TP 13479E

Contaminated Aircraft Takeoff Tests for the 1998-99 Winter

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On behalf of
Civil Aviation
Transport Canada

APS AVIATION INC.

October 1999

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by

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Medhat Hanna

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Un sommaire français se trouve avant la table des matières.

PREFACE

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

- To develop holdover time tables for new anti-icing fluids, and to validate fluid-specific and SAE holdover time tables;
- To gather enough supplemental experimental data to support the development of a *deicing only* table as an industry guideline;
- To examine conditions for which contamination due to anti-icing fluid failure in freezing precipitation fails to flow from the wing of a jet transport aircraft when subjected to speeds up to and including rotation;
- To measure the jet-blast wind speeds developed by commercial airliners in order to generate air-velocity distribution profiles (to predict the forces that could be experienced by deicing vehicles), and to develop a method of evaluating the stability of deicing vehicles during live deicing operations;
- To determine the feasibility of examining the surface conditions on wings before takeoff through the use of ice-contamination sensor systems, and to evaluate the sensitivity of one ice-detection sensor system;
- To evaluate the use of warm fuel as an alternative approach to ground deicing of aircraft;
- To evaluate hot water deicing to determine safe and practicable limits for wind and outside ambient temperature;
- To document the appearance of fluid failure, to measure its characteristics at the point of failure, and to compare the failures of various fluids in freezing precipitation;
- To determine the influence of fluid type, precipitation (type and rate), and wind (speed and relative direction) on both the locations and times to fluid failure initiation, with special attention to failure progression on the Bombardier Canadair Regional Jet and on high-wing turboprop commuter aircraft;
- To evaluate snow weather data from previous winters to identify a range of snow-precipitation suitable for the evaluation of holdover time limits;
- To compare the holdover times from natural and artificial snow trials and to evaluate the functionality of NCAR's prototype simulated snowmaking system; and
- To develop a plan for implementing a full-scale wing test facility that would enable the current testing of deicing and anti-icing fluids in natural and artificial freezing precipitation on a real aircraft wing.

The research activities of the program conducted on behalf of Transport Canada during the 1998-99 winter season are documented in twelve reports. The titles of these reports are as follows:

- TP 13477E Aircraft Ground De/Anti-Icing Fluid Holdover Time Field Testing Program for the 1998-99 Winter;
- TP 13478E Aircraft Deicing Fluid Freeze Point Buffer Requirements for Deicing Only Conditions;
- TP 13479E Contaminated Aircraft Takeoff Tests for the 1998-99 Winter;
- TP 13480E Air Velocity Distribution Behind Wing-Mounted Aircraft Engines;
- TP 13481E Feasibility of Use of Ice Detection Sensors for End-of-Runway Wing Checks;
- TP 13482E Evaluation of Warm Fuel as an Alternative Approach to Deicing;
- TP 13483E Hot Water Deicing of Aircraft;
- TP 13484E Characteristics of Failure of Aircraft Anti-Icing Fluids Subjected to Precipitation;
- TP 13485E Aircraft Full-Scale Test Program for the 1998-99 Winter;
- TP 13486E Evaluation of Snow Weather Data for Aircraft Anti-Icing Holdover Times;
- TP 13487E Development of a Plan to Implement a Full-Scale Test Site; and
- TP 13488E A Snow Generation System – Prototype Testing.

This report, TP 13479E, addresses the following objective:

- To further examine conditions for which contamination due to anti-icing fluid failure in freezing precipitation fails to flow from the wing of a jet transport aircraft when subjected to speeds up to and including rotation.

This objective was met by conducting simulated takeoff runs with the National Research Council Falcon 20D research aircraft. Aircraft wings were treated with an anti-icing fluid and then subjected to artificial precipitation to cause contamination of varying degrees. Fluid condition was examined and recorded before and after takeoff runs.

ACKNOWLEDGEMENTS

This research has been funded by the Civil Aviation Group, Transport Canada, and with support from the Federal Aviation Administration. This program could not have been accomplished without the participation of many organizations. APS would like to thank, therefore, the Transportation Development Centre of Transport Canada, the Federal Aviation Administration, the National Research Council Canada, Atmospheric Environment Services Canada, Transport Canada, and several fluid manufacturers. Special thanks are extended to US Airways Inc., Delta Air Lines, Royal Airlines, Air Canada, the National Research Council Canada, Canadian Airlines International, AéroMag 2000, Aéroport de Montreal, the Greater Toronto Airport Authority, Hudson General Aviation Services Inc., Union Carbide, RVSI, Cox and Company Inc., the Department of National Defence, and Shell Aviation, for provision of personnel and facilities and for their co-operation on the test program. APS would like also to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data.

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Research reports produced on behalf of Transport Canada for testing during previous winters are available from the Transportation Development Centre (TDC). Twelve reports (including this one) were produced as part of this winter's research program (1998-99). Their subject matter is outlined in the preface. This project was cosponsored by the Federal Aviation Administration (FAA) and the SAE.

16. Abstract

The objective of this study was to examine conditions for which contamination due to anti-icing fluid failure in freezing precipitation fails to flow from the wing of a jet transport aircraft when subjected to speeds up to rotation speed. This study provides additional data to supplement results from an initial series of tests conducted during the 1997-98 winter.

Simulated takeoff runs were performed with the NRC Falcon 20D research aircraft to examine the behaviour of different levels of contamination. A defined wing area was sprayed with anti-icing fluid that was then subjected to artificial precipitation to produce several levels of contamination severity. The aircraft was operated through a simulated takeoff, including rotation at normal rotation speed. The nature and extent of contamination was examined and recorded before and after the takeoff run.

Uncontaminated fluid, both ethylene glycol-based (EG) and propylene glycol-based (PG), was nearly completely eliminated from the wing surface during the takeoff run. In trials with EG SAE Type IV fluid, ice formations that had existed prior to the takeoff run continued to exist following takeoff regardless of the extent of contamination and regardless of adhesion or lack of adhesion to the wing skin prior to the takeoff run. PG SAE Type IV fluid was completely eliminated when a reasonable level of contamination was tested.

For similar exposure times, the PG Type IV fluid gave the appearance of being contaminated to a greater extent than the EG fluid. Conversely, the contamination developed on the PG Type IV fluid was completely eliminated from the wing during the takeoff run, whereas the contamination on the EG fluids remained. This may have an implication on decision-making to proceed with takeoff or return for deicing, based solely on the extent of contamination as assessed visually or as indicated by a remote ice detection sensor.

Rotation of the aircraft at normal rotation speed during the takeoff run did not eliminate contaminated fluid remaining on the wing at that stage.

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Les rapports sur les essais réalisés pour le compte de Transports Canada au cours des hivers passés peuvent être obtenus auprès du Centre de développement des transports (CDT). Le programme de recherche de l'hiver 1998-1999 a donné lieu à douze rapports (dont celui-ci). Le contenu de ces rapports est donné dans la préface. Les travaux dont rend compte le présent rapport ont été financés par la Federal Aviation Administration (FAA) et la SAE.

16. Résumé

Cette étude avait pour objectif de cerner les conditions où, après perte d'efficacité du fluide antigivre exposé à des précipitations givrantes, les contaminants restent collés sur l'aile d'un avion à réaction pendant l'accélération jusqu'à la vitesse de rotation. De ces travaux sont issues des données nouvelles qui ont été ajoutées aux résultats d'une première série d'essais menés à l'hiver 1997-1998.

Les essais consistaient à simuler la course au décollage de l'avion de recherche Falcon 20D du CNRC et à étudier le comportement des fluides antigivre présentant divers degrés de contamination. Une zone sélectionnée de l'aile avait été pulvérisée de fluide antigivre, après quoi elle avait été exposée à des précipitations artificielles qui avaient produit divers degrés de contamination. Le pilote exécutait alors un décollage simulé, amenant l'appareil jusqu'à la vitesse normale de rotation et le cabrant. Les chercheurs examinaient et notaient la nature et l'étendue de la contamination, avant et après la course au décollage.

Les fluides à l'éthylène glycol (EG) et au propylène glycol (PG) non contaminés ont été presque complètement chassés de la surface de l'aile pendant la course au décollage. Lors des essais du fluide EG type IV de la SAE, les dépôts de givre présents sur l'aile avant la course au décollage s'y trouvaient toujours après, peu importe l'étendue de la contamination et peu importe si celle-ci adhérait ou non au revêtement de l'aile avant la course au décollage. Le fluide PG type IV de la SAE a été complètement chassé de l'aile à des degrés de contamination raisonnables.

Pour des durées d'exposition similaires, le fluide PG type IV semblait être davantage contaminé que le fluide EG. Par contre, il était complètement chassé de l'aile pendant la course au décollage, tandis que les fluides EG contaminés demeuraient en place. Ces résultats peuvent avoir une incidence sur la décision de décoller ou de retourner au poste de dégivrage, lorsqu'il faut se fier uniquement à l'étendue de la contamination telle qu'appréciée visuellement ou indiquée par un détecteur de givrage à distance.

Le fait de cabrer l'avion à la vitesse normale de rotation n'a pas éliminé le fluide contaminé qui restait encore sur l'aile.

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EXECUTIVE SUMMARY

At the request of the Transportation Development Centre of Transport Canada, APS Aviation Inc. has undertaken a research program to further examine the elimination of failed fluids from aircraft wings during takeoff runs up to and including rotation. The objective of this report is to determine conditions under which contaminated fluid adheres to aircraft lifting surfaces.

Regulations dictate that aircraft are restricted from takeoff if ice, frost, snow, or slush is adherent to the critical surfaces of an aircraft. Currently, failure of anti-icing fluid is identified visually by observing frozen contamination on the fluid surface. Providing the frozen contamination is in fact visible, the observer cannot judge whether this visible frozen contamination is actually adherent to the wing surface.

During the 1997-98 winter season, several trials that involved simulated takeoff runs with a Falcon 20D aircraft were conducted to examine whether failed anti-icing fluid remained adherent to a wing at liftoff. These trials were intended to satisfy an information gap thus far unanswered by either theoretical analysis or wind tunnel laboratory research. These trials were reported in TP 13316E, *Contaminated Aircraft Takeoff Test for the 1997/98 Winter* (1).

The 1997-98 series of simulated takeoff run trials provided an initial level of understanding of the issue, and did prove to be a useful approach toward gaining a more complete understanding of the issue of elimination of contaminated failed fluid. The conclusions from those trials were as follows:

1. The trials provided the first documented evidence related to the nature of the process of contaminated aircraft anti-icing fluid elimination from aircraft wings during the takeoff run.

2. In some cases, slush in the contaminated fluid did not adhere to the wing surface and did show freedom of movement, but remained on the wing after the takeoff run.

3. In general, the contamination was not completely eliminated from the wing surface during acceleration of the aircraft to rotation speed in the simulated takeoff runs.

4. The trials identified the need to conduct a further series of tests at takeoff speeds up to and including rotation to verify the results.

As other avenues of research have not yet provided resolution of the issue, it was decided to conduct additional simulated takeoff runs during the 1998-99 winter. A perceived shortcoming of the 1997-98 series of runs was that, although aircraft speed was increased to normal takeoff speed, the aircraft was not rotated and therefore did not offer a complete representation of the true takeoff condition. It was proposed that the 1998-99 series of trials examine ways to include rotation at takeoff speed as part of the simulation, and that both ethylene and propylene glycol-based SAE Type IV fluids be tested.

To satisfy these objectives, nine simulated takeoff runs were conducted with a National Research Council Falcon 20D research aircraft at Montreal International Airport (Mirabel) during the 1998-99 winter. A test area on the wing was first cleaned with an SAE Type I fluid and then treated with neat SAE Type IV fluid. Artificial freezing rain precipitation was then applied over the test fluid until specified levels of contamination were achieved.

The extent and nature of the contamination was documented by observer comments, photography and videotape. The aircraft was then operated through a simulated takeoff run, including aircraft rotation at prescribed rotation speed, followed by the aircraft coasting to a halt. The behaviour of the fluid during the takeoff run was videotaped using a camera temporarily installed in the aircraft's emergency exit, and focused on the test area. The aircraft speed was recorded on the videotape by voice-over. Upon the aircraft's return for inspection, the wing condition was again examined and documented.

Results and Conclusions of the 1998-99 Trials

These trials demonstrated that uncontaminated Type IV fluids, both ethylene and glycol-based, are almost completely eliminated from the wing surface during the takeoff run by the time that the aircraft reaches speeds of 60 to 80 knots.

Trials conducted with ethylene glycol-based SAE Type IV fluid contaminated with artificial freezing rain precipitation demonstrated that ice/slush formations present on the wing prior to the takeoff run persisted through rotation. This held true regardless of the extent of contamination. In these trials, ice formation coverage ranged from 1 to 40 percent of the test area on the wing surface.

Adhesion or lack of adhesion of ice formations to the wing skin prior to the takeoff run did not influence the removal of contaminated fluid from the wing. In these trials, none of the ice formation patches were adherent to the wing prior to the takeoff run. However, on return from the takeoff run, it was noted that many of the ice formations developed some degree of adhesion to the wing skin *during* the takeoff run.

Any fluid that existed outside of the ice patches was almost completely removed from the wing surface during the takeoff run.

A trial conducted on propylene glycol-based SAE Type IV fluid having a contamination level of 100 percent slush/ice coverage of the test area demonstrated that complete removal of propylene glycol-based fluid can be expected when reasonable levels of contamination are experienced. This result is attributed to the nature of failure of propylene glycol-based fluids, whereby failures typically occur on the top surface of the fluid, overlying a layer of relatively uncontaminated fluid underneath.

A trial involving an extended duration of precipitation to produce continued contamination far in excess of complete failure resulted in eventual deterioration of the underlying fluid layer. Patches of thicker ice were developed, some of which were in contact with the wing skin, and this contamination was not removed during the takeoff run. The level of contamination in this run was extreme, and far beyond that which would be expected to exist at time of takeoff in operational practice.

Rotation of the aircraft did not appear to cause any further elimination of persistent ice formations.

Samples of uncontaminated fluids were obtained from the aircraft wing subsequent to fluid application. The viscosity values of these samples varied significantly from the measured viscosities of the same fluids as received from the manufacturers. Furthermore, the relative viscosities of the same fluid brands also varied significantly from one simulation to another when the wing samples viscosities were compared.

Following the same duration of exposure to freezing precipitation, the extent of contamination may appear to be much greater for the propylene glycol-based Type IV fluids than for ethylene glycol-based Type IV fluids tested. Conversely, the contamination developed on the propylene glycol-based Type IV fluid may be expected to be completely removed during the takeoff run, whereas for the apparent lower levels of contamination on the ethylene glycol-based fluid, the contamination may be expected to persist on the wing through rotation.

This may have an implication for future *deice/takeoff* decision making.

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SOMMAIRE

À la demande du Centre de développement des transports de Transports Canada, APS Aviation Inc. a lancé un programme de recherche qui visait à examiner plus avant l'élimination de fluides antigivre contaminés des ailes d'un avion pendant la course au décollage jusqu'à la vitesse de rotation et au cabrage de l'avion. Ce rapport vise à cerner les conditions où le fluide contaminé reste collé aux surfaces portantes de l'avion.

La réglementation interdit aux pilotes de décoller lorsque du givre, de la glace, de la neige ou de la neige fondante adhère aux surfaces critiques de l'avion. Présentement, le pilote se rend compte de la perte d'efficacité des fluides antigivre en observant visuellement la présence de contamination gelée à la surface du fluide. En supposant que la contamination gelée soit effectivement visible, il ne peut, par simple observation visuelle, déterminer si celle-ci adhère réellement à la surface de l'aile.

Plusieurs essais consistant à simuler la course au décollage d'un avion Falcon 20D ont été menés à l'hiver 1997-1998. Ces essais avaient pour but d'examiner si le fluide antigivre devenu inefficace restait collé à l'aile de l'avion au moment du cabrage. Ils visaient de fait à répondre à une question que ni la recherche théorique ni des essais en soufflerie n'avaient encore résolue. Ils sont décrits dans le rapport TP 13316E, *Contaminated Aircraft Takeoff Test for the 1997/98 Winter* (1).

Les courses au décollage simulées réalisées en 1997-1998 ont permis de défricher le terrain et de confirmer la valeur de cette méthode pour une étude approfondie de la question de l'élimination des fluides contaminés des ailes d'avions. Voici les conclusions tirées de ces essais :

1. Pour la première fois, on disposait de données empiriques sur le processus d'élimination des fluides antigivre contaminés des ailes d'un avion pendant la course au décollage.

2. Dans certains cas, la neige fondante contenue dans le fluide antigivre contaminé n'adhérait pas à la surface de l'aile et montrait même une certaine mobilité, mais elle se trouvait toujours sur l'aile après la course au décollage.

3. Règle générale, lors des courses au décollage simulées, l'accélération de l'avion jusqu'à la vitesse de rotation ne réussissait pas à chasser complètement le fluide contaminé de la surface de l'aile.

4. Les essais ont révélé la nécessité de vérifier les résultats au moyen d'autres essais qui consisteraient non seulement à amener l'avion jusqu'à la vitesse de rotation mais aussi à cabrer l'avion.

Comme des recherches menées par d'autres moyens n'avaient pas encore résolu la question, il a été décidé de reprendre des essais de course au décollage pendant l'hiver 1998-1999. Une faiblesse était d'ailleurs perçue dans les essais de 1997-1998 : le pilote accélérait jusqu'à la vitesse normale de décollage, mais sans cabrer l'avion. Il manquait donc cette étape pour avoir une représentation complète de la phase du décollage. Il a été proposé, pour la campagne d'essais de 1998-1999, d'examiner des façons d'intégrer aux simulations le cabrage de l'avion, une fois atteinte la vitesse de rotation, et de mettre à l'essai deux fluides type IV de la SAE, l'un à l'éthylène glycol, l'autre au propylène glycol.

Neuf courses au décollage simulées ont donc été effectuées avec l'avion de recherche Falcon 20D du Conseil national de recherches, à l'aéroport international de Montréal (Mirabel), pendant l'hiver 1998-1999. Une zone de l'aile a d'abord été nettoyée avec un fluide de type I de la SAE, puis pulvérisée de fluide antigivre de type IV de la SAE non dilué. L'avion a alors été exposé à des précipitations artificielles de pluie verglaçante jusqu'à ce que divers degrés de contamination aient été atteints.

Les commentaires d'observateurs, des photographies et des vidéocassettes ont servi à documenter l'étendue et la nature de la contamination. Le pilote exécutait alors un décollage simulé, amenant l'appareil jusqu'à la vitesse de rotation prescrite et le cabrant, puis coupant les moteurs jusqu'à l'arrêt. Le comportement du fluide pendant la course au décollage a été enregistré sur vidéocassette à l'aide d'une caméra temporairement installée dans la sortie de secours de l'avion, et pointant sur la zone d'essai. La vitesse de l'avion était enregistrée sur la vidéocassette en voix hors-champ. Au retour de l'avion pour inspection, l'état de l'aile était à nouveau examiné et documenté.

Résultats et conclusions des essais de 1998-1999

Ces essais ont montré que les fluides de type IV à l'éthylène glycol et au propylène glycol non contaminés sont presque complètement chassés de la surface de l'aile lorsque l'avion atteint des vitesses de 60 à 80 noeuds pendant la course au décollage.

Les essais menés avec le fluide à l'éthylène glycol de type IV de la SAE contaminé par des précipitations de pluie verglaçante ont montré que les dépôts de givre ou de neige fondante qui s'étaient formés sur l'aile avant la course au décollage demeuraient en place lors du cabrage. Cela était vrai peu importe l'étendue de la contamination. Lors des essais, le givre recouvrait de 1 à 40 p. cent de la zone d'essai.

L'adhérence ou la non-adhérence du givre au revêtement de l'aile avant la course au décollage n'a pas eu d'effet sur l'élimination du fluide contaminé. Lors des présents essais, aucune des plaques de givre n'adhérait à l'aile avant la course au décollage. Mais les observations au retour de l'avion ont permis de noter que de nombreuses plaques avaient gagné une certaine adhérence au revêtement de l'aile *durant* la course au décollage.

Les fluides présents sur l'aile à l'extérieur des zones recouvertes de givre ont presque complètement été chassés pendant la course au décollage.

Un essai mené avec un fluide au propylène glycol de type IV de la SAE recouvert à 100 p. cent de neige fondante et de givre a révélé qu'une élimination complète du fluide est possible à des degrés de contamination raisonnables. Ce résultat est attribué à l'évolution caractéristique des fluides au propylène glycol vers la perte d'efficacité : celle-ci survient habituellement à la surface du fluide, ce qui laisse une couche sous-jacente de fluide relativement intouchée.

Lors d'un des essais, l'avion a été exposé à des précipitations givrantes prolongées, qui ont produit une contamination continue qui dépassait de beaucoup la perte d'efficacité complète. Il en est résulté, à terme, la détérioration de la couche sous-jacente de fluide. Des plaques de givre relativement épaisses se sont formées, dont certaines touchaient le revêtement de l'aile. Celles-ci sont restées collées à l'aile pendant la course au décollage. Le degré de contamination pendant cet essai était extrême, dépassant de beaucoup celui auquel on peut s'attendre lors d'un décollage en service réel.

Le cabrage de l'avion a semblé inefficace à éliminer les dépôts de givre encore sur l'aile.

Des échantillons de fluides non contaminés ont été prélevés sur l'aile de l'avion, après l'application du fluide. Les valeurs de viscosité de ces échantillons différaient considérablement des valeurs de viscosité affichées par les mêmes fluides dans leur contenant. De plus, la viscosité des échantillons prélevés sur les ailes d'une même marque de fluide variait beaucoup d'un essai à l'autre.

Après la même durée d'exposition à des précipitations givrantes, la contamination peut sembler beaucoup plus étendue pour les fluides de type IV au propylène glycol que pour les fluides de type IV à l'éthylène glycol mis à l'essai. Malgré cela, on peut s'attendre que la contamination qui recouvre le fluide de type IV au propylène glycol soit complètement chassée pendant la course au décollage, mais que la contamination apparemment moindre recouvrant le fluide à l'éthylène glycol reste collée sur l'aile, même après le cabrage de l'avion.

Ces résultats peuvent avoir une incidence sur la décision de *décoller* ou de se présenter au poste de *dégivrage*.

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GLOSSARY

APS	APS Aviation Inc.
DND	Department of National Defence
ISO	International Organization for Standardization
NRC	National Research Council Canada
READAC	Remote Environmental Automatic Data Acquisition Concept
RVSI	Robotic Vision Systems Inc.
SAE	Society of Automotive Engineers

1. INTRODUCTION

At the request of the Transportation Development Centre (TDC) of Transport Canada, APS Aviation Inc. has undertaken a research program to further examine the elimination of contaminated and failed anti-icing fluid mixtures from aircraft wings during takeoff.

1.1 Background

Regulations that relate to aircraft departures in icing conditions require that no takeoff be attempted as long as any form of contamination (ice, frost, snow, or slush) is adherent to the lift-critical surfaces of an aircraft. The method of identifying that some form of contamination does exist on the aircraft surface generally relies on visual indications, as perceived by personnel on the ground or by flight crew from flight decks and/or aircraft cabins. When fluid failure is identified, it can only be assumed that it is adhering.

In some situations a tactile test may be applied, either in response to regulations or as a voluntary practice to provide additional information on the wing condition. This test consists of passing the naked hand over an area of the wing surface such as the leading edge, or of scraping the surface with the fingernails to identify any very thin ice film.

During the 1997-98 winter season, several trials of simulated takeoff runs using a Falcon 20D aircraft were conducted to examine the issue of removal of contaminated fluid from aircraft wings during takeoff. Those trials were intended to fill an information gap thus far not resolved by either theoretical analysis or wind tunnel laboratory research. These trials were reported in TP 13316E, *Contaminated Aircraft Takeoff Test for the 1997/98 Winter* (1).

That series of simulated takeoff runs provided an initial level of understanding of the issue and did prove to be a useful approach toward gaining a more complete understanding of elimination of contaminated fluid. The conclusions from those trials were as follows:

1. The trials provided the first documented evidence related to the nature of the process of contaminated aircraft anti-icing fluid elimination from aircraft wings during takeoff.

2. In some cases, the contaminated fluid did not adhere to the wing surface and did show freedom of movement, but stayed on the wing.

3. In general, the contamination was not completely eliminated from the wing surface during acceleration of the aircraft to rotation speed in the simulated takeoff run.

4. These trials identified the need to conduct a further series of tests at takeoff speeds up to and including rotation to verify the results.

As other avenues of research have not yet provided resolution of the issue, it was decided to conduct additional simulated takeoff runs during the 1998-99 winter. A perceived shortcoming of the 1997-98 series of runs was that, although aircraft speed was increased to normal takeoff speed, the aircraft was not rotated at takeoff speed and therefore did not offer a complete representation of the true takeoff condition. It was proposed that this series of trials examine ways to include rotation at takeoff speed as part of the simulation, and that both ethylene and propylene glycol-based SAE Type IV fluids be tested.

1.2 Work Statement

Appendix A presents an excerpt from the work statement for the APS Aviation Winter 1998-99 research program. Section 5.4 of Appendix A, Flow of Contaminated Fluids from Wings During Takeoff, describes this project.

1.3 Objectives

The objective of this project was to examine the conditions for which contamination due to anti-icing fluid failure, as a result of accumulated freezing precipitation, fails to be shed from the wing of a jet transport aircraft during simulated takeoff runs up rotation speed, including actual aircraft rotation.

In satisfying this objective, simulated takeoff runs were performed with a National Research Council Canada (NRC) Falcon 20D research aircraft. Type IV fluids (ethylene and propylene glycol-based) were tested. The test wing was first cleaned with an SAE Type I fluid, and the test area on the wing was then treated with a neat SAE Type IV fluid. Artificial freezing rain was then sprayed over the test fluid until specified levels of contamination were achieved.

After the level of contamination was documented, the aircraft was operated through a simulated takeoff run, including aircraft rotation at normal rotation speed. The behaviour of the fluid during the takeoff run was documented with a video camera temporarily installed in an emergency exit and focused on the test area. The aircraft speed was recorded on the videotape by voice-over. Upon the aircraft's return to the inspection pad, the wing condition was again examined and documented.

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2. METHODOLOGY

This section describes the test conditions and the experimental methodologies followed in the current (1998-99) series of trials, as well as the test equipment and the personnel requirements.

2.1 Test Site

This series of simulated takeoff runs was conducted at Montreal International Airport (Mirabel). As experienced during the previous trials, this airport offered an ideal facility for these trials, having long runways with a low level of traffic and a central deicing facility. Figure 2.1 provides a schematic of the airport showing the runway used (Runway 24) and the location of the Deicing Centre.

The tests were carried out over a two-day period. The research aircraft, with crew, returned to home base in Ottawa at the end of the first day of tests and returned early in the morning on the second day of tests.

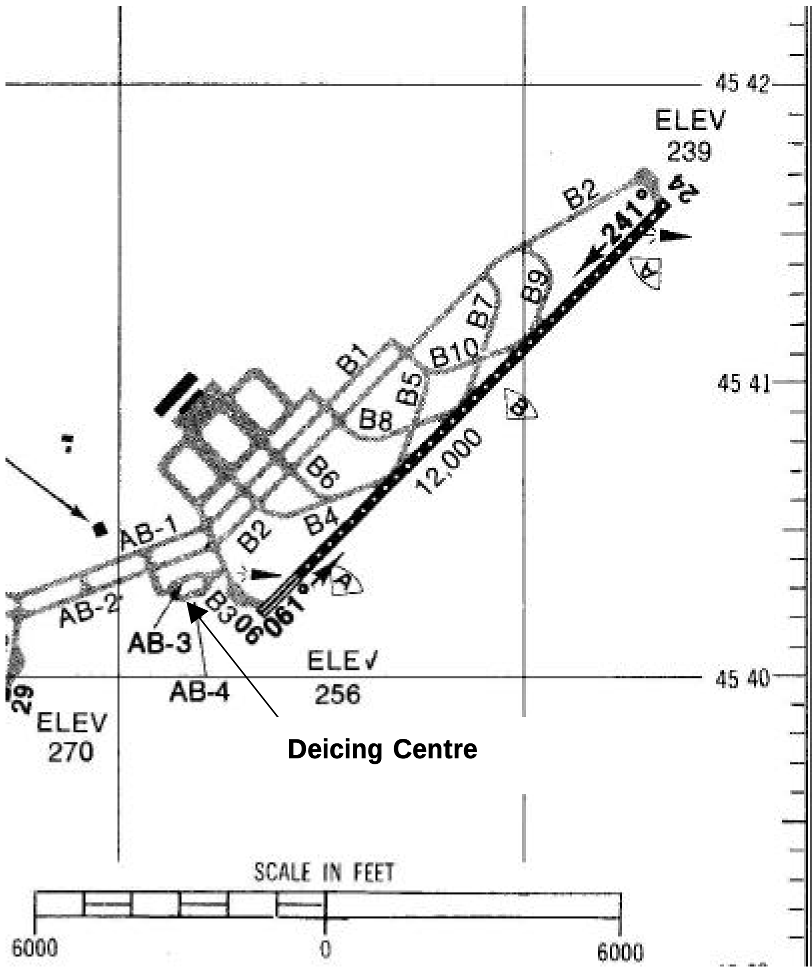
2.2 Description of Test Procedures

Test dates were selected based on weather forecast and availability of the test aircraft. Desired weather conditions for the trials were dry with sub-freezing outside air temperatures. Overcast skies were preferred to reduce surface warming of the wing surfaces being tested. It was necessary for safety purposes that runway conditions be clear and dry. The aircraft was to be parked in such a heading as to maintain maximum shadow from the fuselage over the test area. Actual test conditions are reported in Section 3.

A single area on the port wing just inboard of the fence was selected to serve as the test surface on the Falcon 20D research aircraft (Figure 2.2 and Photos 2.1 and 2.2). The wing test surface area selected of the boundary layer fence was the portion of the wing with a fixed leading edge. A test location inboard on the wing was chosen to reduce the aerodynamic asymmetry between the wings during the rotation phase of the operation.

The application of deicing and anti-icing fluids, as well as the contamination of the fluids with artificial freezing rain, were conducted at the central deicing facility. For each trial, any fluid remaining from the previous trial was removed with the use of Type I fluid following standard deicing

Figure 2.1
Montreal International Airport (Mirabel) Deicing Centre



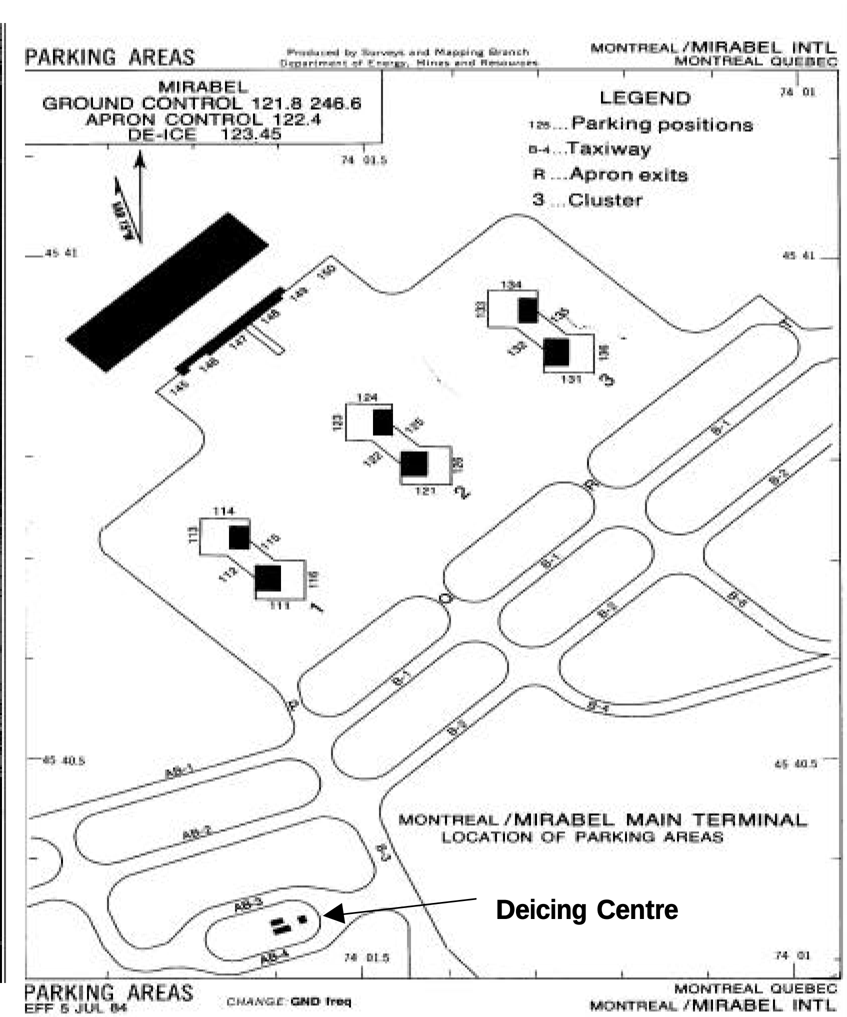
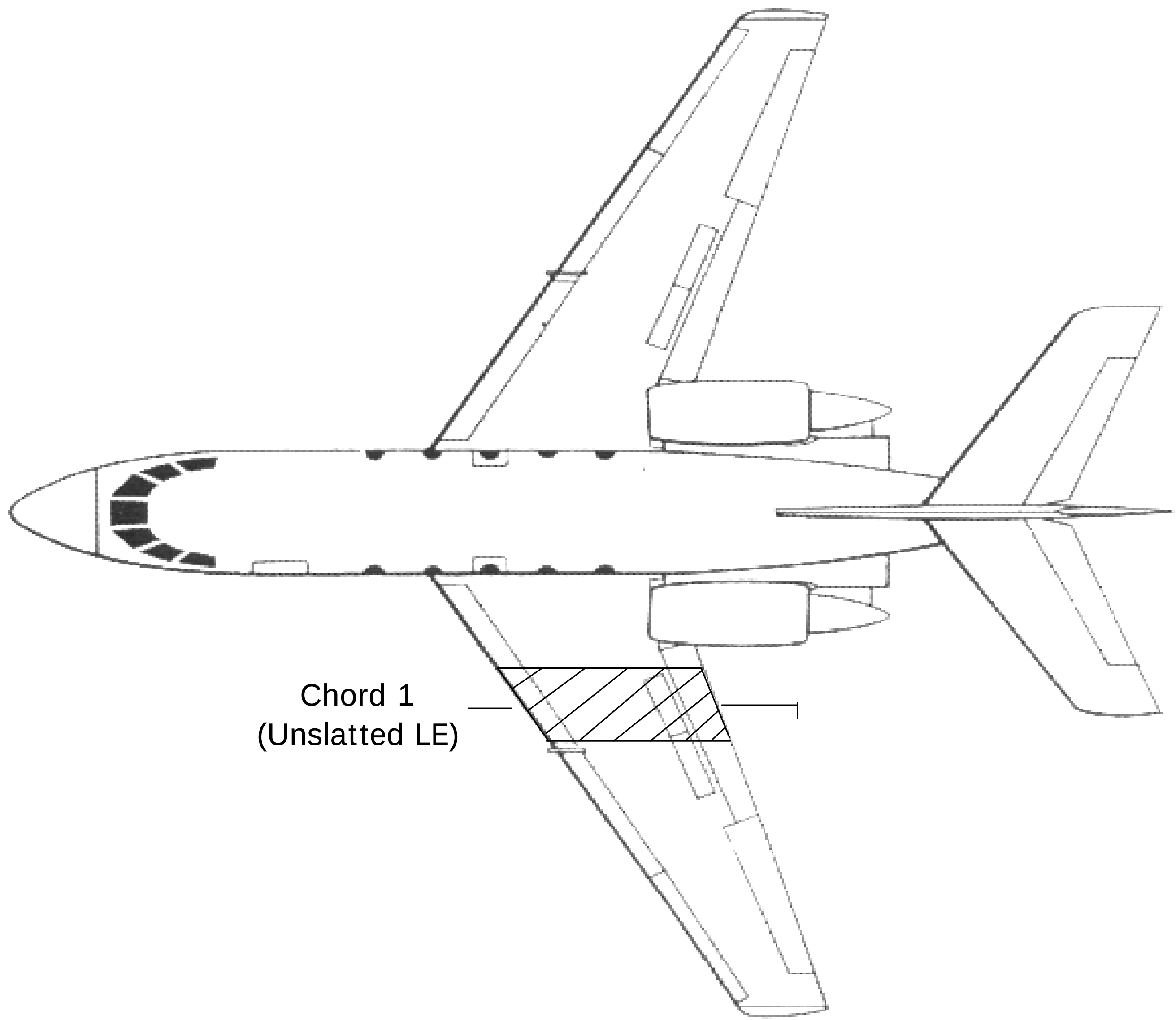


FIGURE 2.2

AIRCRAFT TEST AREA FORM FOR TAKEOFF RUN TRIALS

FALCON 20D



Cross-hatched area = Area of wing to be tested

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practice. The Type IV fluid to be tested was then sprayed onto the test area.

The thickness of the Type IV fluid film was measured at specified points along a chord of the wing through the test area. Fluid thickness was measured after allowing a delay of about two minutes for fluid levelling following application. The spray application and the appearance of the resulting fluid film on the wing surface were photographed and videotaped.

Takeoff run trials without precipitation were conducted for each SAE Type IV fluid tested (ethylene and propylene glycol-based). The simulated takeoff run for those trials followed documentation of the initial fluid application.

For trials involving fluid contamination, precipitation in the form of freezing rain was applied with the use of a custom-designed hand-held sprayer by an operator located in the bucket of the deicing truck. Artificial freezing rain was applied until the level of contamination reached a predetermined level, based on visual observation.

A ground observer mapped the point of initiation of failure on the test area of the wing, and noted the progress of failure. The final pattern of fluid contamination was mapped by this observer, by an experienced observer stationed in the aircraft cabin, and by the test pilot.

A Spar/Cox ice detection camera mounted on a truck mast (Photo 2.3) was focused on the test area to record the camera's response to the fluid failure and to provide supplementary evidence of areas of fluid contamination. Photo 2.4 shows the test set-up with the ice detection camera truck, the fluid spray vehicle, and the water spray van parked near the aircraft.

Once the fluid had reached the desired level of contamination, the state of the fluid/contaminant mixture was again photographed and videotaped by ground observers. A camera mounted in the aircraft also recorded the appearance of the fluid at this phase.

Other measurements of the fluid condition at this stage included tests for contaminant adhesion and fluid viscosity (via samples taken for later analysis). The temperature of the test surface was measured at several locations both inside and outside the area shaded by the aircraft fuselage.

The simulated takeoff run was then executed. The camera mounted in the aircraft filmed the appearance of the fluid contaminant mixture throughout the taxi phase, the takeoff run, and the subsequent return to the inspection pad at the central deicing facility. During the takeoff run, the First Officer read off the ground speed from aircraft instrumentation for the audio track on the videotape.

On return to the deicing centre, the aircraft was again parked at a heading such that the maximum shadow was cast by the fuselage over the test area. The nature and condition of the fluid remaining on the wing was then re-examined and documented.

The temperature of the wing skin was measured, before and after the takeoff run, at several positions within the test area, both shaded and in direct sunlight.

The test plan is shown in Table 2.1.

Appendix B describes the experimental program for these trials.

2.3 Data Forms

Several different forms were used to facilitate the documentation of the various data collected in this trial. These forms included:

- General Form (Once per Session);
- General Form (Every Test);
- Final Failure Pattern for Aircraft Wing;
- Progressive Failure Pattern for Aircraft Wing;
- Fluid Sampling and Temperature Recording for Aircraft Wing;
- Fluid Adherence for Aircraft Wing; and
- Fluid Thickness on Aircraft.

Copies of these forms are included in Appendix B.

2.4 Equipment

A considerable array of test equipment was required to perform these trials, some of which is worthy of comment.

2.4.1 Mobile Type IV Fluid Sprayer

This series of trials included the examination of propylene glycol-based Type IV fluids in addition to ethylene glycol-based fluids. Because the

TABLE 2.1
TEST PLAN – REMOVAL OF CONTAMINATED FLUID FROM AIRCRAFT WINGS DURING TAKEOFF RUN

Run	Fluid	Level of Contamination
1	Type IV Ethylene-based Neat	None
2	Type IV Ethylene-based Neat	1% (initial)
3	Type IV Ethylene-based Neat	10%
4	Type IV Ethylene-based Neat	25%
5	Type IV Propylene-based Neat	None
6	Type IV Propylene-based Neat	10%
7	Type IV Propylene-based Neat	25%
8	Type IV Propylene-based 75%	None

local operator's equipment is dedicated to the use of ethylene glycol-based fluids, the mobile Type IV sprayer developed during the previous winter season was used for the application of the propylene glycol-based Type IV fluid.

