TP 13482E

# Evaluation of Warm Fuel as an Alternative Approach to Deicing

Prepared for

**Transportation Development Centre**
On behalf of
**Civil Aviation**

**Transport Canada**

APS AVIATION INC.

October 1999

Final - Version 4.0

TP 13482E

# Evaluation of Warm Fuel as an Alternative Approach to Deicing

by

Peter Dawson and
Medhat Hanna

APS AVIATION INC.

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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 the NCAR 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 Test 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 13482E, has the following objective:

- To evaluate the use of warm fuel as an alternative approach to ground deicing of aircraft.

This objective was met through conduct of trials on two National Defence Canadair Challenger 600 aircraft at Ottawa International Airport. Temperature profiles of selected locations on wing surfaces were recorded after boarding warm fuel in one aircraft and cold fuel in the other.

## 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.

16. Abstract

The objective of this project was to examine the feasibility of using warmed fuel as a means of facilitating ground deicing of aircraft.

A field trial was conducted at Ottawa International Airport using two Bombardier Canadair Challenger aircraft belonging to the Department of National Defence. Warmed fuel was boarded on one aircraft and unheated fuel on the other. Wing skin temperatures were recorded while the aircraft were parked on the ramp overnight.

The influence of the warmed fuel on wing skin temperatures is discussed. Patterns and locations of frost deposition are reported and discussed relative to wing skin temperatures and ambient weather conditions.

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16. Résumé

L'objectif de ce projet était d'étudier la faisabilité d'utiliser du carburant chauffé pour faciliter les opérations de dégivrage au sol des aéronefs.

Un essai en vraie grandeur a eu lieu à l'Aéroport international d'Ottawa, à l'aide de deux Bombardier/Canadair Challenger, propriété du ministère de la Défense nationale. Un des avions était avitaillé en carburant chauffé, l'autre, en carburant non chauffé. Pendant toute une nuit, les avions sont demeurés immobilisés sur une aire de trafic et on notait la température du revêtement de la voilure.

Le rapport examine l'effet du carburant chauffé sur les températures enregistrées. Il examine également la formation de givre et les zones de givrage par rapport à la température du revêtement de la voilure et aux conditions météorologiques.

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# EXECUTIVE SUMMARY

At the request of the Transportation Development Centre (TDC) of Transport Canada, APS Aviation undertook a research program to examine the feasibility of using pre-warmed fuel as a means of facilitating ground deicing of aircraft.

In this approach, heat transfer from the fuel to the wing surface is used to facilitate the deicing process. Proponents of this approach believe that bringing the wing surface to a temperature higher than normal may prevent or delay some types of freezing contamination, and may prevent or reduce adherence to the wing surface of any contamination that may also occur. Some initial investigation of this approach has been conducted and was reported during the 1998 SAE G-12 Committee meeting on aircraft ground deicing by Polaris Thermal Energy Systems, Inc. (Polaris) of Fort Worth, Texas.

The concept is based on pre-warming the fuel during winter conditions at a temperature control station. The temperature desired is similar to that found during summer operations. The fuel would then be transferred by a refuelling tender or hydrant system to the flight line and loaded conventionally into the aircraft. The heat from the fuel is then expected to be conducted throughout the wing structure.

## Objective

The objective of this project was to determine the feasibility of using warmed fuel to address specific issues related to ground deicing of aircraft:

- Will it extend the holdover times normally following de/anti-icing operations?
- Will it reduce the amount of de/anti-icing fluid required?
- Does it resolve the cold soaked wing problem, imparting sufficient heat to the fuel already on board to raise the total fuel/wing temperature to match the ambient temperature?
- How practical is boarding warmed fuel in actual operations?

## Method

A detailed test plan was developed based on the use of a fuel heating system, to be provided by Polaris, and using a commercial aircraft, to be provided by an airline operator. Neither of these provisions could be met during the 1998-99 winter season, so an alternative was developed that allowed some testing before the end of the winter season. This resulted in trials at Ottawa International Airport on two National Defence Bombardier Canadair Challenger 600 aircraft, which have “wet” wings.

Tests were conducted on the ramp of the Transport Canada hangar. Warmed fuel was boarded on one aircraft and cold fuel on the other. Wing skin temperatures were then logged throughout the night.

During the test, ambient temperature was –12°C, relative humidity was 60 percent, and winds were generally calm.

## Results and Conclusions

The objective was to test with fuel at about 30°C. The delay in delivery of the fuel heating unit resulted in using an alternative heating procedure, wherein fuel was loaded into a fuel tender, which was then parked in a heated hangar for a period of time.

The temperature of the pre-warmed fuel at 8°C as tested was considerably lower than that planned and the results were affected somewhat by this shortcoming. Nonetheless, valuable data and observations were collected that allow useful preliminary conclusions to be drawn. In addition, observations of temperature profiles of different wing components and patterns of frost deposition during the test provide an increased understanding of the nature of frost formation as might typically be experienced in actual operations.

From these trials it can be concluded that:

- The fuel tested did not impart sufficient heat to various wing surface areas to maintain a temperature above freezing.
- Fuel temperature influences the main wing skin temperature only where the mass of fuel is close to the inner wing skin.
- The added hot fuel quantity and cold fuel already in the tanks tested in this trial represented the fuel load of a typical mission. As fuel quantities are selected on the basis of next flight requirements, and excess fuel loads are operationally undesirable, fuel loads boarded may limit the benefits of this approach.
- The heat content of the fuel may have warmed the inner flap surface on both wings, as they maintained a temperature higher than that of the aileron and outer main wing.
- The aileron temperature was equivalent to that of the skin on the outer main wing, so the fuel did not warm either of these surfaces.

- Heat transmitted from the warmed fuel warmed the wing leading edges, at least in calm wind conditions. On both test wings, the temperature of the leading edge dropped rapidly with an increase in wind speed, but remained above the outside air temperature (OAT).

- The polished aluminum surfaces comprising the wing leading edges lost less heat through radiation than did other (painted) wing surfaces, and did not experience frost formation. The skin temperature of other wing surfaces, such as the outer wing and ailerons, quickly dropped below OAT by as much as 4-5°C and accumulated frost deposits.

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# SOMMAIRE

À la demande du Centre de développement des transports (CDT) de Transports Canada, APS Aviation a entrepris un programme de recherche sur la faisabilité d'utiliser du carburant préchauffé pour faciliter les opérations de dégivrage au sol des aéronefs.

Cette technique mise sur le transfert thermique du carburant à la surface de la voilure pour faciliter le dégivrage. Selon les tenants de cette méthode, le fait de porter la surface de la voilure à une température plus élevée que sa température normale peut prévenir ou retarder certains types de contamination par le givre, et empêcher ou réduire l'adhésion de toute contamination éventuelle. Polaris Thermal Energy Systems Inc. (Polaris), de Fort Worth, au Texas, a consacré une première étude à cette méthode et en a rendu compte lors de la réunion de 1998 du Comité G-12 de la SAE sur le dégivrage au sol des aéronefs.

Le principe est de préchauffer, en hiver, le carburant des avions. Pour cela, on le fait passer dans une station de régulation thermique, où il est porté à une température voisine de sa température normale en été. Il est alors acheminé par citerne ou par canalisation à l'aire de trafic, et l'avitaillement se fait de la manière habituelle. On table sur le fait que la chaleur du carburant se transmettra par conduction à toute la structure de l'aile.

## Objectif

L'objectif de ce projet était d'étudier la faisabilité d'utiliser du carburant chauffé pour faciliter le dégivrage au sol des aéronefs. Les chercheurs se sont notamment intéressés aux questions suivantes :

- Le préchauffage du carburant peut-il allonger la durée d'efficacité des liquides dégivrants/antigivrage?
- Cette mesure peut-elle réduire la quantité de liquide dégivrant/antigivrage nécessaire?
- Permet-elle de parer au problème des ailes sur-refroidies, le carburant transmettant suffisamment de chaleur au carburant déjà à bord pour porter la température globale du carburant et de l'aile à la température ambiante?
- Dans quelle mesure l'avitaillement des avions en carburant chauffé peut-il s'intégrer, pratiquement, aux opérations aériennes?

## Méthode

Un plan d'essai détaillé a été mis au point, qui faisait appel à un système de chauffage du carburant, à être fourni par Polaris, et à un avion commercial, à

être prêté par un transporteur aérien. Mais ni le système de chauffage ni l'avion n'ont été rendus disponibles au cours de l'hiver 1998-1999. Un plan de rechange a donc été mis au point, qui permettait la tenue d'essais avant la fin de l'hiver, dont l'essai à l'Aéroport international d'Ottawa. Celui-ci mettait en jeu deux Challenger 600 de Bombardier/Canadair, propriété de la Défense nationale, dotés de réservoirs structuraux.

Les essais ont eu lieu sur l'aire de trafic du hangar de Transports Canada. Un des avions était avitaillé en carburant chauffé, l'autre, en carburant froid. Pendant toute la nuit, la température du revêtement de la voilure était enregistrée.

La température ambiante lors des essais était de –12 °C, l'humidité relative, de 60 p. 100, et les vents étaient généralement calmes.

## Résultats et conclusions

Les essais devaient être réalisés avec du carburant chauffé à environ 30 °C. Mais comme on a dû se passer de l'appareil de chauffage prévu, il a fallu s'y prendre autrement pour chauffer le carburant, c'est-à-dire le charger dans une citerne, et laisser celle-ci pendant un certain temps dans un hangar chauffé.

Le carburant ainsi préchauffé était à une température de 8 °C, beaucoup plus basse que celle d'abord prévue, ce qui s'est répercuté sur les résultats. L'essai n'en a pas moins permis de recueillir de précieuses données et observations et de tirer des conclusions utiles. De plus, les observations touchant les profils de températures des différentes parties de la voilure et les zones d'accrétion de givre ont permis de mieux comprendre le phénomène de formation du givre en conditions réelles.

Voici les conclusions tirées des essais :

- Le carburant n'a pas transmis suffisamment de chaleur aux différentes zones de la surface de la voilure pour maintenir la température de celles-ci au-dessus du point de congélation.

- La température du carburant n'influe sur la température du revêtement de l'aile que pour autant que la masse du carburant soit à faible distance du revêtement intérieur de l'aile.

- La quantité de carburant chauffé ajouté au carburant froid dans les réservoirs correspondait à la quantité qui aurait été embarquée au cours d'une mission type. Comme les quantités de carburant sont établies d'après les besoins du vol jusqu'au prochain avitaillement, et comme il n'est pas souhaitable, d'un point de vue opérationnel, d’embarquer des quantités excessives de carburant, il se peut que le chauffage du carburant à embarquer ne donne pas les résultats escomptés, vu les faibles quantités en jeu.

- Tout porte à croire que la chaleur du carburant s’est transmise à la surface du volet intérieur des deux ailes, car la température y est demeurée supérieure à celle de l’aileron et de la demi-aile externe.

- La température de l’aileron était équivalente à celle de la demi-aile externe, ce qui donne à penser que la chaleur du carburant ne s’est transmise à ni l’une ni l’autre de ces surfaces.

- La chaleur transmise par le carburant préchauffé a élevé la température du bord d’attaque des ailes, à tout le moins par vent calme. Mais un vent plus fort faisait rapidement chuter la température du bord d’attaque des deux ailes d’essai, sans pour autant les ramener à la température extérieure.

- Les surfaces en aluminium poli, dont sont faits les bords d’attaque, ont subi une perte de chaleur par rayonnement moins importante que les autres surfaces (peintes) des ailes, et on n’y a observé aucune formation de givre. Le revêtement des autres parties des ailes, comme la demi-aile externe et les ailerons, a rapidement atteint une température de 4 à 5 degrés Celsius inférieure à la température extérieure, et on y a observé la formation de givre.

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# GLOSSARY

| | |
|---|---|
| APS | APS Aviation Inc. |
| NRC | National Research Council Canada |
| OAT | Outside Air Temperature |
| SAE | Society of Automative Engineers |
| TDC | Transportation Development Centre |

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# 1 INTRODUCTION

At the request of the Transportation Development Centre (TDC) of Transport Canada, APS Aviation has undertaken a research program to examine the use of warmed fuel as a means of facilitating ground deicing of aircraft.

## 1.1 Background

A proposed alternative approach to current methods of aircraft ground deicing is based on the boarding of heated fuel. In this approach, the resulting heat transfer from the pre-warmed fuel to the wing surfaces is intended to facilitate the process of deicing. The proponents of this approach believe that maintaining the wing surface at a temperature higher than normal may prevent or delay some types of contamination from occurring, and may reduce adhesion to the wing surface of any contamination that might occur. Some initial investigation of this approach has been conducted and was reported during the 1998 SAE G-12 Committee meeting on Aircraft Ground Deicing, by Polaris Thermal Energy Systems, Inc. (Polaris) of Fort Worth, Texas.

The concept is based on pre-warming the fuel during winter operations at a temperature control station. The desired fuel temperature would be similar to fuel temperatures experienced during typical summer operations. The fuel would then be transferred either by a refuelling vehicle or by a hydrant system, to the flight line and loaded conventionally into the aircraft. The heat from the fuel is then expected to be conducted throughout the wing structure, particularly those wing sections adjacent to the fuel reservoir.

## 1.2 Work Statement

Appendix A presents the work statement for the APS Aviation Winter 1998/99 research program. Section 5.12 of Appendix A, Evaluation of Warm Refuelling, describes this project.

## 1.3 Objective

The objective of this project was to determine the feasibility of using warmed fuel to address specific issues related to ground deicing of aircraft:

- Will it extend the holdover times normally experienced following de/anti-icing operations?
- Will it reduce the amount of fluid required to be applied?

- Does it resolve the cold soaked wing problem, inputting sufficient heat to the fuel already on board to raise the total fuel/wing temperature to match the ambient temperature?
- How practical is boarding warmed fuel in actual operations?

To examine the feasibility of this approach, a detailed test plan was developed based on the use of a fuel heating system to be provided by Polaris, and commercial aircraft for test purposes to be provided by an airline operator. When it was learned that neither of these provisions could be satisfied during the 1998/99 winter season, an alternative simplified test plan was defined that allowed some testing to be conducted prior to the end of the winter season. That plan resulted in trials being conducted on two National Defence Canadair Challenger 600 aircraft, at Ottawa International Airport.

# 2 METHODOLOGY

## 2.1 Initial Test Plans

The initial test plans were developed based on the expectation that test aircraft would be made available on several overnight occasions at Montreal International Airport (Dorval). A copy of the experimental program based on that expectation is contained in Appendix B.

Three test sessions were anticipated: one during active precipitation, either natural or artificial; and two during non-precipitation conditions.

In all three tests, thermistor probes were to be installed at selected positions on the wing surfaces of the test aircraft. This instrumentation was to be interfaced to a dedicated PC to provide a log of wing skin temperature over time, commencing prior to boarding of the heated fuel. To provide a basis for comparison, it was proposed to transfer cold fuel to one wing, and board heated fuel onto the other, if technically feasible.

Polaris was responsible for manufacturing and delivering the fuel heating system to a suitable location at Dorval Airport. Shell Canada Products Limited, a participant in the trial, was responsible for making the fuel available, and for fuelling the aircraft. It was proposed to warm the fuel to a temperature near 30°C.

The aircraft operator was responsible for making the aircraft available, advising on the amount of fuel required for the next operation, and for towing the aircraft to the central deicing facility for any test conducted during conditions of precipitation.

Deicing of the test aircraft was to be performed by the Central Deicing Facility operator (Aéromag 2000). The quantity of fluid required to deice each of the test wings (one containing heated fuel and one containing cold fuel) and any effect(s) with respect to the ease of deicing was to be monitored and documented. Finally, the resulting holdover times were to be recorded.

For tests during non-precipitation periods, the effect of heated fuel on wing surface temperature profiles over time was to be recorded. The intent was to conduct these trials with the aircraft parked at the passenger terminal.

## 2.2 Modification of Test Plans

As the preparations for testing were being finalized, two problems arose which prevented the test activity from proceeding as planned:

- The participating aircraft operator was unable to continue to provide support for the project during the current season. A search for an alternative test aircraft at Dorval airport was not successful;
- Delivery of the fuel heating system fabricated for the trial was delayed.

Subsequently, an agreement was reached with the Department of National Defence to conduct tests on Canadair Challenger 600 aircraft, based with 412 Transport Squadron at Ottawa International Airport. As the wing design of these aircraft is common to the Bombardier RJ aircraft, this aircraft was deemed to be a satisfactory alternative. Note that both have ‘wet’ wing fuel tanks. To warm the fuel, it was proposed that simply parking a loaded fuel tender for a period of time in a heated building would satisfy the elevated fuel temperature requirements. The objective of the test was to determine the effect of the heated fuel on wing surface temperatures over time.

## 2.3 Test Site

Tests were conducted on the ramp of the Transport Canada hangar at Ottawa International Airport, where the 412 Transport Squadron Challenger aircraft are maintained and housed. Tests were conducted on one overnight occasion: March 8-9, 1999. Photo 2.1 shows the ramp area in front of the Transport Canada hangar.

## 2.4 Description of Test Procedures

Two Challenger aircraft were made available for testing. One is shown in Photo 2.2. The test was planned to be conducted on a Monday night. When the test team arrived to prepare the aircraft for testing, it was learned that the aircraft had been parked in the heated hangar for the previous three days (over the weekend).

Before moving the aircraft from the hangar, the port wing on one aircraft, and the starboard wing on the second aircraft, were outfitted (Photo 2.3) with thermistor probes installed at predetermined positions on the wing surface. These positions were selected to provide data for distinct components of the wing, such as the leading edge, several positions on the main wing section over the fuel tank, the aileron, flaps, and spoiler panels. The exact location of each thermistor was measured against reference points on the aircraft and recorded. Locations are shown in Figure 2.1 and in Photo 2.4.

The aircraft were moved from the hangar at about 2030 h, and parked on the ramp to cool. On the ramp, the aircraft were parked side by side with the test wings in proximity to facilitate common use of temperature logging equipment and lighting (Photo 2.5).

Fuel samples were taken from the aircraft prior to boarding fuel, and the temperatures were recorded. The amount of fuel in each wing tank prior to fuelling was also recorded.

Cold fuel was then boarded on one aircraft, and warmed fuel was boarded on the other (Photos 2.6 and 2.7). Parking a loaded fuel tender in a heated hangar for some time had warmed this fuel to 8ºC. The time of boarding fuel was near midnight.

Wing surface temperatures were then logged until early morning. The appearance of the frost that developed on the wings was recorded and photographed at the end of the test period (0430 h).

## 2.5 Data Forms

Two data forms were employed for these trials:

- The “General Form” (Figure 2.1) was used to record aircraft designations, details on the fuel initially on board and the fuel added during the test; and

- The “Thermistor Locations on Aircraft Wing Form” (Figure 2.2), which was used to indicate pre-planned locations for installation, and to record the exact measurements of the installed thermistor locations. The drawing of the wing indicates the boundaries of the fuel tank.

## 2.6 Equipment

The principal equipment used for the tests was the temperature logging kit, composed of 21 thermistor probes, and three data loggers. Fourteen

FIGURE 2.1

# GENERAL FORM (ONCE PER SESSION)

## (TO BE FILLED IN BY OVERALL COORDINATOR)

---

**AIRPORT:** YOW

**AIRCRAFT TYPE:** Challenger

**EXACT PAD LOCATION OF TEST:** ____________________

**AIRLINE:** ____________________

**DATE:** ____________________

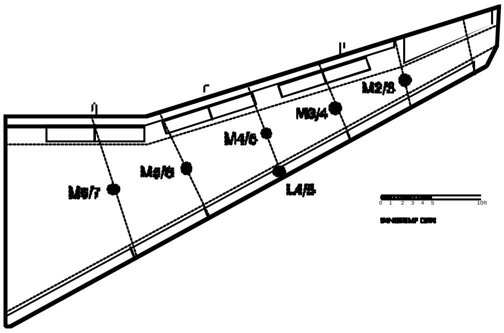
**FIN #:** ______________

**APPROX. AIR TEMPERATURE:** ______________ °C

**Wind Speed:** ______________ kph

| **FUEL LOAD** | **ON BOARD INITIALLY** | | **ADDED** | | |
|---|---|---|---|---|---|
| | **Quantity lb / kg** | **Temp (°C)** | **Quantity lb / kg** | **Temp (°C)** | **Time** |
| **Port Wing Tank** | | | | | |
| **Starboard Wing Tank** | | | | | |

***TEMPERATURE MEASUREMENTS***



| **TIME (min)** | **TEMPERATURE AT LOCATION (°C)** | | | | | |
|---|---|---|---|---|---|---|
| | **M6/7** | **M5/6** | **L4/5** | **M4/5** | **M3/4** | **M2/3** |
| **Start** | | | | | | |
| **End** | | | | | | |

**COMMENTS:** ____________________

(1) Actual Time Before Fluid Application

**MEASUREMENTS BY:** ____________________

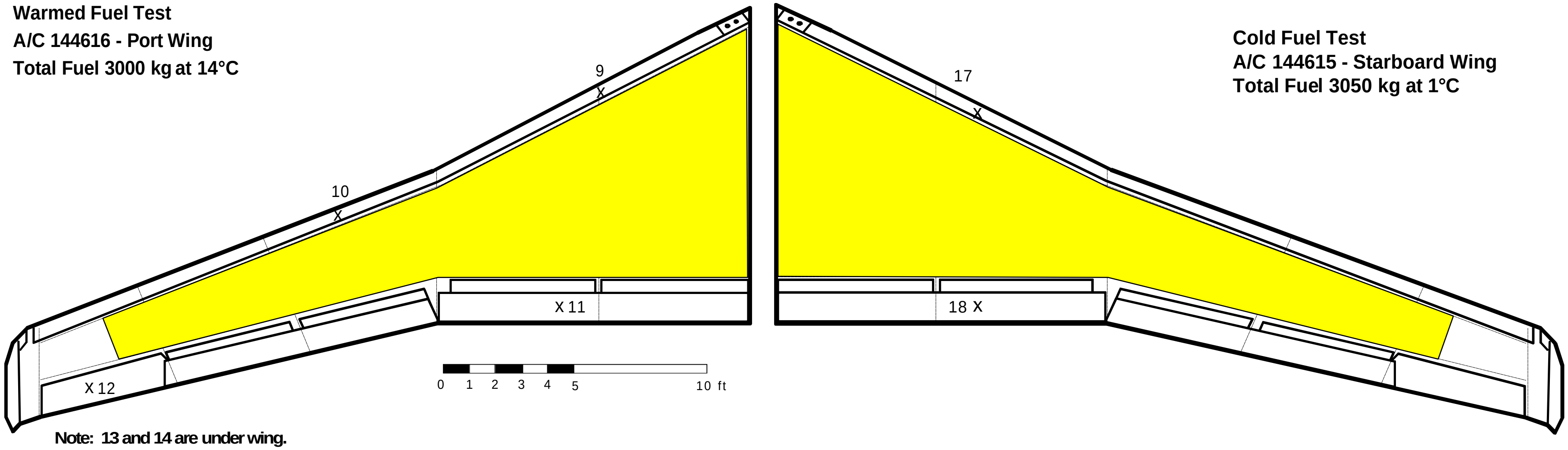
**HANDWRITTEN BY:** ____________________

FIGURE 2.2

# THERMISTOR LOCATIONS ON AIRCRAFT WING

## WARM FUEL TRIALS - MARCH 08/09, 1999

### CL600 Challenger



**Warmed Fuel Test**
**A/C 144616 - Port Wing**
**Total Fuel 3000 kg at 14°C**

**Cold Fuel Test**
**A/C 144615 - Starboard Wing**
**Total Fuel 3050 kg at 1°C**

**Note: 13 and 14 are under wing.**

Shaded areas indicate wing tank boundary.

thermistor probes were installed on the port wing of one aircraft in which heated fuel was to be boarded, six probes on the starboard wing of the second aircraft planned for boarding of cold fuel, and one probe was used to record the outside air temperature.

