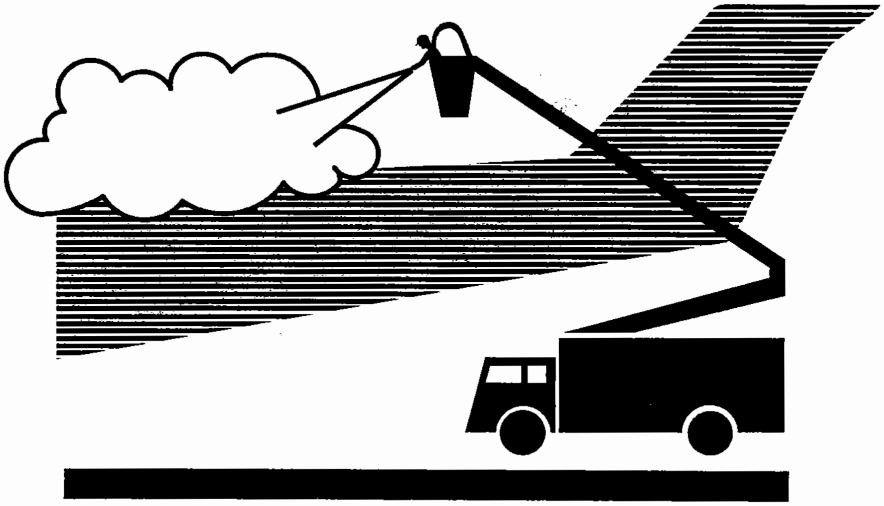
TP 12899E

Validation of Methodology for Simulating a Cold-Soaked Wing



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by

APS AVIATION INC. APS

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The Transportation Development Centre does not endorse products or manufacturers. Trade or manufacturers' names appear in this report only because they are essential to its objectives.

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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 further advance aircraft ground deicing/anti-icing technology. Specific objectives of the overall program were:

- To complete the substantiation of the existing Type I and Type II fluid SAE/ISO holdover time tables by conducting cold-soak tests and very low temperature tests;

- To determine the holdover time performance of the proposed Type IV fluids over the range of characteristic conditions and develop a generic Type IV holdover time table;

- To establish the precipitation, wind and temperature values that delimit the holdover times given in the tables;

- To validate that test data on Type IV fluid performance on flat plates used to establish the SAE holdover time tables is representative of Type IV fluid performance on service aircraft under conditions of natural freezing precipitation;

- To document the characteristics of frost deposits occurring naturally during very cold temperatures;

- To validate that fluid performance on cold-soaked boxes used for establishing holdover times is representative of fluid performance on a cold-soaked wing;

- To identify potential means of enhancing the visibility of failed wing surfaces from inside the aircraft; and

- To identify optimum wing locations to be used as representative surfaces by measuring the wet film thickness profiles of fluid application to aircraft wing surfaces.

The research activities of the program conducted on behalf of Transport Canada during the 1995/96 winter season are documented in six separate reports. The titles of these reports are as follows:

- TP 12896E Aircraft Ground De/Anti-icing Fluid Holdover Time Field Testing Program for the 1995/96 Winter;
- TP 12897E Evaluation of Frost Formations at Very Cold Temperatures;
- TP 12898E Feasibility of Enhancing Visibility of Contamination on a Wing;
- TP 12899E Validation of Methodology for Simulating a Cold-Soaked Wing;
- TP 12900E Evaluation of Fluid Thickness to Locate Representative Surfaces; and
- TP 12901E Aircraft Full-Scale Test Program for the 1995/96 Winter;

This report, TP 12899E, addresses the objective of validating that fluid performance on cold-soaked boxes used for establishing holdover times is representative of fluid performance on a cold-soaked wing.

Funding for the research has come from the Civil Aviation Group, Transport Canada, with support from the Federal Aviation Administration. This program of research could not have been accomplished without the assistance of many organizations. APS would therefore like to thank the Transportation Development Centre, the Federal Aviation Administration, the National Research Council, Atmospheric Environment Services, Transport Canada and the fluid manufacturers for their contribution and assistance in the project. Special thanks are extended to Air Canada for provision of personnel and facilities and for their cooperation on the test program. The assistance and cooperation provided by Delta Airlines and American Airlines were most valuable and much appreciated, as was the Wing Icing Test Data provided by McDonnell Douglas Corporation. APS would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data leading to the preparation of this document.

