TP 13662E

Ice Detection Sensor Capabilities for End-of-Runway Wing Checks: Phase 2 Evaluation

Prepared for

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APS AVIATION INC.

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Ice Detection Sensor Capabilities for End-of-Runway Wing Checks: Phase 2 Evaluation

by

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Marc Hunt

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PREFACE

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

- To develop holdover time data for Type IV fluids using lowest-qualifying viscosity samples, and to develop holdover time data for all newly qualified de/anti-icing fluids;
- To conduct flat plate holdover time tests under conditions of frost;
- To further evaluate the flow of contaminated fluid from the wing of a Falcon 20D aircraft during simulated takeoff runs;
- To determine the patterns of frost formation and of fluid failure initiation and progression on the wings of commercial aircraft;
- To evaluate whether the proposed locations of Allied Signal's wing-mounted ice sensors on an Air Canada CL65 are optimally positioned;
- To evaluate the second generation of the NCAR snowmaking system;
- To evaluate the capabilities of ice detection camera systems;
- To examine the feasibility of and procedures for performing wing inspections with a remote ice detection camera system at the entrance to the departure runway (end-of-runway);
- To reassemble and prepare the JetStar aircraft wing for mounting, to modify the wing to obtain cold-soak capabilities, and to conduct fluid failure tests in natural precipitation using the JetStar wing;
- To extend hot water deicing tests to aircraft in natural outdoor precipitation conditions, and to correlate outdoor data with 1998-99 laboratory results;
- To examine safety issues and concerns of forced air deicing systems; and
- To evaluate snow weather data from previous winters to establish a range of snow precipitation suitable for the evaluation of holdover time limits.

The research activities of the program conducted on behalf of Transport Canada during the 1999-2000 winter season are documented in nine reports. The titles of these reports are as follows:

- TP 13659E Aircraft Ground De/Anti-icing Fluid Holdover Time and Endurance Time Testing Program for the 1999-2000 Winter;
- TP 13660E Aircraft Full-Scale Test Program for the 1999-2000 Winter: Evaluation of the Positioning of Surface-Mounted Ice Detection Sensors on the Bombardier CL-65 Aircraft;
- TP 13661E A Second-Generation Snowmaking System: Prototype Testing;
- TP 13662E Ice Detection Sensor Capabilities for End-of-Runway Wing Checks: Phase 2 Evaluation;
- TP 13663E Hot Water Deicing of Aircraft: Phase 2;
- TP 13664E Safety Issues and Concerns of Forced Air Deicing Systems;
- TP 13665E Snow Weather Data Evaluation (1995-2000);

- TP 13666E Contaminated Aircraft Simulated Takeoff Tests for the 1999-2000 Winter: Preparation and Procedures; and
- TP 13667E Preparation of JetStar Wing for Use in Deicing Research.

This report, TP 13662E, has the following objectives:

1. To evaluate the capabilities of ice detection camera systems under particular conditions; and
2. To examine the feasibility of and procedures for performing wing inspections with a remote ice detection camera system at the entrance to the departure runway (end-of-runway).

Objective (1) was met by conducting sensor capability tests at Montreal International Airport (Dorval) and at the National Research Council Climatic Engineering Facility in Ottawa. Ice of varying thickness was formed using Federal Aviation Administration ice detection plates. The tests were conducted in conjunction with simulated end-of-runway tests and fluid holdover time tests.

Objective (2) was met by positioning the ice detection sensor to simulate an end-of-runway orientation relative to the aircraft stopping position at the central deicing facility at Montreal International Airport (Dorval). Aircraft arriving for deicing were scanned prior to being cleaned, and the actual extent and pattern of contamination was documented. Sensor indications of contamination were then compared to the actual contamination. Tests on a static test wing were also performed to examine the accuracy of ice detector indications of known areas of applied contamination.

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This research has been funded by the Civil Aviation Directorate of Transport Canada. This program could not have been accomplished without the participation of many organizations. APS would therefore like to thank the Transportation Development Centre of Transport Canada, the U.S. Federal Aviation Administration, National Research Council Canada, the Meteorological Service of Canada (previously known as Atmospheric Environment Services Canada), and several fluid manufacturers. Special thanks are extended to US Airways Inc., Air Canada, the National Center for Atmospheric Research, AéroMag 2000, Aéroports de Montreal, G. Vestergaard A/S, Hudson General Aviation Services Inc., Union Carbide, Cryotech, BFGoodrich, Cox and Company Inc., Fortier Transfert Ltée, and MTN Snow Equipment Inc. for provision of personnel and facilities and for their co-operation with the test program. APS would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data. The authors gratefully acknowledge the contribution of the APS Aviation test preparation team: Antoni Peters, Medhat Hanna, Jeff Mayhew, and Don Robitaille. Special thanks are extended to Frank Eyre and Barry Myers of the Transportation Development Centre for their participation in, contribution to, and guidance in the preparation of this document.

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16. Abstract

This study examined the ability of a prototype remote ground ice detection sensor to provide reliable and accurate indications of the condition of aircraft wings when positioned in a typical end-of-runway orientation relative to the observed aircraft, and the ice thickness sensitivity limits as a function of distance and viewing angle.

Reliability of ice detection by the sensor in conditions typical of an end-of-runway installation was examined by scanning operating aircraft during snowstorms just prior to being deiced. The ice detection sensor was positioned to simulate an end-of-runway orientation relative to the aircraft stopping position at the deicing pad. An observer located in the bucket of a deicing truck documented the extent of snow on the wings. Trials were also conducted using known contamination on a static test wing. Sensor indications of contamination were compared to the known extent of contamination.

The sensitivity of the sensor system was examined by scanning ice in a range of thicknesses, from varying distances and viewing angles.

The study documents some specific considerations that remote ground ice detection sensors must satisfy in order to comply with an end-of-runway wing-check application.

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Les rapports de recherche produits au nom de Transports Canada sur les essais réalisés au cours des hivers antérieurs peuvent être obtenus auprès du Centre de développement des transports (CDT). Le programme de recherche de la saison hivernale 1999-2000 a donné lieu à neuf rapports (dont celui-ci). On trouvera dans la préface l’objet de ces rapports.

16. Résumé

Cette étude a consisté à examiner la capacité d’un prototype de détecteur de givrage au sol de donner des indications fiables et exactes de l’état des ailes d’un avion, lorsque placé dans une position représentative de celle d’un détecteur en bout de piste, et à déterminer les limites de sensibilité de détection de l’épaisseur du givrage en fonction de la distance et de l’angle de prise de vue.

Pour étudier la fiabilité de détection de givrage par le détecteur dans des conditions représentatives d’une installation en bout de piste, on a soumis à sa détection des avions en service réel, pendant des tempêtes de neige, juste avant qu’ils soient dégivrés. Le détecteur était placé de façon à simuler la position qu’il aurait en bout de piste par rapport à l’avion immobilisé au poste de dégivrage. Un observateur documentait l’étendue de la neige sur les ailes, à partir de la nacelle d’un camion de dégivrage. D’autres essais ont eu lieu à l’aide d’une aile d’essai statique, dont les données de contamination étaient connues. Les indications du détecteur concernant la contamination étaient comparées aux données connues sur la contamination.

Pour examiner la sensibilité du système de détection, on a procédé à la détection de diverses épaisseurs de contamination, à des distances et selon des angles de prise de vue variables.

L’étude expose certains critères précis auxquels les détecteurs de givrage au sol doivent satisfaire pour répondre aux exigences d’une application de vérification des ailes en bout de piste.

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EXECUTIVE SUMMARY

Under contract to the Transportation Development Centre (TDC) of Transport Canada (TC), APS Aviation Inc. (APS) undertook a research program to examine the application of a ground-based ice detection system to provide information on the condition of aircraft wings just prior to departure.

Background

During the 1998-99 winter, APS conducted an initial series of field tests to study the feasibility of using a remote ground ice detection system (GIDS) at a fixed location to assess ice contamination on aircraft wings just prior to entering the departure runway. Results of that study were reported in the TC report, TP 13481E, *Feasibility of Use of Ice Detection Sensors for End-of-Runway Wing Checks*.

The results of tests performed at test locations near the departure runway demonstrated that the GIDS could be used at this site to inspect departing aircraft. It was found that the distance between the sensor camera and the aircraft tested was excessive, and a reduced distance was recommended. As well, supporting the camera from a higher mast was recommended to obtain a better angle of viewing, particularly for larger aircraft. It was recommended that the camera be positioned where departing aircraft hold, awaiting normal takeoff clearance.

The report concluded that the ability of the sensor to reliably identify and provide an accurate image of the extent of the area subject to contamination required further study to develop confidence in the system. It was therefore recommended that tests be performed to examine a test wing with known contamination, as well as aircraft just prior to being deiced.

Objectives

The overall test program was composed of four elements:

1. Tests at the Central Deicing Facility (CDF) at Montreal International Airport (Dorval) simulating end-of-runway conditions – the remote sensor was used to scan the wings of aircraft during deicing operations. The simulated end-of-runway tests conducted in the 1998-99 winter season were part of this stage. Tests during the 1999-2000 winter were planned to be conditional on findings regarding reliability of ice detection in conditions typical of an end-of-runway installation.

2. Developing Confidence in Ice Detection Images – the reliability of ice detection was examined in conditions typical of an end-of-runway installation by comparing sensor images of contamination to actual contamination on operating aircraft and on a test wing.
3. Sensitivity Limits –the capability of the sensor system was examined (mainly laboratory).
4. Tactile Tests – the human limitations in identifying the existence of ice through tactile examination were to be studied.

This study was performed in two parts. The first part addressed the first two elements above (tests at end-of-runway and reliability of ice detection images), although approval to conduct further end-of-runway tests was withheld. The second part of the study addressed the issue of sensitivity limits. The performance of tactile tests was not approved by Transport Canada for study at this time.

Reliability of ice detection in conditions typical of an end-of-runway installation was examined through scanning operating aircraft during snowstorms just prior to being deiced at the CDF. A prototype ice detection system provided by Cox and Co. was used for these tests. An observer located in the bucket of a deicing truck documented the extent of snow on the wings. The ice detection sensor was positioned to simulate an end-of-runway orientation relative to the aircraft stopping position at the deicing pad.

Tests were also conducted using known contamination on a static test wing. Sensor indications of contamination were compared to the known extent of contamination.

The capability of the sensor system was examined through tests conducted both at Montreal International Airport and at the NRC Climatic Engineering Facility in Ottawa. The Federal Aviation Administration (FAA) ice detection plates, with ice of varying thickness, were scanned by the ice detection sensor from different distances and viewing angles. Limited tests were conducted in conjunction with the simulated end-of-runway tests and the holdover time tests.

Results and Conclusions

1. The findings from these tests led to the conclusion that further development of ice detection sensors is necessary if they are to function satisfactorily in an end-of-runway application. The considerations particular to this application that must be addressed include:

   - Distances and viewing angles obtainable when operating at typical end-of-runway sensor positions relative to departing aircraft. Sensitivity is a function of distance and viewing angle. At greater distances and flatter viewing angles, larger areas of contamination are required for the sensor to detect ice on the aircraft.

- Sensitivity to distance and angle of viewing complicates Go/No-Go decision making:
  - Detection of ice on the areas of the wing farther from the sensor is less sensitive than for parts of the wing that are nearer and
  - Detection of ice on aircraft with higher wings is less sensitive than on aircraft with lower wings due to the flatter angle of viewing.

- At the required distances, the indication provided by the sensor of any contaminated area is limited.
  - Need to be able to zoom-in to focus entirely on the suspect area.

- Against a snow-covered background, indications from the sensor of contamination on the edge of a wing are impossible to identify. The system detection image must produce a clearly defined outline of the area of the aircraft being scanned.

- Relative movement between aircraft and sensor must not produce false indications that will prevent scanning of the leading edge while the aircraft is approaching the sensor position.

- At night, scanning operations require supplemental lighting provided by the sensor. To be operationally successful for night time operations, the system:
  - Must have the same sensitivity at night as in daylight;
  - Must not give false readings due to reflections from surface discontinuities;
  - Must be able to detect frost at night in an end-of-runway environment; and
  - Changing levels of ambient light must not degrade performance, such as at dawn and dusk.

2. The basis of Go/No-Go decision making based on sensor indications of contamination should be examined. The extent of contamination actually existing on aircraft at departure should be determined by observation during snowstorms.

3. Further sensor capability evaluation tests are not required due to the implementation of the new SAE/EUROCAE Working Group 54, Minimum Operational Performance Specification (MOPS) for Ground Ice Detection Systems (MOPS). Under these requirements, manufacturers are required to conduct tests to evaluate the capability of their system to detect ice in various conditions.

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SOMMAIRE

À la demande du Centre de développement des transports (CDT) de Transports Canada, APS Aviation inc. (APS) a entrepris un programme de recherche sur l'utilisation d'un système de détection de givrage au sol pour informer les pilotes sur l'état des ailes de leur appareil immédiatement avant le décollage.

Contexte

Au cours de l'hiver 1998-1999, APS a mené une première série d'essais sur le terrain pour étudier la possibilité de faire appel à un système de détection de givrage au sol (GIDS, *ground ice detection system*), placé à un endroit fixe, pour évaluer la contamination par le givre des ailes d'un avion juste avant qu'il s'engage sur la piste de départ. Les résultats de cette étude sont consignés dans le rapport TP 13481E de TC, intitulé *Feasibility of Use of Ice Detection Sensors for End-of-Runway Wing Checks* (sommaire en français).

Les résultats des essais réalisés à des endroits situés à proximité de la piste de départ ont montré que le GIDS pouvait effectivement être utilisé pour inspecter les avions en partance. Mais la distance entre la caméra de détection et l'avion s'est révélée trop grande, et il a été recommandé de réduire cette distance. Il a aussi été recommandé de hausser la caméra, afin d'obtenir un meilleur angle de prise de vue, notamment pour le contrôle de gros porteurs. Enfin, il a été recommandé de placer la caméra là où les avions en partance s'immobilisent en attendant l'autorisation de décoller.

Le rapport a conclu que la capacité du détecteur de déceler de façon fiable la zone contaminée et d'en donner une image exacte devait faire l'objet d'autres études, afin que l'on puisse se fier au système. Il a donc été recommandé que le détecteur soit essayé sur une aile d'essai dont la contamination est connue, de même que sur un avion, juste avant son dégivrage.

Objectifs

Le programme d'essai comportait quatre volets :

1. Essais au poste de dégivrage de l'Aéroport international de Montréal (Dorval) simulant les conditions en bout de piste – le détecteur au sol examinait les ailes des avions au cours des opérations de dégivrage. Les essais de simulation des conditions en bout de piste menés au cours de l'hiver 1998-1999 faisaient partie de ce volet. Des essais étaient prévus pour l'hiver 1999-2000, sous réserve des résultats obtenus concernant la

fiabilité de la détection de givrage dans des conditions représentatives d'une installation en bout de piste.

2. Fiabilité des images de détection de givrage – pour examiner la fiabilité de la détection de givrage dans des conditions représentatives d'une installation en bout de piste, les chercheurs ont comparé les images de contamination prises par la caméra de détection et la contamination réelle sur un avion en service et sur une aile d'essai.
3. Limites de sensibilité – la capacité du système de détection a été examinée (surtout en laboratoire).
4. Essais tactiles – il avait été convenu d'étudier les limites de la capacité de l'être humain de déceler au toucher la présence de contamination.

La présente étude a été subdivisée en deux parties. La première a porté sur les deux premiers volets ci-dessus (essais en bout de piste et fiabilité des images de détection de givrage), malgré que l'autorisation de mener d'autres essais en bout de piste n'ait pas été accordée. La deuxième partie de l'étude s'est penchée sur les limites de sensibilité. La réalisation des essais tactiles n'a pas été approuvée pour l'étude.

Pour étudier la fiabilité de détection de givrage dans des conditions représentatives d'une installation en bout de piste, on a soumis à l'examen du détecteur des avions en service réel, pendant des tempêtes de neige, juste avant qu'ils soient dégivrés au poste de dégivrage. Un prototype de système de détection de givrage fourni par Cox et Co. a été utilisé pour ces essais. Un observateur documentait l'étendue de la contamination des ailes par la neige à partir de la nacelle d'un camion de dégivrage. Le détecteur était placé de façon à simuler la position qu'il aurait en bout de piste par rapport à l'avion immobilisé au poste de dégivrage.

D'autres essais ont aussi eu lieu, qui mettaient en jeu une contamination connue sur une aile d'essai statique. Les indications de contamination données par le détecteur ont été comparées à l'étendue connue de la contamination.

La capacité du système de détection a été examinée par des essais menés à l'Aéroport international de Montréal (Dorval) et à l'Installation de génie climatique du CNRC, à Ottawa. Des plaques d'essai de la FAA (*Federal Aviation Administration*), revêtues de givrage de différentes épaisseurs, ont été examinées par le détecteur à partir de différentes distances et selon différents angles de prise de vue. Des essais limités ont été menés avec ces plaques, parallèlement aux essais simulant une position en bout de piste et aux essais de durée d'efficacité.

Résultats et conclusions

1. Les résultats de ces essais ont mené à conclure que les détecteurs de givrage ont encore besoin de développement avant de pouvoir être utilisés de façon satisfaisante dans une application en bout de piste. Voici quelques considérations particulières à cette application dont il y a lieu de tenir compte :

- Les distances et angles de prise de vue qui peuvent être obtenus lorsque le système de détection est placé dans une position représentative de celle d'un détecteur en bout de piste, par rapport à l'avion en partance. La sensibilité de détection est fonction de la distance et de l'angle de prise de vue. Plus la distance est grande et plus l'angle de prise de vue est obtus, plus les zones de contamination sur les ailes doivent être étendues pour que le détecteur puisse les déceler.

- La sensibilité à la distance et à l'angle de prise de vue complique la prise de décision de décoller ou non :
  - la sensibilité de détection du givrage est plus grande lorsque les zones des ailes sont rapprochées du détecteur que lorsqu'elles en sont éloignées;
  - la sensibilité de détection du givrage sur un avion dont les ailes sont élevées est moins grande que sur un avion dont les ailes sont basses, à cause de l'angle de prise de vue qui est plus obtus.

- Aux distances requises, l'indication donnée par le détecteur de la présence d'une contamination, quelle qu'elle soit, est limitée.
  - Nécessité de pouvoir faire un zoom avant pour mieux examiner la zone suspecte.

- Sur un arrière-plan enneigé, le détecteur ne peut donner d'indication de la présence de contamination sur le bord d'une aile. L'image de détection doit produire un contour net de la zone de l'avion examinée.

- Le mouvement relatif entre l'avion et le détecteur ne doit pas produire de fausses indications qui empêcheraient l'examen du bord d'attaque pendant que l'avion s'approche de l'emplacement du détecteur.

- Dans l'obscurité, le détecteur a besoin d'un éclairage d'appoint. Pour que le système puisse être utilisé avec succès au cours d'opérations nocturnes :
  - il doit avoir la même sensibilité, qu'il fasse jour ou qu'il fasse nuit;
  - il ne doit pas donner de fausses lectures attribuables à des réflexions de discontinuités de surface;
  - il doit pouvoir détecter le givre la nuit, en bout de piste;

- ses performances ne doivent pas être altérées par les variations d'intensité de la lumière ambiante, comme à l'aube et à la brunante.

2. Il y a lieu d'examiner les critères qui déterminent la décision de décoller ou non, à partir des indications du détecteur de givrage. Lors de tempêtes de neige, l'étendue réelle de la contamination présente sur l'avion au départ doit être déterminée par l'observation.

3. Il n'est pas nécessaire de procéder à d'autres essais d'évaluation des capacités du détecteur, en raison de l'entrée en vigueur des nouvelles normes de performances minimales (MOPS) pour les systèmes de détection de givrage au sol, publiées par le groupe de travail 54 de la SAE/EUROCAE, qui obligent les fabricants à mener des essais pour évaluer les capacités de leur système dans diverses conditions.

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GLOSSARY

A/C	Aircraft
APS	APS Aviation Inc.
CDF	Central Deicing Facility
CEF	Climatic Engineering Facility
Cox	Cox & Company, Inc.
FAA	Federal Aviation Administration
GIDS	Ground Ice Detection System
IR	Infrared
LE	Leading Edge
MOPS	Minimum Operational Performance Specification
MSC	Meteorological Service of Canada (previously known as Atmospheric Environmental Services Canada)
NRC	National Research Council Canada
OAT	Outside Air Temperature
RF	Radio Frequency
SAE	Society of Automotive Engineers
TDC	Transportation Development Centre
TE	Trailing Edge
WG54	EUROCAE Working Group 54
YUL	Montreal International Airport (Dorval)

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1. INTRODUCTION

Under contract to the Transportation Development Centre (TDC) of Transport Canada (TC), APS Aviation Inc. (APS) undertook a research program to examine the application of a *ground ice detection system* to provide information on the condition of aircraft wings just prior to departure.

1.1 Background

During the 1998-99 winter, APS conducted an initial series of field tests to study the feasibility of using a remote ground ice detection system (GIDS) at a fixed location to assess ice contamination on aircraft wings just prior to entering the departure runway. Results of that study were reported in the TC report, TP 13481E, *Feasibility of Use of Ice Detection Sensors for End-of-Runway Wing Checks* (1).

In that study, test locations close to runways historically used for departures during storm conditions were selected in collaboration with airport authorities. Procedures for scanning wings of departing aircraft during inclement weather operations were also developed in collaboration with airport authorities.

The Cox and Co. (Cox) GIDS was used for these tests. The camera was installed on a vehicle with a 40-foot mast. Two sessions of scanning tests of live aircraft during deicing operations were conducted. As well, tests were attempted at the entrance to the Central Deicing Facility (CDF) of Montreal International Airport (Dorval) to inspect aircraft with a reasonable amount of snow on their wings.

The results of the tests near the departure runway demonstrated that the GIDS could be used at that location to inspect departing aircraft. It was found that the distance between the sensor camera and the aircraft tested was excessive, and testing at a reduced distance was recommended. As well, use of a higher mast was recommended to obtain an increased angle of viewing, particularly for larger aircraft. It was recommended that the camera be positioned to take advantage of stationary aircraft at the location where they normally await takeoff clearance.

Several cases of sensor indications of snow contamination on departing aircraft were documented. The associated sensor images of contamination, however, lacked detail and distinctness, and could not be confirmed by visual or tactile inspection of the aircraft surface prior to takeoff. Furthermore, the area identified as contaminated changed with subsequent scans. It was concluded that the ability of the sensor to reliably identify and provide an accurate image of the extent of the area subject to contamination requires further study to develop confidence in the system. It was recommended that tests be conducted to determine the reliability of the system using a test wing on which contamination is applied to defined areas, and to scan aircraft at the CDF prior to deicing. Because the sensor system was upgraded following the 1998-99 winter season, tests to establish confidence in the system's ability to detect contamination were justified.

Thus far, this series of tests has been limited to use of the Cox GIDS. Separately, the BFGoodrich GIDS has been tested in an end-of-runway application by Delta Airlines. In those tests, the sensor was mounted on a mobile vehicle that traversed along the leading edge of the wings of stationary aircraft (that had been halted for this purpose), capturing one or more images of portions of the wing surface. This method of operation was based on the operating capabilities of that particular sensor system; that is, viewing distance, area viewable, and ability to scan a moving object.

1.2 Work Statement

Appendix A presents an excerpt from the project description of the work statement for the APS Aviation 1999-2000 winter research program.

1.3 Test Program Elements

The overall test program proposed to examine remote ice detection sensors is shown in Figure 1.1. The overall test program was composed of four separate segments:

1. *Tests at End-of-Runway* – use of the remote sensor to scan wings of departing aircraft during deicing operations. The simulated end-of-runway tests conducted in the 1998-99 winter season were part of this stage, and confirmed the feasibility of scanning aircraft near the departure runway. Further tests during the 1999-2000 winter were planned conditional on findings relative to the reliability of ice detection in conditions typical of an end-of-runway installation (distance to aircraft sensor height and angle of viewing).
2. *Developing Confidence in Ice Detection Images* – an examination of the reliability of ice detection in conditions typical of an end-of-runway installation by comparing sensor images of contamination to actual contamination on operating aircraft and on a test wing.
3. *Sensitivity Limits* – an examination (mainly laboratory) of the capability of the sensor system.
4. *Tactile Tests* – an examination of the human limitations in identifying the existence of ice through the tactile senses.

FIGURE 1.1

OVERALL PROGRAM

REMOTE ICE DETECTION SENSORS

SENSITIVITY LIMITS

- Ice thickness threshold
- Ice under fluid
- Contamination roughness
- Visibility in snow
- Changing light conditions
- Roughness profiles of slush

END-OF-RUNWAY APPLICATION

DEVELOPING CONFIDENCE IN ICE DETECTION IMAGES

- Test wing with applied contamination
- Test wing in natural snow
- Operational aircraft at deicing facility

END-OF-RUNWAY TESTS

- Trials at better sites - YUL

TACTILE TESTS

Tests on live subjects:
pilots, deicing operators

This study was performed in two parts that are discussed separately throughout this report. The first part (End-of-Runway) addresses Program Elements 1 and 2, and the second part (Sensor Capability) addresses Element 3. Tactile tests (Element 4) were not conducted, as they were not approved by Transport Canada for study at this time.

1.4 Objectives

1.4.1 End-of-Runway

The objectives of this study were to:

- Study the accuracy and reliability of indications of contamination as provided by a remote ice detection sensor in a simulated end-of-runway application.

  This objective was satisfied by scanning aircraft during snowstorms, prior to being deiced, at the CDF at Dorval Airport, Montreal. An observer located in the bucket of a deicing truck documented the actual extent of snow on wings. The Cox and Co. ice detection sensor was positioned to simulate an end-of-runway orientation relative to the aircraft stopping position at the deicing pad.

  Tests were also conducted using applied patches of contamination on a static test wing. Sensor indications of contamination were compared to documentation of the actual extent of contamination.

- Conduct further field tests near the hold-for-takeoff clearance point adjacent to the departure runway.

  Tests to address this objective were not approved following conduct of the tests at the CDF.

1.4.2 Sensor Capability

The objective of this study was to:

- Investigate sensor capabilities with respect to ice thickness, detection of ice under de/anti-icing fluid, and sensor accuracy in changing light conditions. Ice thickness tests were conducted in the cold chamber and at the airport. Tests in changing light were conducted in natural lighting conditions at the airport.

- This objective was satisfied by conducting sensor capability tests at Montreal International Airport (Dorval) and at the National Research Council (NRC) Climatic Engineering Facility (CEF) in Ottawa, using the ice detection system supplied by Cox and Co. Ice of varying thicknesses was formed using the Federal Aviation Administration (FAA) ice detection plates. These tests were conducted in conjunction with the simulated end-of-runway tests and the holdover time tests.

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2. METHODOLOGY

2.1 Simulated End-of-Runway

This subsection describes the methods used to perform simulated end-of-runway tests.

Test methodology was developed for both *Developing Confidence in Ice Detection Images* and *Tests at End-of-Runway.* Approval to proceed with *Tests at End-of-Runway* was initially withheld, subject to a later decision. Later in the winter season, it was decided not to proceed with simulated end-of-runway tests.

Appendix B provides the detailed test plan for these tests.

2.1.1 Studying the Accuracy and Reliability of Remote Ice-Detection Sensor Indications

The test program examines the ability of the sensor to accurately report the extent and area of contamination actually existing on a wing surface. A matrix of planned tests is provided in Table 2.1. The study consisted of three types of tests:

1. Scanning operating aircraft at the CDF;
2. Testing with the TC JetStar test wing with applied contamination during dry, cold weather; and
3. Testing with the JetStar test wing during conditions of natural snow.

All tests involved comparing the detail of sensor camera images of contamination to the actual extent of contamination as noted by an experienced observer and as obtained from photographs and videotape records. Electronic files of the sensor camera image were retained, as were visual and photographic documentation of the extent of contamination.

2.1.1.1 Test site

These tests were conducted at the CDF at Montreal International Airport (Dorval).

A construction crane was selected as a practical and not overly expensive method of positioning the sensor at the desired variable

TABLE 2.1

PLANNED MATRIX OF TESTS FOR REMOTE SENSOR SIMULATED END-OF-RUNWAY

Run Number	Day or Night	Type of Contaminant	Test Surface	View of Wing	Sensor Distance (m)	Sensor Height (m)
1	Day	Applied Snow	JetStar	Top	26	12
2	Day	Applied Snow	JetStar	Top	26	18
3	Day	Applied Snow	JetStar	Top	48	12
4	Day	Applied Snow	JetStar	Top	48	18
5	Day	Applied Snow	JetStar	Leading Edge	40	12
6	Day	Applied Snow	JetStar	Leading Edge	40	18
7	Day	Applied Snow	JetStar	Leading Edge	80	12
8	Day	Applied Snow	JetStar	Leading Edge	80	18
9	Day	Applied Ice	JetStar	Top	26	12
10	Day	Applied Ice	JetStar	Top	26	18
11	Day	Applied Ice	JetStar	Top	48	12
12	Day	Applied Ice	JetStar	Top	48	18
13	Day	Applied Ice	JetStar	Leading Edge	40	12
14	Day	Applied Ice	JetStar	Leading Edge	40	18
15	Day	Applied Ice	JetStar	Leading Edge	80	12
16	Day	Applied Ice	JetStar	Leading Edge	80	18
17	Night	Applied Snow	JetStar	Top	26	12
18	Night	Applied Snow	JetStar	Top	26	18
19	Night	Applied Snow	JetStar	Top	48	12
20	Night	Applied Snow	JetStar	Top	48	18
21	Night	Applied Snow	JetStar	Leading Edge	40	12
22	Night	Applied Snow	JetStar	Leading Edge	40	18
23	Night	Applied Snow	JetStar	Leading Edge	80	12
24	Night	Applied Snow	JetStar	Leading Edge	80	18
25	Night	Applied Ice	JetStar	Top	26	12
26	Night	Applied Ice	JetStar	Top	26	18
27	Night	Applied Ice	JetStar	Top	48	12
28	Night	Applied Ice	JetStar	Top	48	18
29	Night	Applied Ice	JetStar	Leading Edge	40	12
30	Night	Applied Ice	JetStar	Leading Edge	40	18
31	Night	Applied Ice	JetStar	Leading Edge	80	12
32	Night	Applied Ice	JetStar	Leading Edge	80	18
33	Day	Natural Snow	JetStar	Top	26	12
34	Day	Natural Snow	JetStar	Top	26	18
35	Day	Natural Snow	JetStar	Top	48	12
36	Day	Natural Snow	JetStar	Top	48	18
37	Day	Natural Snow	JetStar	Leading Edge	40	12
38	Day	Natural Snow	JetStar	Leading Edge	40	18
39	Day	Natural Snow	JetStar	Leading Edge	80	12
40	Day	Natural Snow	JetStar	Leading Edge	80	18
41	Night	Natural Snow	JetStar	Top	26	12
42	Night	Natural Snow	JetStar	Top	26	18
43	Night	Natural Snow	JetStar	Top	48	12
44	Night	Natural Snow	JetStar	Top	48	18
45	Night	Natural Snow	JetStar	Leading Edge	40	12
46	Night	Natural Snow	JetStar	Leading Edge	40	18
47	Night	Natural Snow	JetStar	Leading Edge	80	12
48	Night	Natural Snow	JetStar	Leading Edge	80	18
49	Day	Natural Snow	A/C at CDF	Top	26	12
50	Day	Natural Snow	A/C at CDF	Top	26	18
51	Day	Natural Snow	A/C at CDF	Leading Edge	40	12
52	Day	Natural Snow	A/C at CDF	Leading Edge	40	18
53	Day	Natural Snow	A/C at CDF	Top	48	12
54	Day	Natural Snow	A/C at CDF	Top	48	18
55	Day	Natural Snow	A/C at CDF	Leading Edge	80	12
56	Day	Natural Snow	A/C at CDF	Leading Edge	80	18

height (up to 18 m or 60 ft.) at the test location. A suitable crane was located and arrangements were made to have the crane and operator available at short notice based on forecasted weather conditions. For each test, the crane was delivered to the APS test site for installation of the GIDS system on the truck boom. Photo 2.1 shows the mobile crane positioned for testing, with the mast extended and the sensor camera installed. Photo 2.2 shows the sensor camera installation on the crane bucket in more detail. A comprehensive description of the crane and sensor installation is given in the equipment section.

At the test site, the sensor system mounted on the crane boom was positioned relative to the aircraft wing on the deicing pad (or to the test wing) to represent the viewing geometry and distances typical of end-of-runway installations. The tested distance is compatible with the clearances recommended in the 1998-99 study, in TC report TP 13481E(1), that indicated 26 m (85 ft.) for narrow-body aircraft and 47.5 m (156 ft.) for large wide-body aircraft (Figure 2.1).

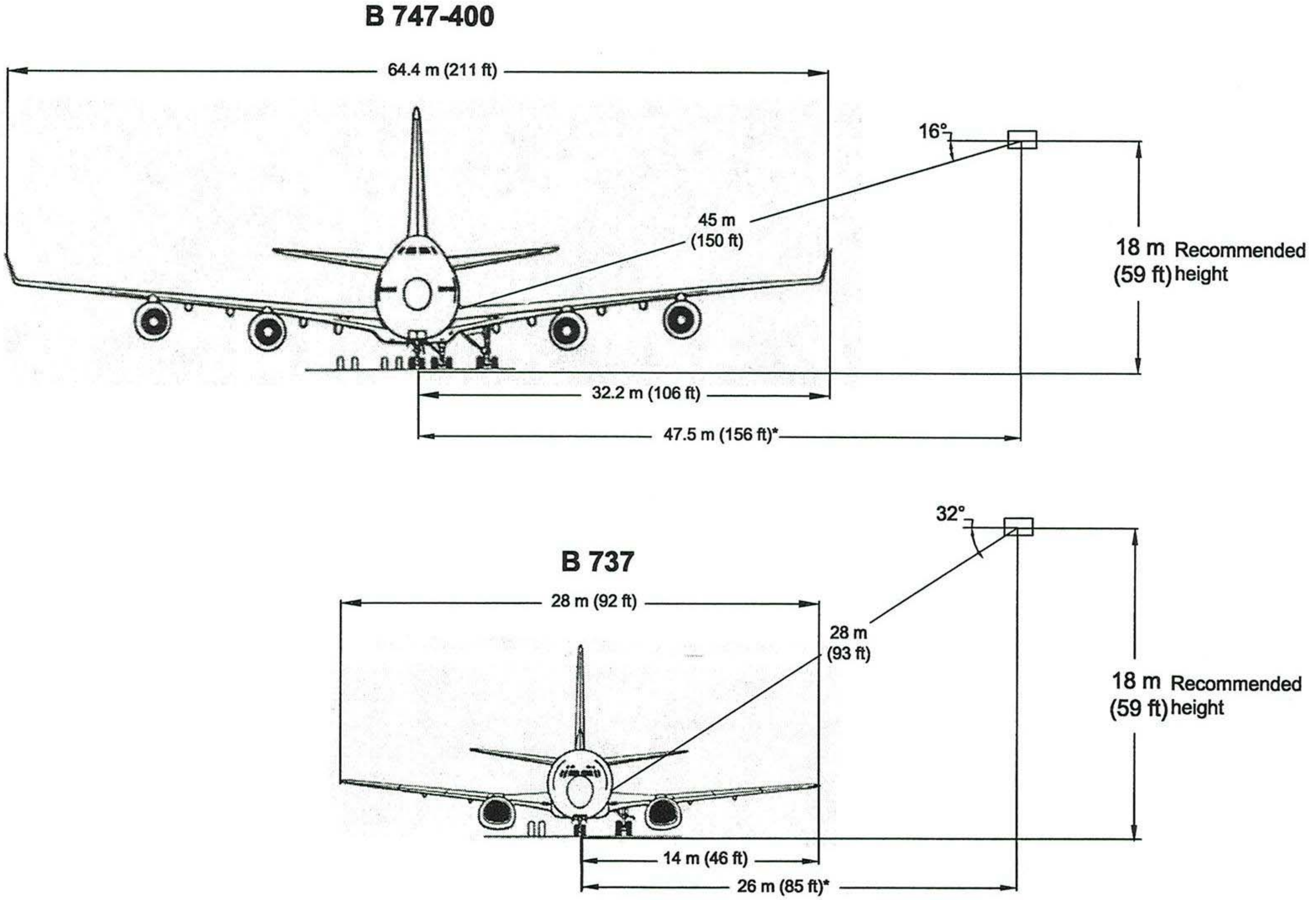
The precise positioning of the crane at Pad 1 was jointly identified by APS and AéroMag 2000 to ensure compliance with airport safety regulations. Wing clearances were based on AéroMag 2000 pad assignment controls that ensured that no aircraft larger than small wide-body aircraft would be processed at Pad 1. Photo 2.3 shows the location of the mast truck relative to the aircraft on Pad 1. The horizontal distance from centre-line to the sensor installation on the crane boom was 33 m (110 ft.). The truck body was farther back, with the boom slanted toward the pad. Photo 2.4 provides a view from the test position of an aircraft undergoing deicing.