The Type IV fluid spray unit developed by APS is shown Photo 2.5. The mobile sprayer was designed to enable outdoor and indoor testing in all conditions using different Type IV fluids as required. It comprises three interrelated components: a fluid reservoir, a fluid pump, and a fluid application nozzle. The components of the mobile sprayer are described as follows:

- A non-shearing fluid pump, identical to those installed in deicing vehicles, forces the fluid from the reservoir. The fluid reservoir is a 200–L drum adapted with the appropriate fittings and hoses to supply the pump and receive fluid when the application nozzle is closed.
- A pressure gauge is used to monitor the pump system fluid pressure. An adjustable relief valve controls the system pressure. A check valve mounted at the root of the fluid supply hose prevents any fluid from draining back to the reservoir when the pump is turned off.
- The pump is driven by an electric motor, which requires a generator capable of producing a minimum of 550 V, 30 kW, and three-phase current.
- A Task Force Tips nozzle, shown in Photo 2.6, is connected to the pump with a pressure-resistant rubber hose fitted with locking couplings.

The sprayer system weighs approximately 315 kg (not including the generator) and can be easily transported with a pickup truck although a winch is required for loading. The generator used was a large portable unit mounted on its own trailer as shown in Photo 2.7.

AéroMag 2000 performed the propylene glycol-based fluid spray application using this system.

2.4.2 Freezing Rain Sprayer Unit

A water sprayer to produce artificial freezing rain was used to support these trials. The principal elements of the sprayer system included:

- A liquid pumping unit;
- An air compressor;

- A portable generator;
- An ice bath/water reservoir; and
- A hand-held spray bar (Photo 2.8).

System controls and the overall system installation in the rented van are shown in Photos 2.9 and 2.10.

The spray bar was made available by the NRC, which had previously used it for production of freezing rain at the Climate Engineering Facility. The unit was equipped with two spray heads that accepted hypodermic needles of various gauges as used at the NRC Climatic Engineering Facility to produce different droplet sizes. In this application, 20-gauge hypodermic needles were installed to produce droplet sizes appropriate to freezing rain.

In the process of designing the sprayer system, a similar system previously assembled by AlliedSignal was examined to take advantage of its experience.

Evaluation trials conducted at the APS Dorval test site during the 1997-98 winter demonstrated that rates typical of freezing rain could be achieved using the portable unit. As the spray bar was hand-held and manipulated by an operator (Photo 2.11) to provide coverage over the desired area, rates and consistency of coverage were operator dependent. For these trials, a single operator was used who developed a satisfactory level of skill. Calm wind conditions were a prerequisite to achieving satisfactory coverage.

2.4.3 Fluid Adhesion Measurement Unit

The extent of fluid adhesion was measured using a method developed during the previous winter season trials.

During the 1997-98 study characterizing the nature of aircraft anti-icing fluids during the process of contamination – TP 13317E, *Characteristics of Aircraft Anti-icing Fluids Subjected to Precipitation* (2) – a method of determining the extent of failure adhesion dimensionality and degree of bonding was developed. This method was based on the use of an electric dental flossing device (Photo 2.12).

In operation (Photo 2.13), a thread of floss was spun by the device. A floss segment extended radially about 3 to 4 mm from the tip of the unit, and upon spinning could carve out a circle (or not, depending upon whether adhesion had occurred) 3 to 4 mm in radius on a failed surface element. In a layer of non-adhered fluid, the force of the spinning floss was sufficient to expose the surface of the test plate. As the rotation speed of the unit was fixed, the applied force was constant for all trials, providing a basis of comparison among various test conditions, and between different stages of contamination for individual tests. This device provided a satisfactory approach to establishing areas that had undergone bonding of contamination to the substrate and gave a measure of the strength of the bond formed.

An analysis of the shearing force exerted by this instrument (presented in Appendix C) determined it to be in the range of 1.2×10^{-4} to 2.0×10^{-4} MPa. As discussed in the analysis, this shear force value lies in a range similar to the wind shear developed on a wing during takeoff.

2.4.4 Measuring Fluid Viscosity

Fluid samples for viscosity tests were gathered from various points on the wing test area and stored in small wide-mouth glass bottles with screw caps. Viscosity measurements of these samples were carried out using a Brookfield viscometer (Model DV-1+; Photo 2.14) fitted with a thermostatted recirculating fluid bath and micro sampling option.

2.4.5 Remote Ice Detection Camera

During the 1998-99 winter test program, an ice contamination sensor camera was installed on a mast-equipped vehicle for fieldwork as part of another research project. That installation was used for these trials to provide supplementary information regarding the extent of fluid contamination on the aircraft wing.

The installation included the following:

- A Bell microwave truck (Photo 2.3) equipped with a 12.6 m (42 ft.) mast and a cabin designed to facilitate electronics installations. The electronics cabin, situated behind the vehicle operator position, was sufficiently spacious to comfortably accommodate three observers. An integrated power supply was provided.
- A Spar/Cox ice detection sensor camera mounted on the vehicle mast (Photo 2.15).
- A camera pan/tilt feature with controls installed in the vehicle (Photo 2.16).
- Ice detection sensor system controls installed in the vehicle cabin.
- A monitor and VCR to videotape all sensor images (Photo 2.17).

2.4.6 Video Camera Mounted in Aircraft Emergency Exit

A video camera was installed on the aircraft to videotape the appearance of the fluid on the wing during the course of the takeoff run. This camera was mounted in a temporary structure that replaced the normal aircraft emergency exit hatch. Photo 2.18 shows the installation on the interior of the temporary door. Photo 2.19 is an external view, showing the camera lens in the door, directed down onto the test area. The camera was fixed in position and focused on the forward portion of the test area, including the leading edge.

During the takeoff run, readout of aircraft speed by the co-pilot was recorded on the audio track of the videotape to associate fluid appearance at any moment with the corresponding aircraft speed.

2.4.7 Other Equipment

Octagonal wet film thickness gauges, shown in Figure 2.3, were used to measure fluid film thickness. These gauges were selected because they provide an adequate range of thickness (0.01 mm to 10.2 mm) for Type IV fluids. The rectangular gauge shown in the figure has a finer scale and was used in some cases when the fluid film was thinner (toward the end of a test).

A full list of equipment is provided in Appendix B.

2.5 Fluids

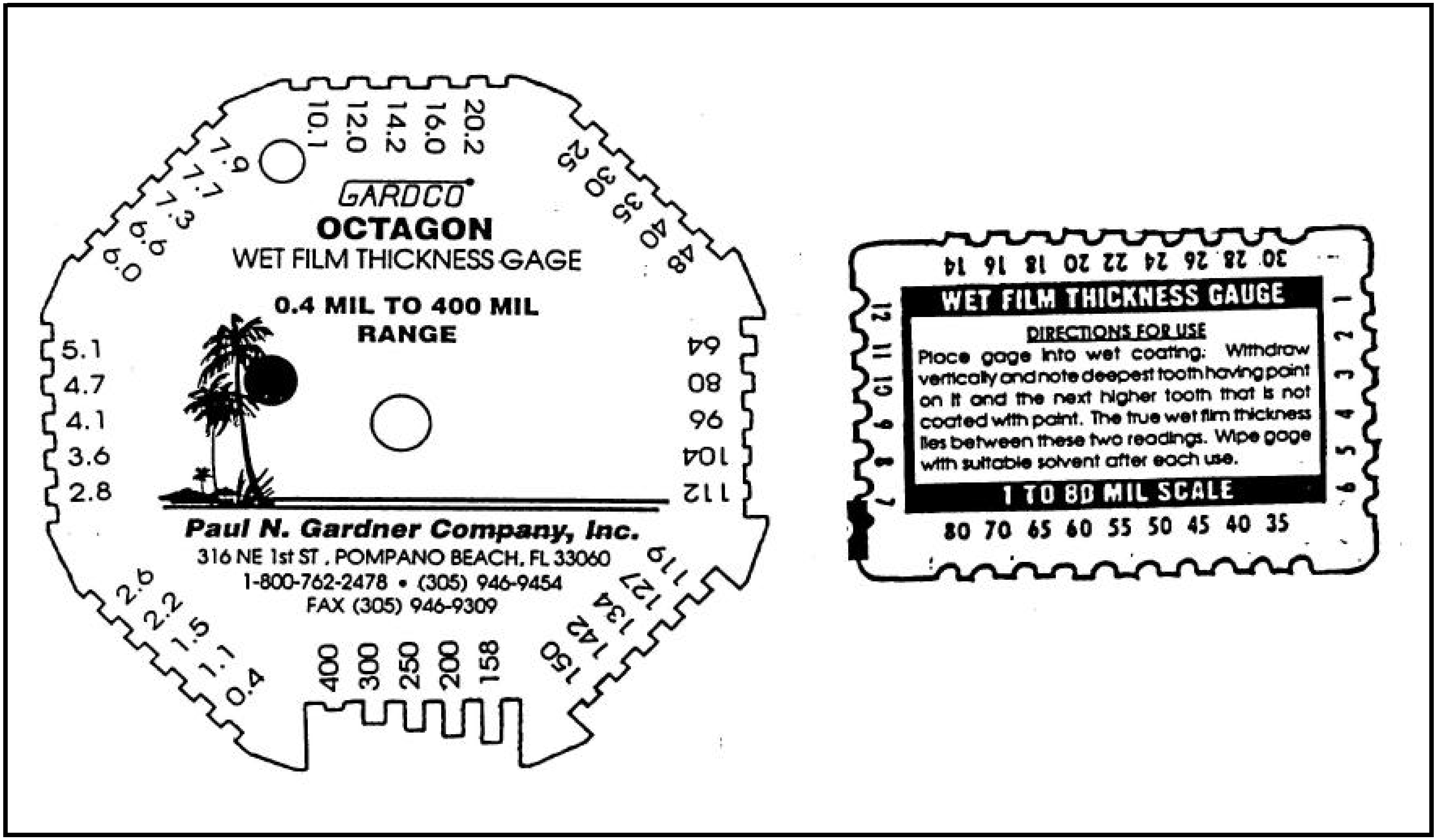
Fluids employed in the trials included:

- Union Carbide XL54 Type I fluid;
- Union Carbide Ultra+ Type IV fluid; and
- Kilfrost ABC/S Type IV fluid.

The Union Carbide fluids were supplied from the local AéroMag 2000 fluid inventory. The Kilfrost fluid was supplied in barrels. All fluids were applied by AéroMag 2000 operators.

FIGURE 2.3

WET FILM THICKNESS GAUGES



2.6 Personnel

The NRC Falcon 20D research aircraft was operated by an NRC crew out of Ottawa, Ontario.

Representatives from Cox and Company were present to operate the ice contamination sensor system.

Representatives from Transport Canada's Transportation Development Centre participated as observers.

AéroMag 2000 conducted aircraft spray operations in conformance with its standard procedures.

Photo 2.1
NRC Falcon 20D

Photo 2.2
Test Area – Inboard of Fence

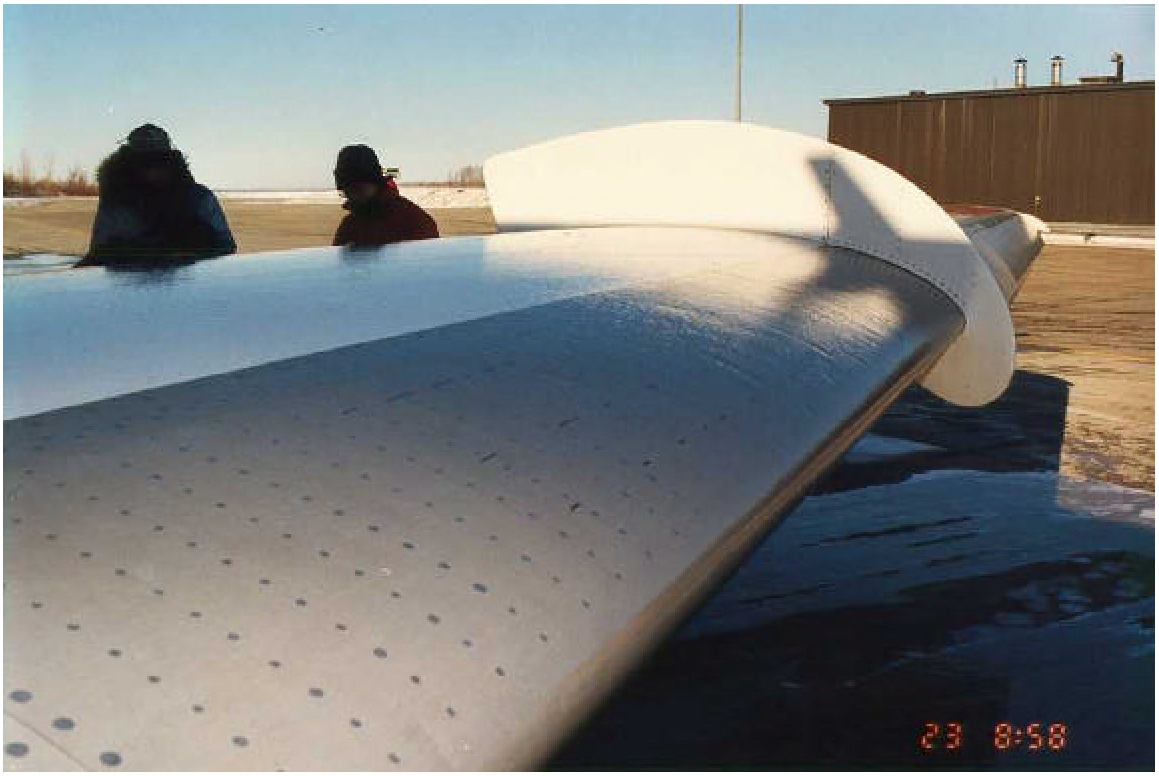


Photo 2.3
Spar/Cox Ice Sensor Camera on Mast

Photo 2.4
Test Set-Up

Photo 2.5
Mobile Type IV Fluid Sprayer Unit

Photo 2.6
Task Force Tips Nozzle

Photo 2.7
Type IV Mobile Sprayer Set–Up

Photo 2.8
Water Spray Bar

Photo 2.9
Freezing Rain Sprayer System Control

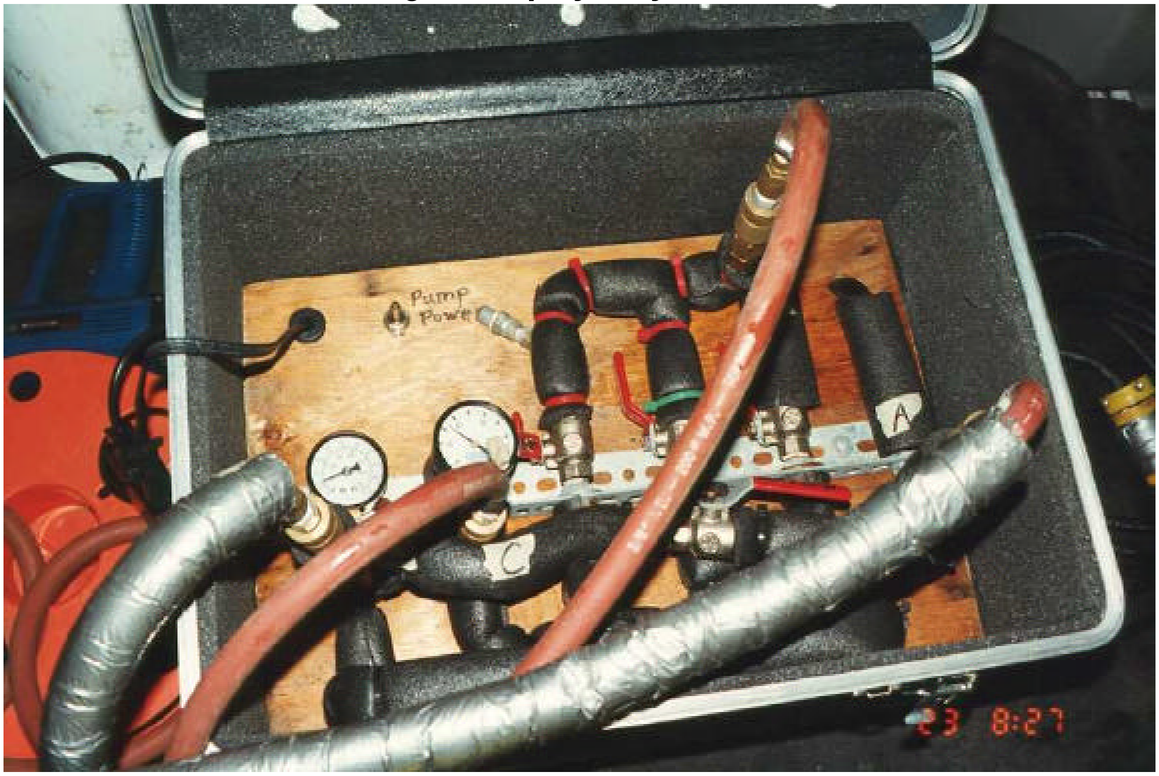


Photo 2.10
Freezing Rain Sprayer System Installed in Van

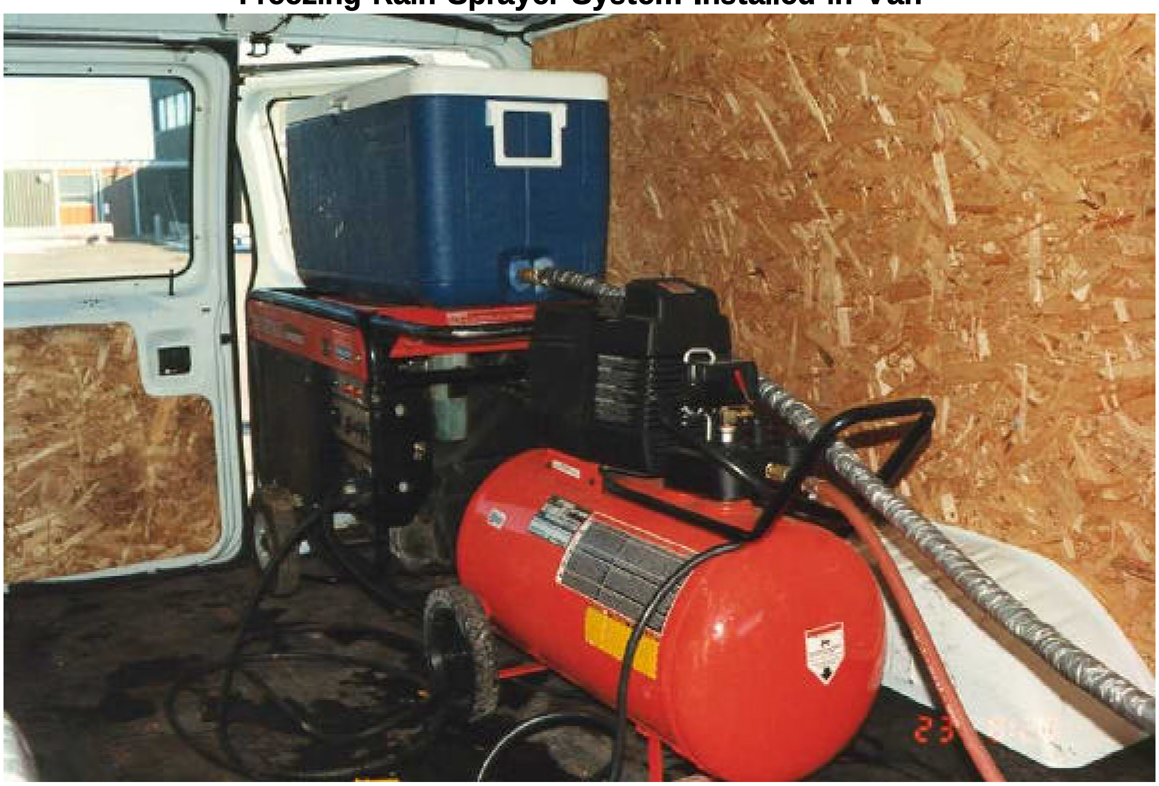


Photo 2.11
Applying Water Spray from Bucket

Photo 2.12
Dental Flossing Device Used to Test Adherence

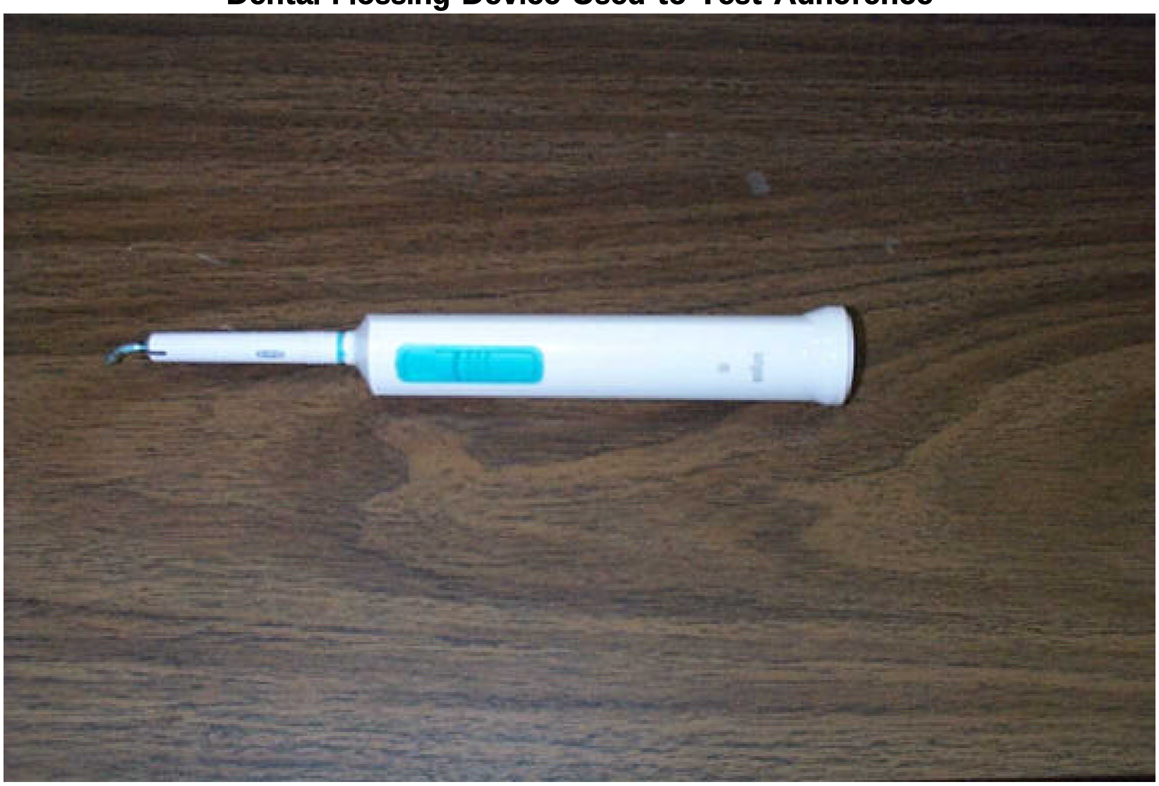


Photo 2.13
Adhesion Testing

Photo 2.14
Brookfield Digital Viscometer Model DV-I+ and Temperature Bath

Photo 2.15
Ice Detection Camera Mounting

Photo 2.16
Ice Detection Camera Control Unit

Photo 2.17
Ice Detection Camera Monitor and VCR in Cabin

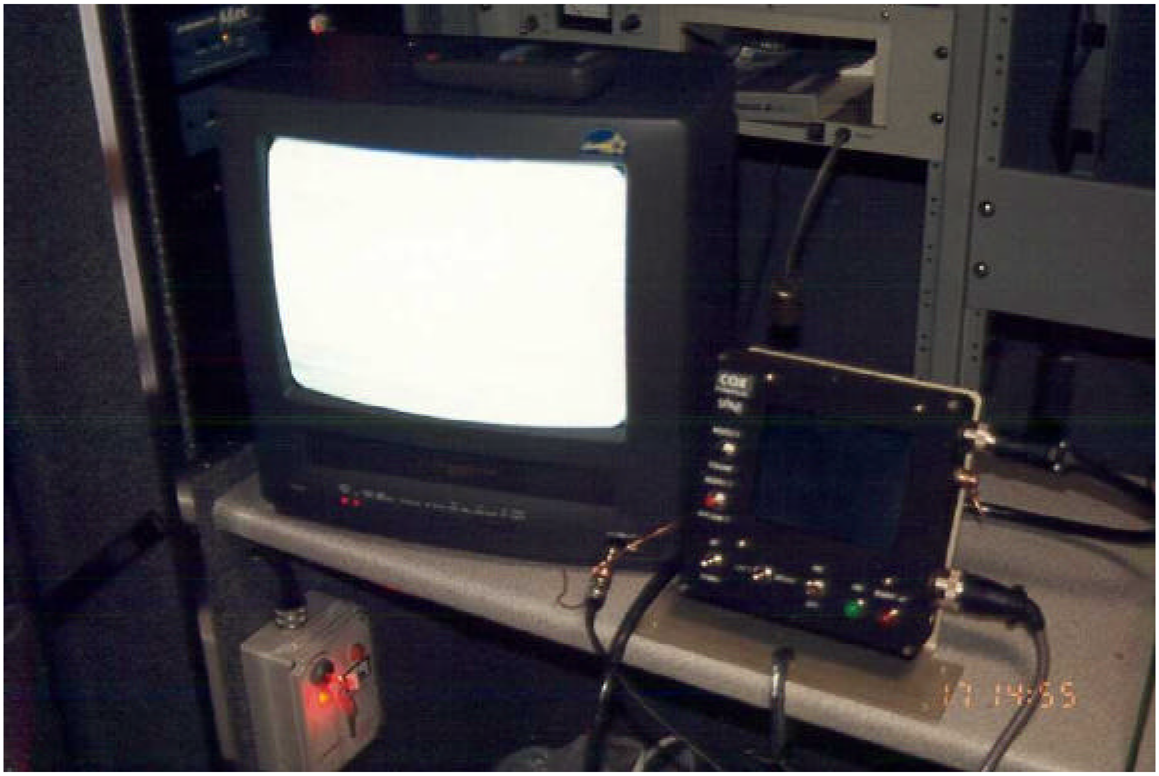


Photo 2.18
Video Camera Installation

Photo 2.19

Video Camera Lens Trained on Test Area

3. DESCRIPTION AND PROCESSING OF DATA

3.1 Overview of Tests

This series of takeoff run trials was conducted on February 22 and 23, 1997, at Montreal International Airport (Mirabel).

The NRC Falcon 20D research aircraft arrived from Ottawa at 08:00 and tests commenced immediately. Tests on the first day included trials of both ethylene and propylene glycol-based Type IV fluid without contamination, and two trials of ethylene glycol-based Type IV fluids at different levels of contamination.

Although the ambient conditions were satisfactory (temperature -19° to -13°C and calm to light winds), by midday the clear sky condition resulted in a notable temperature rise of any wing surfaces exposed to the sun. As this affected the results, it was decided to cut the day short and recommence testing early in the morning of the second day.

On day two, the aircraft arrived at 06:00 and tests got under way quickly to allow completion before the sun rose too high.

Five runs were conducted on day two, including three with an ethylene and two with a propylene glycol-based Type IV fluid, each at various stages of contamination.

On both days, Runway 24 was used for the takeoff run trials. As can be seen in the airport diagram (Figure 2.1), this resulted in long taxi runs to the departure runway. Fortunately, as the taxi runs were to the east, the test area on the port wing was shaded by the aircraft fuselage until the point where the aircraft turned onto the runway for takeoff.

During the takeoff run, the aircraft accelerated to normal takeoff speed (125 kn) and rotated at normal rotation speed. A predetermined operating procedure was followed to prevent the aircraft from lifting off. The long runway (3657 m, 12,000 ft.) resulted in light use of the aircraft brakes and there was no need for special brake cooling procedures. Because the end of the takeoff run placed the aircraft near the inspection pad, there was no need to intercept the aircraft during its return taxi run to examine fluid conditions on the wing. The wing test area was examined immediately following the parking of the aircraft on its return. For all runs, the aircraft was parked in such a heading so as to cause maximum shadowing of the test area by the aircraft fuselage.

A summary of trials conducted is presented in Table 3.1.

3.2 Description of Data Collected and Analysis

For every trial, data collection followed the same pattern at each of the three distinct stages in the trial progression. This data collection procedure enabled comparison of the nature of fluid on the wing and the level of contamination at each stage. These stages were:

1. Following application of fluid and prior to application of artificial freezing rain contamination;
2. Following contamination of the fluid to the desired level and prior to takeoff run; and
3. Following takeoff run.

Data for each trial run is discussed in Section 4, where data values and failure patterns are compared within trials for the before and after (takeoff run) condition. Photographs of the extent of contamination at each stage of every trial are also presented in these discussions.

The videotape documentation of fluid appearance on the wing during the takeoff run as provided by the onboard camera was reviewed for each trial. This documentation provided an appreciation of the mechanism by which fluid was eliminated from the wing, and provided some insight regarding the relationship between fluid contamination/elimination and aircraft speed. Observations related to contaminated fluid elimination are presented in Section 4.

In many cases, samples of contaminated fluid intended for viscometric analysis contained some ice at the time of collection. These samples were subsequently measured in liquid form at a temperature of 20ºC.

During these trials, the ice detection sensor system experienced difficulty providing clear images of ice build-up during the contamination of the wing. Some of this difficulty was due to the extreme difference in brightness between the shaded and non-shaded area of the wing test area. As a consequence, the videotape of images from the ice detection sensor system was not useful in providing supplemental evidence of the extent of fluid contamination at different stages during the trials.

TABLE 3.1

CONTAMINATED AIRCRAFT TAKEOFF TRIALS
WINTER 1998/99

DATE	TIME OF TAKEOFF RUN	RUN #	OAT ºC	FLUID TYPE IV	CONTAMINATION LEVELS
Feb. 22, 1999	9:25	1	-19	Ethylene	None
Feb. 22, 1999	10:30	2	-17	Ethylene	25%
Feb. 22, 1999	12:10	3	-16	Ethylene	10%
Feb. 22, 1999	15:50	4	-13	Propylene	None
Feb. 23, 1999	7:05	5	-23	Ethylene	40%
Feb. 23, 1999	8:05	6	-20	Ethylene	5%
Feb. 23, 1999	8:55	7	-17	Propylene	100%
Feb. 23, 1999	9:40	8	-14	Ethylene	1%
Feb. 23, 1999	10:40	9	-14	Propylene	Beyond 100%

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4. ANALYSIS AND OBSERVATIONS

In this section, data and observations taken prior to and following each takeoff run are discussed for each trial. Remarks on fluid viscosity are based on the fluid samples recovered during the trials. The viscosity measurements were made after the conclusion of the tests, and the results of the viscometric analysis are presented in Table 4.1.

4.1 Run One: Ethylene Glycol-Based Type IV Fluid; No Contamination

4.1.1 Prior to Takeoff Run

4.1.1.1 Extent and Pattern of Contamination

This trial was conducted without the application of artificial freezing rain contamination.

4.1.1.2 Fluid Thickness

The profile of fluid thickness along the chord of the wing running through the test area was typical of the Type IV fluid applications observed in previous tests. Pre-stabilized and stabilized ethylene glycol-based Type I and Type IV fluid thickness values are documented in a 1995-96 study of fluid thickness on wing surfaces (see TP 12900E, *Evaluation of Fluid Thickness to Locate Representative Surfaces*) (3).

In this trial (Figure 4.1) the stabilized fluid thickness took on values ranging up to 1.8 mm (72 mil) over the leading edge and forward wing. Photo 4.1 provides a view of the fluid on the wing at this stage of the trial.

4.1.1.3 Contaminant Adhesion

As this was uncontaminated fluid, there was no adhesion.

TABLE 4.1

FLUID VISCOSITY VALUES

CONTAMINATED AIRCRAFT TAKEOFF TESTS

February 22 and 23, 1999

Run #	Fluid	Container #	Sample Label	Comment	Brix	Freeze Point (°C)	Viscosity (0.3 r/min) mPa*s	Viscosity (6 r/min) mPa*s	Viscosity (30 r/min) mPa*s
1	Ucar Ultra+	73	F1B1	Before Takeoff Uncontaminated	39.75	-59	6800	955	383
1	Ucar Ultra+	74	F1B2	Before Takeoff Uncontaminated	40.25	-60			
1	Ucar Ultra+	75	F1C1	After Takeoff Uncontaminated	41	-62	100	115	90
2	Ucar Ultra+	76	F2B1	Before Takeoff	13	-8	N/A	N/A	N/A
2	Ucar Ultra+	77	F2C1	After Takeoff	10.25	-5	N/A	N/A	N/A
2	Ucar Ultra+	78	F2C2	After Takeoff	14.25	-9	0	0	3
2	Ucar Ultra+	79	F2C3	After Takeoff	7	-3	N/A	N/A	N/A
3	Ucar Ultra+	80	F3B1	Before Takeoff	15.75	-11	N/A	N/A	N/A
3	Ucar Ultra+	81	F3C1	After Takeoff	8	-3	100	0	3
3	Ucar Ultra+	82	F3C2	After Takeoff	9.25	-4			
3	Ucar Ultra+	83	F3C3	After Takeoff	10	-5	N/A	N/A	N/A
4	Kilfrost ABC-S	84	F4B1	Before Takeoff Uncontaminated	35.75	-48	10600	1335	526
4	Kilfrost ABC-S	85	F4B2	Before Takeoff Uncontaminated	35.5	-47	11300	1400	539
4	Kilfrost ABC-S	86	F4C1	After Takeoff Uncontaminated	36.25	-49	14200	1630	623
5	Ucar Ultra+	87	F5B1	Before Takeoff	27	-28	N/A	N/A	N/A
5	Ucar Ultra+	88	F5C1	After Takeoff	16	-11	0	0	11
5	Ucar Ultra+	89	F5C2	After Takeoff	16	-11			
6	Ucar Ultra+	90	F6B1	Before Takeoff	12	-7	N/A	N/A	N/A
6	Ucar Ultra+	91	F6C1	After Takeoff	16.5	-12	N/A	N/A	N/A
6	Ucar Ultra+	92	F6C2	After Takeoff	12.25	-7	0	10	5
7	Kilfrost ABC-S	93	F7B1	Before Takeoff	32	-39	13800	1560	573
7	Kilfrost ABC-S	94	F7B2	Before Takeoff	33.5	-42	13400	1580	616
7	Kilfrost ABC-S	95	F7C1	After Takeoff	32.5	-40	8500	1035	416
7	Kilfrost ABC-S	96	F7C2	After Takeoff	33.5	-42	19500	2030	726
8	Ucar Ultra+	97	F8B1	Before Takeoff	30.5	-36	100	50	43
8	Ucar Ultra+	98	F8C1	After Takeoff	19	-15	0	5	8
9	Kilfrost ABC-S	99	F9A1	Clean Fluid	36	-49	17700	1935	703
9	Kilfrost ABC-S	100	F9C1	After Takeoff	8	-3	N/A	N/A	N/A
N/A	Kilfrost ABC-S	101	Kilfrost ABC-S from Barrel	From Barrel	35.75	-48	20100	2210	800
N/A	Kilfrost ABC-S	102	Kilfrost ABC-S from Barrel	From Barrel	36	-49	21000	2190	790
N/A	Ucar Ultra+	103	Ultra + from Truck	From Truck	40.5	-61	14100	1490	507

Note:
- Fluid concentrations at application were 'Neat'
- Viscosity values 'N/A' indicate insufficient fluid quantity for testing
- Viscosity method, dynamic at 20ºC (ASTM D 2196) (Brookfield LVT spindle 31, 10 ml small sample adaptor, rotation speeds as shown)
- Label coding, e.g. F1B1:
    - F - Falcon Tests
    - 1 - Run 1
    - A,B or C - after fluid spray; after freezing rain contamination; after takeoff run
    - 1 - Sample location noted on observer data form

FIGURE 4.1

FLUID THICKNESS ON AIRCRAFT

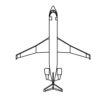
AIRPORT: YMX

AIRCRAFT TYPE: FALCON 20

DATE: 22-Feb-99

WING: PORT (A)

DRAW DIRECTION OF WIND WRT WING:

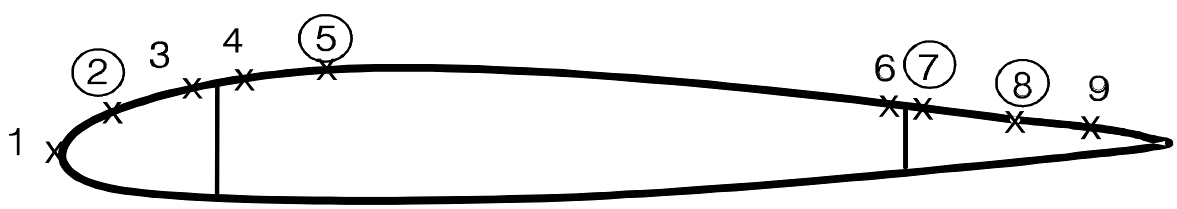


Calm Wind

RUN #: 1

DIRECTION OF AIRCRAFT: 60 DEGREES

	Before Contamination		Before Takeoff		After Takeoff	
Location	**Time**	**Thick. (mm)**	**Time**	**Thick. (mm)**	**Time**	**Thick. (mm)**
1			8:45:00	0.83	9:29:55	0.06
2			8:45:15	0.83	9:30:09	0.14
3			8:45:25	1.84	9:30:17	0.14
4			8:45:30	1.09	9:30:00	0.14
5			8:45:40	1.09	9:30:00	0.14
6			8:46:05	0.83	9:31:00	0.44
7			8:46:19	0.83	9:31:00	0.04
8			8:46:22	0.69	9:32:00	0.14
9			8:46:30	0.83	9:32:00	0.14



Location
1 **- LE Nose**
2,8 **- Half-way**
3,4,6,7 **- 1" from joint**
5 **- As far as can reach**
9 **- 6" from TE**

Note:
Give priority to circled locations; measure other locatios only if time allows.

COMMENTS:

MEASUREMENTS BY:

HAND WRITTEN BY:

4.1.1.4 Fluid Viscosity

Fluid application was performed with a deicing vehicle manufactured by FMC equipped with a Napiro nozzle. The measured viscosity of a sample of uncontaminated fluid was recovered from the wing surface (see Table 4.1). It was considerably lower than the typical *as received* fluid viscosity.

4.1.2 Following Takeoff Run

4.1.2.1 Extent and Pattern of Contamination

Although the remaining initially uncontaminated fluid layer was observed to be substantially reduced following the takeoff run, a film of fluid did remain at final inspection.

4.1.2.2 Fluid Thickness

Following the takeoff run (see Figure 4.1), the fluid thickness generally took on a value of about 0.14 mm (5 mL). Some puddling of remaining fluid was seen farther back on the wing surface just forward of the spoiler panel. Here thickness values of 0.5 mm were measured. This evidently occurred as a result of the disruption in airflow caused by the spoiler panel being raised as part of each simulated takeoff run, following aircraft rotation. Photo Set 4.2 illustrates the appearance of any fluid remaining on the wing following the takeoff run.

4.1.2.3 Adhesion

There was no adhesion in this uncontaminated fluid.

4.1.2.4 Viscosity

The viscosity of a sample of the fluid residue (see Table 4.1) was very low. The Brix value of this fluid sample was slightly higher than the fluid on the wing prior to the takeoff run.

4.1.3 Observations from Videotape of Fluid During the Takeoff Run

During the taxi phase (speed 28 kn) prior to the takeoff run, a clearly visible persistent rippled pattern developed in the fluid film on the wing as a result of wind shear.

During the takeoff run, the major part of the fluid layer was shed from the wing by the time the aircraft speed reached 80 kn. At time of rotation (125 kn), some ripples could still be seen in the thin film of fluid that remained on the wing. As noted, on the aircraft's return to the inspection pad, this film was only 0.1 mm thick.

4.2 Run Two: Ethylene Glycol-Based Type IV Fluid; Contamination to 25 Percent

4.2.1 Prior to Takeoff Run

4.2.1.1 Extent and Pattern of Contamination

The duration of contaminant exposure required to achieve a 25 percent level of contamination was 20 minutes.

Ground Observer
The ground observer noted extensive fluid contamination at the leading edge and on the rear of the wing, covering the spoiler panel and the flap area (Figure 4.2). Photo Set 4.3 shows the appearance of the failed fluid on the flap area. The effect of wing temperature as a result of heat radiation from the sun was apparent in this trial, where the fuselage cast a shadow over only the inner portion of the test area. Wing surface temperature in the shaded area was measured at about –11°C and in the sunny area was measured to be about –5°C. The pattern of contamination for the forward part of the wing showed ice formation within the shaded, colder area of the wing surface. Photo Set 4.3 also shows ice formations on the leading edge.