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Research reports produced on behalf of Transport Canada for testing during previous winters are availbale from TDC. Six reports (including this report) were produced as part of the 1995-1996 winter research program. The subject matter of these reports is provided in the preface. Funding for this project was provided by TDC and, in part, by the FAA.

16\. Abstract

A cold-soaked wing condition may occur on aircraft during landing when wing tanks contain very cold fuel. Clear ice may form on the wing even in above-freezing temperatures during rain, drizzle, fog or high humidity. The ice film is difficult to see and a thick layer may form, which may be dislodged during take-off and ingested by rear-mounted engines.

During the 1994-95 winter season, APS Aviation performed laboratory tests on sealed cold-soaked boxes to identify holdover times (HOT) and developed an analytical approach to relate holdover times experienced on the test boxes to holdover times on aircraft wings. This study conducted experiments to validate that cold-soaked boxes behave in a manner similar to cold-soaked wings, and to verify that fluid holdover times determined on cold-soaked boxes in a laboratory setting are applicable to aircraft wings.

Tests were conducted on MD-80 aircraft and on the Canadair RJ aircraft. Tests on cold-soaked boxes were conducted in the Climatic Engineering Facility of the National Research Council in Ottawa. Data provided by McDonnell Douglas from tests conducted on an MD-80 aircraft were used. Test temperature parameters were based on data from a survey of aircraft wing temperatures in Canadian winter weather.

It was concluded that the tested cold-soaked boxes provide a satisfactory representation of aircraft wings, and can be used to establish fluid holdover times for cold-soaked wings. The principal influences on time to fluid failure were found to be the precipitation rate and the temperature of the test surface. The influence of box size (for the sizes tested) was not significant.

Future trials on fluid holdover times for freezing precipitation conditions should include tests on cold-soaked boxes.

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Les rapports sur les recherches effectuées au cours des hivers précédents pour le compte de Transports Canada sont disponibles au CDT. Six rapports, dont le présent, ont été produits dans le cadre des recherches menées cet hiver. L'objet de ces recherches figure dans l'avant-propos. Les recherches ont été financées par le CDT et en partie par la FAA.

16. Résumé

Les avions peuvent présenter une condition d'aile sur-refroidie à l'atterrissage lorsque la température du carburant dans les réservoirs d'aile est très basse. Dans des conditions de pluie, de bruine, de brouillard ou d'humidité relative élevée, de la glace transparente peut se former sur les ailes même si la température ambiante est supérieure à 0° Celsius. La couche de glace, difficile à détecter, peut devenir très épaisse, auquel cas elle risque de décoller des ailes au décollage et aboutir dans les réacteurs montés à l'arrière de l'avion.

Au cours de l'hiver 1994-1995, APS Aviation a réalisé des essais en laboratoire sur des boîtes scellées sur-refroidies pour déterminer les durées d'efficacité de liquides antigivrage et mis au point une méthodologie analytique de corrélation des durées d'efficacité obtenues en laboratoire à celles observées sur les ailes d'avions en exploitation normale. Au cours de la présente étude, les chercheurs ont mené des expériences visant à confirmer que le comportement des boîtes scellées simulant une aile sur-refroidie correspond bien à celui des voilures d'un avion. Il s'agissait également de vérifier que les durées d'efficacité observées en laboratoire peuvent être appliquées directement in situ.

Les essais ont été réalisés sur des appareils MD-80 et Regional Jet de Canadair. Quant aux essais sur boîtes sur-refroidies, ils ont eu lieu à l'Installation de génie climatique du Conseil national de recherches, à Ottawa. Les chercheurs ont également utilisé des données de McDonnell Douglas concernant des essais sur un appareil MD-80. Les températures d'essai ont été établies en fonction des données obtenues sur la température des voilures lors de la campagne de mesurage mentionnée plus haut.

L'analyse des résultats indique que les boîtes scellées sur-refroidies sont raisonnablement représentatives des voilures d'aéronef et qu'en conséquence on peut les utiliser pour déterminer les durées d'efficacité des liquides antigivrage sur les voilures d'appareil en service. Ces durées ont surtout varié en fonction de l'intensité des précipitations et de la température des surfaces d'essai. La dimension des boîtes d'expérimentation a eu peu d'effet sur les valeurs de durée d'efficacité observées.

À l'avenir, les essais de détermination de la durée d'efficacité des liquides antigivrage sur ailes sur-refroidies devraient comporter des essais sur boîtes sur-refroidies en conditions de précipitations givrantes.