2.1.1.2 Procedures for scanning live aircraft prior to deicing

These tests involved scanning wings of aircraft during deicing operations just after arrival at the CDF. A matrix of planned tests is shown in Table 2.1.

Procedures were developed with AéroMag 2000 to position an APS observer in an open bucket of a deicing vehicle along with the deicing operator. AéroMag 2000 offered to assign an open-bucket deicing vehicle to Pad 1 whenever testing was to take place. As soon as an aircraft came to a stop on the deicing pad, the AéroMag deicing operator positioned the bucket so as to allow the APS observer to quickly videotape or photograph the wing condition, and sketch the area of contamination on a generic wing data form, prior to proceeding with deicing. Documentation was done very quickly so as not to delay the

FIGURE 2.1
RECOMMENDED POSITION OF GIDS SENSOR FOR END-OF-RUNWAY APPLICATION



* Aerodrome Standards and Recommended Practices - Minimum Separation Distances.

(Aircraft not drawn to scale.)

cm1589/Reports/Ice Detect./figure21.dwg

aircraft operation. Photo 2.5 shows the APS observer outfitted with a safety harness, ready for testing.

For any future tests of this nature, it is recommended that photography with reliable time stamps be the principal method of documenting the existing contamination.

A second observer was responsible for operating the GIDS system installed in a cube van beside the crane. This function included taking sensor images of contamination, ensuring ongoing recording of sensor images, and directing the sensor view toward the wing being examined. The wing leading edge was scanned by the sensor as the aircraft turned onto the centre-line of the pad and approached the stop point of the deicing pad (and sensor position). As soon as the aircraft came to a stop, the top of the wing (directly in front of the sensor position) was scanned.

Aircraft operator, fin number, and event time were noted to enable comparison between sensor image and actual wing condition.

After the deicing process, the wing was scanned again.

2.1.1.3 Procedures for testing with the JetStar test wing with applied contamination

These tests were also conducted at the CDF at Montreal International Airport (Dorval). Arrangements were made with AéroMag for access to the CDF during quiet periods and to deice the test wing as required. The actual testing was conducted overnight.

The sensor was installed on a mobile crane as described in Section 2.1.1.1. These tests were based on scanning known areas of artificially applied contamination on the JetStar test wing.

Required weather for this test was dry and below freezing. One test was planned for daytime with an overcast sky, and the other at night using only the sensor system lighting to replicate operational conditions at the end-of-runway. Only the night test was conducted.

For the tests with snow, the wing was first treated with anti-icing fluid (Type IV, UCAR Ultra+). Patches of snow were then applied by shaking snow (taken from snow banks) over the wing surface. For tests with ice, the anti-icing fluid was cleaned off the wing surface and a water mist was sprayed to form a thin film of ice. The patches of snow and ice varied in size and shape. As a guide to the size of snow and ice patches, ice length expected to be viewable at specific distances and viewing angles as reported in TP 13481E (1) (pertinent extract follows in Subsection 2.1.1.3.1) was used. As well, placement of patches of contamination on the test wing surface was based on fluid failure patterns documented in previous full-scale fluid failure tests on aircraft. As a guide (and shown in Figure 2.2), patterns of failure on aircraft wings determined from a previous study, in TC report TP13130E (2), were used.

Photo 2.6 shows the JetStar wing mounted on the trailer for testing. Photo 2.7 shows the application of a water mist to form an ice film on the wing leading edge.

Distances from sensor to wing were varied to reflect the clearances recommended for viewing at an end-of-runway installation. Sensor elevation was varied to test different viewing angles. The orientation of the test wing to the sensor camera was also varied. The wingtip was pointed toward the sensor to simulate the case of scanning the wing of a live aircraft stopped at the end-of-runway in front of the sensor location. The orientation of the leading edge to face the sensor simulated the scanning of the leading edge of an approaching aircraft.

2.1.1.3.1 Extract from TC report, TP 13481E, *Feasibility of Use of Ice Detection Sensors for End-of-Runway Wing Checks* (1)

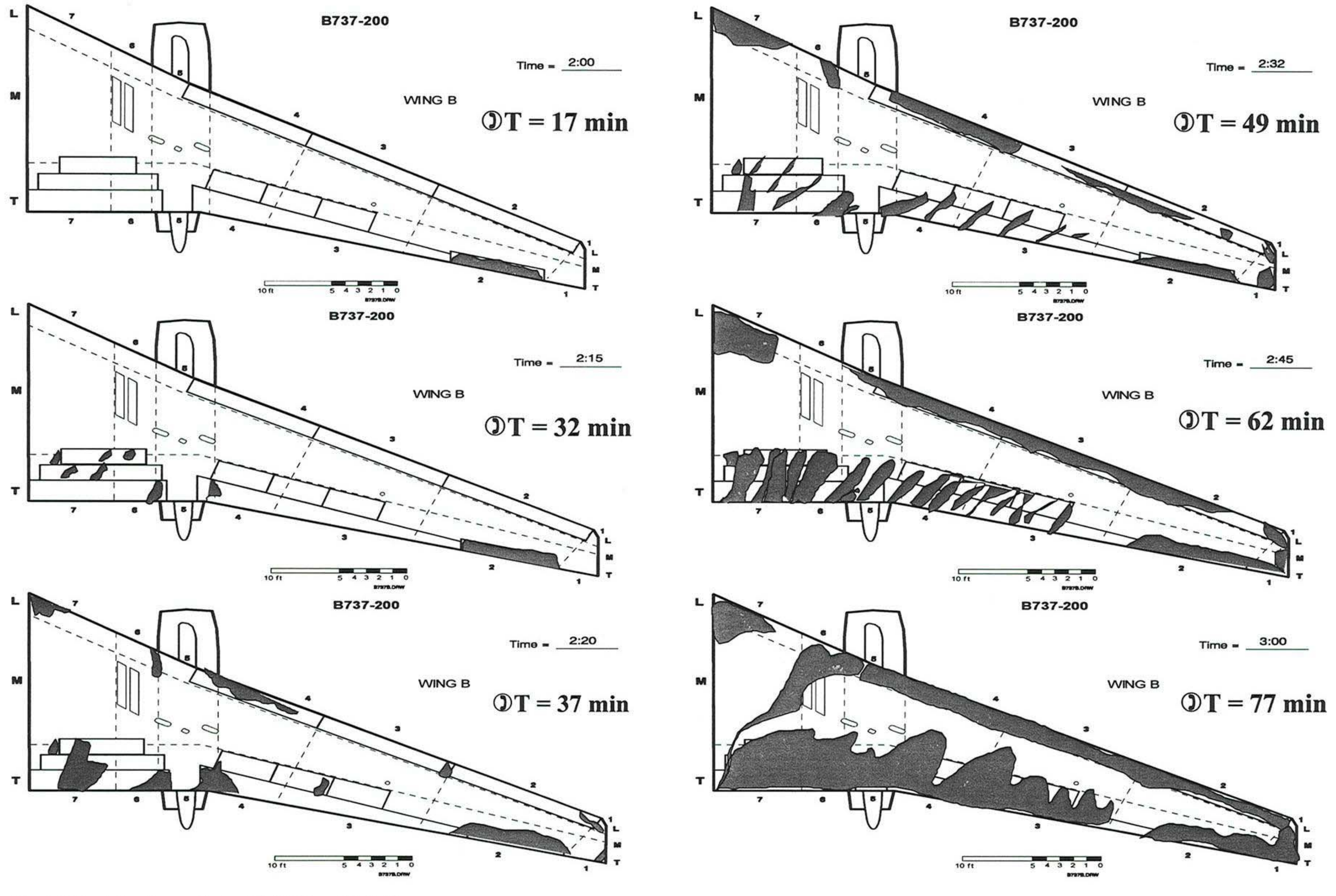
Size of Ice Length Viewable as a Function of Distance and Viewing Angle

The topic of size of patches of ice contamination viewable by the sensor is an important one. In preparation for the associated sensitivity tests on the ice detection sensor, the sensor system manufacturer provided a grid of values for ice length viewable at different combinations of distances and viewing angles. Values provided in that grid were seen to vary directly with distance and with the sine function of the viewing angle, and values were then extrapolated to represent the distances and viewing angles experienced during this test. The values for Ice Length Viewable in Table 2.2 result from that exercise.

For high sensitivity, the viewing angle should be greater than about 25 degrees. At lower viewing angles, reliable ice detection might not be expected.

FIGURE 2.2

TYPICAL PROGRESSION OF FAILURES ON WING



Source: Aircraft Full-Scale Test Program for the 1996/97 Winter TP13130E

Table 2.2
Expected Ice Length Viewable as Function of Distance and Viewing Angle

Distance to Target (m)	Expected Ice Length (cm) Viewable at Viewing Angle					
	90°	30°	20°	15°	10°	6°
15	6	11	16	22	32	53
22	8	17	25	32	48	80
30	11	22	33	43	64	107
38	14	28	41	54	80	134
46	17	34	49	65	97	160
53	20	39	57	76	113	187
68	25	50	74	97	145	241
80	29	58	85	113	170	280

Example: at a distance of 53 m and a viewing angle of 10°, minimum length of ice expected to be viewable by the sensor is 113 cm.

The beneficial impact of reduced distances and increased viewing angles is illustrated in the following chart (Table 2.3) which compares the ice length viewable based on the set-up during the test with that of the suggested set-up.

Table 2.3
Expected Ice Length Viewable at Recommended Distance and Viewing Angle

Aircraft Type	Test Set-up			Suggested Set-up		
	Distance from camera to wing (m)	Viewing Angle (degrees)	Ice Length Viewable (cm)	Distance from camera to wing (m)	Viewing Angle (degrees)	Ice Length Viewable (cm)
B737	54	10	113	28	32	20
B747	68	6	241	45	16	60

2.1.1.4 Procedures for testing with the JetStar test wing in natural snowfall

Two sessions were planned: one during daylight and one at night. Arrangements were made with CDF staff for a test location not interfering with the deicing operation, and for periodic cleaning of the test wing. It was planned to locate the test wing in the snow dump area of the CDF for these tests.

Test procedures specified recording sensor camera images of progressive natural contamination while an experienced observer simultaneously documented the actual extent of contamination by sketching on a wing plan form (as shown in Figure 4 of Appendix B).

Photographs and videotape records were required at each test. Recording of events at progressively increasing levels of contamination was to be initiated by the wing observer and communicated to the photographer and the sensor operator. A variety of sensor viewing distances and angles were to be tested as noted in the test matrix (Table 2.1).

These tests were not conducted due to lack of suitable weather conditions.

2.1.2 Conducting Field Tests near the Hold-for-Takeoff Clearance Point

2.1.2.1 Description of tests

These tests were to be conducted conditional on confirmation of ice detection sensor image accuracy and reliability. During the season, it was decided not to conduct these tests.

The purpose was to demonstrate use of the sensor camera to scan wings of departing aircraft for contamination during live operations using clearance distances and mast heights such as recommended in the 1998-99 study, in TC report TP 13481E (1). The condition of wings of operational aircraft was to be documented with the sensor camera during natural precipitation associated with deicing activities. Data on any detected icing contamination on the wings was to be collected for subsequent analysis, but not be communicated to the operator nor to any other party.

For the tests, a reference surface with a predetermined area of contamination was to be located nearby and scanned periodically.

Preparation activities for operational tests over three sessions included:

- Defining test locations in conjunction with airport authorities;
- Establishing operational procedures to support the tests in conjunction with airport authorities;
- Arranging equipment for scanning: vehicle, sensor installation, and radios;
- Arranging for retrieval of details of each aircraft's deicing history from the CDF; and
- Notifying all concerned, including aircraft operators, that test scanning activities will be taking place.

2.1.2.2 End-of-runway tests

APS monitored weather forecasts and initiated operational tests based on suitable conditions. Contacts at the TDC, Aéroports de Montréal, and Nav Canada were advised when tests were planned.

Tests involved positioning the sensor vehicle at a location beside the taxiway, near the hold-for-takeoff clearance point. The wing on the near side of the aircraft was to be scanned, and any evidence of contamination was recorded. Aircraft operator and serial number were to be recorded.

An exposed reference test plate surface located at a measured distance and angle of incidence was to be scanned periodically to confirm sensor ability to identify contamination.

At the end of the test session, the deicing history of each aircraft was to be retrieved from the deicing operator and incorporated into the database for analysis. Weather conditions were to be recorded on an ongoing basis. Results from simultaneous testing on flat plates conducted at the nearby APS test site were to be incorporated into the data analysis.

At least three test sessions (2 daytime and 1 night) during periods of snow or freezing precipitation were to be attempted.

Complete photo and video records of test set-up were required.

2.1.3 Equipment

The principal equipment required for these tests was the remote GIDS and the mobile crane used for positioning the sensor at the specified heights.

Cox provided the remote GIDS used for the tests. This system measures the intensity of infrared (IR) light in specific bandwidths. The contrast between the ambient IR intensity and the IR intensity from the surface image is used to detect contamination on the surface being inspected. A brief description of the system is given in the previous TC Report, TP 13481E, in Section 3.1.3 (1). The system threshold for ice detection was set at a thickness of 0.5 mm, a level at which the system's display showed a 'red' area.

For these tests, the focal length was adjusted from the normal 9 m (30 ft.) to 18 m (60 ft.) giving it a working depth of field from 18 m (60 ft.) to 45 m (150 ft.). Also, the supplementary light was changed from 500 W to 1000 W. A laptop PC interface was provided to enable changing of settings such as turning the supplementary light on or off.

The sensor system included a camera mount with remote tilt and pan controls. A TV monitor and VHS recorder were integrated into the system to support monitoring and recording of the camera view. The monitor allowed viewing by several observers during the actual tests, and displayed the normal video view from the camera with the ice detection indications superimposed onto the video image momentarily after a scan was triggered. During the first test session it was found that the VCR tape record of camera images did not include a time stamp function. As the images being recorded were generated from the camera system, it was not possible to superimpose time stamps using the VCR controls. This was corrected for subsequent tests.

A mobile crane with a hydraulically actuated boom was selected to serve as the platform for positioning the sensor system at the required heights. For these operations, a bucket was included at the boom end, to serve as a mounting platform for the sensor.

The camera pan/tilt controls, the monitor, the VCR (to videotape all video and sensor images), and the remote GIDS controls were installed in the back of a cube van parked beside the mobile crane. The cube van was parked with the nose pointing away from the deicing pad. The back door was kept open to give the sensor operator a full view of the deicing operation at Pad 1.

The van was parked beside the mast truck, leaving only enough room for the mast truck stabilizers. With this set-up, the cable to the camera in the bucket was only just long enough to satisfy the desired height. This set-up should be reviewed for any future sessions.

Two portable generators supported the operation: one to power the Cox system and one to provide light and run a dish heater in the back of the cube van.

A complete list of test equipment is included in Attachment B.

2.1.4 Personnel

Cox provided initial training on the operation of the sensor.

An operator for the mobile crane was present during all tests to adjust the boom position as needed.

Representatives from TDC observed several tests.

Requirements for APS staff varied with different tests in the following manner:

For Sensor Accuracy and Reliability tests

1. Scanning operating aircraft at the CDF required three APS staff for the following functions:
    - Team Leader;
    - Sensor Image Observer; and
    - Wing Observer/Photographer/Videographer.

2. Testing with the TC JetStar test wing with applied contamination during dry cold weather and during natural snow required five APS staff for the following functions:
    - Team Leader;
    - Sensor Image Observer;
    - Wing Observer and Assistant; and
    - Photographer/Videographer

For Simulated End-of-Runway tests

Three APS staff were required for the following functions:
- Team Leader;
- Sensor Image Observer; and
- Radio Monitor.

2.1.5 Data Forms

The following data forms (included in Appendix B) were required:

- *Contamination Form for JetStar Wing*: this form was used to record the actual area of contamination on a wing. One version of the form allowed progressive levels of contamination to be sketched.
- *Contamination Form for Live Deicing Operations*: this was a generic form to be used when documenting actual levels of contamination on the wings of operating aircraft arriving for deicing.
- *Record of Scanned Aircraft*: this form was used for identifying aircraft that had been scanned at the end-of-runway.

- *Deicing History:* This form was used to record aircraft scanned at the CDF.

2.2 Sensor Capability

This subsection describes the methods used to perform indoor and outdoor sensor tests.

2.2.1 Test Sites

The outdoor sensor capability tests were conducted concurrently with a series of tests performed on the test wing at the CDF at Montreal International Airport (Dorval). These were night tests, with lighting provided by the ice detector's supplementary light source. The sensor was mounted on the bucket of a boom truck, as shown in Photo 2.1. The target used for the majority of the tests was a test stand designed to support the FAA ice detection plates. Rotating the plate support surface of the test stand, shown in Photo 2.8, varied the angle between the sensor line of sight and the test surfaces.

The indoor tests were conducted at the NRC CEF in Ottawa, concurrently with fluid holdover time tests. The sensor was mounted on a set of rolling stairs, as shown in Photo 2.10, and the test stand described above was used to support the test surfaces.

2.2.2 Test Plates

The FAA ice detection plates (shown in Photo 2.9) were aluminum plates 12.7 X 12.7 X 0.64 cm (5 X 5 X 0.25 in.). Circular recesses 7.6 cm (3 in.) in diameter and 0.3 to 2.5 mm (0.01 to 0.1 in.) deep had been machined in the plates.

2.2.3 Test Procedures

The test procedures established by APS for the conduct of these tests are included in Appendix C. The distance between the sensor and the test surface was recorded using a laser distance measuring device, and the angle between the test surface and the line-of-sight of the sensor was measured with a digital inclinometer.

A matrix of planned tests is shown in Table 2.4.

The sensor capability tests included the following six subsets. Not all the tests were fully completed.

FIGURE 2.4
TEST PLAN FOR ESTABLISHING SENSITIVITY LIMITS FOR AN ICE DETECTION CAMERA

Distance (Horizontal)		Viewing Angle				
m	ft	10°	20°	30°	45°	60°
4.6	15	A	A (0.04 [1.9])	A (0.03 [1.3])	A (0.02 [0.9])	A (0.02 [0.8])
7.6	25	A	A,B,C,E,F (0.08 [3.2])	A,B,C,E,F (0.05 [2.2])	A,C (0.04 [1.6])	A (0.03 [1.3])
15.2	50		A (0.17 [6.5])	A,B,C,E,F (0.11 [4.4])	A (0.08 [3.1])	A (0.06 [2.5])
30.5	100			C,E,F	(0.16 [6.2])	(0.13 [5.1])
45.7	150			C,E,F		

TEST TYPE

A Ice thickness threshold tests
B Ice under Type IV fluid tests; Type IV Ethylene & Type IV Propylene
C Contamination roughness; 3 levels will be attempted
E Visibility in Snow Conditions
F Adaptability to Changing Light Conditions

NOTES

- Within the cells, values in brackets indicate the minimum length (meters [inches]) of ice viewable by the sensor (Source: Cox & Co.). The diameter of the ice disc in the ice thickness threshold plates is 7.6 cm (3 in.).
- The viewing angle is measured as the angle between the normal to the camera lens and the plane of the target object (ex. ⇒----| 90°, ⇒----/ 60°).
- If the distance between the camera and the target object increases the diameter of ice required for the sensor to detect ice, increases.
- If the angle between the camera and the target object decreases the diameter of ice required for the sensor to detect ice, increases.

2.2.3.1 Ice thickness threshold

The objective was to determine the detection threshold for thickness of smooth ice as a function of camera distance and viewing angle, using the FAA ice detection plates.

In preparing the FAA ice detection plates for testing, they were to be first filled with water and then frozen to form ice discs in the plate recesses of various depths. It is necessary to add a wetting agent such as a small amount of household detergent to the water to avoid cavities at the edges of the disc recess and to ensure a flat surface. The plates with ice discs were placed on test areas for the ice detection evaluation.

Cox provided the distance and angle limitations for the GIDS system to APS (Table 2.2). Distance is measured in a straight line from the sensor head to the viewing surface. Viewing angle is measured between the direct line of sight of the sensor and the plane of the test surface. For example, if the sensor were positioned directly above a horizontal surface, the viewing angle would be 90°. If the surface were then rotated by 30° off the horizontal, the resulting viewing angle would be 60°.

The ability of the system to detect ice of various depths was to be determined for the matrix of test conditions, as specified in the procedure and shown in Table 2.4.

The positions of the FAA ice detection plates on the test stand and the associated ice depths were as shown in Table 2.5 for both outdoor and indoor tests.

Table 2.5
Depth of Ice Discs Tested

Plate Position #	Depth of Ice Disc (in)	(mm)
1	.01	0.3
2	Missing	Missing
3	.03	0.8
4	Missing	Missing
5	.05	1.3
6	.06	1.5
7	.07	1.8
8	.08	2.0
9	.09	2.3
10	Missing	Missing

2.2.3.2 Detection of ice under anti-icing fluid

The objective was to determine the effect of a layer of fluid on an ice film on the ice detection capability of the camera.

SAE Type I and Type IV anti-icing fluids, ethylene and propylene glycol-based and from different manufacturers, were applied over ice samples on the ice detection plates or on standard plates with contamination.

2.2.3.3 Effect of contamination roughness

The objective was to assess the effect of surface roughness on the camera images of contamination and on the system's ability to detect contamination.

An attempt was made to generate rough ice surfaces with roughness profiles in excess of 0.5 mm. Smooth ice was created by hand-polishing the ice discs formed in the FAA ice detection plates. Scratching the ice surface with fine grain sandpaper created ice of medium roughness, and scratching the ice with large grain sandpaper produced rough ice.

2.2.3.4 Determine typical roughness profiles of slush

The objective was to record the roughness profiles as a function of time at selected intervals up to and including plate failure, and during standard fluid holdover tests.

During a standard anti-icing fluid holdover time test, the roughness profile of the resultant slush was to be measured as accurately as possible. The ice sensor camera was to simultaneously observe the test plate, and levels of roughness were then to be correlated with the camera observations.

2.2.3.5 Visibility in snow conditions

The objective was to determine the ability of the sensor camera to detect ice through falling snow.

For distances up to 15 m (50 ft.), the tests used ice detection plates. For longer distances, tests were to be conducted using the TC JetStar test wing. The tests were to be conducted outdoors during natural snowfall.

2.2.3.6 Adaptability to changing light conditions

The objective was to determine sensitivity of the system to changing natural light conditions. The tests were to be conducted outdoors without precipitation. The test subject (ice formed on FAA test plates) was to be examined at predetermined intervals during the two-hour period encompassing sunrise or sunset.

2.2.4 Data Forms

The data forms designed for the sensor capability tests are shown in Figures 2 and 3 of Appendix C.

2.2.5 Equipment

A complete list of equipment is included in the test procedure shown in Attachment I of Appendix C.

2.2.6 Personnel

A comprehensive list of the number of personnel required for each test set is given in Attachment II of Appendix C. A single tester conducted the completed tests, with the assistance of a second tester for set-up and test stand positioning.

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Photo 2.1
Mobile Crane with Sensor Installed

Photo 2.2
Sensor Installation on Bucket

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Photo 2.3
Mobile Crane and Cube Van at CDF Pad 1

Photo 2.4
Aircraft on Pad 1 Viewed from Open Cube Van

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Photo 2.5

APS Observer Equipped with Safety Harness and RF Hearing Protectors

Photo 2.6

JetStar Test Wing on Trailer

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Photo 2.7

Spraying Water Mist to Form Ice Film

Photo 2.8

Stand for FAA Ice Detection Plates

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Photo 2.9

FAA Ice Detection Plates

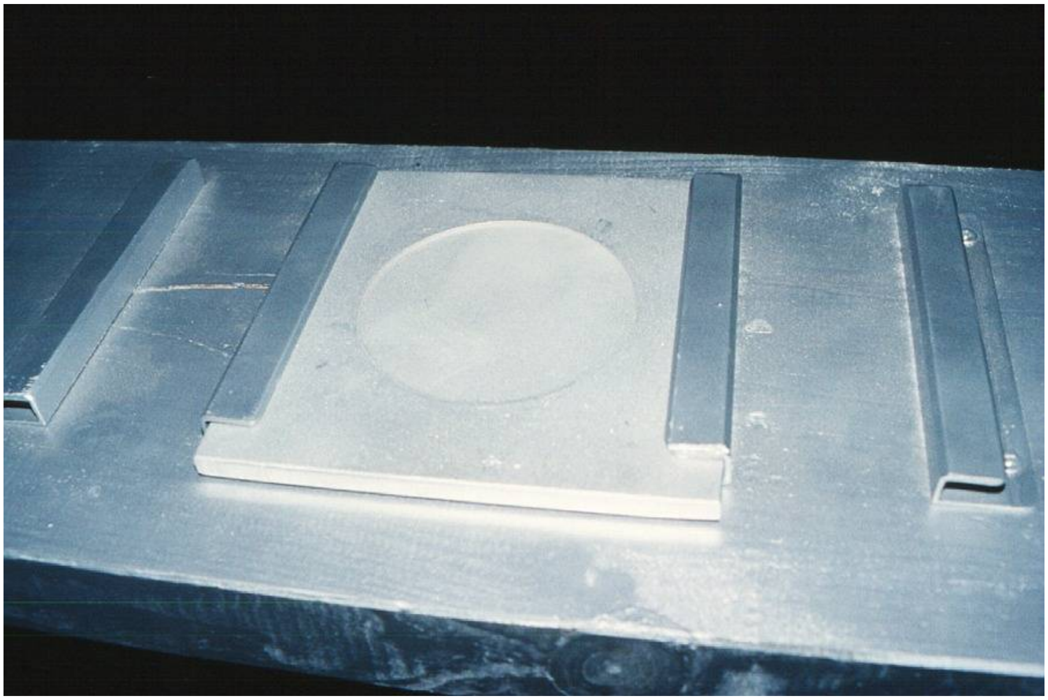
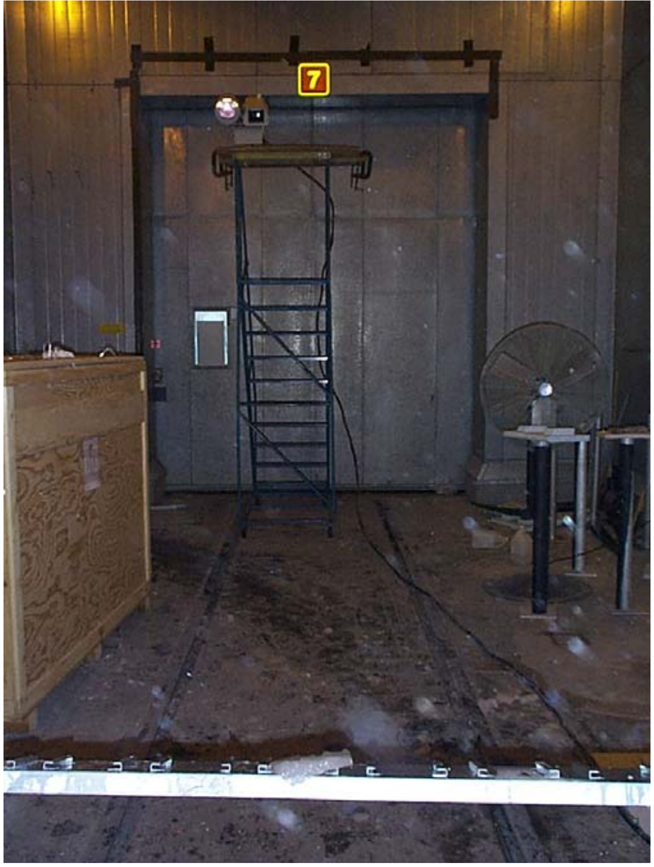


Photo 2.10

Sensor Mounted on Rolling Stair



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3. DESCRIPTION AND PROCESSING OF DATA

3.1 Simulated End-of-Runway

3.1.1 Overview of Tests

Four test sessions were conducted in February and March 2000 at the CDF. Two of these were conducted on live aircraft and two on the test wing. Table 3.1 provides an overview of the test sessions.

The ice detection system was equipped with a monitor that provided the user with a video image of the area of the aircraft being scanned. Any scanned area that the system sensed was contaminated was presented as a *red* area on the monitor image. During the tests conducted on March 11 and 14, a problem was experienced with the GIDS indications of contamination; the area indicated was not representative of the actual area contaminated. When this condition was first encountered during the overnight tests on March 11, it was believed to be associated with the level of lighting at the test site, because the system had operated satisfactorily during previous tests conducted in daylight (February 16). The problem was reported to Cox; however, when the system was used again during daylight on March 14, 2000, the poor performance recurred. These tests were terminated after two hours of attempted scans.

It was subsequently determined that a program setting in the system software (selection of ambient light or supplementary system lighting) had been altered during a software update from Cox that had been downloaded by modem. Cox believed that sensor images of contamination could be recovered by rerunning the data with the appropriate settings. Accordingly, the sensor data for the March 14 tests were returned to Cox along with photo images documenting the actual pattern of contamination on aircraft arriving at the CDF, with times indicated for each image.

3.1.2 Scanning Live Aircraft Prior to Deicing

3.1.2.1 Description of data

A log of aircraft scanned at the CDF was maintained, indicating aircraft operator, type and fin number, and time of arrival at the CDF. The height of the sensor, comments about the extent of contamination visible on the aircraft, and current weather conditions were also recorded. Table 3.2 provides a log of aircraft scanned during the February 16 test session.

TABLE 3.1

TEST SESSIONS CONDUCTED – WINTER 1999-2000
SIMULATED END-OF-RUNWAY TESTS

Date	Test Subject/Extent of Tests	Lighting	Condition
Feb 16	Aircraft before deicing; 15 aircraft scanned	Daylight	Snowstorm
Mar 10/11	JetStar wing during Hot Water test; 4 wing tests	Night	Snow pellets
Mar 14	Aircraft before deicing; 7 aircraft scanned	Daylight	Overnight snow
Mar 20/21	JetStar wing; 14 wing/camera orientations	Night	Applied snow and ice

TABLE 3.2

RECORD OF AIRCRAFT SCANNED AT CDF – FEBRUARY 16, 2000

SIMULATED END-OF-RUNWAY TESTS

Aircraft Operator	Aircraft Type & Fin Number	Arrival Time At CDF	Sensor Height (m)	Comments from Observer at Monitor Position in Van
Air Canada	B767/602	745	12	Heavy snowfall. Sensor screen completely red.
HydroQuebec	Convair/GFHH	800	12	Sensor screen still fully red, obscuring wing outline.
Delta	MD80/9018	825	12	Wing completely snow-covered, still in falling snow. Sensor now working OK with distinct image of wing. Snow on ramp now mostly melted around aircraft. Wing leading edge slats were lowered prior to deicing, giving good image of area on wing without contamination, against background of remainder of wing and lowered slat, which were completely contaminated.
Air Canada	DHC-8/809	845	12	Wings appeared to be clear of snow. Believe a/c didn't overnight at YUL. A small amount of snow appears to be on fuselage top.
Air Canada	A320/203	845	12	This aircraft was parked at Pad 2 for deicing, and could be seen by the sensor camera over the top of the aircraft in Pad 1. System image shows some snow on the fuselage. The angle is too low to scan the top of the wing, but the wing leading edge can be seen.
Royal	A310/GRVV	850	12	Sensor shows completely clean wing on arrival.
Air Alma	N/A	N/A	N/A	Trailing edge contamination.
Air Canada	A320/210	955	12	The wing is partially covered with snow, should be a good case for comparison.
AmericanAirlines	MD80/513	1008	12	Wing is partially snow-covered, at wing root, trailing edge, leading edge. Expect to be good case for comparison.
Air Canada	A319/267	1030	12	Wing partially covered with snow. Camera height was adjusted from 12 to 15 m during deicing of this aircraft.
Air Canada	CL65/115	1115	18	Snow on flaps, aileron and wingtip
AmericanEagle	Saab340/N2734E	1130	18	Thin strip of snow on leading edge.
Air Nova	DHC-8/810	1150	18	No comment.
AmericanAirlines	MD80/574	1223	18	Scattered snow on wing. Some seems to be in thick patches. Wing is deiced in 3 stages with breaks while undercarriage and underside of wing and flaps are deiced.
Air Nova	DHC-8/805	1252	18	No comment.

N/A = Not Available

Both an observer and the deicing operator were positioned in the open bucket of a deicing vehicle. Before the wing was deiced, the observer documented the pattern of snow contamination on the wing by photography and videotape, and by sketching the observed contamination on a wing plan form. The wing plan form was generic to allow recording of any type of aircraft.

3.1.2.2 Test session – February 16, 2000

On arrival at the CDF, the mast truck was positioned at Pad 1 in conjunction with AéroMag 2000. The clearance position used throughout the test session for the truck bucket with the scanner camera installed was 33 m back from the pads centre-line. The truck body was farther back, with the mast slanted toward the pad. No large wide-body aircraft were involved in this morning operation. The largest aircraft at Pad 1 during the scanning operation was a B-767.

Initial scanner height was set at 12 m. This was later adjusted to 15 and 18 m.

The Cox system was set up in a cube van parked with the open back toward the deicing pad. A TV screen and VCR were included in the set-up. One problem encountered was that the VCR tape record of camera images did not include time stamps. As the recorded images were generated from the ice detector system, it was not possible to superimpose time stamps using the VCR controls. Cox corrected this for future tests.

The van was parked beside the mast truck, leaving only enough room for the mast truck stabilizers. With this set-up, the cable to the camera in the bucket was only just long enough to satisfy the desired 18 m height.

Two portable generators were operated: one powered the Cox system and one provided light and ran a dish heater in the cube van.

The first scanning operation was performed at 0745 during a heavy snowfall. At this time, the ice detection monitor screen was nearly completely red, to the extent that the wing outline was obscured. The system continued to perform in this manner until 0815, when the monitor image suddenly cleared up. The only red colour remaining on the screen appeared in those areas where the system sensed contamination on the wing. From discussions with Cox, it was determined that snow on the camera lens was probably the cause of the unserviceability. Snow may have accumulated on the lens while the camera was mounted at the APS test site, or during the short trip to the CDF while the camera was facing into the wind and falling snow. The camera heater eventually cleared the lens, and no further problems of this nature were encountered. In subsequent test sessions, attention was given to cleaning any excess amount of snow from the lens prior to raising the camera to the test position. There was no indication during subsequent operations that the ongoing snowfall interfered with sensor performance.

During the test session, a number of wings partially or completely covered with snow were scanned. The ice detector images and documentation of actual contamination resulting from one typical case are discussed in the Section 3.1.2.3. Although all other cases were examined, they are not presented here due to the inability to reproduce the ice detector image of contamination.

Attempts to scan aircraft leading edges as the aircraft approached the stop position were unsuccessful as the rate of change of the viewing angle was too great.

3.1.2.3 American Airlines MD80 time 10:08 16 February 2000

Figure 3.1 is a typical sketch of snow on a wing (in this figure, an MD-80 is recorded). The *grey* area of the wing represents snow cover. Photo 3.1 is a photo of the same case. Here, snow cover is shown in *white* and the area of the wing that is bare, is *grey*. Sensor Images 1 and 2 give the corresponding indications of contamination provided by the ice detection system. The indication of contamination on the sensor monitor is *red*, and in this report is shown in *black*.

Although these representations of contamination on the wing were taken from different orientations to the wing, it can be seen that the ice detector image provides a realistic representation of the actual snow-covered area.