Experienced Cabin Observer
The experienced cabin observer noted a pattern of failure almost the same as the ground observer.

Pilot
The pilot noted a pattern of failure almost identical to the experienced cabin observer.

4.2.1.2 Fluid Thickness

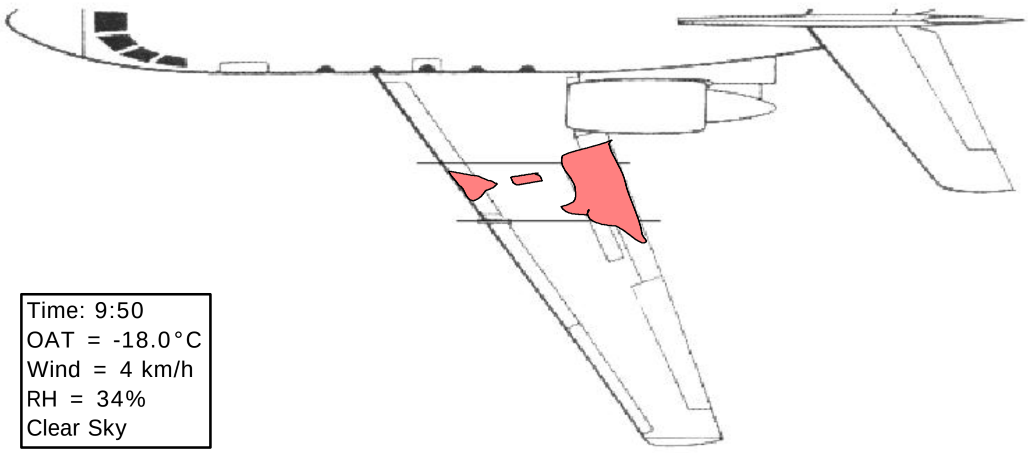
See Figure 4.3. Following contamination, the fluid film thickness could not be measured at those locations where ice had formed. This included the whole of the rear of the wing. Where a film of fluid remained, the fluid thickness was reduced by about 40 percent from that measured just after spray application. The incompletely contaminated fluid remaining on the forward part of the wing had thickness values of about 0.6 to 1 mm, as compared to 1 to 2 mm prior to contamination with freezing rain.

FIGURE 4.2

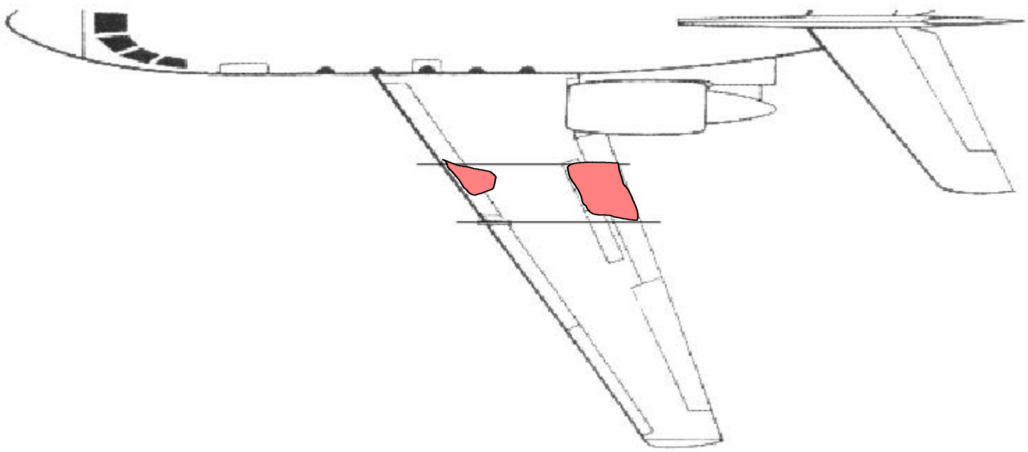
Run 2 - Failure Pattern Before Takeoff Run

22-Feb-99

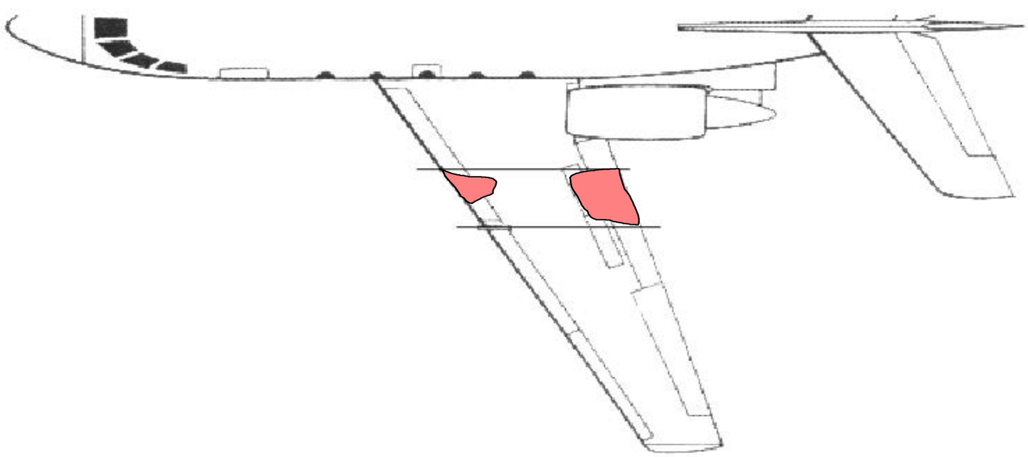
a) Failure Pattern Reported by Ground Observer



b) Failure Pattern Reported by Experienced Cabin Observer



c) Failure Pattern Reported by Pilot



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At: Before
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FIGURE 4.3

FLUID THICKNESS ON AIRCRAFT

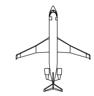
AIRPORT: YMX

AIRCRAFT TYPE: FALCON 20

DATE: 22-Feb-99

WING: PORT (A)

DRAW DIRECTION OF WIND WRT WING:

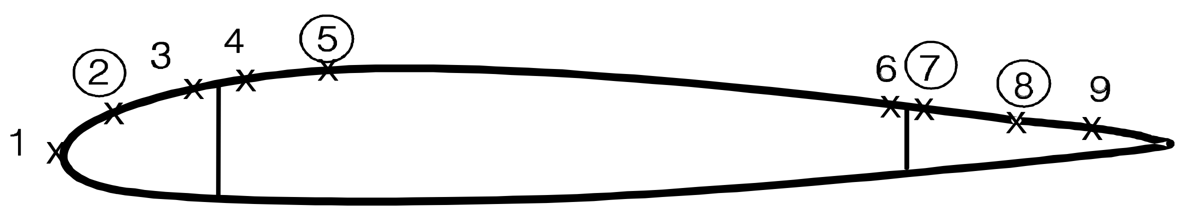


Calm Wind

RUN #: 2

DIRECTION OF AIRCRAFT: 60 DEGREES

	Before Contamination		Before Takeoff		After Takeoff	
Location	**Time**	**Thick. (mm)**	**Time**	**Thick. (mm)**	**Time**	**Thick. (mm)**
1	9:50	0.74	10:10	0.24	10:34	0.04
2	9:50	0.95	10:10	0.58	10:34	0.04
3	9:50	1.09	10:10	0.70	10:34	0.04
4	9:50	1.46	10:10	0.83	10:34	0.04
5	9:51	1.97	10:11	Ice	10:34	0.04
6	9:51	0.38	10:11	Ice	10:34	Ice
7	9:51	0.48	10:11	Ice	10:34	Ice
8	9:51	0.44	10:11	Ice	10:34	Ice
9	9:52	0.53	10:11	Ice	10:34	Ice



Location

1 **- LE Nose**

2,8 **- Half-way**

3,4,6,7 **- 1" from joint**

5 **- As far as can reach**

9 **- 6" from TE**

Note:

Give priority to circled locations; measure other locatios only if time allows.

COMMENTS:

MEASUREMENTS BY:

HAND WRITTEN BY:

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4.2.1.3 Contaminant Adhesion

The ice formation patch that covered the rear test area of the wing became adhered to the wing surface. The ice that developed on the forward test portion of the wing did not demonstrate any adhesion (Figure 4.4).

4.2.1.4 Viscosity

The sample of fluid obtained from the wing section following fluid contamination was subsequently found to be too small to support a viscosity measurement. In some locations where there was a significant amount of ice present, some ice was unavoidably included as part of the fluid sample. When the ice subsequently melted, the reduced volume of fluid was for some samples barely sufficient for viscosity measurements.

4.2.2 Following Takeoff Run

4.2.2.1 Extent and Pattern of Contamination

Ground Observer
The ice-covered area was somewhat reduced following the takeoff run; however, it was noted that some of the ice remaining appeared to be thicker than it had been previously. Any fluid that had previously existed at non-iced areas had generally flowed off the wing. See Figure 4.5 and Photo Set 4.4.

Experienced Cabin Observer
The failure pattern recorded by the experienced cabin observer corresponds well to that noted by the ground observer with somewhat less contamination noted on the leading edge, which is likely due to visibility constraints.

4.2.2.2 Fluid Thickness

The thickness of any fluid film remaining was measured at less than .04 mm.

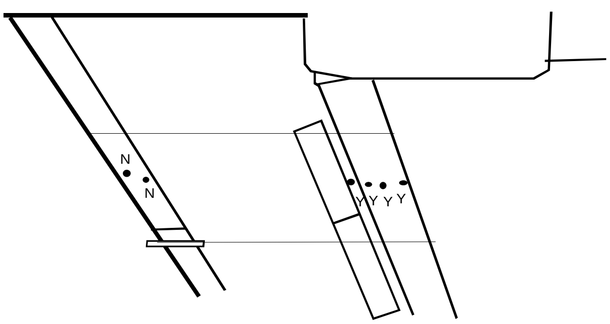
FIGURE 4.4

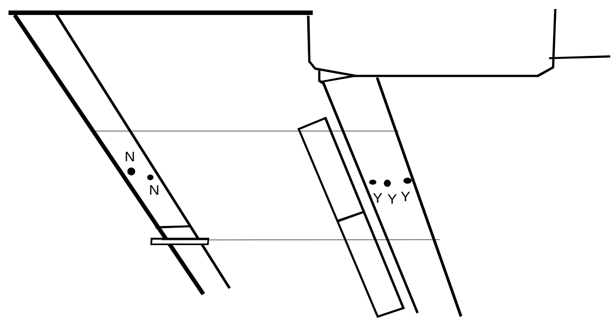
Run 2 - Fluid Adhesion and Wing Skin Temperature

22-Feb-99

ADHESION

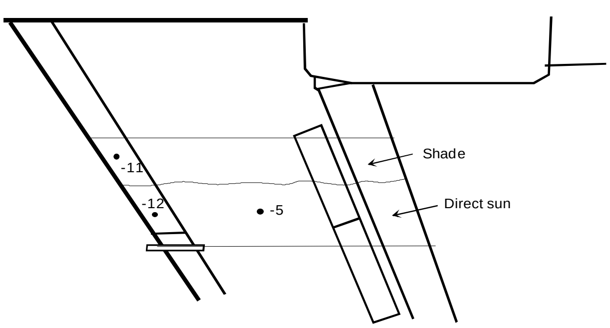
Before Takeoff	After Takeoff





WING SKIN TEMPERATURE (°C)

Before Takeoff	After Takeoff



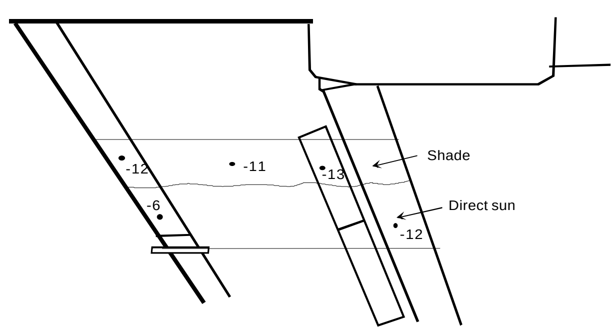
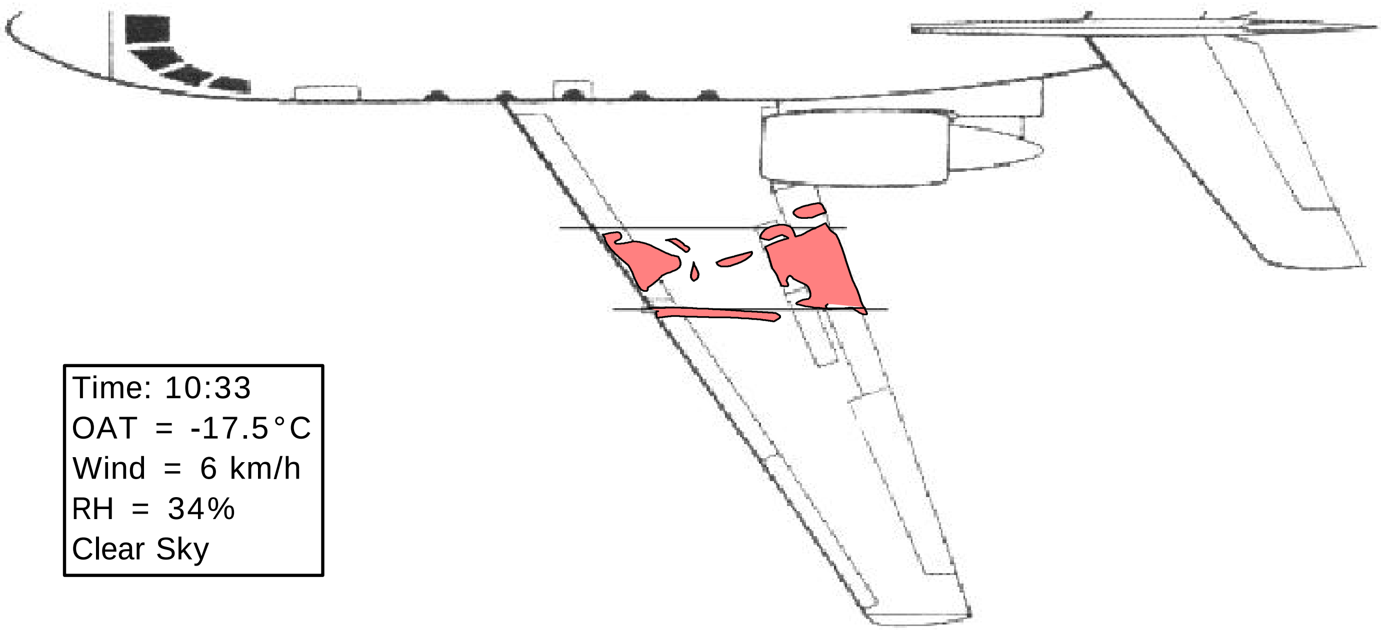


FIGURE 4.5

Run 2 - Failure Pattern After Takeoff Run

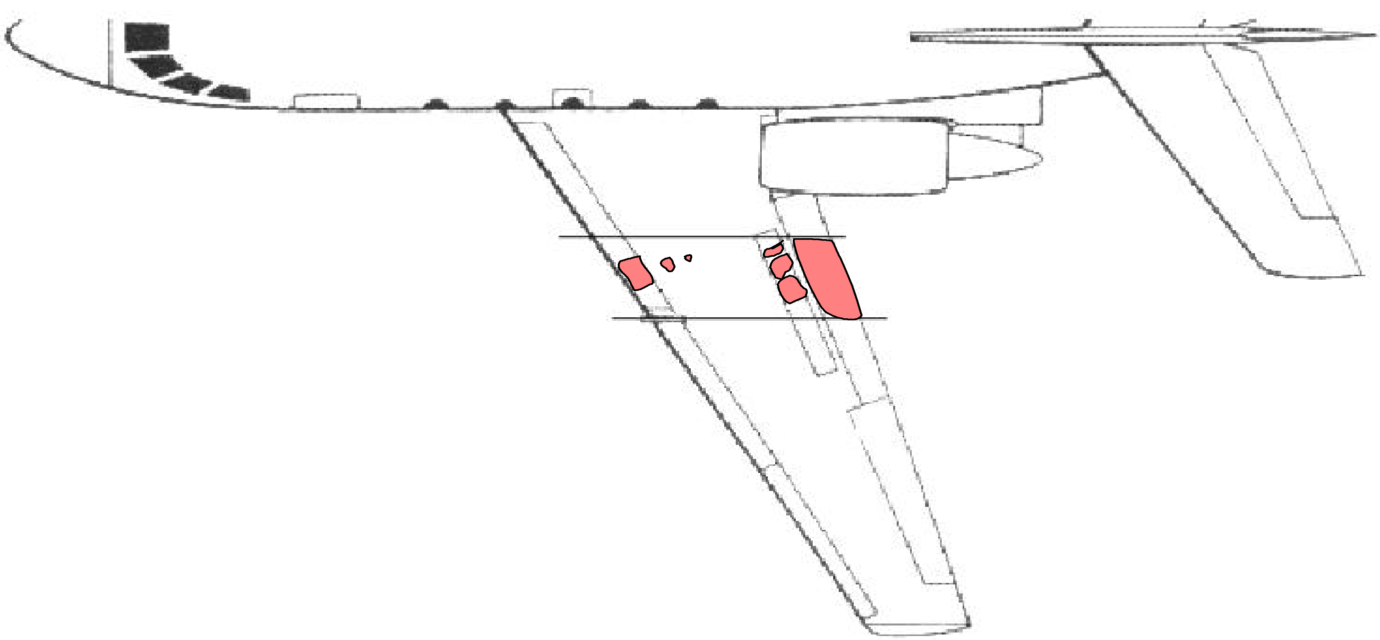
February 22, 1999

a) Failure Pattern Reported by Ground Observer



Time: 10:33
OAT = -17.5°C
Wind = 6 km/h
RH = 34%
Clear Sky

b) Failure Pattern Reported by Experienced Cabin Observer



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4.2.2.3 Contaminant Adhesion

Ice formations at the rear of the wing remained adhered to the wing surface. Ice formations at the front of the wing could still be moved about on the wing surface and showed no evidence of adhesion.

4.2.2.4 Viscosity

A sample of contaminated fluid taken following the takeoff run had a viscosity value below the lowest response value of the instrument (0 mPas registered at 0.3 r/min, Table 4.1). The Brix value for this fluid was 14.25, indicating a freeze point of –9ºC.

4.2.3 Observations from Videotape of Fluid During the Takeoff Run

During the taxi phase of this run (speed 28 kn), a clearly visible persistent rippled pattern developed in the fluid film on the wing as a result of wind shear.

During the takeoff run, the fluid could be seen to be moving toward and off the trailing edge of the wing when the aircraft speed was 60 kn. Solids could be seen moving once the aircraft had achieved speeds in the range of 80 to 100 kn.

4.3 Run Three: Ethylene Glycol-Based Type IV Fluid; Contamination to 10 Percent

4.3.1 Prior to Takeoff Run

4.3.1.1 Extent and Pattern of Contamination

The duration of contaminant exposure required to achieve a 10 percent contamination level was 15 minutes.

Ground Observer
The ground observer noted an area of extensive fluid contamination at the leading edge and also farther back on the main wing extending forward from the spoiler panel area (Figure 4.6). The flap area was mainly clear of contamination. Photo 4.5 shows the appearance of the failed fluid. This observer noted that contamination started to melt once the freezing rain application was stopped. The skin temperature on the forward part of the wing was –11° to –12°C in the shaded area, and -5ºC in the sun.

Experienced Cabin Observer
The experienced cabin observer noted an iced area remarkably similar to that noted by the ground observer.

Pilot
The pilot record of the iced area was quite similar to the other two observers with the exception that icing was noted on the flap surface.

4.3.1.2 Fluid Thickness

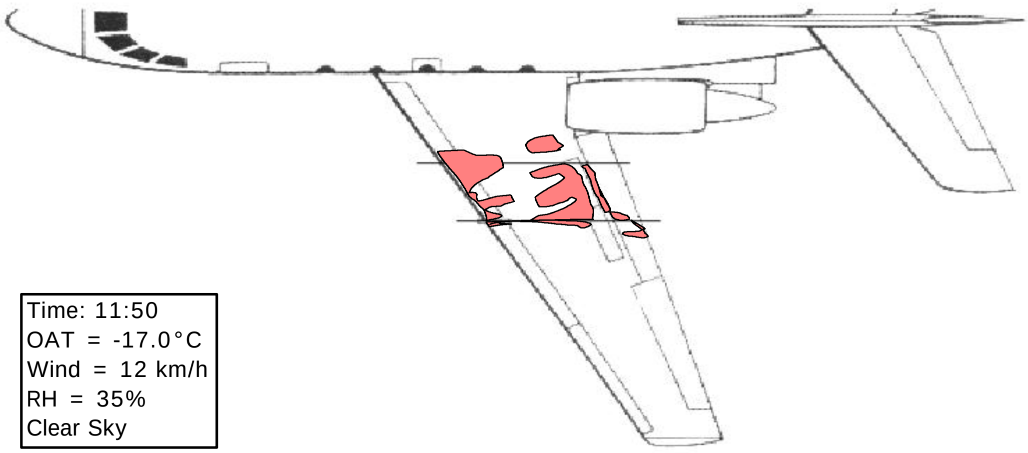
See Figure 4.7. Fluid thickness (where fluid remained on the forward and main part of the wing) showed a reduction of about 60 percent following application of the artificial freezing rain. Fluid on the flap area exhibited a smaller reduction in thickness (15 to 30 percent), which indicates that the level of contamination in this area was not as heavy as that applied to the leading edge and forward mid-wing section, and explains the lack of ice over the flap.

FIGURE 4.6

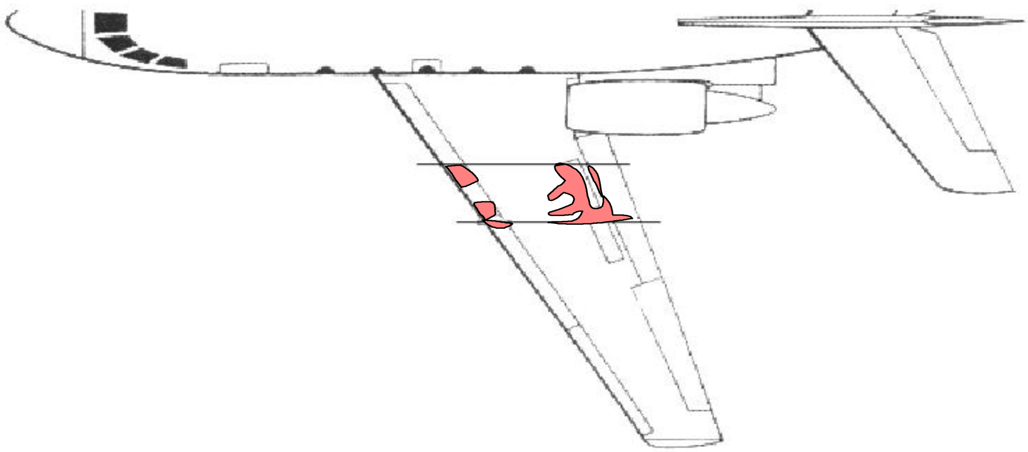
Run 3 - Failure Pattern Before Takeoff Run

February 22, 1999

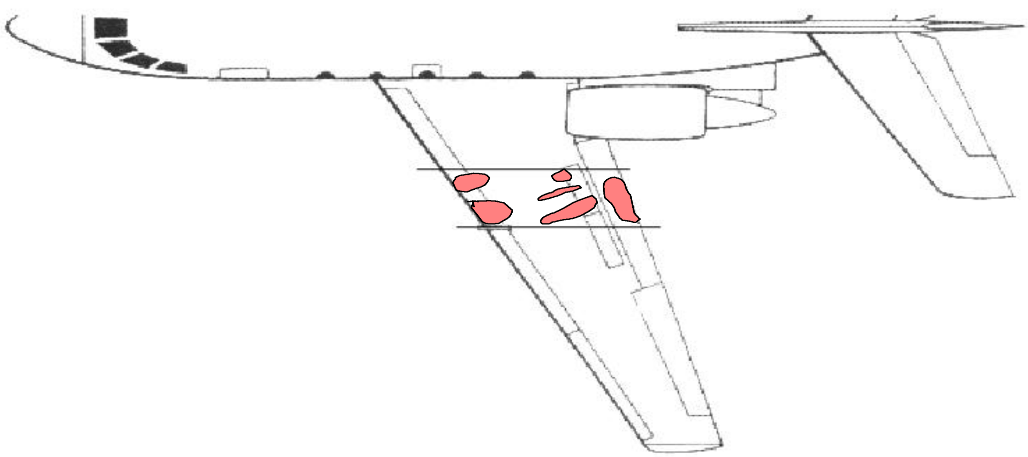
a) Failure Pattern Reported by Ground Observer



b) Failure Pattern Reported by Experienced Cabin Observer



c) Failure Pattern Reported by Pilot



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At: Before
Printed: 1/14/02, 4:04 PM

FIGURE 4.7

FLUID THICKNESS ON AIRCRAFT

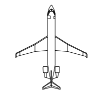
AIRPORT: YMX

AIRCRAFT TYPE: FALCON 20

DATE: 22-Feb-99

WING: PORT (A)

DRAW DIRECTION OF WIND WRT WING:



RUN #: 3

Calm Wind

DIRECTION OF AIRCRAFT: 60 DEGREES

	Before Contamination		Before Takeoff		After Takeoff	
Location	**Time**	**Thick. (mm)**	**Time**	**Thick. (mm)**	**Time**	**Thick. (mm)**
1	11:36	0.53	11:50	0.23	12:17	0.00
2	11:36	0.69	11:50	0.23	12:17	0.00
3	11:36	0.95	11:50	0.38	12:17	0.00
4	11:36	1.33	11:50	0.53	12:17	0.00
5	11:36	1.97	11:50	0.74	12:17	0.00
6	11:36	1.42	11:50	1.09	12:17	0.19
7	11:36	1.09	11:50	0.38	12:17	0.00
8	11:36	0.74	11:50	0.48	12:17	0.04
9	11:36	0.70	11:50	0.53	12:17	0.04

Location

1 **- LE Nose**
2,8 **- Half-way**
3,4,6,7 **- 1" from joint**
5 **- As far as can reach**
9 **- 6" from TE**

Note:
Give priority to circled locations; measure other locatios only if time allows.

COMMENTS:

MEASUREMENTS BY:

HAND WRITTEN BY:

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4.3.1.3 Contaminant Adhesion

The failed fluid layer had not adhered (Figure 4.8) prior to the takeoff run. The adhesion test instrument was capable of carving through the iced fluid layer to the wing surface.

4.3.1.4 Viscosity

The sample of contaminated fluid obtained following contamination was subsequently found to be too small to support a measurement of viscosity.

4.3.2 Following Takeoff Run

4.3.2.1 Extent and Pattern of Contamination

Ground Observer
On return from the takeoff run, the ice-covered area had been reduced in area by about 50 percent (Figure 4.9). Photo Set 4.6 shows the ice formations remaining on the leading edge. The iced area farther back on the wing appeared to have undergone a greater reduction than that at the leading edge. This indicated either that a greater degree of adhesion existed on the leading edge or that the fluid shedding action on the takeoff run partially cleared off the rear wing contamination as the fluid was swept off the wing.

Experienced Cabin Observer
The reported ice-covered area was similar in distribution but less extensive.

4.3.2.2 Fluid Thickness

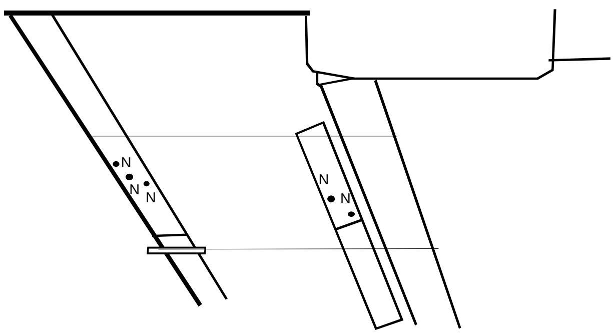
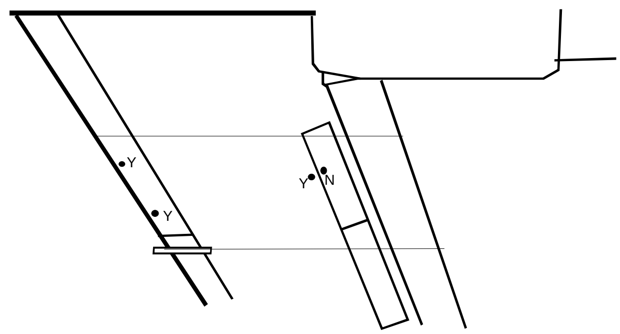
Following the takeoff run, no fluid remained over the leading edge or forward part of the wing, and only a trace remained on the flap area. A measurable thickness existed just forward of the spoiler panel, as a result of the disrupted airflow caused by the raised panel following rotation.

FIGURE 4.8

Run 3 - Fluid Adhesion and Wing Skin Temperature

February 22, 1999

ADHESION

Before Takeoff	After Takeoff
	

WING SKIN TEMPERATURE (°C)

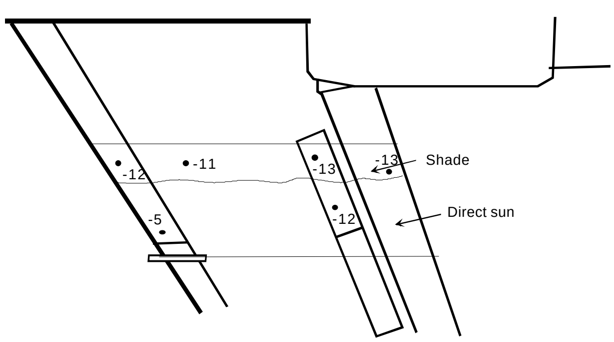
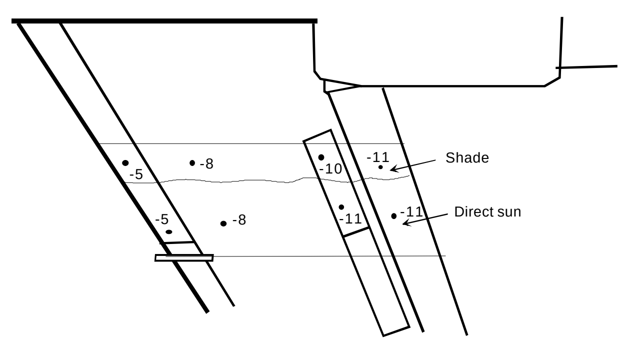
Before Takeoff	After Takeoff
	

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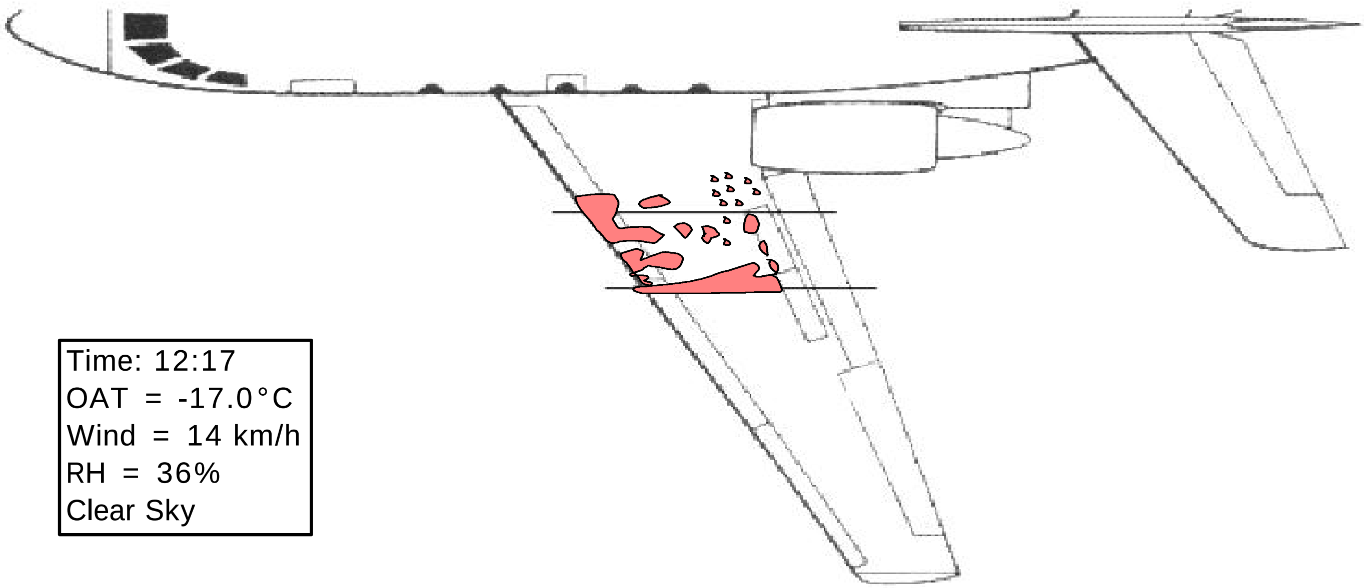
FIGURE 4.9

Run 3 - Failure Pattern After Takeoff Run

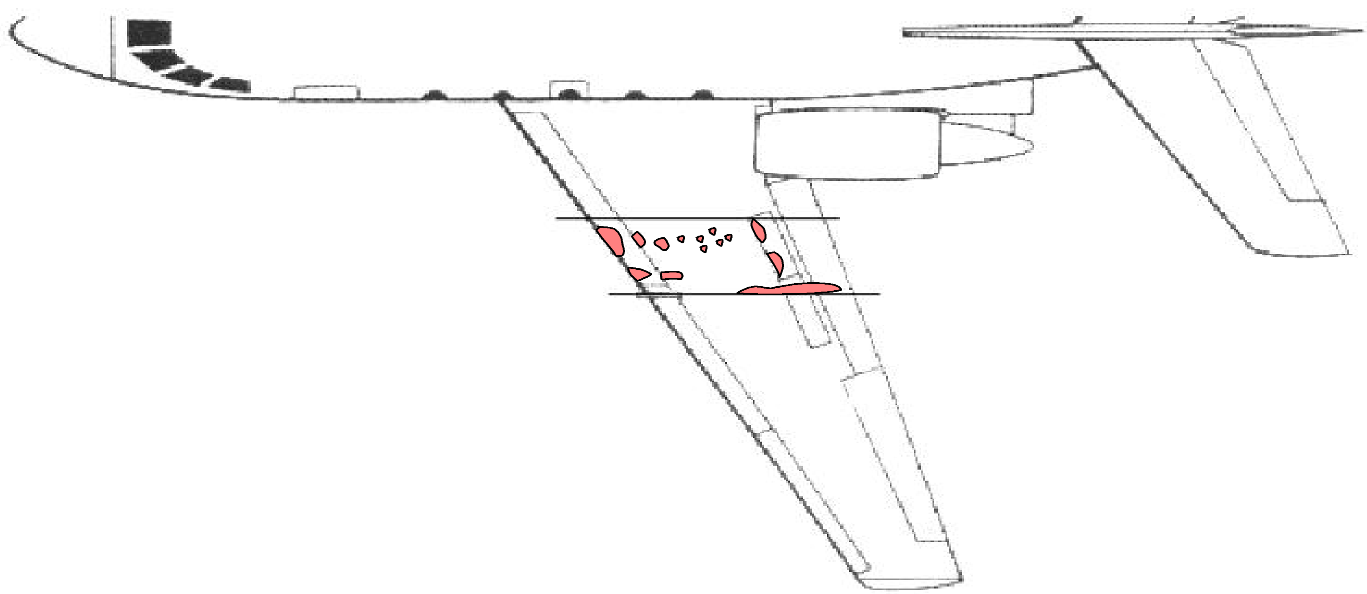
February 22, 1999

a) Failure Pattern Reported by Ground Observer



Time: 12:17
OAT = -17.0°C
Wind = 14 km/h
RH = 36%
Clear Sky

b) Failure Pattern Reported by Experienced Cabin Observer



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Printed: 15/01/02, 9:15 AM

4.3.2.3 Contaminant Adhesion

Where there had been no adhesion prior to the takeoff run there was now evidence of adhesion to the wing surface. This was the case both on the leading edge and farther back on the wing, just forward of the spoiler panel.

4.3.2.4 Viscosity

A sample of contaminated fluid remaining after the takeoff run was determined to have a viscosity of 100 mPas at 0.3 r/min. The Brix value of the fluid sample was about 8.5, indicating a fluid freeze point of about –5°C.

4.4 Run Four: Propylene Glycol-Based Type IV Fluid; No Contamination

4.4.1 Prior to Takeoff Run

4.4.1.1 Extent and Pattern of Contamination

Ground Observer
This observer noted that the application of Type IV fluid over the flap area appeared to be lighter than on the main wing. Being a trial without contamination, no icing was noted. Photo Set 4.7 shows the appearance of the layer of propylene glycol-based fluid on the wing surface.

Experienced Cabin Observer
A pool of fluid was noted just forward of the spoiler panel.

Pilot
No observations noted.

4.4.1.2 Fluid Thickness

Fluid thickness values measured on the wing chord after fluid application (Figure 4.10) ranged from 1 to 2.5 mm. The layer of fluid appeared to be more consistent than in the case of the ethylene glycol-based fluid, with less thinning on the leading edge and over the rear of the wing.

4.4.1.3 Adhesion

There was no adhesion, as this fluid was not subjected to contamination.

4.4.1.4 Viscosity

The average viscosity value of two samples of the uncontaminated fluid (Table 4.1) on the wing was 11,000 mPas at 0.3 r/min. The fluid in the

FIGURE 4.10

FLUID THICKNESS ON AIRCRAFT

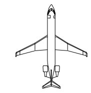
AIRPORT: YMX

AIRCRAFT TYPE: FALCON 20

DATE: 22-Feb-99

WING: PORT (A)

DRAW DIRECTION OF WIND WRT WING:



Calm Wind

RUN #: 4

DIRECTION OF AIRCRAFT: 60 DEGREES

	Before Contamination		Before Takeoff		After Takeoff	
Location	**Time**	**Thick. (mm)**	**Time**	**Thick. (mm)**	**Time**	**Thick. (mm)**
1			15:26	1.09	15:55	0.04
2			15:26	1.83	15:55	0.04
3			15:26	1.83	15:55	0.14
4			15:26	1.71	15:55	0.22
5			15:26	2.24	15:55	0.22
6			15:26	1.97	15:55	0.83
7			15:26	1.46	15:55	0.06
8			15:26	1.46	15:55	0.14
9			15:26	1.71	15:55	0.19

Location

1 **- LE Nose**
2,8 **- Half-way**
3,4,6,7 **- 1" from joint**
5 **- As far as can reach**
9 **- 6" from TE**

Note:
Give priority to circled locations; measure other locatios only if time allows.

COMMENTS:

MEASUREMENTS BY:

HAND WRITTEN BY:

barrel had a viscosity of 20,500 mPas at 0.3 r/min. This fluid has a higher initial viscosity than the ethylene glycol-based fluid. This factor accounts for the relatively slower flow of fluid off the wing and the reduced thinning of fluid observed on the leading and trailing edges.

4.4.2 Following Takeoff Run

4.4.2.1 Extent and Pattern of Contamination

Ground Observer

Following the takeoff run, any fluid remaining on the main wing (Photo Set 4.8) had taken on a ridged form, similar to the ridges formed by wave action on sand at a beach. These ridges ran laterally on the wing, perpendicular to the chord and to the direction of airflow over the wing during the run.

4.4.2.2 Fluid Thickness

The fluid flowed from the wing during the takeoff run. On return, fluid at the rear part of the leading edge was reduced to 0.1 mm maximum, with no fluid on the forward part. Photo Set 4.8 shows the wing surface, bare of fluid. Some fluid (0.2 mm thick) was noted over the main wing and on the flap area. Again, some pooling (with a thickness of 0.9 mm) was observed just forward of the spoiler panel, as a result of the disturbed airflow when the spoiler panel was raised following rotation.

4.4.2.3 Adhesion

There was no adhesion with this uncontaminated fluid.

4.4.2.4 Viscosity

A sample of fluid taken from the wing following the takeoff run was determined to have a viscosity of 14,200 mPas at 0.3 r/min, higher than that measured for the fluid on the wing prior to the run. The brix value had increased slightly from 35.5 to 36.25, indicating a small increase in glycol concentration.

4.4.3 Observations from Videotape of Fluid During the Takeoff Run

No wave formation was evident during the taxi phase with this uncontaminated fluid.

During the takeoff run, much of the fluid had flowed from the wing by the time that the aircraft speed had reached 60 kn. By the time the aircraft speed had reached 100 kn, the green coloration of the fluid had completely disappeared, which provided a practical visual means of gauging the reduction in fluid thickness during the takeoff run.