17. Mots clés
Aéronef, durée d'efficacité, sur-refroidi, précipitation

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EXECUTIVE SUMMARY

At the request of the Transportation Development Centre of Transport Canada, APS Aviation Inc. undertook a study to validate that anti-icing fluid behavior on sealed boxes used for measuring holdover times (HOT) for the cold-soaked wing condition is representative of anti-icing fluid behaviour on actual cold-soaked wings in operation.

The condition of cold-soaked wings is observed on aircraft that land with fuel in wing tanks that has been chilled to very low temperatures which prevail at higher altitudes. Aircraft designed with tanks that allow the fuel to wet the upper wing skin are of particular concern. In conditions of rain, drizzle or fog, or high humidity when condensation forms on wing surfaces, clear ice may form on the wing upper surface, as well as underwing. This presents a particularly insidious hazard as it may occur while outside air temperatures are above freezing and therefore is unexpected. This condition typically produces a clear ice film that is very difficult to identify, especially during precipitation. Frost may also be produced by these conditions.

There is a substantial risk that a thick layer of ice may form, be dislodged during take-off, and be ingested by rear-mounted engines.

A good deal of attention has been given to the problem, including implementing special operating procedures and system modifications to control fuel temperature by managing fuel during flight and installing heating units to counteract cooling during flight. Potential solutions include regulated special inspections, aids to identify the existence of clear ice, and application of new anti-icing fluids with extended holdover times capable of protecting the wing during these conditions. This study deals with the evaluation of fluid holdover times.

During the 1994-95 winter season, APS Aviation performed laboratory tests on sealed cold-soaked boxes to identify holdover times and developed a methodology based on an analytical approach to relate holdover times experienced on the test boxes to holdover times on aircraft wings.

The objective of this study was to conduct experiments to validate that cold-soaked boxes behave in a manner similar to cold-soaked wings, and to verify that fluid holdover times determined on cold-soaked boxes in a laboratory setting are applicable to aircraft wings. This necessitated testing both on operational aircraft and on the sealed cold-soaked boxes used for laboratory testing.

The MD-80 aircraft was selected as the ideal test subject due to its wet wing design, and to the possibility of locating a flight exhibiting suitable cold-soaked wing conditions. The Canadair RJ aircraft was also selected for testing.

In preparation for the study, other research conducted on cold-soaked wings was reviewed and is referred to in the report. This included a survey of aircraft wing temperatures in Canadian winter weather along with data developed by SAS. As well, McDonnell Douglas provided results from intensive flight tests that they had conducted on an MD-80 aircraft to evaluate potential solutions (various fuel management procedures) to maintain fuel temperatures during flight, along with practical advice based on their test experience.

Air Canada, Delta Airlines, American Airlines and USAir were contacted to request their participation and all agreed subject to finding a suitable flight. Arrival flights at Dorval Airport, Montreal and Bradley International at Hartford, Connecticut, were observed and tested for wing skin temperatures.

Preliminary cold-soaked box tests in ambient conditions were conducted at the APS Aviation test site at Dorval Airport, and tests in controlled conditions were conducted in the Climatic Engineering Facility of the National Research Council in Ottawa.

Data Collection

Temperature parameters for testing were established based on wing survey data. An outside air temperature range of 0°C to 5°C was specified along with an aircraft wing temperature range of -5°C to -10°C. Laboratory tests of cold-soaked boxes were initiated at a skin temperature of

-10°C. For fluid holdover time trials on aircraft, conditions of light rain or drizzle precipitation were required.

Thermistor probes were mounted on the test surface (aircraft wing or surface of cold-soaked box) to track the temperature profile of the surface skin as it warmed from its cold-soaked temperature to that of ambient air. Subsequently, thermal time constant values were calculated for each body tested to serve as a benchmark for comparison.

Results

Concerted attempts to locate a flight to serve as a suitable test subject proved unsuccessful. Aircraft wings at arrival displayed a degree of cold-soaking below ambient air temperature but not below 0°C. Limited data were gathered for the purpose of determining a wing temperature profile; however, tests to measure holdover times on wings could not be conducted.

Data made available from McDonnell Douglas proved useful in calculating thermal time constants for MD-80 wings and constituted the principal source of data for this purpose.