3.1.2.4 Snow-covered background

In a different case, it was noted that a snow-covered ramp in the background made it difficult for the user to determine the edge of the wing from the image provided by the ice detector monitor. Sensor Images 1 and 2 represent snow on the wings of an MD-80 aircraft scanned at 0825 on February 16, 2000. In Sensor Image 3, the entire wing is snow-covered (the snow is shown here in *black*). However, the ramp in

FIGURE 3.1

CONTAMINATION FORM FOR LIVE DEICING OPERATIONS

FIELD TESTS FOR SIMULATED END-OF-RUNWAY

DATE: February 16, 2000

TIME: 10:15

LOCATION: YUL - CDF

OAT: ____________

PRECIPITATION: Snow

AIRCRAFT TYPE: MD-80

FIN# ____________

OPERATOR: American Airlines

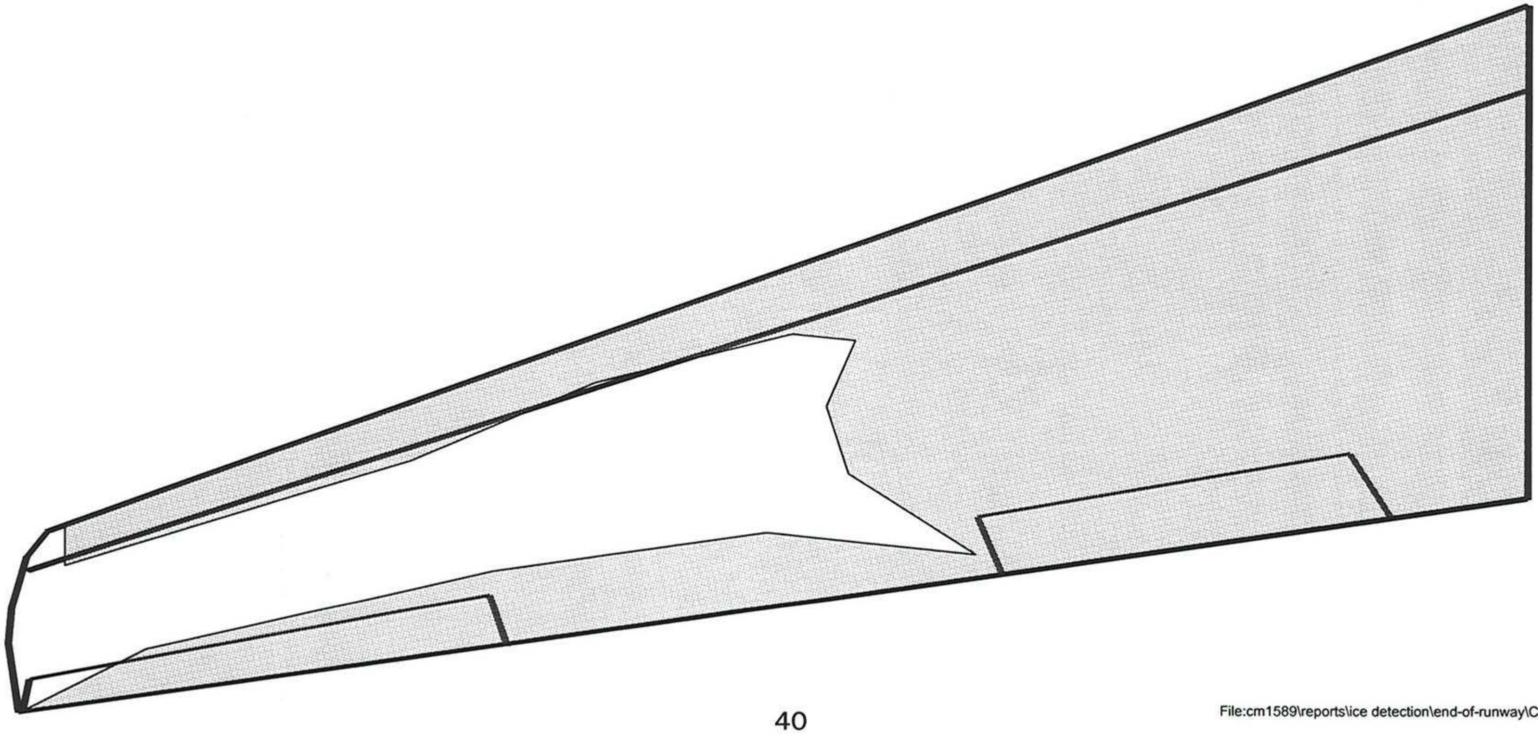
TYPE OF CONTAMINATION: ____________

SENSOR LOCATION:

Horizontal Distance to Wing Tip: 110 ft

Mast Height: 40 ft

Sensor Light? Y or N: ____________



File:cm1589\reports\ice detection\end-of-runway\Contamination Tests
At: AC Wing (Port)

the background beyond the wing is also snow-covered, and is also indicated as contaminated (*black*) in the ice detector image. Where the contaminated wing is viewed against the backdrop of the snow-covered ramp, the outline of the wing is not visible. Had contamination existed only along the edge of the wing when the background was also contaminated, the wing outline would not have been discernible to the monitor observer.

These two sensor images are useful in demonstrating the ability of the sensor to differentiate between contaminated and non-contaminated wing areas. In Sensor Image 3, the wing leading edge slat is in the retracted position and the entire wing surface is shown as being contaminated. In Sensor Image 4, the wing leading edge slat has been extended forward. The uncovered wing area is bare of snow and appears *grey* (uncontaminated) in the image.

3.1.2.5 Test methodology

For the purpose of comparing documented actual contamination to the ice detector image of contamination, it was found that the best representation of actual contamination was a still photograph. The sketches of actual contamination on a wing form were unsatisfactory because insufficient time was available during a live operation to draw a sketch accurately and with good detail. The videotape footage was not as satisfactory as still photos as the observer had to scan the entire video footage to seek an appropriate image for comparison, and then select specific (still) frames for documentation.

It was also found that comparing images of contamination taken from different wing orientations was not ideal. In future tests, attempts should be made to photograph the wing from the same perspective as the ice detector.

3.1.3 Scanning Applied Contamination on the JetStar Test Wing

3.1.3.1 Description of data

The overnight tests conducted on March 20/21, 2000, involved an examination of areas of applied contamination on the test wing. A log (Table 3.3) was maintained of the various orientations of the wing to sensor, as well as the sensor distance and height relative to the wing. The nature and size of applied patches of contamination were recorded on a test wing plan form data sheet. Completed data sheets showing

TABLE 3.3

END OF RUNWAY TRIALS ON TEST WING

RECORD OF APPLIED CONTAMINATION – MARCH 20/21, 2000

RUN #	TIME	DISTANCE (ft)	HEIGHT (ft)	WING ORIENTATION	TYPE OF CONTAM.	AMBIENT LIGHT	LOCATION ON WING	COMMENTS
1	1:15:00	60	40	LE 30 to Camera	Old Snow	Night	Inner LE & root	Granular snow was taken from snow bank
2	1:30:00	60	40	LE 30 to Camera	Old Snow	Night	Inner TE & root	Typical failure pattern
3	1:50:00	60	40	LE 30 to Camera	Old Snow	Night	Outer TE	Small patches
4a	2:09:00	60	40	LE 30 to Camera	Old Snow	Night	Flaps	Small patches
4b	2:09:00	60	40	Tip to Camera	Old Snow	Night	Flaps	Small patches
5	2:23:00	60	40	Tip to Camera	Old Snow	Night	various	New patches > 10 mm thick
6	2:29:00	60	60	Tip to Camera	Old Snow	Night	Same as 5	Same as 5
7	2:35:00	60	20	Tip to Camera	Old Snow	Night	Same as 5	Same as 5
8	2:54:00	60	20	LE to camera	Old Snow	Night	LE	New patches
9	3:16:00	100	20	LE to camera	Old Snow	Night	LE	Same as 8, plus sheet of ice
10a	3:50:00	100	12	LE to camera	Ice film	Night	LE	Iced with water sprayed from backpack sprayer
10b	3:58:00	100	20	LE to camera	Ice film	Night	LE	Same as above
10c	4:03:00	100	60	LE to camera	Ice film	Night	LE	Same as above
11a	4:32:00	60	60	LE to camera	Ice film	Night	LE	Add more ice mist
11b	4:40:00	60	40	LE to camera	Ice film	Night	LE	Same as above
11c	4:50:00	60	20	LE to camera	Ice film	Night	LE	Same as above
12	4:57:00	60	20	Tip to Camera	Ice film	Night	LE & TE	Same as above
13	5:05:00	60	40	Tip to Camera	Ice film	Sunrise	LE & TE	Same as above, effect of increasing daylight
14	5:58:00	60	60	Tip to Camera	Ice film	Sun-up	LE & TE	Same as above, full daylight, camera light on & off

the size and locations of applied contamination for all test runs during this session are included in Appendix D.

3.1.3.2 Test session March 20/21, 2000

These tests were conducted overnight on March 20/21 at the CDF on the JetStar test wing. Limited areas of contamination were developed on the wing surface by shaking snow (taken from the snow dump) onto the bare surface, or by spraying a mist of water to freeze on the surface. The mobile crane with the installed ice detection sensor was positioned to simulate an end-of-runway orientation to the wing. Before starting the tests, the wing was deiced with SAE Type I fluid and anti-iced with SAE Type IV fluid (UCAR Ultra+).

At the start of the tests (2200 hrs) it was discovered that the special 1000 W lamp installed by Cox for night-simulated end-of-runway tests had burned out. It was necessary to replace it with a standard 500-watt lamp. To compensate for the reduced light intensity, the wing was relocated closer to the sensor. Initial tests were conducted at a horizontal distance of 18 m (60 ft.). Distance was adjusted during the test session to 30 m (100 ft.). Sensor heights were varied from 6 m (20 ft.) to 18 m (60 ft.).

Following treatment with an anti-icing fluid (SAE Type IV, UCAR Ultra+), contamination was applied to limited areas, and then the wing was scanned with the sensor, which was progressively repositioned at different heights. The following discussion describes the area and nature of contamination, and the related sensor results.

Because the ice detection sensor system images are small and contamination is indicated by the colour *red*, the images do not reproduce well in black-and-white, and the sensor images are not generally included in this report. A number of photos showing the location, size, and nature of the applied contamination have been included, and are referred to in the following discussion.

Also in the discussion, the degree that the sensor successfully identified existing contamination is rated as follows:

None	no indication of existing contamination
Very weak	a trace of the actual contamination is identified
Weak	indication is much less than actual
Medium	area indicated is about one-half of actual
Strong	area indicated is close to actual
Very strong	an accurate indication

3.1.3.3 Run 1

Horizontal Distance	18 m (60 ft.)
Sensor Height	12 m (40 ft.)
Wing Orientation	Leading Edge (LE) positioned at 30° to the sensor. This is a typical orientation when an aircraft is stopped directly in front of the sensor.
Contamination	3 patches of granular snow on the main wing-top at the root and on the leading edge near the inner end. Size of snow particles ranged from 1 to 5 mm.

Table 3.4
Sensor Response – Run 1

Patch #	Patch Area (cm x cm)	Snow Roughness (mm)	Patch Location	Photo	Sensor Indication
1	180 x 30	2 – 4	Behind LE	3.2	Weak
2	15 x 15	2 – 4	LE	3.2	None
3	30 x 30	3 – 5	Wing top	3.3	Strong

Comments: Over several scans, a false positive indication was given for a narrow streak running along the wing, just behind the leading edge. On closer examination, a slight ridge on the wing surface was apparent here, and this was believed to be causing a reflection from the sensor light source back to the sensor camera. This false indication continued throughout the entire test session.

3.1.3.4 Run 2

Horizontal Distance	18 m (60 ft.)
Sensor Height	12 m (40 ft.)
Wing Orientation	Leading Edge (LE) positioned at 30º to the sensor. This is a typical orientation when an aircraft is stopped directly in front of the sensor.
Contamination	4 patches of granular snow. Size of snow particles ranged from 1 to 6 mm.

Table 3.5
Sensor Response – Run 2

Patch #	Patch Area (cm x cm)	Snow Roughness (mm)	Patch Location	Photo	Sensor Indication
1	60 x 38	2 - 4	Wing top	N/A	None
2	45 x 30	1 – 3	Flap	3.4	Strong
3	60 x 45	1 - 3	Flap	3.4	Medium
4	90 x 30	3 - 6	Wing ahead of flap	3.5	Weak

Comments: Patch 4 reproduced better when the camera was panned farther toward the wing tip.

3.1.3.5 Run 3

Horizontal Distance	18 m (60 ft.)
Sensor Height	12 m (40 ft.)
Wing Orientation	Leading Edge (LE) positioned at 30° to the sensor. This is a typical orientation when an aircraft is stopped directly in front of the sensor.
Contamination	4 patches of granular snow. Size of snow particles ranged from 1 to 10 mm.

Table 3.6
Sensor Response – Run 3

Patch #	Patch Area (cm x cm)	Snow Roughness (mm)	Patch Location	Photo	Sensor Indication
1	13 x 10	5 - 10	Aileron	3.6	Strong
2	13 x 10	2 - 5	Aileron	3.6	Very weak
3	5 x 5	5 - 10	Aileron	3.6	Very weak
4	8 x 8	2 - 5	Aileron	3.6	None

Comments: Patch 1 reproduced consistently. Patches 2 and 3 indicated intermittently on repeat scans, but never showed the full area as contaminated.

3.1.3.6 Runs 4a and 4b

Horizontal Distance	18 m (60 ft.)
Sensor Height	12 m (40 ft.)
Wing Orientation	Run 4a - Leading Edge (LE) positioned at 30º to the sensor. Run 4b - Wing turned so wingtip pointed to the sensor.
Contamination	8 patches of granular snow as in Runs 2 and 3 combined. Size of snow particles ranged from 1 to 6 mm although somewhat diminished since Run 2.

Table 3.7
Sensor Response – Runs 4a and 4b

Patch #	Patch Area (cm x cm)	Snow Roughness (mm)	Patch Location	Photo	Sensor Indication
1	60 x 38	2 – 4	Wing top	N/A	None
2	45 x 30	1 – 3	Flap	3.4	Strong (4a & b)
3	60 x 45	1 – 3	Flap	3.4	None
4	90 x 30	3 – 6	Wing ahead of flap	3.5	None
5	13 x 10	5 - 10	Aileron	3.6	Medium (4b)
6	13 x 10	2 - 5	Aileron	3.6	None
7	5 x 5	5 - 10	Aileron	3.6	None
8	8 x 8	2 - 5	Aileron	3.6	None

Comments: Patch 2 reproduced at both orientations. Patch 5 reproduced when the wing tip was pointed to the sensor.

3.1.3.7 Run 5

Horizontal Distance	18 m (60 ft.)
Sensor Height	12 m (40 ft.)
Wing Orientation	Wingtip pointed to the sensor.
Contamination	Previous snow patches fortified with additional granular snow. Snow particle roughness was greater than 10 mm.

Table 3.8
Sensor Response – Run 5

Patch #	Patch Area (cm x cm)	Snow Roughness (mm)	Patch Location	Photo	Sensor Indication
1	15 x 15	>10	Leading edge	N/A	Strong
2	60 x 38	>10	Wing top at root	3.7	Strong
3	45 x 30	>10	Flap	3.8	Strong
4	60 x 45	>10	Flap	3.8	Strong
5	90 x 30	>10	Wing ahead of flap	3.9	Strong
6	13 x 10	>10	Aileron	3.10	Strong
7	13 x 10	>10	Aileron	3.10	Strong
8	5 x 5	>10	Aileron	3.10	Strong
9	8 x 8	>10	Aileron	3.10	Strong
10	60 x 38	>10	Wing top at tip	3.11	Strong

Comments: All patches reproduced at this level of snow roughness. This angle of viewing (30º) appears to give the best results.

3.1.3.8 Run 6

Horizontal Distance	18 m (60 ft.)
Sensor Height	18 m (60 ft.)
Wing Orientation	Wingtip pointed to the sensor.
Contamination	Previous snow patches. Snow particle roughness was greater than 10 mm.

Table 3.9
Sensor Response – Run 6

Patch #	Patch Area (cm x cm)	Snow Roughness (mm)	Patch Location	Photo	Sensor Indication
1	15 x 15	>10	Leading edge	N/A	Strong
2	60 x 38	>10	Wing top at root	3.7	Strong
3	45 x 30	>10	Flap	3.8	Strong
4	60 x 45	>10	Flap	3.8	Strong
5	90 x 30	>10	Wing ahead of flap	3.9	Very weak
6	13 x 10	>10	Aileron	3.10	Strong
7	13 x 10	>10	Aileron	3.10	Strong
8	5 x 5	>10	Aileron	3.10	Strong
9	8 x 8	>10	Aileron	3.10	Strong
10	60 x 38	>10	Wing top at tip	3.11	Very weak

Comments: The sensor height was raised to 18 m (42°) and the same patches used in the previous run (at 12 m) were scanned.

3.1.3.9 Run 7

Horizontal Distance	18 m (60 ft.)
Sensor Height	6 m (20 ft.)
Wing Orientation	Wingtip pointed to the sensor.
Contamination	Previous snow patches. Snow particle roughness was greater than 10 mm.

Table 3.10
Sensor Response – Run 7

Patch #	Patch Area (cm x cm)	Snow Roughness (mm)	Patch Location	Photo	Sensor Indication
1	15 x 15	>10	Leading edge	N/A	Strong
2	60 x 38	>10	Wing top at root	3.7	Strong
3	45 x 30	>10	Flap	3.8	Strong
4	60 x 45	>10	Flap	3.8	Strong
5	90 x 30	>10	Wing ahead of flap	3.9	Medium
6	13 x 10	>10	Aileron	3.10	Strong
7	13 x 10	>10	Aileron	3.10	Medium
8	5 x 5	>10	Aileron	3.10	Medium
9	8 x 8	>10	Aileron	3.10	Medium
10	60 x 38	>10	Wing top at tip	3.11	Medium

Comments: The sensor height was lowered to 6 m (14º) and the contamination patches used in the previous two runs were scanned.

3.1.3.10 Run 8

Horizontal Distance	18 m (60 ft.)
Sensor Height	6 m (20 ft.)
Wing Orientation	Wing turned so leading edge is 90º to the sensor.
Contamination	New snow patches on leading edge and remnant of old snow patch on top.

Table 3.11
Sensor Response – Run 8

Patch #	Patch Area (cm x cm)	Snow Roughness (mm)	Patch Location	Photo	Sensor Indication
1	200 x 30	>10	Leading edge	3.12	None to Medium
2	60 x 30	>10	Leading edge	3.13	Weak to strong
3	30 x 30	Remnant	Wing top at root	3.14	Strong

Comments: The wing was turned so the leading edge faced the sensor. The sensor height was kept at 6 m. Reproduction varied with repeated scans, with indications changing from none to medium, or from weak to strong.

3.1.3.11 Run 9

Horizontal Distance	30 m (100 ft.)
Sensor Height	6 m (20 ft.)
Wing Orientation	Wing moved to 30 m and leading edge kept at 90° to the sensor.
Contamination	Same snow patches on leading edge and piece of ice placed on top.

Table 3.12
Sensor Response – Run 9

Patch #	Patch Area (cm x cm)	Snow Roughness (mm)	Patch Location	Photo	Sensor Indication
1	200 x 30	>10	Leading edge	N/A	Weak to Medium
2	60 x 30	>10	Leading edge	N/A	Weak to strong
3	8 x 13	Ice	Wing top	3.15	Strong

Comments: The wing was moved to 30 m from the sensor. As in the previous run, the leading edge faced the sensor, and the sensor height was kept at 6 m. Reproduction varied with repeated scans; indications changed from none to medium, or from weak to strong.

3.1.3.12 Runs 10a, 10b, and 10c

Horizontal Distance	30 m (100 ft.)
Sensor Height	Runs 10a, 10b, and 10c: 4, 6, and 18 m (12, 20, and 60 ft.), respectively.
Wing Orientation	Leading edge at 90° to the sensor.
Contamination	A thin layer of frozen mist was produced on the leading edge by spraying water.

Table 3.13
Sensor Response – Runs 10a, 10b, and 10c

Patch #	**Patch Area (cm x cm)**	**Photo**	**Sensor Indication**		
			Sensor Height (m)		
			4	6	18
1	200 x 30	3.16	None	Very Weak	Weak
2	60 x 30	N/A	None	None	Medium to Strong

Comments: As in the previous run, the leading edge faced the sensor, and distance was maintained at 30 m. Sensitivity improved as the viewing angle was increased from 5° to 30°.

Note that the thin film of ice on the leading edge is existent but difficult to see on Photo 3.16.

3.1.3.13 Run 11a, 11b, and 11c

Horizontal Distance	18 m (60 ft.)
Sensor Height	Runs 11a, 11b, and 11c: 18, 12, and 6 m (60, 40, and 20 ft.), respectively.
Wing Orientation	Leading edge at 90° to the sensor.
Contamination	The two patches of ice on the leading edge were thickened by spraying more water mist. Thickness varied from 2 to 5 mm.

Table 3.14
Sensor Response – Runs 11a, 11b, and 11c

Patch #	**Patch Area (cm x cm)**	**Ice Thick-ness (mm)**	**Photo**	**Sensor Indication**		
				Sensor Height (m)		
				18	**12**	**6**
1	200 x 30	2 to 3	N/A	None	None to very weak	Very strong but ice missed on nose of LE
2	60 x 30	3 to 5	N/A	None to strong – see comments	Strong to very strong, but ice missed on nose of LE	Very strong but ice missed on nose of LE

Comments: As in the previous run, the leading edge faced the sensor, but distance was reduced to 18 m.
The portion of ice Patch 2 that overlaid a painted area reproduced strongly, but that portion overlaying aluminum did not indicate.
As the sensor was lowered, the indications became more accurate, however the nose of the leading edge (where ice did exist) did not reproduce.

3.1.3.14 Run 12

Horizontal Distance	18 m (60 ft.)
Sensor Height	6 m (20 ft.)
Wing Orientation	Leading edge turned so wingtip point toward sensor.
Contamination	Same ice on the leading edge as the previous test. Thickness varied from 2 to 5. Previous snow patches from Run 7. Snow particle roughness was greater than 10 mm.
Ambient Light	Just before 0500, the sky was still dark.

Table 3.15
Sensor Response – Run 12

Patch #	Patch Area (cm x cm)	Ice / Snow Thickness (mm)	Patch Location	Photo	Sensor Indication
1	200 x 30	2 to 3	LE	N/A	None, and Weak to Medium
2	60 x 30	3 to 5	LE	N/A	Strong
3	45 x 30	>10	Flap	3.8	Strong
4	60 x 45	>10	Flap	3.8	Strong
5	90 x 30	>10	Wing ahead of flap	3.9	Strong
6	13 x 10	>10	Aileron	3.10	Strong
7	13 x 10	>10	Aileron	3.10	Strong
8	5 x 5	>10	Aileron	3.10	Strong
9	8 x 8	>10	Aileron	3.10	Strong
10	60 x 38	>10	Wing top at tip	3.11	Weak to Medium

Comments:	A portion of ice Patch 1 reproduced and varied from weak to medium, but most of the patch was not identified. The leading edge of ice Patch 2 still did not reproduce.

3.1.3.15 Tests on JetStar Wing - Run 13

Horizontal Distance	18 m (60 ft.)
Sensor Height	12 m (40 ft.)
Wing Orientation	Wing tip pointed toward sensor.
Contamination	Same ice and snow patches as the previous test. Ice thickness varied from 2 to 5 mm. Snow particle roughness was greater than 10 mm.
Ambient Light	The tests were run from 0505 to 0535. The sky started to get light just after 0500, and progressively lightened during the run.

Table 3.16
Sensor Response – Run 13

Patch #	Patch Area (cm x cm)	Ice / Snow Thickness (mm)	Patch Location	Photo	Sensor Indication
1	200 x 30	2 to 3	LE	N/A	Weak
2	60 x 30	3 to 5	LE	N/A	Very strong
3	45 x 30	>10	Flap	3.8	Very strong
4	60 x 45	>10	Flap	3.8	Very strong
5	90 x 30	>10	Wing ahead of flap	3.9	Very strong
6	13 x 10	>10	Aileron	3.10	Very strong
7	13 x 10	>10	Aileron	3.10	Very strong
8	5 x 5	>10	Aileron	3.10	Very strong
9	8 x 8	>10	Aileron	3.10	Very strong
10	60 x 38	>10	Wing top at tip	3.11	None

Comments:	The full area of ice Patch 1 was now reproduced although still somewhat weak. The leading edge of ice patch 2 was identified as ice partway through this test as the sky further lightened. An area within this patch was scraped clean – this area reproduced successfully. The beneficial influence of the ambient light was now quite evident as ice indications were much stronger than previously.

3.1.3.16 Run 14

Horizontal Distance	18 m (60 ft.)
Sensor Height	18 m (60 ft.)
Wing Orientation	Wing tip pointed toward sensor.
Contamination	Same ice and snow patches as the previous two tests. Ice thickness varied from 2 to 5 mm. Snow particle roughness was greater than 10 mm.
Ambient Light	These tests started at about 0600. By test end, the sky was fully light.
Comments	When the sensor light was turned off, the complete wing was indicated as contaminated. When the sensor light was turned back on, the contaminated areas reproduced successfully. As the sun rose in the sky, more and more of the wing surface was falsely indicated as being iced.

3.2 Ice Detection Sensor Capability

Tests were conducted outdoors at the CDF of the Montreal International Airport (Dorval) overnight on March 20/21, 2000, and in the cold chamber laboratory at NRC CEF on April 3 and 4, 2000.

Similar data were collected for each of the various types of tests. For each test, the following data were recorded of a data sheet:

- The test date;
- The test time;
- The distance between the sensor and the test surface;
- The angle between the plane of the test surface and the line of sight from the sensor to the surface; and
- A brief description of the image of contamination observed from the sensor monitor.

The sensor recorded on a database all the images captured during both test sessions, along with a time stamp. This allowed examination of images after the test.

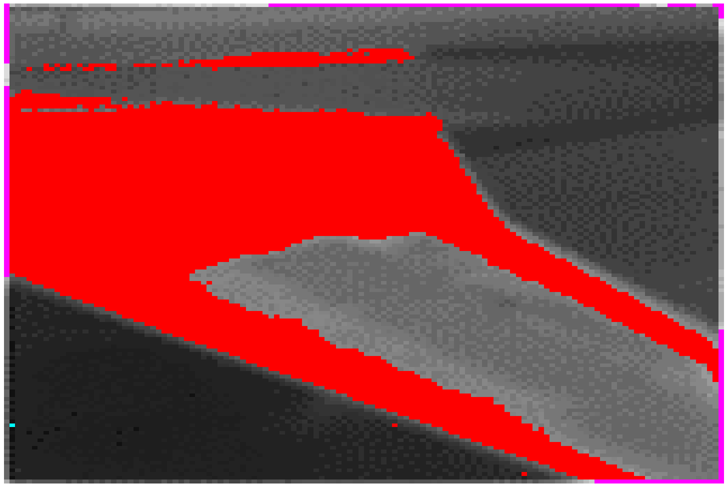
Other data such as type of test, condition of the test surfaces, type of surface or the process used to create the contamination roughness were also recorded on the data sheets. A summary of results for various tests is included in Appendix E.

Photo 3.1

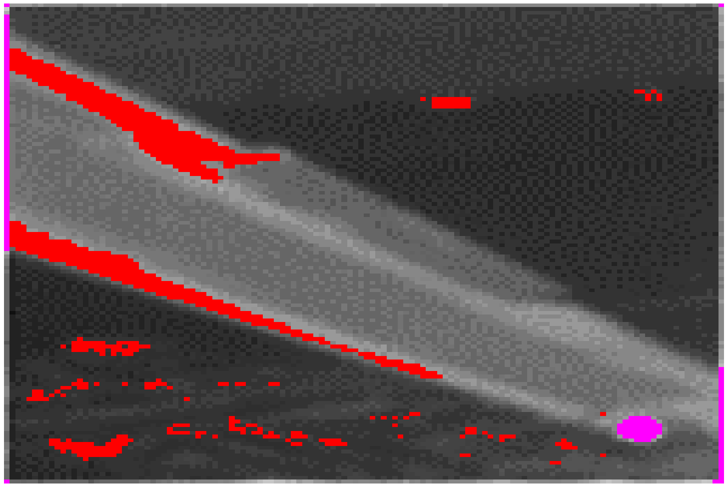
Photo of Snow on Wing MD-80

Corresponding Sensor Images of Snow on Wing MD-80

Sensor Image 1



Sensor Image 2



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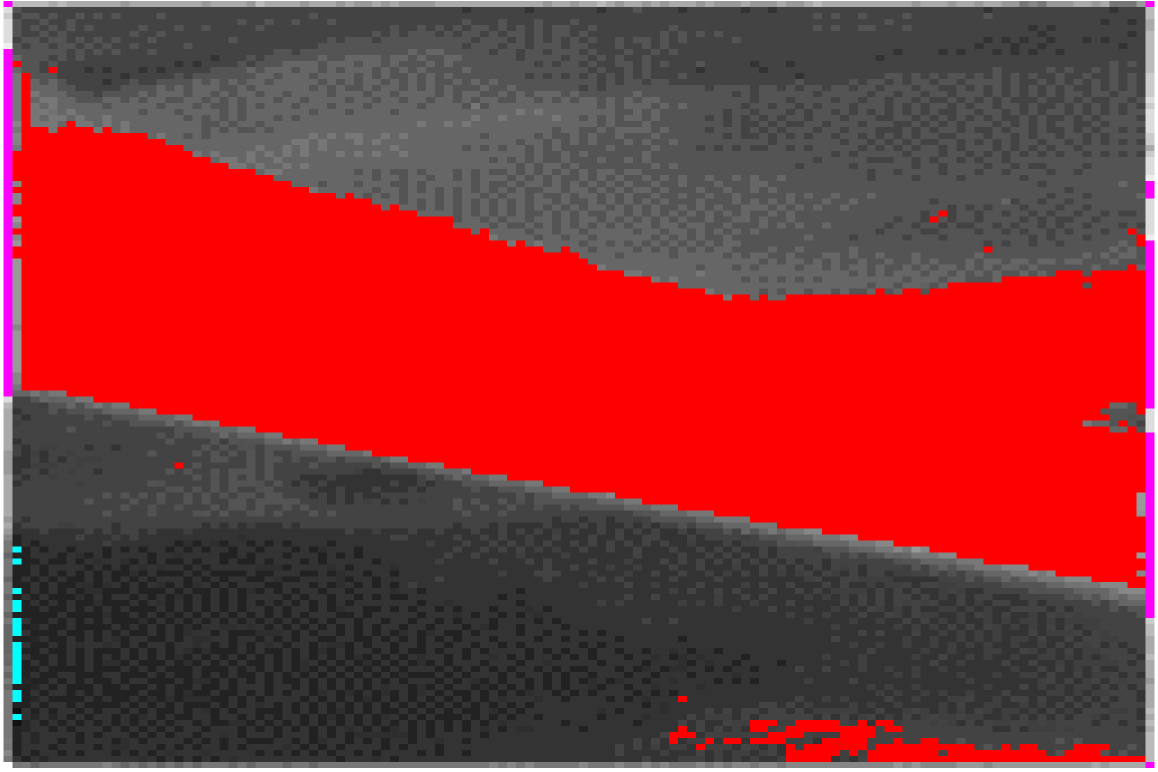
Sensor Image 3