4.5 Run Five: Ethylene Glycol-Based Type IV Fluid; Contamination to 40 Percent

4.5.1 Prior to Takeoff Run

4.5.1.1 Extent and Pattern of Contamination

Ground Observer
See Figure 4.11. The ground observer noted extensive fluid contamination distributed uniformly over the entire wing test surface area. Photo 4.9 shows the appearance of the failed fluid. This run was conducted very early in the morning and the wing was not yet exposed to radiant heating by the sun. The skin temperature on the forward part of the wing was –18° to –21°C, and –23°C on the rear of the wing.

This trial was initially intended to result in an iced area of 10 percent of the test area. In the trial, this level was quickly reached, and the contamination already sprayed continued to freeze once the freezing rain spray was stopped, resulting in a higher than desired level of ice coverage.

Experienced Cabin Observer
The experienced cabin observer noted an area of icing only on the leading edge. This observer noted that observations were made difficult by the lack of natural light and the fact that the windows were blurry due to fluid on their surfaces.

Pilot
The pilot recorded an area of failed fluid on the leading edge, similar to the area recorded by the experienced cabin observer.

4.5.1.2 Fluid Thickness

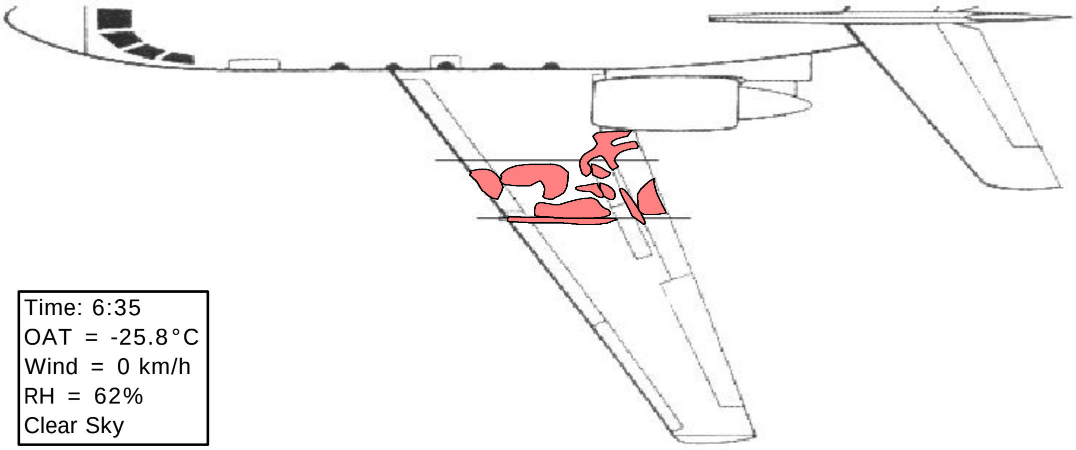
See Figure 4.12. The initial fluid application was typical in thickness, and varied from 0.8 to 1.5 mm. Following exposure to contamination, the fluid outside the iced areas took on thickness values of about 50 percent of the uncontaminated levels. It was noted that slush appeared within the fluid layer at some locations. This indicated that the frozen

FIGURE 4.11

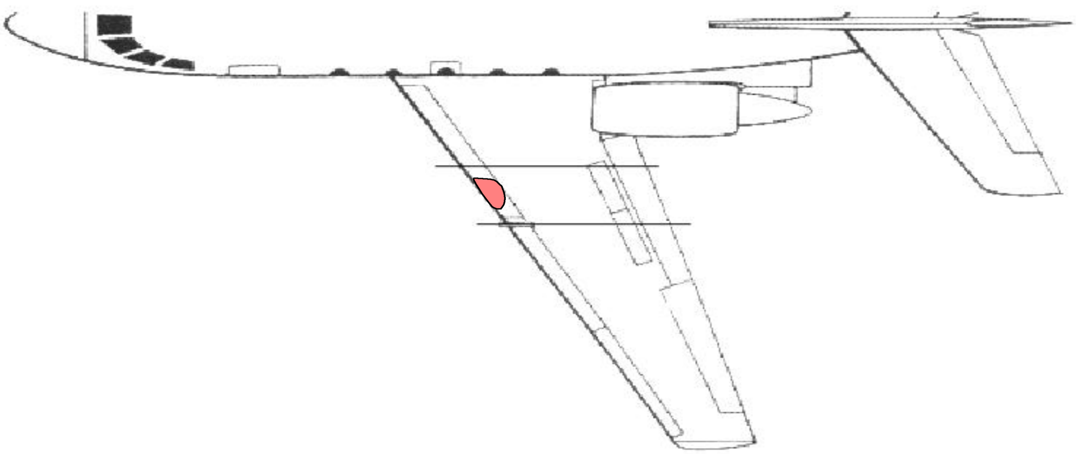
Run 5 - Failure Pattern Before Takeoff Run

February 23, 1999

a) Failure Pattern Reported by Ground Observer



b) Failure Pattern Reported by Experienced Cabin Observer



c) Failure Pattern Reported by Pilot

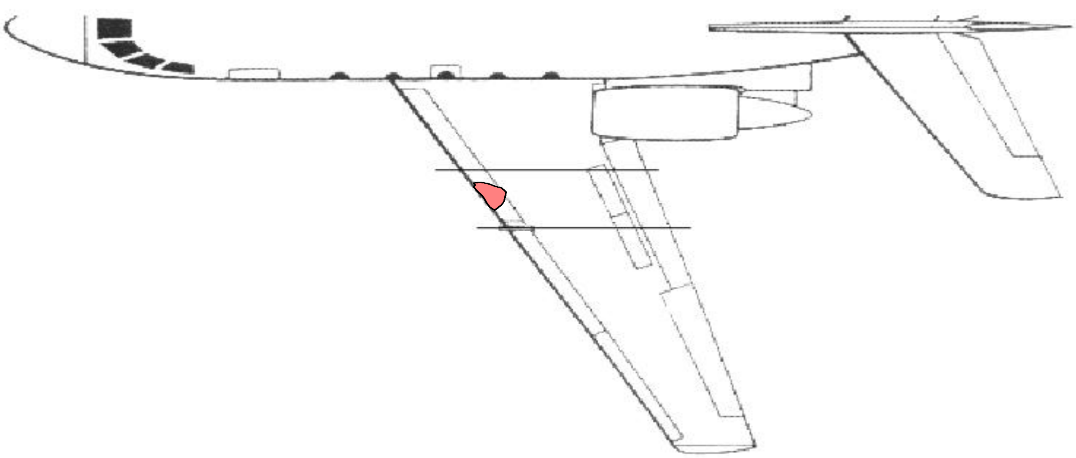


FIGURE 4.12

FLUID THICKNESS ON AIRCRAFT

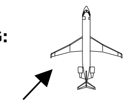
AIRPORT: YMX

AIRCRAFT TYPE: FALCON 20

DATE: 23-Feb-99

WING: PORT (A)

DRAW DIRECTION OF WIND WRT WING:



RUN #: 5

DIRECTION OF AIRCRAFT: 40 DEGREES

	Before Contamination		Before Takeoff		After Takeoff	
Location	**Time**	**Thick. (mm)**	**Time**	**Thick. (mm)**	**Time**	**Thick. (mm)**
1	6:25	0.69	6:34	Ice	7:09	Slush
2	6:25	0.83	6:34	0.27	7:09	Ice
3	6:25	0.74	6:34	0.38	7:09	Ice
4	6:25	0.74	6:34	0.58	7:09	0.04
5	6:25	0.83	6:34	0.58	7:09	0.24
6	6:25	1.46	6:34	0.74	7:09	0.38
7	6:25	0.74	6:34	0.33	7:09	0.09
8	6:25	0.83	6:34	0.53	7:09	0.09
9	6:25	0.83	6:34	0.53	7:09	0.09

Location

1 **- LE Nose**
2,8 **- Half-way**
3,4,6,7 **- 1" from joint**
5 **- As far as can reach**
9 **- 6" from TE**

Note:
Give priority to circled locations; measure other locatios only if time allows.

COMMENTS:

MEASUREMENTS BY:

HAND WRITTEN BY:

contamination was being accepted into the bulk of the applied fluid layer, not just sitting on the surface.

4.5.1.3 Contaminant Adhesion

The iced areas had not adhered to the wing surface (Figure 4.13) although it was noted that the instrument carved through some semi-fused solid areas and areas of slush.

4.5.1.4 Viscosity

The sample of contaminated fluid recovered following contamination was subsequently found to be too small to support a measurement of viscosity.

4.5.2 Following Takeoff Run

4.5.2.1 Extent and Pattern of Contamination

Ground Observer
On return from the takeoff run, the ice-covered area showed little reduction in size (Figure 4.14). Photo Set 4.10 shows ice patches remaining on the forward wing, and ice on the flap surface.

Experienced Cabin Observer
This observer recorded a contaminated area smaller than that noted by the ground observer. More contamination could be seen after takeoff than before takeoff, presumably because the volume of the fluid film prior to takeoff hid some of the contamination.

4.5.2.2 Fluid Thickness

Following the takeoff run, ice was observed at certain locations where slush had previously been noted. In areas where no ice had been noted prior to the takeoff run, the fluid thickness was reduced to about 0.1 mm.

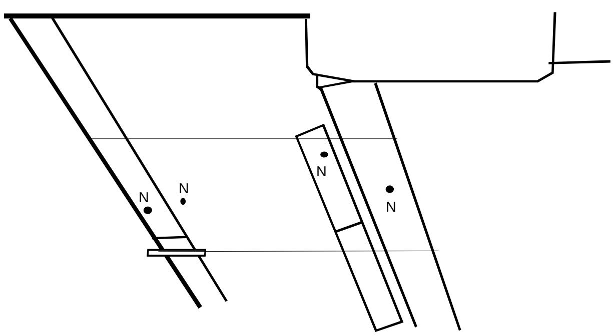
FIGURE 4.13

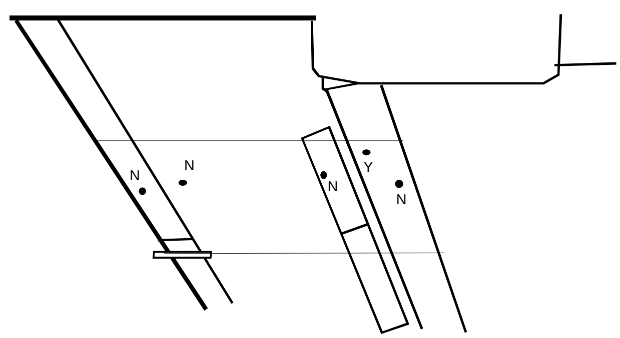
Run 5 - Fluid Adhesion and Wing Skin Temperature

February 23, 1999

ADHESION

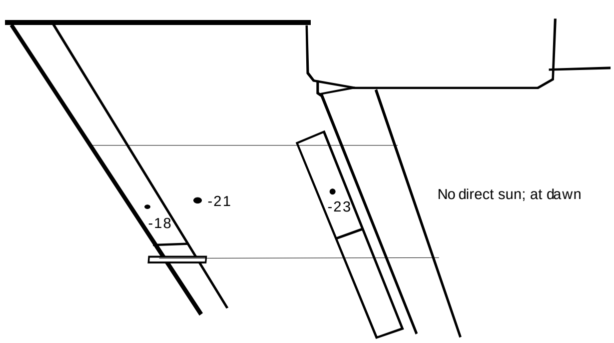
Before Takeoff	After Takeoff





WING SKIN TEMPERATURE (°C)

Before Takeoff	After Takeoff



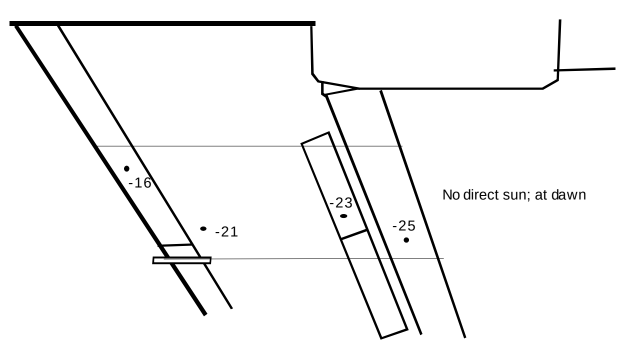
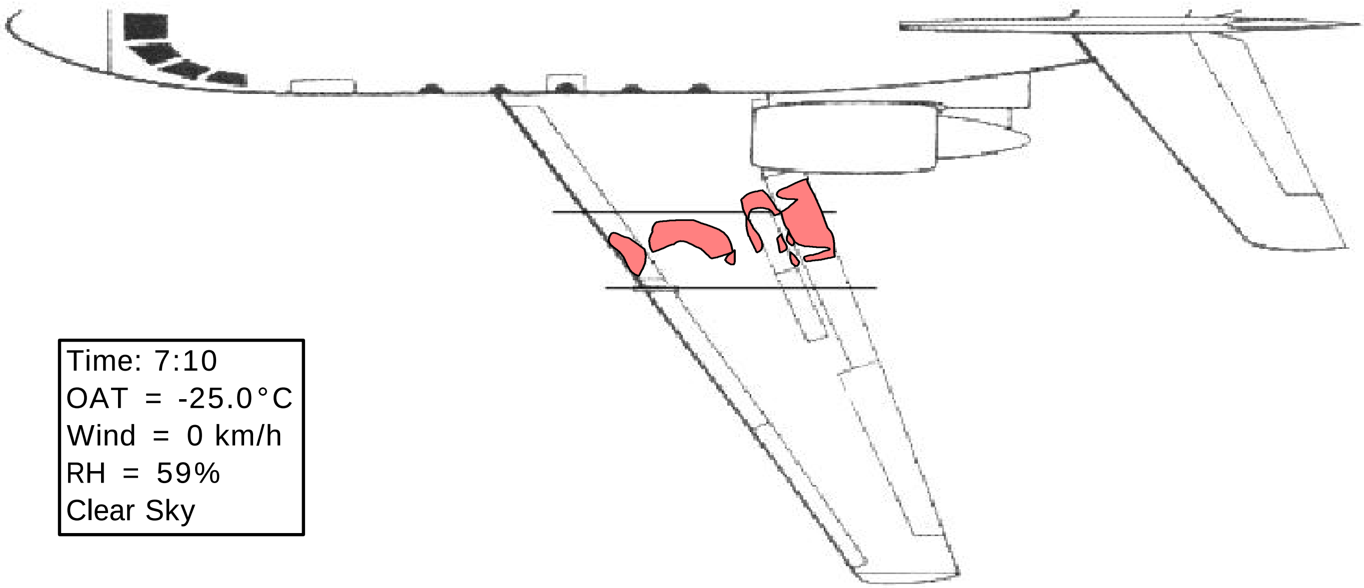


FIGURE 4.14

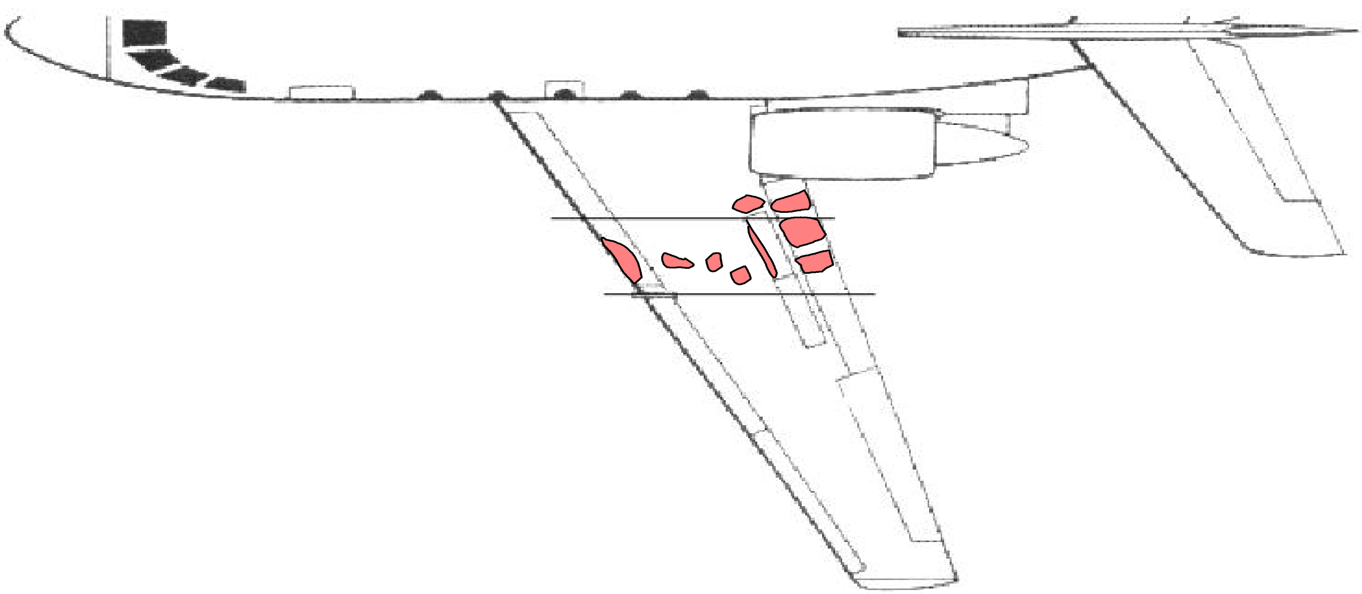
Run 5 - Failure Pattern After Takeoff Run

February 23, 1999

a) Failure Pattern Reported by Ground Observer



b) Failure Pattern Reported by Experienced Cabin Observer



4.5.2.3 Contaminant Adhesion

Some contaminant adhesion was noted following the takeoff run. In general, the adhesion test instrument experienced more difficulty in carving through iced areas after the takeoff run.

4.5.2.4 Viscosity

The viscosity of a sample of contaminated fluid remaining on the wing after the takeoff run was determined to be zero.

4.5.3 Observations from Videotape of Fluid During the Takeoff Run

A still image captured from the onboard video (Video Image 4.1), taken at the point when the aircraft was turning onto the runway following the taxi run, shows the ridging of fluid on the wing. This image also shows a patch of contaminated fluid and ice that serves as a visual reference during the subsequent takeoff run.

Video Image Set 4.2 shows the wave formations on the fluid surface as the aircraft gains speed. The patch of fluid and ice mentioned earlier can be seen eroding in this sequence of images.

4.6 Run Six: Ethylene Glycol-Based Type IV Fluid; Contamination to 5 Percent

4.6.1 Prior to Takeoff Run

4.6.1.1 Extent and Pattern of Contamination

The duration of exposure to precipitation was 11 minutes.

Ground Observer
This trial was initially intended to result in an iced area of 1 percent of the test area. In an attempt to contain the extent of icing to that level, the freezing rain spray was terminated at the first sign of icing, which in this case occurred on the leading edge. See Figure 4.15 and Photo 4.11. As in the previous test, freezing of contamination continued after the spray had ceased, resulting in a final iced area of about 5 percent.

Ice patches appeared both on the leading edge and on the rear of the wing, with only small amounts on the mid-wing portion of the test surface. Icy patches on the leading edge were noted to be thicker than elsewhere on the wing.

Experienced Cabin Observer
The experienced cabin observer noted an icy area very similar to that recorded by the ground observer. A slightly smaller icy area was noted on the leading edge.

Pilot
The pilot record of ice on the leading edge and on the spoiler panel was similar to that recorded by the other observers. The pilot did not record ice on the flap, whereas the other two observers did.

4.6.1.2 Fluid Thickness

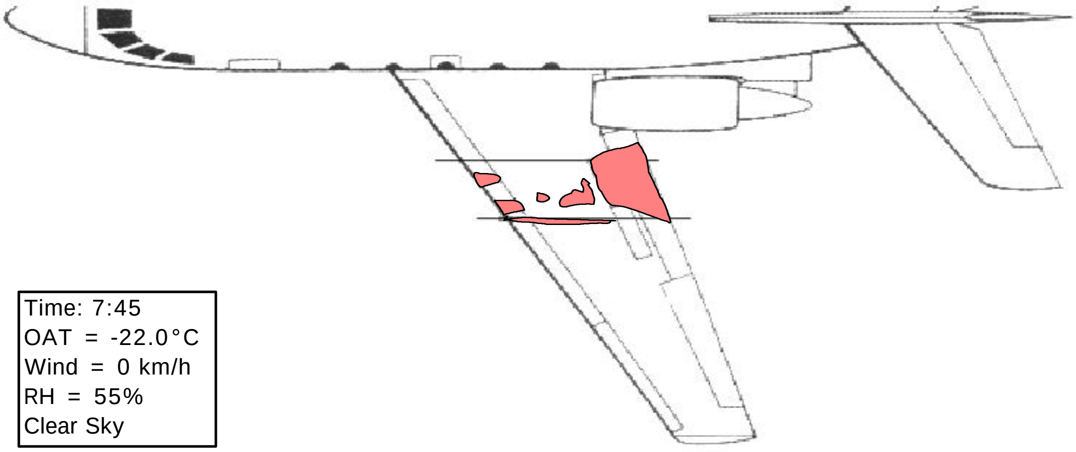
The initial fluid application was of typical thickness, with a slightly heavier application on the top of the main wing where the fluid layer took on a thickness value of nearly 3.0 mm. See Figure 4.16. Following contamination, any fluid existing outside of the iced areas exhibited

FIGURE 4.15

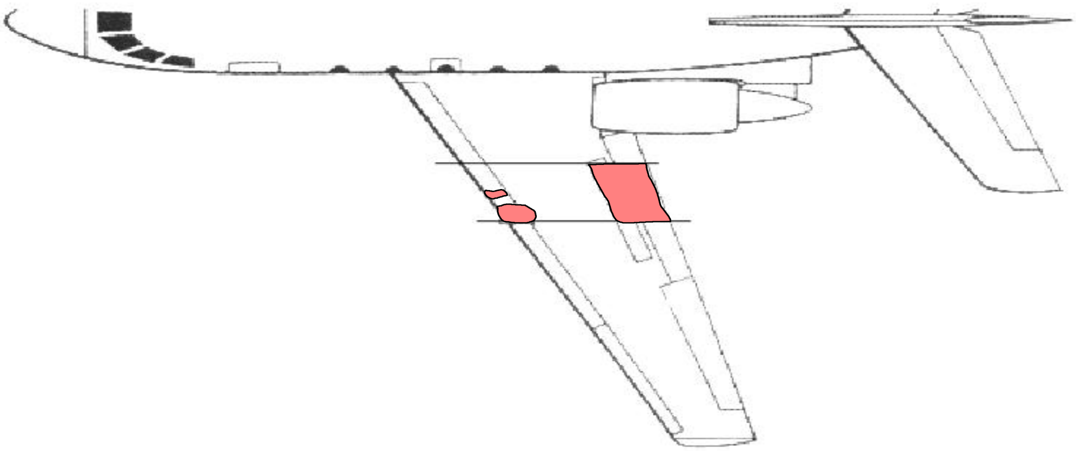
Run 6 - Failure Pattern Before Takeoff Run

February 23, 1999

a) Failure Pattern Reported by Ground Observer



b) Failure Pattern Reported by Experienced Cabin Observer



c) Failure Pattern Reported by Pilot

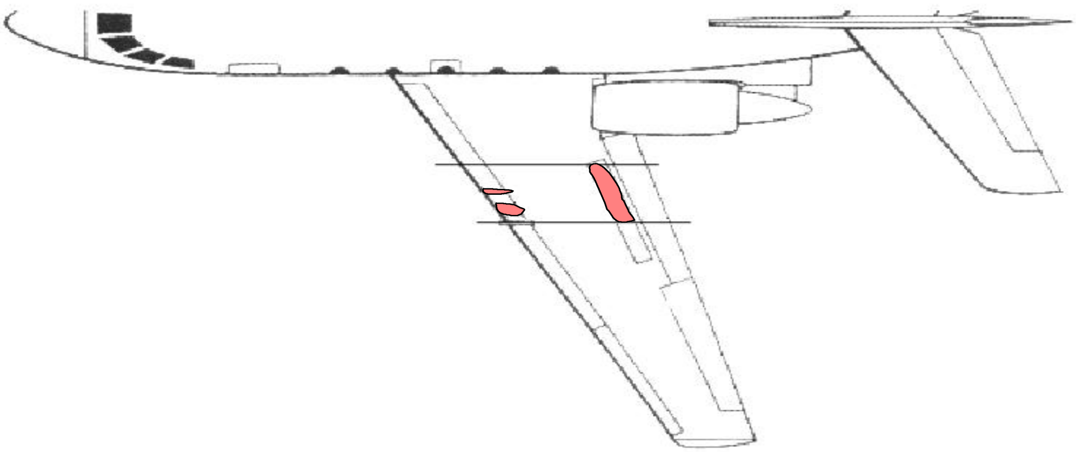


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FIGURE 4.16

FLUID THICKNESS ON AIRCRAFT

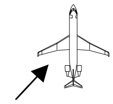
AIRPORT: YMX

AIRCRAFT TYPE: FALCON 20

DATE: 23-Feb-99

WING: PORT (A)

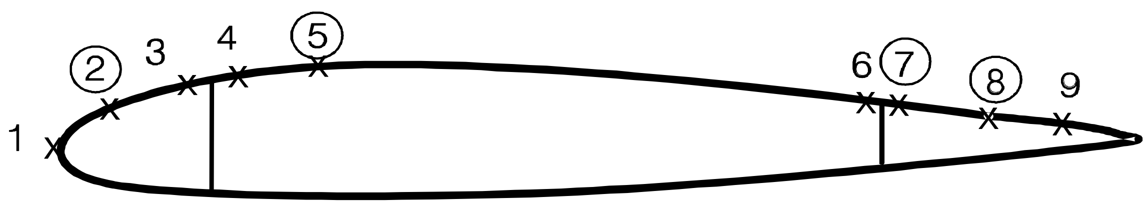
DRAW DIRECTION OF WIND WRT WING:



RUN #: 6

DIRECTION OF AIRCRAFT: 40 DEGREES

	Before Contamination		Before Takeoff		After Takeoff	
Location	**Time**	**Thick. (mm)**	**Time**	**Thick. (mm)**	**Time**	**Thick. (mm)**
1	7:32	0.74	7:43	0.33	8:09	0.04
2	7:32	0.95	7:43	0.58	8:09	0.04
3	7:32	1.42	7:43	0.58	8:09	0.04
4	7:32	1.42	7:43	0.74	8:09	0.04
5	7:32	2.74	7:43	1.97	8:09	0.09
6	7:32	0.83	7:43	Ice	8:09	0.29
7	7:32	0.69	7:43	Ice	8:09	Ice
8	7:32	0.69	7:43	Ice	8:09	Ice
9	7:32	0.69	7:43	Ice	8:09	Ice



Location

1 **- LE Nose**
2,8 **- Half-way**
3,4,6,7 **- 1" from joint**
5 **- As far as can reach**
9 **- 6" from TE**

Note:
Give priority to circled locations; measure other locatios only if time allows.

COMMENTS:

MEASUREMENTS BY:

HAND WRITTEN BY:

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thickness values equivalent to about 50 percent of the uncontaminated fluid thickness values.

4.6.1.3 Adhesion

The iced areas did not adhere to the wing surface (Figure 4.17); however, it was noted that the instrument was able to carve through some semi-fused areas of frozen precipitation.

4.6.1.4 Viscosity

No value was determined.

4.6.2 Following Takeoff

4.6.2.1 Extent and Pattern of Contamination

Ground Observer
On return from the takeoff run, the ice-covered area at the rear of the wing showed little reduction in size (Figure 4.18 and Photo Set 4.12). The ice patches on the leading edge appeared to have grown in a lateral direction.

Experienced Cabin Observer
The recorded areas of ice were similar in dimension to those recorded by the ground observer.

4.6.2.2 Fluid Thickness

Following the takeoff run, ice was observed and recorded at certain locations where slush had previously been observed. In areas where no ice had been noted prior to the takeoff run, the fluid thickness was reduced to about 0.1 mm.

4.6.2.3 Contaminant Adhesion

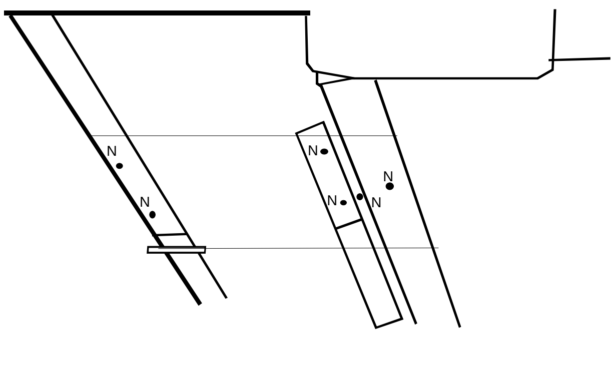
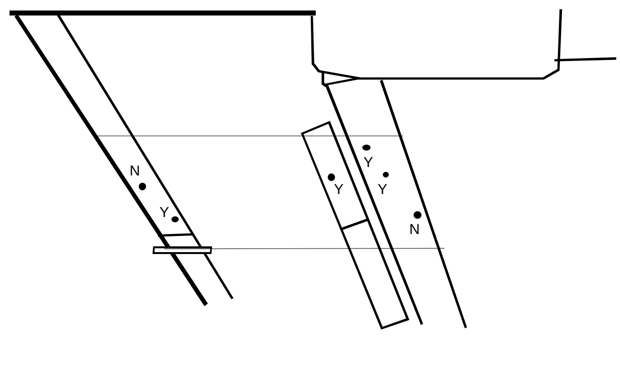
An increased level of adhesion was noted following the takeoff run.

FIGURE 4.17

Run 6 - Fluid Adhesion and Wing Skin Temperature

February 23, 1999

ADHESION

Before Takeoff	After Takeoff
	

WING SKIN TEMPERATURE (°C)

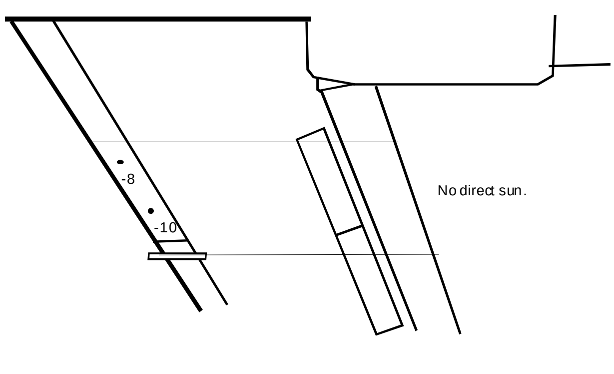
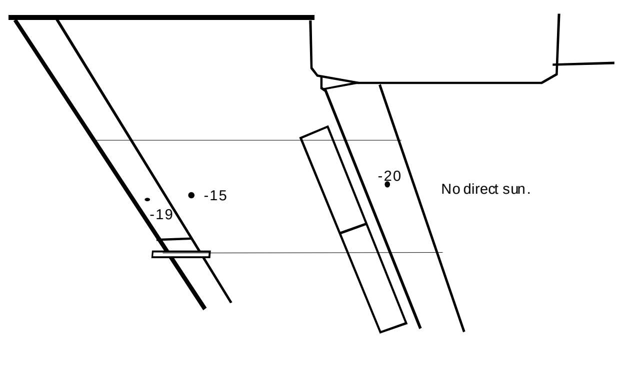
Before Takeoff	After Takeoff
	

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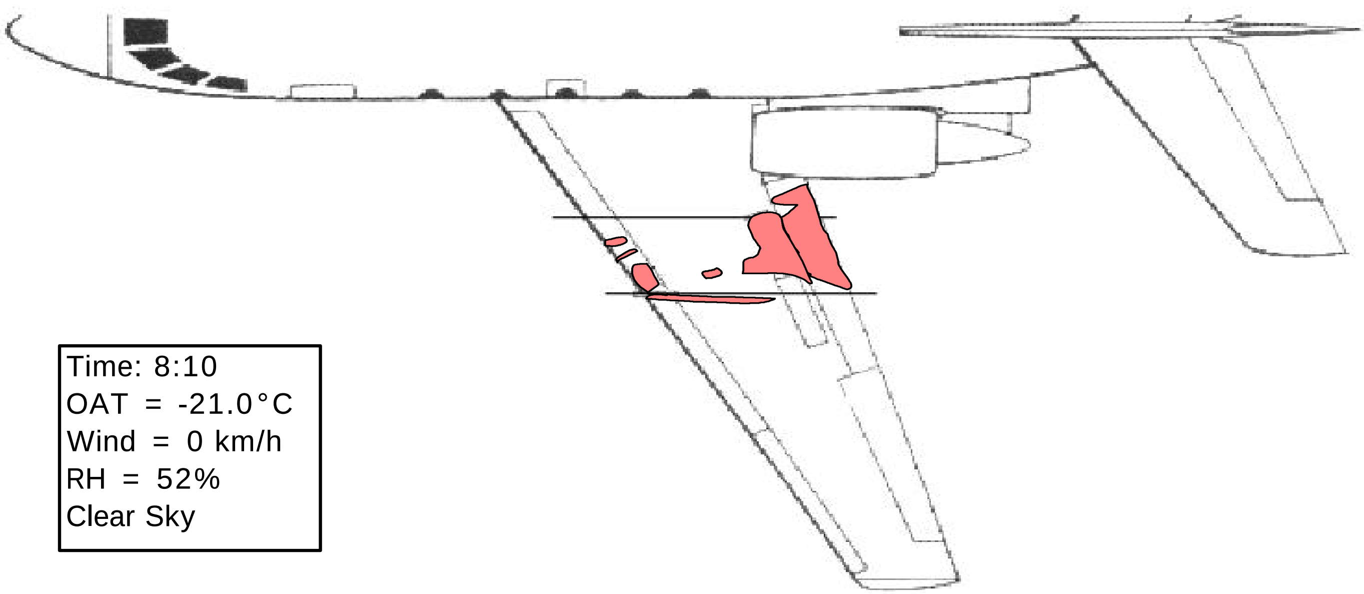
FIGURE 4.18

Run 6 - Failure Pattern After Takeoff Run

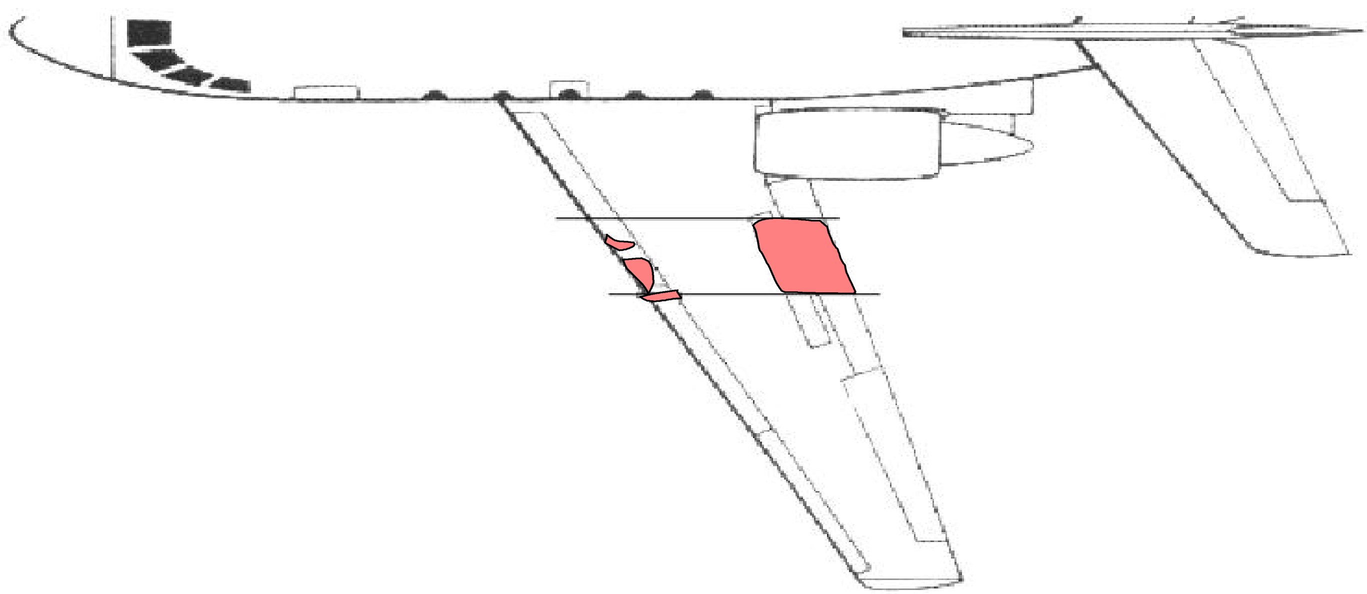
February 23, 1999

a) Failure Pattern Reported by Ground Observer



Time: 8:10
OAT = -21.0°C
Wind = 0 km/h
RH = 52%
Clear Sky

b) Failure Pattern Reported by Experienced Cabin Observer



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At: After
Printed: 15/01/02, 9:51 AM

4.6.2.4 Viscosity

The viscosity of a sample of contaminated fluid recovered from the wing was determined to be zero by the viscometer used in this study.

4.7 Run Seven: Propylene Glycol-Based Type IV Fluid; Contamination to 100 Percent

4.7.1 Prior to Takeoff Run

The duration of exposure to freezing precipitation was 8 minutes.

4.7.1.1 Extent and Pattern of Contamination

Ground Observer
This trial was initially intended to result in an iced area of 5 percent of the test area. The artificial freezing rain application resulted in a thin layer of fused ice over the fluid layer. This ice layer covered the entire test area. See Figure 4.19 and Photo 4.13. The resultant level of contamination was identified as 100 percent.

Experienced Cabin Observer
The experienced cabin observer noted that the fluid appeared to be slushy but that no ice was distinguishable. No failure pattern was recorded.

Pilot
The pilot indicated that ice had formed on the leading edge with patches farther back on the main wing. The pilot noted that the appearance of the fluid was not similar to previous runs.

4.7.1.2 Fluid Thickness

See Figure 4.20. The initial fluid application was very similar to Run 4. Following contamination, the fluid still retained a thickness of 75 to 80 percent of stabilized thickness of the same uncontaminated fluid.

4.7.1.3 Contaminant Adhesion

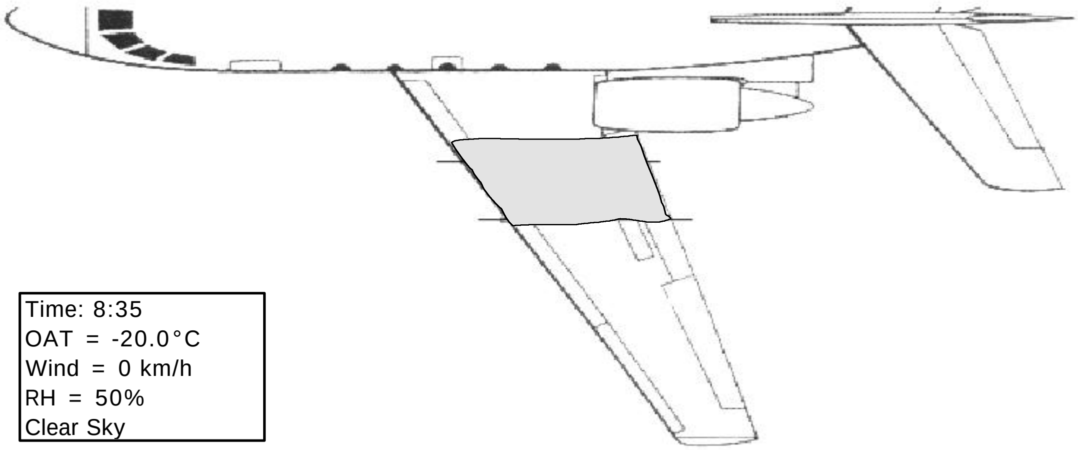
The thin layer of solid precipitation was essentially supported on the upper strata of the fluid layer that covered the wing. There was no adhesion (Figure 4.21) and solids still flowed with the fluid. The fluid layer underneath and in contact with the wing surface appeared to be minimally contaminated.