A mast light generator, shown in Photo 2.5, was rented locally and used to provide sufficient lighting on the ramp for observation and photography.

## 2.7 Fluids

These tests were conducted on bare wings. No deicing or anti-icing fluids were applied.

## 2.8 Personnel

Four APS personnel were required for these tests. An observer from the Transportation Development Centre (TDC) was present, along with a representative from Heatec, a company associated with Polaris Thermal Energy Systems Inc.

Photo 2.1

**Ramp at Transport Canada Hanger**

Photo 2.2

**National Defence Challenger Aircraft**

Photo 2.3

**Installing Thermistor Probes**

Photo 2.4

**Thermistor Probe Installation**

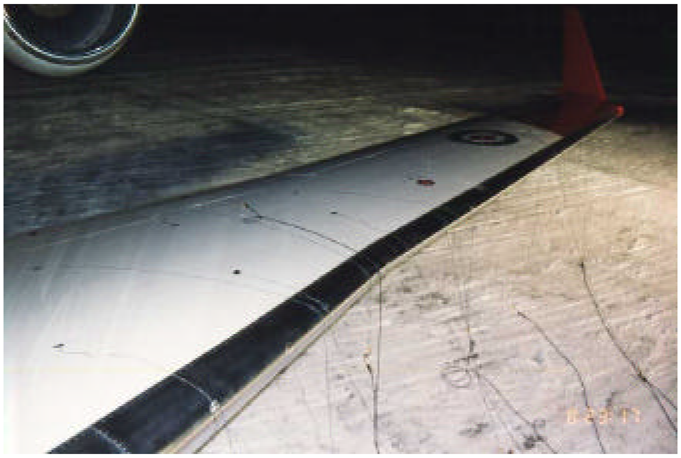


Photo 2.5
**Aircraft Positioned for Testing**

Photo 2.6
**Boarding Warmed Fuel**

Photo 2.7
**Boarding Cold Fuel**

# 3 DESCRIPTION AND PROCESSING OF DATA

## 3.1 Test Conditions

Tests were conducted overnight on March 8-9, 1999 with two National Defence Canadair Challenger 600 aircraft belonging to 412 Transport Squadron. Warmed fuel was boarded on one of these aircraft, while cold fuel (at normal fuelling temperature) was boarded on the other. Details of the fuel boarded are presented in Table 3.1. The fuel capacity of the main wing tanks on these aircraft is 4318 kg, thus the total fuel load as tested was at 70 percent capacity.

TABLE 3.1

EVALUATION OF WARMED FUEL TEST RECORD
March 8–9, 1999
Transport Canada Hangar, Ottawa International Airport
OAT -10°C, Calm Wind
RH 68%

| Aircraft # | Wing | Fuel Details | | | | | |
|---|---|---|---|---|---|---|---|
| | | On Board Initially | | Boarded During Test | | Total Tested | |
| | | Kg | °C | Kg | °C | Kg | °C[1] |
| DND144616 | Port | 1950 | 17.8 | 1050 | 8.0 | 3000 | 14.4 |
| DND144615 | Starboard | 1300 | 16.0 | 1750 | -9.6 | 3050 | 1.3 |

[1] Calculated temperature based on mix of fuel initially on board and additional fuel boarded for test.

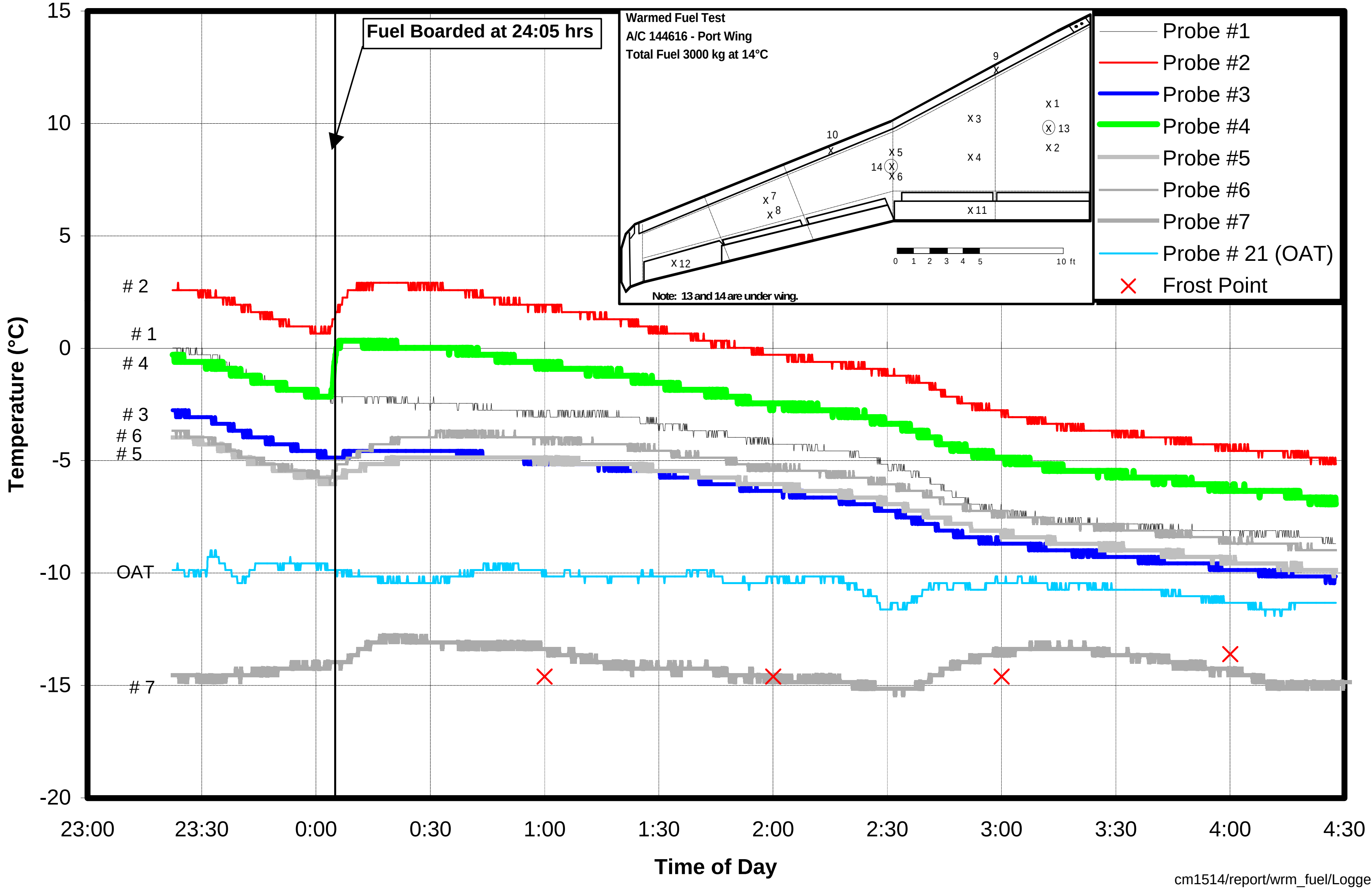
The tests were initiated near midnight March 8-9 with the boarding of fuel, and thereafter ran until 0430 h on March 9. During that period, OAT and wing temperatures were logged continually as reported in Figures 3.1 to 3.3. Subsequent to the test session, other weather data was retrieved from Environment Canada records. Dew-point values were provided on

FIGURE 3.1

# WING SKIN TEMPERATURES - WARM FUEL LOAD

## POSITIONS 1 TO 7

Challenger - Port Wing, March 8-9, 1999



cm1514/report/wrm_fuel/Logger1.xls
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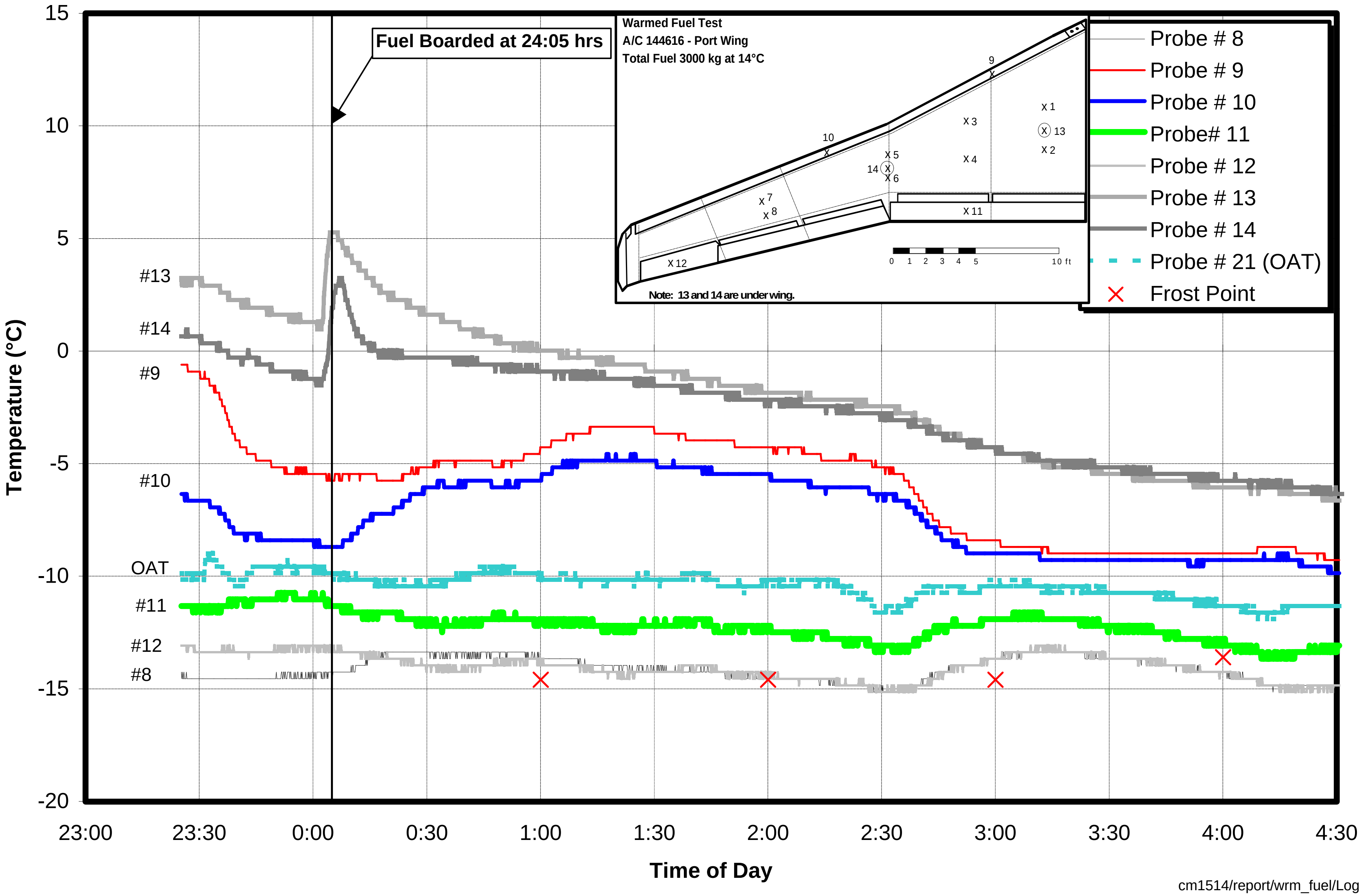
FIGURE 3.2

# WING SKIN TEMPERATURES - WARM FUEL LOAD

## POSITIONS 8 TO 14

Challenger - Port Wing, March 8-9, 1999



cm1514/report/wrm_fuel/Logger2.xls
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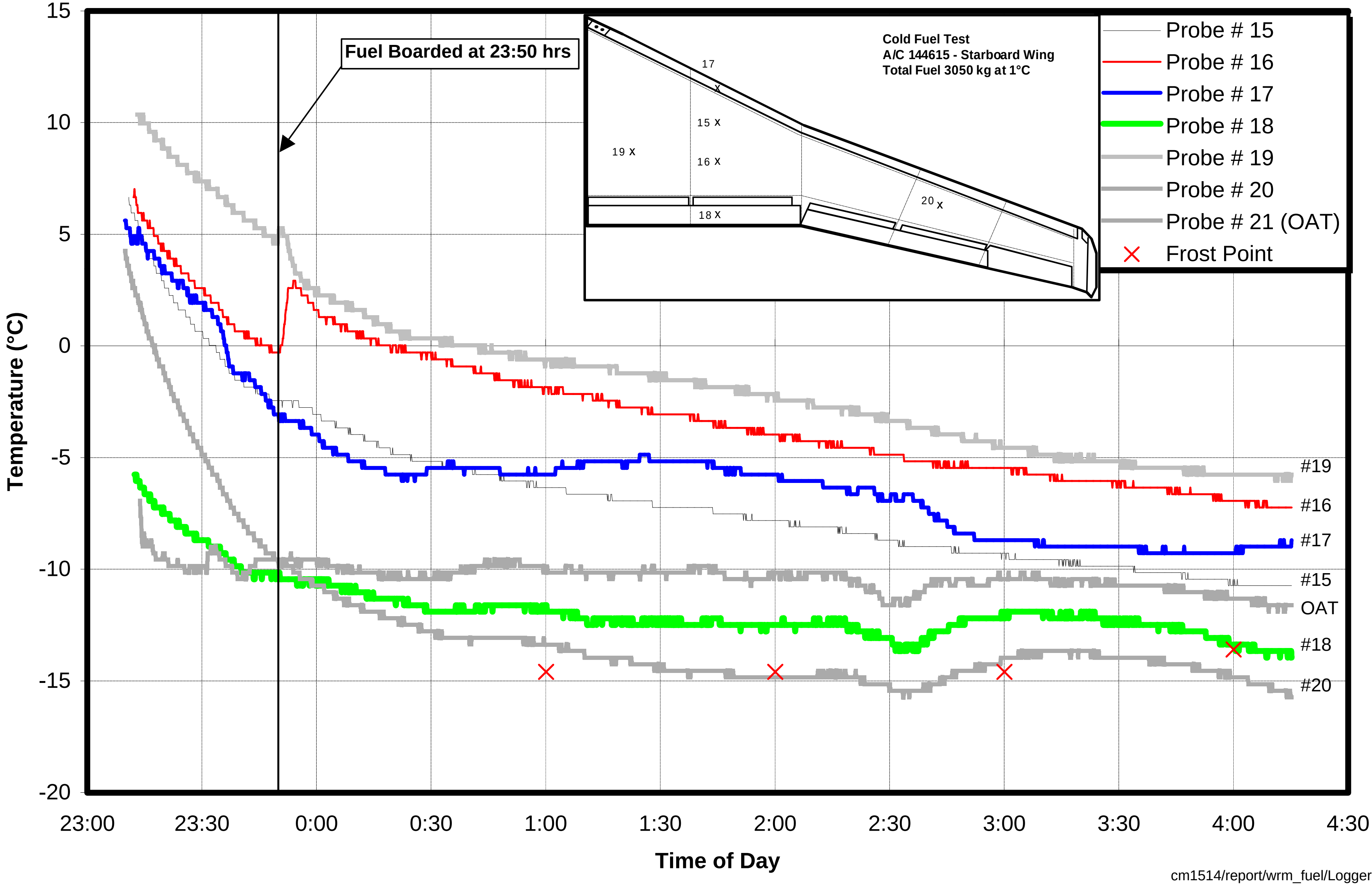
FIGURE 3.3

**WING SKIN TEMPERATURES - COLD FUEL LOAD**

**POSITIONS 15 TO 20**

Challenger - Starboard Wing, March 8-9, 1999


Fuel Boarded at 23:50 hrs

cm1514/report/wrm_fuel/Logger3.xls
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an hourly basis for the test period. From these values, frost points were extracted through the use of tables of saturation mixing ratios over water and over ice for various temperatures. These hourly frost points are shown as data points in Figures 3.1 to 3.3. Details of wind conditions (speed and direction) were provided in the form of a paper spool record from a pen recorder. A copy of the record for the test period is provided in Figure 3.4.

## 3.2 Wing Skin Temperature Profiles

The temperature profiles recorded at each probe location on the wing surfaces are presented in chart form in Figures 3.1 to 3.3. In these charts, the temperature values of several positions on each wing can be seen cooling prior to boarding of fuel. The fuel was boarded shortly after midnight.

At the time of refuelling, the temperatures of some locations on the wing rapidly increased.

The other positions on the surface had already cooled to ambient temperature or lower prior to refuelling.

The test results are discussed in detail in Chapter 4. To facilitate comparison of the test results from the two test wings, Figures 4.1 to 4.6 were constructed using the acquired data. In these figures, the temperature profiles for matching locations on the two wings are plotted. A wing schematic is included in each figure, which identifies locations where temperatures were recorded.

The frost deposits on the two wings were photographed at the end of the test period. These photographs were analysed and frost patterns were drawn. The pattern of occurrence of frost was analysed against surface temperature values.

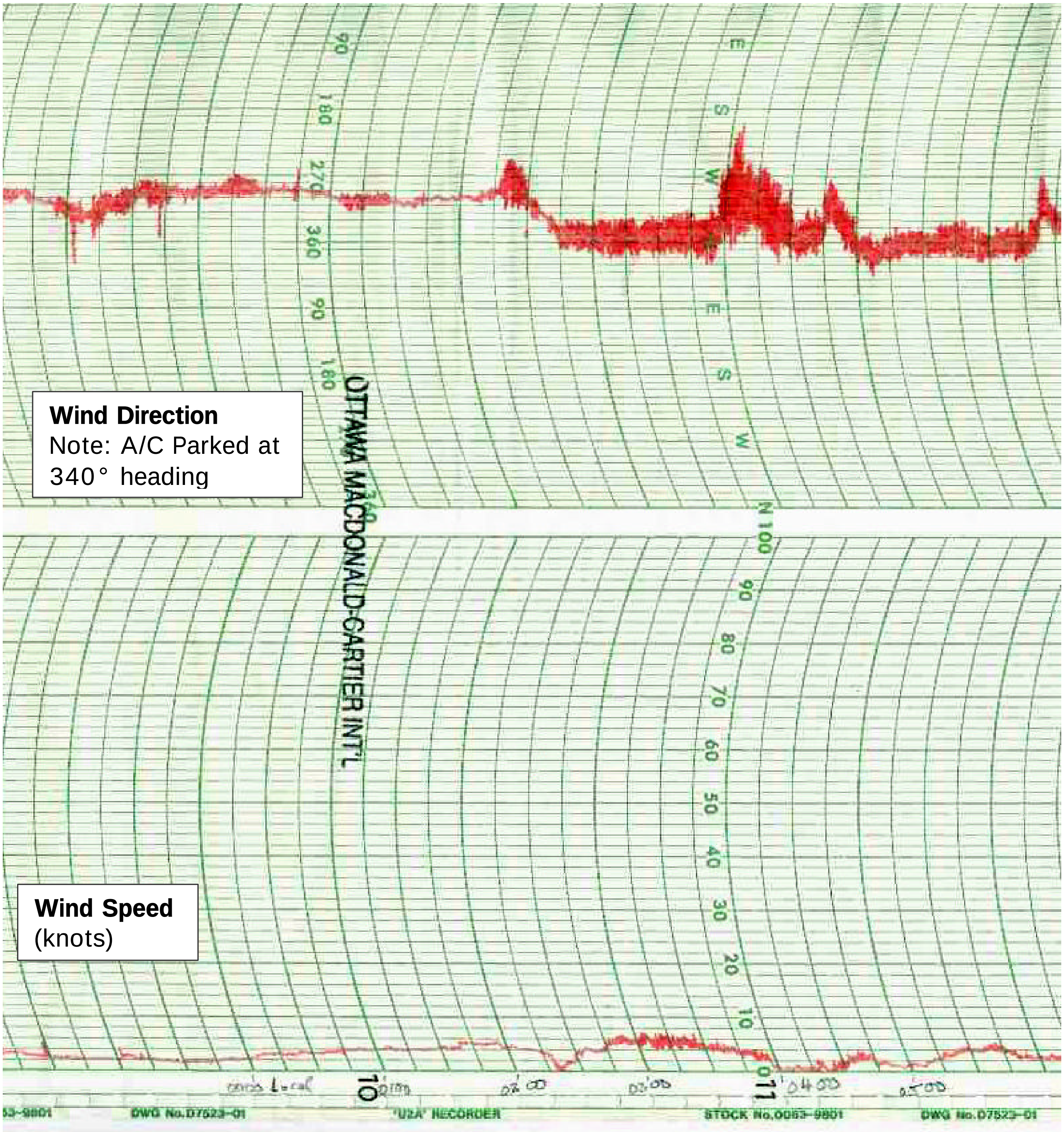
## 3.3 Thermal Time Constant

Thermal time constants were calculated for those positions on the main wing that showed a relatively smooth temperature profile without noticeable deviations. The thermal time constant is an indication of the ability of a body, in this case the various components of the wing, to sustain its temperature over time. A high time constant means the body is capable of sustaining its temperature for a long period. The time constant is defined as

Figure 3.4

**WIND SPEED AND DIRECTION**

Warm Fuel Tests March 08/09, 1999



**Wind Direction**
Note: A/C Parked at 340° heading

**Wind Speed**
(knots)

the time taken for the temperature gradient of a surface to be reduced by 63 percent. It is generally accepted that a temperature gradient will stabilize after the passage of time equivalent to about four or five time constants.