Snow-Covered Wing – Snow on Ramp



Sensor Image 4

Snow-Covered Wing – Leading Edge Slat Extended

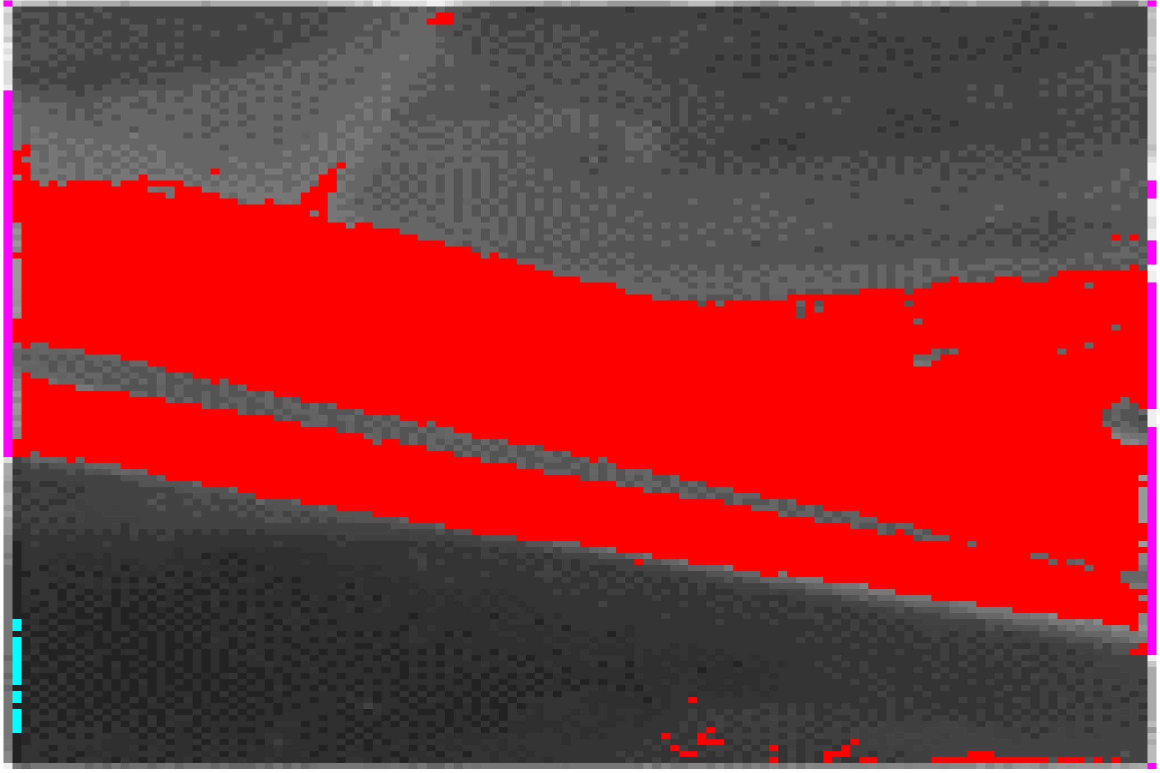


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Photo 3.2

Granular Snow Behind Leading Edge, 2 to 4 mm Thick

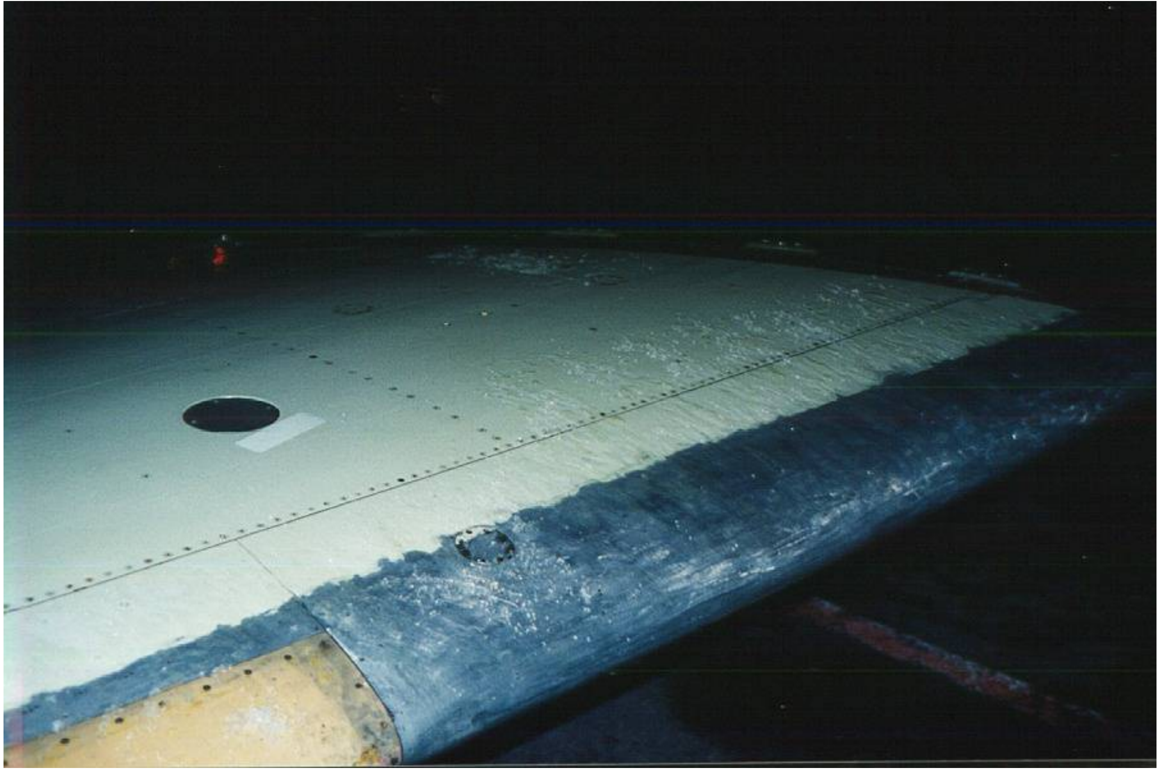

Photo 3.3

Granular Snow on Main Wing, 3 to 5 mm Thick

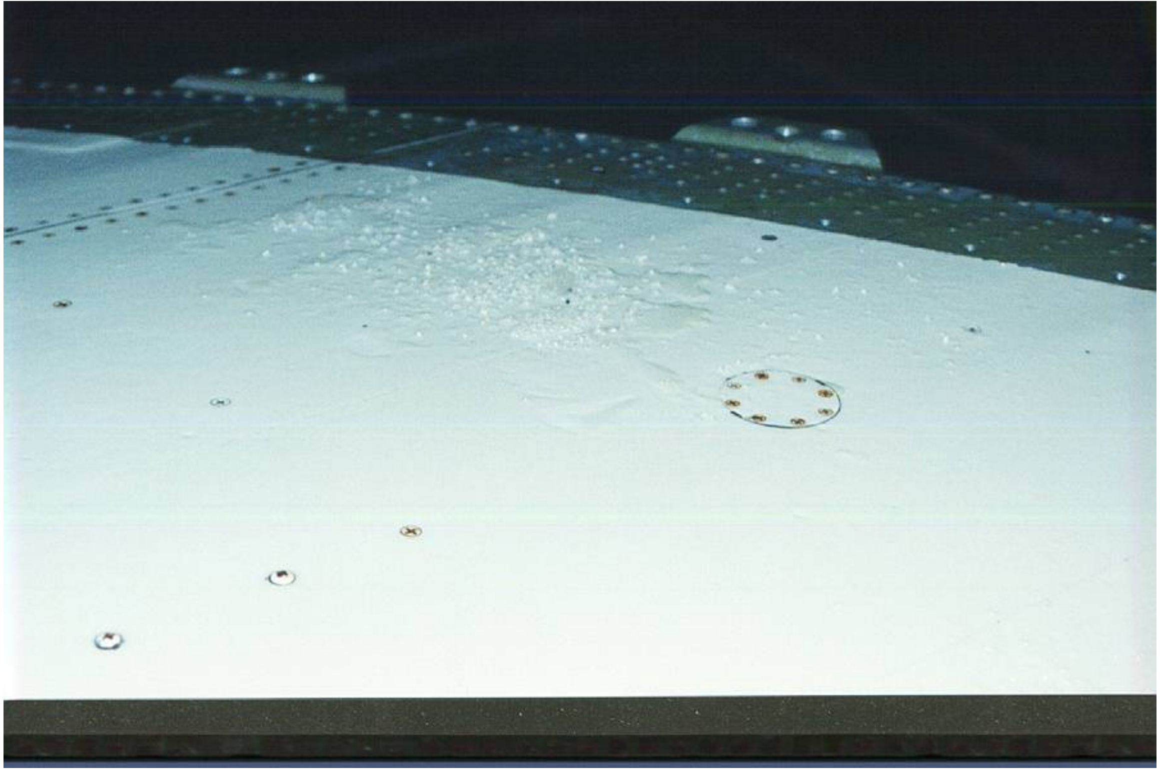

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Photo 3.4

Granular Snow on Flap, 1 to 3 mm Thick

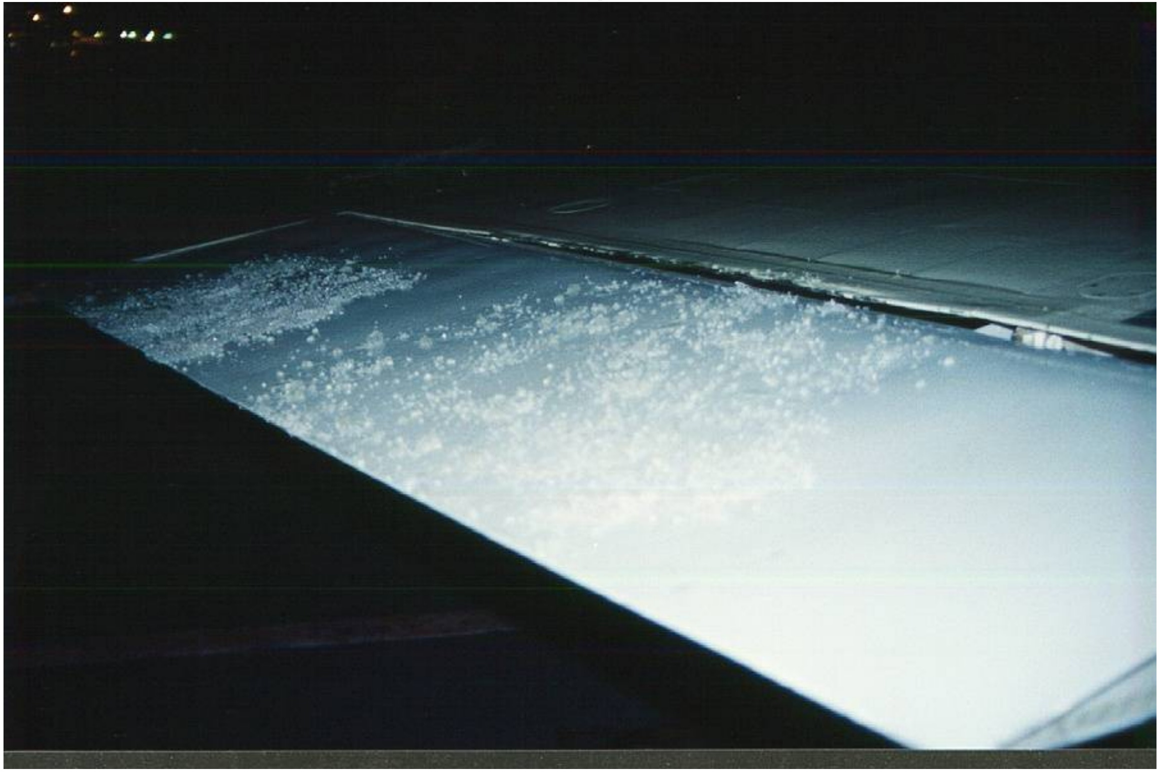

Photo 3.5

Granular Snow on Wing Ahead of Flap, 3 to 6 mm Thick

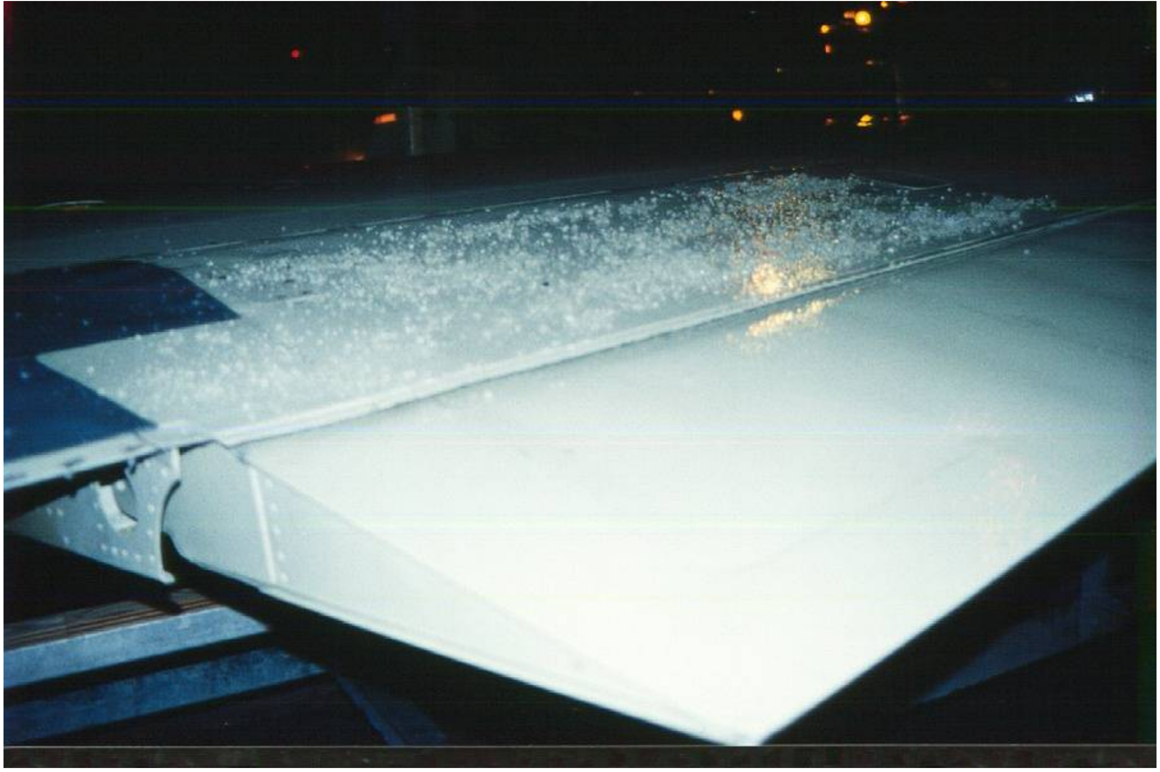

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Photo 3.6

Granular Snow Patches on Aileron

Photo 3.7

Granular Snow Patch at Wing Root, 10+ mm Thick

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Photo 3.8

Granular Snow Patch on Flap, 10+ mm Thick

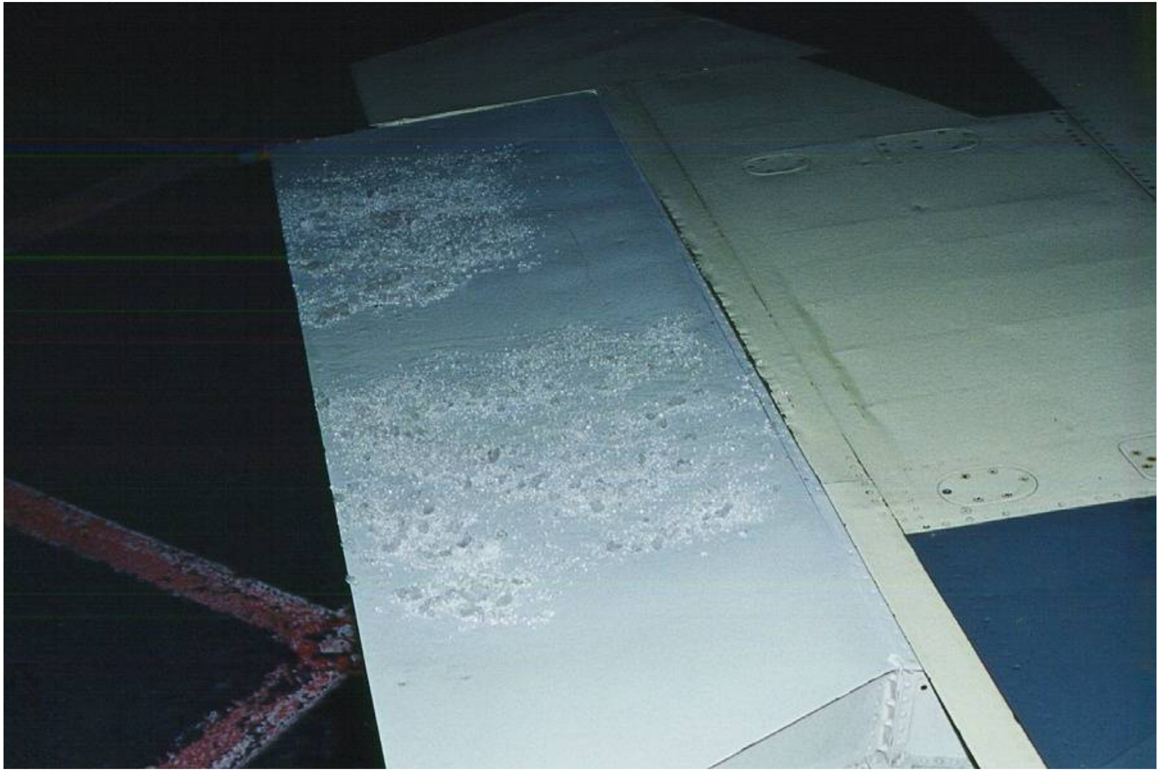

Photo 3.9

Granular Snow Patch on Main Wing, 10+ mm Thick

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Photo 3.10

Granular Snow Patch on Aileron, 10+ mm Thick

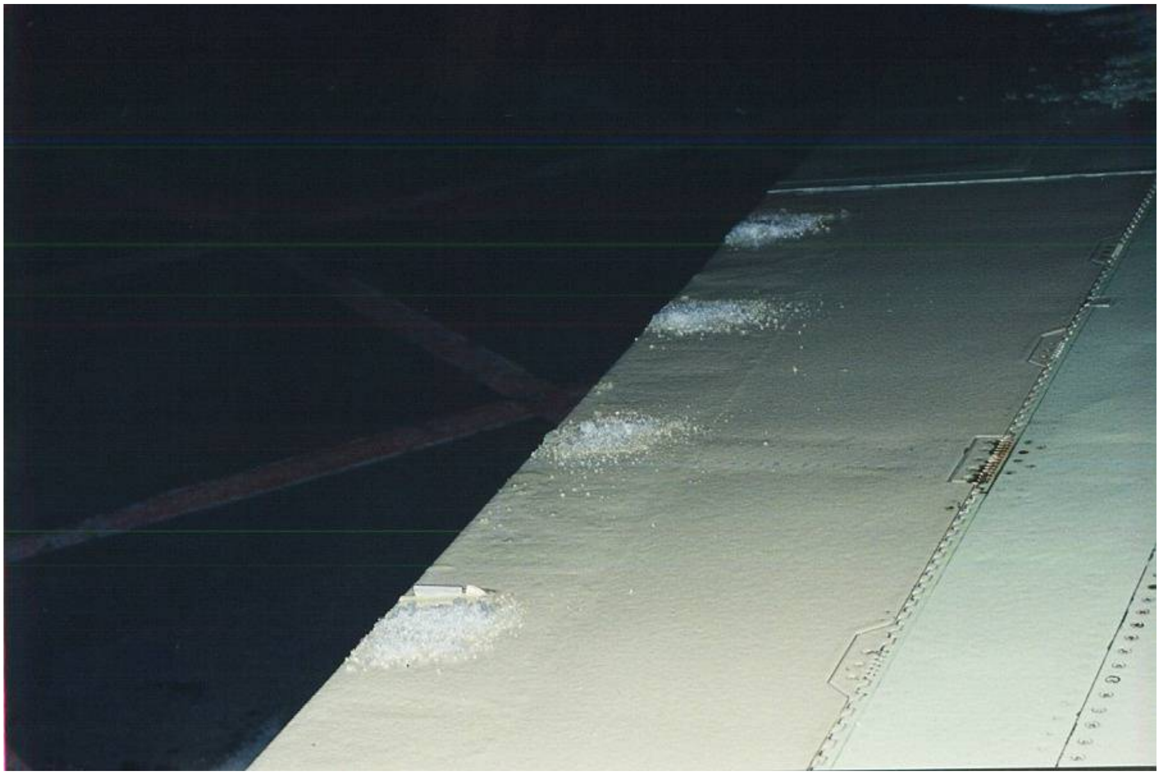

Photo 3.11

Granular Snow Patch Near Wingtip, 10+ mm Thick

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Photo 3.12

Granular Snow on Leading Edge, 10+ mm Thick

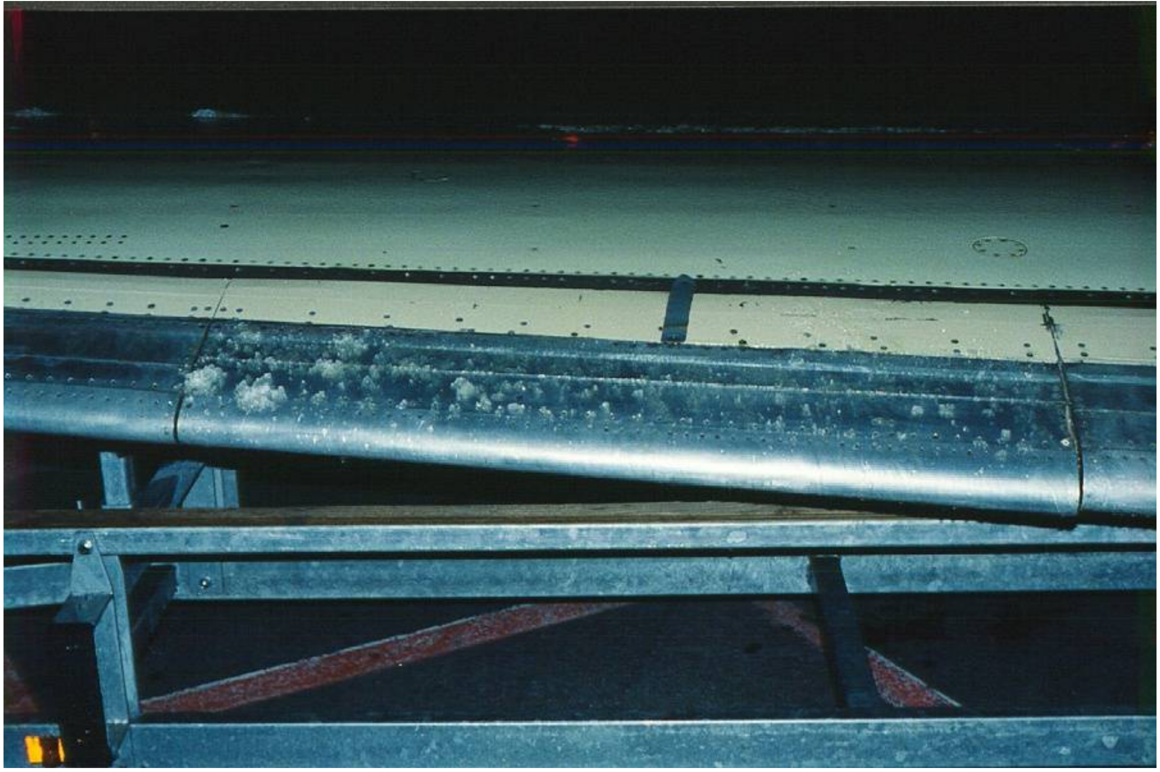

Photo 3.13

Granular Snow on Leading Edge, 10+ mm Thick

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Photo 3.14

Remnants of Granular Snow Patch on Main Wing

Photo 3.15

Ice Patch Placed on Main Wing

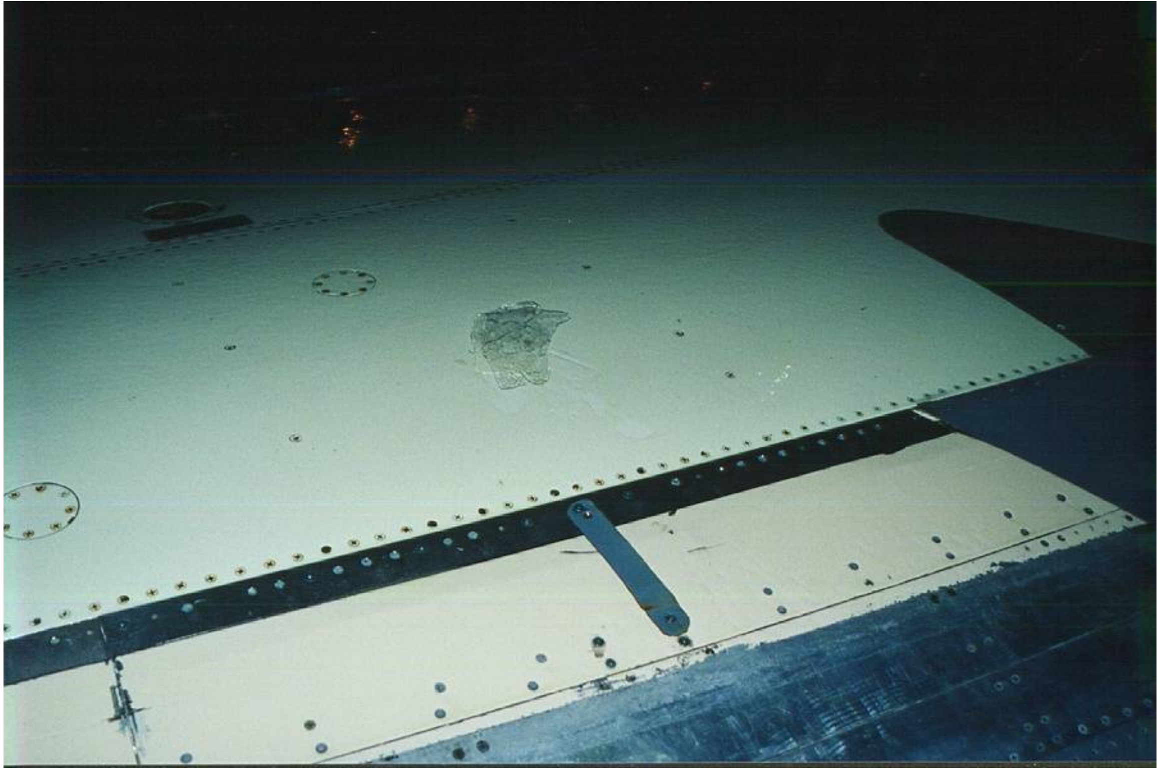

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Photo 3.16

Thin Ice Film on Leading Edge

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4. ANALYSIS AND OBSERVATIONS

4.1 Simulated End-of-Runway

4.1.1 Scanning Live Aircraft

In the test session conducted on February 16, 2000, it was observed that the ice detector system generally provided a realistic representation of snow contamination on the scanned wings. This session was conducted during daylight hours, and supplementary lighting was not used.

The sensor contamination images were not sufficiently detailed to enable an accurate assessment of the size of the contaminated areas. Enlarging the sensor images to enable more precise visual estimations of the contaminated area was not a satisfactory solution due to the poor image definition.

The manufacturer advised that the minimum length of the contaminated area visible at the tested distance and viewing angle was about 33 cm (1.1 ft.). This length represented three pixels from a total image array of 128 by 128 pixels.

The system software logic that interprets the presence of ice requires contamination to appear in the same pixel for three consecutive frames in order to indicate icing. Any relative movement between camera and aircraft can cause local contamination to appear in a different pixel area. The software then does not display this as icing as the contamination didn’t appear in the same pixel for three consecutive frames. This was seen to occur when scanning stationary aircraft, and the edges of the area indicated as contaminated (red on the screen) shifted position from one scan to the next. Presumably this was due to some swaying of the truck mast.

Background contamination, such as snow on the ramp behind or under the aircraft, made it difficult for the system user to identify the edge of the wing when contamination was also present on the wing. A means is needed to differentiate between contamination on the aircraft and background contamination, to enable detection of any contamination existing just at the wing edge.

As dawn approached and the sky started to become light, the system experienced a problem in coping with the changing light intensity. When the sensor light was turned off, the complete wing was indicated as being contaminated. When the sensor light was turned back on, the contaminated areas reproduced successfully. However, as the sun rose in the sky, more and more of the wing surface was falsely indicated as being iced.

4.1.2 Scanning Applied Contamination on JetStar Wing

The system was delivered with a 1000 W lamp installed to serve as a light source for night operations. When it was found that that light was broken, it was replaced with a 500 W lamp. To compensate for the reduced lighting, many tests were conducted at a reduced distance of 18 m (60 ft.) instead of the planned 30 m (100 ft.).

Given that the lighting was reduced, there appeared to be a notable reduction in detection sensitivity as compared to daylight scanning. At a distance of 20 m, granular snow patches as large as 60 X 40 cm and up to 4 mm in depth were not identified. During the daytime tests, although the depth of snow on wings of operating aircraft was not measured, much smaller snow patches were detected.

When snow depth was increased to 10 cm and greater during the night-time tests, snow patches as small as 5 X 5 cm were indicated successfully.

Over several scans, a false positive indication was given for a narrow streak running along the wing, just behind the leading edge. On closer examination, a slight ridge on the wing surface was apparent here, and this was believed to be causing a reflection from the sensor light source back to the sensor camera. This false indication continued throughout the entire test session.

Test results gained from varying the sensor height from 6 to 18 m (20 to 60 ft.) at a horizontal distance of 18 m (60 ft.) indicated that the optimum viewing angle appeared to be around 30°.

At a horizontal distance of 30 m (100 ft.), viewing angles less than 30° gave very weak or no indication of contamination.

4.1.3 Challenges Associated with Using a Remote GIDS for End-of-Runway Inspections

While considering and testing ice detection systems for the end-of-runway application, a number of important considerations became apparent:

1. Distances and viewing angles obtainable when operating at distances and viewing angles typical of end-of-runway sensor positioning relative to departing aircraft cause variations in sensitivity. Sensitivity is a function of distance and angle-of-viewing;
   - When distance increases 2 times, the minimum discernible area increases 4 times and
   - Flatter angle requires larger area of contamination for equivalent detection sensitivity.

2. Sensitivity to distance and angle-of-viewing complicates Go/No Go decision-making:
   - Detection of ice on the wing farther from the sensor is less sensitive than near ice; and
   - Detection of ice on higher wings is less sensitive than detection of ice on wings closer to the ground due to the flatter angle of viewing.

3. At the required distances, the indications of any contaminated area as provided by the sensor is limited by the 128 X 128 pixel array. Attempts to obtain a better assessment of the extent of the area contaminated by enlarging the image are not successful.
   - The camera operator needs to be able to zoom-in to suspect areas to focus the entire array on the suspect area.

4. Snow-covered background makes contamination on the edge of a wing impossible to identify. The system detection image requires a clearly defined outline of the area of the aircraft being scanned.

5. Relative movement between aircraft and sensor produces false indications thereby limiting the ability to scan the leading edge while the aircraft is approaching the sensor position.

6. Scanning operations at night depend on supplemental lighting provided by the sensor:
   - The sensor must produce same sensitivity as during daylight;
   - The sensor must eliminate false readings from reflections from surface discontinuities;
   - The sensor must be able to detect frost at night, in an end-of-runway environment; and
   - Changing levels of ambient light such as at dawn and dusk must not degrade performance.

4.2 Sensor Capability

This section discusses observations made during the tests and compares visual observations of contamination to sensor-recorded observations. The data recorded during all the sensor capabilities tests is summarized in Tables 4.1, 4.2, and 4.3.

4.2.1 Distance Validation and Ice Thickness Tests

These tests were performed to validate the distance versus angle limitations provided by the sensor manufacturer. These limitations indicate the minimum area of ice that the sensor can detect for a specified distance and viewing angle. At each of these combinations, multiple ice detection plates were tested to observe the minimum ice thickness detected for each distance angle combination.

The distance validation tests were conducted on two separate and significantly different occasions. The first set of tests was conducted at Dorval airport during the night of March 20/21, 2000. The second set of tests was conducted indoors at the NRC climactic chamber on April 3 and 4, 2000.

One of the factors that had a significant impact on the performance of the sensor was the ambient lighting. The artificial light created by the airport lights was very different than the artificial light used in the cold chamber. The sensor did not respond in the same way during the two sets of tests. The area detected by the sensor was more consistent during the tests conducted at the NRC CEF.

Other influences on the sensor response are the sensor settings and the system light. The 1000-watt bulb initially installed on the camera burned out before these tests were performed. A back-up 500-watt light was then installed on the sensor. To obtain usable data from the sensor, Cox suggested changes to various sensitivity parameters during active testing. It is not clear whether the settings used during the outdoor tests were the same settings as those used during the indoor tests.

TABLE 4.1

DISTANCE VALIDATION TESTS

Ice Detection with Ice Sensor Camera

Date	Time	Distance (m)	Angle (degree)	Ice Thickness Detected (mm)												Comments
				0.3	0.5	0.8	1	1.3	1.5	1.8	2	2.3	2.5	Plate 1	Plate 2	
21-Mar	*3:32*	*4.6*	*60*	▨	▨	▨	▨	no ice	√	▨	√	√	▨	▨	▨	
21-Mar	*3:34*	*4.6*	*45*	▨	▨	▨	▨	no ice	√	▨	√	√	▨	▨	▨	
21-Mar	*3:36*	*4.6*	*30*	▨	▨	▨	▨	no ice	√	▨	√	√	▨	▨	▨	
21-Mar	*3:38*	*4.6*	*20*	▨	▨	▨	▨	no ice	√	▨	√	√	▨	▨	▨	
21-Mar	*3:40*	*4.6*	*10*	▨	▨	▨	▨	no ice	0%	▨	10%	10%	▨	▨	▨	
21-Mar	*3:44*	*4.6*	*10*	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	0%	60%	
21-Mar	*2:44*	*7.6*	*60*	▨	▨	▨	▨	N/A	N/A	▨	N/A	N/A	▨	▨	▨	
21-Mar	*2:46*	*7.6*	*45*	▨	▨	▨	▨	N/A	N/A	▨	N/A	N/A	▨	▨	▨	
21-Mar	*2:50*	*7.6*	*30*	▨	▨	▨	▨	N/A	N/A	▨	N/A	N/A	▨	▨	▨	
21-Mar	*2:58*	*7.6*	*20*	▨	▨	▨	▨	N/A	N/A	▨	N/A	N/A	▨	▨	▨	
21-Mar	*3:00*	*7.6*	*10*	▨	▨	▨	▨	N/A	N/A	▨	N/A	N/A	▨	▨	▨	
21-Mar	*3:06*	*7.6*	*10*	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	0%	N/A	Plate 2, some ice detected, mostly on rougher sections
21-Mar	*1:20*	*14.6*	*90*	▨	▨	▨	▨	75%	√	▨	0%	25%	▨	▨	▨	
21-Mar	*1:23*	*14.6*	*60*	▨	▨	▨	▨	50%	50%	▨	25%	√	▨	▨	▨	
21-Mar	*1:25*	*14.6*	*45*	▨	▨	▨	▨	75%	75%	▨	50%	√	▨	▨	▨	
21-Mar	*1:28*	*14.6*	*30*	▨	▨	▨	▨	0%	10%	▨	10%	75%	▨	▨	▨	
21-Mar	*1:50*	*14.6*	*30*	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	0%	90%	
21-Mar	*2:06*	*14.6*	*20*	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	0%	70%	
3-Apr	*14:17*	*4.6*	*60*	60%	▨	60%	▨	√	√	√	√	√	▨	▨	▨	
3-Apr	*14:23*	*4.6*	*45*	√	▨	√	▨	√	√	√	√	√	▨	▨	▨	
3-Apr	*14:43*	*4.6*	*30*	√	▨	√	▨	√	√	√	√	√	▨	▨	▨	
3-Apr	*14:46*	*4.6*	*20*	√	▨	√	▨	√	√	√	√	√	▨	▨	▨	
3-Apr	*14:52*	*4.6*	*10*	50%	▨	√	▨	√	√	√	√	√	▨	▨	▨	
3-Apr	*15:00*	*4.6*	*6*	50%	▨	0%	▨	0%	0%	0%	50%	50%	▨	▨	▨	Some ice detected on all plates
3-Apr	*15:10*	*7.56*	*10*	0%	▨	0%	▨	0%	0%	0%	0%	0%	▨	▨	▨	
3-Apr	*15:14*	*7.56*	*20*	50%	▨	25%	▨	50%	0%	0%	0%	0%	▨	▨	▨	Inconsistent results
3-Apr	*15:23*	*7.56*	*30*	70%	▨	50%	▨	50%	70%	70%	70%	70%	▨	▨	▨	
3-Apr	*15:26*	*7.56*	*45*	70%	▨	50%	▨	50%	√	√	√	50%	▨	▨	▨	
3-Apr	*15:28*	*7.56*	*60*	70%	▨	50%	▨	50%	√	√	√	√	▨	▨	▨	
3-Apr	*15:52*	*15.15*	*30*	0%	▨	25%	▨	50%	√	√	√	√	▨	▨	▨	Significant background noise in image
3-Apr	*15:54*	*15.15*	*45*	0%	▨	√	▨	√	√	√	√	√	▨	▨	▨	
3-Apr	*15:51*	*15.15*	*60*	0%	▨	0%	▨	0%	√	√	√	√	▨	▨	▨	

▨ - No tests conducted

TABLE 4.2

CHANGING LIGHT CONDITION AND ICE ROUGHNESS TESTS

Ice Detection with Ice Sensor Camera

Changing Light Condition Trials

Date	Time	Distance (m)	Angle (degree)	Ice Thickness Detected (mm)										Comments
				0.3	0.5	0.8	1	1.3	1.5	1.8	2	2.3	2.5	
21-Mar	5:07	12.4	wing	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	Patches of ice clearly detected
21-Mar	5:08	17.3	30	▨	▨	▨	▨	no ice	40%	▨	60%	90%	▨	
21-Mar	5:12	12.4	wing	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	Paches of ice are shown as smaller
21-Mar	5:14	17.3	30	▨	▨	▨	▨	no ice	50%	▨	50%	90%	▨	
21-Mar	5:17	12.4	wing	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	Extra failures indicated on the leading edge
21-Mar	5:22	17.3	30	▨	▨	▨	▨	no ice	10%	▨	40%	80%	▨	Extra failure indicated around stand
21-Mar	5:26	12.4	wing	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	
21-Mar	5:29	17.3	30	▨	▨	▨	▨	no ice	0%	▨	50%	30%	▨	
21-Mar	5:29	12.4	wing	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	Square scraped into failure
21-Mar	5:35	12.4	wing	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	More failures are visible
21-Mar	5:38	12.4	wing	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	Better resolution

Ice Roughness Trials

Date	Time	Distance (m)	Angle (degree)			Smooth	Smooth	Medium	Medium	Rough	Rough			Comments
4-Apr	17:02	7.5	30	▨	▨	√	√	√	√	√	√	▨	▨	
4-Apr	17:04	7.5	45	▨	▨	√	√	√	√	√	√	▨	▨	
4-Apr	18:06	7.5	60	▨	▨	√	√	√	√	√	√	▨	▨	
4-Apr	18:08	7.5	90	▨	▨	√	√	√	√	√	√	▨	▨	Sensor warning "UNABLE TO DETECT ICE"
4-Apr	17:29	15	30	▨	▨	N/A	N/A	N/A	N/A	N/A	N/A	▨	▨	Too much background noise to interpret image

▨ - No tests conducted

Note: In some cases, special tests were conducted and comments are provided.

TABLE 4.3

FROST, ICE UNDER FLUID, AND SOLID ICE TESTS

Ice Detection with Ice Sensor Camera

Date	Time	Distance (m)	Angle (degree)	Ice Thickness Detected (mm)										Comments
				0.3	0.5	0.8	1	1.3	1.5	1.8	2	2.3	2.5	
Frost on a Cold Soaked Box (CSB)														
21-Mar	*4:30*	*20*	*60*	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	Thick frost on CSB, 26 mils, not detected by sensor
21-Mar	*4:37*	*16.8*	*30*	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	Thick frost on CSB, 26 mils, not detected by sensor
4-Apr	*13:59*	*7.5*	*45*	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	Frost on ice
4-Apr	*14:06*	*7.5*	*30*	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	Frost on ice
Ice under Fluid														
3-Apr	*17:21*	*7.5*	*20*	√	▨	√	▨	√	√	√	√	√	▨	Ice under Ultra+
3-Apr	*17:23*	*7.5*	*30*	√	▨	√	▨	√	√	√	√	√	▨	Ice under Ultra+
3-Apr	*17:26*	*15*	*30*	50%	▨	50%	▨	√	√	√	√	√	▨	Ice under Ultra + Significant noise
4-Apr	*14:23*	*7.5*	*30*	no ice	▨	40%	▨	√	√	√	√	60%	▨	Octoflo EG poured on all plates
4-Apr	*14:29*	*7.5*	*20*	no ice	▨	75%	▨	√	√	√	√	75%	▨	Octoflo EG poured on all plates 0.3 ice melted
4-Apr	*14:42*	*7.5*	*30*	no ice	▨	50%	▨	▨	√	▨	√	▨	▨	Octoflo foam poured on 0.3; 2.0; 1.5, 0.3 no ice present and no ice detected
4-Apr	*14:48*	*7.5*	*30*	▨	no ice	▨	▨	√	▨	60%	▨	▨	▨	UCAR NEW foam poured on 0.5; 1.3; 1.8, 0.5 no ice present and no ice detected
Block of Ice														
4-Apr	*16:20*	*7.5*	*30*	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	Large block of ice placed on test stand, not detected by sensor

▨ - No tests of specific ice thickness.