FIGURE 4.19

Run 7 - Failure Pattern Before Takeoff Run

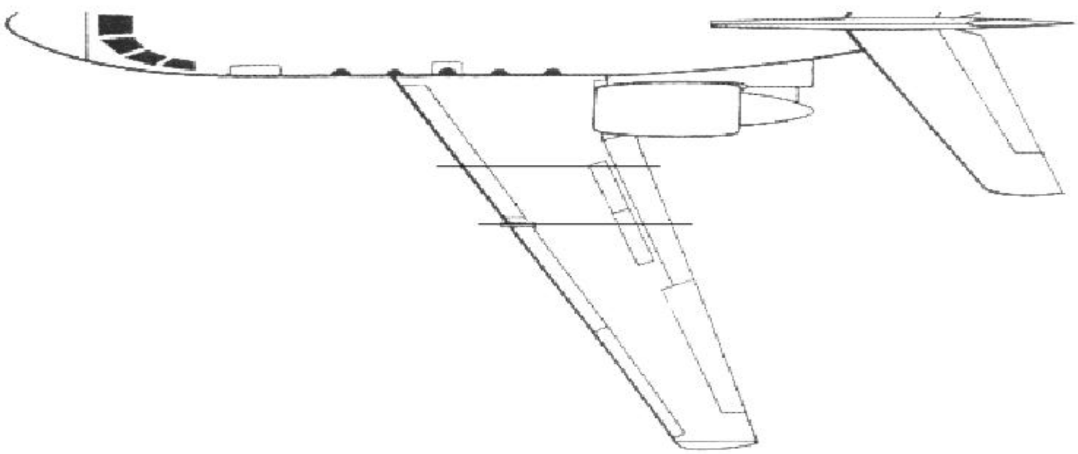
February 23, 1999

a) Failure Pattern Reported by Ground Observer

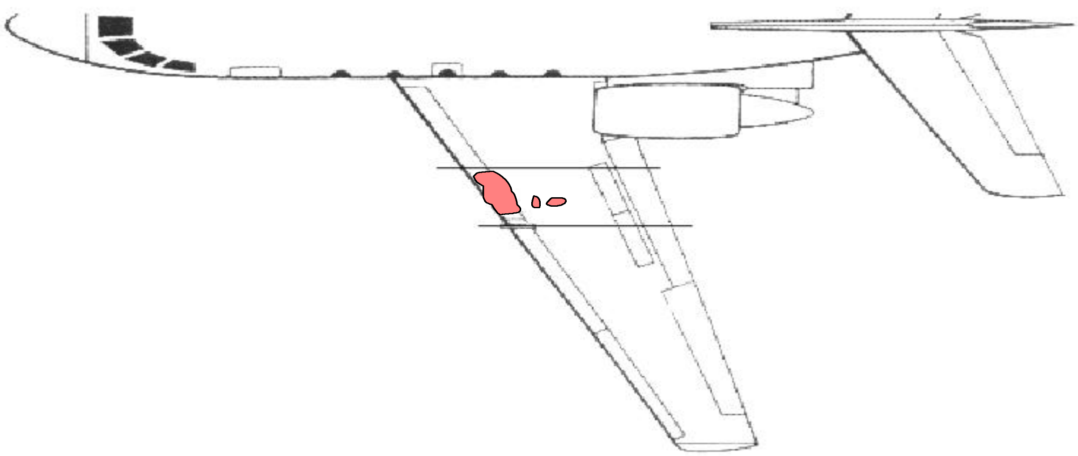


Time: 8:35
OAT = -20.0°C
Wind = 0 km/h
RH = 50%
Clear Sky

b) Failure Pattern Reported by Experienced Cabin Observer



c) Failure Pattern Reported by Pilot



File: \cm1514\analysis\falc_20\RUN7_YMX(issue 2).XLS
At: Before
Printed: 15/01/02, 9:53 AM

FIGURE 4.20

FLUID THICKNESS ON AIRCRAFT

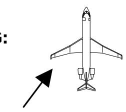
AIRPORT: YMX

AIRCRAFT TYPE: FALCON 20

DATE: 23-Feb-99

WING: PORT (A)

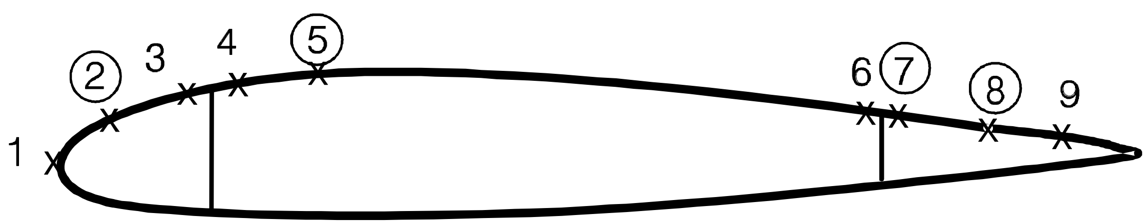
DRAW DIRECTION OF WIND WRT WING:



RUN #: 7

DIRECTION OF AIRCRAFT: 40 DEGREES

	Before Contamination		Before Takeoff		After Takeoff	
Location	**Time**	**Thick. (mm)**	**Time**	**Thick. (mm)**	**Time**	**Thick. (mm)**
1	8:25	0.74	8:34	0.48	8:56	0.04
2	8:25	1.42	8:34	0.64	8:56	0.14
3	8:25	1.42	8:34	1.33	8:56	0.14
4	8:25	1.83	8:34	1.71	8:56	0.14
5	8:25	2.24	8:34	1.97	8:56	0.19
6	8:25	1.97	8:34	1.83	8:56	0.95
7	8:25	1.71	8:34	1.42	8:56	0.14
8	8:25	1.83	8:34	1.42	8:56	0.19
9	8:25	1.46	8:34	1.09	8:56	0.00



Location

1 **- LE Nose**
2,8 **- Half-way**
3,4,6,7 **- 1" from joint**
5 **- As far as can reach**
9 **- 6" from TE**

Note:
Give priority to circled locations; measure other locatios only if time allows.

COMMENTS:

MEASUREMENTS BY:

HAND WRITTEN BY:

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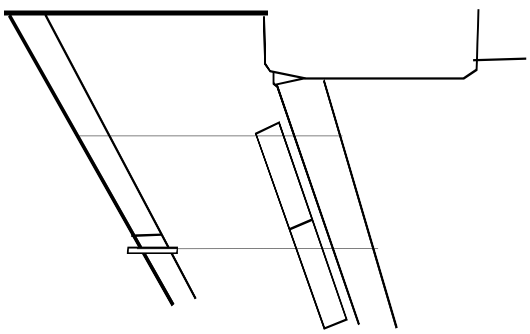
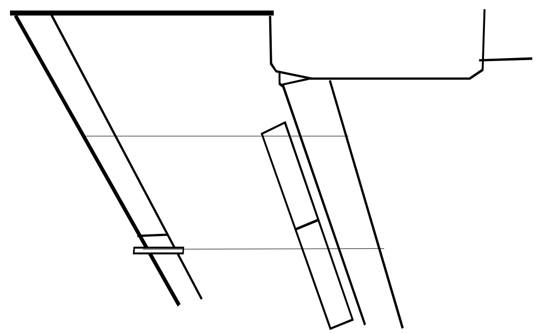
FIGURE 4.21

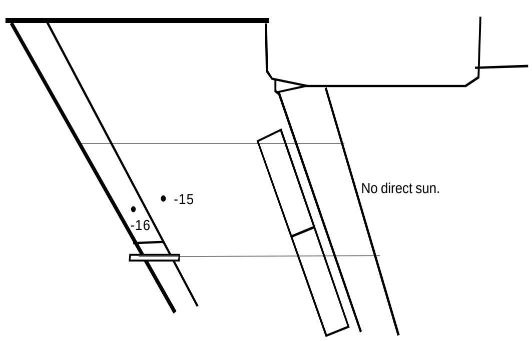
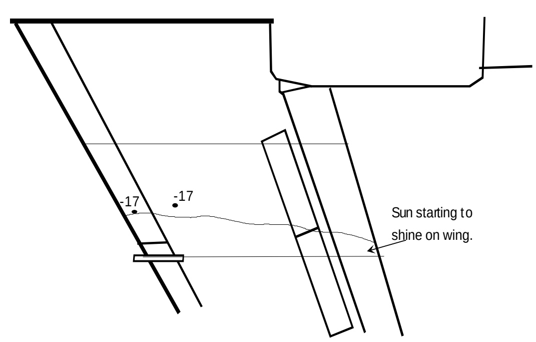
Run 7 - Fluid Adhesion and Wing Skin Temperature

February 23, 1999

ADHESION

Before Takeoff	After Takeoff
	
(No adhesion noted)	(No adhesion noted)

WING SKIN TEMPERATURE (°C)

Before Takeoff	After Takeoff
	

4.7.1.4 Viscosity

The viscosity values of two samples of contaminated fluid taken from the wing prior to the takeoff run were 13,800 and 13,400 mPas at 0.3 r/min. The average Brix value was 32.75. This corresponds to a freeze point of –27ºC. Note that these viscosity values are consistently higher than those measured for the uncontaminated fluid.

4.7.2 Following Takeoff Run

4.7.2.1 Extent and Pattern of Contamination

Ground Observer
On return from the takeoff run, it was observed that the entire fluid layer had been eliminated from the wing (Figure 4.22). The results are similar to those of Run 4, which also employed the propylene glycol-based fluid, but with no contamination. No solids remained, and any fluid that remained on the wing took on the appearance of lateral ridges running perpendicular to the wing chord. Photo 4.14 shows the clean wing following the takeoff run.

Experienced Cabin Observer
The observer noted that the wing was clean and that the slush had been sheared off completely and rather spectacularly during the takeoff run.

4.7.2.2 Fluid Thickness

Following the takeoff run, the remaining fluid had taken on the same appearance and thickness as the uncontaminated fluid did in Run 4.

4.7.2.3 Contaminant Adhesion

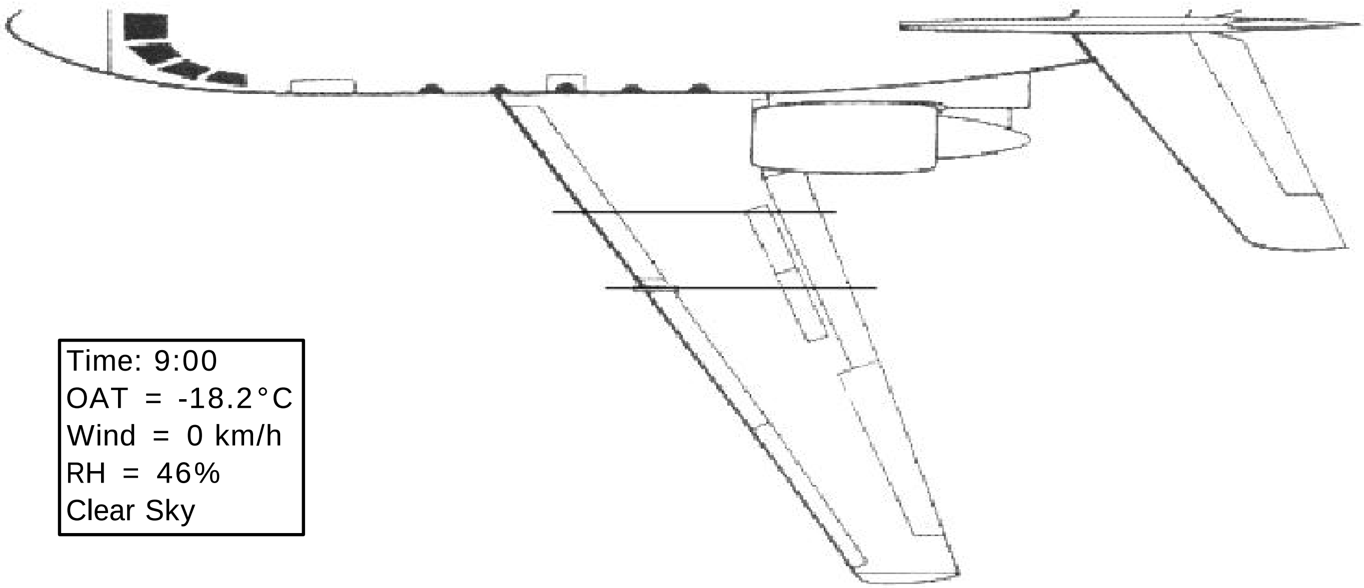
No solids remained on the wing following the takeoff run so no adhesion took place.

FIGURE 4.22

Run 7 - Failure Pattern After Takeoff Run

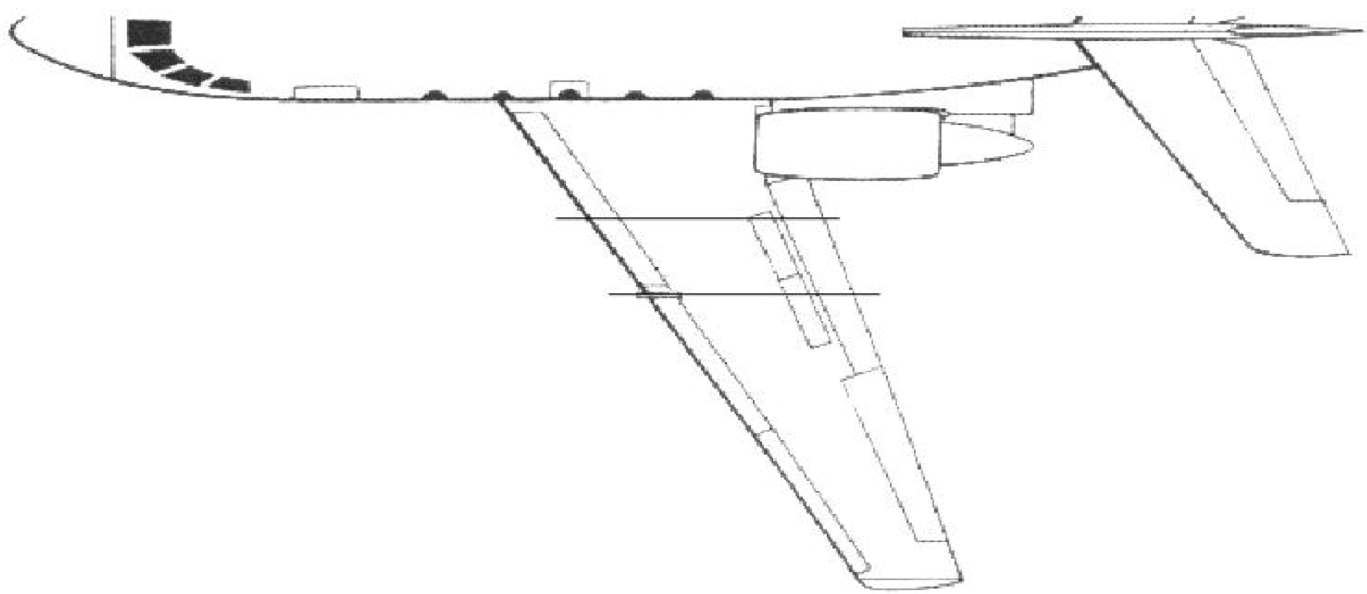
February 23, 1999

a) Failure Pattern Reported by Ground Observer



Time: 9:00
OAT = -18.2°C
Wind = 0 km/h
RH = 46%
Clear Sky

b) Failure Pattern Reported by Experienced Cabin Observer



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At: After
Printed: 15/01/02, 10:40 AM

4.7.2.4 Viscosity

Two samples of contaminated fluid remaining after the takeoff run were determined to have viscosity values of 8500 and 19,500 mPas at 0.3 r/min. Their corresponding Brix values were 32.5 and 33.5.

4.7.3 Observations from Videotape of Fluid During the Takeoff Run

Video Image 4.3 provides a good view of the appearance of the layer of solid precipitation on the top surface of this fluid. As the aircraft turned off the taxiway and onto the runway, the wing passed through direct sunlight, which afforded this view. A good deal of this contaminant layer had already been eroded from the wing during the taxi phase; however, a conspicuous patch of contamination on the top of the mid-wing section still remained at the beginning of the takeoff run.

During the takeoff run, this patch could be seen to fragment (Video Image Set 4.4) and shear off the wing along with the underlying, uncontaminated fluid.

4.8 Run Eight: Ethylene Glycol-Based Type IV Fluid; Contamination to 1 Percent

4.8.1 Prior to Takeoff Run

4.8.1.1 Extent and Pattern of Contamination

Ground Observer
This was a second attempt to produce an iced area equivalent to 1 percent of the test area. Exposure to artificial freezing rain spray was about 9 minutes.

A small ice patch (Figure 4.23 and Photo 4.15) appeared on the leading edge and slightly larger patches were observed on the spoiler panel and on the flap. The wing observer noted that flow off from the top of the main wing eroded the fluid in these areas, leading to failures. The iced area on the leading edge was located at a seam in the leading edge structure. This area had also been the site of initial failures in previous tests.

Experienced Cabin Observer
The experienced cabin observer noted the patch of ice on the leading edge and on the spoiler panel.

Pilot
The pilot noted the existence of an ice patch on the spoiler panel and some on the flap, but did not identify the small area on the leading edge.

4.8.1.2 Fluid Thickness

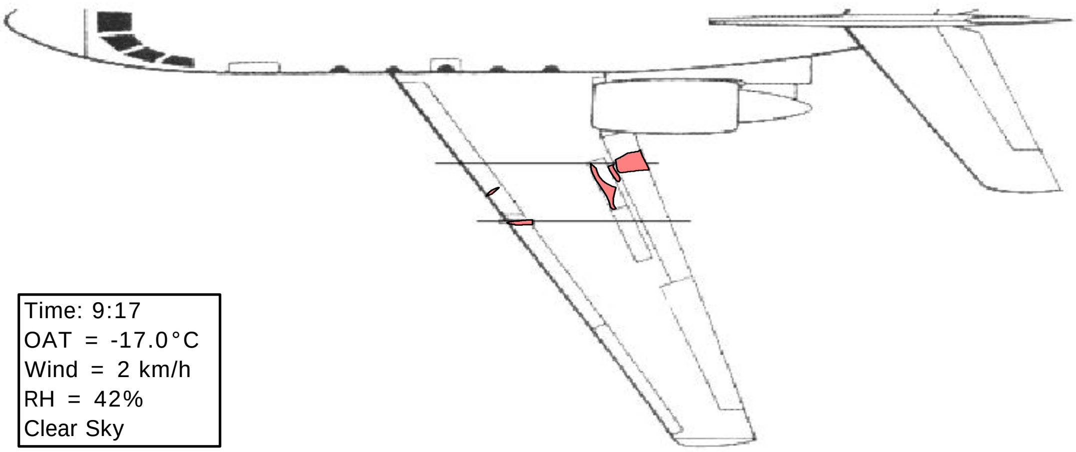
The initial fluid application was of typical thickness and appearance. See Figure 4.24. Following contamination, the fluid layer over the forward part of the wing exhibited thickness values equivalent to about 50 percent of the uncontaminated fluid. On the rear of the wing, the fluid thickness was closer to initial values except at the trailing edge of the flap, where the thickness was reduced to about 50 percent of its initial measured value.

FIGURE 4.23

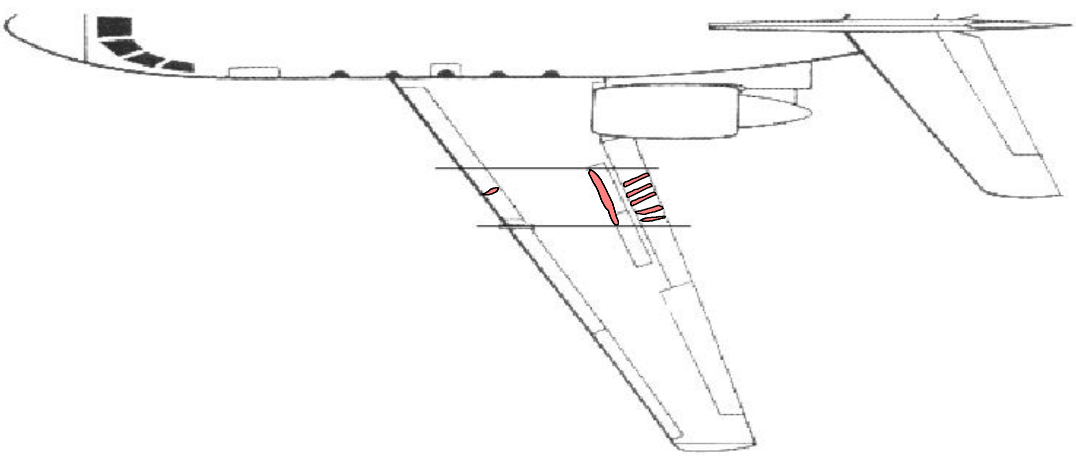
Run 8 - Failure Pattern Before Takeoff Run

February 23, 1999

a) Failure Pattern Reported by Ground Observer



b) Failure Pattern Reported by Experienced Cabin Observer



c) Failure Pattern Reported by Pilot

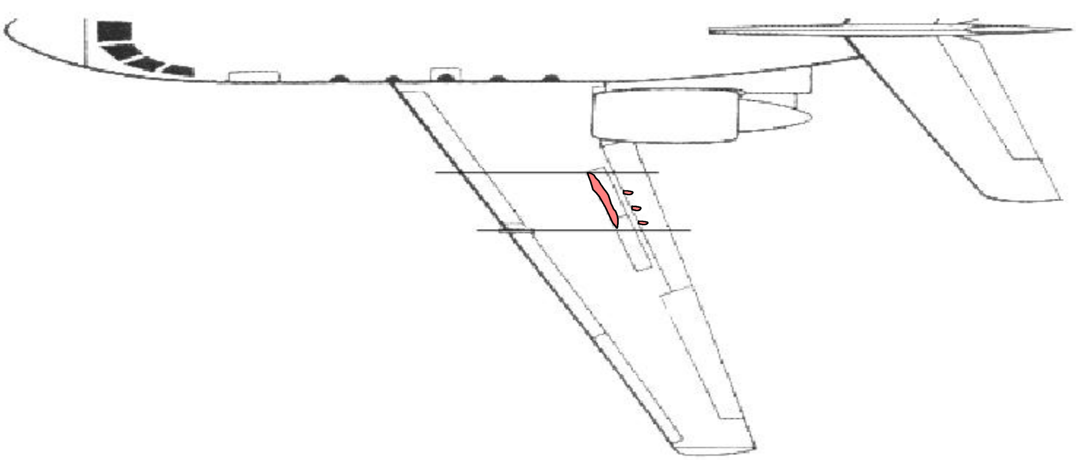


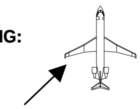
FIGURE 4.24

FLUID THICKNESS ON AIRCRAFT

AIRPORT: YMX **AIRCRAFT TYPE:** FALCON 20

DATE: 23-Feb-99 **WING:** PORT (A)

DRAW DIRECTION OF WIND WRT WING:



RUN #: 8

DIRECTION OF AIRCRAFT: 40 DEGREES

	Before Contamination		Before Takeoff		After Takeoff	
Location	**Time**	**Thick. (mm)**	**Time**	**Thick. (mm)**	**Time**	**Thick. (mm)**
1	9:08	0.70	9:17	0.29	9:45	0.02
2	9:08	0.74	9:17	0.38	9:45	0.04
3	9:08	0.83	9:17	0.38	9:45	0.04
4	9:08	0.83	9:17	0.44	9:45	0.04
5	9:08	1.33	9:17	0.74	9:45	0.04
6	9:08	0.74	9:17	0.74	9:45	0.33
7	9:08	0.70	9:17	0.70	9:45	0.14
8	9:08	0.69	9:17	0.58	9:45	0.14
9	9:08	0.74	9:17	0.44	9:45	0.16

Location

1 **- LE Nose**
2,8 **- Half-way**
3,4,6,7 **- 1" from joint**
5 **- As far as can reach**
9 **- 6" from TE**

Note:
Give priority to circled locations; measure other locatios only if time allows.

COMMENTS:

MEASUREMENTS BY:

HAND WRITTEN BY:

4.8.1.3 Contaminant Adhesion

No adhesion was observed (Figure 4.25).

4.8.1.4 Viscosity

A sample of contaminated fluid taken before the takeoff run had a viscosity value of 100 mPas at 0.3 r/min and a Brix of 30.5, which indicated a freeze point of –35ºC.

4.8.2 Following Takeoff Run

4.8.2.1 Extent and Pattern of Contamination

Ground Observer
On return from the takeoff run, the ice on the spoiler panel had disappeared, but the ice patch on the flap remained (Figure 4.26 and Photo 4.16). The ice patch at the seam in the leading edge was somewhat reduced in size but was still visible.

Experienced Cabin Observer
Ice-covered regions were recorded on the spoiler panel and flap.

4.8.2.2 Fluid Thickness

Following the takeoff run, the fluid layer on the forward part of the wing had been eliminated from the surface. A thin fluid layer existed at the rear of the wing, about 0.1 mm in thickness.

4.8.2.3 Contaminant Adhesion

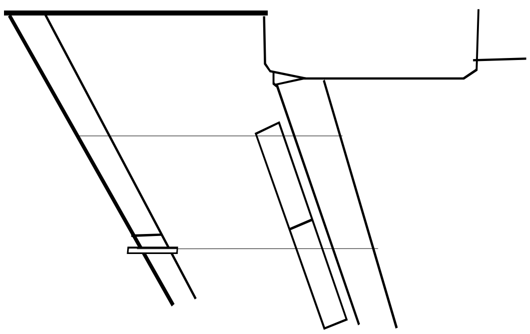
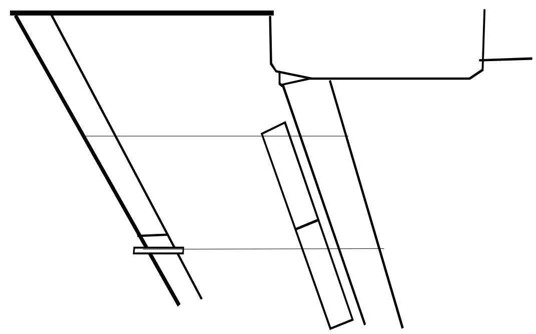
No adhesion was observed following this takeoff run.

FIGURE 4.25

Run 8 - Fluid Adhesion and Wing Skin Temperature

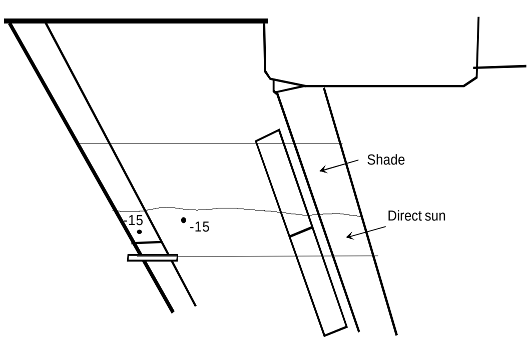
February 23, 1999

ADHESION

Before Takeoff	After Takeoff
	
(No adhesion noted)	(No adhesion noted)

WING SKIN TEMPERATURE (°C)

Before Takeoff



After Takeoff

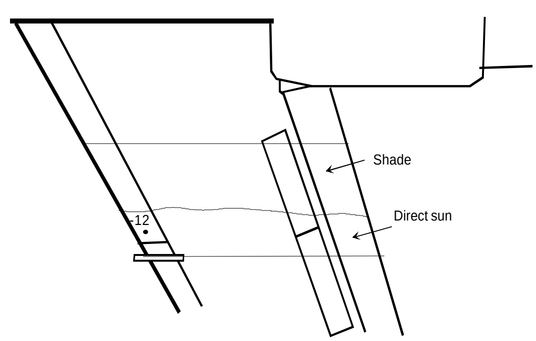
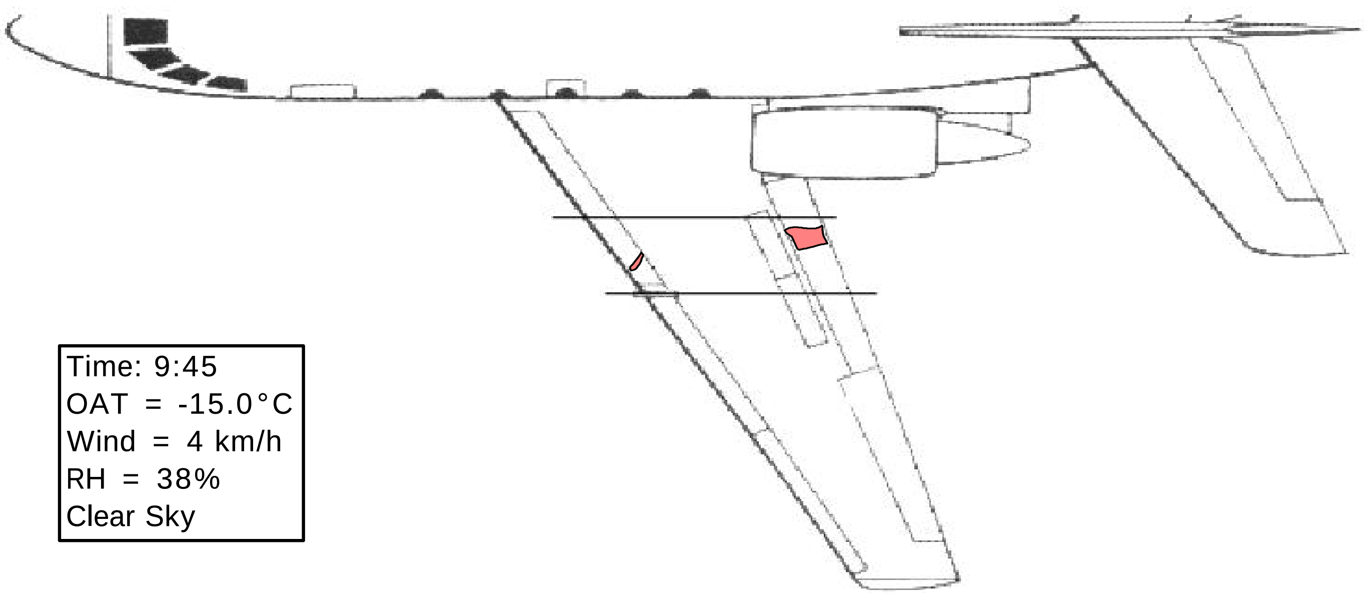


FIGURE 4.26

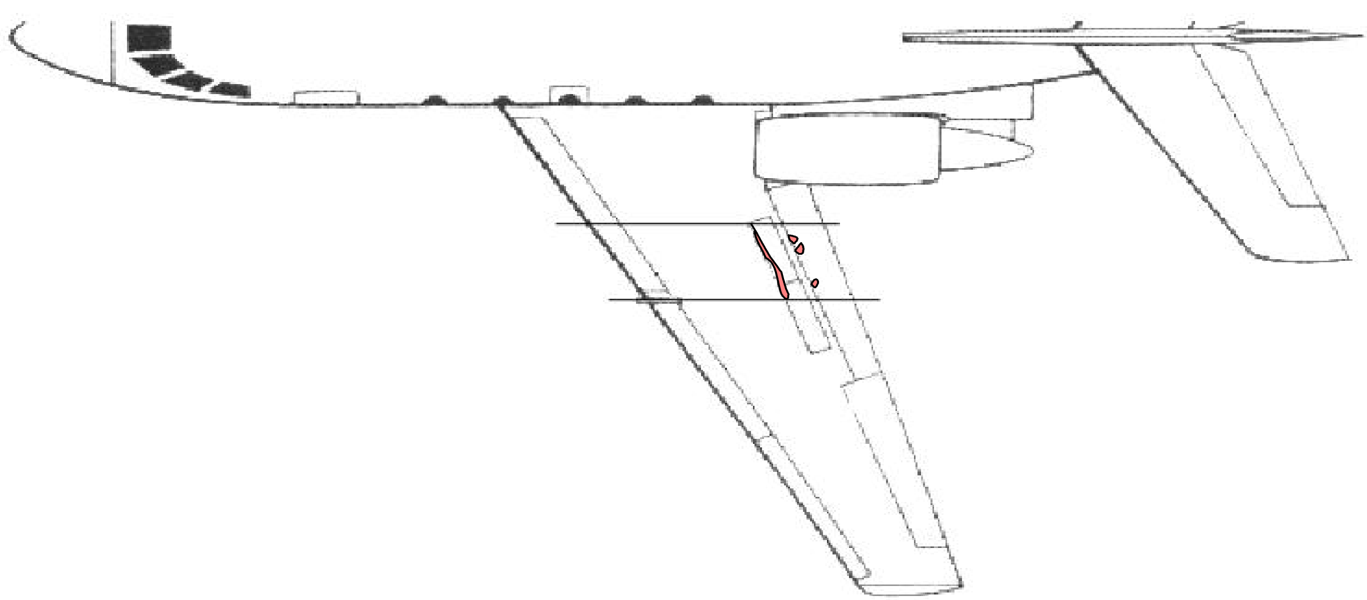
Run 8 - Failure Pattern After Takeoff Run

February 23, 1999

a) Failure Pattern Reported by Ground Observer



b) Failure Pattern Reported by Experienced Cabin Observer



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4.8.2.4 Viscosity

The viscosity of a sample of contaminated fluid taken prior to the takeoff run was 100 mPas at 0.3 r/min.

The viscosity of a sample of contaminated fluid taken following the takeoff run was recorded to be 0 mPas at 0.3 r/min, using the same viscometer.

4.9 Run Nine: Propylene Glycol-Based Type IV Fluid; Contamination Beyond 100 Percent

4.9.1 Prior to Takeoff Run

4.9.1.1 Extent and Pattern of Contamination

Artificial freezing rain was applied to the test area for 25 minutes.

Ground Observer
The objective of this trial run was to examine whether a severely contaminated propylene glycol-based fluid would be completely eliminated from the wing surface during the takeoff run.

The initial fluid layer prior to contamination was of typical thickness with values up to 2.7 mm on the top of the main wing. See Figure 4.27. The application of artificial freezing rain was continued well beyond the point where contamination was evident on the top layer of the fluid. By comparison, 100 percent contamination in Run 7 was achieved in 8 minutes of precipitation.

This run took place from 9:45 to 10:45, and the sun was now having a significant effect on wing skin temperatures. While the OAT was -14°C, the leading edge skin temperature was -6°C in the shade and -3°C in the sun.

These skin temperatures affected the formation of ice. A reasonably thick layer of frozen contamination was eventually built up in the shaded areas. The final distribution of ice over the test area is shown in Photo Set 4.17. Light surface ice covered a large part of the test surface area, especially over the mid-wing and the flap surface.

Photo Set 4.17 shows the appearance of the fluid while the freezing rain was being applied. An ice crust can be seen sliding over the underlying fluid. This photo set captured the appearance of the final degree of contamination achieved prior to the takeoff run.

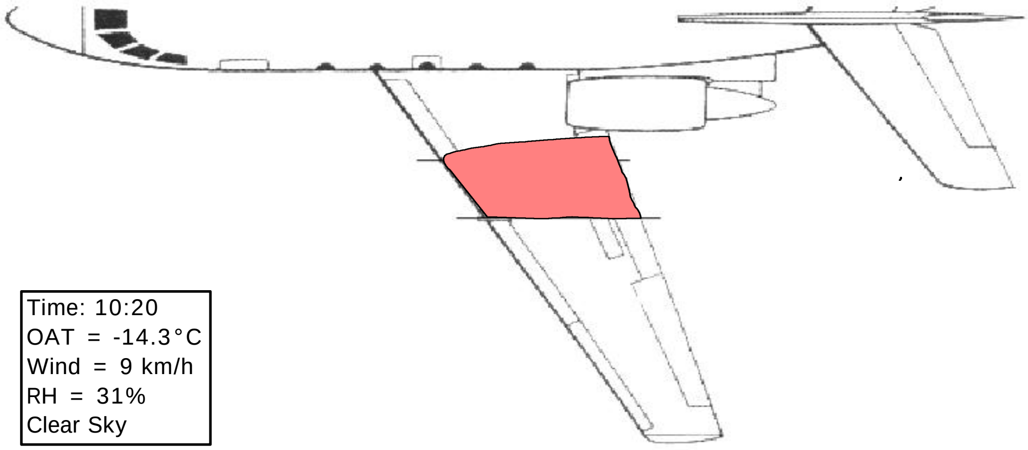
Experienced Cabin Observer
The experienced cabin observer noted very distinct areas of icing, similar to the areas of thicker ice recorded by the ground observer. Areas of light surface ice were not identified or noted.

FIGURE 4.27

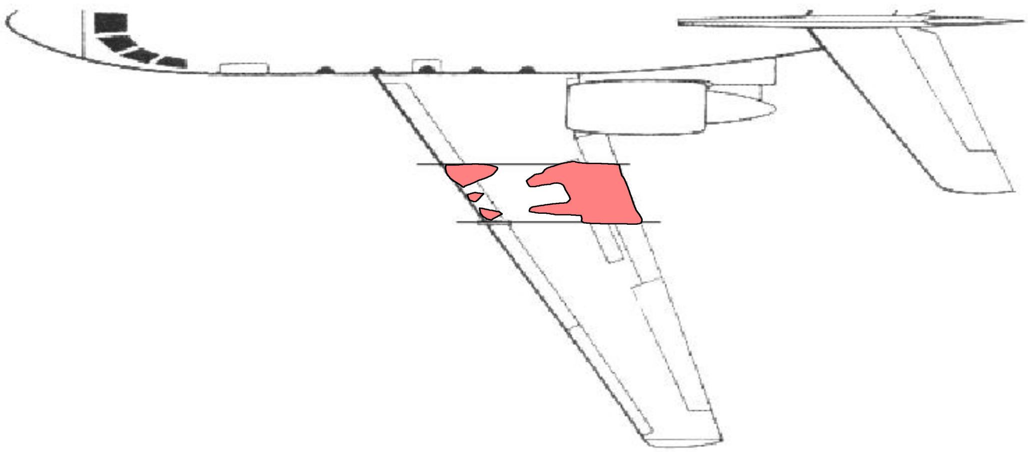
Run 9 - Failure Pattern Before Takeoff Run

February 23, 1999

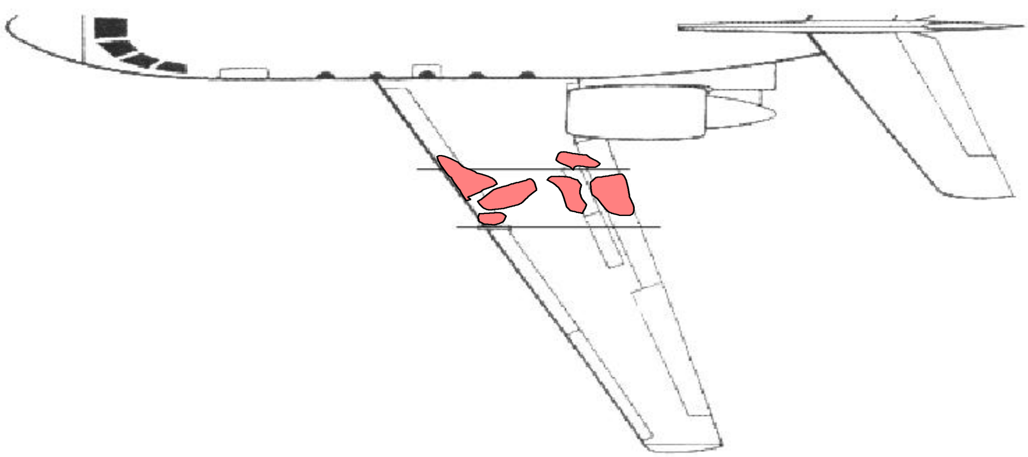
a) Failure Pattern Reported by Ground Observer



b) Failure Pattern Reported by Experienced Cabin Observer



c) Failure Pattern Reported by Pilot



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At: Before
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Pilot

The pilot record indicates patches of ice distributed over the entire test area.

4.9.1.2 Fluid Thickness

See Figure 4.28. The initial fluid application was very similar to the two previous runs with propylene glycol-based fluid. Following contamination, the fluid thickness was reduced to about 15 percent of that of the uncontaminated fluid thickness.

4.9.1.3 Contaminant Adhesion

Contaminant adhesion was noted on the leading edge (Figure 4.29) where an ice patch existed within the shaded area of the wing. Some adhesion was also noted within ice patches at the rear of the wing. This indicates that wing surface temperatures play an important role in contaminant adhesion.

4.9.1.4 Viscosity

The viscosity of a sample of uncontaminated fluid taken from the wing was 17,700 mPas at 0.3 r/min.

4.9.2 Following Takeoff Run

4.9.2.1 Extent and Pattern of Contamination

Ground Observer

On return from the takeoff run, it was observed that those areas where, prior to takeoff, a light layer of ice had formed on the fluid surface were now clean of ice *and* of fluid. Areas where ice of substantial thickness had formed prior to the takeoff run remained ice-covered after the aircraft returned to the inspection pad. See Figure 4.30 and Photo 4.18.