When a surface temperature profile is available, the corresponding time constant can be calculated by selecting two points on the temperature curve and applying the following formula:

$$t_{\mathrm{T}} = \frac{\left(t_2 - t_1\right)}{\ln\left[\frac{\Theta_1}{\Theta_2}\right]}$$

where $t_T$ = time constant
$t$ = time
$T_\infty$ = ambient temperature °K
$T$ = wing temperature °K at time t
$\Theta$ = $T - T_\infty$

During these tests, the winds were calm. This resulted in a very slow heat loss to the ambient air by convection and heat transfer.

As discussed in the next section, the wing skin temperatures at some locations had stabilized at values below outside air temperature (OAT). This indicates that heat loss through radiation to the open sky had an important contribution to the overall heat transfer equation.

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# 4 ANALYSIS AND OBSERVATIONS

## 4.1 Test Conditions

These tests were carried out overnight on March 8 and 9, 1999. In this study of warm fuel as a means to facilitate aircraft deicing, it was planned that the fuel would be warmed to a temperature near 30°C. This would conform to the concept proposed and reported by Polaris Thermal Energy Systems, Inc. In the actual test, the fuel was delivered at a temperature of only 8°C. Due to equipment demands, the fuel tender had been made available for heating fuel only at mid-day on the day of tests, resulting in an insufficient period of warming to achieve the desired temperature.

A further deviation from the originally planned test conditions concerned the ambient temperature of the aircraft surfaces. In the original test plan, it was expected that those aircraft made available for testing would have been exposed to the outside ambient temperatures for some time, and conceivably even have cold soaked fuel on board from previous flights. In fact, the test aircraft had been parked in a heated hangar since the previous Friday. The tests were conducted on Monday night.

Aircraft 144616 (with a 45 percent fuel load) was moved from the hangar about 3.5 hours before test time to allow the surfaces to cool prior to test. Aircraft 144615 (with a 30 percent fuel load) was also moved out of the hangar at that time for an engine run-up, and then was towed back in to the hangar where it remained until about 2300 h. As a result, the aircraft were warmer than normal when tests commenced. Some of the wing surfaces cooled down fairly quickly, flight control surfaces in particular. The main wing surfaces at the inner end of the wing near the wing root were still considerably warmer than OAT (-12°C) when tests were initialized. Positions on the outer main wing, further away from the heat reservoir of the on-board fuel, had cooled to below OAT at the start of tests.

The fuel already on board the aircraft at the time of refuelling was considerably warmer (17.8 and 16°C) than the heated fuel provided for testing (8°C).

The fuel temperatures in the two test wings after being refuelled were neither very warm nor very cold at 14.4°C and 1.3°C. The two wings are hereafter referred to as the warm wing and the cold wing. Although this temperature differential was not as large as initially planned for, it still provided a large enough difference to allow the acquisition of meaningful data.

The ambient conditions were very suitable for the test, with outside ambient temperatures of –10 to -12°C, clear skies and calm winds. The humidity was such that the frost point ranged from –13.5 to –14.6°C for the duration of the test. This resulted in frost deposition at certain locations on the test aircraft wing surfaces.

The data collected and the observations recorded permit the effect of warmed fuel to be determined through examination of the temperature profiles of the various wing sections selected as thermistor locations, and also from consideration of the distribution of frost which formed on either of the test wings.

## 4.2 General Comparison of Wing Surface Temperatures to OAT

As noted earlier, the various components of the wing attained significantly different temperatures prior to boarding the fuel required to initiate the test.

In both wings, surface temperatures outboard on the main wing (positions 7 and 20 in Figures 3.1 and 3.3) fairly quickly assumed values well below that of the outside air; as much as 5 degrees colder. Based on the quantity of fuel on board at this stage, it could be expected that the fuel heat was not affecting this area of the wing. *These surfaces experienced frost deposition during the trial period.*

By comparison, surface temperatures inboard on the main wing (positions 2 and 19 in Figures 3.1 and 3.3) were still well above ambient just prior to the boarding of the test fuel.

Temperatures on the inner flaps of both wings (positions 11 and 18 in Figures 3.1 and 3.3) were very similar; both were measured to have temperatures colder than the OAT by about 2 to 3 degrees C., but warmer than the top outboard wing surfaces. *Frost did not deposit on these surfaces during the trial.*

Temperatures on the leading edge were still above OAT prior to refuelling, being warmer than the outboard wing and the flap, but colder than the inboard wing. *Frost did not deposit on these surfaces during the trial.*

An important influence on these various surface temperatures was heat loss to the open sky due to radiation. Ambient conditions prior to and for the major part of the test period, included a clear sky with very calm winds. The main wing had a painted surface (Photo 4.1) whereas the leading edge surface was polished aluminum. Polished aluminum has a very low radiative emissivity, whereas painted surfaces typically have considerably (up to 20 times) higher emissivities. Therefore, the main wing should tend to experience greater energy loss due to thermal radiation than would the leading edge.

In the case of the inner wing, the heat loss due to radiative energy transfer to the open sky was over-compensated for by the thermal reservoir of the mass of onboard fuel. As a result, the inner wing experienced a temperature which was well above the OAT.

In the case of the outer wing (outboard of the fuel tank), the heat loss due to radiation to the open sky was *not* compensated by heat gain from the more distant mass of onboard fuel. The resulting temperature was below the OAT. Heat transfer by convection was not a factor in the prevailing calm wind condition, but did occur at 0230hrs when a short period of winds gusting to 6 kts occurred.

## 4.3 Temperature Profiles

Temperature profiles for various thermistor locations on the wing surface are examined in the following sections in order to understand the nature of heat transfer from the warmed fuel in particular, and for the wing in general.

Figure 4.1 is a typical chart presenting temperature profiles for corresponding positions on the two test wings, as well as the profile of the OAT. A sketch of the warm (port) wing is provided, showing the locations of temperature measurement points for reference. The legend box shows symbols for the two corresponding positions charted on each figure. For Figure 4.1, position 2 on the warm wing is located at a point corresponding to position 19 on the cold wing.

In some figures, the calculated time constant values are shown for later discussion.

For the purpose of comparison, the temperature profile for the cold wing has been shifted in time (15 minutes later) to align the time of refuelling with that of the warm wing.

### 4.3.1 Inner Wing

Figures 4.1, 4.2, and 4.3 present temperature profiles for corresponding positions on the inboard area of the two test wings, as well as the profile for OAT. In these figures, note that the temperature of one wing is higher than the temperature of the other prior to refuelling.

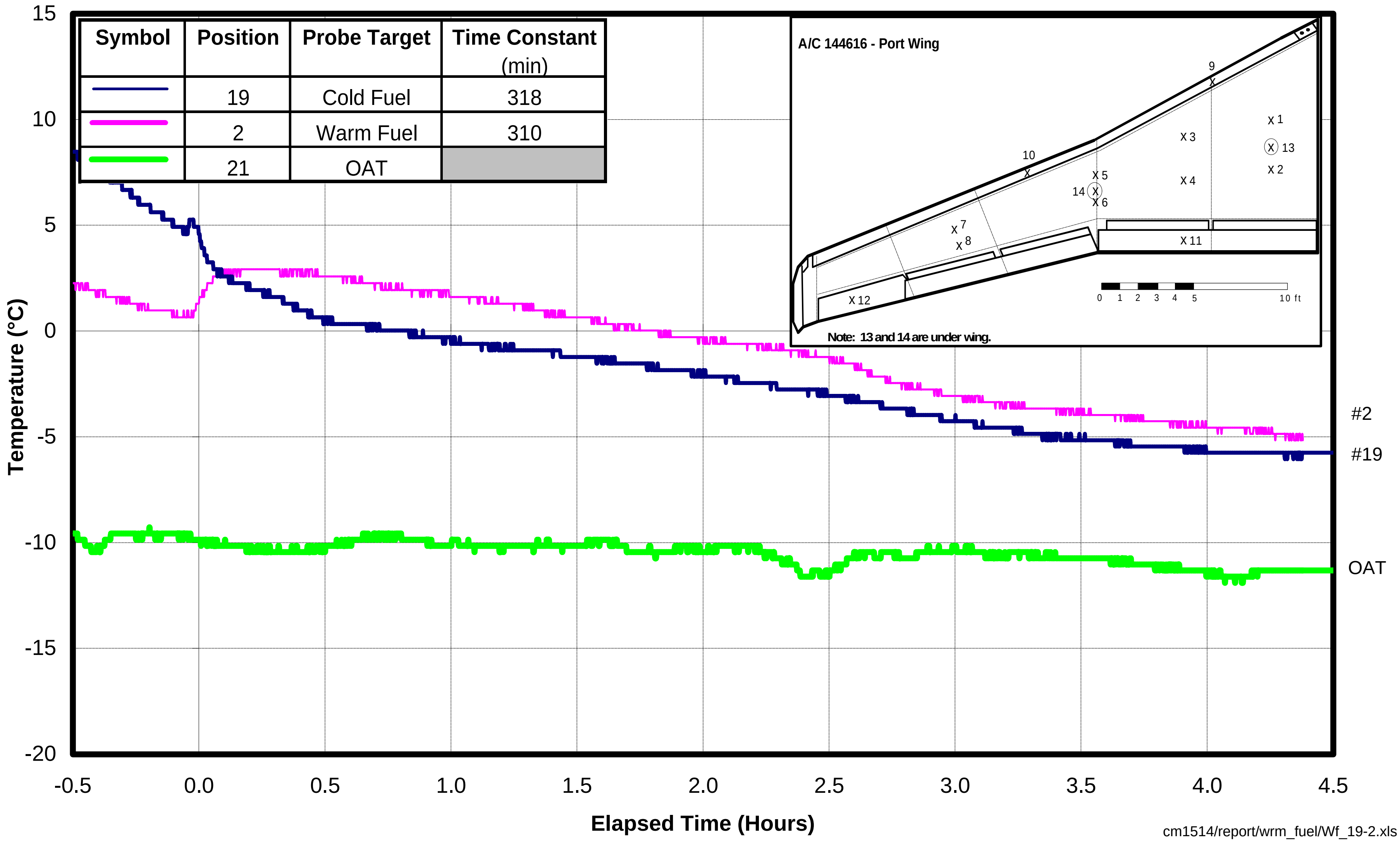
FIGURE 4.1

# WING SKIN TEMPERATURE COMPARISON

## COLD FUEL VERSUS WARM FUEL

### POSITIONS 19 AND 2

DND Challenger Aircraft, March 8-9, 1999



cm1514/report/wrm_fuel/Wf_19-2.xls
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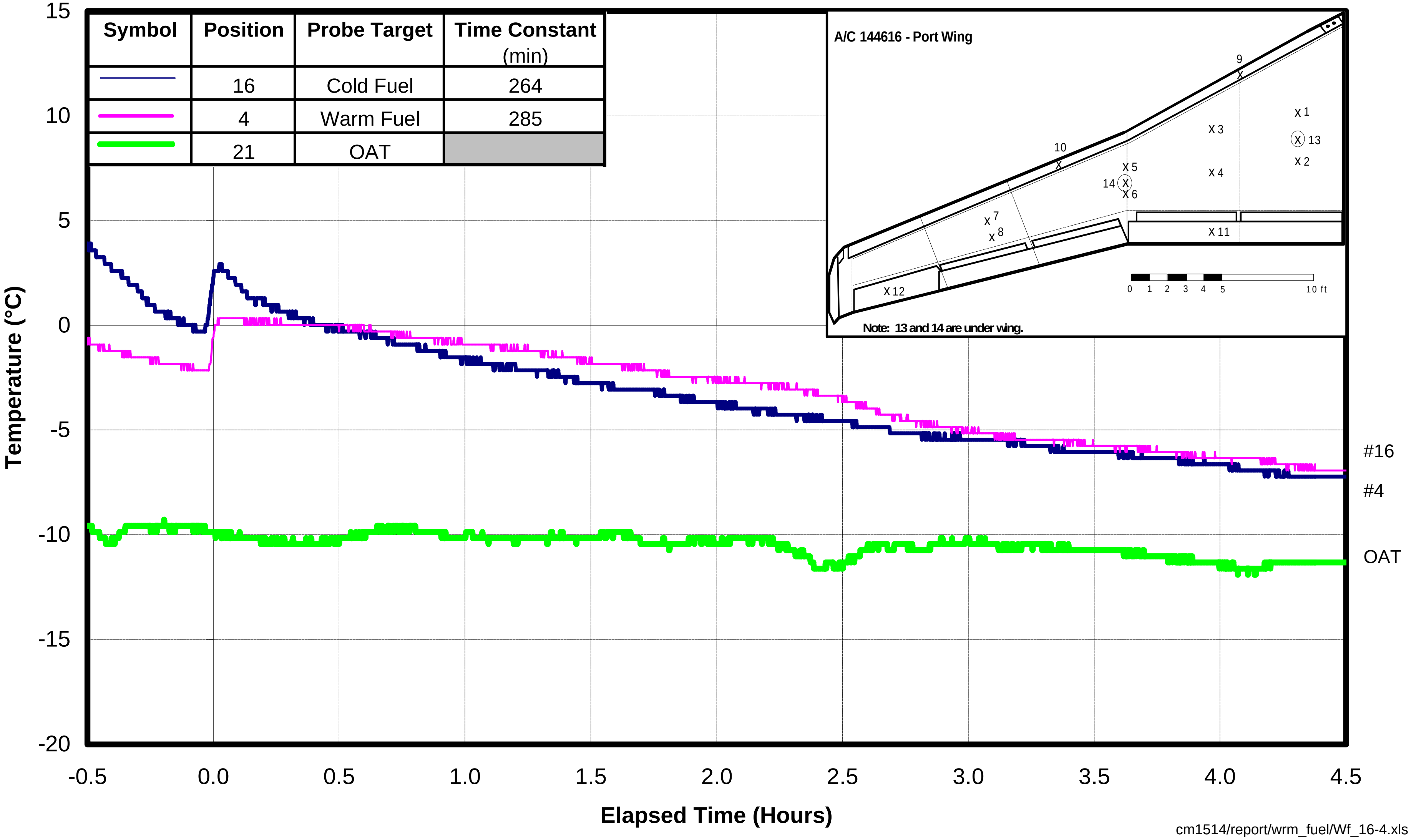
FIGURE 4.2

# WING SKIN TEMPERATURE COMPARISON

## COLD FUEL VERSUS WARM FUEL

### POSITIONS 16 AND 4

DND Challenger Aircraft, March 8-9, 1999



cm1514/report/wrm_fuel/Wf_16-4.xls
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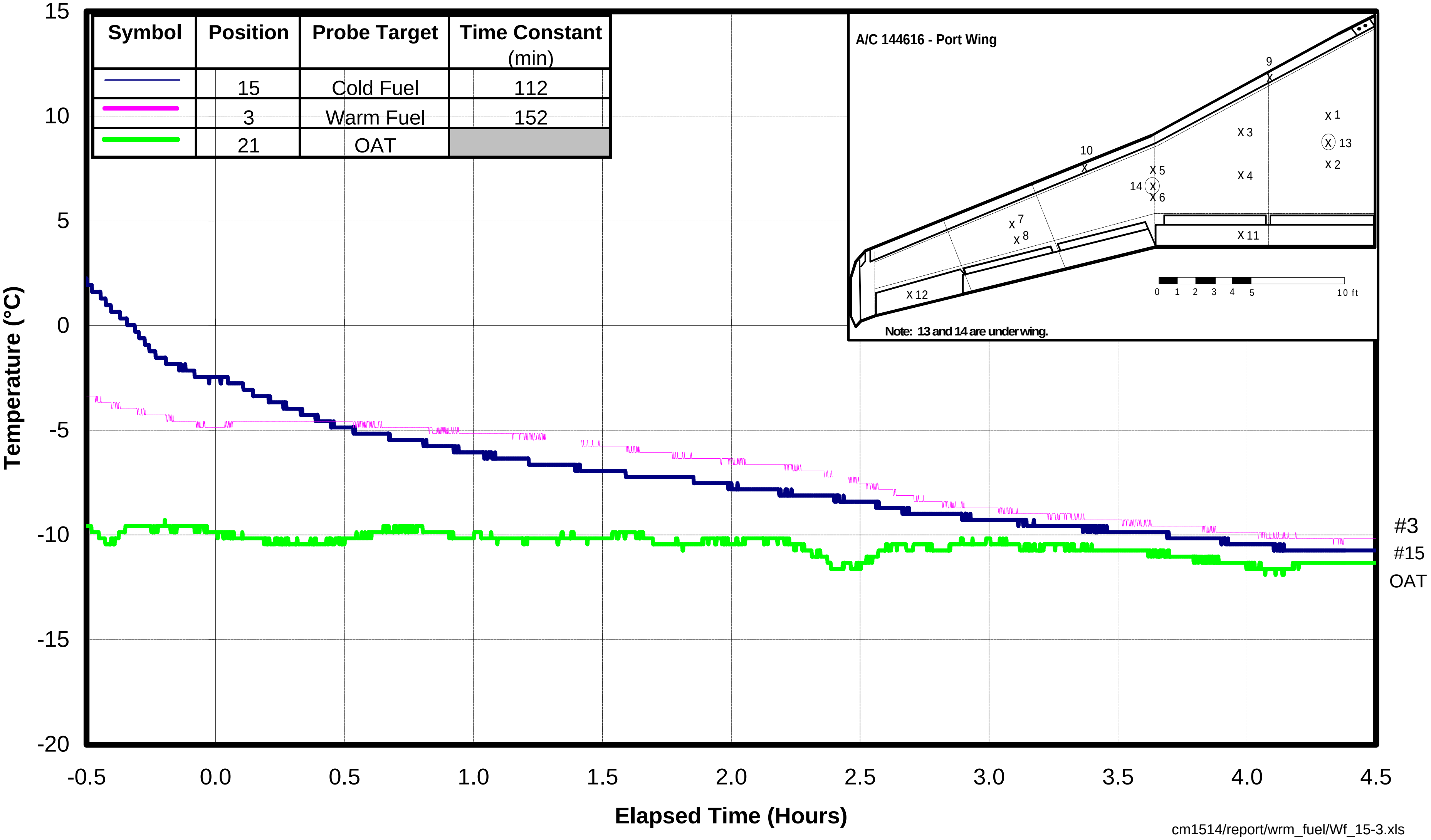
FIGURE 4.3

# WING SKIN TEMPERATURE COMPARISON

## COLD FUEL VERSUS WARM FUEL

### POSITIONS 15 AND 3

DND Challenger Aircraft, March 8-9, 1999



| Symbol | Position | Probe Target | Time Constant (min) |
|---|---|---|---|
| ━ | 15 | Cold Fuel | 112 |
| ━ | 3 | Warm Fuel | 152 |
| ━ | 21 | OAT | ▨ |

cm1514/report/wrm_fuel/Wf_15-3.xls
4/30/02, 1:31 PM

In Figure 4.1, location 2 shows rapid warming when fuel is boarded, and then reaches a steady state of heat loss after about 30 minutes, at which point the curve follows a smoothly descending profile for the remainder of the test. At test end (4.5 hours duration) the temperature at positions 2 and 19 was about 7 degrees warmer than the OAT.

The temperature of the resulting mixture of *initially onboard* and *newly boarded* fuel in the warm wing was 14°C, cooler than the initial fuel on board (18°C). Despite the cooler fuel, the wing skin temperature showed an increase following refuelling. The explanation for the rise in skin temperature lies with the amount of fuel in the wing tank and the resulting proximity of the fuel surface to the inner wing skin. At location 2, it is expected that the additional amount of fuel caused wetting of the inner wing surface.