Note: In some cases, special tests were conducted and comments are provided.

4.2.1.1 Outdoor results

During the outdoor tests, the sensor frequently did not produce repeatable results. Variations in lighting conditions, target location, and sensor location affected the ice detection capabilities of the sensor. During the tests performed at the airport, the distance and angle limitation for most ice to be detected were the following:

Distance (m)	Angle (°)	Ice Thickness Detected
4.6	20	1.6 mm (0.06 in)
7.6	20	1.3 mm (0.05 in)
14.6	45	1.3 mm (0.05 in)

Some ice was detected below these levels but the results were not conclusive since some thinner areas of ice were detected and some thicker areas were not. Successive images were frequently different, with ice being detected during some scans but not detected during following scans.

4.2.1.2 Indoor results

During the indoor tests, the distance and angle limitation for most ice to be detected were the following:

Distance (m)	Angle (°)	Ice Thickness Detected
4.6	10	0.3 mm (0.01 in)
7.56	30	0.3 mm (0.01 in)
15.15	30	1.3 mm (0.05 in)

Some ice was detected below these levels but the results were not consistent since only small portions of the iced area were detected.

An additional test was performed with a large block of ice placed directly on the test stand. This block, shown in Photo 4.1, was significantly thicker than 2.5 cm (1 in.) and was not displayed as ice by the sensor. It was subsequently learned that the system software included a limit in ice thickness displayed.

4.2.2 Changing Light Condition Tests

Changing light tests were performed at the Dorval airport at sunrise. The sensor response was frequently monitored for the first 30 minutes of dawn. The target location and angle were not changed for the majority of these scans. Images of the test wing with patches of contamination were also captured during this time frame.

The ice disc detection was not consistent from one image to the next. The sensor experienced significant difficulties adjusting to the changing light conditions. The amount of ice detected on the test stand decreased as the sun rose. The most significant change was seen on the 2.3 mm (0.09 in) thick disc, where 90 percent of the ice was detected before sunrise and only 30 percent was detected after.

The sensor's ability to detect ice patches on the test wing was also affected by the changing light. The size of contamination detected varied greatly during sunrise. The sensor indicated contamination on areas of the test wing where no contamination was present.

4.2.3 Ice Roughness Tests

The sensor response was not significantly affected by the variation in ice roughness from one disc to another. The sensor correctly identified ice on all the discs at a distance of 7.5 m with an angle between 30° and 90°. The test conducted at 15 m did not produce conclusive data since too much background noise was present. The sensor image was very hard to interpret and no conclusions can be made regarding the sensor's ability to identify rough versus smooth ice at that distance.

At an angle of 90°, the sensor displayed a warning that read "UNABLE TO DETECT ICE". The ice discs were correctly identified despite the warning.

The smooth ice was created by hand polishing the ice discs after it was formed. Scratching the ice surface with fine grain sandpaper created the medium ice, and the rough ice was produced by scratching the ice with coarse grain sandpaper. It is possible that smoother ice may or may not be detected by the sensor, but the levels of roughness tested did not cause any difficulty for the sensor.

4.2.4 Frost on a Cold-Soaked Box

The sensor was tested on frost on two separate occasions. The first tests were performed outdoors during the night tests at the Dorval airport. The frost on the box was very thick (approximately 0.6 mm) and dense due to the large temperature differential between the box surface and the surrounding air. The sensor did not detect any frost contamination on the cold-soaked box surface when scanned.

The second series of frost tests were performed at the NRC CEF. These tests were performed at closer distances.

4.2.5 Ice under Fluid

Tests were performed at the NRC CEF to determine the sensor's ability to detect ice beneath a layer of fluid. Tests were performed with Type IV Ultra+, Type I Octoflo EG, and Type I UCAR 55A. The fluid above the ice did not affect the sensor. The performance of the sensor was equivalent to the tests performed without fluid on the ice discs.

Tests were also performed to examine the impact of fluid foam on the sensor's response, as shown in Photo 4.2. Two Type I fluids, Octoflo EG and UCAR 55A, were shaken to produce foam. The foam was then poured on the test plates. The sensor correctly identified clean surfaces and ice-covered surfaces under the fluid foam.

Photo 4.1

Block of Ice on Test Stand

Photo 4.2

Fluid Foam Test

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5. CONCLUSIONS

Many of these conclusions are specific to the Cox and Co prototype system, which has been further developed following these tests.

5.1 Simulated End-of-Runway

1. The GIDS performed reasonably well during daylight at tested distances and angles of viewing. Realistic representations of existing snow contamination were provided.
2. Detailed comparison of sensor images to documentation was limited by the small size of sensor images that lost definition when enlarged. This is a function of the sensor array composed of 128 X 128 pixels. At the viewed distances, each pixel represents a large surface area. A means to zoom-in and to focus the entire array on the suspect area is needed.
3. Snow on the ground behind the wing obscured the wing outline making any snow on the edge of the wing difficult to detect. The system image should clearly indicate the outline of the aircraft being scanned.
4. Relative motion between sensor and aircraft gives false readings. This precludes scanning of the wing leading edge while the aircraft is approaching the sensor position, and while the tracking angle is changing rapidly as the aircraft comes nearer.
5. Night viewing distance as a function of lighting power needs to be addressed. The strength of the supplementary infrared light source should be sufficient to provide a level of sensitivity equivalent to that of daylight operations.
6. False readings as result of IR reflection from wing discontinuities need to be resolved.
7. The system experienced a problem at dawn giving false indications of contamination, as ambient lighting progressively increased.

5.2 Sensor Capability

The preliminary tests performed represent a sample of the tests required to determine the performance of an ice detection sensor. Solid conclusions on the sensor's ability to identify various ice thickness levels cannot be made solely based on the data obtained during these tests.

The level of ambient light significantly affected by the level of thickness detected, the distance between the sensor and the target and the angle between the sensor line of sight and the target surface. The 0.3 mm (0.01 in.) thick ice was rarely detected and the 1.3 mm (0.05 in.) thick ice was usually detected. The sensor's ice detection capability probably lies between these values. Unfortunately plates with discs 0.5 to 1 mm (0.02 and 0.04 in.) thick were not available for the tests.

The sensor did not respond well to changing light conditions. The ice thickness threshold and the ice area detected were not constant during the transition from night to day. The sensor also experienced difficulty identifying frost during both sets of tests.

6. RECOMMENDATIONS

It is recommended that:

1. GIDS manufacturers address challenges particular to the end-of-runway application.

2. The basis of Go/No-Go decision-making based on sensor indications of contamination should be examined. The extent of contamination actually existing on aircraft at departure should be determined by actual observation during snowstorms.

3. As a result of the implementation of the new SAE/EUROCAE Working Group 54, Minimum Operational Performance Specification (MOPS) requirements, further sensor capability evaluation tests are not required. Under these requirements, sensor manufacturers are required to conduct tests to evaluate the capability of their systems to identify ice in various conditions. The set of tests specified in the SAE/WG54 MOPS is much more comprehensive than the tests performed for this study.

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REFERENCES

1. Dawson, P., Peters, A., *Feasibility of Use of Ice Detection Sensors for End-of-Runway Wing Checks,* APS Aviation Inc., Montreal, October 1999, Transportation Development Centre report, TP 13481E, 48.

2. D'Avirro, J., Chaput, M., Dawson, P., Hanna, M., Fleming, S., *Aircraft Full-Scale Test Program for the 1996/97 Winter,* APS Aviation Inc., Montreal, December 1997, Transportation Development Centre report, TP 13130E, 180.

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APPENDIX A

Terms of Reference – Project Description

APPENDIX A

PROJECT DESCRIPTION EXCERPT FROM TRANSPORTATION DEVELOPMENT CENTRE WORK STATEMENT

AIRCRAFT AND FLUID HOLDOVER TIME TESTS FOR WINTER 1999-2000

(December 1999)

5.7 Capability Testing of Ice Contamination Sensors

The contractor shall conduct a series of tests to determine:

a) the capabilities of one or more remote ice detection camera systems; and

b) the human limits in identifying ice through tactile senses.

5.7.1 Capabilities Of Remote Ice Detection Camera Systems

The objective of this series of tests is to determine operational limits for a remote ice detection camera system. Test parameters will include:

- Ice thickness threshold: determining the smooth ice thickness threshold as a function of camera distance and viewing angle, using the FAA Ice Detection Thickness Plates;
- Detection of ice under anti-icing fluid: determining the effect on ice detection of an overlying layer of Type IV fluid of varying thickness and fluid brand; and
- Effect of contamination roughness: generate rough ice surfaces to assess the effects of surface roughness on camera image and on the sensor ability to identify contamination.

The following parameters will be examined in outdoor conditions:

- Visibility in falling snow conditions. These trials will use both the ice detection thickness plates and the Transport Canada test wing;
- Accuracy in changing light conditions. The contamination target will be examined progressively during the 2-hour period encompassing sunrise or sunset; and
- Accuracy and reliability of images of real contamination on wing surfaces. This examination will include comparison of the contaminated area as indicated by the sensor, and the true area as measured. These trials will be conducted as part of the related study examining the feasibility of performing wing inspections at the end of runway, where trials will be conducted on the Transport Canada test wing, as well as on operating aircraft at the Central Deicing Facility during actual deicing conditions.

5.7.2 Conduct of Trials and Assembly of Results

The contractor shall develop a test plan with a matrix of all test parameters, detailing equipment requirements, and responsibilities of all test team members. The contractor shall co-ordinate all test activities with the laboratory staff as required. The contractor shall collect test data, including photo, video and ice detection camera records, analyze results and document findings in a final technical report and in presentation format.

5.7.3 Human Limits in Identifying Ice through Tactile Senses

The objective of this series of tests is to determine human limits in identifying ice through tactile senses.

These tests will require the development of a test set-up that supports using ice films of different thickness and levels of roughness for testing. Ideally, the test set-up will be brought to the subjects workplace, to avoid the complications and cost of bringing subjects to a laboratory facility. To accomplish this, the use of a refrigerated truck will be explored.

The experiment will involve sufficient participants and test conditions to ensure statistically reliable results. Test subjects will include active deicing staff and airline pilots.

The services of a professional human factors scientist will be utilized to assist in establishing test parameters such as:

- What percentage of test plates should be bare;
- Whether subjects should be blindfolded to eliminate visual clues;
- Whether the same plate should be judged more than once;
- How to ensure that subjects do not compare their judgements; and
- What should be the minimum time between plate sampling.

TDC will participate in the experimental design, and in seeking participation from airlines and deicing organizations.

5.7.4 Conduct of Trials and Assembly of Results

The contractor shall develop a test plan with a matrix of all test parameters, detailing equipment requirements, and responsibilities of all test team members. The contractor shall develop the test set-up in conjunction with the advice from a human factors expert. The contractor shall co-ordinate tests with subject personnel. Results of the tests will be analyzed statistically to determine reliability and confidence limits of the findings.

5.8 Feasibility of Performing Wing Inspections at the End-of-Runway

The contractor shall conduct further trials to examine the feasibility of performing wing inspections with remote ice detection camera systems, at the entrance to the departure runway during precipitation conditions requiring deicing. The Cox and the BFGoodrich (RVSI) sensor systems will both be utilized in these trials.

5.8.1 Test Phases

These trials will be conducted in two phases:
Phase I: Accuracy and reliability of images of real contamination on wing surfaces
This series of trials will compare the contaminated area as indicated by the sensor, to the real extent of the contaminated area as documented

by observation. These trials will be conducted on the Transport Canada test wing, as well as on operating aircraft at a Central Deicing Facility during actual deicing conditions. Three outdoor sessions each on the test wing and at a deicing centre (either Montreal or Toronto) are planned. Two sessions on the test wing at a cold chamber facility are also planned, to provide supporting data gathered under controlled conditions.

Phase II: Field Trials of Wing Inspections at End-of-Runway
This series of trials will further examine the feasibility of integrating the examination of wings by ice detection sensors, into the aircraft departure operation during deicing conditions.
The contractor shall develop a test plan for field trials that will include:

- establishing test locations with airport authorities;
- establishing operational procedures with airport authorities;
- arranging equipment for scanning; vehicle, sensor installation and radios;
- collecting and co-ordinating information from the deicing activity at the deicing centre;
- test procedures with detailed responsibilities for all participants;
- control of the confidential data gathered on wing condition; and
- notification to all concerned in the project, including aircraft operators, that scanning activities will take place.

Three end-of-runway sessions each are planned for Montreal (Dorval) and for Toronto.

The contractor shall co-ordinate activities with authorities representing Aéroports de Montréal and the Greater Toronto Airport Authority, with Transport Canada at Toronto, and with representatives of the ice detection manufacturers (Cox & Co. and/or BFGoodrich). The areas for locating sensor equipment near the departing runway will be reviewed with airport authorities with the aim of locating the sensor camera closer to the departing aircraft.

The contractor shall develop test procedures in conjunction with the Central Deicing Facility operator to allow scanning of wings of aircraft at the deicing center, prior to deicing, and to enable documentation of the actual extent of contamination.

5.8.2 Conduct of Trials and Assembly of Results

The contractor shall co-ordinate the rental of a suitable vehicle for the installation of an ice detection sensor, at Montreal and at Toronto. The contractor shall co-ordinate all test activities, initiating tests based on suitable weather conditions in conjunction with airport authorities and central deicing facility operators. The contractor shall monitor the test activity, ensuring the collection and protection of all scanning data, as well as the collection of all data related to weather conditions and previous aircraft deicing activities. The contractor shall analyze results and document findings in a final technical report and in presentation format.

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APPENDIX B

Experimental Program – Accuracy and Reliability of Remote Ice Detection Sensor for End-of-Runway

CM1589.001

EXPERIMENTAL PROGRAM
ACCURACY AND RELIABILITY OF REMOTE ICE-DETECTION SENSOR FOR END-OF-RUNWAY

Winter 1999/2000

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Peter Dawson

Reviewed by: John D'Avirro

APS AVIATION INC.

January 25, 2000
Version 2.0

EXPERIMENTAL PROGRAM
ACCURACY AND RELIABILITY OF REMOTE ICE-DETECTION SENSOR FOR END-OF-RUNWAY

Winter 1999/2000

1. BACKGROUND

During the 1998/99 Winter, APS conducted an initial series of field trials to study the feasibility of using a remote ice-detection-sensor to assess ice contamination on aircraft wings just prior to entering the departure runway. Results of that study were reported in TP 13481E Evaluation of Ice Detection Sensor Capabilities for End-of-Runway Application.

For that study, test locations close to runways normally used for departures during storm conditions were selected in collaboration with airport authorities. Procedures to support execution of the trials on live aircraft during live departure operations were also developed in collaboration with airport authorities.

A vehicle with a 12 m (40 ft.) mast was selected for camera installation. Two sessions of scanning trials on live aircraft departures during deicing operations were conducted. As well, trials were attempted at the entrance to the central deicing facility (CDF). These trials were intended to allow inspection of some aircraft having a reasonable amount of snow on the wings. The SPAR/Cox ice contamination sensor was used for these trials.

The results of the trials near the departure runway demonstrated that the contamination detection sensor could be used at that location to inspect departing aircraft. The distance as tested between the camera and aircraft was too great and testing at reduced distance was recommended. As well, a higher mast was recommended. It was recommended that the camera be positioned to take advantage of static aircraft at the location where they normally hold awaiting takeoff clearance.

Several cases were documented where the sensor indicated that snow contamination was present on departing aircraft. The sensor images of contamination for these cases lacked in detail and distinctness and could not be used to assess the extent of contamination with any degree of confidence. Further, the area identified as contaminated changed with subsequent scans. The ability of the sensor to reliably identify and provide an accurate image of the extent of the area subject to contamination required further study to develop confidence in the sensor output. It was recommended that trials to this end be conducted using a test wing having controlled areas of contamination, as well as scanning trials of aircraft at the central deicing facility prior to being de-iced. Because the sensor system was upgraded following the 1998/99 winter season, trials to establish confidence in the systems contamination sensing ability are now justified.

Thus far, examination of the end-of-runway application of an ice contamination sensor has been limited to trials using the Cox sensor. The BFGoodrich sensor has been tested in an end-of-runway application by Delta Airlines. The sensor was mounted on a mobile vehicle that traversed along the leading edge of the wings of aircraft that had been halted for this purpose, capturing one or more images of portions of the wing surface. This method of operation was based on the operating capabilities (viewing distance, area viewable, ability to scan a moving subject) of that particular sensor system.

The procedures presented in this document are based on use of a sensor camera at a fixed location, but at variable height. Aircraft will be scanned from two perspectives. While the aircraft is approaching the sensor position, the wing leading edge will be scanned. When the aircraft is in front of the sensor position, the top of the wing will be scanned.

Evaluation of the use of a sensor system in an end-of-runway application in which the camera is mounted in a vehicle which drives along the aircraft wings is not included in this document.

The overall program proposed to examine remote ice detection sensors is shown in Figure 1. Four separate elements are involved:

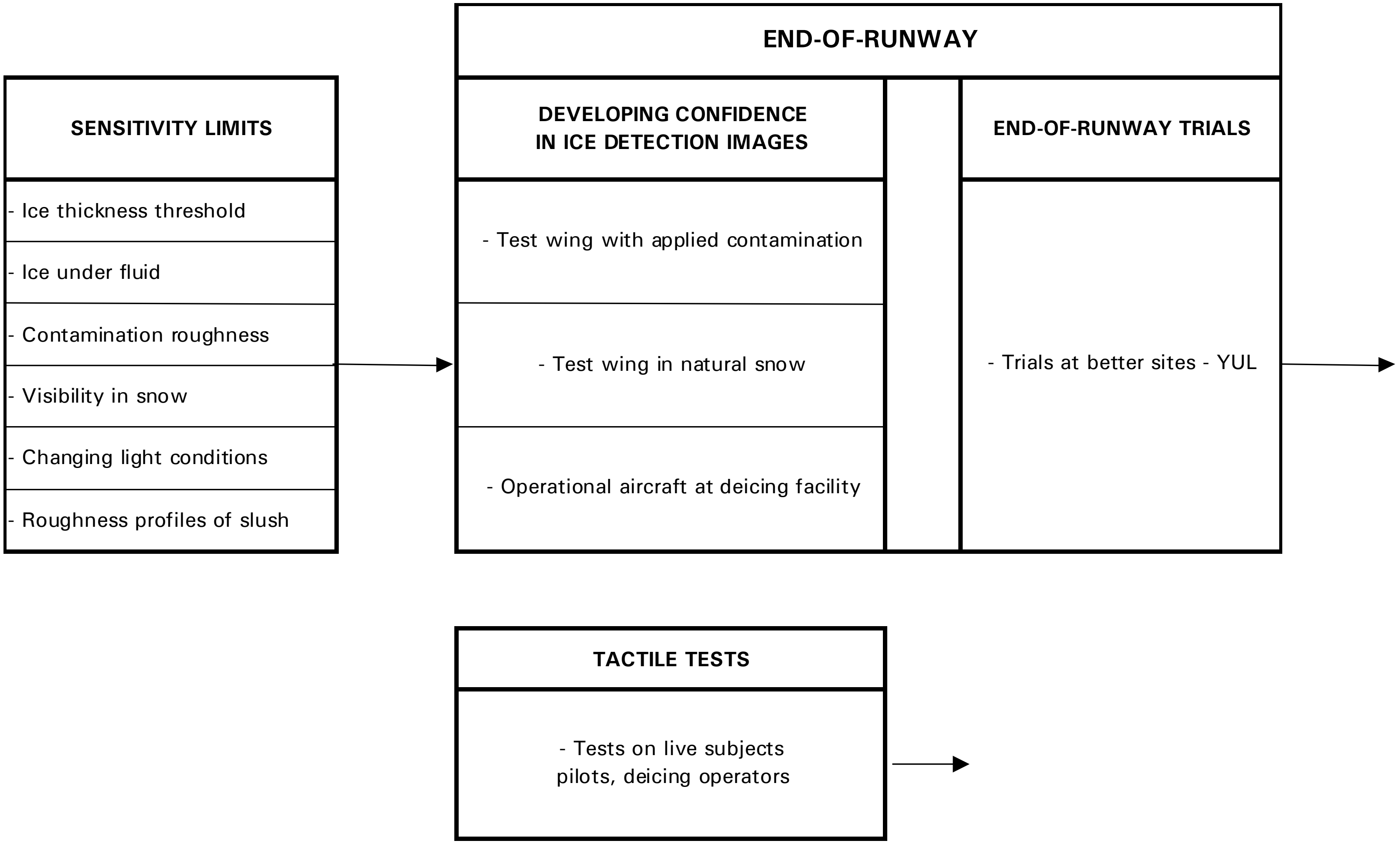
1. Sensitivity Limits – an examination (mainly laboratory) of the capability of the sensor system
2. Tactile Tests – an examination of the human limitations in identifying the existence of ice through tactile senses
3. Developing Confidence in Ice Detection Images – comparing sensor images of contamination to actual extent of contamination
4. Trials at End-of Runway – further trials using the remote sensor to scan wings of departing aircraft during deicing operations

Elements 1 and 2 are addressed in a separate project. This procedure addresses elements 3 and 4. Initially, only element 3 (Phase 1 of this procedure) is approved for test.

FIGURE B-1

REMOTE ICE DETECTION SENSORS

OVERALL PROGRAM



2. OBJECTIVES

- To study the accuracy and reliability of indications of contamination as provided by a remote ice-detection sensor, based on an end-of-runway application.

In satisfying this objective, views of the wing leading edge (as would be seen on an aircraft approaching the sensor position) as well as of the top of the wing (as on an aircraft directly in front of the sensor position) will be examined. The sensor will be located to simulate an end-of-runway position relative to the wing test subject.

- To conduct field trials near the hold-for-takeoff-clearance point prior to the departure runway.

3. PROCEDURE/TEST REQUIREMENTS

3.1 Phase 1: Studying the Accuracy and Reliability of Remote Ice-Detection Sensor Indications

The test program examines the ability of the sensor to accurately report the extent and area of contamination existing on a wing surface. A matrix of planned tests is provided as Table B-1. The study consists of three stages:

1. Testing with the Jetstar test wing with applied contamination during dry cold weather.
2. Testing with the Jetstar test wing during natural snow.
3. Scanning aircraft arriving at the central deicing facility.

In each of these stages, sensor camera images of contamination will be compared to the actual extent of contamination as noted by an experienced observer and as recorded by photography and videotaping. These tests will be conducted at the central deicing facility (CDF). The sensor system will be so situated to represent the viewing geometry and distances recommended for end-of-runway testing (Figure B-2). Views of the wing leading edge (as would be seen on an aircraft approaching the sensor position) (Figure B-3) as well as of the top of the wing (as on an aircraft directly in front of the sensor position) will be examined. The test wing will be turned to the appropriate orientation for these views. The camera will be mounted on the mast of a vehicle suitable for testing at the departure runway. A mast height up to 18 m (60 ft.) is desired.

Electronic files of the sensor camera image will be retained, along with visual and photographic documentation of the extent of contamination.

Stage 1

It is planned that this stage of testing be conducted at the Central Deicing Facility (CDF) at the Montreal International Airport (Dorval). These tests are based on a sensor camera mounted on a mast extended to at a height of 12 and18 meters (40 and 60 ft.).

The weather for this test should be dry and below freezing. One test will be conducted in daytime with an overcast sky, and the other at night using only the sensor system lighting to duplicate operational conditions at an end-of-runway site. Patches of snow and of ice contamination will be applied on the wing surface. The patches will be varied in size and shape. As a guideline to the size of the various patches of snow and ice, ice length expected to be viewable at specific distances and viewing angles as reported in TP 13481E (pertinent extract follows) will be used. As well, fluid failure patterns documented in previous full-scale fluid failure trials on aircraft will be referred to when producing patches of contamination on the test wing surface.

Two set-up distances from camera to wing will be tested to represent the recommended parameters (from TP 13481E) for viewing the top-of-wing, reflecting 2 taxi guidelines, one for narrow-body (example B737) and one for wide-body aircraft (example B747). For viewing the approaching wing leading-edge, distances will be 40m and 80m.

The angle of viewing will represent 2 different mast heights, one at 12 m (40 ft) as tested in the 1998/99 study, and one at a height near that of the B747 vertical fin 18 m (60 ft.), as recommended in the study. Arrangements will be made with Aéromag to clean the test wing as required.

Extract from TP 13481E

Size of ice detection images

The topic of size of patches of ice contamination viewable by the sensor is an important one. In preparation for the associated sensitivity trials on the ice detection sensor, the sensor system manufacturer provided a grid of values for ice length viewable at different combinations of distances and viewing angles. Values provided in that grid were seen to vary directly with distance and with the sine function of the viewing angle, and values were then extrapolated to represent the distances and viewing angles experienced during this trial. The following values for Ice Length Viewable results from that exercise:

Distance to Target (m)	Ice Length (cm) Viewable at Viewing Angle					
	90°	30°	20°	15°	10°	6°
15	6	11	16	22	32	53
22	8	17	25	32	48	80
30	11	22	33	43	64	107
38	14	28	41	54	80	134
46	17	34	49	65	97	160
53	20	39	57	76	113	187
68	25	50	74	97	145	241
80	29	58	85	113	170	280

Example: at a distance of 53 m and a viewing angle of 10°, minimum length of ice expected to be viewable by the sensor is 145 cm.

The beneficial impact of reduced distances and increased viewing angles is illustrated in the following chart which compares the ice length viewable based on the set-up during the trial with that of the suggested set-up.

Aircraft Type	Trial Set-up			Suggested Set-up		
	Distance from camera to wing (m)	Viewing Angle (degrees)	Ice Length Viewable (cm)	Distance from camera to wing (m)	Viewing Angle (degrees)	Ice Length Viewable (cm)
B737	54	10	112	28	32	20
B747	68	6	240	45	16	60

Stage 2

This stage will be conducted during natural snowfall. Two sessions are planned: one during daylight and one at night. Arrangements will be made with CDF staff for a test location not interfering with the deicing operation, and for periodic cleaning of the test wing. Records of the sensor camera image of progressive natural contamination will be documented for comparison with the actual extent of contamination as noted by an experienced observer and recorded by photographs and videotape. Recording events for level of contamination will be initiated by the wing observer and communicated to the photographer and the sensor operator. Sensor viewing distances and angles will be as in Stage 1.

Stage 3

This stage of testing involves scanning wings of aircraft just after arrival at the central deicing facility, during deicing operations. Procedures will be developed with Aéromag 2000 to enable an APS observer to quickly view the subject wing to document its condition, and to allow a sensor scan of the wing, just after arrival and prior to deicing. One APS technician will be positioned in an open deicing bucket along with the Aéromag 2000 deicing operator, and will document the extent of contamination on the wing.

Aircraft operator and fin number, and event time will be noted to enable comparison between sensor image and actual wing condition.

After the wing has been deiced, it will again be scanned by the sensor camera.

Two set-up distances from camera to wing will be tested to represent the recommended parameters (from TP 13481E) for locating ice detection cameras, reflecting 2 taxi guidelines, one for narrow-body (example B737) and one for wide-body aircraft (example B747). The sensor vehicle will be positioned outboard from either of the two end deicing pads, where it won't interfere with the deicing operation. The exact location for positioning the sensor camera will be predetermined in conjunction with Aéromag 2000. During the trials, coordination with Aéromag 2000 will allow specific aircraft appropriate to the sensor positioning to be routed to the deicing pad adjacent to the sensor camera.

3.2 Phase 2: Conducting Field Trials Near The Hold-For-Takeoff-Clearance Point

3.2.1 Description of Tests

These trials will be conducted subsequent to confirmation of ice detection sensor image accuracy and reliability.

The purpose is to demonstrate use of the sensor camera to scan wings of departing aircraft for contamination during live operations using clearance distances and mast heights such as recommended in the 1998/99 study. The condition of wings of operational aircraft will be documented with the sensor camera during natural precipitation resulting in deicing activities. Data on any actual icing contamination on the wings will be collected for subsequent analysis, but will remain confidential.

For the trials, a reference surface with a predetermined area of contamination will be located nearby, and will be periodically scanned.

Preparation for operational trials (three sessions) will include:

- Defining test locations in conjunction with airport authorities.
- Establishing operational procedures to support the trials in conjunction with airport authorities.
- Arranging equipment for scanning; vehicle, sensor installation and radios.
- Arranging for retrieval of details of each aircrafts deicing history form the CDF.
- Notification to all concerned, including aircraft operators, that trial scanning activities will be taking place.

APS will coordinate the installation of a Spar/Cox contamination sensor in a mobile vehicle, which will be made available for a two week period. The type of vehicle selected will be based on capability to raise the camera to the 18 m (60 ft.) height recommended in the 1998/99 study, and ease of operation. Camera pan and tilt controls are required.

3.2.2 End-of-Runway Trials

APS personnel will monitor forecasted weather and initiate operational trials based on suitable conditions. Contacts at the Transportation Development Centre, Aéroports de Montréal and Nav Canada will be advised when tests are planned.

Trials during actual operations will involve positioning the sensor vehicle at a location beside the taxiway, near the hold-for-takeoff-clearance point.

The sensor will scan the wing on the near side of the aircraft and record any evidence of contamination. Aircraft identification will be recorded.

An exposed reference test plate surface located at a defined distance and angle of incidence, will then be scanned periodically to confirm sensor ability to see contamination.

At the end of the test session, deicing history of each aircraft will be retrieved from the deicing operator, to be incorporated into the data analysis. There will be no communication of results of sensor readings. Weather conditions will be recorded on an ongoing basis. Simultaneous testing on flat plates will be conducted (at the nearby APS test site) to assist in documenting actual operating conditions and related fluid holdover times.

At least three trial sessions (2 daytime and 1 night) during periods of snow or freezing precipitation will be attempted.

Complete photo and video records of test set-up will be maintained.

4 EQUIPMENT

Test equipment is included in Attachment B-I.

5 PERSONNEL

For all tests, on-site support from the sensor manufacturer (Cox) is planned. Requirements for APS staff vary with different test stages.

Phase I: Sensor Accuracy and Reliability tests

Stages 1 and 2

Five APS staff are required to act in the following functions:

- Team Leader
- Sensor Image Observer
- Wing Observer and Assistant
- Photography/Video

Stage 3

Three APS staff are required to act in the following functions:

- Team Leader
- Sensor Image Observer
- Wing Observer/Photography/Video

Phase 2: End-of-Runway tests

Three APS staff are required to act in the following functions:

- Team Leader
- Sensor Image Observer
- Radio Monitor

Descriptions of responsibilities and duties of each team member are given in Attachment B-II.

6 DATA FORMS

The following data form will be used:

Figure B-4	Contamination Form for Jetstar Wing – Stage 1
Figure B-5	Contamination Form for Jetstar Wing – Stage 2
Figure B-6A and B	Contamination Forms for Live Deicing Operations
Figure B-7	Record of Scanned Aircraft
Figure B-8	Deicing History

TABLE B-1

MATRIX OF TESTS FOR REMOTE SENSOR END-OF-RUNWAY

Run Number	Phase/ Test	Day or Night	Type of Contaminant	Test Surface	View of Wing	Sensor Distance (m)	Sensor Height (m)
1	1.01	Day	Snow	Jetstar	Top	26	12
2	1.02	Day	Snow	Jetstar	Top	26	18
3	1.03	Day	Snow	Jetstar	Top	48	12
4	1.04	Day	Snow	Jetstar	Top	48	18
5	1.05	Day	Snow	Jetstar	Leading Edge	40	12
6	1.06	Day	Snow	Jetstar	Leading Edge	40	18
7	1.07	Day	Snow	Jetstar	Leading Edge	80	12
8	1.08	Day	Snow	Jetstar	Leading Edge	80	18
9	1.09	Day	Ice	Jetstar	Top	26	12
10	1.10	Day	Ice	Jetstar	Top	26	18
11	1.11	Day	Ice	Jetstar	Top	48	12
12	1.12	Day	Ice	Jetstar	Top	48	18
13	1.13	Day	Ice	Jetstar	Leading Edge	40	12
14	1.14	Day	Ice	Jetstar	Leading Edge	40	18
15	1.15	Day	Ice	Jetstar	Leading Edge	80	12
16	1.16	Day	Ice	Jetstar	Leading Edge	80	18
17	1.17	Night	Snow	Jetstar	Top	26	12
18	1.18	Night	Snow	Jetstar	Top	26	18
19	1.19	Night	Snow	Jetstar	Top	48	12
20	1.20	Night	Snow	Jetstar	Top	48	18
21	1.21	Night	Snow	Jetstar	Leading Edge	40	12
22	1.22	Night	Snow	Jetstar	Leading Edge	40	18
23	1.23	Night	Snow	Jetstar	Leading Edge	80	12
24	1.24	Night	Snow	Jetstar	Leading Edge	80	18
25	1.25	Night	Ice	Jetstar	Top	26	12
26	1.26	Night	Ice	Jetstar	Top	26	18
27	1.27	Night	Ice	Jetstar	Top	48	12
28	1.28	Night	Ice	Jetstar	Top	48	18
29	1.29	Night	Ice	Jetstar	Leading Edge	40	12
30	1.30	Night	Ice	Jetstar	Leading Edge	40	18
31	1.31	Night	Ice	Jetstar	Leading Edge	80	12
32	1.32	Night	Ice	Jetstar	Leading Edge	80	18
33	2.01	Day	Natural Snow	Jetstar	Top	26	12
34	2.02	Day	Natural Snow	Jetstar	Top	26	18
35	2.03	Day	Natural Snow	Jetstar	Top	48	12
36	2.04	Day	Natural Snow	Jetstar	Top	48	18
37	2.05	Day	Natural Snow	Jetstar	Leading Edge	40	12
38	2.06	Day	Natural Snow	Jetstar	Leading Edge	40	18
39	2.07	Day	Natural Snow	Jetstar	Leading Edge	80	12
40	2.08	Day	Natural Snow	Jetstar	Leading Edge	80	18
41	2.09	Night	Natural Snow	Jetstar	Top	26	12
42	2.10	Night	Natural Snow	Jetstar	Top	26	18
43	2.11	Night	Natural Snow	Jetstar	Top	48	12
44	2.12	Night	Natural Snow	Jetstar	Top	48	18
45	2.13	Night	Natural Snow	Jetstar	Leading Edge	40	12
46	2.14	Night	Natural Snow	Jetstar	Leading Edge	40	18
47	2.15	Night	Natural Snow	Jetstar	Leading Edge	80	12
48	2.16	Night	Natural Snow	Jetstar	Leading Edge	80	18
49	3.01	Day	Natural Snow	A/C at CDF	Top	26	12
50	3.02	Day	Natural Snow	A/C at CDF	Top	26	18
51	3.03	Day	Natural Snow	A/C at CDF	Leading Edge	40	12
52	3.04	Day	Natural Snow	A/C at CDF	Leading Edge	40	18
53	3.05	Day	Natural Snow	A/C at CDF	Top	48	12
54	3.06	Day	Natural Snow	A/C at CDF	Top	48	18
55	3.07	Day	Natural Snow	A/C at CDF	Leading Edge	80	12
56	3.08	Day	Natural Snow	A/C at CDF	Leading Edge	80	18

ATTACHMENT B-I
TEST EQUIPMENT CHECKLIST

TEST EQUIPMENT	STATUS
For Stage 1 Tests on Jetstar Wing at CDF	
COX Sensor System, installed on vehicle mast	
Mast vehicle with driver	
Vehicle to house sensor controls and displays, and test team	
Vehicle to tow test wing	
Generator for sensor system 2kw minimum	
Jetstar Wing	
Still digital camera	
Digital Video camera	
Placard to place on wing, to record run and time	
Mast Light for night tests	
Snow spreader for wing	
Water sprinkler for making ice on wing	
Thickness gauges	
Tape measures; 1 long and 2 short	
Inclinometer	
Security passes	
Scrapers	
Deicing vehicle to clean wing between tests	
Cell phones	
For Stage 2 Tests on Jetstar Wing at CDF	
COX Sensor System, installed on vehicle mast	
Mast vehicle with driver	
Vehicle to house sensor controls and displays, and test team	
Vehicle to tow test wing	
Generator for sensor system	
Jetstar Wing	
Still digital camera	
Digital Video camera	
Placard to place on wing, to record run and time	
Mast Light for night tests	
Thickness gauges	
Tape measures; 1 long and 2 short	
Inclinometer	
Security passes	
Scrapers	
Deicing vehicle to clean wing between tests	
Cell phones	

For Stage 3 Tests at CDF	
COX Sensor System, installed on vehicle mast	
Mast vehicle with driver	
Vehicle to house sensor controls and displays, and test team	
Generator for sensor system	
Still camera	
Video camera	
Tape measures; 1 long and 2 short	
Inclinometer	
VHS radio with audio cassette recorder	
Security passes	
Binoculars	
Cell phones	
Cherry-picker vehicle with driver and with operator and APS observer in bucket	
For Tests at End-of-Runway	
COX Sensor System, installed on vehicle mast	
Mast vehicle with driver	
Vehicle to house sensor controls and displays, and test team	
Generator for sensor system	
Still camera	
Video camera	
Tape measures; 1 long and 2 short	
Inclinometer	
VHS radio with audio cassette recorder	
Security escort	
Security passes	
Binoculars	
Reference contaminated surface for scanning (portable plate stand with plate)	
Plate failure data forms	
Deicing fluids; XL54	
Ultra+	
Scrapers	
Cellular phones	

ATTACHMENT B-II
RESPONSIBILITIES/DUTIES OF TEST PERSONNEL

Phase 1: Sensor Accuracy and Reliability tests

Stages 1 and 2

Team Leader

- Outlook weather forecasts and initiate trials.
- Co-ordinate with Aéromag 2000.
- Establish cell phone contact with Aéromag 2000 representative.
- Ensure safe operation of test activities.