Tests conducted in the Climatic Engineering Facility to establish time constant values for cold-soaked boxes provided satisfactory results although a good deal of variability in time constant values from repeated tests was experienced. This variability was believed to be typical of any physical body including aircraft wings.

In a separate study, fluid holdover times in cold-soaked conditions were conducted at the same facility, and temperature profile results from these tests were used to supplement data.

Although fluid holdover time on aircraft was not tested, sufficient data were available to make a comparative analysis and develop relationships between actual cold-soaked wing surfaces and cold-soaked boxes. Analysis of results led to the conclusion that thermodynamic properties of the tested cold-soaked boxes provide a satisfactory representation of aircraft wings, and hence, the test boxes can be used to establish fluid holdover times for cold-soaked wings.

The influence of box size (of the boxes tested) was not important in establishing fluid holdover times. The principal influences on time to fluid failure were found to be the precipitation rate and the temperature of the test surface.

Recommendations

- Cold-soaked boxes should be accepted as satisfactory representations of cold-soaked wings for the purpose of laboratory trials to evaluate fluid holdover times.
- Future trials to establish fluid holdover times should include tests on cold-soaked boxes to determine the impact of a cold-soaked wing on fluid holdover times for freezing precipitation conditions.

SOMMAIRE

À la demande du Centre de développement des transports, Transports Canada, APS Aviation Inc. a entrepris une étude visant à confirmer que le comportement d'un liquide antigivrage sur boîtes scellées simulant une aile sur-refroidie correspond bien au comportement de ce liquide sur l'aile sur-refroidie d'un avion en exploitation normale.

Les avions présentent une condition d'aile sur-refroidie à l'atterrissage lorsque le carburant dans les réservoirs d'aile a été refroidi à une température très basse durant un vol en haute altitude. Les avions les plus susceptibles de présenter cette condition sont ceux où le carburant stocké dans les réservoirs d'aile peut mouiller le revêtement supérieur de la voilure. Dans des conditions de pluie, de bruine ou de brouillard, ou encore d'humidité relative élevée propice à la condensation sur les surfaces d'aile, de la glace transparente peut se former aussi bien sur l'extrados que l'intrados des ailes. Cette situation présente un danger particulièrement insidieux du fait que la glace peut se former, contre toute attente, même lorsque la température ambiante est supérieure au point de congélation de l'eau. Qui plus est, la couche de glace transparente est très difficile à détecter, surtout dans des conditions de précipitations. Du givre peut également se former dans ces conditions.

Il existe également un grand risque d'accumulation d'une épaisse couche de glace qui peut décoller des ailes au décollage et aboutir dans les réacteurs montés à l'arrière de l'avion.

Les compagnies d'aviation ont porté une attention spéciale à ce problème. Pour contrôler le refroidissement du carburant embarqué, elles ont mis en oeuvre des procédures d'exploitation particulières, apporté des modifications aux circuits d'alimentation et installé des éléments chauffants. D'autres solutions sont envisagées, notamment des inspections spéciales imposées par réglementation, des avertisseurs de givrage transparent et l'application de nouveaux liquides antigivrage à durée d'efficacité prolongée. La présente étude porte sur l'évaluation de la durée d'efficacité des liquides en question.

Au cours de l'hiver 1994-1995, APS Aviation a réalisé des essais en laboratoire sur des boîtes scellées sur-refroidies pour déterminer les durées d'efficacité de liquides antigivrage et mis au point une méthodologie analytique de corrélation des durées d'efficacité obtenues en laboratoire à celles observées sur les ailes d'avions en exploitation normale.

La présente étude avait pour objet la conduite d'expériences visant à confirmer que le comportement des boîtes scellées simulant une aile sur-refroidie correspond bien à celui des voilures d'un avion. Il s'agissait également de vérifier que les durées d'efficacité observées en laboratoire peuvent être appliquées directement in situ. Pour cela, il a fallu mener des essais aussi bien sur des avions en exploitation normale que sur les boîtes scellées sur-refroidies utilisées en laboratoire.

Les chercheurs ont choisi comme banc d'essai idéal un appareil MD-80 parce que celui-ci comporte des ailes-réservoirs de type approprié et qu'il y a des appareils de ce type en service dans des régions présentant des conditions propices au sur-refroidissement des ailes. Ils ont également retenu l'appareil Regional Jet de Canadair pour les essais.