Following refuelling, (each wing contained roughly the same total fuel load; recall Table 3.1), the cold wing fuel temperature was calculated to be about 1ºC. After about 30 minutes, the temperature profile smoothed out and assumed a well-behaved descending profile thereafter.

Thirty minutes following refuelling, the temperature of the cold wing was 3 degrees colder than the warm wing. At test end, the cold wing was 2 degrees colder than the warm wing, and 5 degrees warmer than the OAT.

The thermal time constants for the matched thermistor positions (2 and 19) were 318 and 310 minutes, respectively.

Similarly, temperature profiles for matched thermistor positions 4 and 16 (Figure 4.2) follow smoothly descending curves after a period of stabilization to steady state conditions. The temperature values at this location were not very different for each of the two wings and became virtually identical at test end. Both of these matched positions exhibited final temperatures which were about 4 degrees warmer than the OAT.

The time constants at this location are also very similar for the two wings (264 and 285 minutes), although somewhat shorter than for the previously discussed location. The time constants at this location are very similar to the time constants determined for MD-80 aircraft in a previous study, Transport Canada report, TP12899E, Validation of Methodology for Simulating a Cold-Soaked Wing (1). In that study, the time constant value for a location on the wing where fuel wetting was in effect, was 256 minutes.

Positions 3 and 15 were located on the high point of the wing chord, forward of positions 2 and 16. Similarly, position 1 (Figure 3.1) was located on the high point of the wing chord. Compared to the results obtained from previously discussed positions, this location had cooled to a greater extent prior to refuelling. The addition of fuel resulted in less impact on the temperature profile. The final temperature at this location was one to two degrees above the OAT at test end. It is believed that the inner surface of the wing at the high point of the chord, was well above the fuel surface, even after refuelling.

No frost was observed anywhere on the inner wing.

### 4.3.2 Outboard Wing

Position 7 (Figure 4.4) on the warm fuel aircraft had cooled to –15°C prior to refuelling, 5 degrees colder than the OAT. This aircraft had been parked outside the hangar for about 3.5 hours by the time of refuelling. Position 20 on the second aircraft cooled very rapidly. Its temperature was at the OAT at the time of refuelling. The temperature profiles for the two positions became coincident after about one hour and thereafter remained the same.

An excursion in the profile for the OAT and for skin temperature at this location occurred at 0230 h. This was related to a short period of elevated wind speed, with gusts to 6 kts (Figure 3.4). At the same time, wind direction changed from 300º to 350º. The aircraft was parked at a heading of 340º, and so faced directly into the wind. The OAT dropped by about 2 degrees for a short period, and then returned to its previous steady state value. The wing skin temperature (both wings) increased by about 2 degrees over a one-half hour period and then slowly cooled back down to previous values. During this period the skin temperature was above the frost point. The sky stayed clear throughout the test period.

Frost deposits were observed on the outer wing but time constants were not calculated for this location.

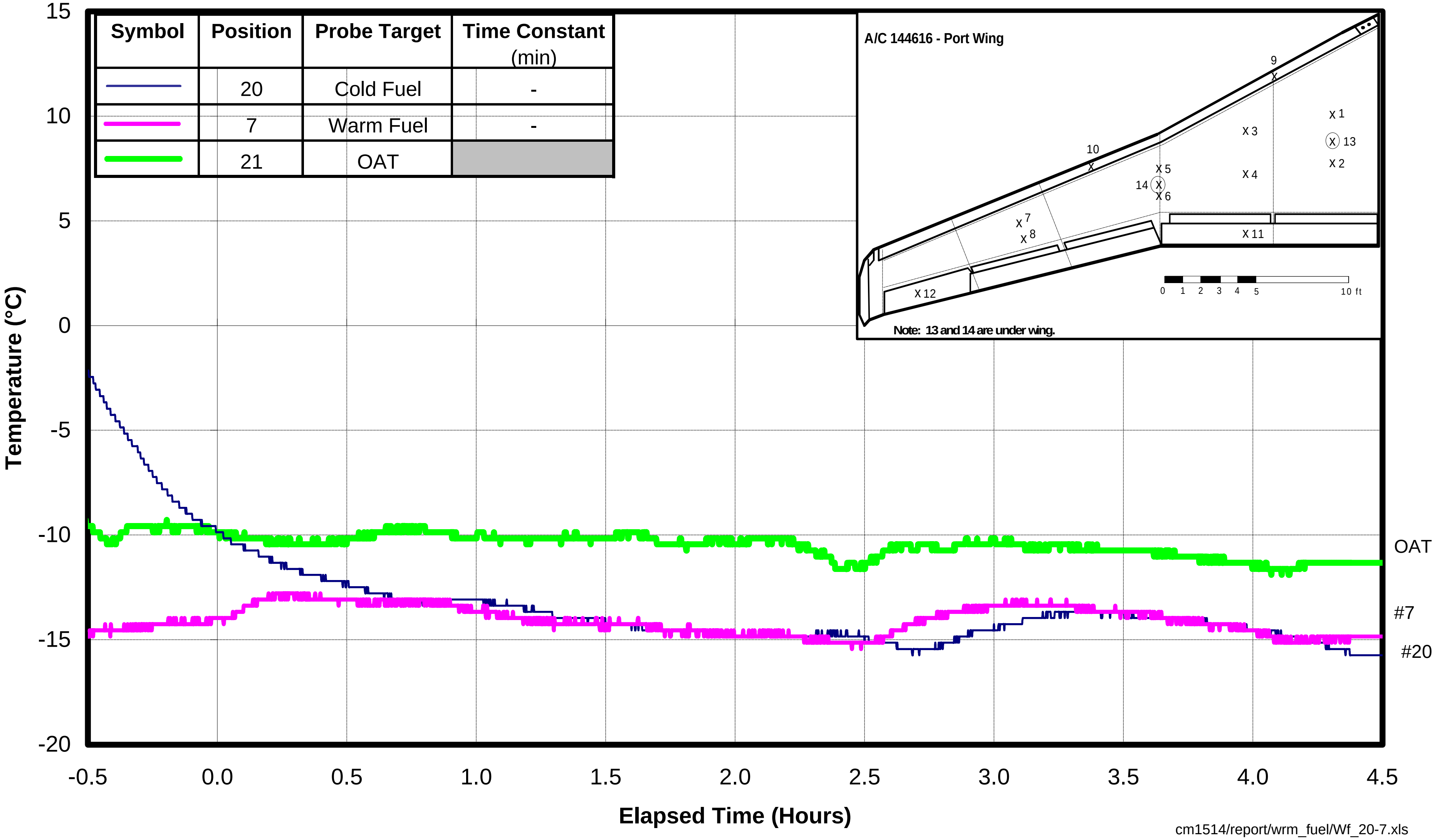
FIGURE 4.4

# OUTBOARD WING SKIN TEMPERATURE COMPARISON

## COLD FUEL VERSUS WARM FUEL

### POSITIONS 20 AND 7

DND Challenger Aircraft, March 8-9, 1999



cm1514/report/wrm_fuel/Wf_20-7.xls
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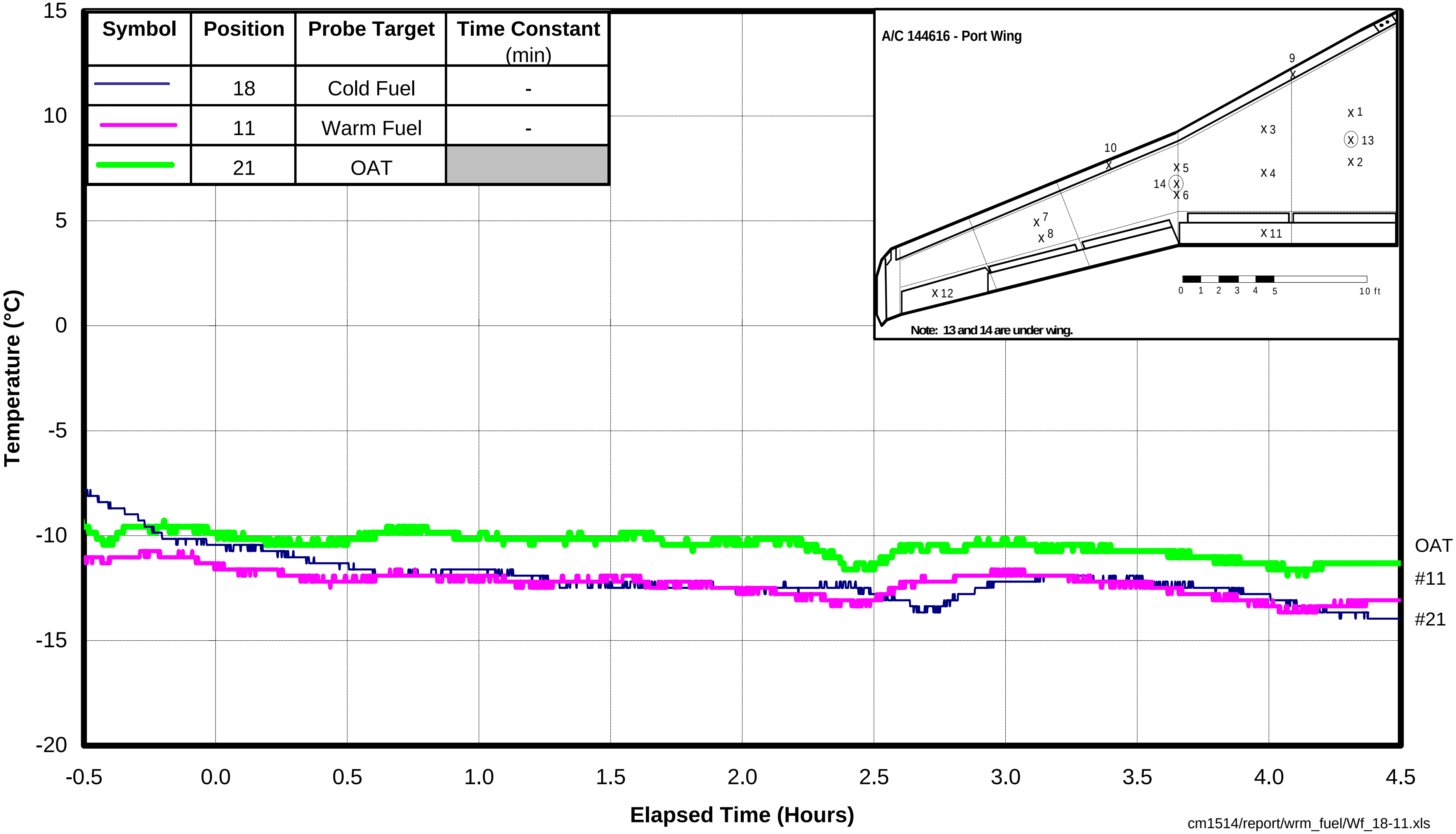
FIGURE 4.5

# INBOARD FLAP SKIN TEMPERATURE COMPARISON COLD FUEL VERSUS WARM FUEL

### POSITIONS 18 AND 11

DND Challenger Aircraft, March 8-9, 1999



cm1514/report/wrm_fuel/Wf_18-11.xls
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### 4.3.3 Inboard Flap

The inboard flap temperatures for the two wings, measured at locations 18 and 11 (Figure 4.5), were practically identical. Thirty minutes following refuelling, the two test positions reached a common temperature of –12ºC, about 2 degrees below the OAT. The positions continued to experience identical temperatures throughout the test period, and maintained a constant –2º to –2.5ºC difference relative to the OAT.

An excursion in skin temperature similar to those recorded at locations on the outer wing was also noted.

Frost was not observed on the inboard flaps.

### 4.3.4 Aileron

Aileron skin temperatures were measured only for the warm wing (Position 12, Figure 4.6). The temperature of this surface followed a profile identical to the outer wing. The shape was similar to that of the inner flap (Position 11), but at a constant differential of 2 degrees colder relative to the inner flap. During the test, the aileron temperature dropped to the frost point and, in consequence, the aileron was observed to accumulate frost.

### 4.3.5 Leading Edge

The wing leading edge temperatures were measured at matching thermistor positions: position 17 on the cold wing and position 9 on the warm wing (Figure 4.7). On the warm wing, position 10 was measured as well.

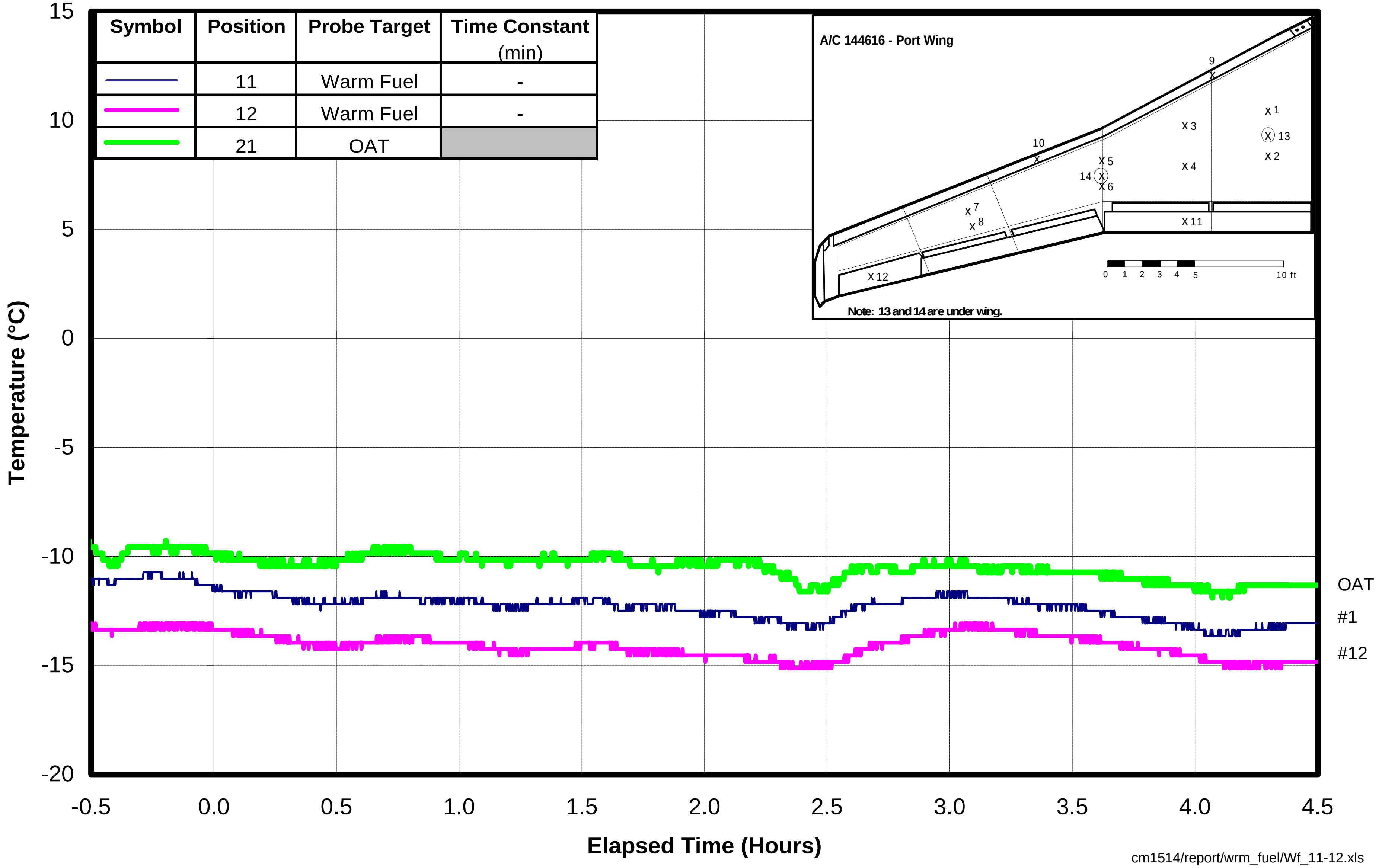
The temperature of Position 9 on the leading edge of the warm wing aircraft had stabilised to –5.5°C by the time of refuelling. This is the aircraft that that had been outside for 3.5 hours prior to the start of tests. Following refuelling, the leading edge on the warm wing gradually warmed to about –3°C, an increase of 2.5 degrees over a one hour period. It then gradually cooled at a slower rate to reach –5°C after a further 1.5-hour interval.

Position 10 also showed a pronounced increase in temperature (about 3.5 degrees) following refuelling.

FIGURE 4.6

# AILERON SKIN TEMPERATURE

### DND Challenger Aircraft
### March 8-9, 1999



cm1514/report/wrm_fuel/Wf_11-12.xls
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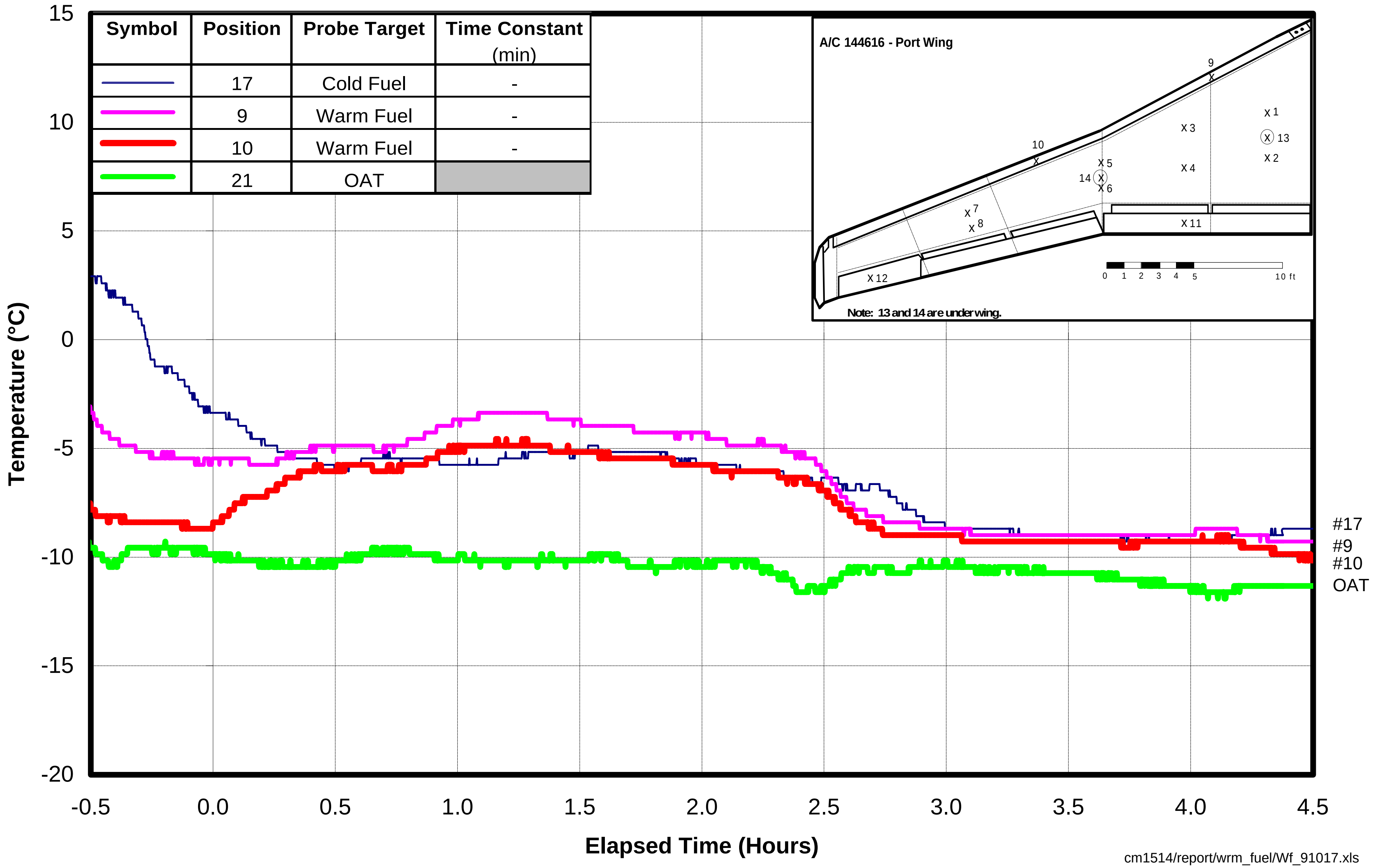
FIGURE 4.7

# LEADING EDGE SKIN TEMPERATURE

## DND Challenger Aircraft
## March 8-9, 1999



cm1514/report/wrm_fuel/Wf_91017.xls
4/30/02, 1:33 PM

The gain in temperature of the leading edge following refuelling occurred despite the fact that temperature of the final mix of fuel on board was actually cooler than the fuel initially on board. It is believed that the gain in leading edge temperature was a function of the greater final quantity of fuel resident in the wing tanks. The greater depth of fuel must have wetted a larger area of the inner surface of the front spar, from which heat was conducted toward the inner surface of the leading edge.

At 0230 hrs, when the OAT profile experienced a temporary drop of 2 degrees C, the leading edge temperature dropped by almost 4 degrees to –9°C and thereafter remained at that temperature. This appears to coincide with a small increase in wind, with some gusts, at that time.

The leading edge on the cold fuel aircraft (Position 17) was still in the process of cooling at the time of refuelling. The cooling trend slowed during refuelling, and the temperature gradually levelled off at –6°C, one-half hour after refuelling. Thereafter it slowly rose about one degree over a one-hour period and then resumed cooling to lose two degrees over a 1.5-hour period. This trend was similar to that recorded for the warm wing.