Sensor Image Observer

- Assist in installation of sensor.
- Ongoing operation of sensor, directing it toward test surface.
- Based on the sensor image, record areas of controlled contamination (Stage 1) using Data Form Figure 4.
- Coordinate times of recording progress of contamination with sensor operator (in Stage 2). Based on the sensor image, record extent of contamination using Data Form Figure 5.
- Record comments on performance of sensor.
- Co-ordinate timing of sensor shots with the wing observer.

Wing Observer and Assistant

- Set-up test wing in test location.
- Place contamination on wing (Stage 1).
- Record areas of controlled contamination (Stage 1) using Data Form Figure 4.
- Coordinate times of recording progress of contamination with sensor operator (in Stage 2). Record extent of contamination using Data Form Figure 5.

Photography/Video

- Photograph and videotape test set-up.
- Photograph and videotape contamination on the wing. Provide clear images of the size and shape of patches of contamination.
- In Stage 2, co-ordinate timing of shots with the wing observer / sensor operator. Use placard on wing to record test run and time.

Stage 3

Team Leader

- Outlook weather forecasts and initiate trials.

- Co-ordinate with Aéromag 2000.
- Establish cell phone contact with Aéromag 2000 representative.
- Ensure safe operation of test activities.

Sensor Image Observer

- Assist in installation of sensor.
- Ongoing operation of sensor, directing it toward test surface.
- Record areas of contamination based on the sensor image using Data Form Figure 6.
- Record comments on performance of sensor.

Wing Observer

- Photograph and videotape test set-up.
- Record areas of contamination on aircraft wing using Data Form Figure 6.
- Photograph and videotape contamination on the wing. Provide clear images of the size and shape of patches of contamination.

Phase 2: End of Runway Tests

Team Leader

- Outlook weather forecasts and initiate scanning trials.
- Advise Aéroports de Montréal of intent to conduct trials.
- Establish cell phone contact with ADM and Aéromag 2000 representatives.
- Ensure safe operation of test activities.
- Ensure deicing records for trial period retrieved from Aéromag.

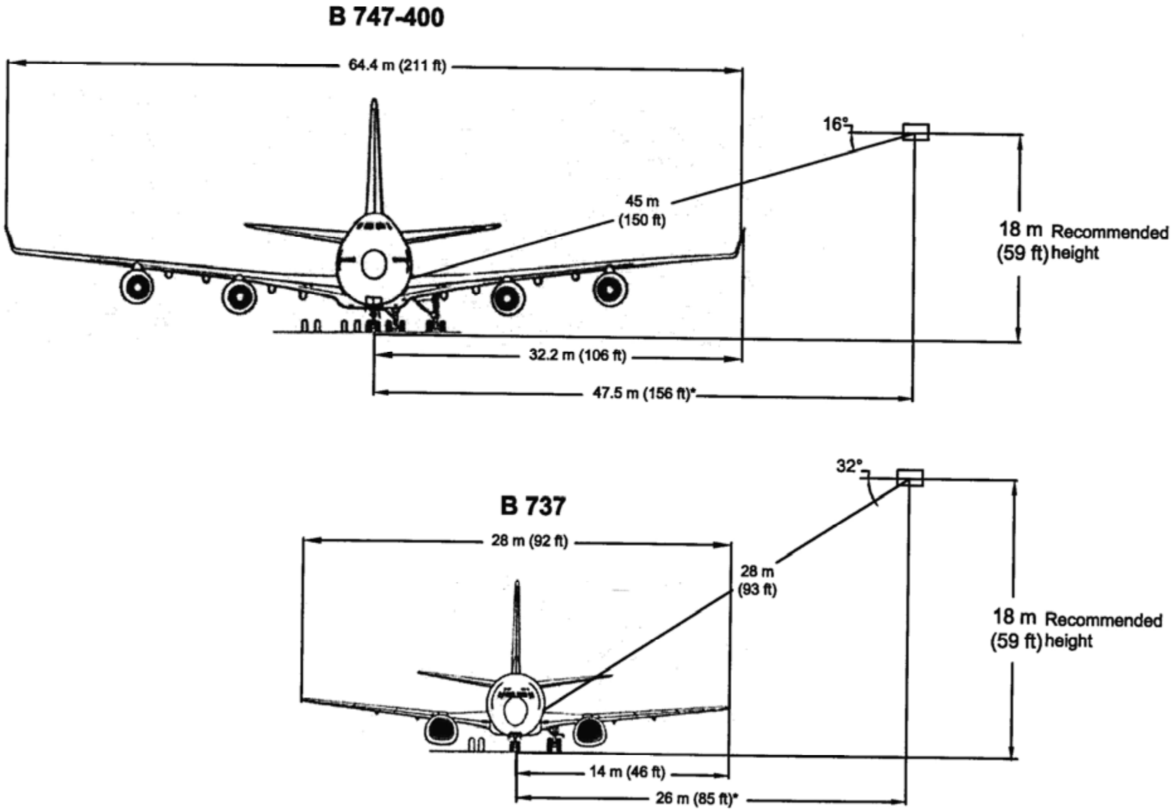
Sensor Observer

- Ongoing operation of sensor.
- Direct sensor camera toward aircraft surfaces, to obtain various views of the wing while the aircraft is approaching and taxiing past.
- Periodic scanning of reference surface to confirm sensor operation

Radio Monitor

- Monitor deicing facility radio frequency, record data on deicing history form Figure 7. Note any contamination condition observed visually.
- Advise team regarding aircraft approaching for departure.
- Maintain record of aircraft scanned using data form Figure 8.

FIGURE 2
REMOTE ICE DETECTION SENSOR SCANNING TOP-OF-WING FROM RECOMMENDED POSITION

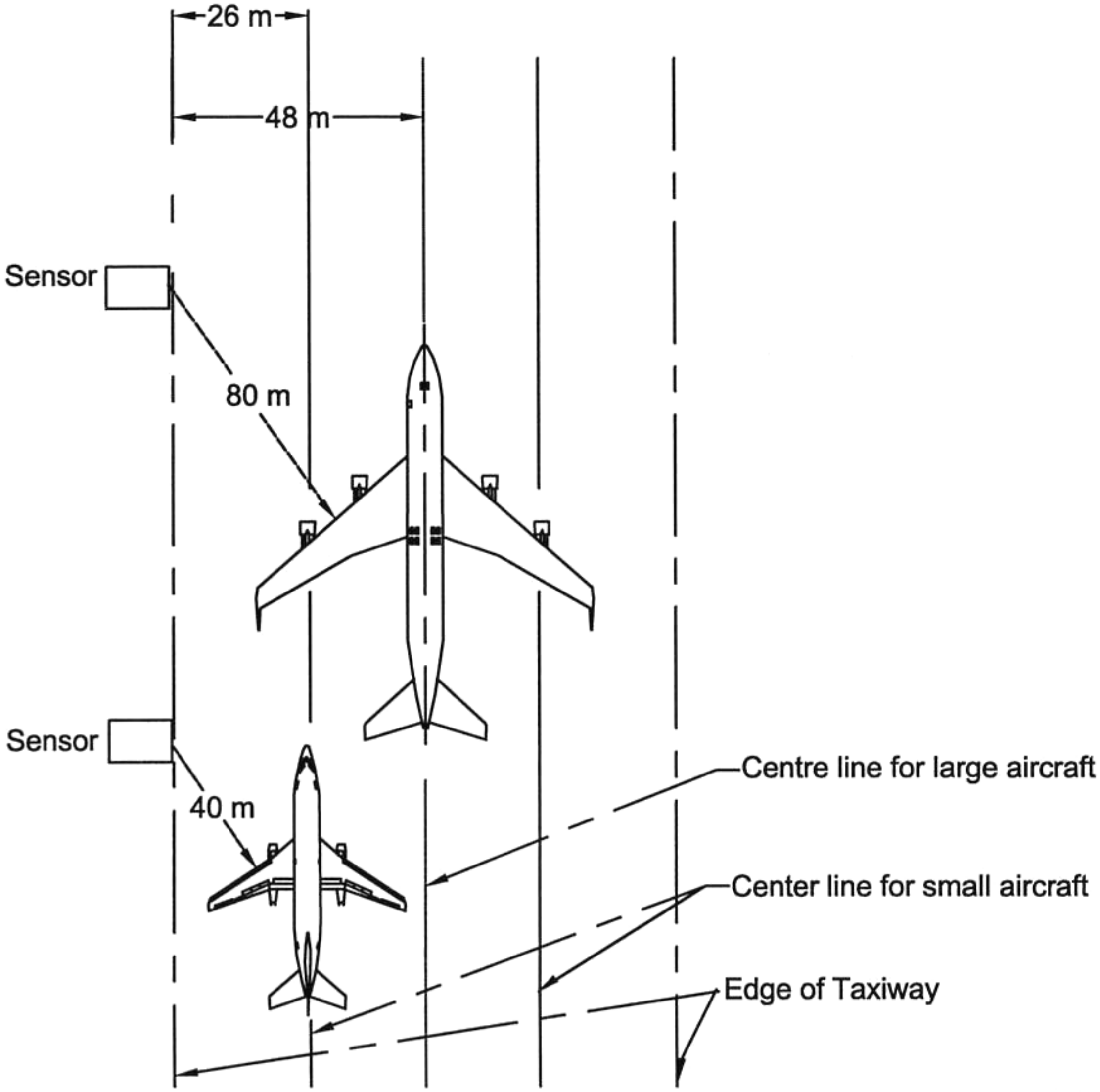


* Aerodrome Standards and Recommended Practices - Minimum Separation Distances.

(Aircraft not drawn to scale.)

cm1589/procedure/end_rwy/Scan Angles 2.DWG

FIGURE 3
REMOTE ICE DETECTION SENSOR SCANNING LEADING EDGE OF TAXIING AIRCRAFT



cm1589/procedure/end_rwy/LE SCAN.DWG

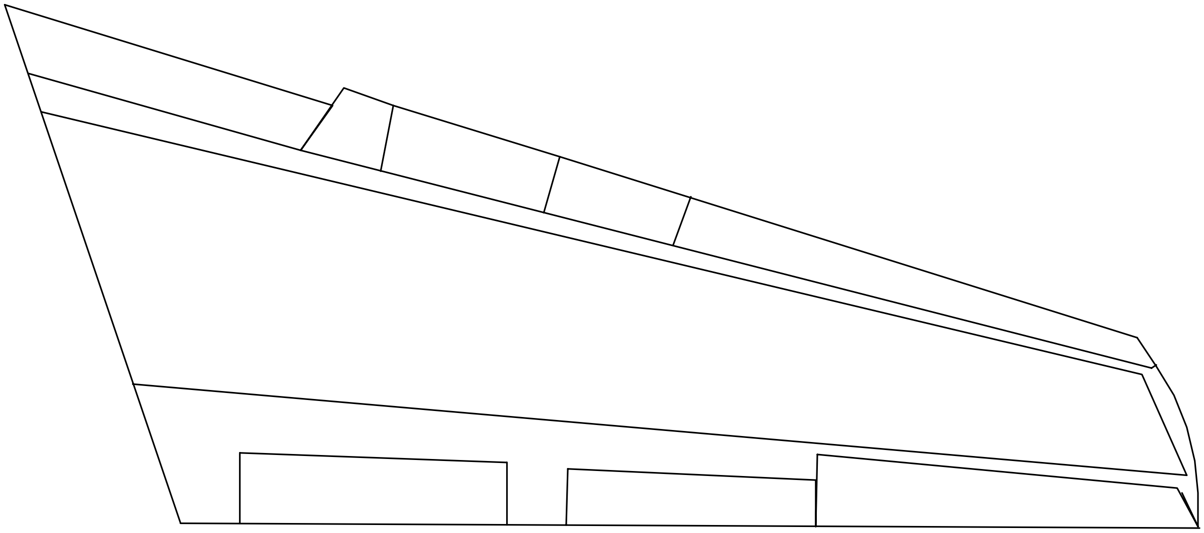
FIGURE B-4
CONTAMINATION FORM FOR JETSTAR WING - PHASE 1 - STAGE 1
FIELD TRIALS FOR END-OF-RUNWAY

DATE:____________________ **RUN #:**______________

TIME:____________________ **OAT:**______________

DAY OR NIGHT:____________________

Contamination Patches				
Location	Type (Snow or Ice)	Thickness (mil)	Roughness	Dimensions



Horizontal Distance to Wing Tip: ____________________

Mast Height: ____________________

Sensor Light? Y or N: ____________________

COMMENTS: ____

ICING RECORD BY: ____________________

OBSERVER LOCATION: ____________________
(Wing or Sensor)

FIGURE B-5

CONTAMINATION FORM FOR JETSTAR WING - PHASE 1 - STAGE 2

FIELD TRIALS FOR END-OF-RUNWAY

FAILURE CALLED BY: ____________________

DAY OR NIGHT: ____________

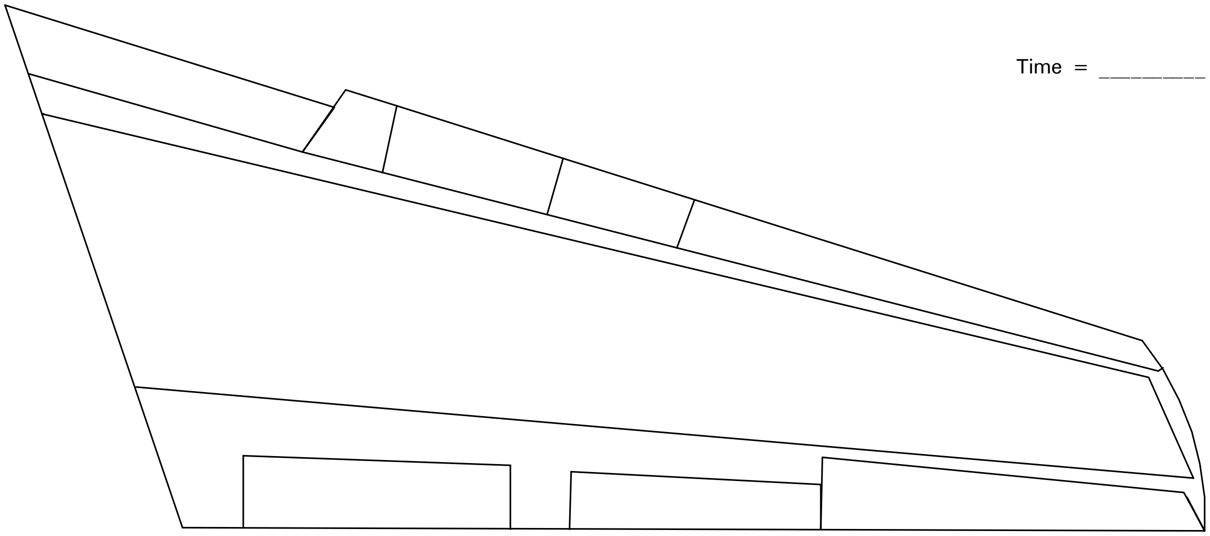
OBSERVER LOCATION: (WING OR SENSOR) ____________________

TYPE OF CONTAMINATION: ____________

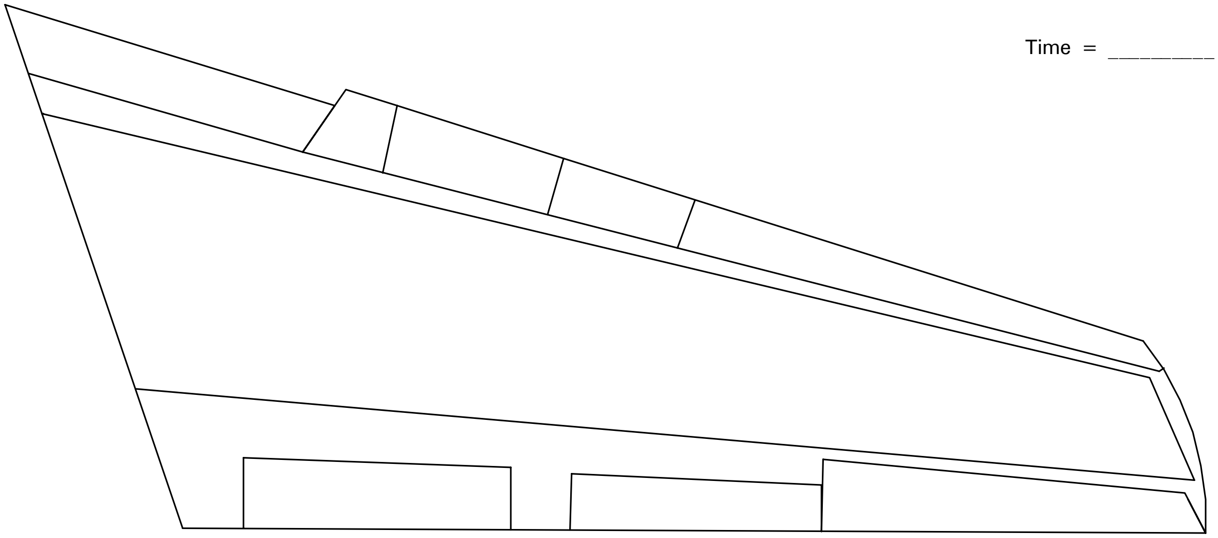
ASSISTED BY: ____________________

PRECIPITATION: ____________

OAT: ____________



Time = ________



Time = ________

FIGURE B-6A

CONTAMINATION FORM FOR LIVE DEICING OPERATIONS

FIELD TRIALS FOR END-OF-RUNWAY

DATE: ________________ **TIME:** ________________ **LOCATION:** ________________

OAT: ________________ **PRECIPITATION:** ________________

AIRCRAFT TYPE: ________________ **FIN#** ________________

OPERATOR: ________________ **TYPE OF CONTAMINATION:** ________________

SENSOR LOCATION:

Horizontal Distance to Wing Tip: ________________ **Mast Height:** ________________

Sensor Light? Y or N: ________________

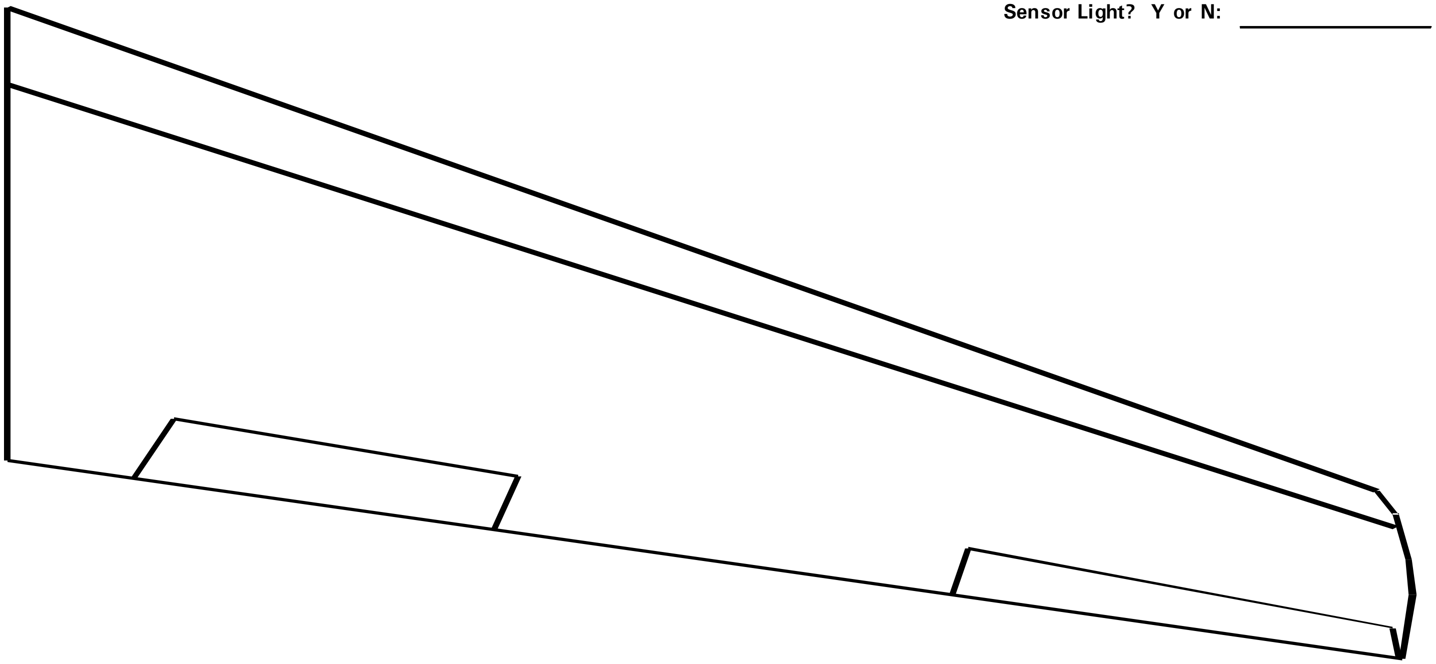


FIGURE 6B

CONTAMINATION FORM FOR LIVE DEICING OPERATIONS

FIELD TRIALS FOR END-OF-RUNWAY

DATE: ______________ **TIME:** ______________ **LOCATION:** ______________

OAT: ______________ **PRECIPITATION:** ______________

AIRCRAFT TYPE: ______________ **FIN#** ______________

OPERATOR: ______________ **TYPE OF CONTAMINATION:** ______________

SENSOR LOCATION:

Horizontal Distance to Wing Tip: ______________ **Mast Height:** ______________

Sensor Light? Y or N: ______________

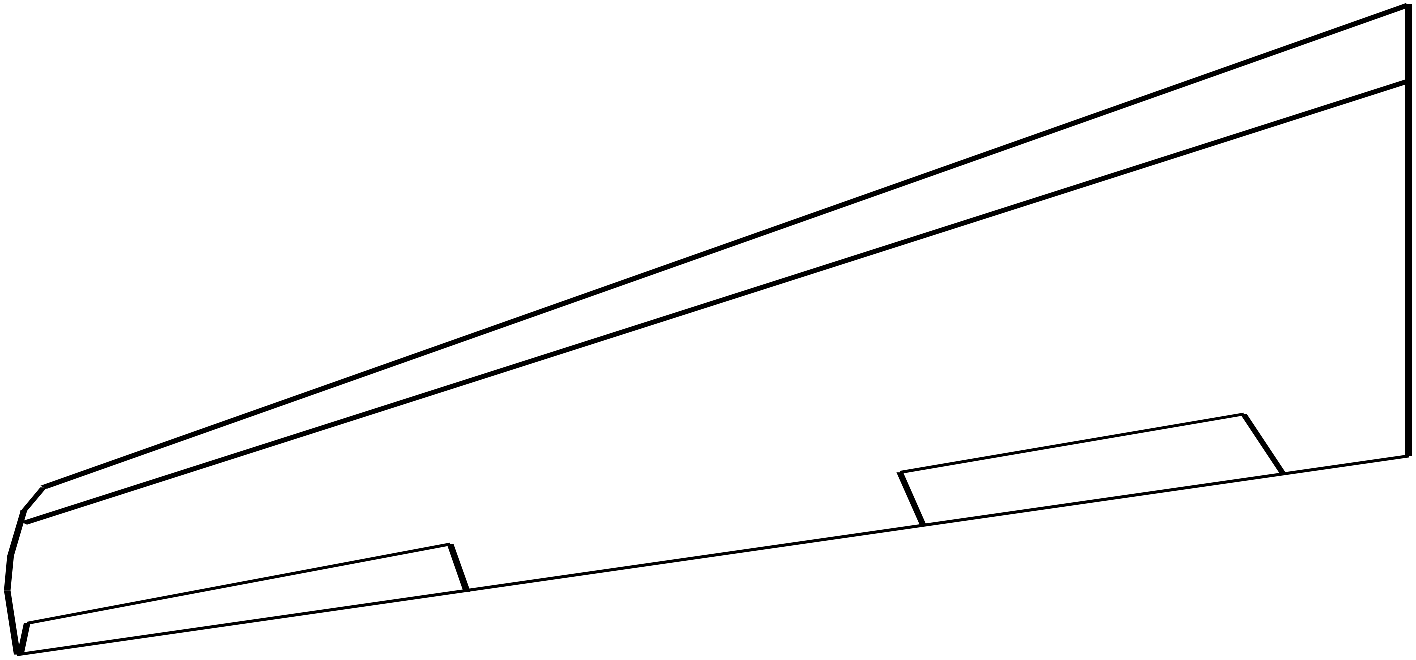


FIGURE B-

DEICING HISTORY FOR END-OF-RUNWAY TEST

Date	Flight ID	Aircraft Type or Code/ Fin #	Fluid Type	Start of HOT	Reason for Deicing	Amount of Precip. On ground

FIGURE B-8

RECORD OF SCANNED AIRCRAFT

Montreal International

Date ______________ **Runway** ______________

Aircraft	Fin #	Carrie	Time	Wing

APPENDIX C

Experimental Program – Tests to Evaluate Sensitivity Limits for an Ice Detection Camera

CM1589.001

EXPERIMENTAL PROGRAM TRIALS TO EVALUATE SENSITIVITY LIMITS FOR AN ICE DETECTION CAMERA

Winter 1999/2000

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Marc Hunt

Reviewed by: John D'Avirro

APS AVIATION INC.

January 21, 2000
Version 1.0

EXPERIMENTAL PROGRAM
TRIALS TO EVALUATE SENSITIVITY LIMITS
FOR AN ICE DETECTION CAMERA

Winter 1999/2000

APS will conduct a series of tests on specially designed ice contamination discs and other test surfaces, both in a controlled environment offered by a laboratory facility and under natural environmental conditions. This document provides the procedures and equipment required for the conduct of these tests.

1. OBJECTIVE

The objective of this series of tests is to evaluate operational limits for an ice detection camera system. The SPAR/COX and/or the BF Goodrich/RVSI ice detection camera system will be the subjects of this examination.

The principal parameters to be examined will include:

- Ice thickness threshold; determining the smooth ice thickness threshold as a function of camera distance and viewing angle, using FAA Ice Detection Thickness Plates;

- Detection of ice under anti-icing fluid; determining the effect of an overlying layer of Type I or Type IV fluid of varying thickness, and form different manufactures, on the ice detection capability of the camera;

- Effect of contamination roughness; generate rough ice surfaces to assess the effects of surface roughness on camera image and identification of contamination; and

- Determine typical roughness profiles of slush; during standard fluid holdover trials, record the resultant roughness profile as a function of time at selected intervals until test end.

Additionally, the following parameters will be examined in outdoor conditions:

- Visibility in snow conditions: These trials will use the ice detection thickness plates, standard flat plates and the Transport Canada test wing; and

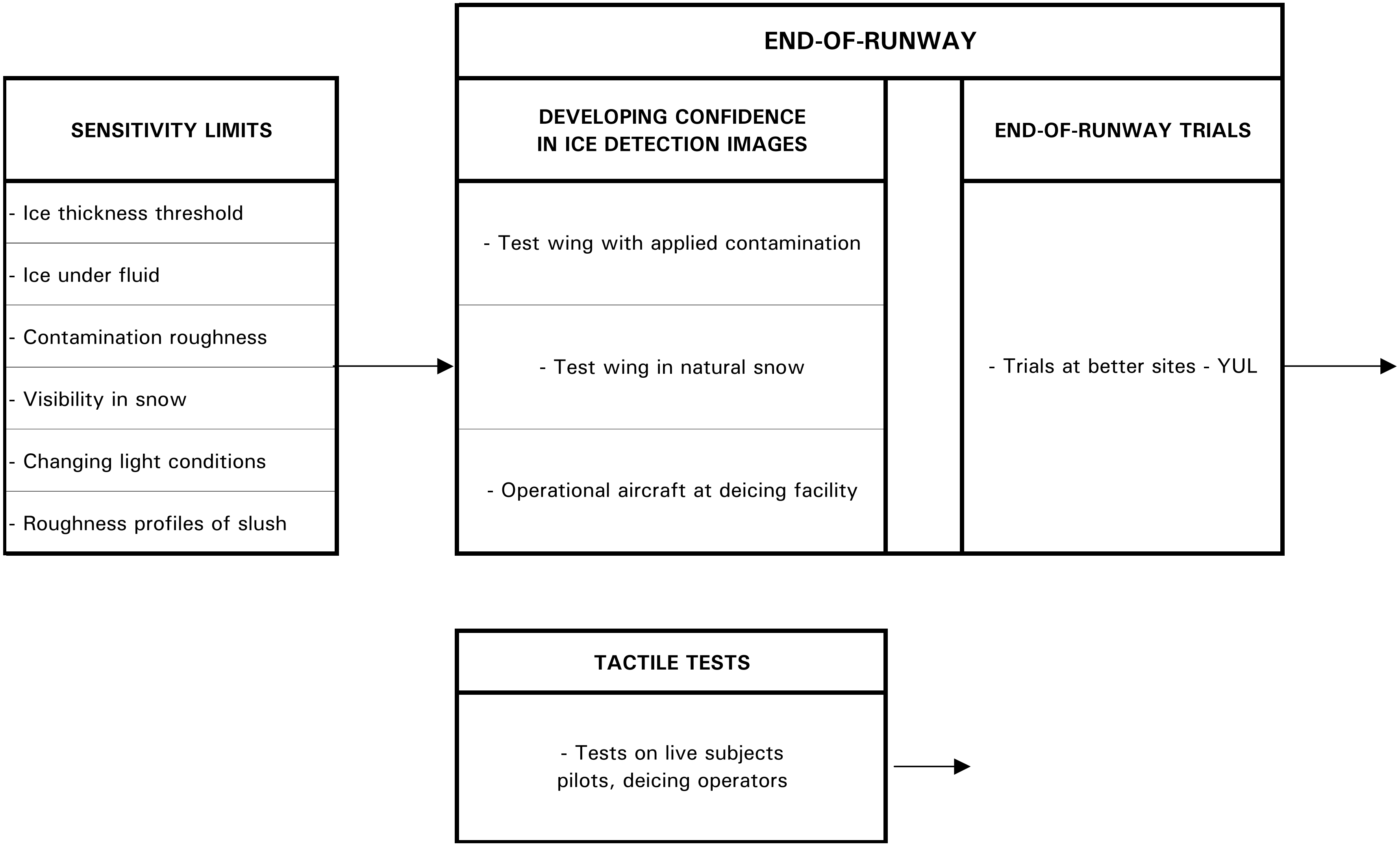
- Accuracy in changing light conditions: A contamination target will be examined progressively during the 2-hour period encompassing sunrise or sunset.

The flowchart shown in the following figure shows the relationship between the ice detection camera sensitivity limits trials and the overall area ice detection sensor program. The trials detailed in this procedure are a precursor to the end-of-run way trials. The overall program is designed to evaluate the feasibility of an end-of-runway camera sensor operation.

The roughness of slush profile trials will be conducted when suitable conditions are available. The remaining sensitivity limit trials are delayed until further funding is provided.

ICE DETECTION SENSORS

OVERALL PROGRAM



SENSITIVITY LIMITS

- Ice thickness threshold
- Ice under fluid
- Contamination roughness
- Visibility in snow
- Changing light conditions
- Roughness profiles of slush

END-OF-RUNWAY

DEVELOPING CONFIDENCE IN ICE DETECTION IMAGES

- Test wing with applied contamination
- Test wing in natural snow
- Operational aircraft at deicing facility

END-OF-RUNWAY TRIALS

- Trials at better sites - YUL

TACTILE TESTS

- Tests on live subjects
pilots, deicing operators

2. TEST REQUIREMENTS

Procedures addressing each of the camera parameters follow. Test types A, B and a portion of C will be performed in a cold chamber. No artificial precipitation is required and the ambient temperature should be between 0° and −30°C. These trials can be performed in conjunction will other laboratory trials.

The remaining trials will be performed at the APS test site. These trials must be performed between early January and late March.

2.1 Ice Thickness Threshold (A)

The objective is to determine the smooth ice thickness threshold as a function of camera distance and viewing angle, using FAA Ice Detection Thickness Plates.

The ice detection plates are to be filled with water and then frozen to form ice discs in plate recesses of various depths. It may be necessary to add a wetting agent such as a small amount of household detergent to the water to avoid cavities at edges of the disc recess and to ensure a flat surface.

The major steps for these trails are
- Prepare the ice thickness plates or standard plates
- Mount plates in test stand
- Place stand at distances and angles specified in the test matrix
- Capture images with camera sensor
- Record required data for each image

Ability of the system to detect ice of the various depths will be determined for the matrix of test conditions as provided in Figure C-1.

2.2 Detection of Ice under Anti-icing Fluid (B)

The objective is to determine the effect of an overlying layer of Type I or Type IV fluid of varying thickness, and form different manufactures, on the ice detection capability of the camera.

SAE Type I and Type IV anti-icing fluid, both ethylene glycol and propylene glycol-based, will be applied over ice samples on the ice detection plates described in Test A. If none of the FAA plates are viewable at a designated test cell, such as the cell 15 m (50 ft.) / 30 degrees, then a standard plate with contamination will be employed as the test subject.

The major steps for these trails are:

- Prepare the ice thickness plates or standard plates
- Mount plates in test stand
- Place stand at distances and angles specified in the test matrix
- Pour fluid
- Capture images with camera sensor
- Record required data for each image

The effect of overlying fluid on the system ability to detect ice contamination will be measured for the matrix of test conditions as provided in Figure C-1.

2.3 Effect of Contamination Roughness (C)

The objective is to assess the effects of surface roughness on the camera images and the system's ability to identify contamination.

An attempt will be made to generate rough ice surfaces to serve as subjects for this test. Generation of frost with the use of cold soaked boxes will be examined, with and without the use of ice detection plates on top of the box surface. Roughness profiles should be in excess of 0.5 mm.

Another possibility for producing rough surfaces includes the failing of fluid on a cold soaked box by the sprinkling of snow.

The major steps for these trails are:

- Prepare the ice thickness plates with required roughness
- Mount plates in test stand
- Place stand at distances and angles specified in the test matrix
- Capture images with camera sensor
- Record required data for each image

Some of these trials will be conducted outdoors to satisfy distance parameters requirements. These trials must be performed in non-precipitation conditions

2.4 Determine Typical Roughness Profiles of Slush (D)

The objective is to record the roughness profiles as a function of time at selected intervals up to and including plate failure during standard fluid holdover trials.

During a standard anti-icing fluid holdover time test, the roughness profile of the resultant slush will be measured as accurately as possible, as a function of time, at selected intervals, until test end.

Some possible methods of measuring the height of the slush roughness are:

- The height of the roughness will be measured from the plate using thickness gauges;
- The height of the roughness will be measured from photographs of the slush. A scale will be included in the pictures; and,
- Other potential methods may be developed during trials.

The ice sensor camera will simultaneously observe the test plate and levels of roughness will be correlated with the camera observations. The slush appearance at the time of profile measurement will be monitored and recorded with a video camera.

2.5 Visibility in Snow Conditions (E)

The objective is to determine the ability of the sensor camera to see ice through falling snow.