FIGURE 4.28

FLUID THICKNESS ON AIRCRAFT

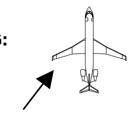
AIRPORT: YMX

AIRCRAFT TYPE: FALCON 20

DATE: 23-Feb-99

WING: PORT (A)

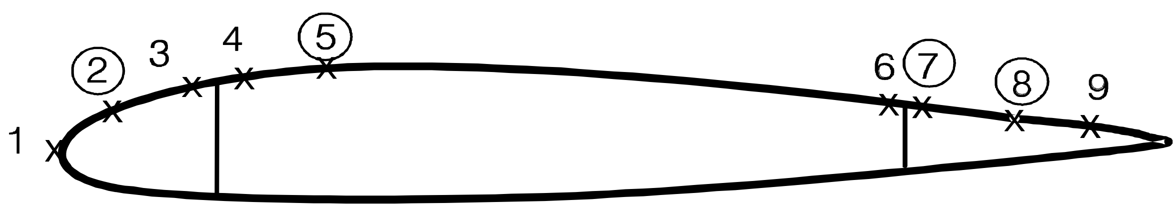
DRAW DIRECTION OF WIND WRT WING:



RUN #: 9

DIRECTION OF AIRCRAFT: 40 DEGREES

Location	Before Rain Spray Time	Before Rain Spray Thick. (mm)	Before Takeoff Time	Before Takeoff Thick. (mm)	After Takeoff Time	After Takeoff Thick. (mm)
1	8:25	0.95	8:34	0.11	8:56	0.04
2	8:25	1.71	8:34	0.24	8:56	0.04
3	8:25	2.54	8:34	0.38	8:56	0.04
4	8:25	2.54	8:34	0.44	8:56	0.04
5	8:25	2.24	8:34	0.83	8:56	0.04
6	8:25	1.97	8:34	Ice	8:56	0.48
7	8:25	1.42	8:34	Ice	8:56	0.04
8	8:25	1.33	8:34	0.70	8:56	0.06
9	8:25	1.33	8:34	0.58	8:56	0.16



Location

1 **- LE Nose**
2,8 **- Half-way**
3,4,6,7 **- 1" from joint**
5 **- As far as can reach**
9 **- 6" from TE**

Note:
Give priority to circled locations; measure other locatios only if time allows.

COMMENTS:

MEASUREMENTS BY:

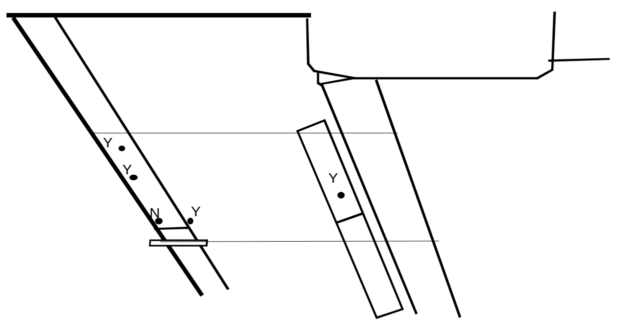
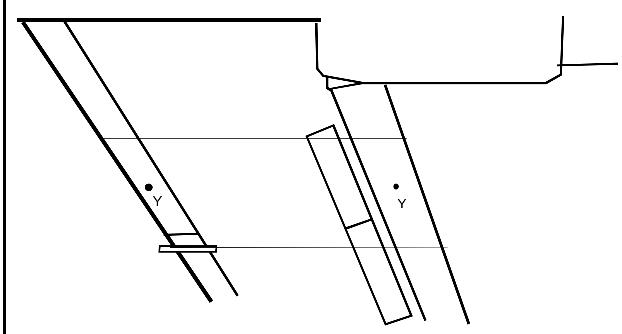
HAND WRITTEN BY:

FIGURE 4.29

Run 9 - Fluid Adhesion and Wing Skin Temperature

February 23, 1999

ADHESION

Before Takeoff	After Takeoff
	

WING SKIN TEMPERATURE (°C)

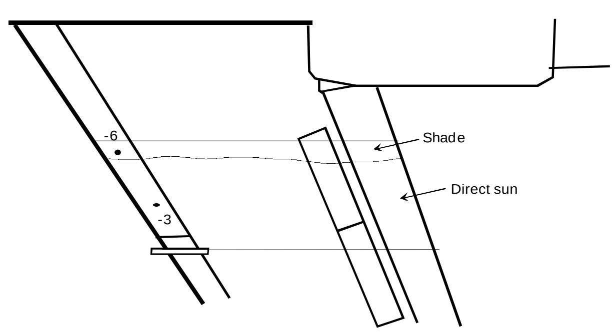
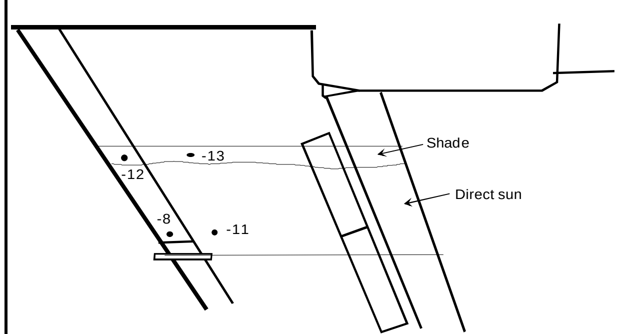
Before Takeoff	After Takeoff
	

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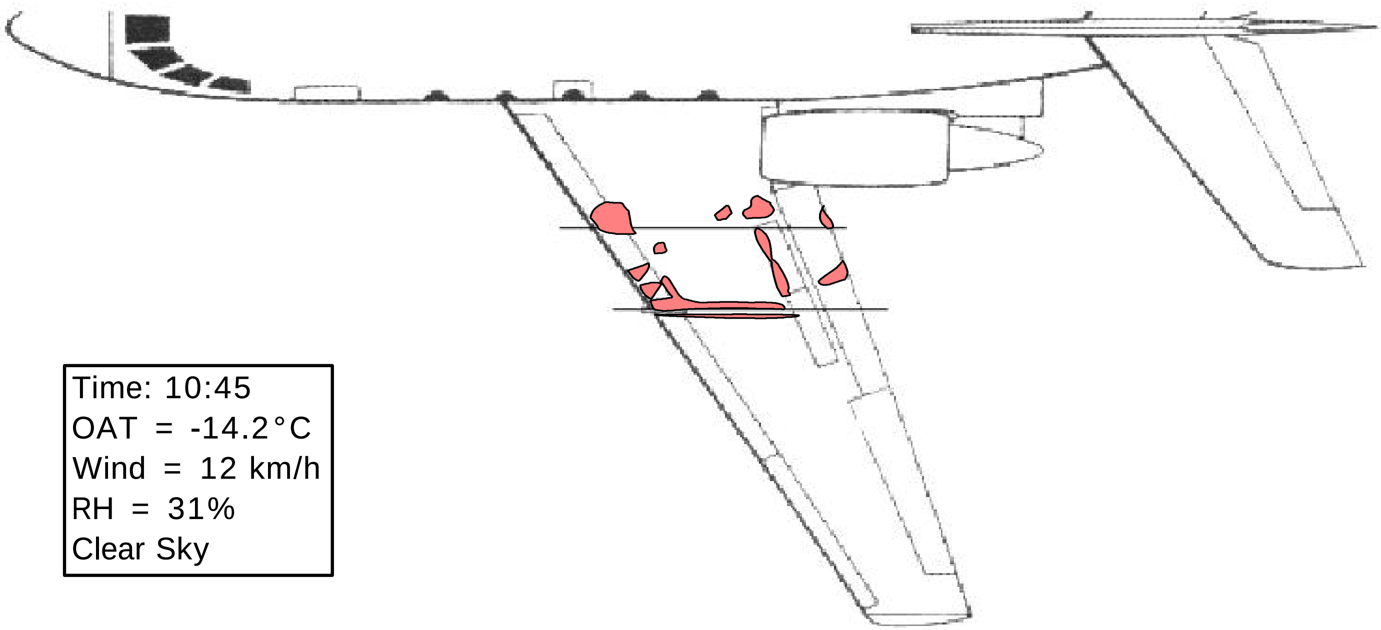
FIGURE 4.30

Run 9 - Failure Pattern After Takeoff Run

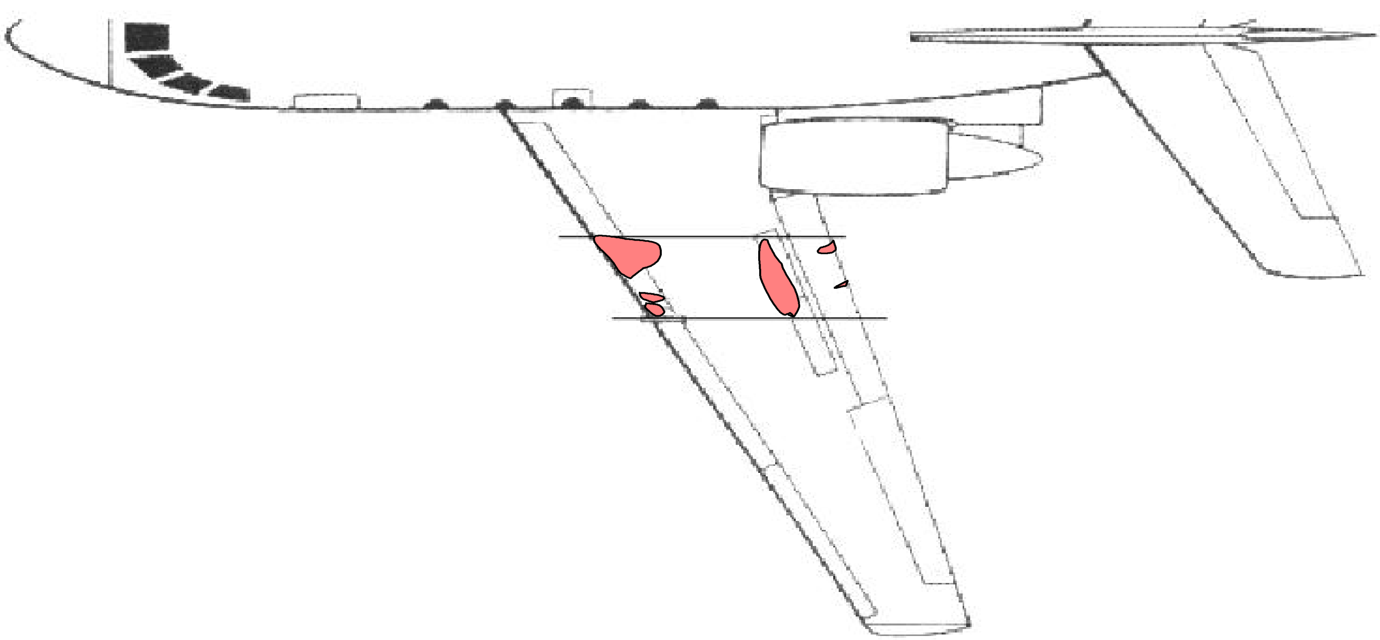
February 23, 1999

a) Failure Pattern Reported by Ground Observer



Time: 10:45
OAT = -14.2°C
Wind = 12 km/h
RH = 31%
Clear Sky

b) Failure Pattern Reported by Experienced Cabin Observer



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Experienced Cabin Observer

The cabin observer recorded the ice remaining on the wing surface as very similar to that recorded by the ground observer.

4.9.2.2 Fluid Thickness

Following the takeoff run, the fluid remaining on the non-iced test areas had a thickness comparable to previous propylene glycol-based fluid runs.

4.9.2.3 Contaminant Adhesion

Following the takeoff run, the major portion of the ice remaining on the wing had undergone adhesion.

4.9.2.4 Viscosity

The solid ice formations that remained on the wing after the takeoff run were not subject to viscosity measurements in their liquid state.

4.9.3 Observations from Videotape of Fluid During the Takeoff Run

During the takeoff run, the contaminated fluid could be seen peeling away and lifting off the wing surface at about 60 kn. The mechanism of elimination from the wing was notably different in this run. In previous runs, the fluid took on a waveform and progressively migrated to the rear of the wing and thence into the air stream. In this run, the fluid peeled away from the wing surface and lifted vertically into the air stream. This effect was even more dramatic than that recorded in Run 7. This mechanism of elimination may be associated with high dilution levels of propylene glycol-based Type IV fluid as was the case in this run.

4.10 Elimination of Ethylene Glycol-Based SAE Type IV Fluid During Takeoff

4.10.1 Elimination of Uncontaminated Fluids

The uncontaminated fluid was completely eliminated during the takeoff run, leaving behind only a very thin film, maximum 0.1 mm in thickness.

During the taxi phase, the layer of uncontaminated fluid on the wing was deformed by wind shear into a dynamic array of lateral ridges oriented perpendicular to the direction of airflow, all the while being swept toward the trailing edge.

By the time the aircraft reached 80 kn during the takeoff run, most of the fluid had been eliminated from the wing through migration of the fluid to the rear of the wing and thence into the air stream.

4.10.2 Elimination of Contaminated Fluids

Five takeoff runs (2, 3, 5, 6, and 8) were conducted with contaminated ethylene glycol-based SAE Type IV fluid. In each run, the degree of fluid contamination with respect to the extent and location was varied by the duration of exposure to freezing precipitation and by direction of the contaminant to selected areas of the wing test surface. A summary of observations and measurements from these runs is presented in Table 4.2.

Regardless of the initial level of contamination, where ice existed prior to takeoff, ice persisted at these coordinates upon return to the inspection pad. At most of these locations, the sizes of the iced regions were diminished, but some amount of ice remained.

In most cases, prior to the takeoff run, existing ice contamination was not adherent to the aircraft wing surface. Many of those ice patches (about 50 percent) showed some level of adhesion following the takeoff run.

Any fluid that had existed outside the ice patches prior to the takeoff run had been eliminated from the wing upon the aircraft's return to the inspection pad. The fluid had been diluted to various concentrations by exposure to the freezing rain spray. During the takeoff run, fluid was eliminated from the wing via migration toward the rear of the wing and thence into the airstream.

TABLE 4.2

SUMMARY OF TAKEOFF RUN RESULTS

CONTAMINATED ETHYLENE-BASED SAE TYPE IV FLUID

Run #	OAT (°C)	Level of Contamination (%)	Spray Duration	Adhesion						Fluid Eliminated?	Ice Eliminated?		
				Before Run			After Run						
				LE	MW	TE	LE	MW	TE		LE	MW	TE
8	-14	1%	9	N		N	N		N	Y	N		N
6	-20	5%	11	N		N	Some		Y	Y	N		N
3	-16	10%	15	N	N		Y	Y		Y	N	N	
2	-17	25%	20	N		Y	N		Y	Y	N		N
5	-23	40%	11	N	N	N	N	N	Some	Y	N		N

Legend:

LE - Leading Edge

MW - Main Wing

TE - Trailing Edge

cm1514/analysis/falcon20/Summary.xls
At: Ethylene
Printed: 1/21/02, 1/21/02

4.11 Elimination of Propylene Glycol-Based SAE Type IV Fluid During Takeoff

4.11.1 Elimination of Uncontaminated Fluids

The uncontaminated fluid was completely eliminated during the takeoff run, leaving behind only a very thin film, maximum 0.1 mm in thickness.

With this uncontaminated fluid, wave formation was not evident during the taxi phase.

During the takeoff run, much of the fluid had been eliminated from the wing by the time the aircraft reached 60 kn. By the time the aircraft reached 100 kn, the green coloration of the fluid had completely disappeared.

4.11.2 Elimination of Contaminated Fluids

Two contaminated fluid takeoff runs (7 and 9) were conducted, each with a different level of fluid contamination (Table 4.3).

In Run 7, 100 percent contamination was identified after an 11-minute exposure to the freezing rain spray. As described earlier, this contamination took the form of a thin layer of solid precipitation distributed over the entire test area and overlying a thick layer of minimally contaminated fluid. A good deal of the layer of contamination was swept from the wing during the taxi phase; however, a conspicuous patch of contaminant remained on the top of the mid-wing at the beginning of the takeoff run.

Once into the takeoff run, this patch was observed to fragment and to flow to the rear and off the wing along with the underlying layer of relatively uncontaminated fluid.

In Run 9, the freezing rain spray was continued far beyond the level of contamination described above. The intent was to determine the level of contamination required for the ice formations *not* to be eliminated during the takeoff run.

During the takeoff run, some ice patches were eliminated while others remained on the wing surface. The majority of those ice formations that remained following the takeoff run had become adhered to the wing surface.

TABLE 4.3

SUMMARY OF TAKEOFF RUN RESULTS

CONTAMINATED PROPYLENE-BASED SAE TYPE IV FLUID

Run #	OAT (°C)	Level of Contamination (%)	Spray Duration	Adhesion						Fluid Eliminated?	Ice Eliminated?		
				Before Run			After Run						
				LE	MW	TE	LE	MW	TE		LE	MW	TE
7	-17	100%	11	N	N	N	N	N	N	Y	Y	Y	Y
9	-14	Beyond 100%	25	Some		Some	Y		Y	Y	N	N	N

<u>Legend:</u>

LE - Leading Edge

MW - Main Wing

TE - Trailing Edge

The mechanism of elimination from the wing was notably different in this run, wherein the failed fluid became detached, peeled away from the wing surface, and lifted vertically into the air stream. This mechanism of elimination may be associated with the degree of fluid dilution, but may also be a result of the contamination layer lifting off the wing in an inherent airfoil shape and experiencing immediate abrupt fragmentation.

It should be noted that 100 percent failure was called for Run 7 following only 8 minutes of exposure to freezing rain precipitation. In comparison, for ethylene glycol-based fluids, 10 minutes of exposure resulted in a contamination level of 5 percent in Run 6. In general, ethylene glycol-based fluid trials to various levels of contamination experienced ice formations that remained on the wing following the takeoff run. In contrast, the propylene glycol-based fluid at the 100 percent failure call resulted in a clean wing at takeoff. This is an important consideration in light of decision-making. It has important implications regarding the remote ice detection cameras currently being developed. The different fluids undergo visual failures at different time intervals and, in the case of the propylene glycol-based fluid, considerable contamination (100 percent) resulted in a clean wing upon takeoff. There are two further considerations here: first, although this fluid was 100 percent *visually* failed, it performed well; second, optoelectronic devices may indicate that these fluids have failed well before they have lost their protection capacity.

4.12 Viscosity Levels of Fluid Samples

4.12.1 Uncontaminated Fluids

Viscosity measurements performed on samples of uncontaminated fluid recovered from the wing (Table 4.1) showed the viscosities to have dropped to 50 percent of their corresponding drum values.

A sample of the uncontaminated ethylene glycol-based Type IV fluid (Run 1) taken from the aircraft wing demonstrated a notable decrease in viscosity (6800 mPas at 0.3 r/min versus 14,800 mPas at 0.3 r/min for the fluid as received from the manufacturer (Run 3). Following the takeoff run, the viscosity was even further diminished to 100 mPas.

Samples of the uncontaminated propylene glycol-based Type IV fluid (Run 4) taken from the aircraft wing had values of 10,600 and 11,300 mPas at 0.3 r/min while samples taken from a drum of delivered fluid had values of 20,100 and 21,000 mPas at 0.3 r/min. Following the takeoff run, viscosity had a greater value of 14,200 mPas at 0.3 r/min. A separate sample of uncontaminated propylene glycol-based Type IV fluid, taken before the application of freezing rain precipitation in Run 9, had a viscosity of 17,700 mPas at 0.3 r/min, somewhat closer to the drum values.

The viscosity values were determined subsequent to the field test. There was no mandate to rationalize these findings. The values are reported as consequential data. Some fluid shear and some dilution from absorbed surface water may be responsible for this phenomenon.

4.12.2 Contaminated Fluids

For the ethylene glycol-based fluid, the sample of fluid recovered before the takeoff run (Run 8) had a viscosity level of 100 mPas at 0.3 r/min.

Samples of fluid recovered after the takeoff run had viscosity values of zero, except in one case (Run 3) where the viscosity was 100 mPas at 0.3 r/min.

For the propylene glycol-based Type IV fluid, the viscosities of contaminated fluid (Run 7) were determined to be 13,800 and 13,400 mPas at 0.3 r/min, somewhat higher than values reported for uncontaminated fluid in Run 4.

4.13 Roughness Profile of Contaminated Wing Surface

Subsequent to conducting the field tests, interest was expressed in the determination of a surface roughness profile developed during the takeoff run.

To satisfy this need, video and photo records of selected takeoff runs were reviewed. From this record, visual estimates of surface roughness were deduced.

These estimates were very approximate, but provide some appreciation of the surface profile. The estimates developed are provided in Table 4.4.

TABLE 4.4

NOTES ON SURFACE ROUGHNESS FROM CONTAMINATED AIRCRAFT TAKEOFF TESTS
Notes on roughness, estimated from video footage of test results, after takeoff run.

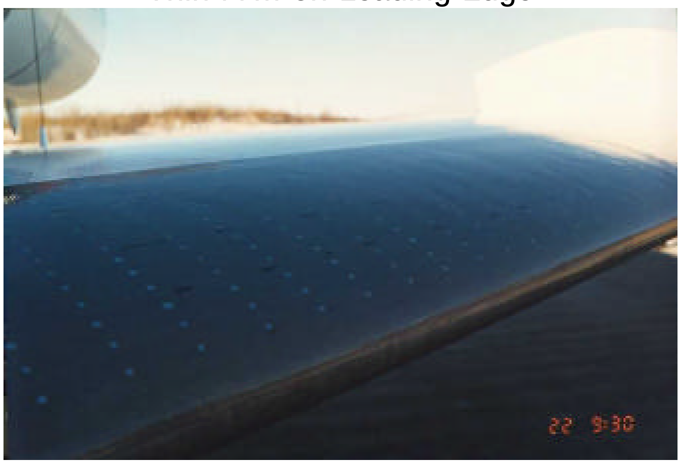
RUN 5 **SAE Type IV Ethylene-Based Fluid** **Contaminated to 40% Level**	Position 5: main wing behind leading ege, fluid is in slush condition 0.25 mm depth. Position 2: on leading edge, 1/2 way from nose to rear of leading edge joint to main wing, ice condition exists. Estimated maximum thickness is 3 mm. Ice surface has been smoothed during the takeoff run, and forms a knobby type of surface, without sharp peaks. Estimate about 5 peaks/in^2 maximum.
RUN 6 **SAE Type IV Ethylene-Based Fluid** **Contaminated to 5% Level**	Position 2: on leading edge, 1/2 way from nose to rear of leading edge joint to main wing, ice condition exists. Estimated maximum thickness is 1.5 mm. As before, ice surface has been eroded and smoothed during the takeoff run, and is a relatively snooth but knobby surface. Knobs exist at about 2/in^2. Further back on main wing, just ahead of flight control surfaces. Ice remaining is thinner than on leading edge, estimated at 0.5 mm. Appearance is rougher, with less smoothing due to air flow. Peaks about 5/in^2.
RUN 7 **SAE Type IV Propylene-Based Fluid** **Contaminated to 100% Level**	Although the entire fluid surface was contaminated prior to the takeoff run, all traces of contamination were removed during the takeoff run.
RUN 9 **SAE Type IV Propylene-Based Fluid** **Contaminated Beyond the 100% Level**	Position 2: on leading edge, 1/2 way from nose to rear of leading edge joint to main wing. Ice about 2 mm depth. About 4 peaks/in^2.

Photo 4.1
Run 1 - Appearance of Fluid Prior to Takeoff Run

Uncontaminated Ethylene Glycol-Based Type IV Fluid

Photo Set 4.2
Run 1 - Appearance of Fluid Following Takeoff Run

Thin Film on Leading Edge



Film on Rear of Wing

Puddling Ahead of Spoiler Panel

Fluid Ahead of Spoiler Panel

Photo Set 4.3

Run 2 - Appearance of Fluid Prior to Takeoff Run

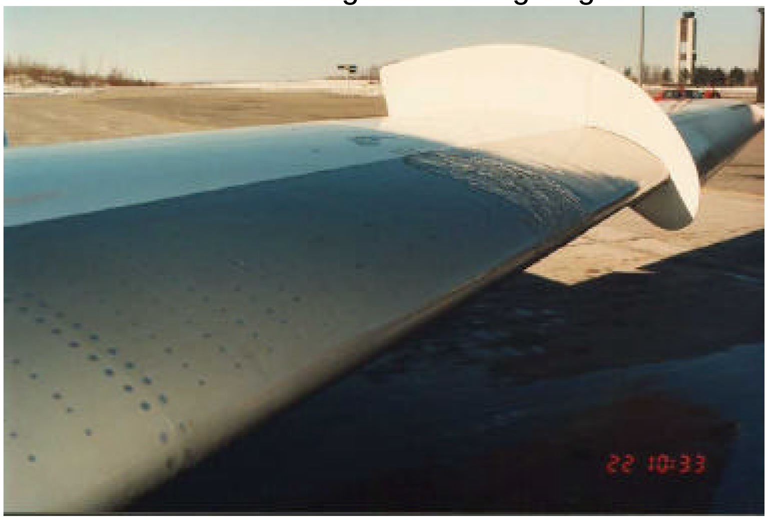
Ethylene Glycol-Based Type IV Fluid at 25 Percent Contamination

Failed Fluid on Flap

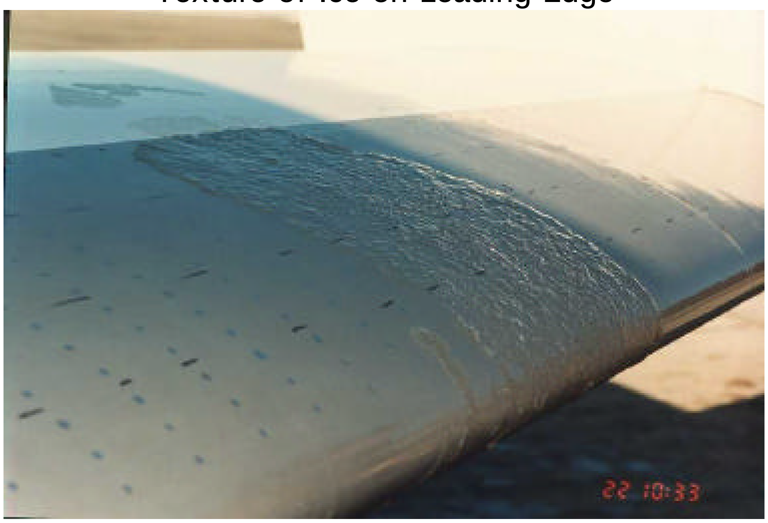
Ice on Leading Edge

Photo Set 4.4
Run 2 - Appearance of Fluid Following Takeoff Run

Ice Remaining on Leading Edge



Texture of Ice on Leading Edge



Ice on Flap Surface

Photo 4.5

Run 3 - Appearance of Fluid Prior to Takeoff Run
Ethylene Glycol-Based Type IV Fluid at 10 Percent Contamination

Ice on Leading Edge

Photo Set 4.6

Run 3 - Appearance of Fluid Following Takeoff Run

Ice on Leading Edge

Ice Texture

Photo Set 4.7

Run 4 - Appearance of Fluid Prior to Takeoff Run

Uncontaminated Propylene Glycol-Based Type IV Fluid

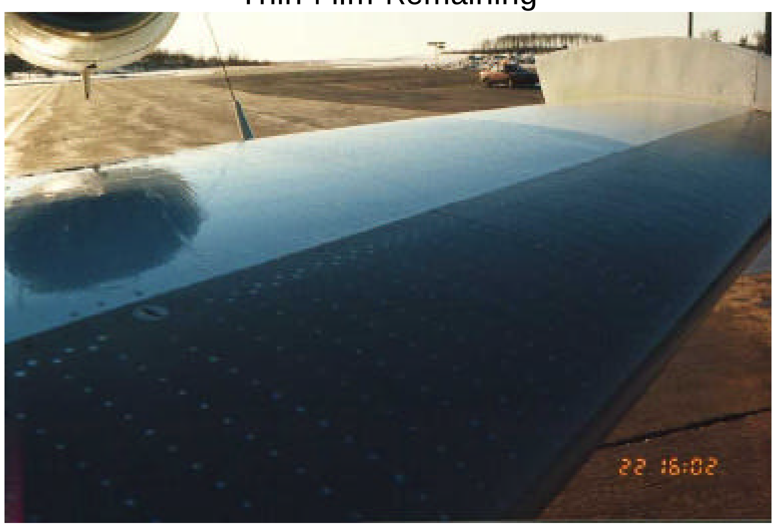
Fluid on Leading Edge

Photo Set 4.8

Run 4 - Appearance of Fluid Following Takeoff Run

Ridges in Fluid Film

Thin Film Remaining



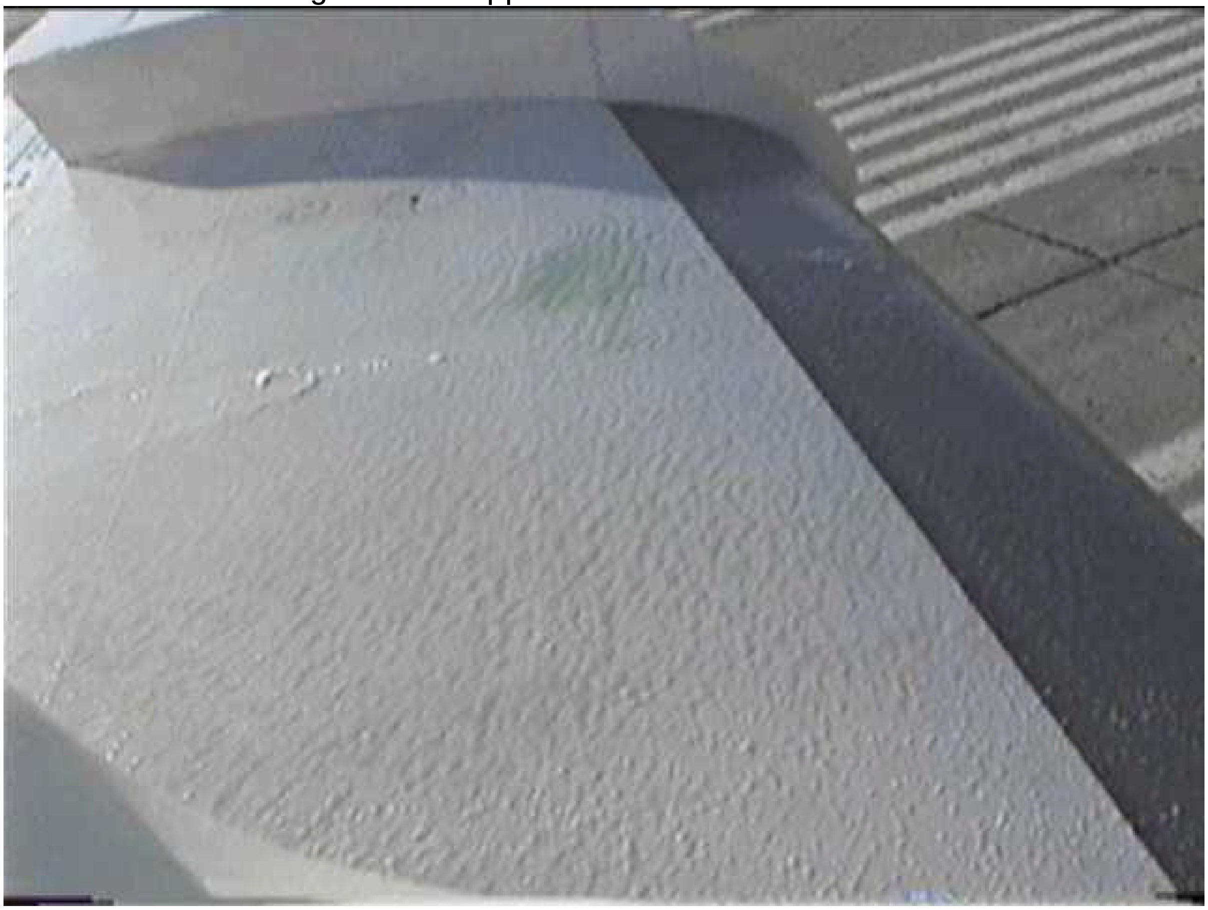
Puddling Ahead of Spoiler Panel

Photo 4.9
Run 5 - Appearance of Fluid Prior to Takeoff Run
Ethylene Glycol-Based Type IV Fluid at 40 Percent Contamination

Failed Fluid on Leading Edge

Video Image 4.1
Run 5 - Ethylene Glycol-Based Fluid, at 40 Percent Failure

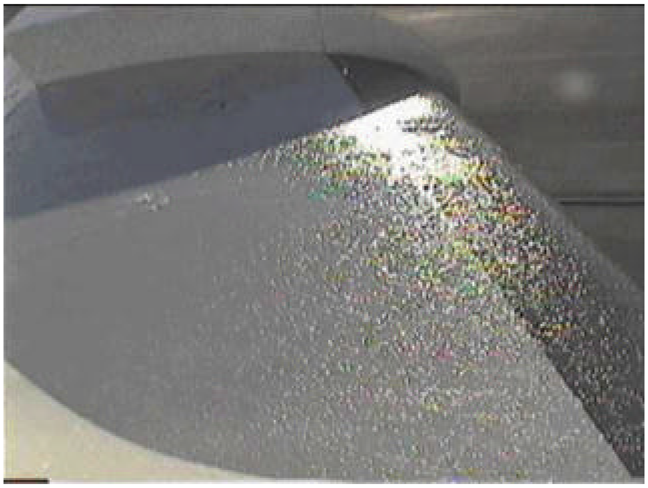
Wing Surface Appearance at End of Taxi Phase

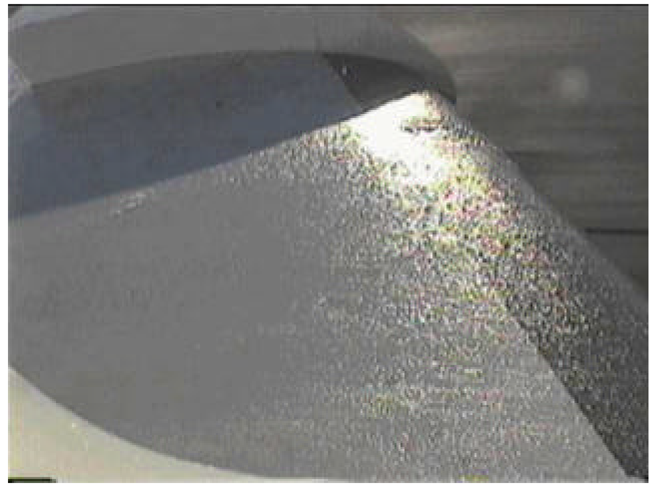


Video Image Set 4.2

Run 5 - Ethylene Glycol-Based Fluid, at 40 Percent Failure

Wing Surface Appearance During Takeoff





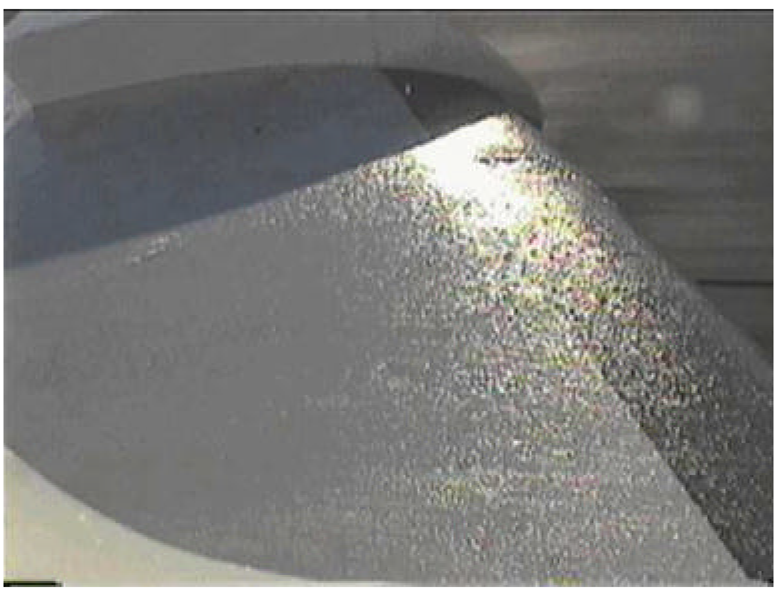


Photo Set 4.10
Run 5 - Appearance of Fluid Following Takeoff Run

Ice on the Forward Wing

Ice on the Forward Wing

Ice on the Flap Surface

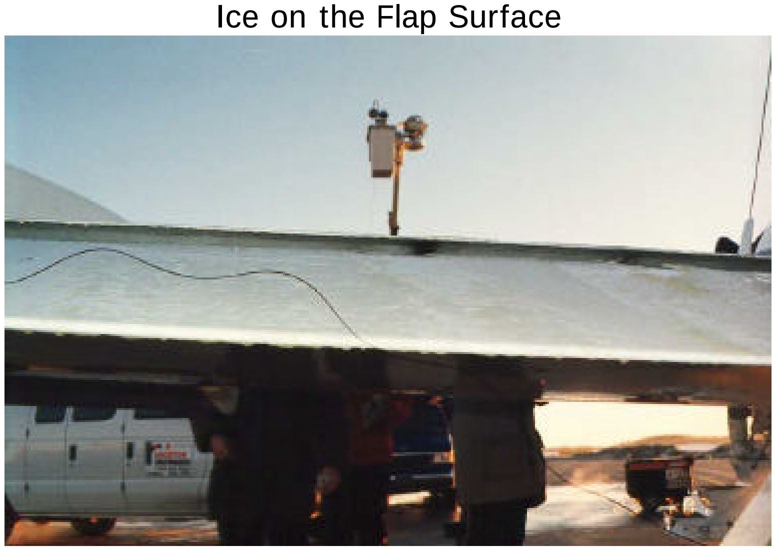


Photo 4.11

Run 6 - Appearance of Fluid Prior to Takeoff Run
Ethylene Glycol-Based Type IV Fluid at 5 Percent Contamination