### 4.3.6 Under-Wing

The under-wing skin temperatures were measured on the warm wing only, at two positions (Figure 4.8, positions 13 and 14). Position 13 was at the inner end of the wing. This position's proximity to the large thermal reservoir of the fuel caused it to initially exhibit a higher temperature than position 14, located further out on the wing. After 2 hours, the temperature of the two positions became equal. The under wing temperature cooled progressively during the test interval, with a final temperature of –6ºC at test end.

At test end, a sample of fuel from each wing also gave a temperature reading of about –6°C.

## 4.4 Occurrence of Frost Deposits

### 4.4.1 Frost on the Warm Wing

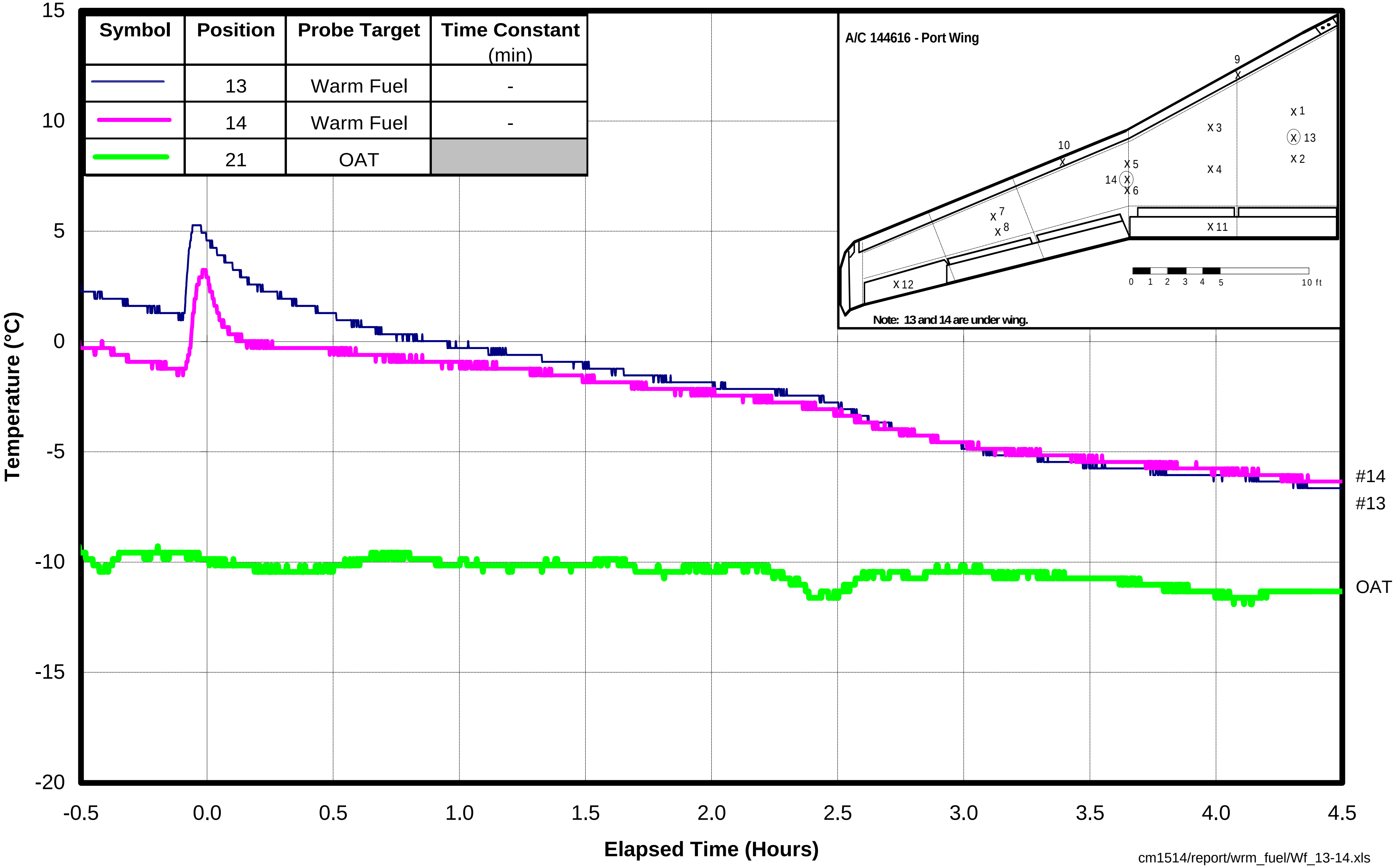
Prior to boarding of the test fuel, this aircraft had been parked outdoors for about 3.5 hours, and some areas of this wing had already cooled to

FIGURE 4.8

# UNDER WING SKIN TEMPERATURE

## DND Challenger Aircraft

## March 8-9, 1999



cm1514/report/wrm_fuel/Wf_13-14.xls
4/30/02, 1:34 PM

below the OAT. In Figures 3.1 and 3.2, these cooler areas are seen on the outer wing (positions 7 and 8), the inner flap (position 11) and the aileron (position 12).

Of these surfaces, frost had started to be deposited on the outer wing and the aileron which were at temperatures in the range of –13 to –14.5°C, very close to the indicated point shown in the figures. The inner flap skin temperature was –12°C (2 degrees warmer than the frost point) and did not develop frost deposits. Figure 4.9 provides a sketch of the pattern of this frost deposition.

Following boarding of fuel, these frost deposits did not dissipate.

At test end (4.5 hours duration), the frost deposits remained in much the same pattern but were heavier (Figure 4.10). Details of these frost deposits are shown in Photo 4.1 and Photo Set 4.2. The inner flap did not accumulate frost during the test. The temperature of this surface remained a constant 2 degrees warmer than the aileron and the outer wing (and the frost point), and 2 degrees colder than OAT.

The leading edge did not undergo frost deposition during the test.

### 4.4.2 Frost on the Cold Wing

There was no frost on this wing prior to refuelling as the skin temperatures were well above the OAT.

At test end, frost had appeared on the outer wing surfaces. This corresponds to the profile of calculated frost points (Figure 3.3) which shows the outer wing skin temperature reaching the frost point at about 0130 h. The pattern of frost deposition was similar to that of the warm aircraft, except that frost did not appear on the outer flap and aileron of this aircraft (Figure 4.11). Detail is shown in Photo Set 4.3.

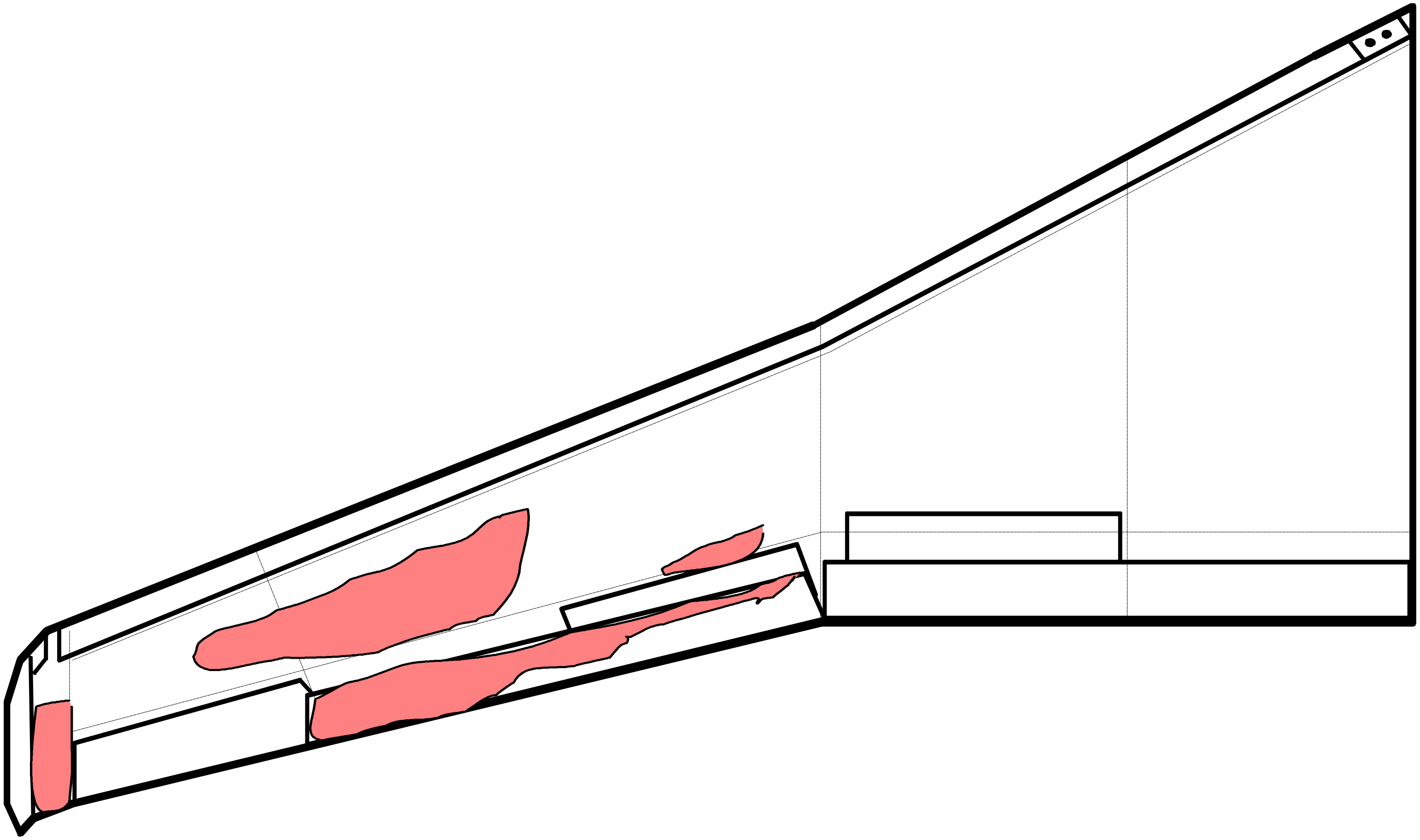
### 4.4.3 Frost on Canadair RJ Aircraft Parked Overnight

Coincidentally, two Air Canada Canadair RJ aircraft were parked nearby on the same ramp. Upon investigation, it was observed that these aircraft had developed frost deposition patterns very similar to those observed on the test aircraft.

The leading edge was clean of frost, while the outer wing and both the inner and outer flap were frosted. Details are shown in Photo Set 4.4.

FIGURE 4.9

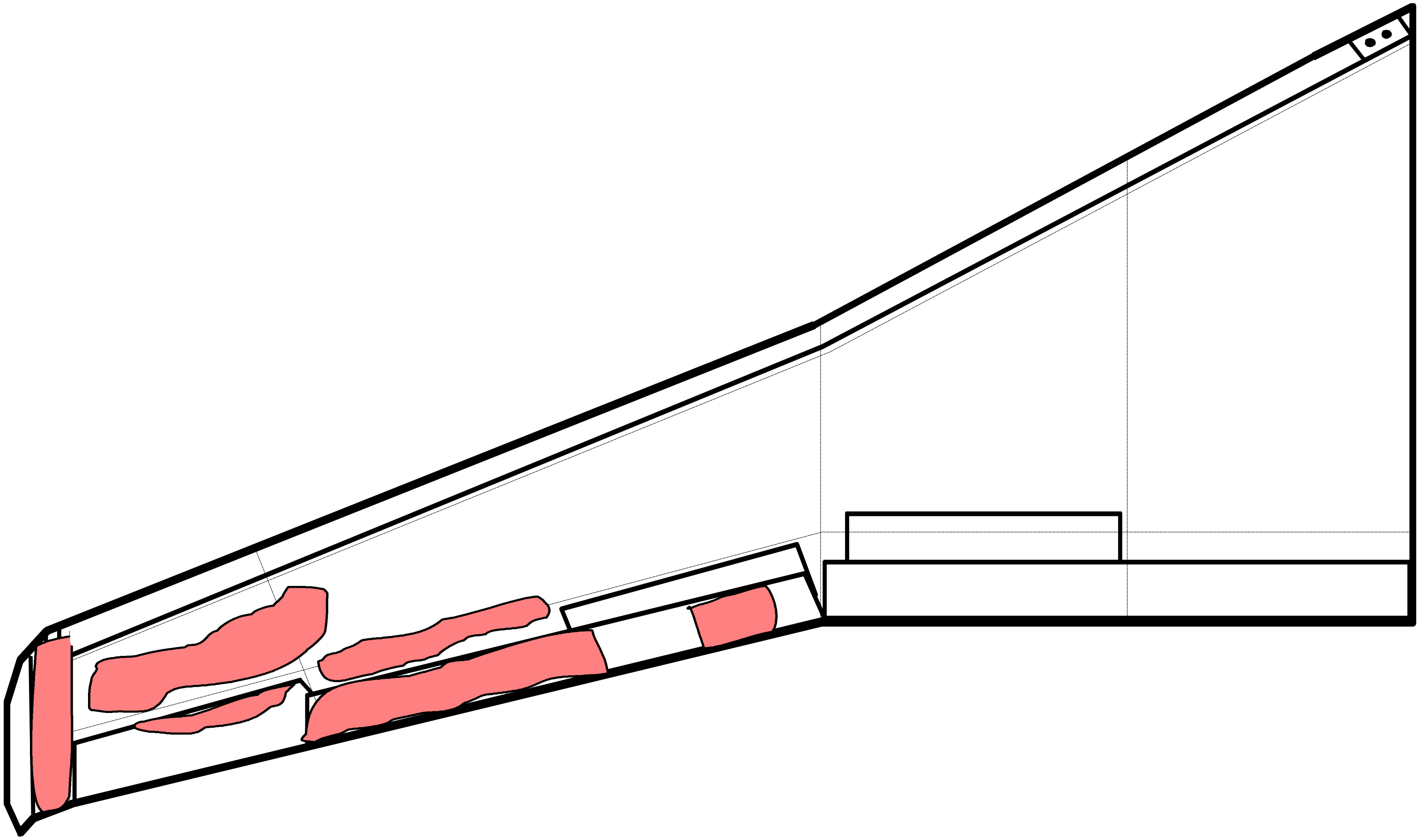
## FROST PATTERN ON WARM FUEL WING PRIOR TO REFUELLING



cm1514\report\warmfuel\Frst_wb.xls
4/30/02, 1:35 PM

## FIGURE 4.10

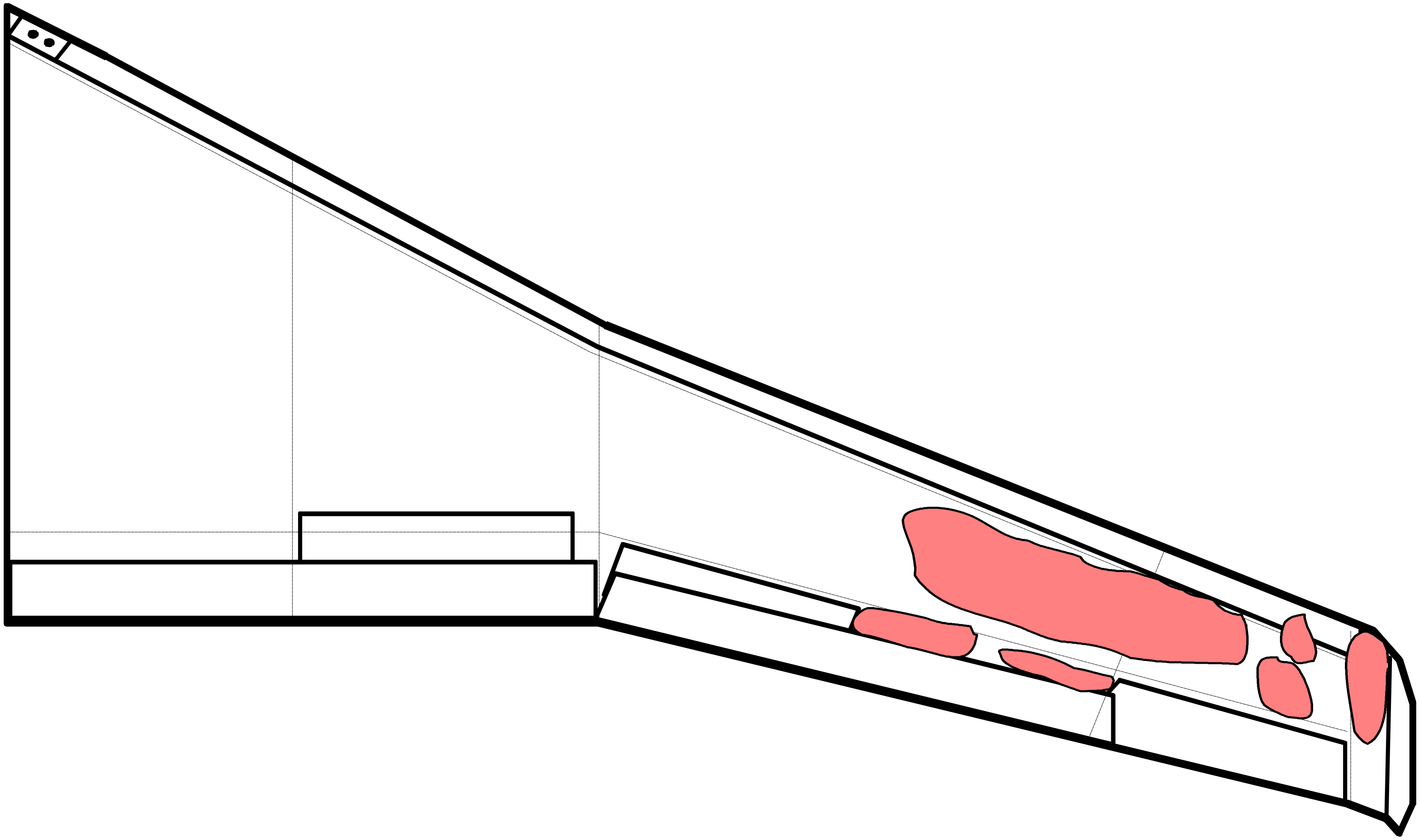
# FROST PATTERN ON WARM FUEL WING AT TEST END



cm1514\report\warmfuel\Frst_wa.xls
4/30/02, 1:35 PM

FIGURE 4.11

## FROST PATTERN ON COLD FUEL WING AT TEST END



cm1514\report\warmfuel\Frst_ca.xls
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## Photo Set 4.1
## Wing Surface Appearance

## Photo Set 4.2
## Appearance of Frost on the Warm Fuel Wing

## Photo Set 4.3
## Appearance of Frost on the Cold Fuel Wing

## Photo Set 4.4

## Appearance of Frost on Canadair RJ Aircraft

# 5 CONCLUSIONS

In this evaluation of the approach to use warmed fuel to facilitate aircraft deicing, the intent was to test by boarding fuel warmed to a temperature in the range of 30°C to 32ºC. The temperature of the fuel tested was considerably lower than planned and the results are affected somewhat by this deficiency. Nevertheless, valuable data and observations were collected that allow useful preliminary conclusions to be drawn. In addition, observations of temperature profiles of different wing components and patterns of frost deposition while the test aircraft were parked outdoors overnight serve to provide an improved understanding of the nature of frost deposition as experienced in actual operations on this aircraft.

From these trials it can be concluded that:

- The temperature of the warm fuel boarded was too low to impart sufficient heat to the wing surfaces to maintain a temperature above freezing.
- Fuel temperature influences the main wing skin temperature only where the mass of fuel is in close proximity to the inner wing skin. At a location near the warm wing root, the skin temperature showed an increase following refuelling even though the temperature of the total fuel mixture following refuelling was lower than the fuel temperature prior to refuelling. Further out on the wing, more distant from the mass of fuel, the wing skin temperature was not affected by the boarding of fuel, for either the warm wing or the cold wing.
- The fuel quantity tested in this trial represented the fuel load of a typical mission. As fuel quantities are selected on the basis of next flight requirements, and excess fuel loads are operationally undesirable, fuel loads boarded may limit the benefits of this approach.
- The temperature of the inner flap surface was the same for both wings and did not appear to be influenced by the different fuel temperatures achieved upon refuelling. However, this surface did maintain a temperature higher than that of the aileron and outer main wing, and so appears to have received some temperature support from the thermal reservoir of the fuel.
- The aileron temperature was equivalent to that of the skin on the outer main wing. No noticeable temperature support was received from the fuel by either of these surfaces.
- Wing leading edge temperatures were supported by heat transmitted from the warmed fuel, at least in calm wind conditions. Heat from the fuel in the warm wing (14°C) caused the leading edge temperature to rise by about 3

degrees. In the cold wing where the fuel was 1.3°C, the leading edge temperature rose by about 1 degree. In both wings, the temperature of the leading edge dropped rapidly with a small increase in wind, but still remained above the OAT.

- The polished aluminum surfaces of the wing leading edges lost less heat through radiation than did other (painted) wing surfaces, and did not experience frost formation. The skin temperature of other wing surfaces such as the outer wing and ailerons quickly dropped below the OAT by as much as 4 to 5 degrees C, and did accumulate frost.

- The thermal time constant for the Canadair Challenger 600 (and the Bombardier RJ) wing at a location where the inner wing skin is wetted by fuel, is very similar to that of an MD-80 aircraft with a wetted wing.

- Convective heat transfer (from the wing skin to the ambient air) which resulting from a relatively light wind is sufficient to offset the heat loss due to thermal radiation exchange between the wing surface and the open sky, and thereby prevent frost deposition. This phenomenon suggests the potential application of preventing frost deposition by blowing air at ambient temperature over the wings of parked aircraft during frost forming conditions.

This alternative trial procedure did not address all of the original goals of the study; the effect of warmed fuel on holdover times and on quantities of fluids could not be examined. However, the results indicate that the procedure shows promise in resolving the cold-soaked wing problem. The trial highlighted one potential problem with the practicality of the procedure. Because fuel loads are dictated by flight requirements, the total fuel is often less than a full tank, which constrains the transfer of heat to the complete wing surface.