These trials will use ice detection thickness plates for shorter distances up to 15 m (50 ft.). If none of the FAA plates are viewable at a designated test cell, such as the cell 15 m (50 ft.) / 30 degrees and cells beyond, then a standard plate with a level of contamination known to be discernible at that distance in non-precipitation conditions, will be employed as the test subject. This level of contamination must be determined.

Trials will also be conducted with the Transport Canada test wing to observe the wing visibility through falling snow. These trials will be run in conjunction with the accuracy and reliability of sensor images in snow conditions trials detailed in the End of Runway procedure.

The major steps for these trails are:

- Prepare the ice thickness plates or standard plates
- Mount plates in test stand
- Place stand at distances and angles specified in the test matrix or place wing at distances specified in the test matrix
- Capture images with camera sensor
- Record required data for each image

These trials will be conducted outdoors during natural snowfall.

2.6 Adaptability to Changing Light Conditions (F)

The objective is to determine how susceptible the system is to changing natural light conditions.

These trials will use ice detection thickness plates for shorter distances up to 15 m (50 ft.). If none of the FAA plates are viewable at a designated test cell, such as the cell 15 m (50 ft.) / 30 degrees and cells beyond, then a standard plate with a level of contamination known to be discernible at that distance in non-precipitation conditions, will be employed as the test subject.

The major steps for these trails are:

- Prepare the ice thickness plates or standard plates
- Mount plates in test stand
- Place stand at distances and angles specified in the test matrix
- Capture images with camera sensor
- Record required data for each image

These trials will be conducted outdoors without precipitation. The test subject will be examined at predetermined intervals during the 2-hour period encompassing sunrise or sunset.

3. EQUIPMENT AND FLUIDS

Equipment to be employed is listed in detail in Attachment C-I.

Type I and Type IV fluids involved will include ethylene-glycol based fluids and propylene-glycol based fluids.

4. PERSONNEL

A test team of two personnel and a coordinator will conduct these trials. The duties of each personnel are listed in Attachment C-II.

Representatives from the ice detection sensor manufacturer will be invited to be present for these trials.

5. TEST PLAN

A test matrix is shown in Figure C-1.

A detailed test plan is provided in Attachment C-III.

6. DATA FORMS

The following data forms are required:

- Ice Thickness Threshold and Ice Under Fluid Test Form (Figure C-2); and
- Ice Detection Sensitivity Trials Contamination Roughness (Figure C-3).

ATTACHMENT C-I

ICE DETECTION CAMERA SENSITIVITY TRIALS

TEST EQUIPMENT CHECKLIST

Test Equipment
Procedure
All data forms
Pens and
3
2 Two black
1 Modified stand to allow variable
1 Portable test stand with 4 plates W,X,Y,Z
Backing for Cox
2 Cold-Soak boxes, filled with
Fluids: Type I and Type IV in red
Detergent (for
Extension
1 tool kit including socket set, hammer, tie-wraps, duct tape, safety goggles, spare
1
2
1 Adherence tester (dental floss
4 extended Octagon thickness gauges + 4 ordinary Octagon
3 Tape measures (1 long, 2
Laser distance
Steel rule for scale in
1 large and 1 small
2 small plate
Snow
Paper Towels and

REN
Mobile cooler for cold-soak boxes
Rent chamber
Hi-

PHOTOGRAPHIE
Cameras - still & video with all
Film - still &

FIGURE C-1

TEST PLAN FOR ESTABLISHING SENSITIVITY LIMITS FOR AN ICE DETECTION CAMERA

Distance (Horizontal)		Viewing Angle				
m	**ft**	**10°**	**20°**	**30°**	**45°**	**60°**
4.6	**15**	**A**	**A** **(1.9)**	**A** **(1.3)**	**A** **(0.9)**	**A** **(0.8)**
7.6	**25**	**A**	**A,B,C,E,F** **(3.2)**	**A,B,C,E,F** **(2.2)**	**A,C** **(1.6)**	**A** **(1.3)**
15.2	**50**		**A** **(6.5)**	**A,B,C,E,F** **(4.4)**	**A** **(3.1)**	**A** **(2.5)**
30.5	**100**			**C,E,F**	**(6.2)**	**(5.1)**
45.7	**150**			**C,E,F**		

TEST TYPE

A Ice thickness threshold tests
B Ice under Type IV fluid tests; Type IV Ethylene & Type IV Propylene
C Contamination roughness; 3 levels will be attempted
E Visibility in Snow Conditions
F Adaptability to Changing Light Conditions

NOTES

- Within the cells, values in brackets indicate the minimum length (inches) of ice viewable by the sensor (Source: Cox & Co). The diameter of the ice disc in the ice thickness threshold plates is 3 inches.
- The viewing angle is measured as the angle between the normal to the camera lens and the plane of the target object (ex. ⇒----| 90°, ⇒----/ 60°).
- If the distance between the camera and the target object increases the diameter of ice required for the sensor to detect ice, increases.
- If the angle between the camera and the target object decreases the diameter of ice required for the sensor to detect ice, increases.

Figure C-2

Ice Sensor Camera Picture Description

1999/2000

Date	Time	Test #	Description of picture

Figure C-3

Sheet _____ of

Ice Sensor Camera Failure Validation

<u>Test Type :</u> • Visibility •Light Conditions •Distance validation

1999/2000

Date	Time	Distance (ft.)	Angle (degree)	Description of Failures (plates) & Environmental Conditions

ATTACHMENT C-II
PERSONNEL ASSIGNMENT

Overall Coordinator

- Assists test team as required; and
- Discusses and approves any changes to test procedures as determined necessary from test results or circumstances.

Test Team

- Prior to testing, mount FAA ice thickness plates on plywood backing
- Predetermine area of contamination that is visible on standard plates to serve as a baseline for tests using standard plate surfaces
- Prepare stand to enable test subject to be mounted at varying slopes
- Prepare ice on thickness plates
- Prepare cold soak boxes to generate frost
- Operate ice detection camera and record pertinent images
- Position test plates and camera to match test requirements
- Conduct tests and record observations

The test team will consist of one or two members, depending on the series of trials being performed. The first tester will prepare the test set-up and capture images with the ice detection camera. A second tester will prepare test surfaces including FAA and standard flat plates when required. The following table shows the number of testers initially anticipated for each series of trials.

	A	**B**	**C**	**D**	**E**	**F**
Overall Coordinator	√	√	√	√	√	√
Tester 1	√	√	√	√	√	√
Tester 2		√		√		

ATTACHMENT C-III

ICE DETECTION SENSOR SENSITIVITY TRIALS

TEST	A	Ice Thickness Threshold
TYPE	B	Ice under Type IV Fluid
	C	Contamination Roughness
	D	Determine Typical Roughness Profiles during HOT Trials
	E	Visibility in Falling Snow Condiitions
	F	Adaptability to Changing Light Conditions

TEST #	TEST RUN	DISTANCE		VIEW ANGLE (Deg)	TEST TYPE	FLUID TYPE	LEVEL OF ROUGHNESS	TRIAL LOCATION	TEST SURFACE
		M	FT						
1	1	4.5	15	10	A			LAB	FAA and Std Plate
2	1	4.5	15	20	A			LAB	FAA Plates
3	1	4.5	15	30	A			LAB	FAA Plates
4	1	4.5	15	45	A			LAB	FAA Plates
5	1	4.5	15	60	A			LAB	FAA Plates
6	2	7.5	25	10	A			LAB	FAA and Std Plate
7	2	7.5	25	20	A			LAB	FAA Plates
8	2	7.5	25	30	A			LAB	FAA Plates
9	2	7.5	25	45	A			LAB	FAA Plates
10	2	7.5	25	60	A			LAB	FAA Plates
11	3	15	50	20	A			LAB	Std Plate
12	3	15	50	30	A			LAB	FAA and Std Plate
13	3	15	50	45	A			LAB	FAA Plates
14	3	15	50	60	A			LAB	FAA Plates
15	4	7.5	25	20	B	Type I Eth		LAB	FAA Plates
16	4	7.5	25	30	B	Type I Eth		LAB	FAA Plates
17	5	7.5	25	20	B	Type I Pro		LAB	FAA Plates
18	5	7.5	25	30	B	Type I Pro		LAB	FAA Plates
19	6	7.5	25	20	B	Type IV Eth		LAB	FAA Plates
20	6	7.5	25	30	B	Type IV Eth		LAB	FAA Plates
21	7	7.5	25	20	B	Type IV Pro		LAB	FAA Plates
22	7	7.5	25	30	B	Type IV Pro		LAB	FAA Plates
23	8	15	50	30	B	Type I Eth		LAB	FAA and Std Plate
24	9	15	50	30	B	Type I Pro		LAB	FAA and Std Plate
25	10	15	50	30	B	Type IV Eth		LAB	FAA and Std Plate
26	11	15	50	30	B	Type IV Pro		LAB	FAA and Std Plate
27	12	7.5	25	20	C		a	LAB	ColdSoak BOX
28	12	7.5	25	30	C		a	LAB	ColdSoak BOX
29	12	7.5	25	45	C		a	LAB	ColdSoak BOX
30	13	7.5	25	20	C		b	LAB	ColdSoak BOX
31	13	7.5	25	30	C		b	LAB	ColdSoak BOX
32	13	7.5	25	45	C		b	LAB	ColdSoak BOX
33	14	7.5	25	20	C		c	LAB	ColdSoak BOX
34	14	7.5	25	30	C		c	LAB	ColdSoak BOX
35	14	7.5	25	45	C		c	LAB	ColdSoak BOX
36	15	15	50	30	C		a	LAB	ColdSoak BOX
37	15	15	50	30	C		b	LAB	ColdSoak BOX
38	15	15	50	30	C		c	LAB	ColdSoak BOX
39	16	30	100	30	C		a	SITE	ColdSoak BOX
40	16	30	100	30	C		b	SITE	ColdSoak BOX
41	16	30	100	30	C		c	SITE	ColdSoak BOX
42	17	45	150	30	C		a	SITE	ColdSoak BOX
43	17	45	150	30	C		b	SITE	ColdSoak BOX
44	17	45	150	30	C		c	SITE	ColdSoak BOX
45	-	7.5	25	20	E			SITE	Plates and Wing
46	-	7.5	25	30	E			SITE	Plates and Wing
47	-	15	50	30	E			SITE	Plates and Wing
48	-	30	100	30	E			SITE	Plates and Wing
49	-	45	150	30	E			SITE	Plates and Wing
50	18	7.5	25	20	F			SITE	FAA Plates
51	18	7.5	25	30	F			SITE	FAA Plates
52	19	15	50	30	F			SITE	FAA and Std Plate
53	20	30	100	30	F			SITE	Std Plate
54	21	45	150	30	F			SITE	Std Plate

Note: Initial work will be performed to produce various levels of roughness. The anticipated roughnesses will range between 0 and 1 mm.

Test type C will be preformed with three levels of roughness ranging from a (the smoothest) to c (the roughest of the levels)

APPENDIX D

Data Sheets from Tests on Jetstar Test Wing

FIGURE 4

CONTAMINATION FORM FOR JETSTAR WING - PHASE 1 - STAGE 1

FIELD TRIALS FOR END-OF-RUNWAY

DATE: 20-21 | 03 | 2000

RUN #: 1

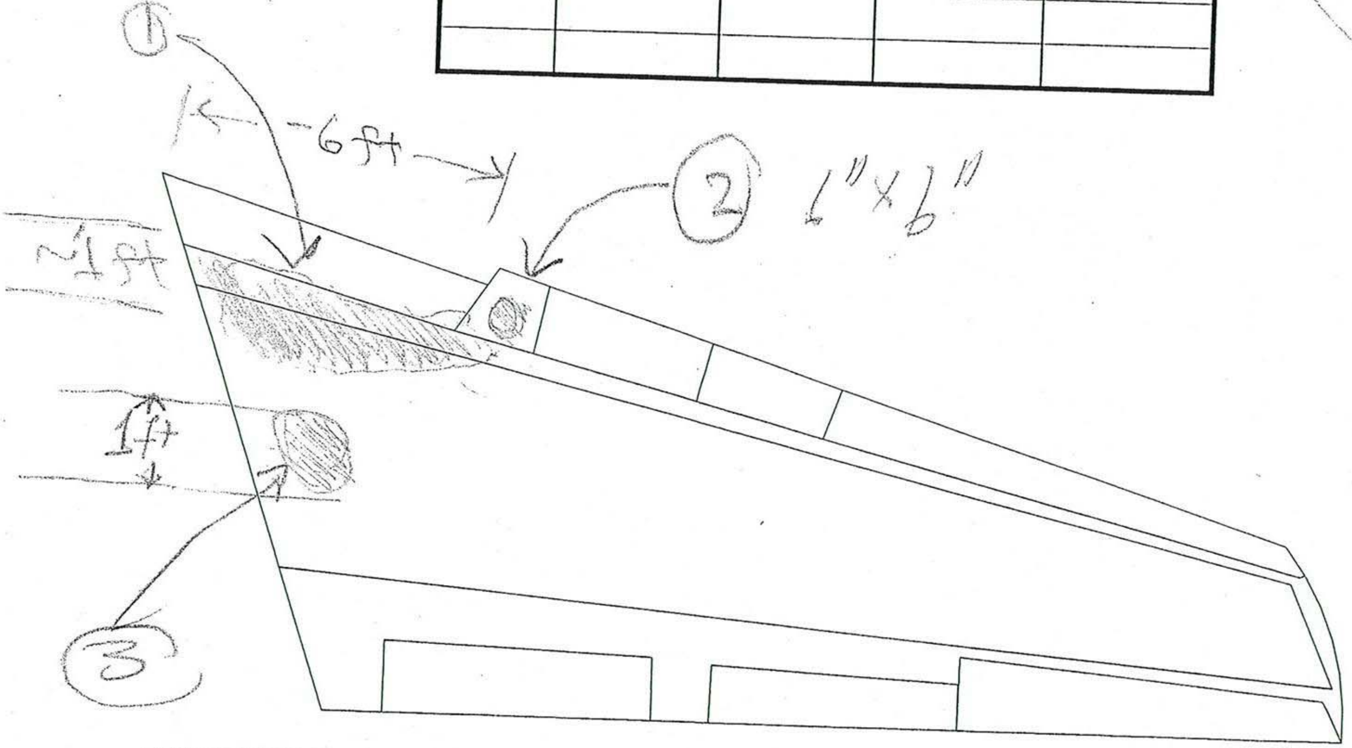
TIME: 0115 HRS

OAT:

DAY OR NIGHT:

Contamination Patches				
Location	* Type (Snow or Ice)	Thickness (mil)	Roughness	Dimensions
1	snow*		2-4 mm	
2	"		"	
3	"		3-5	

* granular snow



SENSOR LOCATION:

Horizontal Distance to Wing Tip: 60'

Mast Height:

Sensor Light? Y or N: Y

COMMENTS: simulated failure
granular snow
1-5 mm particle size

ICING RECORD BY: A Peter

OBSERVER LOCATION:
([✓ Wing] or Sensor)

File:h:\cm1589\procedures\end of runway\Data Forms
At: Cont. Jetstar
Printed: 3/13/00, 2:21 PM

Runs 1-5; hicht of camera = 40'

FIGURE 4

CONTAMINATION FORM FOR JETSTAR WING - PHASE 1 - STAGE 1

FIELD TRIALS FOR END-OF-RUNWAY

DATE: 20-21/03/2000

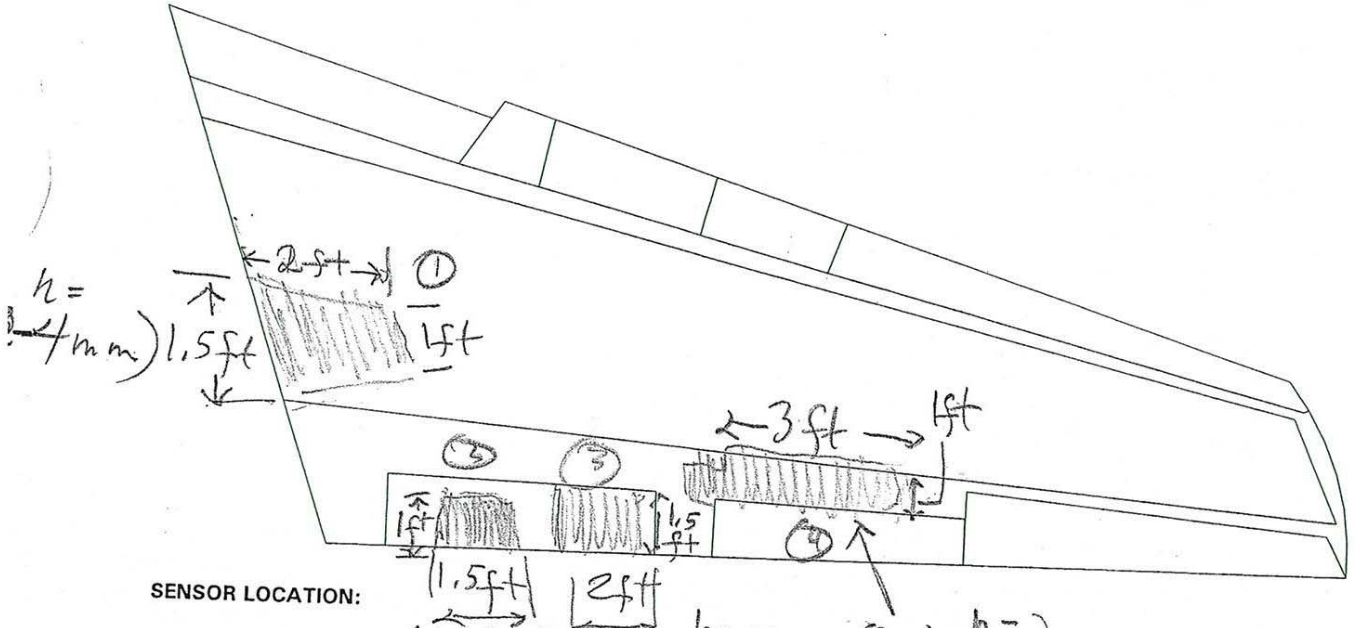
RUN #: 2

TIME: 0130+

OAT:

DAY OR NIGHT: Night

Contamination Patches				
Location	Type (Snow or Ice)	Thickness (mil)	Roughness	Dimensions



SENSOR LOCATION:

Horizontal Distance to Wing Tip:

Mast Height:

Sensor Light? [✓ Y] or N:

COMMENTS: see Run #1 data sheet
trailing edge graduation
of area size of failures

ICING RECORD BY:

OBSERVER LOCATION:
(Wing or Sensor)

File:h:\cm1589\procedures\end of runway\Data Forms
At: Cont. Jetstar
Printed: 3/13/00, 2:21 PM

FIGURE 4

CONTAMINATION FORM FOR JETSTAR WING - PHASE 1 - STAGE 1

FIELD TRIALS FOR END-OF-RUNWAY

DATE: 20-21/03/2000

RUN #: 3

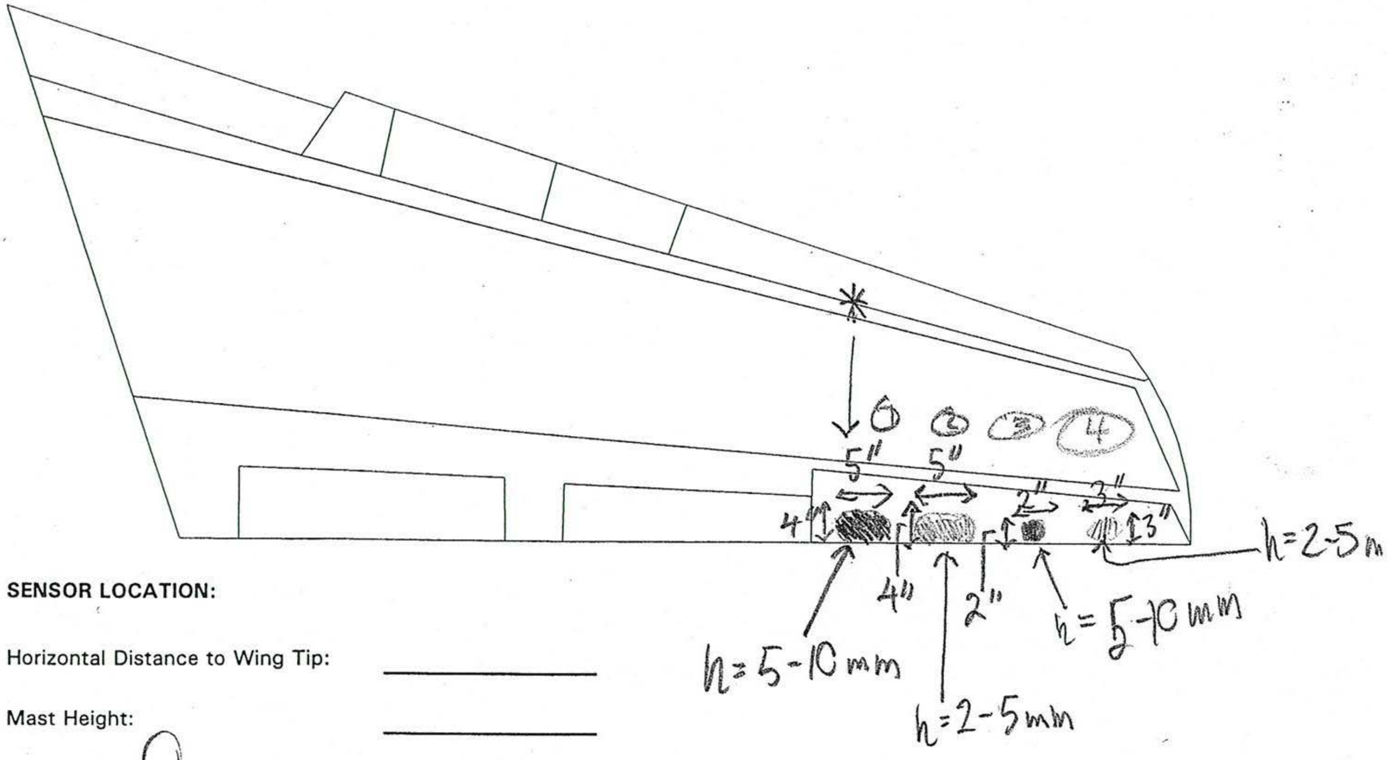
TIME: 0150 HRS

OAT:

DAY OR [✓ NIGHT]:

Contamination Patches

Location	Type (Snow or Ice)	Thickness (mil)	Roughness	Dimensions



SENSOR LOCATION:

Horizontal Distance to Wing Tip:

Mast Height:

Sensor Light? [✓ Y] or N:

COMMENTS: Comparison for resolution + sensitivity test
(area) (thickness)

ICING RECORD BY:

OBSERVER LOCATION:
(Wing or Sensor)

* Detected on COX (repreducibly!)
→ other positions do not always show ice!

FIGURE 4

CONTAMINATION FORM FOR JETSTAR WING - PHASE 1 - STAGE 1

FIELD TRIALS FOR END-OF-RUNWAY

DATE: 20-21/03/2000

RUN #: 4 *

TIME: 0210

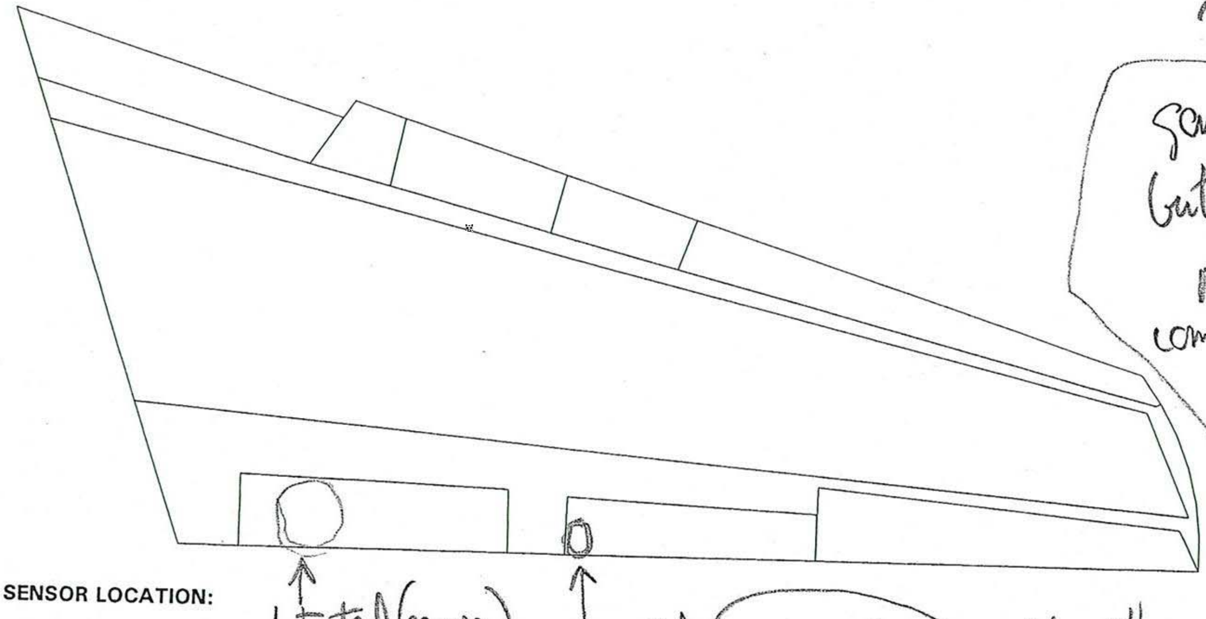
OAT: 0209 - 0210 5°

DAY OR NIGHT:

Contamination Patches				
Location	Type (Snow or Ice)	Thickness (mil)	Roughness	Dimensions

Rotation of wing

~90°



detected (camera angle 1)

detected (camera angle 2)

Same wing position but somewhat melted compared to Run 3

No other wing positions show snow reproducibly

SENSOR LOCATION:

Horizontal Distance to Wing Tip:

Mast Height:

Sensor Light? Y or N:

COMMENTS: Next Run: Same wing orientation, same Camera height but thicken up failure regions

ICING RECORD BY:

OBSERVER LOCATION: (Wing or Sensor)

FIGURE 4

CONTAMINATION FORM FOR JETSTAR WING - PHASE 1 - STAGE 1

FIELD TRIALS FOR END-OF-RUNWAY

DATE: 20-21/03/2000

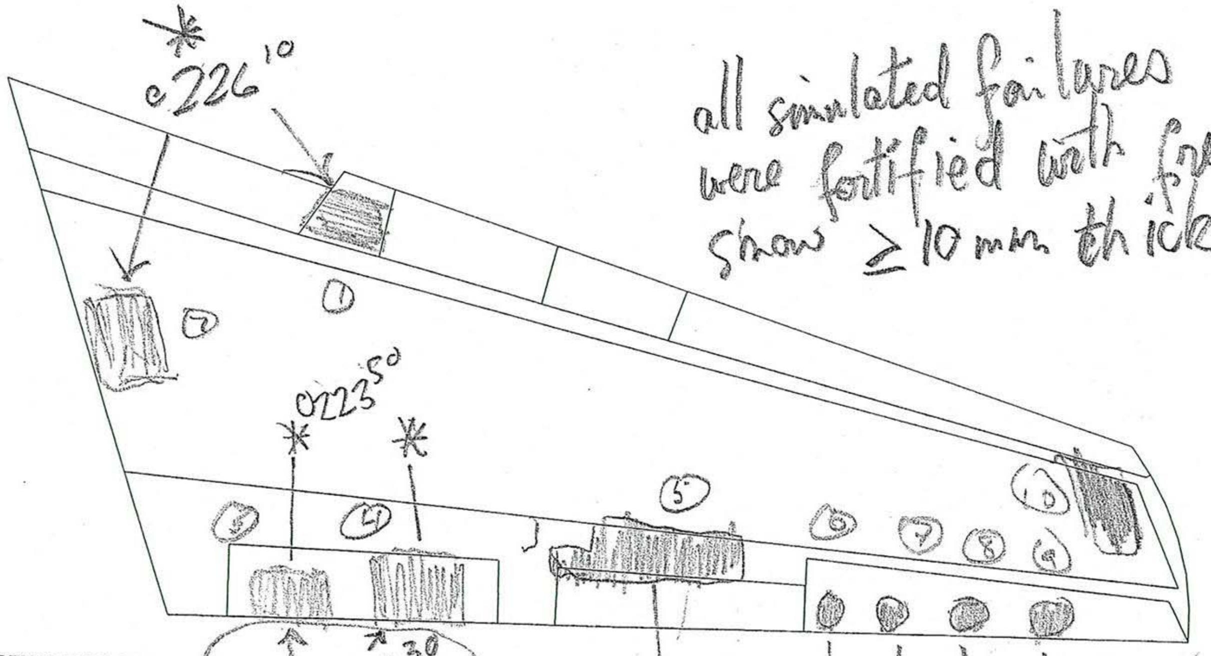
RUN #: 5

TIME: →

OAT: 0223^{20} (+)

DAY OR [✓ NIGHT]:

Contamination Patches				
Location	Type (Snow or Ice)	Thickness (mil)	Roughness	Dimensions



all simulated failures were fortified with fresh snow ≥10 mm thick!

SENSOR LOCATION: * 0225^{30} '' 35

Horizontal Distance to Wing Tip:

Mast Height:

Sensor Light? [✓ Y] or N:

COMMENTS: see page ①

ICING RECORD BY:

OBSERVER LOCATION: ([✓ Wing] or Sensor)

FIGURE 4

CONTAMINATION FORM FOR JETSTAR WING - PHASE 1 - STAGE 1

FIELD TRIALS FOR END-OF-RUNWAY

DATE: 20-21 / 03 / 2000

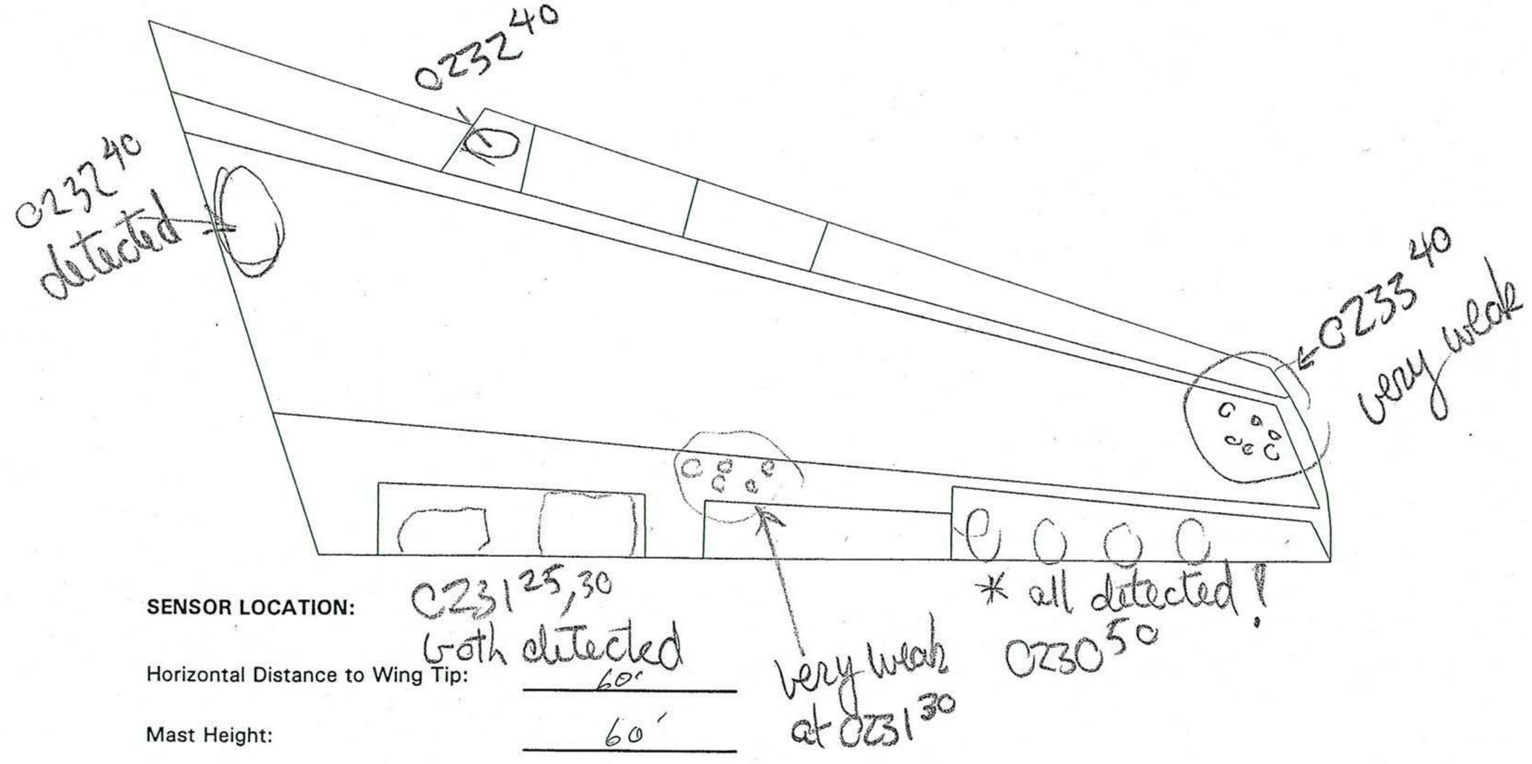
RUN #: 6

TIME: 0229 ⓣ

OAT:

DAY OR [✓ NIGHT]:

Contamination Patches				
Location	Type (Snow or Ice)	Thickness (mil)	Roughness	Dimensions



SENSOR LOCATION:

Horizontal Distance to Wing Tip: 60'

Mast Height: 60'

Sensor Light? [✓ Y] or N:

COMMENTS:

ICING RECORD BY:

OBSERVER LOCATION:
(Wing or Sensor)

File:h:\cm1589\procedures\end of runway\Data Forms
At: Cont. Jetstar
Printed: 3/13/00, 2:21 PM

Run with camera at height = 60'
Same orientation as run 5 and failures same as 5

FIGURE 4

CONTAMINATION FORM FOR JETSTAR WING - PHASE 1 - STAGE 1

FIELD TRIALS FOR END-OF-RUNWAY

DATE: 20-21/03/2000

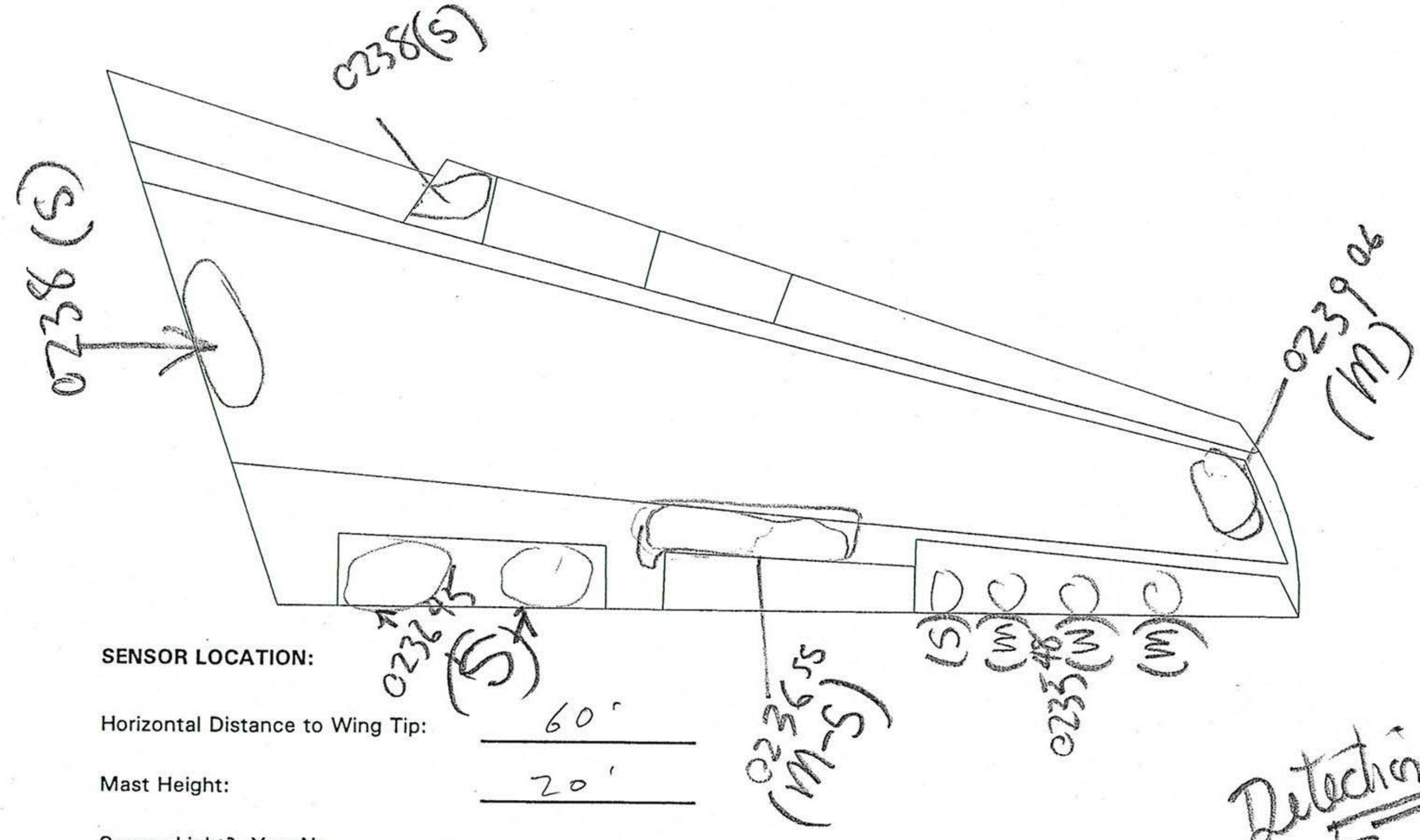
RUN #: 7

TIME: 0235(+)

OAT:

DAY OR [✓ NIGHT]:

Contamination Patches				
Location	Type (Snow or Ice)	Thickness (mil)	Roughness	Dimensions



SENSOR LOCATION:

Horizontal Distance to Wing Tip: 60'

Mast Height: 20'

Sensor Light? Y or N:

COMMENTS:

ICING RECORD BY:

OBSERVER LOCATION:
(Wing or Sensor)

Detection I
S = strong
M = mediu
W = weak

Camera height = 20'
same failure locations and wing orientation as Run#

FIGURE 4

CONTAMINATION FORM FOR JETSTAR WING - PHASE 1 - STAGE 1

FIELD TRIALS FOR END-OF-RUNWAY

DATE: 20-21/03/2000

RUN #: 8

TIME: 0254 ⊕

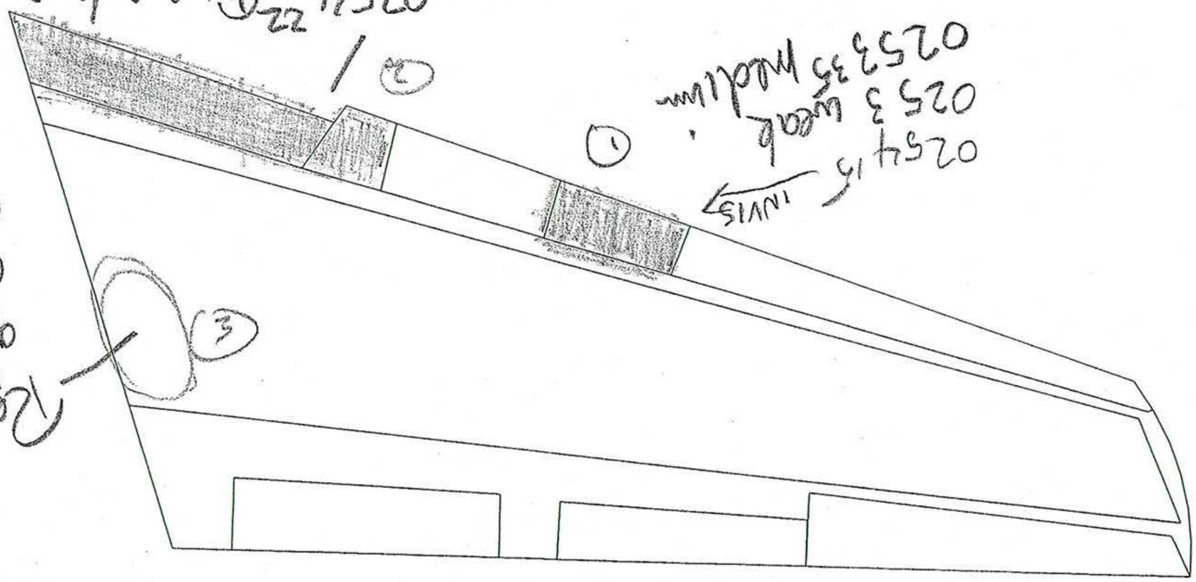
OAT:

DAY OR [✓ NIGHT]:

Contamination Patches				
Location	Type (Snow or Ice)	Thickness (mil)	Roughness	Dimensions

0255 st ⊕ strong !

