be subject to a 'mid-term' review to be called by DCIP.

5.2.9 Videotape tests. Collect, analyse and report test results.

5.3 Correlation of performance of fluids on flat plates with performance on aircraft

Note: Availability of aircraft will be negotiated by DCIP. In general aircraft will be made available for testing outside regular service hours i.e. available between 11:00 hrs. and 06:00 hrs. Aircraft types to be used will be representative of those in common use by airlines in Canada. Test programs will be conducted at Toronto, Pearson international Airport, using aircraft made available by Canadian International Airlines Ltd. (CAI); at Montreal, Dorval International Airport, using aircraft made available by Air Canada; and in St. John's International Airport, Newfoundland using aircraft to be negotiated.

5.3.1 Develop experimental programs, for review and approval by the DCIP project officer, for concurrent comparison testing of Type I and Type II fluids under conditions of natural freezing precipitation on flat plates and on aircraft. Present the approved programs to the airlines involved prior to start of field tests.

5.3.2 Recruit and train local personnel who will conduct test work. Organize and conduct a 'Kick-off' meeting at each test site with all parties involved in the provision of services and conduct of tests .

5.3.3 Provide all fluids, equipment, an RVSI remote sensor, and all other instrumentation necessary for conduct of tests and recording of data. Ancilliary equipment shall include lighting fixtures as necessary, observation platforms, vehicles, storage facilities, office facilities and personnel rest accomodation for self-contained operations. Secure necessary approvals and passes for personnel and vehicle access and operation on airport airside property. Limit the number of personnel on site to the minimum necessary for execution of test programs: not more than eight persons under normal conditions, not more than ten persons maximum. Co-ordinate with all agencies involved to ensure that these limits are respected.

5.3.4 Include one 'dry run' at each test location prior to start of field tests, under conditions without precipitation, to ensure correct execution of tasks, simulated collection of all data required, and smooth co-ordination of functions.

5.3.5 Schedule tests to determine the comparative performance of Type I and Type II fluids on standard flat plates and aircraft on the basis of forecast significant-duration night-time periods of freezing precipitation. Give advance notice to the airline of the desired test set-up including aircraft orientation to the forecast wind direction, sequence of fluid applications, and any additional services requested. Fluids to be tested shall be from the range of fluids normally used by the airline. Application of different fluids may be requested for each wing in order to maximize test data. Application of fluids will be by airline personnel.

Record pattern of fluid failure. Record effect of aircraft orientation to wind as a variable over the series of tests conducted. The aircraft will in general not be re-oriented during conduct of a test.

5.3.6 Proposed test programs shall assume conduct of five (5) all night test sessions, subject to weather conditions. Additional tests may be requested subject to agreement by all parties involved. Perform tests following plans based on the following:

- A detailed statement of work for each of the participants.
- A specific plan of tests, for review by all parties, which shall include as a minimum:
  - schedule and sequence of activities
  - detailed list of responsibilities
  - complete equipment list
  - list of data, measurements, and observations to be recorded
  - detailed test procedures.
- Activities including:
  - Visual and Instrumented Data Logging.
  - Monitoring and recording environmental conditions, including:
    - -air temperature
    - -Wing surface temperature at selected locations
    - -wind velocity and direction
    - -precipitation type and rate
  - Record of Aircraft and Plate orientation to the wind.
  - Use of Instrumentation to determine condition of the fluid.
- Detailed and rigorous experimental procedures
- Acquisition of data from the tests to address:-
  - Identification of fluid failure criteria.
  - Location of first point of fluid failure on wing, and subsequent failure progression
  - Correlation of fluid failure time to environmental conditions.
  - Correlation of fluid failure times: flat plates and aircraft.
  - Behaviour of fluid on the 'representative' surface.

5.3.7 Anticipate availability at PIA, Toronto, of a Boeing 737 aircraft presently planned to be fitted with Allied Signal C-FIMS contamination sensors on the 'representative' surfaces. Incorporate data available from these sensors into the overall test results. Coordinate data collection activities with Allied Signal. Support visual observations, video records, and

C-FIMS records of fluids behaviour with output from the RVSI remote sensor.

5.3.8 Any equipment obtained from airlines for use during tests shall be returned to its original condition at the end of the test program.

5.3.9 Videotape records of all tests shall be made.

5.4 Forced Air as a de-icing and/or snow removal agent

Note: Hot air is not presently used for de-icing. Criteria for use will be availability of equipment/capital cost, time to de-ice, assurance that all frozen contamination is removed (re-freezing of melted precipitate does not occur), and overall cost effectiveness. Form of initial contamination may be a significant factor.