# 6 RECOMMENDATIONS

It is recommended that:

- Further trials of the warmed fuel deicing concept be conducted using fuel that has been heated sufficiently to satisfy the experimental design. These trials should be based on the test plan originally designed for this evaluation, and should address the impact of sufficiently warmed fuel on wing skin profiles, on fluid amounts needed to deice aircraft, and on resulting holdover times during natural or artificial precipitation.

- The influence that typical operational fuel loads may have on the attainability of the implied benefits of this concept be explored.

- The feasibility of preventing frost formations by blowing air at low speed and ambient temperature over wing surfaces should be examined.

- The feasibility of preventing frost formations using blowing air should be examined.

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# REFERENCES

1. Dawson, P., D'Avirro, J., *Validation of Methodology for Simulating a Cold-Soaked Wing*, APS Aviation Inc., Montreal, October 1996, Transportation Development Centre, TP 12899E.

# APPENDIX A

# STATEMENT OF WORK

APPENDIX A

# TRANSPORTATION DEVELOPMENT CENTRE

# WORK STATEMENT

# AIRCRAFT AND FLUID HOLDOVER TIME TESTS FOR WINTER 98/99

(December 1998)

## 1. INTRODUCTION

Following the crash of a F-28 at Dryden in 1989 and the subsequent recommendations of the Commission of Inquiry, the Dryden Commission Implementation Project (DCIP) of Transport Canada (TC) was set up. Together with many other regulatory activities an intensive research program of field testing of deicing and anti-icing fluids was initiated with guidance from the international air transport sector through the Society of Automotive Engineering (SAE) G-12 Committee on Aircraft Ground De/Anti-icing. As a result of the work performed to date Transport Canada and the US Federal Aviation Administration (the FAA) have been introducing holdover time regulations and the FAA has requested that the SAE, continue its work on substantiating the existing ISO/AEA/SAE Holdover Time (HOT) tables (TC research representing the bulk of the testing).

The times given in HOT Tables were originally established by the Association of European Airlines based on assumptions of fluid properties, and anecdotal data. The extensive testing conducted initially by the DCIP R&D Task Group and subsequently by its successor Transport Canada, Transportation Development Centre (TDC) Aviation Winter Operations R&D (AWORD) Group has been to determine the performance of fluids on standard flat plates in order to substantiate the times or, if warranted, to recommend changes.

TDC has undertaken most of the field research and much other allied research to improve understanding of the fluid HoldOver Times. Most of the HOT table cells been substantiated, however low temperatures have not been adequately explored and further tests are needed.

The development of ULTRA by Union Carbide stimulated all the fluid manufacturers to produce new long lasting anti-icing fluids defined as Type IV. All the Type IV fluids were upgraded in early 1996 and therefore all table conditions need to be re-evaluated and the table revised if necessary. Certain special conditions for which advance planning is particularly difficult such as low temperatures with precipitation, rain or other precipitation on cold soaked surfaces, and precipitation rates as high as 25 gm/dm²/hr need to be included in the data set. All lead to the need for further research.

Although the Holdover tables are widely used in the industry as guides to operating aircraft in winter precipitation the significance of the range of time values given in each cell of the table is obscure. There is a clear need to improve the understanding of the limiting weather conditions to which these values relate.

An important effort was made in the 94/95 and 95/96 seasons to verify that the flat plate data were representative of aircraft wings. Airlines cooperated with DCIP by making aircraft and ground support staff available at night to facilitate the correlation testing of flat plates with performance of fluids on aircraft. An extension of this testing was to observe patterns of fluid failure on aircraft in order to provide data to assist pilots with visual determination of fluid failure, and to provide a data to contamination sensor manufacturers. The few aircraft tests made to validate the flat plate tests were inconclusive and more such tests are needed. Additional tests testing with hot water for special deicing conditions were not completed. All these areas are the subjects for the further research that is planned for the 98/99 winter.

The primary objective of 97/98 testing was the performance evaluation of new and previously qualified Type IV fluids over the entire range of conditions encompassed by the holdover time tables. The effect of different variables on the fluid holdover time, in particular the effect of fluid viscosity, was examined and deemed to be significant. As a result, any future Type IV fluid holdover time testing will be conducted using samples representative of the manufacturers lowest recommended on-wing viscosity. Current methods for establishing holdover times in snow involve outdoor testing, which has been the source of industry concern for some time. It is recommended that a snowmaking device in development need to be evaluated for the future conduct of snow holdover time tests in controlled conditions. The study of fluid buffers was also continued in 97/98 and identified several industry concerns which will be addressed in further research. The adherence of contaminated fluid to aircraft wings was also evaluated in a series of simulated takeoff runs without aircraft rotation. Further research in these areas is needed.

## 2. PROGRAM OBJECTIVE (MCR 16)

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

## 3. PROGRAM SUB-OBJECTIVES

3.1. Develop reliable holdover time (HOT) guideline material based on test information for a wide range of winter weather operating conditions.

3.2. Substantiate the guideline values in the existing holdover time (HOT) tables for fluids that have been qualified as acceptable on the basis of their impact on aircraft take-off performance.

3.3. Perform tests to establish relationships between laboratory testing and real world experience in protecting aircraft surfaces.

3.4. Support development of improved approaches to protecting aircraft surfaces from winter precipitation.

## 4. PROJECT OBJECTIVES

4.1. Develop holdover time data for all newly qualified de/anti-icing fluids.
4.2. Develop holdover time data for Type IV fluids using lowest qualifying viscosity samples.
4.3. Develop supplementary data for a reduced buffer ‘de-icing only’ Table.
4.4. Determine whether recycled, recovered fluid can be used as a ‘De-icing only’ fluid.
4.5. Determine whether the extreme precipitation rates used for laboratory testing of de/anti-icing fluids are in fact encountered in practice.
4.6. Obtain equipment for laboratory production of artificial snow which most closely reproduces natural snow.
4.7. Assess the limiting conditions of wind, precipitation and temperature under which water can be used as the first step of a two-step de-icing procedure.
4.8. Determine the patterns of frost formation and of fluid failure initiation and progression on the wings of high-wing turbo-prop and jet commuter aircraft.
4.9. Assess the practicality of using vehicle-mounted remote contamination detection sensors for pre-flight (end-of-runway) inspection.
4.10. Provide base data on the capabilities of remote sensors.
4.11. Provide pilots with reference data for the identification of fluid failure. Quantify pilot capabilities to identify fluid failure
4.12. Provide support services for the conduct of tests to determine under what conditions contaminated fluid adheres to aircraft lifting surfaces.
4.13. Assess whether pre-warming fuel at time of re-fuelling will help to eliminate the ‘cold soaked’ wing problem.
4.14. Develop a low-cost test wing which can be used in the laboratory in lieu of field testing full scale aircraft.
4.15. Establish the safe limits for de-icing truck operation when de-icing aircraft with the engines running.
4.16. Provide general support services.
4.17. Disseminate test findings

# 5. DETAILED STATEMENT OF WORK

## 5.1. General

### 5.1.1. Planning and Control

Develop a detailed work plan, activity schedule, cash flow projection, project management control and documentation procedures (as specified in Section 9,"Project Control") within three weeks of effective commencement date, confirming task priorities, suggesting hardware and software suppliers, broadly identifying data needs and defining the roles of subcontractors, and submit to TDC for review and approval.

### 5.1.2. Safety and Security

Particular consideration will be given to safety in and around aircraft on the airport and deicing sites In the event of conflict between access for data gathering to obtain required test results and safety considerations, safety shall always govern.

## 5.2. Holdover Time Testing and Evaluation of De/Anti-icing Fluids

### 5.2.1. Newly Certified Fluids

Conduct flat plate tests under conditions of natural snow and artificial precipitation to record the holdover times, and to develop individual Holdover Time Tables based on samples of newly certified or re-certified fluids supplied by Fluid Manufacturers under as wide a range of temperature, precipitation rate, precipitation type, and wind conditions as can be experienced. Anticipate tests for one new fluid. Snow tests shall be conducted outdoors, and ZD, ZR-, Zfog, and CSW tests will be performed in the laboratory. All testing shall be performed using the methodology developed in the conduct of similar tests for Transport Canada in past years.

### 5.2.2. Low Viscosity Type IV Anti-icing Fluids

Fluid holdover time testing of Type IV fluids will be conducted using procedures established during past test seasons but using fluid with the lowest operational use viscosity.

#### *5.2.2.1. Flat Plate Tests for New Type IV Fluids*

Conduct flat plate tests under conditions of natural snow and artificial precipitation to record the holdover times, and develop individual Holdover Time Tables based on samples of new Type IV fluids supplied by Fluid Manufacturers under as wide a range of temperature, precipitation rate, precipitation type, and wind conditions as can be experienced. Anticipate for four new fluids using samples with one viscosity. Snow tests shall be conducted outdoors, and ZD, ZR-, Zfog, and CSW tests shall be performed in the laboratory using methodology applied in past years.

*5.2.2.2.Effect on Holdover Time of Viscosity*

Conduct tests aimed at determining the effect of fluid viscosity on holdover time. Tests shall be conducted in light freezing rain and freezing drizzle conditions at various temperatures in the National Research council (NRC) Climatic Environment facility (CEF) using low and high viscosity samples representing production limits of three anti-icing fluids: a propylene, an ethylene and the Fluid X (which will become the benchmark for laboratory based HOT testing).

Anticipate a total of approximately 100 tests to be conducted under ZR- and ZD at -3 and -10 Celsius at low and high rates.

### 5.2.3.Recycled Fluids as Type I Fluids

*5.2.3.1.Holdover Times*

A complete set of holdover time tests shall be conducted using two fluid test samples of recovered glycol based freezing point depressant fluid which have been recycled and exhibit nominal conformance to Type I de-icing fluid performance characteristics. The objective of this series of tests is to establish a sound base of data sufficient to establish valid holdover time tables for these fluids.

*5.2.3.2.Compatibility with Type IV Fluids*

Fluid compatibilty trials shall be conducted using various combinations of the recycled fluids and commercial Type IV fluids. Determine how the Inland fluids perform when used in conjunction with a Type IV fluid overspray.

## 5.3. Supplementary Data for Deicing Only Table

Evaluate the test conditions used in establishing the deicing only table by undertaking the following test series at sub zero temperatures but with no precipitation.

### 5.3.1. Establish Quantity of Fluid for Field Tests.

Conduct a series of comparative laboratory tests with 0.5, 0.25 and 0.1 litre per plate. Consider the case of spraying for frost with a fan shape to cover a wide area with a small amount of fluid compared with a stream as used to remove snow or ice. Examine typical fluid quantities representing frost removal spray. Conduct some tests on aircraft piggybacking on other testing if feasible.

### 5.3.2.Establish Temperature of Fluid for Field Tests

Laboratory tests will be performed with fluids initial temperatures at the spray nozzle of 60ºC, 50ºC, and 40ºC initial temperature.

Field tests on aircraft will be designed to measure the loss of fluid temperature and to measure fluid evaporation and enrichment during the air transport phase between spray nozzle and wing surfaces, for various distances and shapes of spray pattern (3 distances; 2 spray patterns).

*5.3.2.1.*
Examine the effect on the final freeze point of sprayed fluids on the wing, resulting from variations in the temperature of the fluid (60ºC, 50ºC, and 40ºC).

*5.3.2.2.*
Examine the effect on wing heat and fluid evaporation of removing contaminant from the wing surface. Various degrees of ice depth shall be deposited using a hand-held rainmaker, including a very light coating to simulate frost. The amount of fluid sprayed shall be controlled by the operator, spraying until a clean surface results.

### 5.3.3. Perform tests at current buffer limit as baseline.

Perform a series of comparative tests using buffers at 3ºC and 10ºC to compare to the new data and the data collected last season with buffers at 0ºC .

### 5.3.4. Simulate High Wind Conditions

Tests shall be performed using NRC fans producing winds up to 30 kph for comparison with the earlier series of tests with speeds up to 20 kph

### 5.3.5. High Relative Humidity

Perform a series of plate tests at 90% RH to compare results to those already gathered. Review the condition with weather services to determine typical RH values during deicing only conditions.

### 5.3.6. Cold Soaked Wings

Perform a series of tests on cold soak boxes to establish whether the natural buffer provided by evaporation would be sufficient to provide protection if the wing were in a cold-soaked condition, with wing temperature several degrees below OAT. These tests can be run in conjunction with high humidity tests when deposition of frost on cold soaked surfaces would normally be expected.

### 5.3.7. Effect of Snow Removal on Fluid Heat Input

Perform tests to establish whether removal of snow results in extesive amounts of heat being carried away and insufficient heat being transferred to the wing during deicing.

Expose flat plates to snowfall (either natural or as simulated by approved equipment) and protect snow catches of various thicknesses. Tests shall be run in an area protected from further snowfall. Fluid shall be applied with a hand sprayer, until the plate is cleaned, measuring the amount of fluid applied. The final fluid concentration on the plate shall be measured. The heat lost in fluid run off shall be measured. Parallel tests will be conducted on bare surfaces.

A carefully calculated heat balance shall be determined for each experiment based on the temperatures of the applied fluid, the plate and the collected run-off material.

### 5.3.8. Effect of Composite Surfaces on Evaporation

Evaluate the effects of the use of composite materials in wings on the heat transfer from deicing fluid to the wing. Conduct a series of laboratory comparative tests on a several samples of composite surfaces.

Identify an appropriate aircraft having a wing surface composed of new technology composite material as well as aluminium, determining the thermal pathways connecting the composite surfaces to the main wing structure.

Conduct field tests on a sample aircraft.

### 5.3.9. Unpowered Flight Control Surfaces

Field trials will be conducted on DC9 aircraft to assess the impact of fluids of various buffers on the freedom of operation of the unpowered elevator control tabs to establish whether the natural buffer provided by evaporation would be sufficient to provide protection if the wing were in a cold-soaked condition, with wing temperature several degrees below OAT

### 5.3.10. Field Tests on Aircraft

Three overnight test sessions shall be planned for these tests. Tests shall be conducted on aircraft types including the McDonnell Douglas DC-9 and Canadair RJ, with a minimum of one night for each type. Testing on a third aircraft type would be useful to improve confidence and to confirm the universality of the results. Use an ice detector sensor system to provide a separate source of data.

### 5.3.11. Laboratory Tests

The number of proposed tests shall be controlled by limiting tests to the minimum number of ambient conditions that will support conclusions on the significance of the issues raised while maintaining a good level of confidence. As a minimum, this encompasses about 230 plate tests and would require about 8 days at the NRC CEF Facility or other suitable facility.

## 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.

## 5.5. Aircraft Full-Scale Tests

### 5.5.1. Purpose of Tests

Conduct full-scale aircraft tests:

- To generate data which can be used to assist pilots with visual identification of fluid failure;
- To generate data to be used to assess a pilot's field of view during adverse conditions of winter precipitation for selected aircraft; (See item 5.11)
- To compare the performance of de/anti-icing fluids on aircraft surfaces with the performance of de/anti-icing fluids on flat plates;
- To examine the pattern of failure using Type IV fluid brands not tested in the past; and
- To further investigate progression of failure on the two wings in crosswind conditions.

### 5.5.2. Planning and Coordination

Planning and preparation for tests including provision of facilities, personnel selection and training, and test scheduling shall be the same as provided to TDC in previous years

### 5.5.3. Testing

All tests and dry runs shall be performed using the methodology developed in the conduct of similar tests for Transport Canada in past years.
Test planning will be based on the following aircraft and facilities:

| Aircraft | Airline | Test Locn. | Deicing Pad | Deicing Crew |
|---|---|---|---|---|
| Canadair RJ | Air Canada | Dorval | Central | Aéromag 2000 |
| ATR42 | Inter Canadian | Dorval | Central | Aéromag 2000 |

### 5.5.4. Test Measurements

Make the following measurements during the conduct of each test:

- Contaminated thickness histories at selected points on the wings. The selection of test points shall be made in cooperation with the Transportation Development Centre,
- Contamination histories at selected points on wings (selected in cooperation with the Transportation Development Centre),
- Location and time of first failure of fluids on the wings,
- Pattern and history of fluid failure progression,
- Time to failure of one third of the wing surface
- Concurrent measurement of time to failure of fluids on flat plates. The plates will be mounted on standard frames and on aircraft wings at agreed locations,
- Wing temperature distributions,
- Amount of fluid applied in each test run and fluid temperature,
- Meteorological conditions, and
- For crosswind tasks, effects of rate of accumulation on each wing.

In the event that there is no precipitation during full-scale tests, the opportunity shall be taken to make measurements of fluid thickness distributions on the wings. These measurements shall be repeated for a number of fluid applications to assess the uniformity of fluid application.

#### 5.5.5. Pilot Observations

Contact airlines and arrange for pilots to be present during the tests to observe fluid failure and failure progression, and to record pilot observations from the cockpit and the cabin for later correlation with aircraft external observations.

#### 5.5.6. Remote Sensor Records

Record the progression of fluid failure on the wing using RVSI and/or Cox remote contamination detection sensors if these sensors are made available.

### 5.6. Snowmaking Methods and Laboratory Testing for Holdover Times

#### 5.6.1. Evaluation of Winter Weather Data

##### *5.6.1.1. Snow Rates*

Collect and evaluate snow weather data (precipitation rate/temperature data) during the winter to ascertain the suitability of the data ranges used to date for evaluation of holdover time limits.

Obtain current data from Environment Canada for three sites in Quebec: Rouyn, Pointe-au-père (Mont-Joli), and Ancienne Lorette (Quebec City), in addition to Dorval (Montreal).

##### *5.6.1.2. Fog Deposition Rates*

Devise a procedure and conduct fog deposition measurements outdoors on at least two occasions to determine the range of fog deposition rates which occur in natural conditions.

*5.6.1.3. Frost Deposition Rates*

Frost deposition rates shall be collected at various temperatures in natural conditions in order to determine a deposition range for this condition. Consideration shall be given to collecting deposition rates in cold temperatures (for example in Thompson, Manitoba). A total of five sessions shall be planned.

### 5.6.2. Snowmaking Methods

Acquire a version of the new snow generation system recently developed by the National Centre for Atmospheric Research (NCAR).

Evaluate the NCAR system for the future conduct of holdover time testing in simulated snow conditions. Tests shall be conducted in a small climatic chamber at Concordia University, PMG Technologies, or at NRC. Tests shall also be conducted with one Type IV fluid over a range of temperature and snowfall rates to compare the SAE holdover times for this fluid in natural and simulated conditions.

A further series of tests shall be performed with the system in order to assess the holdover time performance of the reference fluid (as described in the proposed SAE test procedures).

A total of 8 days of climatic chamber rental shall be planned for the conduct of the proposed tests.

## 5.7. Documentation of Appearance of Fluid Failure for Pilots

Current failure documentation deals largely with freezing drizzle and freezing rain conditions

### 5.7.1. Documentation of Failures

Finalise documentation of failure through limited further research as follows:

*5.7.1.1.*

provide similar documentation for fluids exposed to snow conditions, taking advantage of the availability of a snow making device for laboratory use;

*5.7.1.2.*

provide documentation for a propylene based Type IV fluid at typical delivered viscosity, for precipitation conditions tested previously, to determine characteristics at its operational limits and the nature and mechanisms of failure. Conduct selected comparison tests with a second fluid to test commonality of responses. Data from this activity will be cross-analysed with data from proposed research to examine the flow of similar fluids at different levels of contamination from aircraft wings during a simulated takeoff; and

*5.7.1.3.*

examine and document the appearance and nature of failure of propylene base fluids at cold temperatures (-10 C).

*5.7.1.4.*

Conduct tests at the National Research Council Climatic Environmental Facility based on last years' procedures, with enhancements as necessary and available. Snow documentation may be conducted in a different laboratory facility. Documentation under outdoor snow conditions will be conducted for comparison purposes to laboratory conditions.

### 5.7.2. Conduct of trials/assembly of results

Coordinate all test activities, scheduling tests with NRC CEF in conjunction with other test activities. Analyse results and document all findings, recommendations and conclusions in a final technical report and in presentation format. Provide timely updates of schedule revisions to TDC.

### 5.7.3. Pilot Observations

Contact airlines and arrange for pilots to be present during tests to observe fluid failure and failure progression. Record pilot observations for later correlation with aircraft external observations.

## 5.8. Feasibility of Performing Wing Inspections at End-of-runway

### 5.8.1. Requirement

Examine the feasibility of scanning aircraft wings with ice contamination sensors just prior to aircraft entering the departure runway using Dorval airport as an example scenario.

Explore ways of positioning sensors at agreed locations on an airport.

Composition and conduct of tests shall be adapted as information is gained on the practicality of this activity.

### 5.8.2. Planning

A Project Plan shall be prepared which will include:

a) activities to determine the parameters, operational issues and constraints related to the proposed process, and

b) a test plan for operational trials to examine the capabilities of the contamination sensors to determine the feasibility of their operational use.

The test plan for operational trials (three sessions) shall include:

- establishing test locations with airport authorities,
- establishing operational procedures with airport authorities,
- arranging equipment for scanning; vehicle, sensor installation and radios,
- collecting and coordinating information from the deicing activity at the deicing centre,
- test procedures with detailed responsibilities for all participants,
- control of the confidential data gathered on wing condition, and

- notification to all concerned in the project, including aircraft operators, that scanning activities will take place.