0254 22 30 ⊕ weak



0253 35 medium

0253 weak .

0254 15 INVIS

Remnant also detected 0255 st

SENSOR LOCATION:

Horizontal Distance to Wing Tip:

Mast Height: 20'

Leading Edge toward Camera

Sensor Light? [✓ Y] or N:

COMMENTS: 20' Camera height!

ICING RECORD BY:

OBSERVER LOCATION: ([✓ Wing] or Sensor)

File:h:\cm1589\procedures\end of runway\Data Forms
At: Cont. Jetstar
Printed: 3/13/00, 2:21 PM

FIGURE 4

CONTAMINATION FORM FOR JETSTAR WING - PHASE 1 - STAGE 1

FIELD TRIALS FOR END-OF-RUNWAY

DATE: 20-21/03/2000

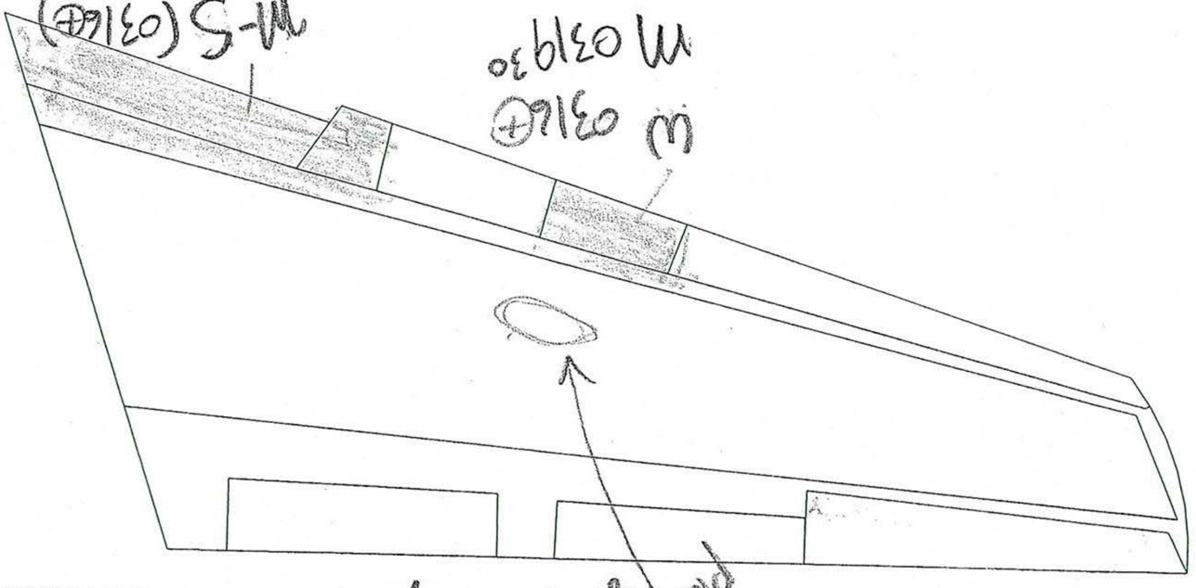
RUN #: 9

TIME: 0316(+) for ice détection

OAT:

DAY OR NIGHT:

Contamination Patches				
Location	Type (Snow or Ice)	Thickness (mil)	Roughness	Dimensions



m-m(0319:30)

S(03:18:25)

m-S (0316+)

m 0319 30

0316+ m

0316+ clear sheet of ice placed on surface (S)

SENSOR LOCATION:

Horizontal Distance to Wing Tip: LE 100'

Mast Height:

Sensor Light? [✓ Y] or N:

COMMENTS:

ICING RECORD BY:

OBSERVER LOCATION:
[✓ Wing] or Sensor)

File:h:\cm1589\procedures\end of runway\Data Forms
At: Cont. Jetstar
Printed: 3/13/00, 2:21 PM

FIGURE 4

CONTAMINATION FORM FOR JETSTAR WING - PHASE 1 - STAGE 1

FIELD TRIALS FOR END-OF-RUNWAY

DATE: 20-21 | 03 | 2000

RUN #: 10

TIME: 0350t

OAT:

DAY OR [✓ NIGHT]:

water/ice
using back-pack
sprayer

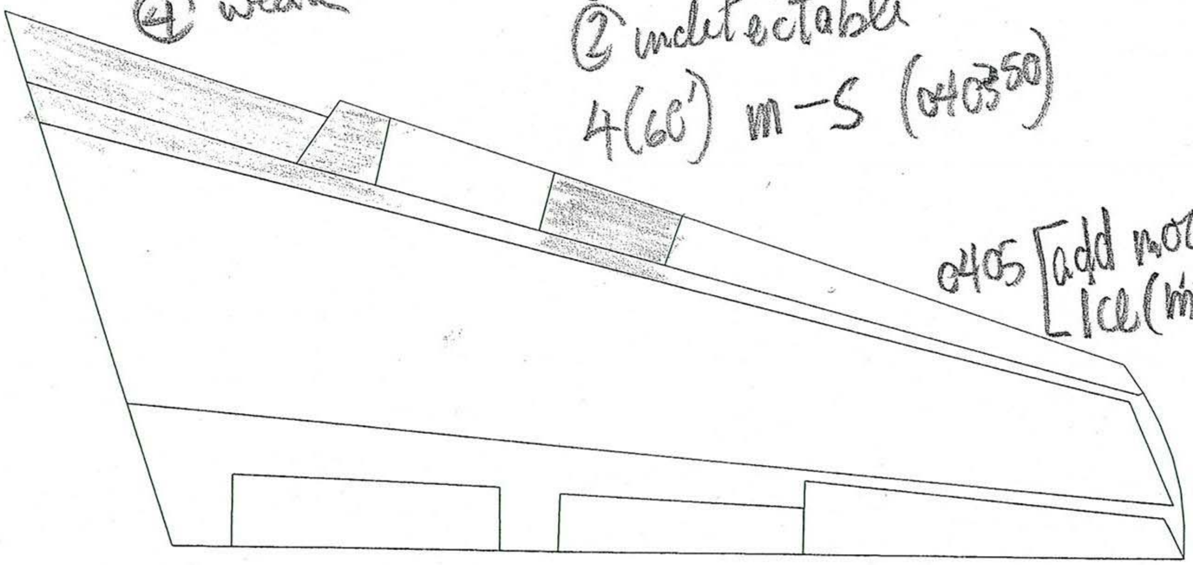
Contamination Patches				
Location	Type (Snow or Ice)	Thickness (mil)	Roughness	Dimensions
	Y.			

–indetectable
① v.weak
② /
④ weak

① indetectable
② indetectable
4(60') m-S (0403 50)

Camera height 1=12
2=20'
4=60'

0405 [add more ice (mist)] → 4=60'



SENSOR LOCATION:

Horizontal Distance to Wing ~~Tip~~ LE: 100'

Mast Height:

Sensor Light? Y or N:

COMMENTS: [redacted] ← thin layer of frozen mist

ICING RECORD BY: AP

OBSERVER LOCATION:
(Wing or Sensor)

FIGURE 4

CONTAMINATION FORM FOR JETSTAR WING - PHASE 1 - STAGE 1

FIELD TRIALS FOR END-OF-RUNWAY

DATE: 20-21/03/2000

RUN #: 11

TIME: 0436

OAT:

DAY OR [✓ NIGHT]:

Contamination Patches				
Location	Type (Snow or Ice)	Thickness (mil)	Roughness	Dimensions

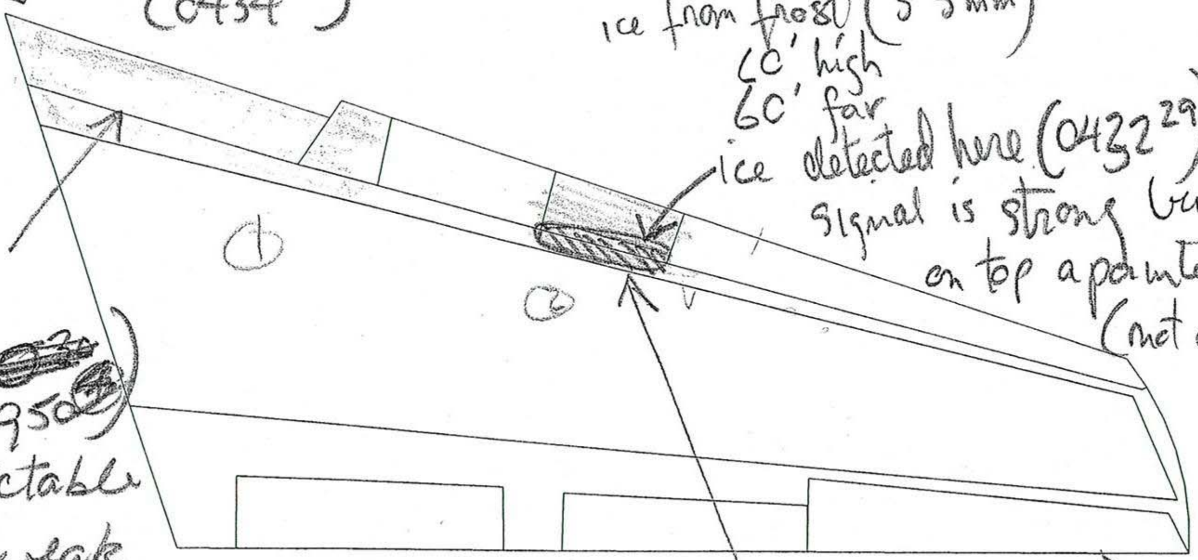
ice from mist (2-3 mm)
60' high
60' far

No detection (0434 20)

ice from frost (3-5 mm)
60' high
60' far

ice detected here (0432 29)
signal is strong but only
on top a painted strip
(not on Alumin

)



40' high
60' far
~~[illegible]~~
0459 50
undetectable
to
very weak

40' high
60' far
(0440 50) ~~undetectable~~
~~to weak~~

strong-V. strong
(except extreme LE
-where no ice is
detected-
but ice is present
there!

SENSOR LOCATION:

Horizontal Distance to Wing Tip:

Mast Height:

Sensor Light? Y or N: H=20'

COMMENTS: l=60'

=0450 00

same distance but at h=20'

V-strong ice detection over whole contaminated
inside leading edge, but undetectable at
outer leading edge.

ICING RECORD BY:

OBSERVER LOCATION:
(Wing or Sensor)

File:h:\cm1589\procedures\end of runway\Data Forms
At: Cont. Jetstar
Printed: 3/13/00, 2:21 PM

FIGURE 4

CONTAMINATION FORM FOR JETSTAR WING - PHASE 1 - STAGE 1

FIELD TRIALS FOR END-OF-RUNWAY

DATE: 20-21/03/2000

RUN #: 12

TIME: 0457(+)

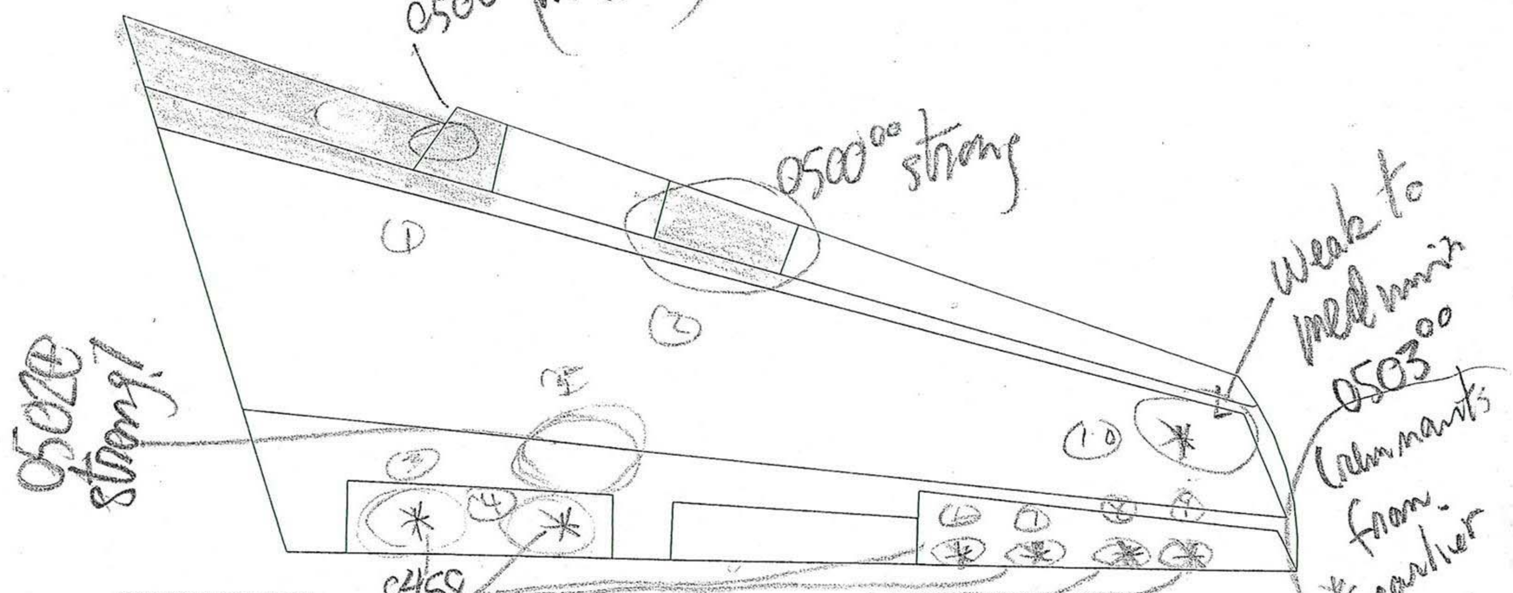
OAT:

DAY OR [✓ NIGHT]:

TRIAL "A": l = 60'
h = 20'

Rotate wing so [illegible] tip is closer to camera

Contamination Patches				
Location	Type (Snow or Ice)	Thickness (mil)	Roughness	Dimensions



SENSOR LOCATION:

Horizontal Distance to Wing Tip: 60'

Mast Height:

Sensor Light? [✓ Y] or N:

COMMENTS: Same Contamination as Run 11.

ICING RECORD BY: AP

OBSERVER LOCATION:
([✓ Wing] or Sensor)

FIGURE 4

CONTAMINATION FORM FOR JETSTAR WING - PHASE 1 - STAGE 1

FIELD TRIALS FOR END-OF-RUNWAY

DATE: 20-21/03/2000

RUN #: 13

TIME: 0505⊕

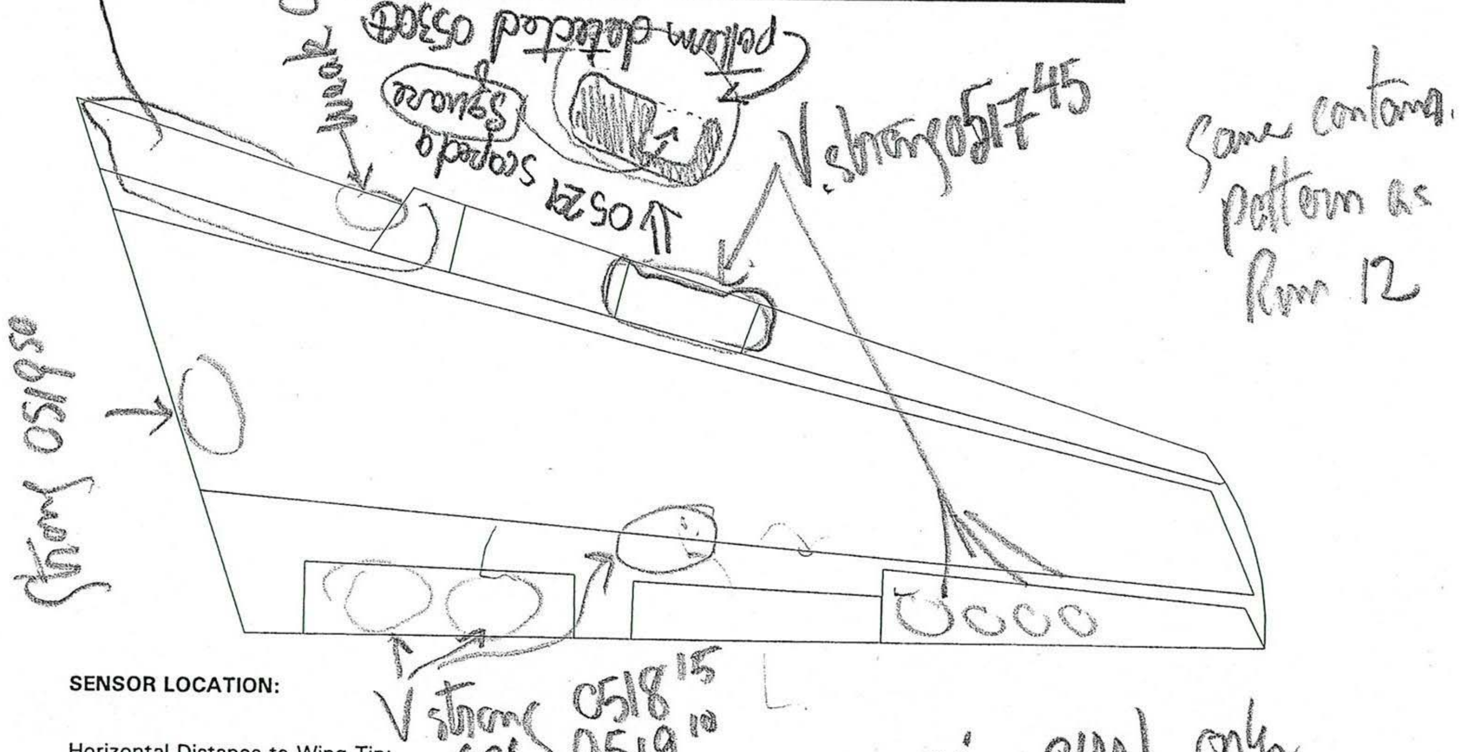
OAT:

DAY OR NIGHT: [✓ DAY] early morning (sky is getting lighter)

h=40'
l=60'

pattern detected 0523⊕ (It's getting clearer)

Contamination Patches				
Location	Type (Snow or Ice)	Thickness (mil)	Roughness	Dimensions



SENSOR LOCATION:

Horizontal Distance to Wing Tip: 60'

Mast Height: 40'

Sensor Light? [✓ Y] or N:

COMMENTS:

FOR THIS RUN, only "ice detected" is shown on digram

ICING RECORD BY: AP

OBSERVER LOCATION: ([✓ Wing] or Sensor)

File:h:\cm1589\procedures\end of runway\Data Forms
At: Cont. Jetstar
Printed: 3/13/00, 2:21 PM

FIGURE 4

CONTAMINATION FORM FOR JETSTAR WING - PHASE 1 - STAGE 1

FIELD TRIALS FOR END-OF-RUNWAY

DATE: 20-21 | 03 | -2000

RUN #: 14

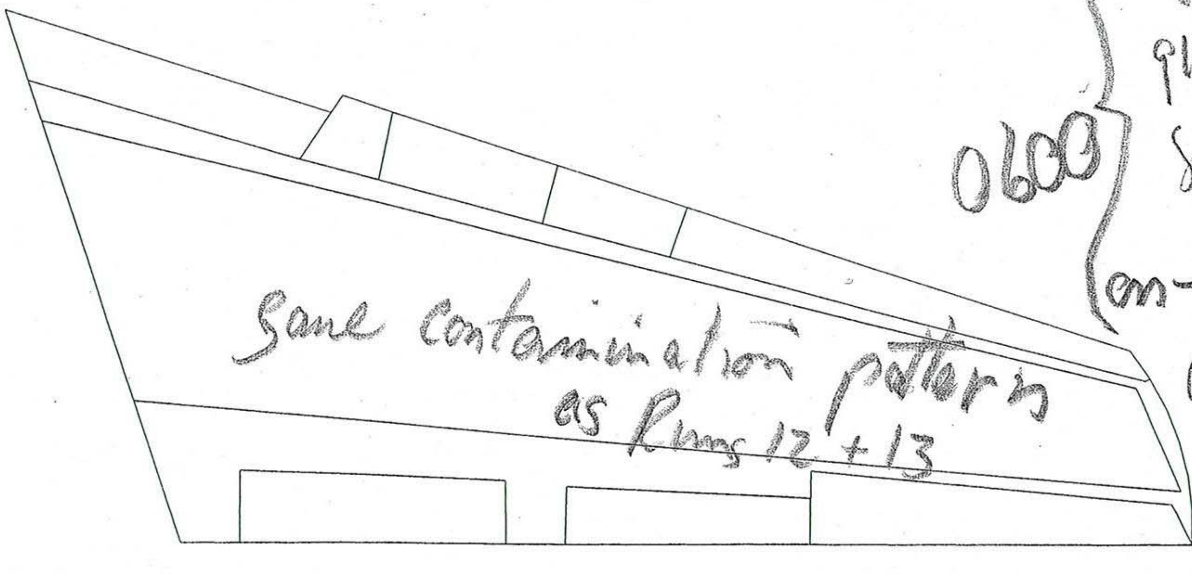
TIME: 0558+

OAT:

DAY OR NIGHT:

Contamination Patches				
Location	Type (Snow or Ice)	Thickness (mil)	Roughness	Dimensions

height = 60'
instr. light: off - whole field gives ice signal!
0600 on - only contaminated areas show ice!



Same contamination pattern as Runs 12 + 13

SENSOR LOCATION:

Horizontal Distance to Wing Tip: 60'

Mast Height: 60'

Sensor Light? Y or No 1st No!

COMMENTS: then

0603 hrs: as sun rises more and more surface shows AP ice. But it is not actually there!

ICING RECORD BY:

OBSERVER LOCATION:
(Wing or Sensor)

APPENDIX E

Data Summaries from Sensitivity Tests

Sheet __1__ of ___7__

Ice Detection with Ice Sensor Camera

Test Type :   • Visibility   • Light Conditions   [✓ • Distance validation]

1999/2000

Date	Time	Distance (m)	Angle (degree)	Description of Failures (plates) & Conditions	
21-Mar	*1:20:18*	*14.6*	*90*	*Plates with 0.05"; 0.09"; 0.06" and no ice; detected OK. 0.08" thin patchy ice not fully detected*	*Disk*
21-Mar	*1:23:12*	*14.6*	*60*	*Good detection; 0.08" area indicated is small*	*Disk*
21-Mar	*1:25:16*	*14.6*	*45*	*Good*	*Disk*
21-Mar	*1:28:27*	*14.6*	*30*	*0.05 and 0.08 only detected*	*Disk*
21-Mar	*1:50:00*	*14.6*	*30*	*Plate 1, thin ice not detected*	*Plate*
21-Mar	*2:00:00*	*14.6*	*30*	*Plate 2, thicker ice detected*	*Plate*
21-Mar	*2:06:00*	*14.6*	*20*	*Plate 1, thin ice not detected*	*Plate*
21-Mar	*2:06:31*	*14.6*	*20*	*Plate 2, thicker ice detected*	*Plate*
21-Mar	*2:44:21*	*7.6*	*60*	*Very clear, good*	*Disk*
21-Mar	*2:46:48*	*7.6*	*45*	*Very clear, good*	*Disk*
21-Mar	*2:50:18*	*7.6*	*30*	*Stand swung 180 degrees; Image very clear, good*	*Disk*
21-Mar	*2:58:02*	*7.6*	*20*	*Stand swung 180 degrees; Image very clear, good*	*Disk*
21-Mar	*3:00:50*	*7.6*	*10*	*Stand swung 180 degrees; No ice detected on any disks*	*Disk*
21-Mar	*3:06:41*	*7.6*	*10*	*Plate 1, thin ice not detected*	*Plate*
21-Mar	*3:07:08*	*7.6*	*10*	*Plate 2, some ice detected, mostly on rougher sections*	*Plate*

Sheet 2 of 7

Ice Detection with Ice Sensor Camera

Test Type : • Visibility •Light Conditions [✓ •Distance validation]

1999/2000

Date	Time	Distance (m)	Angle (degree)	Description of Failures (plates) & Environmental Conditions	
21-Mar	*3:32:00*	*4.6*	*60*	*Really clear, good detection*	*Disk*
21-Mar	*3:34:20*	*4.6*	*45*	*Really clear, good detection*	*Disk*
21-Mar	*3:36:16*	*4.6*	*30*	*Really clear, good detection*	*Disk*
21-Mar	*3:38:30*	*4.6*	*20*	*Not as clear, partial detection at right end*	*Disk*
21-Mar	*3:40:30*	*4.6*	*10*	*Not clear, some ice detected*	*Disk*
21-Mar	*3:44:30*	*4.6*	*10*	*Plate 1 not detected,* *Plate 2 partially detected,*	*Plate*
21-Mar	*4:30:00*	*20*	*60*	*Thick frost on CSB, 26 mils, not detected by sensor*	*CSB*
21-Mar	*4:37:00*	*16.8*	*30*	*Frost not detected*	*CSB*

Sheet __3__ of __7__

Ice Detection with Ice Sensor Camera

Test Type : • Visibility • Light Conditions [✓ • Distance validation]

1999/2000

Date	Time	Distance (m)	Angle (degree)	Description of Failures (plates) & Environmental Conditions	
21-Mar	5:07:00	12.4		Patches of ice clearly detected	Wing
21-Mar	5:08:00	17.3	30	Ice detected on 2 out of 4 surfaces	Disk
21-Mar	5:12:00	12.4		Patches of ice are shown as smaller	Wing
21-Mar	5:14:00	17.3	30	Difficulty with image, failures are not clear	Disk
21-Mar	5:17:00	12.4		False failures indicated on the leading edge	Wing
21-Mar	5:22:00	17.3	30	Unchanged, false failure indicated around stand	Disk
21-Mar	5:26:00	12.4		No difference	Wing
21-Mar	5:29:00	17.3	30	No difference	Disk
21-Mar	5:29:00	12.4		Square scraped into failure	Wing
21-Mar	5:35:00	12.4		More failures are visible as sky lightens (Sunrise occurred at 5:50)	Wing
21-Mar	5:38:00	12.4		Better resolution	Wing

Sheet __4__ of ___7_

Ice Detection with Ice Sensor Camera

Test Type : • Visibility • Light Conditions [✓ • Distance validation]

1999/2000

Date	Time	Distance (m)	Angle (degree)	Description of Failures (plates) & Environmental Conditions
3-Apr	*14:17:00*	*4.6*	*60*	*Ice correctly detected above 0.05*
3-Apr	*14:23:00*	*4.6*	*45*	*Good ice detection, plate 0.05 has thin ice on the bottom half*
3-Apr	*14:43:00*	*4.6*	*30*	*Stand rotated 180, good detection*
3-Apr	*14:46:00*	*4.6*	*20*	*Good ice detction*
3-Apr	*14:52:00*	*4.6*	*10*	*0.01 plate half detected, good detection*
3-Apr	*15:00:00*	*4.6*	*6*	*Some ice detected on all plates*
3-Apr	*15:10:00*	*7.56*	*10*	*NOTHING detected*
3-Apr	*15:14:00*	*7.56*	*20*	*Inconsistent results*
3-Apr	*15:23:00*	*7.56*	*30*	*Stand rotated 180, some ice detected on each plate*
3-Apr	*15:26:00*	*7.56*	*45*	*Some ice detected on plates*
3-Apr	*15:28:00*	*7.56*	*60*	*Good ice detection on all disks*
3-Apr	*15:52:00*	*15.15*	*30*	*Significant background noise in image*
3-Apr	*15:54:00*	*15.15*	*45*	*Good detection from 0.03 up*
3-Apr	*15:51:00*	*15.15*	*60*	*Good detection above 0.05*
3-Apr	*17:21:00*	*7.5*	*20*	*Ice under Ultra+* *Good detection*
3-Apr	*17:23:00*	*7.5*	*30*	*Ice under Ultra+* *Good detection*

The plates were placed in the following positions. Depth of ice discs is shown in inches.

0.01	*empty*	*0.03*	*empty*	*0.05*	*0.06*	*0.07*	*0.08*	*0.09*	*empty*

Sheet __5__ of ___7__

Ice Detection with Ice Sensor Camera

Test Type : • Visibility •Light Conditions [✓ •Distance validation]

1999/2000

Date	Time	Distance (m)	Angle (degree)	Description of Failures (plates) & Environmental Conditions
3-Apr	*16:26:00*	*15*	*30*	*Significant noise, some ice detected*

Sheet __6__ of ___7__

Ice Detection with Ice Sensor Camera

Test Type : • Visibility • Light Conditions [✓ • Distance validation]

1999/2000

Date	Time	Distance (m)	Angle (degree)	Description of Failures (plates) & Environmental Conditions
4-Apr	*11:00:00*	*10*	*20*	*Mode 1 - The sensor shows the ground as ice*
4-Apr	*11:00:00*	*10*	*20*	*Mode 2 - The sensor shows the ground as ice*
4-Apr	*11:00:00*	*10*	*20*	*Mode 3 - The sensor shows the ground as ice*
4-Apr	*11:00:00*	*10*	*20*	*Mode 4 -The sensor does not detect any ice*
4-Apr	*11:11:00*	*10*	*20*	*When the threshold was set to 0.1, no ice was detected on 0.01 plate*
4-Apr	*11:45:00*	*7.5*	*30*	*Mode 1, 0.01 plate not detected but most disks detected OK*
4-Apr	*11:50:00*	*7.5*	*30*	*Mode 4, 0.01 plate not detected but most disks detected OK*
4-Apr	*11:55:00*	*7.5*	*20*	*Mode 4, Good detection*
4-Apr	*11:59:00*	*7.5*	*20*	*Mode 1, Significant noise in image*
4-Apr	*12:05:00*	*7.5*	*20*	*Propylene fluid poured on plates, Mode 1 detects fluid as ice*
4-Apr	*12:05:00*	*7.5*	*20*	*Mode 4 detects most ice disks, some propylene fluid but nothing on the 0.01 plate*
4-Apr	*12:13:00*	*7.5*	*30*	*Mode 4 detects most ice disks but not the 0.01 plate*
4-Apr	*12:20:00*	*15*	*30*	*Fog reduced visibility of camera below the distance to the test stand, nothing detected*

Sheet __7__ of ___7_

Ice Detection with Ice Sensor Camera

Test Type :   • Visibility   • Light Conditions   [✓ • Distance validation]

1999/2000

Date	Time	Distance (m)	Angle (degree)	Description of Failures (plates) & Environmental Conditions
4-Apr	13:59:00	7.5	45	Frost on ice, very crisp images, edge reducer on
4-Apr	14:06:00	7.5	30	Frost on ice, very crisp images, edge reducer on
4-Apr	14:23:00	7.5	30	Octoflo EG poured on all plates, good detection
4-Apr	14:29:00	7.5	20	Octoflo EG poured on all plates, good detection, 0.01 ice melted
4-Apr	14:42:00	7.5	30	Octoflo foam poured on 0.01; 0.08; 0.06, 0.01 no ice present and no ice detected
4-Apr	14:48:00	7.5	30	UCAR NEW foam poured on 0.02; 0.05; 0.07, 0.02 no ice present and no ice detected
4-Apr	16:20:00	7.5	30	Large block of ice placed on test stand, not detected by sensor
4-Apr	17:00:00	7.5	20	Ice roughness trials; P=polished, M=medium,R=rough ▨ ▨ P P M M R R ▨ ▨
4-Apr	17:02:00	7.5	30	All Detected
4-Apr	17:04:00	7.5	45	All Detected
4-Apr	17:29:00	15	30	Too much background noise to interpret
4-Apr		15	45	Too much background noise to interpret
4-Apr	18:06:00	7.5	60	All detected, polished less obvious
4-Apr	18:08:00	7.5	90	All detected, sensor warning "UNABLE TO DETECT ICE"