5.4.1 Conduct a preliminary overview to identify equipment potentially suitable for removal of frost at low (-33°C and lower) temperatures by hot air, and for removal of dry snow and/or wet snow by blown air. Review candidate technologies with personnel of DCIP and the participating Airlines.

5.4.2 Develop experimental programs, for review and approval by the DCIP project officer, for testing of the recommended technology(ies). A test location at Montreal Dorval Airport is anticipated. Recommend alternative test location(s) as appropriate. Arrange for availability of recommended equipment.

5.4.3 Establish test site(s) for conduct of tests. Review truck to be made available by CAIL as a potential mounting platform. Application of blown air will be by airline personnel. Provide support services and appropriate facilities. Recruit and train local personnel as necessary.

5.4.4 Schedule field tests on the basis of forecast weather conditions and plan and co-ordinate test activities in conjunction with airline personnel . Conduct tests under appropriate weather and contamination conditions:
- Aircraft with frost at -33°C or colder.
- Aircraft with accumulated cold dry snow at temperatures below 0°C
- Aircraft with accumulated wet snow at temperatures close to 0°C

5.4.5 Maintain a videotape record of tests. Collect analyse and report test results.

5.5 Hot Water as a de-icing agent

Note: Hot water has been in use as a de-icing agent for many years. Present restrictions limit its use to a minimum ambient air temperature of -3°C. Spent hot water run-off onto a cold-soaked de-icing pad surface will give rise to surface icing/hazards to operators. No anti-icing protection is afforded other than temperature rise of aircraft surfaces above 0°C. Substantiated limits to hot water use are not known. A test location at Montreal Dorval Airport is anticipated for work in conjunction with Air Canada.

5.5.1 Develop a test program to determine the minimum ambient (air and ground) temperature conditions under which hot water can be used for de-icing, for review and approval by the DCIP project officer and Air Canada.

5.5.2 Establish a test site at Montreal, Dorval Airport for conduct of tests. Application of blown air will be by airline personnel. Provide support services and appropriate facilities. Recruit and train local personnel as necessary.

5.5.3 Plan and co-ordinate field tests in conjunction with airline personnel on the basis of forecast weather conditions.

5.5.4 Maintain a video record of conduct of tests. Collect analyse and report test results.

5.6 The remote sensor as an inspection device to detect contamination, under field conditions.

Note: The ability of the RVSI sensor to detect and identify fluid failure on flat plates when exposed to freezing precipitation under field conditions was demonstrated during winter 1994/95 The technological application of the remote sensor, to be procured and installed in support of tests to ascertain the correlation of performance of fluids on flat plates with performance on aircraft, is still under development for application to aircraft inspection.

5.6.1 Develop an experimental program, for review and approval by the DCIP project officer, to verify in the NRC CEF cold chamber over a temperature range down to -30°C the performance and suitability of the sensor .

5.6.2 Develop an experimental program, for review and approval by the DCIP project officer, to verify the performance and suitability of the sensor for field use. Conditions to be examined shall include effect of background lighting; desirable distance of sensor from the wing surface and effective field of view; identification of the zone of the wing under inspection; potential need for scanning; and effects of meteorological conditions and presence of de/anti-icing fluids.

5.6.3 Define equipment requirements and design modifications necessary for mounting the sensor for field use.

5.6.4 Maintain a record of sensor video output with reference data. Collect, analyse and report test results.

5.7 The pattern of fluid run-off from the wing during take-off.

5.7.1 Arrange for de-icing/anti-icing the Boeing 737 aircraft using undiluted fluids during a period of without precipitation in the event that the C-FIMS sensors are installed. Record meteorological conditions; and thickness history of the fluid on each sensor from time of application to take-off, and after take-off if relevant and possible.

5.8 Presentations of test program results

5.8.1 Prepare and present preliminary findings of test programs involving field tests with aircraft to representatives of Transport Canada and the Airlines involved at end of the test season, but no later than April 30 1995.

5.8.2 Prepare and present, in conjunction with Transport Canada personnel, winter test program results at SAE G-12 Committee meetings in Chicago, and London, England.

5.9 Reporting

Reporting shall be in accordance with section 10 "Reporting", below.

5.9.1 Substantiation of HoldOver Time Tables
A final report shall be prepared covering all winter testing sponsored by TDC and DCIP, including that from previous winters, conducted to substatiate the SAE HOT Tables.

5.9.2 Reporting of Other Testing
Separate final reports shall be issued for each area of activity consistent with the project objectives.