### 5.8.3. Coordination

Coordination all activites with authorities from Aéroports de Montréal and arrange support from Cox and/or RVSI

### 5.8.4. Field Trials

Conduct trials to further evaluate the feasibility of integrating such a process within current airport operations management, as well as to gather information on wing condition, just prior to takeoff, during deicing operations. These trials shall be based on the use of mobile equipment currently available. A “truthing” test pannel shall be present at each trial to demonstrate the validity of the wing readings on an ongoing basis

The trials shall be designed to address issues such as:

- equipment positioning versus current runway clearance limitations,
- time delay between inspection and start of take-off
- system capabilityto meet its design objectives in severe weather
- suitability of mobile equipment or fixed facility.
- need for rapid extension and retraction of sensor booms,
- airport support needed, e.g. snow clearance, provision of operating locations,
- accommodating scanner limitations for distance, light, angle of incidence.
- communications needed to support scanning operation,
- recording data from the sensors, and
- communicating results of the scanning to pilots and regulatory authorities.

### 5.8.5. Test Personnel and Participation

Initiate all tests based on suitable weather conditions. The individual test occasions shall be coordinated with Aéroports de Montréal and Aéromag 2000.

Coordinate the provision of a suitable vehicle and the installation of an ice detection sensor. Monitor the test activity, ensuring the collection and protection of all scanning data, as well as the collection of data related to weather conditions and previous aircraft deicing activities. Ensure that the instrument providers deliver data and an objective measure of wing contamination based on scanner information in a timely and reproducible manner.

### 5.8.6. Study Results

Results from the feasibility study shall be presented in technical report format which shall include comments pertinent to long term implementation.

Results from the scanner tests shall be provided in technical report format and shall include analysis of wing contamination data cross-referred to the deicing history of individual aircraft scanned.

## 5.9. Ice Detection Sensor Certification Testing

### 5.9.1. Minimum Ice Thickness Detectable in Tactile Tests

Prepare procedures and conduct tests to establish human limits in identifying ice through tactile senses. These tests shall use the NRC or equivalent test facilities acceptable to TDC and a test setup equivalent to that planned for sensor certification. Several ice thicknesses and textures shall be tested to establish tactile sensing limiting thickness for smooth ice and for roughened ice.

The experiment shall involve sufficient participants and test conditions such as to provide reliable results usable in approving sensors to replace human tactile testing.

TDC shall assist in the experimental design

Tests shall be conducted with both contractor personnel and a selection of pilots as subjects.

A professional human factors scientist shall be used to establish testing parameters such as:

- what proportion of plates should be bare
- whether subjects should be blindfolded to eliminate visual cues.
- whether the same plate should be judged more than once
- how to ensure that subjects do not compare plates
- what should be the minimum time between plate touching

Results of the tests shall be analysed statistically to establish confidence limits for the findings

### 5.9.2. Field Tests for Sensor Distance and View Angle Limits

Develop a detailed test plan with a matrix of all test parameters, required coordination of equipment detailing the responsibilities of all participants.

Collect test data, including photo and video records of all tests.

The areas of ice contamination used for sensor evaluation shall be quantified by size, location and thickness. Angles of incidence, sensor heights and distances shall be verified independently. In concert with the sesor manufacturer, data from sensor readings and observer data shall be collated and analysed to reach conclusions on sensor limitations for distance and angle of incidence in various weather conditions.

## 5.10. Planning a Wing Deicing Test Site

Develop a plan for implementing a deicing test site, centred on an aircraft wing and supported by current fluid and rainmaking sprayers.

The plan shall include the acquisition of a surplus complete wing, from either a scrapped or an accidented moderate sized aircraft or an outboard section of a larger aircraft. The wing section should if possible include ailerons and leading edge slats

The design of the test site shall include a test area that could contain and recover sprayed fluids. Installation of the wing should entail a mounting designed to allow the wing to be rotated relative to current winds. The site must be secure yet allow ease of access and ability to install inexpensive solutions to control sprayed fluid.

Costs shall be estimated for the main elements of the development of a wing test bed site including:

wing purchase and delivery,
site lease and development, and
wing mount design and fabrication.

### 5.11. Evaluation of Hot (and Cold) Water Deicing

Investigate unheated and hot water deicing/defrosting, to determine under what meteorological conditions and temperatures these procedures are safe and practicable.

Unheated water deicing shall be evaluated at air temperatures above 1 degree C(34 degrees F).

Hot water deicing shall be evaluated at air temperatures below 1 degree C and include temperatures below –3 degrees C (27 degrees F).

These experiments shall establish how long it takes for the water to freeze on the surface under these conditions.

This is to be the first step of a two step procedure. From these data, a safe and practical lower limit shall be established considering the three-minute window required for second step anti-icing in the two-step deicing procedure.

Precipitation rates, as utilised in the generation of holdover time tables, shall be considered. Environmental chamber tests shall be correlated with outdoor aircraft tests. All laboratory test procedures and representative test results shall be recorded on videotape, including failure modes where applicable. The video shall depict a recommended full-scale aircraft hot water deicing procedure. A written report shall include the laboratory test results and a recommended aircraft unheated/hot water deicing procedure, including the limitations of precipitation, OAT and wind.

### 5.12. Evaluation of Warm Refuelling

Conduct a feasibility study of the suitability of refuelling with warm fuel to reduce susceptibility to “cold-soaked wing” icing, and to improve holdover times.

Coordinate activities to support testing the “warm fuel” concept using operational aircraft, including arranging;

- Participation of interested airlines, along with provision of aircraft for test purposes;
- Participation of local refueller;
- Arrangements with the equipment supplier (Polaris) to deliver the equipment to the selected airport along with the required technical support.

Testing will be conducted at Dorval on three occasions, one of which will include snow or freezing precipitation. Test aircraft selected should include a representation of both “wet” and “dry” wings if possible.

Wing surface temperatures of test wings will be monitored at several points over a period of time, to assess the influence thereon of warmed fuel. A reference case based on fuel boarded at the normal local temperature will be conducted.

### 5.13. Engine Air Velocity Distributions near Deicing Vehicles

Measure air velocity distributions in the vicinity of a de-icing truck when de-icing a large aircraft whose engines are running.

Tests shall be conducted during a period of no precipitation, either frost deicing or following snowfall, on two separate occasions at the Dorval International Airport deicing facility. Aircraft with engines mounted on the wing (e.g. B737) as well as rear engines mounted aircraft (e.g. DC-9 and RJ) will be sampled during live deicing operations, the precise type to be agreed by TDC. The tests shall be coordinated with Aéroport de Montréal and Aéromag 2000.

Wind velocity shall be measured from an Elephant-mu de-icing truck at locations recommended by TDC around the tail of the aircraft at different elevations and distances from the engines depending on the aircraft type, and the de-icing procedure followed by Aéromag 2000.

Photograph and video record the conduct of all tests.

### 5.14. Provision of Support Services

Provide support services to assist TDC with testing, the reduction of data and presentation of findings in the activites identified below which relate to the content of this work statement, but are not specifically included.

#### 5.14.1. Re-Hydration

Conduct a series of exploratory trials on flat plates at the Dorval site or NRC to observe the behaviour of re-hydrated Type IV fluids and to help determine how re-hydration affects the flow- off characteristics of a Type IV fluid exposed to frost conditions.

#### 5.14.2. Frost Tests on a Regional Jet

Conduct a series of tests to determine the roughness of frost deposition on the wings of a Regional Jet aircraft. Conduct tests on three overnight occasions.

#### 5.14.3. Ice-Phobic Materials Evaluation

Conduct a series of tests on flat plates to determine the effects of ice-phobic materials on the film thickness and on holdover time of de/anti-icing fluids.

### 5.14.4.Evaluation of Infra-Red Thermometers

Evaluate use of infra-red technology as a method of determining accurate skin and fluid temperatures during operational conditions. Conduct tests in conjunction with full-scale and holdover time testing.

### 5.14.5.Frost Self-Elimination

Examine the self-elimination of frost on several test surfaces under variable weather conditions. Conduct test in conjunction with frost deposition trials on flat plates.

### 5.14.6.Environmental Impact Assessment

Assess the environmental issues related to the use of glycol-based products for aircraft de-icing purposes. Examine the waste fluid collection and disposal procedures for several deicing facilities in relation to current and future environmental legislation.

### 5.14.7.An Approach to Establish Wing Contamination

Document an approach to determining operational limits for levels of contamination on aircraft wings. This approach will include consideration of the location of contamination on the wings and the area contaminated. The levels of contamination on aircraft wings prior to takeoff as determined during the scanning trials prior to takeoff will be factored in.

The approach will discuss how the limits (when defined) could be used in software routines to enable sensor systems to provide Go/No-Go indications to the aircraft pilot and regulatory authorities.

### 5.14.8. Accident/incident Database Analysis

Provision of database manipulation and support aimed at establishing problem areas and their significance.

### 5.14.9.Other activities

Other activities, such as the evaluation of forced air technology, the evaluation of alternate (zero glycol) deicing methods, and the evaluation of frost removal equipment at gates, or others may emerge as issues during the course of the winter season.

# APPENDIX B

# EXPERIMENTAL PROGRAM
# EVALUATION OF WARMED FUEL AS A MEANS OF DEICING AIRCRAFT

CM1541.001

# EXPERIMENTAL PROGRAM EVALUATION OF WARMED FUEL AS A MEANS OF DEICING AIRCRAFT

Winter 1998/99

APS AVIATION INC. APS

April 30, 2002
Version 1.0

# EXPERIMENTAL PROGRAM
# EVALUATION OF WARMED FUEL AS A MEANS OF DEICING AIRCRAFT

Winter 1998/99

APS will examine implications and conduct trials to evaluate the use of warmed fuel to facilitate deicing of aircraft.

## 1. OBJECTIVES

The purpose of this project is to determine the feasibility of using warmed fuel to address specific issues related to ground deicing of aircraft:

- Will it extend the holdover times normally expected from anti-icing fluid applications.
- Will it reduce the amount of fluid sprayed.
- Does it resolve the cold soaked wing problem, imputting sufficient heat to the fuel already on board to raise its temperature to match outside ambient temperature.
- How practical is boarding warmed fuel in an actual operation.

## 2. TEST REQUIREMENTS

Warmed fuel trials will be conducted at Dorval Airport using aircraft that are parked overnight, awaiting early morning departure.

Three consecutive overnight sessions are outlooked, one of which would make use of natural snow or natural or simulated freezing precipitation. It is currently expected that the trial involving precipitation will be conducted at the central deicing facility, while the two other trials will be conducted at terminal gates. Towing as required will be coordinated with the aircraft operator. Airport Authorities will be kept apprised of test plans.

APS will prepare the aircraft for test with installation of thermistor probes at selected points over the wing surface.

Polaris will arrange for delivery and installation of the fuel heating equipment at a suitable location at Dorval Airport.

Shell Aviation along with Polaris technicians will arrange for heating and boarding of the heated fuel, using the Polaris equipment and a Shell Aviation refuelling tender.

Fuel amounts will be advised by the aircraft operator, and the required weight of heated fuel will be boarded in one wing. The required weight of fuel at normal operating temperature will be boarded in the other wing. Both wings will be monitored for results, with the cold wing providing a base case for reference.

Test data will include temperature profiles at various points on the wing surface, including leading edge and flight control surfaces. Specifics on fuel amounts and temperatures (already on board and added as test fuel) will be recorded.

For the test involving precipitation, amounts of deicing fluid applied, and resultant holdover times will be measured.

A test plan is shown as Attachment I.

Complete photo and video records of test setup and conduct of test will be maintained.

## 3. EQUIPMENT

Test equipment is included in Attachment I.

### 4. FLUIDS

During the single test under precipitation, Ucar Type I ADF and UCAR Type IV ULtra+ will be applied. The other tests will be conducted with bare wings.

## 5. PERSONNEL

It is anticipated that a team of six APS personnel will be required to conduct the trials. Descriptions of responsibilities and duties of each team member are given in Attachment II.

Support from Shell Aviation, Polaris, Aeromag 2000 and the aircraft operator will be required and will be coordinated by APS.

## 6. DATA FORMS

The following data form will be used:

- General Form (Every Test)
- General Form (Once per Session)
- Thermistor Locations on Aircraft Wing
- De/Anti-icing Form for Aircraft Wing (B737 and DC-9)

Attachment I

## Test Plan for Warmed Fluid Trials

Winter 1998/99

| **RUN** | **A/C TYPE** | **WING** | **FUEL TEMPERATURE** | **WING CONDITION** | **TEST PARA-METERS MEASURED** |
|---|---|---|---|---|---|
| 1 | B737 | PORT | HEATED | BARE | TEMP PROFILE |
| 2 | | STBD | UNHEATED | | |
| 3 | | PORT | HEATED | ANTI-ICING[1] FLUID UNDER PRECIPITATION | TEMP PROFILE |
| 4 | | STBD | UNHEATED | | FLUID QUANTITY<br>FLUID HOT |
| 5 | DC-9 | PORT | HEATED | BARE | TEMP PROFILE |
| 6 | | STBD | UNHEATED | | |

Note 1: The wing will be allowed to accumulate precipitation, either natural snow or ice, or artificial freezing rain, and then be deiced, with standard fluids. Time to fluid failure will be measured in the wing.

## ATTACHMENT II
## RESPONSIBILITIES/DUTIES OF TEST PERSONNEL

*Video and Photographer*

- Video and photograph fuel heating equipment and fuelling operation.
- Video and photograph general test site
- Video and photograph setup, including lighting, probe installation on wings, etc;
- Video application of all fluids;
- Assist in deployment of lighting;
- Ensure areas of wing are identifiable for precise location;
- Pictures to be well lit;
- Knowledge of test procedures;

*Wing Observer (W1 & W2)*

- Responsible for setting up wing for test and mounting thermistor probes as shown on the aircraft wing test form;
- Map out aircraft with pylons and plan view of aircraft;
- Located on rolling stair during HOT test;
- Apply artificial precipitation as required.

*Observer Assistant (B1 & B2)*

- Assist in installing thermistor probes on aircraft ; complete cable linkage to loggers and laptop PC in cube van; check integrity;
- Assist wing observer in identifying fluid failures for observer documentation;
- Communicate initial failure to all;

*Test Coordinator (TC)*

- Direct installation of thermistor probes and loggers; complete cable linkage to loggers and laptop PC in cube van; check integrity;
- Monitor operation of thermistor system during tests;
- Prepare all data forms in advance;
- Complete general data form at beginning of night;
- Complete general data form for each test;
- Record time of fluid application;
- Take sample of fluid from truck nozzle immediately following each spray operation; record Brix value and fluid temperature;
- Call test end;

*Overall Coordinator (T6)*

- Team coordinator;
- Responsible for area and people;
- Monitor operation of thermistor system during tests;
- Approve any changes necessary to test procedures;

- Coordinate actions of APS team and other test personnel;
- Responsible for weather condition observations and forecast, initiate test and calls to tester team;
- Advise Aeromag 2000 of fluid mixes and estimates of quantities required. Assist in preparing mixes during the test session as required.
- Ensure that there are no objects on the ground which may cause FOD at end of session;
- Ensure test site is safe, functional and operational at all times;
- Supervise site personnel during the conduct of tests;
- Review data forms upon completion of test for completeness and correctness (sign);
- Ensure aircraft positioned appropriately; faced into the wind for the HOT trial;
- Monitor weather forecasts during test period;
- Ensure fluids are available and verify fluids being used for test are correct;
- Ensure electronic data is being collected for all tests;
- Ensure proper documentation of tapes, diskettes, cassettes;
- Verify test procedure is correct;
- Ensure all materials are available (pens, paper, batteries, etc.);
- Ensure all equipment is on;
- Ensure aircraft is not damaged.

FIGURE 1

# GENERAL FORM (ONCE PER SESSION)

## (TO BE FILLED IN BY OVERALL COORDINATOR)

---

**AIRPORT:** YOW

**AIRCRAFT TYPE:** Challenger

**EXACT PAD LOCATION OF TEST:** ____________________

**AIRLINE:** ____________________

**DATE:** ____________________

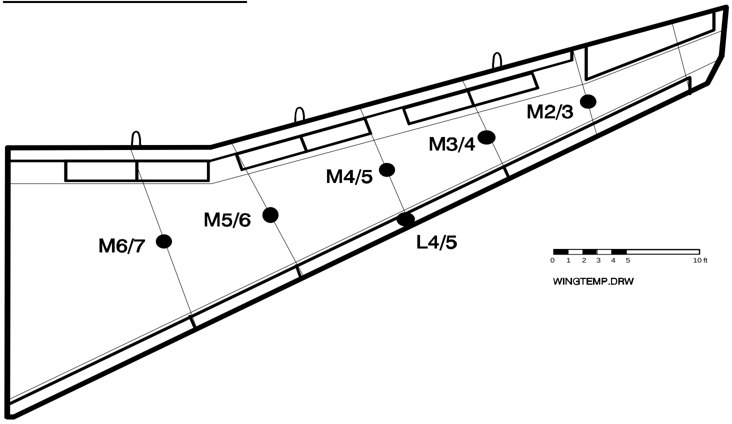
**FIN #:** ________________

**APPROX. AIR TEMPERATURE:** ________________ °C

**Wind Speed:** ________________ kph

| **FUEL LOAD** | **ON BOARD INITIALLY** | | **ADDED** | | |
|---|---|---|---|---|---|
| | **Quantity lb / kg** | **Temp (°C)** | **Quantity lb / kg** | **Temp (°C)** | **Time** |
| **Port Wing Tank** | | | | | |
| **Starboard Wing Tank** | | | | | |

***TEMPERATURE MEASUREMENTS***



| **TIME (min)** | **TEMPERATURE AT LOCATION (°C)** | | | | | |
|---|---|---|---|---|---|---|
| | **M6/7** | **M5/6** | **L4/5** | **M4/5** | **M3/4** | **M2/3** |
| **Start** | | | | | | |
| **End** | | | | | | |

**COMMENTS:** ____________________

(1) Actual Time Before Fluid Application

**MEASUREMENTS BY:** ____________________

**HAND WRITTEN BY:** ____________________

FIGURE 2

# GENERAL FORM (EVERY TEST)

## (TO BE FILLED IN BY PLATE/WING COORDINATOR)

---

**DATE:** ______________________

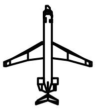
**RUN #:** ______________________

**AIRCRAFT TYPE:** ATR-42 F-100 B-737 RJ DHC-8

**WING:** PORT (A) STARBOARD (B)

**DIRECTION OF AIRCRAFT:** ________ DEGREES

**DRAW DIRECTION OF WIND WRT WING:**



| |
|---|
| ***1st FLUID APPLICATION*** |
| **Actual Start Time:** ____________ **hh:mm:ss** **Actual End Time:** ____________ **hh:mm:ss** |
| **Amount of Fluid Sprayed:** ____________ **L / gal** **Type of Fluid:** ____________ |
| ***2nd FLUID APPLICATION*** |
| **Actual Start Time:** ____________ **hh:mm:ss** **Actual End Time:** ____________ **hh:mm:ss** |
| **Amount of Fluid Sprayed:** ____________ **L / gal** **Type of Fluid:** ____________ |

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

**COMMENTS:**

**MEASUREMENTS BY:** ____________

**HAND WRITTEN BY:** ____________

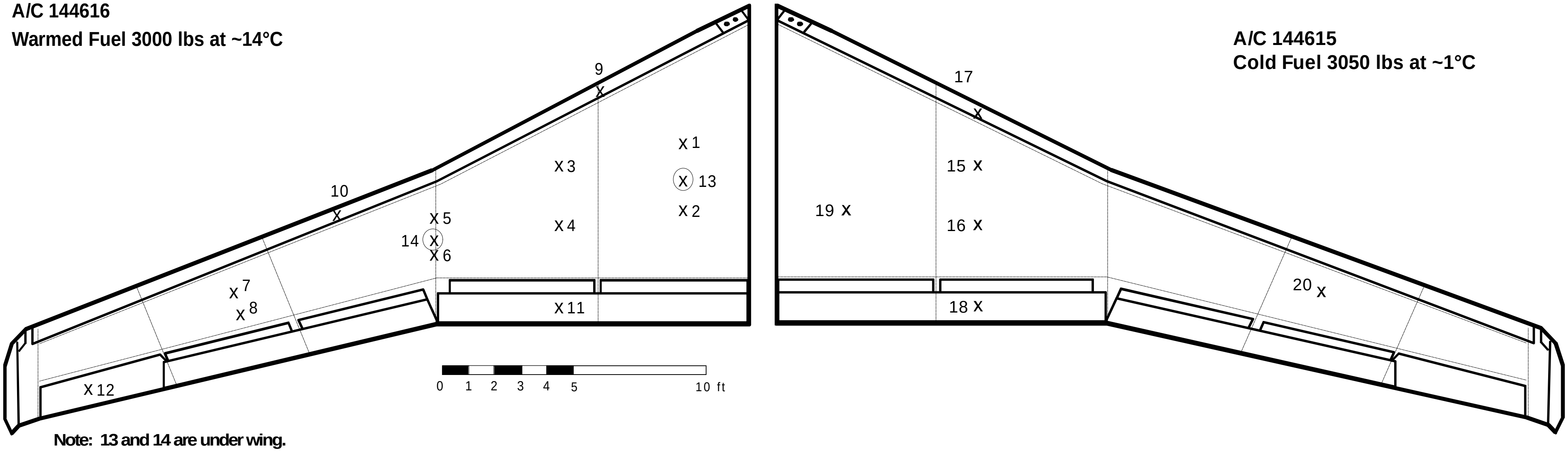
# THERMISTOR LOCATIONS ON AIRCRAFT WING

## TRIALS MARCH 08/09, 1999

## CL600 Challenger

**A/C 144616**
**Warmed Fuel 3000 lbs at ~14°C**

**A/C 144615**
**Cold Fuel 3050 lbs at ~1°C**



**Note: 13 and 14 are under wing.**

cm1514\procedur\warmfuel\Ther_loc.xls
At: Challenger
4/30/02, 2:03 PM

FIGURE 4

# DE/ANTI-ICING FORM FOR AIRCRAFT WING

REMEMBER TO SYNCHRONIZE TIME

Winter 98/99

**DATE:**

**RUN NUMBER:**

**FAILURES CALLED BY:** ____________________

**COMMENTS:** ________________________________________________

**HANDWRITTEN BY:** ____________________

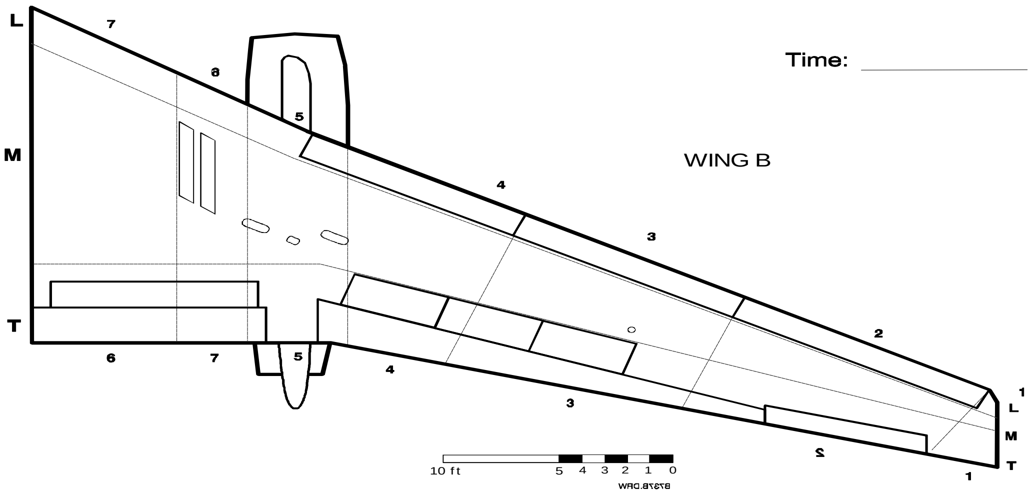
________________________________________________