Ice on the Leading Edge

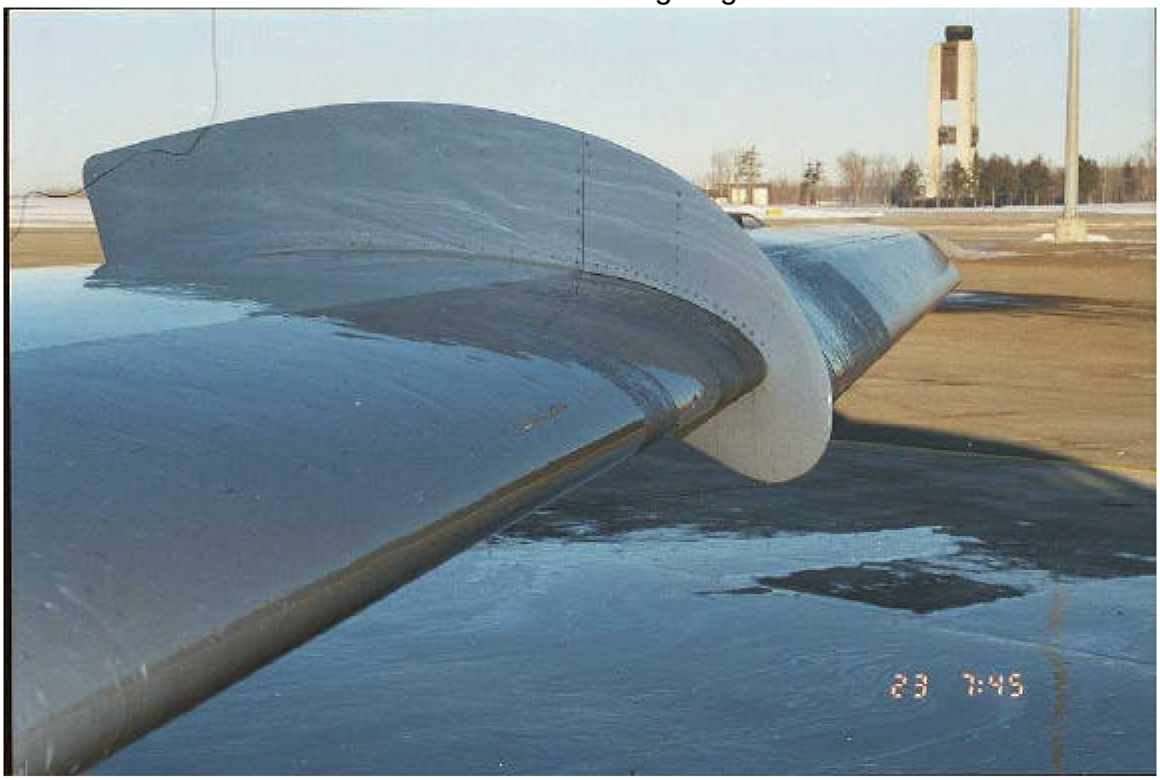


Photo Set 4.12
Run 6 - Appearance of Fluid Following Takeoff Run

Ice Patches on the Rear of the Wing

Ice Patches on the Leading Edge

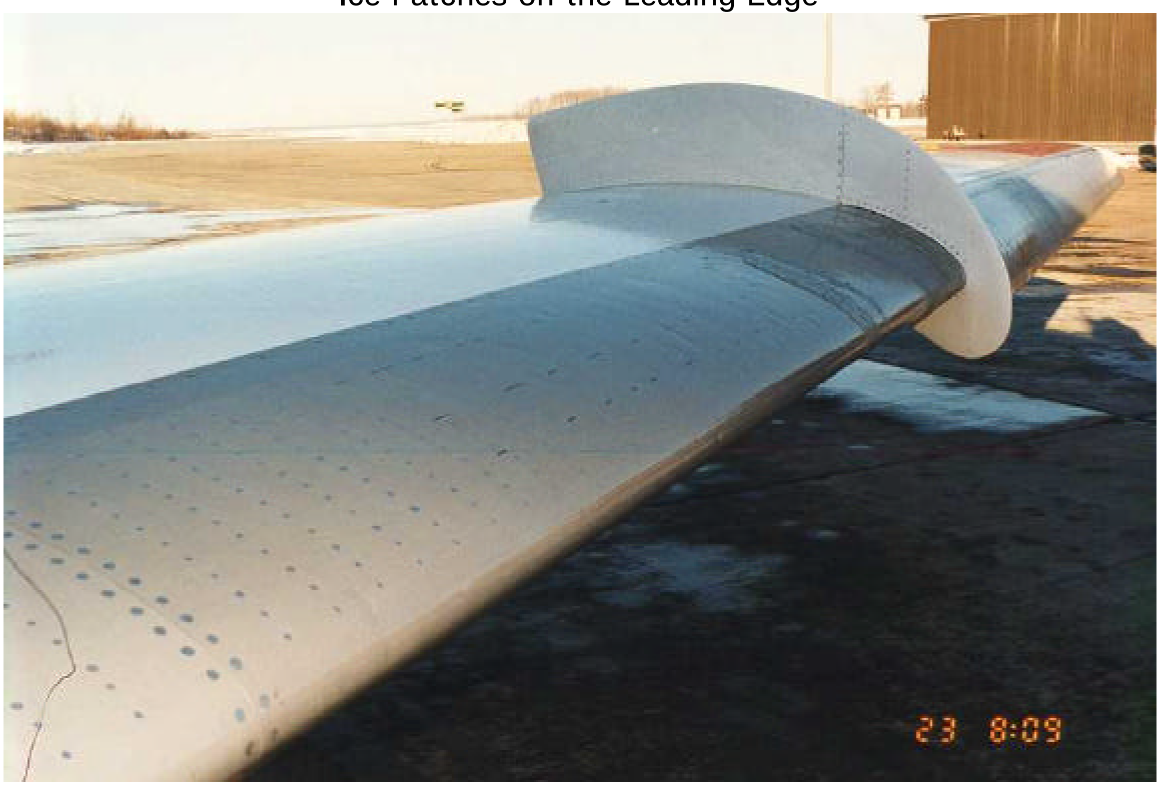
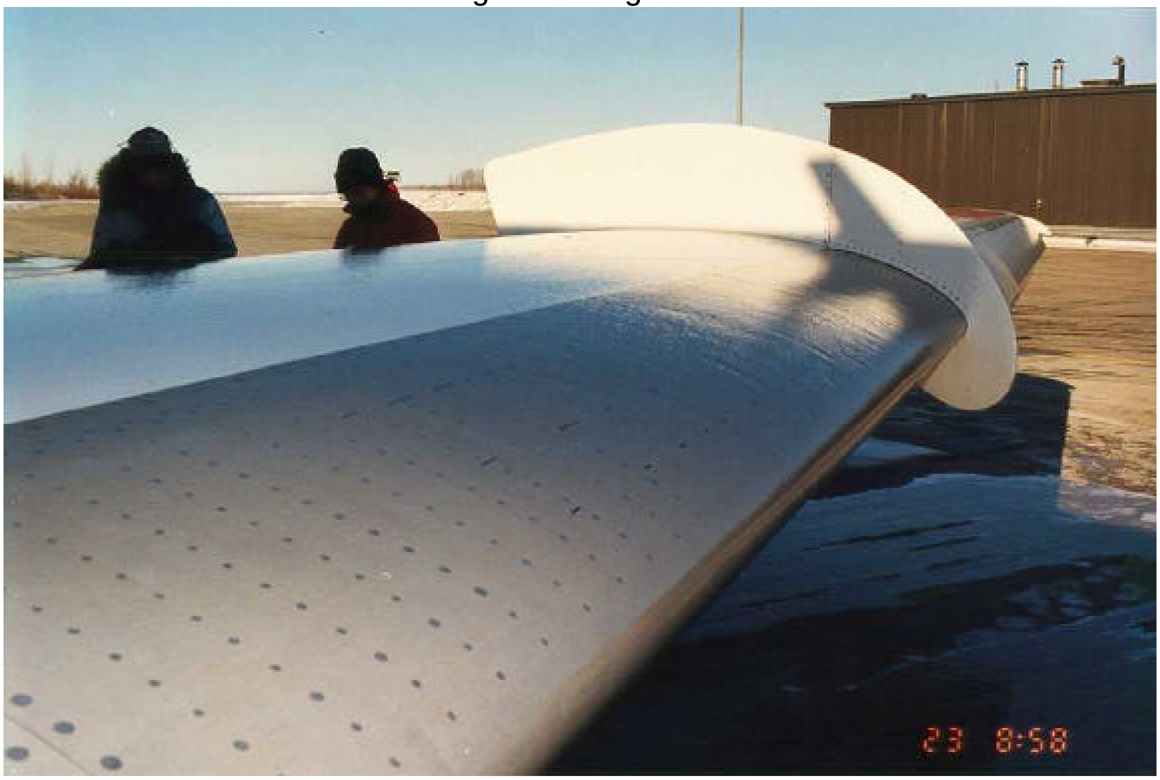


Photo 4.13
Run 7 - Appearance of Fluid Prior to Takeoff Run
Propylene Glycol-Based Type IV Fluid at 100 Percent Contamination

Fluid at 100 Percent Failure

Photo 4.14
Run 7 - Appearance of Fluid Following Takeoff Run

Clear Wing Following Takeoff Run



Video Image 4.3
Run 7 - Propylene Glycol-Based Fluid, at 100 Percent Failure

Wing Surface Appearance at End of Taxi Phase

Video Image Set 4.4
Run 7 - Propylene Glycol-Based Fluid, at 100 Percent Failure

Wing Surface Appearance During Takeoff

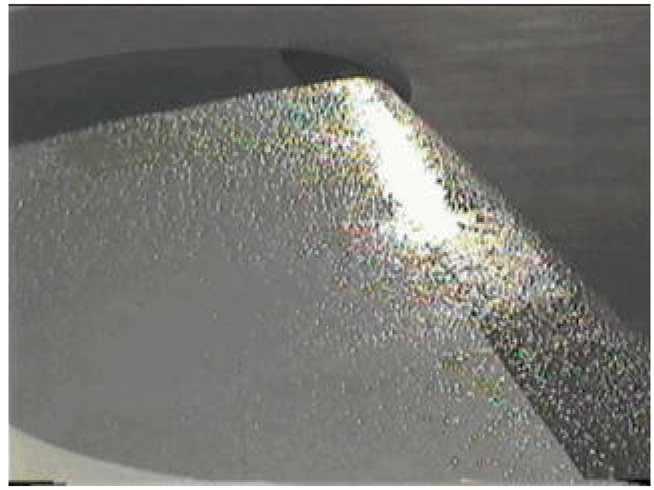
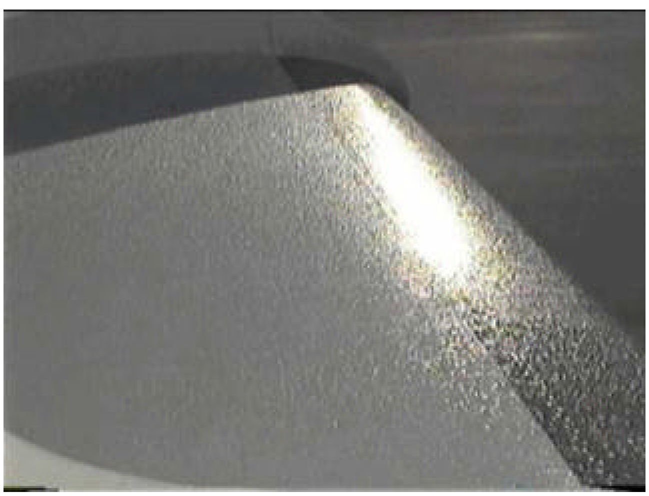
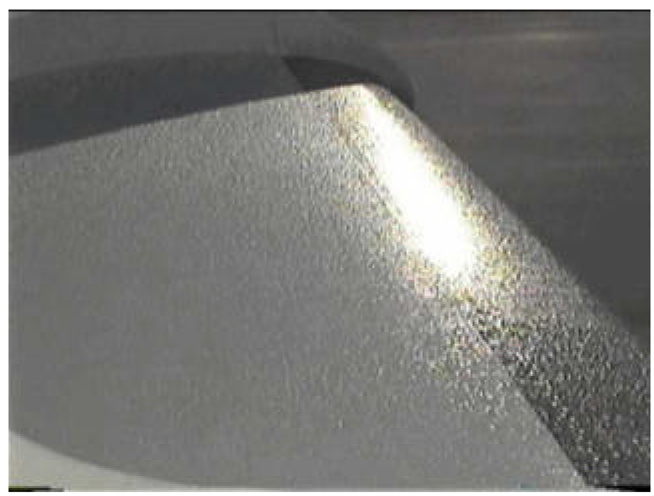





Photo 4.15
Run 8 - Appearance of Fluid Prior to Takeoff Run
Ethylene Glycol-Based Type IV Fluid at 1 Percent Contamination

Ice at Seam on Leading Edge

Photo 4.16
Run 8 - Appearance of Fluid Following Takeoff Run

Remaining Ice at Seam

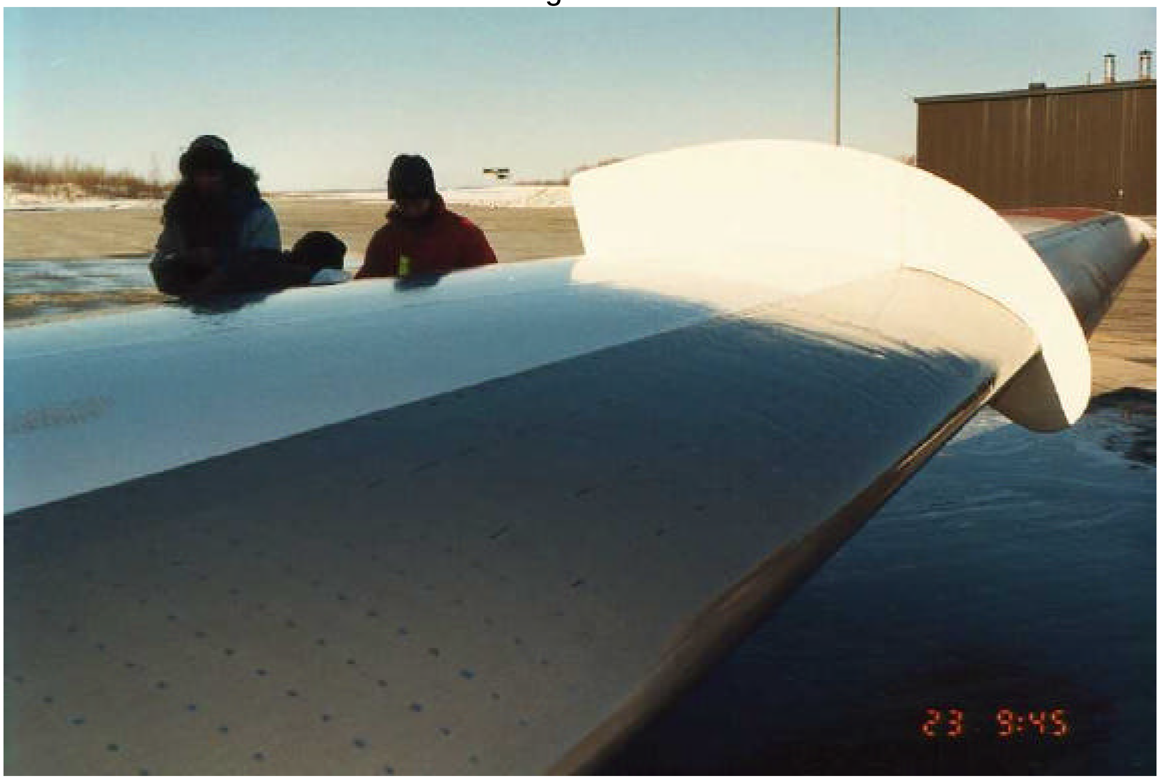


Photo Set 4.17

Run 9 - Appearance of Fluid Prior to Takeoff Run

Propylene Glycol-Based Type IV Fluid at 100 Percent Contamination

Ice Crust Sliding Forward

Ice Crust on Rear Wing

Ice Formation on Leading Edge

Photo 4.18
Run 9 - Appearance of Fluid Following Takeoff Run

Remaining Ice on Leading Edge

5. CONCLUSIONS

5.1 Elimination of Uncontaminated Fluids

Both ethylene and propylene glycol-based Type IV fluids were tested in an uncontaminated state to observe the process of fluid elimination from the wing surface during a simulated takeoff run.

Both fluids underwent near complete elimination, leaving only a very thin film of residual fluid. In either case, the remaining film fluid was in the order of 0.1 mm thick.

The videotape of the fluid surface during the takeoff run showed that the majority of the ethylene glycol-based fluid had been eliminated from the wing surface by the time the aircraft speed had reached 80 kn. The propylene glycol-based fluid appeared to be eliminated even earlier with much of the fluid having been shed by the time the aircraft speed had reached 60 kn. At 100 kn, the green coloration of the fluid had completely disappeared from the wing surface.

5.2 Contaminated Ethylene Glycol-Based SAE Type IV Fluids

Trials conducted with ethylene glycol-based fluid contaminated with freezing rain precipitation to different levels demonstrated that when frozen contamination existed prior to the takeoff run, it remained on the wing following the takeoff. This held true regardless of the extent of contamination. In these trials, ice formation coverage ranged from 1 percent to 40 percent of the test area on the wing surface.

Furthermore, the lack of adhesion of ice to the wing skin prior to the takeoff run did not influence the elimination of contaminated fluid from the wing. In these trials, none of the patches of ice adhered to the wing prior to the takeoff run. However, after the takeoff run, upon the aircraft's return to the inspection pad, it was observed that many of the ice formations had undergone adhesion. About 50 percent of the ice patches had developed adhesion to the wing skin during the takeoff run.

Any fluid that existed outside of the iced regions was eliminated from the wing surface during the takeoff run.

The uncontaminated fluid on the aircraft wing exhibited a significant decrease in viscosity from typical values expected for delivered fluid. Following the takeoff run, viscosity was further degraded. These reductions in viscosity have not yet been completely rationalized. It is suspected that fluid shear upon application and dilution by surface-absorbed water on the wing surface may be possible explanations.

5.3 Contaminated Propylene Glycol-Based SAE Type IV Fluids

Run 7, the takeoff run conducted with a contamination level of 100 percent, demonstrated that complete elimination of propylene glycol-based fluid can be expected when reasonable levels of contamination are experienced, even at low temperatures. This result is attributable to the nature of failure of propylene glycol-based fluids, whereby failures at low temperatures typically occur on the top surface of the fluid, overlying a thick layer of essentially uncontaminated fluid.

The applied fluid was exposed to an extended duration of precipitation to produce contamination far in excess of 100 percent in Run 9. This resulted in the eventual dilution of the underlying fluid layer. Along with this fluid dilution, patches of thicker ice were developed. Some of these patches consequently came into contact with the wing skin. The underlying, initially thick layer of good fluid had partially thinned out. This contamination was not shed during the takeoff run. The level of contamination in this run was extreme, and far beyond that which could be expected to exist at time of takeoff in actual operation.

5.4 Effect of Rotation During the Takeoff Run

Non-frozen fluids on the wing surface were eliminated well before the aircraft reached its rotation speed. In the videotape record taken by the onboard camera, these fluids could be observed to flow off the wing surface when the aircraft speed was in the order of 60 to 80 kn.

Rotation of the aircraft at the prescribed rotation speed during the takeoff run did not appear to cause further elimination of any ice formations that existed on the wing prior to takeoff.

5.5 Identification of Contaminated Areas on the Wing from Inside the Cabin

5.5.1 Contaminated Ethylene Glycol-Based SAE Type IV Fluid

The experienced observer located inside the aircraft cabin identified areas of failure on the test area of the wing that were very similar to those recorded by the outside ground observer. The areas tended to be somewhat smaller but were similar in placement. The flap area appeared to be more difficult to qualify, with missed failures on one occasion and one non-existent failure identified on another.

The identification of the locations and extent of failure appeared to be more accurate in the 'after-takeoff-run' condition. This is likely because of the visibility of ice being enhanced once the fluid was eliminated in the takeoff run.

The pilot's attempt to identify areas of failure in the 'prior-to-takeoff run' condition were largely successful and identified iced areas very similar to those recorded by the experienced cabin observer.

5.5.2 Contaminated Propylene Glycol-Based SAE Type IV Fluid

During Run 7, when a light coating of solid precipitation covered the entire fluid layer (the ground observer judged the fluid to be 100 percent failed), the experienced cabin observer was unable to identify this condition. From inside the cabin, the fluid appearance was recorded as having a 'slushy' appearance.

In the after-takeoff-run condition, the experienced cabin observer had no difficulty identifying a clean wing.

During Run 9, in the prior-to-takeoff-run condition, the experienced observer inside the cabin identified a slightly less extensive area of failure, similar to that identified by the outside ground observer. The area identified in the after-takeoff-run condition was very similar to that recorded by the ground observer.

The calls made by the pilot were, for the most part, very similar to those made by the experienced cabin observer, except that non-existent patches of ice were identified in Run 7 prior to the takeoff run.

5.6 Fluid Viscosity

Viscosity values of uncontaminated Type IV fluids, once applied to the wing, were determined to be significantly different from one run to the next for the same fluid. Also, viscosity values appeared to be significantly reduced relative to the fluids *as received* from the fluid manufacturer. This applied equally to both the ethylene and the propylene glycol-based Type IV fluids.

The viscosity values for samples of contaminated ethylene glycol-based Type IV fluids were very low, in the order of 0 to 100 mPas at 0.3 r/min. Whether these values have significance is questionable, as the makeup of the sample varied from case to case. For some samples, only fluid was included. For others, pieces of the solid ice formation were included along with some fluid. At the time the samples were tested, the ice portions had melted and mixed with the original fluid.

5.7 Go/No-Go Decision Making Based on End-of-Runway Scanning by Sensor Cameras

Following identical duration of exposure to precipitation, the extent of contamination may appear to be much greater for propylene glycol-based Type IV fluids than for ethylene glycol-based Type IV fluids. Conversely, the contamination developed on the propylene glycol-based Type IV fluids may be expected to be completely eliminated during the takeoff run, whereas for the visually lower levels of contamination on the ethylene glycol-based fluids, the contamination may be expected to remain on the wing during the takeoff run.

This has important implications for future decision making based on end-of-runway scanning of aircraft surfaces using remote ice detection sensor cameras. Information on the extent of contamination as provided by the sensor cameras should ideally be evaluated in light of the type of fluid applied. Decisions to return for repeat deicing may depend on the brand of Type IV anti-icing fluid applied. As well, because the fluid manufacturers do not have a very tight set of specifications to which to adhere, large differences in mechanical properties are observed among the propylene glycol-based Type IV fluid brands.

6. RECOMMENDATIONS

1. Further takeoff run trials should be conducted using artificial snow precipitation. The objective of these trials would be to evaluate whether snow provides results similar to freezing rain with respect to the visibility, identification, and elimination of contamination from aircraft wings.

   These trials would provide the opportunity to perform a detailed documentation of the roughness profile of the contaminated surface for subsequent use in wind tunnel research on contaminated surfaces.

2. Viscosities of the Type IV fluids should be examined after application to aircraft wings. This examination of fluid viscosity should explore the influence of differences in spray applications and equipment. Spray application parameters may include distance from wing, spray pattern, and fluid flow rate. Equipment parameters may include truck types, hose length and diameter, nozzle types, fluid temperature, pressure, and flow rate.

   A suggested approach to measure viscosity is to first establish and refine a test procedure at the Dorval Deicing Centre. The procedure could subsequently be followed at any other airport. A study of this nature would require that operations at a number of airport locations be examined to obtain a representation of all important operational parameters.

3. The method used in these trials to measure fluid adhesion should be refined into a standard test method.

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REFERENCES

1. Dawson, P., Hanna, M., Chaput, M., *Contaminated Aircraft Takeoff Test for the 1997/98 Winter*, APS Aviation Inc., Montreal, December 1998, Transportation Development Centre, TP 13316E.

2. Chaput, M., Dawson, P., Hanna, M., Peters, A., D'Avirro, J., *Characteristics of Aircraft Anti-icing Fluid Subjected to Precipitation*, APS Aviation Inc., Montreal, December 1998, Transportation Development Centre, TP 13317E.

3. Dawson, P., D'Avirro, J., *Evaluation of Fluid Thickness to Locate Representative Surfaces*, APS Aviation Inc., Montreal, October 1996, Transportation Development Centre, TP 12900E.

APPENDIX A

TERMS OF REFERENCE – WORK STATEMENT (EXCERPT)

APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE

WORK STATEMENT (EXCERPT)

AIRCRAFT AND FLUID HOLDOVER TIME TESTS FOR WINTER 98/99 (Revised September 1999) DC 176

5.4 Flow of Contaminated Fluids from Wings during Takeoff

5.4.1 Requirement

Evaluate anti-icing fluids for their influence on adherence, in particular, propylene based Type IV fluids which were observed during fluid failure
A test plan shall be developed jointly with NRC.
Two days of testing at Mirabel Airport shall be planned.
Use an ice contamination sensor to assist in documenting contamination levels to provide valuable assistance in data gathering. A contingency allowance to fund sensor company participation shall be included.
Data collected during these trials shall include:

- type of fluid applied;
- record of contamination level prior to take off runs,;record of level of contamination following takeoff runs;
- observations, photography and video taping, and ice sensor records; and
- specifics on aircraft takeoff runs obtained from NRC personnel.

5.4.2 Conduct of Trials and Assembly of Results

Coordinate all test activities, initiating tests in conjunction with NRC test pilots based on forecast weather. Analyse results and document all findings in a final technical report and in presentation format.

APPENDIX B

EXPERIMENTAL PROGRAM

FIELD TRIALS TO EXAMINE REMOVAL OF CONTAMINATED FLUID FROM AIRCRAFT WINGS DURING THE TAKEOFF RUN

CM1514.001

EXPERIMENTAL PROGRAM
FIELD TRIALS TO EXAMINE REMOVAL OF CONTAMINATED FLUID FROM AIRCRAFT WINGS DURING THE TAKEOFF RUN

Winter 1998-99

APS AVIATION INC.

January 21, 2002
Version 4.0

EXPERIMENTAL PROGRAM
FIELD TRIALS TO EXAMINE REMOVAL OF CONTAMINATED FLUID FROM AIRCRAFT WINGS DURING THE TAKEOFF RUN
Winter 1998-99

APS will support a series of trials conducted by the National Research Council examining the elimination of failed fluid from aircraft wings during takeoff.

These trials will be conducted on a Falcon 20 aircraft owned and piloted by the National Research Council. Tests will be conducted at Montreal International Airport (Mirabel) (YMX).

This document provides the detailed procedures and equipment required by APS to support these trials.

1. OBJECTIVES

This project addresses the objective:

i) To establish conditions for which contamination due to anti-icing fluid failure in freezing precipitation fails to flow from the wing of a jet transport aircraft up to rotation speed.

2. TEST REQUIREMENTS

APS will co-ordinate and plan test activities and prepare a final report as well as present results at industry deicing meetings.

APS will provide support to this series of tests in the areas of instrumentation, fluids application, and artificial precipitation application.

Desired weather conditions are dry, with subfreezing outside air temperature, overcast skies and a relative humidity in excess of 75%. Runway conditions are to be clean and dry.

Attachment I provides a description of test procedures. Figure 1 provides a plan overview of the different tests.

3. EQUIPMENT AND FLUIDS

3.1 Equipment

Equipment to be employed is shown in Attachment II.

3.2 Fluids

SAE Type I and Type IV fluids (both ethylene and propylene glycol-based) will be used.

4. PERSONNEL

Six APS staff members are required for tests on aircraft at Mirabel airport.

Aircraft spraying will be provided by AéroMag 2000.

The National Research Council aircraft will be operated by a National Research Council pilot.

Attachment III provides task assignments.

5. DATA FORMS

Figure 1	Test Plan
Figure 2	General Form (Every Test)
Figure 2a	General Form (Once per Session)
Figure 3	Aircraft Test Area for Takeoff Run Trials
Figure 3a	Final Failure Pattern
Figure 3b	Progressive Failure Pattern Form
Figure 3c	Fluid Sampling Form
Figure 3d	Fluid Adherence Form
Figure 4	Fluid Thickness on Aircraft

FIGURE 1

TEST PLAN – REMOVAL OF CONTAMINATED FLUID FROM AIRCRAFT WINGS DURING TAKEOFF RUN

2nd TEST SESSION – MARCH 1999
SNOW CONTAMINATION

Run	Fluid	Level of Contamination
1	Type IV Propylene-based Neat	10%
2	Type IV Propylene-based Neat	10% ± x
3	Type IV Propylene-based Neat	10% ± x
4	Type IV Ethylene-based Neat	10%
5	Type IV Ethylene-based Neat	10% ± x

Note: Levels of contamination will be decided based upon elimination observed at initial (10%) test.

FIGURE 2

GENERAL FORM (EVERY TEST)

(TO BE FILLED IN BY WING OBSERVER)

DATE: ______________________

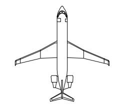
AIRCRAFT TYPE: FALCON 20

RUN #: ______________________

WING: PORT (A) STARBOARD (B)

DIRECTION OF AIRCRAFT: ________ DEGREES

DRAW DIRECTION OF WIND WRT WING:



LEVEL OF CONTAMINATION PRESCRIBED: ____________ %

DEPARTURE FROM DE-ICING BAY TIME: ____________

APPROX. END OF TAKEOFF RUN TIME: ____________

1st FLUID APPLICATION

Actual Start Time: ____________ **am / pm** **Actual End Time:** ____________ **am / pm**

Amount of Fluid Sprayed: ____________ **L / gal** **Type of Fluid:** ____________

2nd FLUID APPLICATION

Actual Start Time: ____________ **am / pm** **Actual End Time:** ____________ **am / pm**

Amount of Fluid Sprayed: ____________ **L / gal** **Type of Fluid:** ____________

End of Test Time: ____________ (hr:min:ss) am/pm

COMMENTS: ______________________

MEASUREMENTS BY: ______________________

HAND WRITTEN BY: ______________________

File: h:\cm1514\procedur\to_run\Gform4.xls
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FIGURE 2a

GENERAL FORM (ONCE PER SESSION)

(TO BE FILLED IN BY OVERALL COORDINATOR)

AIRPORT: YUL YYZ YOW YMX

AIRCRAFT TYPE: FALCON 20

EXACT PAD LOCATION OF TEST: ______________________

AIRLINE: ______________________

DATE: ______________________

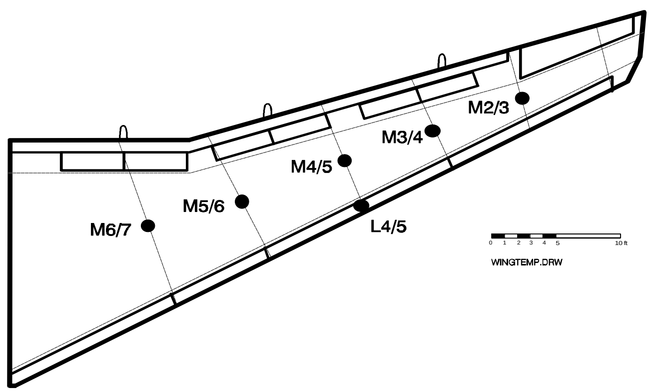
FIN #: ______________________

APPROX. AIR TEMPERATURE: ________ °C

FUEL LOAD: ______________________ **LB / KG**

TYPE I FLUID APPLICATION	***TYPE IV FLUID APPLICATION***
TYPE I FLUID TEMP: ________ °C	**TYPE IV FLUID TEMP:** ________ °C
Type I Truck #: ________	**Type IV Truck #:** ________
Type I Fluid Nozzle Type: ________	**Type IV Fluid Nozzle Type:** ________
Sample collected: Y / N	**Sample collected: Y / N**

TEMPERATURE MEASUREMENTS



ENTER FLUID TYPE:						
TIME	**TEMPERATURE AT LOCATION (°C)**					
(min)	**M6/7**	**M5/6**	**L4/5**	**M4/5**	**M3/4**	**M2/3**
Before[1] ( )						

(1) Actual Time Before Fluid Application

COMMENTS: ______________________

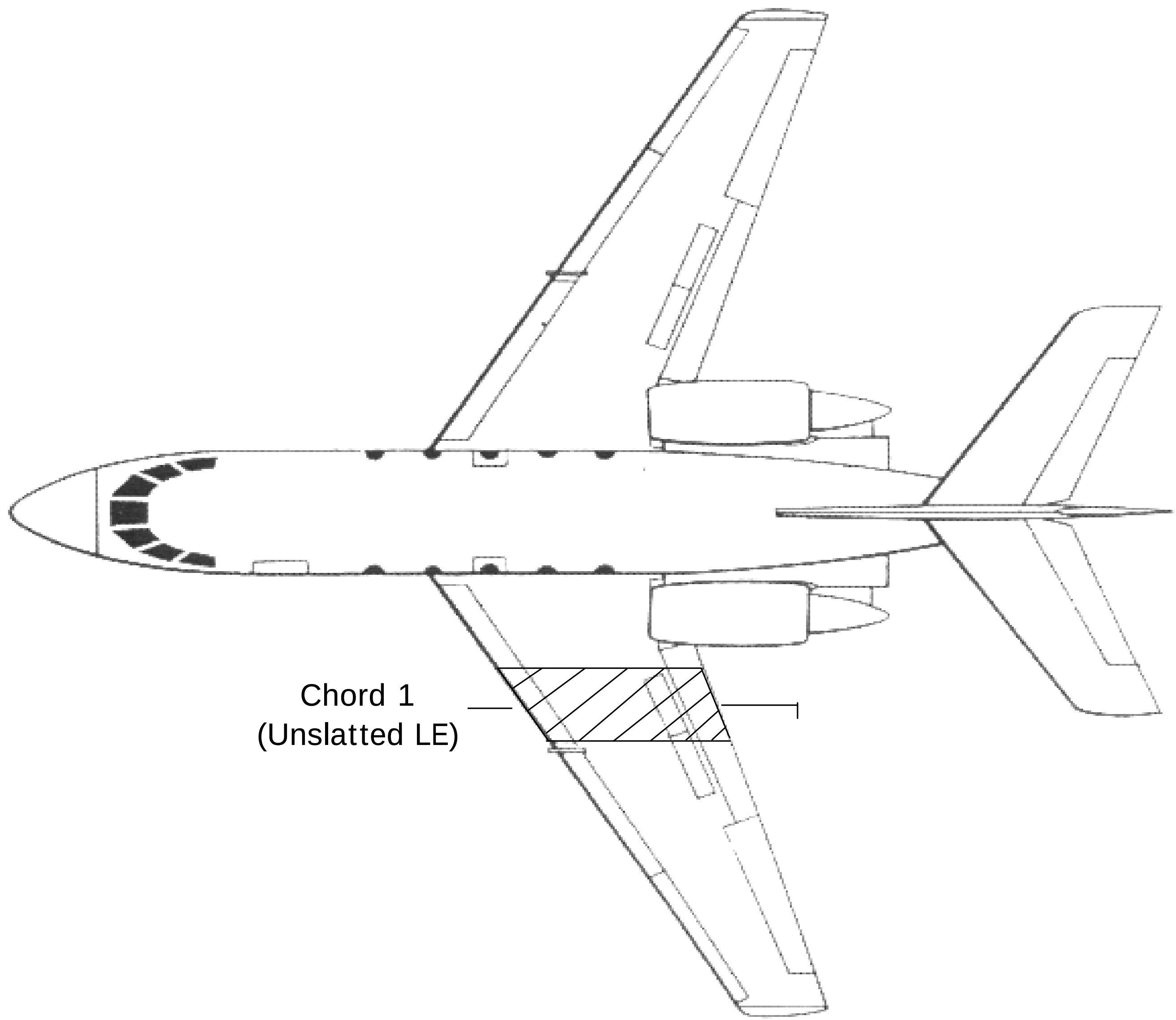
MEASUREMENTS BY: ______________________

HAND WRITTEN BY: ______________________

FIGURE 3

AIRCRAFT TEST AREA FORM FOR TAKEOFF RUN TRIALS

FALCON 20D



Cross-hatched area = Area of wing to be tested

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At: AREA
Printed: 1/21/02, 4:03 PM

FIGURE 3a

FINAL FAILURE PATTERN FORM FOR AIRCRAFT WING

FALCON 20D

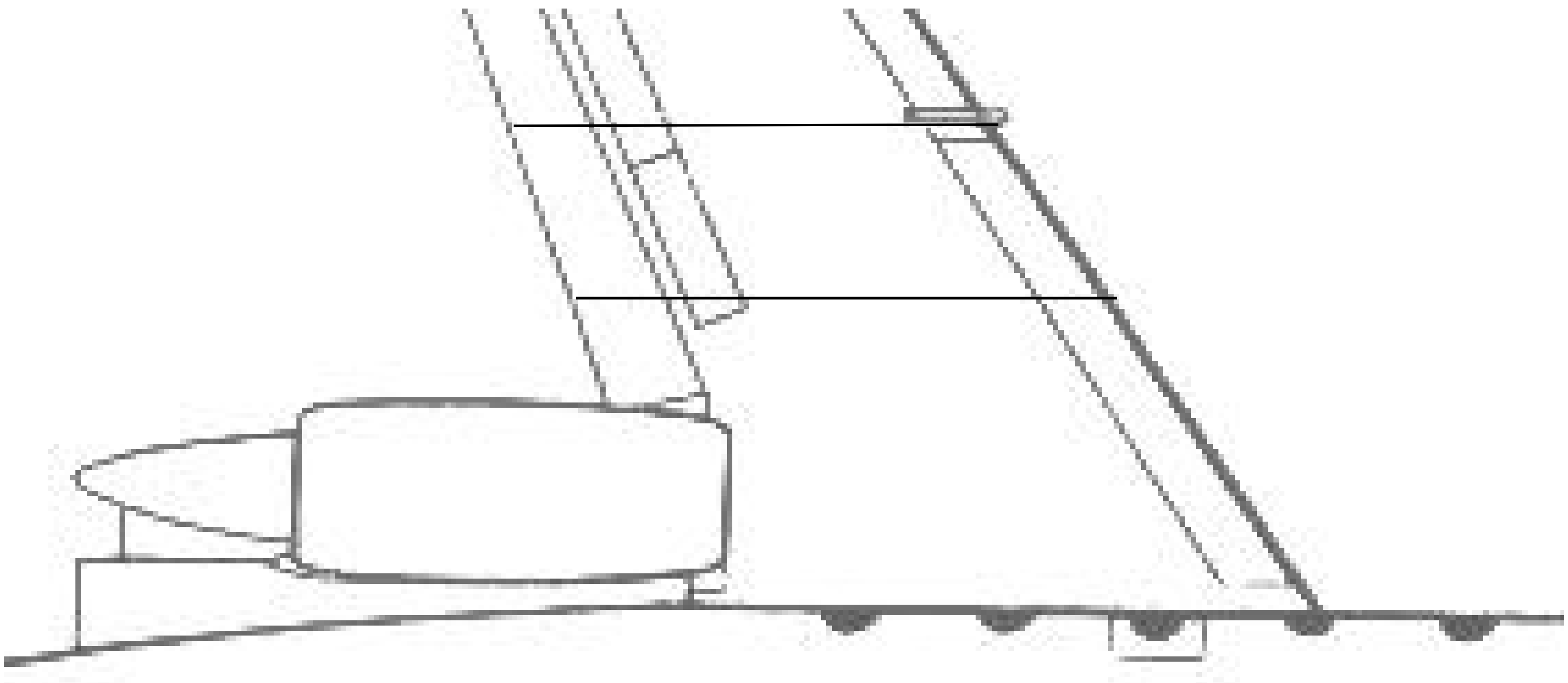
Date: ________________ **Time:** ________________ **Run Number** ________

Failure Contours: Before Takeoff ________ After Takeoff ________

Location of Observer: Cabin ________ Wing ________

Fluid Type: ________________

DRAW FAILURE CONTOURS ACCORDING TO THE PROCEDURE



COMMENTS: ____

____

____

____

FAILURE CALLED BY: ________________________

ASSISTED BY: ________________________

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At: FRM3A
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FIGURE 3b

PROGRESSIVE FAILURE PATTERN FORM FOR AIRCRAFT WING

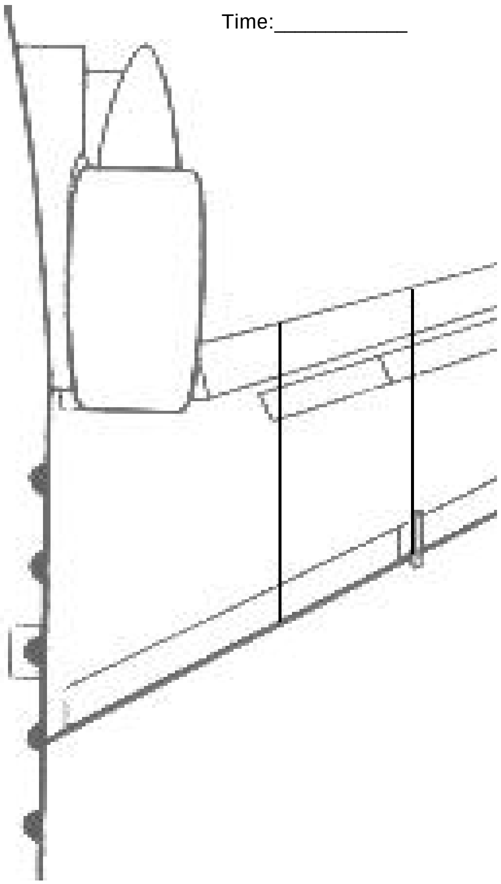
FALCON 20D

Date: ________________ **Start Time:** ________________ **Run Number:** ________

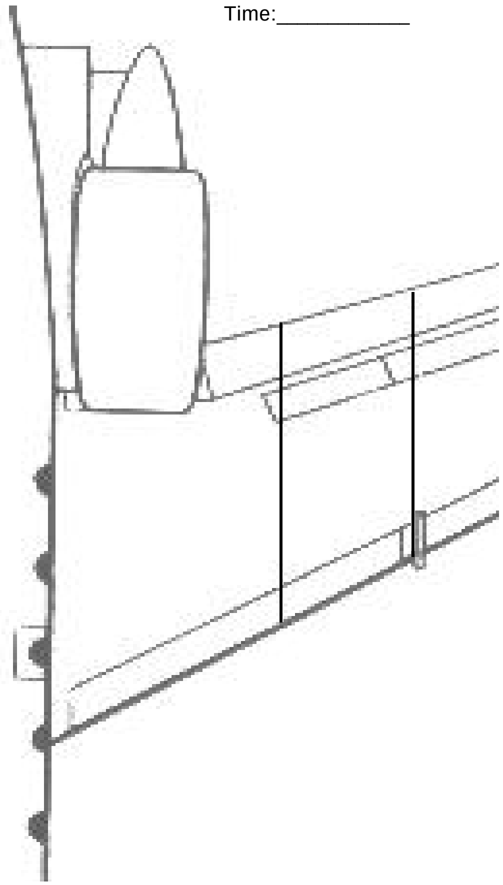
Note: Record Patterns at 5 minutes intervals from start time. **Fluid Type:** ________________

DRAW FAILURE CONTOURS ACCORDING TO THE PROCEDURE

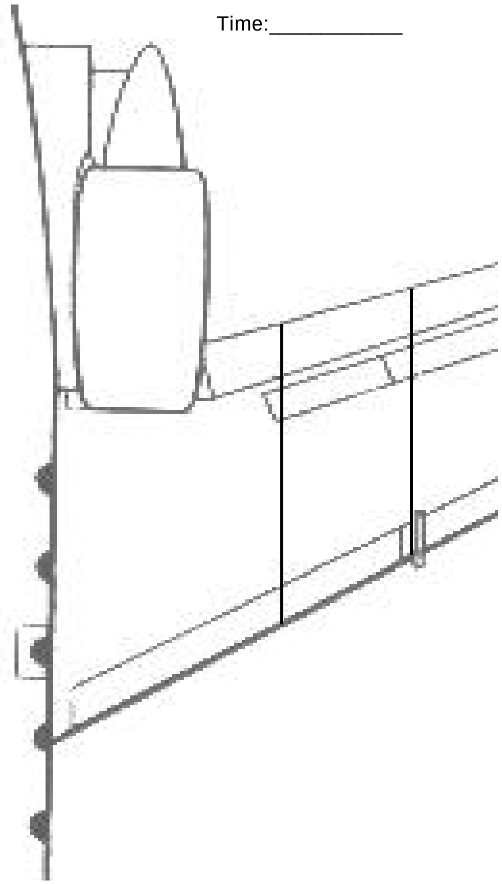
Time:___________



Time:___________



Time:___________



COMMENTS: ____

____

____

____

FAILURE CALLED BY: ________________________

ASSISTED BY: ________________________

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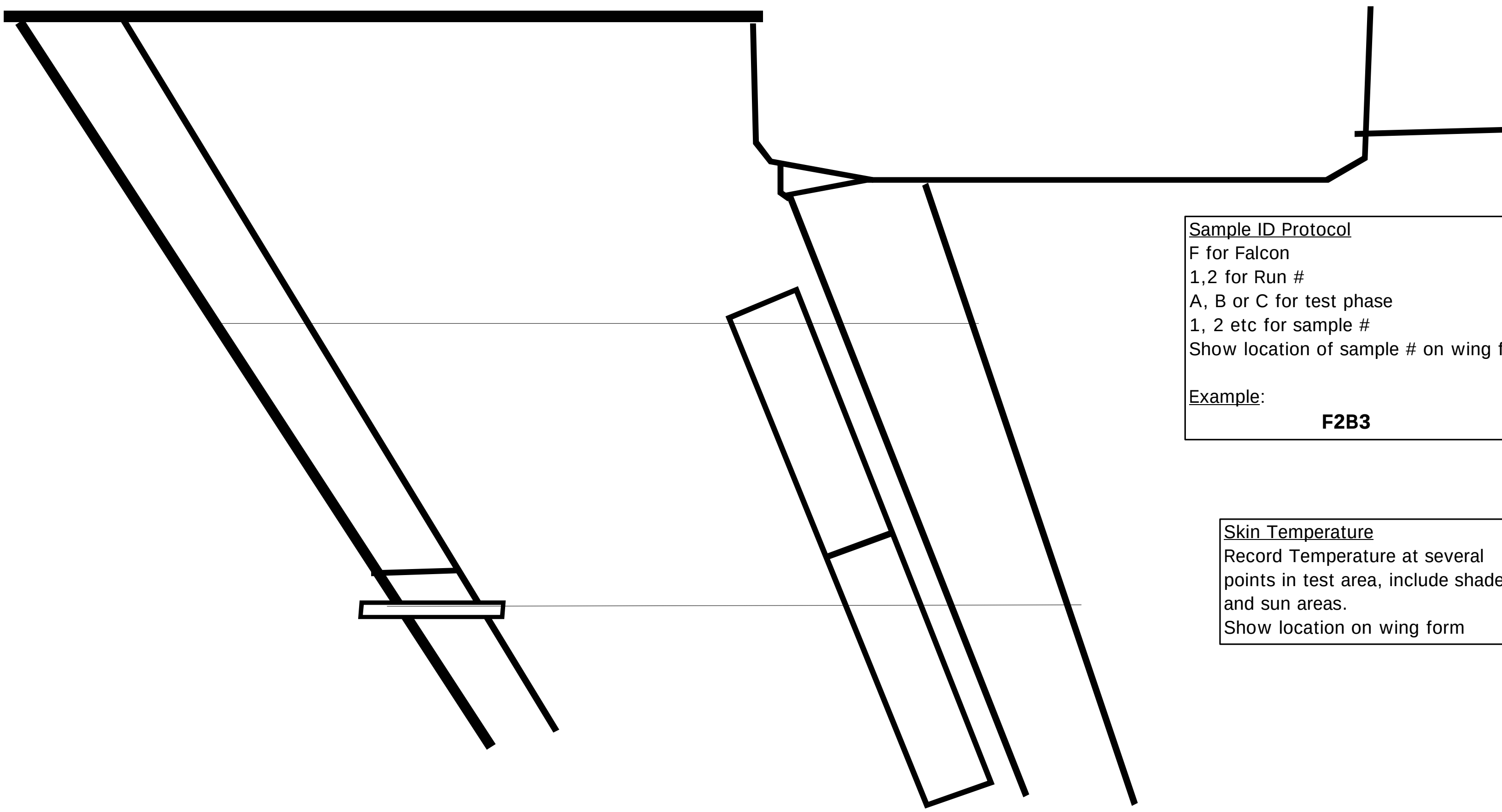
FIGURE 3c

FLUID SAMPLING AND TEMPERATURE RECORDING FORM FOR AIRCRAFT WING

FALCON 20D

Date: ______________ **Time:** ______________ **Run Number** ________

Test Phase: **A- before snow** ☐ **B- before takeoff** ☐ **C- after takeoff** ☐



Sample ID Protocol
F for Falcon
1,2 for Run #
A, B or C for test phase
1, 2 etc for sample #
Show location of sample # on wing form.