**ASSISTED BY:** ____________________

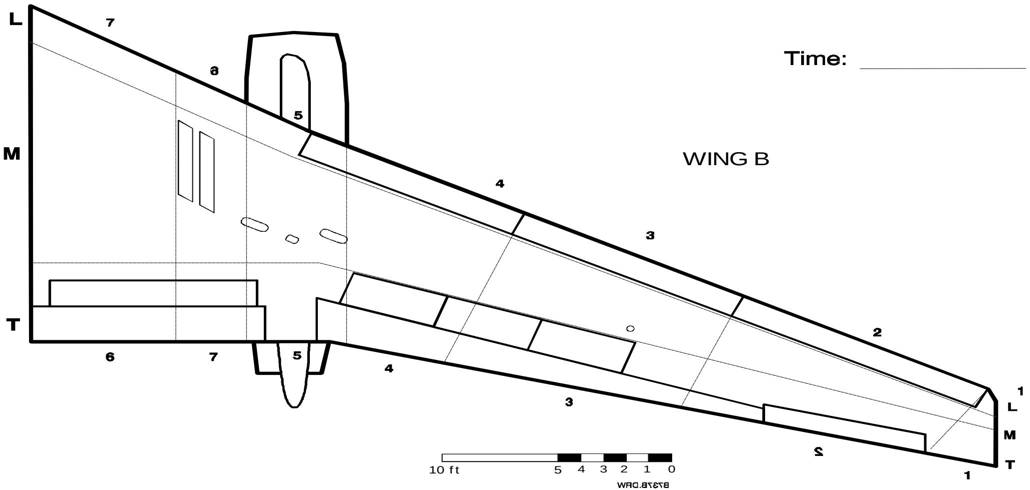
________________________________________________

**DRAW FAILURE CONTOURS (hr:min) ACCORDING TO THE PROCEDURE**

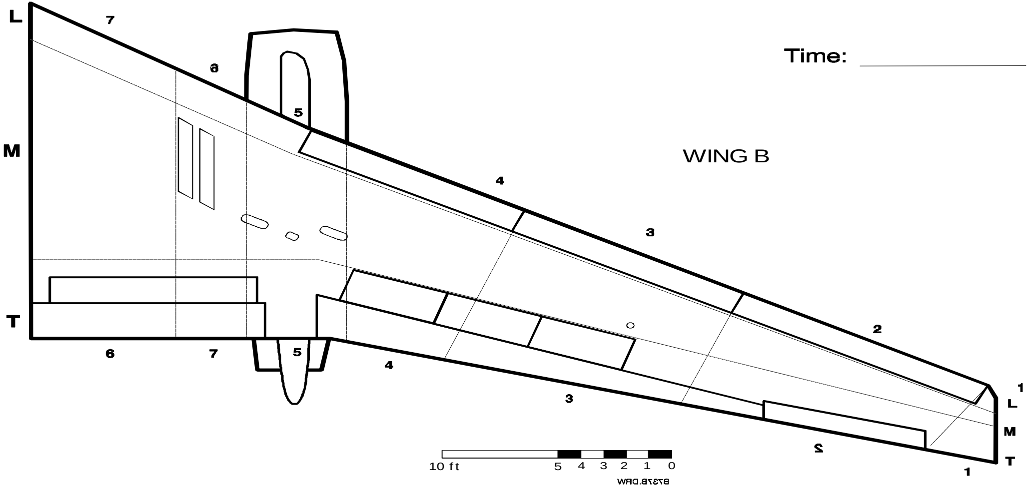
## B737 Series 200



Time: ____________________



Time: ____________________



Time: ____________________

Note: To Compare to Flat Plate testing, subtract "Time of Initial Fluid Apllication".

FIGURE 4

## DE/ANTI-ICING FORM FOR AIRCRAFT WING

REMEMBER TO SYNCHRONIZE TIME Winter 98/99

**DATE:** **RUN NUMBER:**

**FAILURES CALLED BY:** ____________ **COMMENTS:** ____________

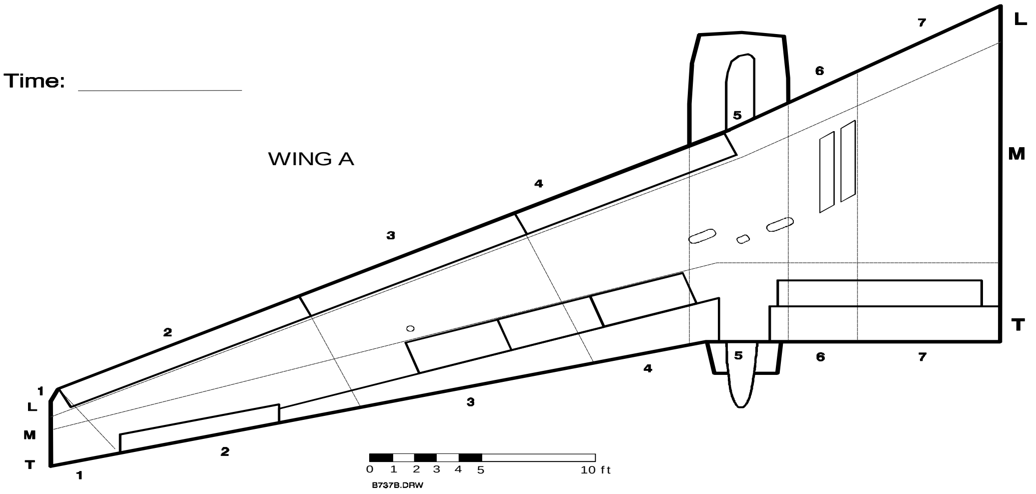
**HANDWRITTEN BY:** ____________

**ASSISTED BY:** ____________

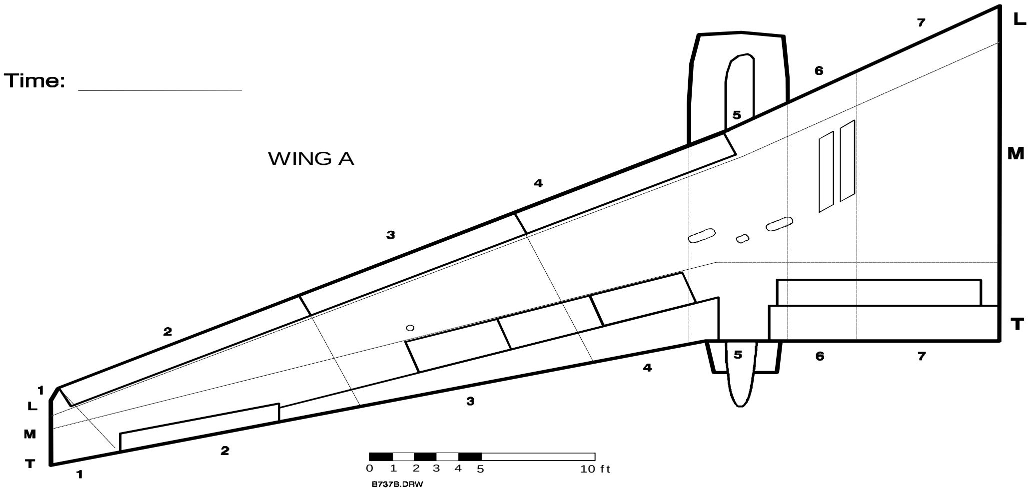
**DRAW FAILURE CONTOURS (hr:min) ACCORDING TO THE PROCEDURE**

## B737 Series 200

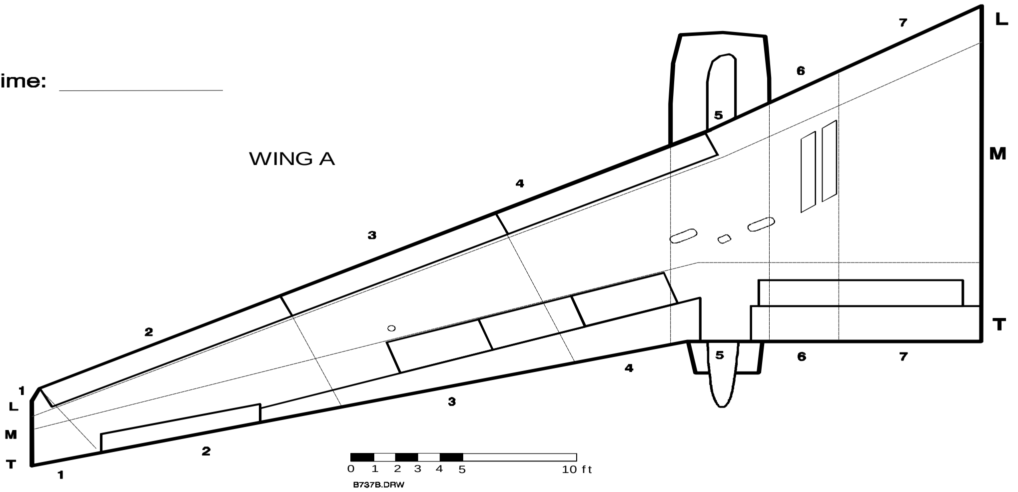
Time: ____________



Time: ____________



Time: ____________



Note: To Compare to Flat Plate testing, subtract "Time of Initial Fluid Apllication".

File: cm1514\procedur\warmfuel\B737_wng.xls
At: Wing A Printed: 4/30/02. 2:05 PM

FIGURE 4

## DE/ANTI-ICING FORM FOR AIRCRAFT WING

REMEMBER TO SYNCHRONIZE TIME

Winter 98/99

| | |
|---|---|
| **DATE:** | **RUN NUMBER:** |

**FAILURES CALLED BY:** ____________ **COMMENTS:** ____________

**HANDWRITTEN BY:** ____________

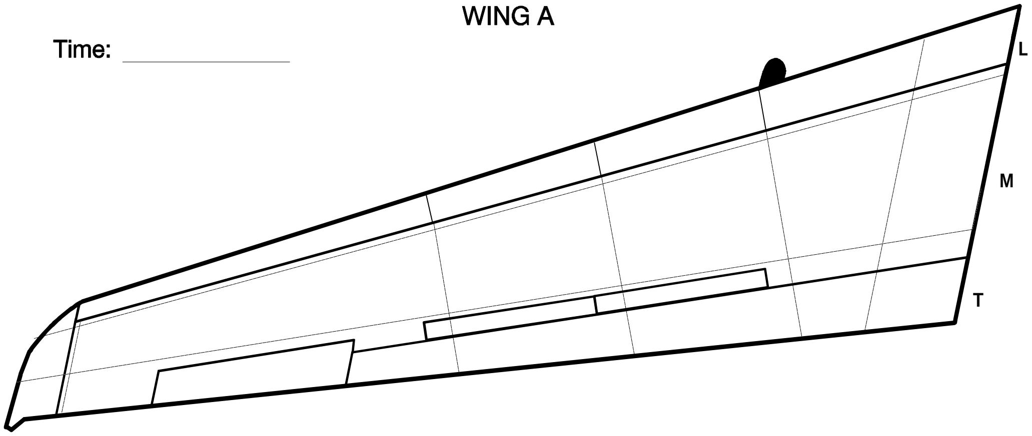
**ASSISTED BY:** ____________

**DRAW FAILURE CONTOURS (hr:min) ACCORDING TO THE PROCEDURE**

## DC-9 Series 30

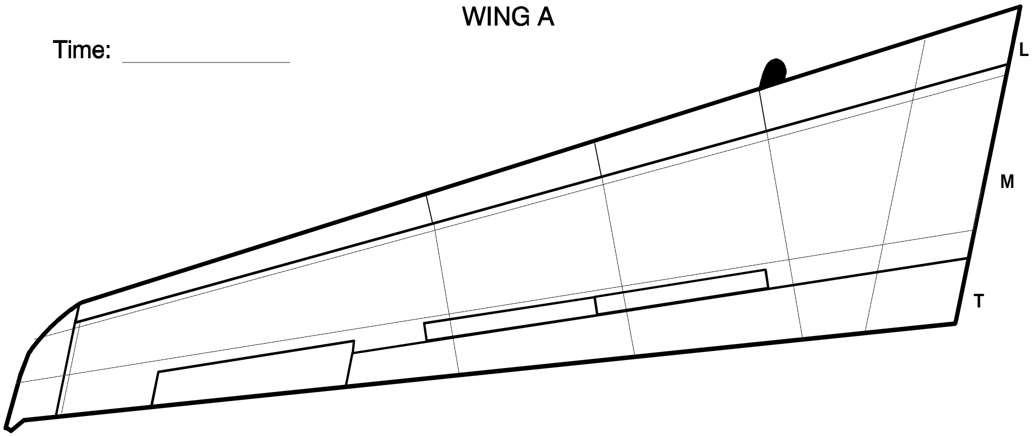
WING A

Time: ____________



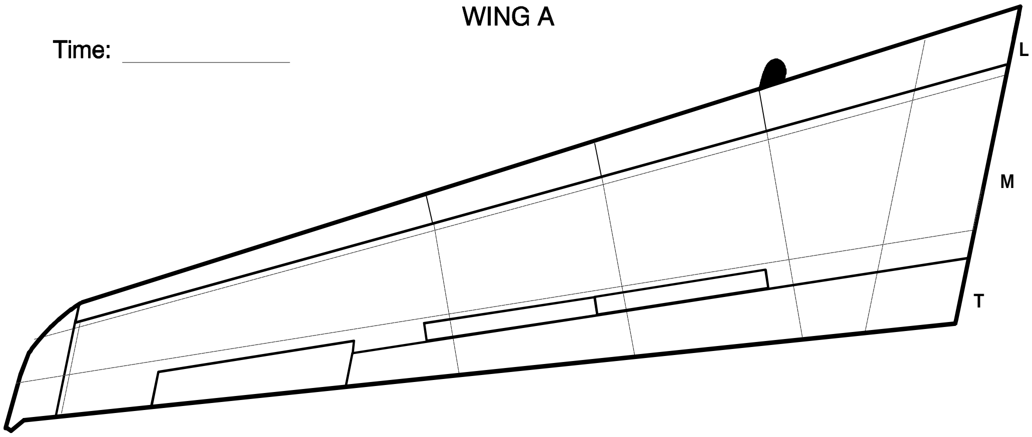
WING A

Time: ____________



WING A

Time: ____________



Note: To Compare to Flat Plate testing, subtract "Time of Initial Fluid Apllication".

File: cm1514\procedur\warmfuel\Dc9_wing.xls
At: Wing A Printed: 4/30/02. 2:05 PM

FIGURE 4

## DE/ANTI-ICING FORM FOR AIRCRAFT WING

REMEMBER TO SYNCHRONIZE TIME

Winter 98/99

**DATE:**

**RUN NUMBER:**

**FAILURES CALLED BY:**

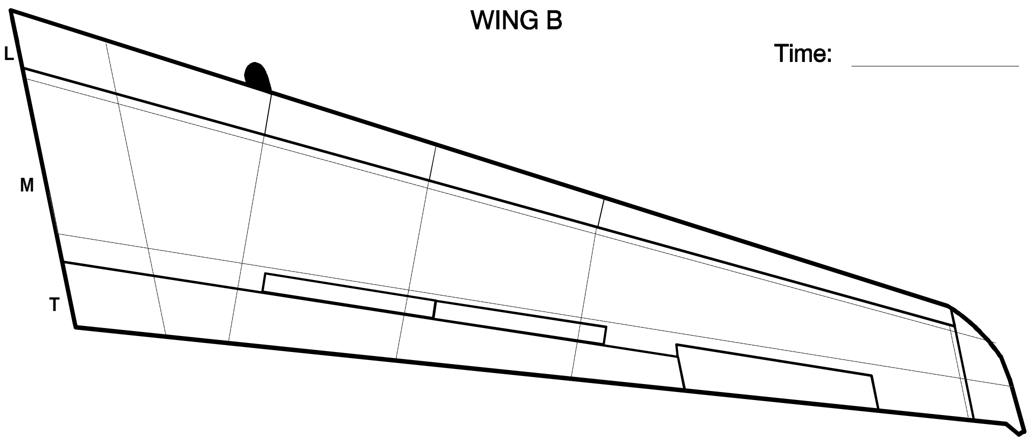
**COMMENTS:**

**HANDWRITTEN BY:**

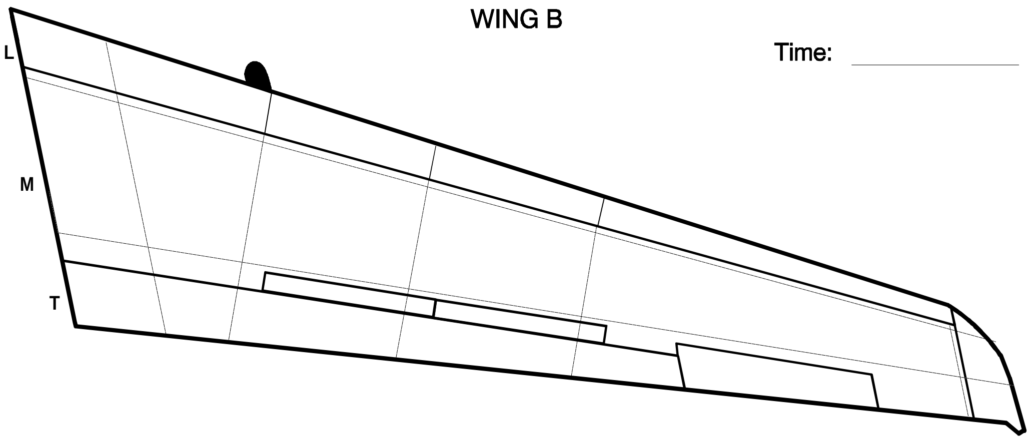
**ASSISTED BY:**

**DRAW FAILURE CONTOURS (hr:min) ACCORDING TO THE PROCEDURE**

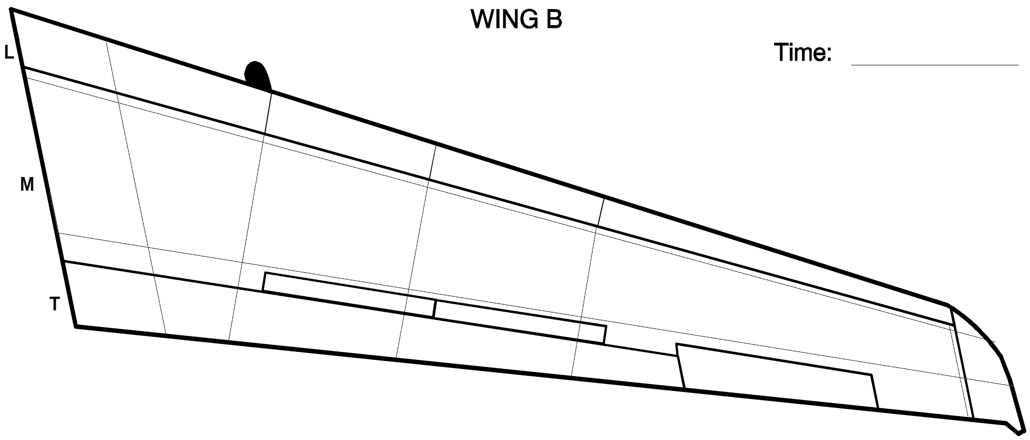
## DC-9 Series 30



Time: ______________



Time: ______________



Time: ______________

Note: To Compare to Flat Plate testing, subtract "Time of Initial Fluid Apllication".

File: cm1514\procedur\warmfuel\Dc9_wing.xls
At: Wing B Printed: 4/30/02. 2:05 PM