Example:
F2B3

Skin Temperature
Record Temperature at several points in test area, include shaded and sun areas.
Show location on wing form

COMMENTS: ____

FAILURE CALLED BY: ______________________

ASSISTED BY: ______________________

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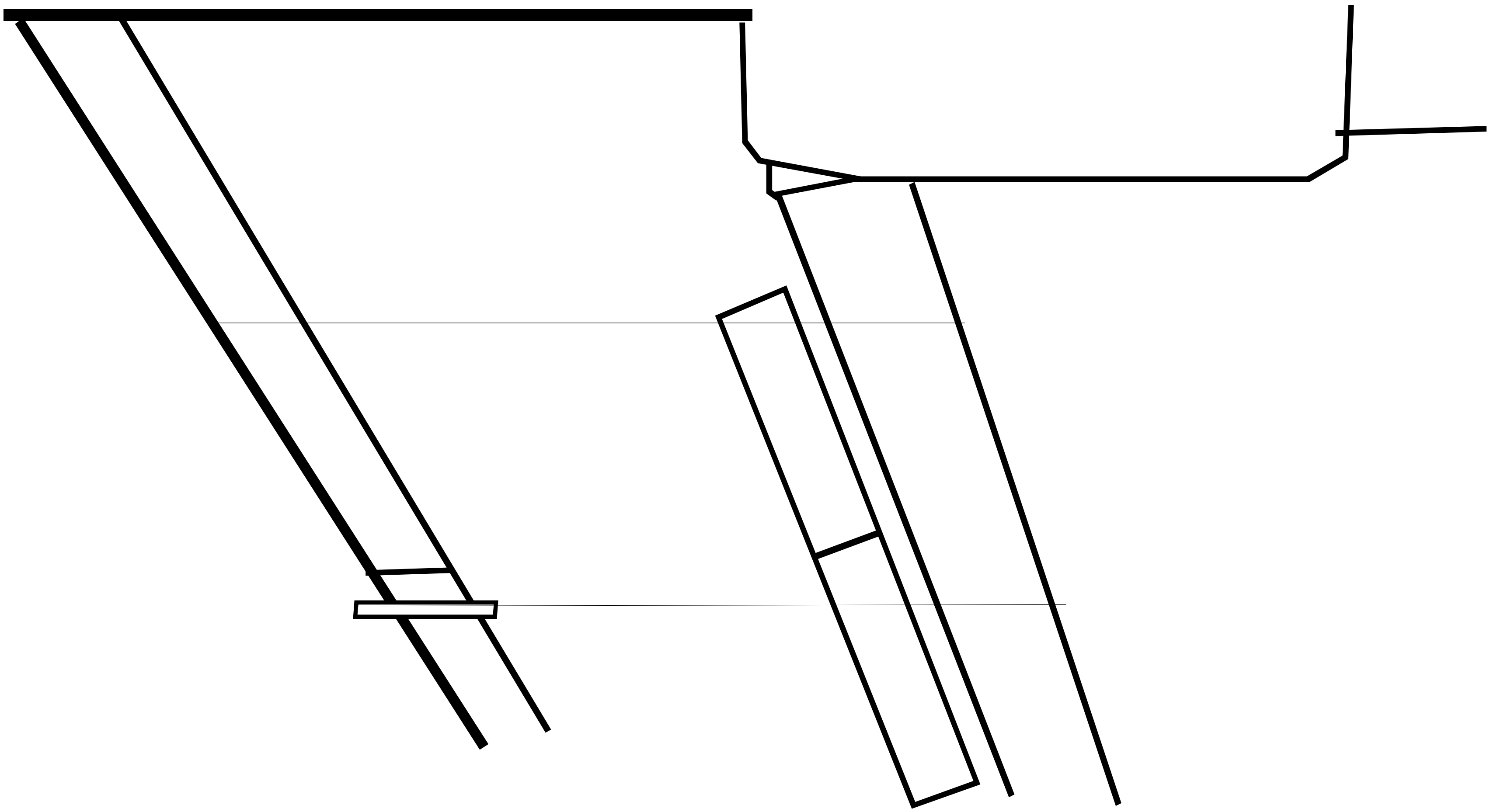
FIGURE 3d

FLUID ADHERENCE FORM FOR AIRCRAFT WING

FALCON 20D

Date: ________________ **Time:** ________________ **Run Number** ________

Fluid Type: ________________



COMMENTS: ____

____

____

____

FAILURE CALLED BY: ________________________

ASSISTED BY: ________________________

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FIGURE 4

FLUID THICKNESS ON AIRCRAFT

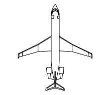
AIRPORT: YMX

AIRCRAFT TYPE: FALCON 20D

DATE: ______________________

WING: PORT (A) STARBOARD (B)

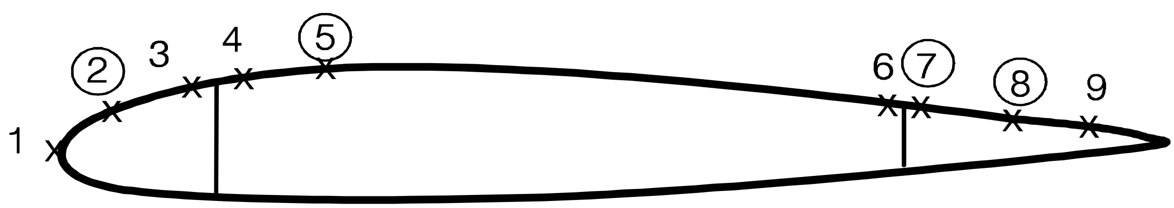
DRAW DIRECTION OF WIND WRT WING:



RUN #: ______________________

DIRECTION OF AIRCRAFT: ____________ DEGREES

	Before Rain Spray		Before Takeoff		After Takeoff	
Location	**Time**	**Gauge**	**Time**	**Gauge**	**Time**	**Gauge**
1						
2						
3						
4						
5						
6						
7						
8						
9						



<u>Location</u>

1 - LE Nose

2, 8- Half-way

3,4,6,7 - 1" from joint

5 - As far as can reach

9 - 6" from TE

<u>Note</u>:

Give priority to circled locations; measure other locations only if time allows.

COMMENTS: ______________________

MEASUREMENTS BY: ______________________

HAND WRITTEN BY: ______________________

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ATTACHMENT I
TEST PROCEDURES

1. PRE-TEST SETUP

Co-ordinate with AéroMag 2000 for deicing spraying, and access to deicing pad;

Co-ordinate with Aéroports de Montréal (Mirabel) and NavCan, including agreement to inspect aircraft on taxiway soon after aircraft turns off the runway;

Co-ordinate with RVSI or Spar/Cox for ice detection sensors;

Identify wing areas to be tested (wing only, Figure 3);

Arrange with the National Research Council to use video camera to record readings from air speed indicator on flight deck;

Prepare Type IV propylene-based fluid, neat and 75% concentration;

Prepare freezing rain sprayer;

Prepare Type IV fluid sprayer unit;

Transport equipment and Type IV propylene-based fluid to Mirabel;

Brief team including AéroMag 2000;

Synchronize times on all test instruments and watches; and

Mark wing for thickness tests.

2. CONDUCT DRY RUN

Set up equipment on board the aircraft and board operating team;

Spray the test area following standard procedures for two step fluid application;

Operate the aircraft through normal taxi and takeoff phases, rejecting takeoff when rotation speed is reached;

- Conduct required documentation of fluid condition during the entire test, checking out the operation of the ice detection sensor and all cameras;

- When the aircraft has returned and parked at the test location, examine the wing to document any remnants of fluid on the wing. Measure thickness of any fluid remaining;

  Ensure that the flight deck camera has filmed the air speed indicator, and that all other cameras and the ice detection sensor operated as planned;

  The aircraft may be flown on a short flight (about five minutes) to cool brakes between tests. Any contamination must be deiced prior to each flight.

3. CONDUCT CONTAMINATION TESTS

Take sample of fluids from the deicing vehicle, measure and record temperature and Brix;

Spray the designated area wing following standard procedures for two step fluid application. Measure fluid thickness at several points;

Collect fluid samples for viscosity tests prior to and following precipitation;

Using the freezing rain sprayer, apply precipitation over the test areas;

Conduct pilot visibility of failure observations from the aircraft cabin;

When the wing has reached the desired level of contamination, cease water application. Identify and record the wing and plate areas contaminated and degree of contamination on the data sheet, and by ice detection sensor. Measure thickness, adherence and dilution of fluid at points of contamination and at several locations along the chord;

Photograph and videotape appearance and pattern of failure;

With test crew onboard, perform the takeoff run to rotation speed. With the video camera, film the nature of the fluid on the wing during the takeoff run, capturing any movement, rippling or flowing action;

With a second video camera, record readings from the air speed indicator;

When the aircraft has turned off the runway and halted on the taxi-strip, examine the wing to document any remnants of fluid on the wing. Measure thickness, adherence and Brix of any fluid remaining. Photograph any remnants of fluid still on the wing and scan the area with the ice detection sensor; and

When the aircraft has returned, deice the aircraft, and repeat the test for different levels of contamination.

ATTACHMENT II

ADHERENCE OF CONTAMINATED FLUID TEST EQUIPMENT CHECKLIST

TASK
Logistics for Every Test
Rent Panel Truck / Rent Pickup / Rent Lighting
Call Personnel
Advise Airlines (Personnel, A/C Orientation, Equip)
Monitor Forecast
Call Potential Participants
Test Equipment
Freezing Rain Sprayer
Generator
Deicing Truck with Types I and IV
Flat Plate with Surrounding Skirt to Mount on Wing
Thickness Gauges
Brixometer Thermometer
Thermometer Probe
Spar/Cox Sensor Mounted on Cherry-Picker Truck
Generator to Support Cox Sensor
Video Camera X 3 Plus Tripod
Support Equipment for Video Camera
Cube Van to Transport Equipment
Personnel Van
Hearing Protectors
Step Ladders - Short + Tall
Thickness Measuring Kit
Contamination Adherence Instrument
Rolling Stair - Medium X 2
Heat Guns
Inclinometer
Type IV Sprayer with Supporting Equipment

ATTACHMENT III

APS STAFF TASK DESCRIPTION
AIRCRAFT TRIALS AT MIRABEL AIRPORT

Co-ordinator

Initiate test with all parties;
Ensure that all required equipment is available and functional;
Provide direction as required during the tests; and
Ensure all data are collected and recorded, and that all test records submitted.

Video

Videotape all test setup, outside and onboard the aircraft;
Videotape fluid on wings "before and after" each run, ensuring constant viewing angles are used, to facilitate comparisons; and
Photograph views of failed fluid on the wing.

Photographer

- Photograph all test setup; and
- Photograph "before and after" views of failed fluid on wing, ensuring constant viewing angles are maintained to enable comparisons.

Ice Detection Sensor Operator

Operate the ice detection sensor during the spray and contamination phase, and following the takeoff run; and
Reposition the sensor during water spraying to test sensitivity.

Wing Observer

Measure wing temperature at beginning of session and record on General Form;
Monitor and record progressive condition of fluid on the wing during the application of water. Alert the water spray operator when desired level of contamination has been reached; and
Examine the wing for fluid or contamination remaining after the takeoff run.

Fluid Sampler

Collect samples of Type IV fluid for subsequent viscosity tests; and
Record specifics for each sample.

Sampling Protocol

a) Before Rain Application
Take 2 samples and note locations on sampling form.

b) Before Takeoff Run
Take samples as directed by PD or JD; note locations on form.

c) After Takeoff Run
Sample any fluid remaining, including at failed area. Note locations on sampling form.

Spray Operator and Assistant

Ensure proper functioning of rain sprayer equipment, giving attention to preventing lines from freezing between tests;

Spray freezing rain over the protected area of the wing until advised that contamination has occurred; and

Operate Type IV fluid sprayer.

Thickness and Adherence

Measure thickness, adherence and dilution of fluid on wing at points of contamination and other selected chordwise locations. Record on aircraft form (Figure 3a) and on fluid thickness form (for taxi-only tests).

Cabin Observer

Make observations of failures on wing from inside the cabin. Enlist and instruct Falcon 20 pilot to record pilot observations; and

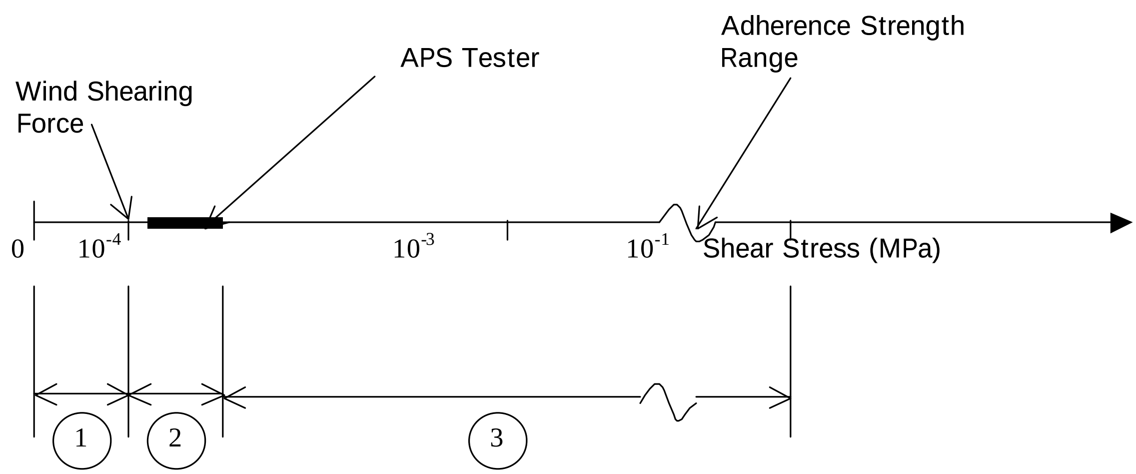
Occupy jump seat during aircraft runs to videotape air speed instrument.

APPENDIX C

EVALUATION OF INSTRUMENT TO DETERMINE ADHESION OF CONTAMINATION TO WING SKIN

ANALYSIS OF ADHERENCE TESTER

The adherence tester exerts a shearing force in the range 1.274×10^{-4} to 2.037×10^{-4} MPa. According to the report of Optima, the maximum wind shearing force acting on the wing is equal to 1×10^{-4} MPa, and the adhesive strength of ice and failed de/anti-icing fluids is of the order 10^{-3} to 10^{-1} MPa. Therefore, the tester shearing force is almost equal to the wind shearing force when compared to the failed fluid adhesive strength. In the Figure below, APS tester agrees with Optima results in range number 1 because both the tester and the wind will shear off the failed de/anti-icing fluid. Also in range number 3, the tester and the wind cannot shear off the failed fluid. Range number 2 is an indeterminate region where the tester may shear off the failed fluid but the wind will not.



Adherence Tester Force Analysis

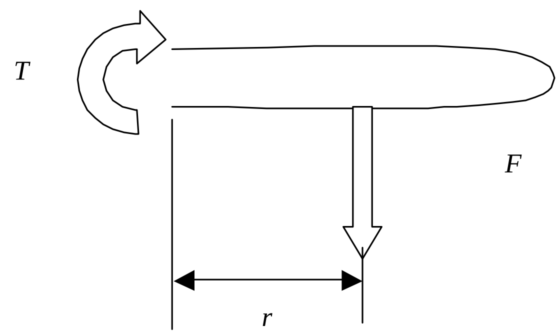
The Adherence Tester exerts a force on the ice particle through the filament. This force can be calculated from the tester motor ratings; namely, the output power, P_{out}, and the shaft rotational speed, w,

$$P_{out} = T.w$$

The above equation gives the shaft torque, *T*, which can be used to find the adherence force, *F*, used to shear off the ice particle,

$$F = \frac{T}{r}$$

where *r* is the torque arm. The figure below illustrates the torque and force on the filament.



The shearing stress is equal to the force divided by the area over which the filament operates

$$\tau = \frac{F}{A} = \frac{F}{\pi(2r)^2}$$

The output power and rotational speed provided by the tester manufacturer are:

P_{out} = 1 Watt and ω = 6500 Hz

Therefore, the torque is

$$T = \frac{1\ W}{6500\ Hz * \frac{2\pi\ rad}{1\ revolution}} = 2.45*10^{-5} N.m$$

The load on the filament is a uniform load. This load can be considered as a concentrated force acting at the average filament radius, *r* = 2.5 mm. Therefore, the shearing force is

$$F = \frac{2.45*10^{-5} N.m}{2.5*10^{-3} m} = 0.0098\ N$$

and the shearing stress is

$$t = \frac{0.0098\ N}{p*(2*2.5*10^{-3})^2 m^2} = 124.8\ \ Pa = 1.248*10^{-4} MPa$$

The above is the theoretical value. If the same analysis was done using the forces obtained from the electric balance, the shearing stress would be in the range $1.274x10^{-4}$ to $2.037x10^{-4}$ MPa.

Notes:

(1) It should be noted that the elasticity of the filament is a source of error in the force measurement using the electric balance.
(2) An electric balance of 0.2 g accuracy was used to verify the calculations.

APPENDIX D

NATIONAL RESEARCH COUNCIL OPERATIONS REPORT ON CONTAMINATED AIRCRAFT TAKEOFF RUNS

File ______________	INSTITUTE FOR AEROSPACE RESEARCH	No. FR-128
Checked by _________	Flight Research Laboratory	Page 1 of 17
Prepared by _________	LABORATORY MEMORANDUM	Date 4-27-1999

Security Classification Open

Subject Contaminated Wing Dynamic Tests Using an NRC Falcon 20 Aircraft

Prepared by Matthew Bastian

This Memorandum is issued to furnish information in advance, or in lieu, of a formal Report. It is preliminary in character, has not received the careful editing of a final report, and is subject to review.

TABLE OF CONTENTS

LIST OF FIGURES

1.0 Introduction

1.1 Background

Transport Canada in collaboration with the National Research Council and APS aviation ran a wing contamination study on February 22 and 23, 1999. The study involved the NRC Falcon 20 aircraft at Mirabel airport for two days of testing, studying the shedding characteristics of anti-icing fluid with varying levels of contamination.

This year's testing was the second year of testing in an on going multi-year testing program. This work follows from testing conducted by NRC in its low speed wind tunnel.

1.2 Objectives and Scope

The objective of the tests is to establish conditions for which anti-icing fluid failure in freezing precipitation fails to flow from the wing of a jet transport aircraft up to rotation speed.

This report covers solely the aspects concerning the physical state of the aircraft as it pertains to each test run. All information pertaining to the behaviour of the anti-icing fluid and wing contamination will be published in reports written by Transport Canada and APS Aviation.

2.0 Aircraft and Test Equipment

The Falcon is equipped with an on board data acquisition system. This DAS is capable of recording all aspects of the aircraft's performance. However due to equipment problems this data is not available.

The primary aircraft test equipment consisted of two video camcorders, one to record the anti-icing fluid / contamination behaviour and the other to record aircraft performance information from the cockpit.

For this years testing the Falcon was equipped with an over wing camera, mounted inside the aircraft cabin to record the shedding of the contaminated anti-icing fluid. The installation consisted of a specially built over-wing emergency exit door, replacing the normal emergency exit door, and was not certified for flight. The door contained a camera mount and viewing/filming hole to the outside, giving an unobstructed view of the wing test section. Figures 1 and 2 show photographs of the emergency door and camera installation. The cockpit intercom channel was fed to the over wing video camera for recording of all audio.

A second video camera was used to record the aircraft airspeed and pitch attitude from the cockpit instruments. No external audio was fed to this camera. Both cameras displayed the time and date on the video channel for future time synchronization of the video.

A wing test section was chosen on the left side of the aircraft, outboard of the engine and inboard of the wing fence. The considerations for this section were first, to avoid ingestion of anti-icing fluid into the engines. It was also desired to have a fixed geometry for the wing leading edge. The Falcon 20 has drooped leading extension out-board of the wing fence. Thus the decision was made to limit the test section to a 2m strip inboard of the wing fence. This location also gave good proximity for observation from inside the cabin. Figure 3 shows the leading edge of the wing in the test section area with anti-icing fluid and contamination applied. (Careful observation shows some small icicles hanging from the leading edge.)

3.0 Crew Members and Duties

The crew duties were assigned as follows. The two pilots controlled all aspects of the aircraft handling. The project leader coordinated the crew, ensured conformance to the test plan, took flight notes, and recorded the aircraft airspeed and pitch attitude indicators from the jump seat via video camera. The instrumentation technician ran the aircraft data acquisition computer and ensured cabin safety. An APS consultant operated the over wing camera and recorded his observations of the anti- icing fluid and contamination. On several test runs an APS or Transport Canada observer was on board and functioned solely in this capacity.

<u>NRC crew (all runs)</u>

Matthew Bastian	Project Leader
John Aitken	Pilot
Tim Leslie	Pilot
Mike Pygas	Instrumentation Technician
Dan Simpson	Aircraft Mechanic, ground support

<u>APS / Transport Canada crew</u>

Mike Chaput	APS consultant, runs 1-9
Barry Myers	Transport Canada, runs 6,8
Dan D'avirro	APS consultant, run 7
Frank Eyre	Transport Canada, run 9

4.0 Test Methods

On each of the two days of testing, the aircraft deployed in the morning to Mirabel (CYMX) from Ottawa (CYOW) and returned to Ottawa the same day after testing was completed.

A typical test run started with the application of deicing fluid (to remove any contamination from the previous run), followed by an application anti-icing fluid and finally by a pre-determined amount of contamination. The contamination consisted of freezing water droplets sprayed on to the inboard section the left wing. Figure 4 shows the equipment used.

When the desired level of contamination was reached the ground crew recorded the condition of the fluid and contamination, as well as a visual description/estimate of the contamination from inside the aircraft. Figure 5 shows the ground crew applying contamination and making observations.

Once the ground crew observations were complete the aircraft engines were started and the aircraft taxied to the button of runway 24. Figure 6 shows the Mirabel airport layout, indicating runway 24 and the de-icing pad.

To achieve the stated objective of accelerating the aircraft to rotation speed (and not becoming airborne) and to minimize brake energy build up, the following piloting techniques were used.

The aircraft was set up in the takeoff configuration (flap 15 degrees and air brake retracted). With full brakes applied the engines were brought up to a setting of about 1.40 EPR. The brakes were released and the aircraft accelerated to an indicated speed of 125 kts (V1) and then on to VR (127 kts). Through out the test run the copilot called out 10 knot airspeed increments.

At VR the throttles were brought back to flight idle and the pilot rotated the aircraft to an of attitude of approximately 7 to 8 degrees nose up (the takeoff attitude is 10 degrees). After approximately a 5 second delay the copilot extended the airbrakes and set the flaps to 40 degrees for maximum aerodynamic drag. The pilot held the 8 degrees nose up attitude for as long as possible (approximately 6 seconds or 90 to 95 kts). The aircraft was allowed to coast almost the full length of the runway before applying the brakes at approximately 50 kts. The flaps and air brakes were retracted at this point. The aircraft was then taxied to the deicing pad for engine shut down and post test run visual inspection and recording of the anti-icing fluid.

5.0 Summary of Test points

On the first day of testing four test runs were completed and on the second day five test runs were completed, for a total of nine test points. See Appendix A for detailed flight notes indicating flight times aircraft configuration and contamination types. These are included to assist Transport Canada and APS in gleaning test information that may not be explicitly noted in this report.

The following table shows the pertinent information for each run and can be used as a cross reference to correlate NRC run numbering and times with TC/APS data notes.

Run #	Date	Time	Fluid Type	Contamination Level
1	22-Feb-99	09:27	Ethylene	None
2	22-Feb-99	10:24	Ethylene	25%
3	22-Feb-99	12:13	Ethylene	25%
4	22-Feb-99	15:52	Propylene	None
5	23-Feb-99	07:00	Ethylene	1% (initial)
6	23-Feb-99	08:04	Ethylene	10%
7	23-Feb-99	08:52	Propylene	10%
8	23-Feb-99	09:40	Ethylene	1% (initial)
9	23-Feb-99	10:41	Propylene	25%

The timing of the various test phases was important to determine if elapsed time had any effect on the anti-icing fluid behaviour. A summary of typical test run timing follows. The application of anti-icing fluid and contamination usually required 15 minutes to complete and ground grew observations required an additional 15 minutes. The taxi period was typically 7 minutes in duration (covering an initial GPS ground speed of 18 kts and peaking at a terminal speed of 35 kts). The typical time required for aircraft acceleration to rotation speeds was one minute and the elapsed time from when the aircraft commenced its deceleration to when the aircraft entered the icing pad and shut engines off was 2 minutes. Post run ground crew observations required approximately 10 minutes.

6.0 Discussion

Previous years testing showed that a hand held video camera was not adequate for recording of the performance of the anti-icing fluid and contamination levels. This was due to two factors: operator motion under aircraft acceleration and opaqueness of the cabin windows. This year's over wing video camera mount installation worked flawlessly. The video image did not appear to be affected by any high frequency aircraft vibrations or by sudden aircraft acceleration when the brakes were released or applied.

It proved difficult to schedule the testing during the desired "ideal" weather conditions (minus 10 degrees, overcast and no precipitation). Since low temperature and zero precipitation were the main requirements, tests were scheduled on cold sunny days. During the first day of testing warming of the wing to above freezing temperatures became a factor in conducting the tests. For the second day of testing the aircraft timed it's departure from Ottawa to arrive in Mirabel for 6am, so as to complete testing in the early morning hours before daytime heating became a factor. An additional Third day of testing was not possible due the warmer temperatures (above zero) encountered during the mid to late March time period when this was attempted.

By design the Falcon aircraft does not generate much cabin heat while on the ground. This is due to a combination of low bleed airflow rate from the engines at idle and the requirement for the bleed air to be shut off to obtain maximum power on takeoff. During these tests it was also difficult to coordinate the number of times that the door of the aircraft was opened and closed, letting in considerable cold outside air. The lack of heat made for very cold working conditions inside the cabin and unfortunately caused a failure of the data acquisition system, precluding the use of any of it's supplementary data. Based on experience from the previous years testing, an external 220-volt electrical heater using a portable generator was available to heat the cabin but could not be used due to plugging incompatibility.

7.0 Conclusions and Recommendations

The video data gathered in this year's testing was of much better quality than the previous year. This was due to the installation of the over wing camera mount. The addition of the cockpit intercom channel to the audio track on the video camera also provided valuable information. It remains to be seen however if the video camera provided enough fidelity and contrast to give a very clear picture of what was happening to the anti-icing fluid and contamination. This installation is recommended for future studies however a different camera may be required.

Daytime heating of the air compromised the tests. This was due to the tests being conducted at the end of the cold weather season. It is recommended that future testing be done earlier in the winter season, to give a longer window of opportunity for testing on an overcast day, hopefully avoiding such early start times.

The cold cabin temperatures caused minor discomfort for the aircraft crew and, more importantly, caused the data acquisition system to fail. It is therefore recommended that:

1) In future testing APS supply both the generator and the appropriate 220v plug, to be connected to the heater. In this way all plug incompatibility issues will be resolved in a straight foreword and expedient manner.

2) A stricter aircraft door usage policy will be enforced. Between test runs the door will be opened/close twice. The first will be for the external heater to be placed inside the aircraft and the second time for its removal. It will only be on these two occasions that people will be able to enter/exit the aircraft.

Figure 1

Figure 2

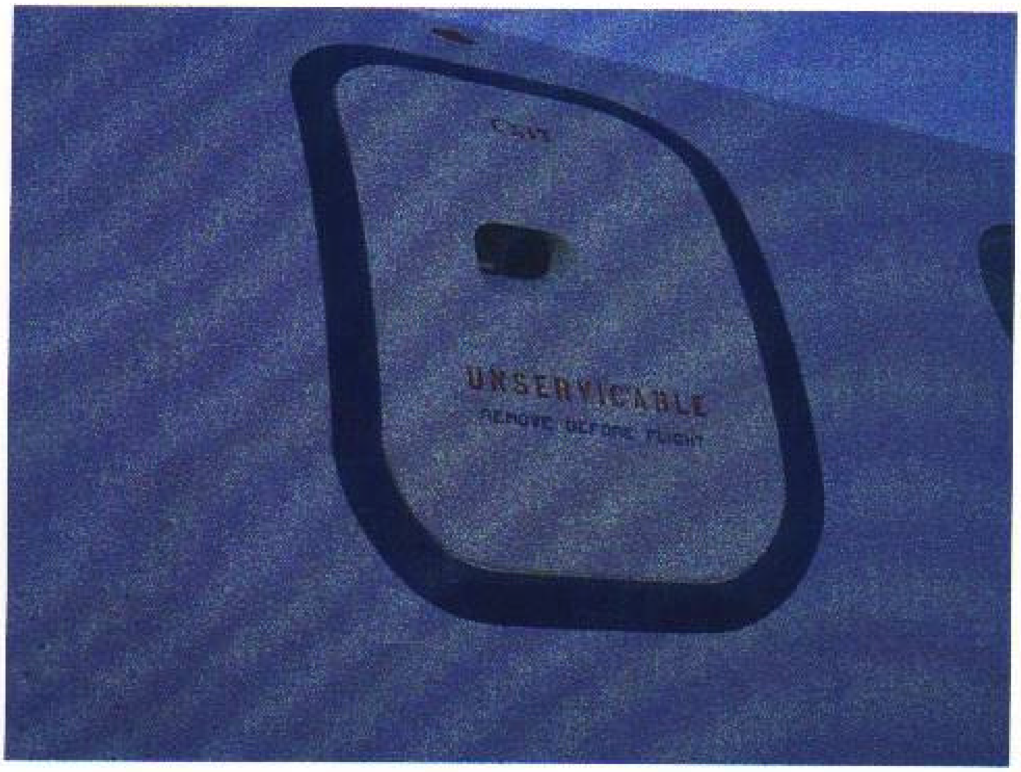
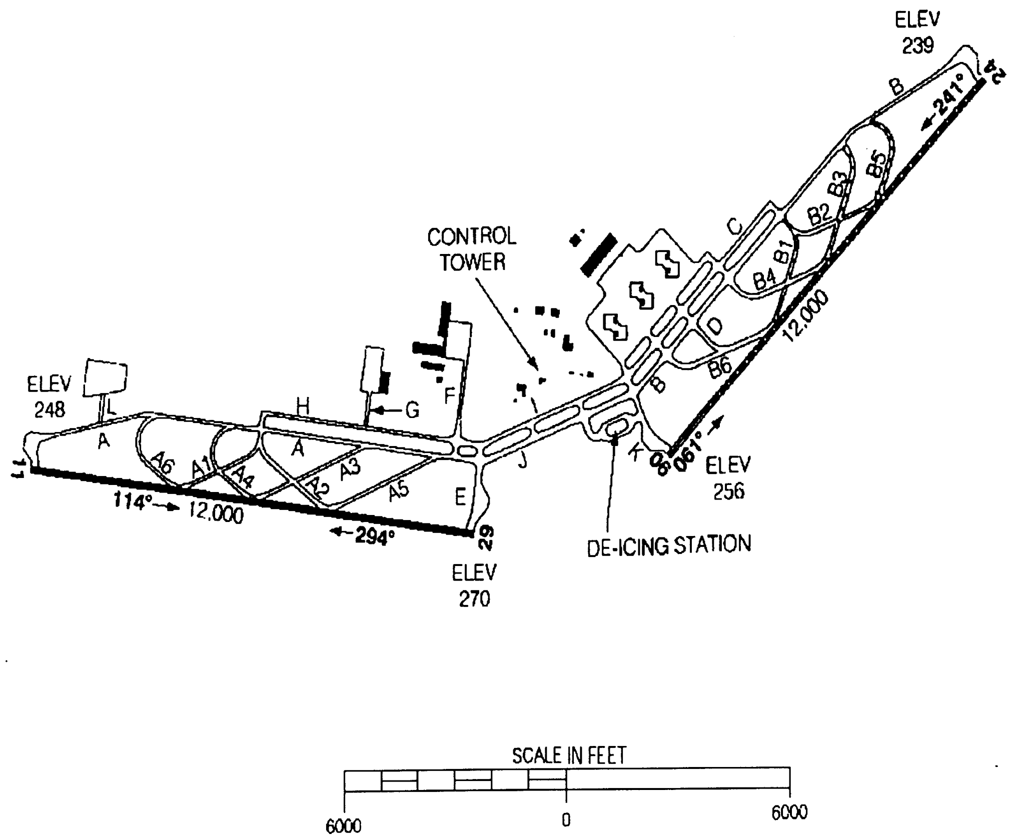


Figure 3

Figure 4

Figure 5

Figure 6


ELEV
239
B
24
241°
B5
B3
B2
B1
B4
C
CONTROL
TOWER
D
12,000
B6
B
ELEV
248
L
A
H
G
F
A6
A1
A4
A
A2
A3
A5
E
J
K
06
061°
ELEV
256
11
114°
12,000
294°
29
ELEV
270
DE-ICING STATION
SCALE IN FEET
6000
0
6000

Appenix A

Flight Notes for 22-Feb-1999

Time	Run	Rwy	QN	Temp	Winds	Fuel Qty L / R	A/C Config	Comments
07:25			30.4		Calm			Take Off CYOW
07:57								Landing CYMX
08:??								Ethylene no contam
09:12								Engines on
09:18		06	30:4	-14		2600/270	Flaps 15	Taxi spd ~25 kts
09:27	1	24			Calm		Flaps 15	Brks on at 100 kts
09:30								Engines off icing pad
09:50								Deicing of wing,
								Ethylene + Freezing h2o
10:17								Engines on
10:24		06				2300/230		Taxi spd 18-?? kts
10:29	2	24			230/4		Flaps 15	Brakes on at 65 kts
10:34								Engines off icing pad
11:35								Deicing of wing,
								Ethylene + freezing h2o
12:00								Engines on
12:02		06				2100/220		Taxi spd 20-35 kts
12:13	3	24			230/6		Flaps 15	Test run
12:17						2050/205		Engines off icing pad
15:00								Refueling of aircraft
15:??								Propylene + No contam
15:37								Engines on
15:43		B	30:4		260/1			Taxi spd 20-29 kts
15:52	4	24			250/1		Flaps 15	Test run
15:56								Engines off icing pad
16:21								Take off CYMX
16:40								Landing CYOW

Flight Notes for 23-Feb-1999

Time	Run	Rwy	QNH	Temp	Winds	Fuel Qty L / R	A/C Config	Comments
06:05								Landing CYMX
06:30								Ethylene + Contam
06:48								Engines on
06:54		06				2500/25		Taxi spd 18-38 kts
07:00	5	24			Calm		Flaps 15	Brakes on at 67 kts
07:05						2300/23		Engines off icing pad
07:30								Ethylene + Contam
07:52								Engines on
07:57		06						Taxi spd 18-26 kts
08:04	6	24	30.54		Calm		Flaps 15	Brakes on at 78 kts
08:10						2175/21		Engines off icing pad
08:??								Propylene +Light Contam
08:41								Engines on
8:45		06	30:5	-21		2250/22		Taxi spd 20-32 kts
8:52	7	24					Flaps 15	Brakes on at 70 kts
8:57						2000/20		Engines off icing pad
09:??								Ethylene + Init Contam
9:38								Engines on
09:33		06				2100/21		Taxi spd 18-?? kts
09:40	8	24			Calm		Flaps 15	Brakes on at 67 kts
09:44						1800/19		Engines off icing pad
10:05								Propylene + Heavy Contam
10:29								Engines on
10:34		06				1800/19		Taxi spd 18-32 kts
10:41	9	24			250/8		Flaps 15	Brakes on at 47 kts
10:46						1700/17		Engines off icing pad
11:00								Deicing
11:15								Eng. on, Taxi for fuel
11:20								Engines off at fuel pad
11:33								Engines on at fuel pad
								Hot #2 Bat 15 min delay

11:50			30:5	-14				Taxi
12:00		29						Take off CYMX
12:17								Landing CYOW
12:20								NRC Ramp
12:21								Engines off