En préparation à cette étude, ils ont passé en revue d'autres recherches faites sur le sujet et auxquelles ils font référence dans le présent rapport. Les recherches en question comprennent une campagne de mesurage de la température des ailes dans les conditions hivernales canadiennes ainsi qu'une étude menée par SAS. Par ailleurs, McDonnell Douglas a fourni les résultats des essais en vol intensifs d'un appareil MD-80 visant à évaluer diverses avenues possibles (procédures de gestion de la réserve de carburant à bord) pour maintenir la température du carburant à des valeurs acceptables. Les chercheurs ont également pu bénéficier de conseils pratiques fondés sur l'expérience acquise par cette société.

Air Canada, Delta Airlines, American Airlines et USAir ont toutes accepté de participer à la recherche à la condition qu'un de leurs vols réguliers convienne au protocole d'essai. Elles ont observé l'atterrissage de leurs avions, et mesuré la température des voilures, aux aéroports internationaux de Montréal à Dorval, et Bradley à Hartford, Connecticut.

APS Aviation a procédé à des expérimentations préliminaires sur des boîtes scellées sur-refroidies en conditions ambiantes à son site d'essais à l'aéroport de Dorval et d'autres essais en conditions contrôlées ont été menés à l'Installation de génie climatique du Conseil national de recherches, à Ottawa.

Collecte des données

Les températures d'essai ont été établies en fonction des données obtenues sur la température des voilures lors de la campagne de mesurage mentionnée plus haut. La plage des températures ambiantes extérieures a été fixée à 0° C - 5° C et celle des températures de voilure à -5° C - -10° C. Les essais en laboratoire des boîtes sur-refroidies ont été faits à une température initiale de paroi de - 10° C. Les essais de détermination de la durée d'efficacité des liquides antigivrage ont été faits en conditions de faible pluie ou bruine.

Des capteurs thermostatiques montés sur les surfaces d'essai (voilure d'aéronef ou paroi de boîte sur-refroidie) ont servi à déterminer le profil des températures de surface au fur et à mesure du réchauffement à partir de la valeur «sur-refroidie» jusqu'à la température ambiante. Par la suite, les chercheurs ont calculé les constantes de temps pour chacun des éléments testés, valeurs à être utilisées comme point de comparaison.

Résultats

Toutes les tentatives visant à obtenir des données représentatives utiles à la recherche ont échoué. Tous les appareils vérifiés à l'atterrissage présentaient une voilure sur-refroidie par rapport à la température ambiante mais la température mesurée n'a jamais été au-dessous de 0° C. Les chercheurs ont pu recueillir quelques données pour déterminer le profil de température des voilures mais ils n'ont pu réaliser des essais de détermination de la durée d'efficacité des liquides antigivrage.

Les données fournies par McDonnell Douglas ont été utiles pour le calcul des constantes de temps caractérisant les ailes des MD-80; en fait, elles ont constitué la principale source de données utilisées à cette fin.

Les essais réalisés à l'Installation de génie climatique du CNR pour déterminer les constantes de temps concernant les boîtes sur-refroidies ont livré des résultats satisfaisants malgré la grande variabilité des valeurs obtenues d'un essai à l'autre. On pense que cette variabilité est inévitable, peu importe le corps matériel considéré, y compris les ailes d'avion.

Une autre recherche menée à cette Installation sur les durées d'efficacité des liquides antigivrage sur surfaces sur-refroidies avait permis d'établir des profils de température dont on s'est servi pour compléter les résultats de la présente étude.

Même si les durées d'efficacité sur voilure n'ont pas été déterminées, les chercheurs disposaient de suffisamment de données pour faire une analyse comparative et établir les relations entre les voilures sur-refroidies en service et les boîtes scellées d'expérimentation. L'analyse des résultats indique que les propriétés thermodynamiques des boîtes scellées sur-refroidies sont raisonnablement représentatives de celles de voilures d'aéronef et qu'en conséquence on peut les utiliser pour déterminer les durées d'efficacité des liquides antigivrage sur les voilures d'appareil en service.

La dimension des boîtes d'expérimentation a eu peu d'effet sur les valeurs de durée d'efficacité observées. Celles-ci ont surtout varié en fonction de l'intensité des précipitations et de la température des surfaces d'essai.

Recommandations

- Accepter la simulation sur boîtes sur-refroidies comme méthode d'estimation en laboratoire de la durée d'efficacité des liquides antigivrage sur ailes sur-refroidies.

- À l'avenir, les essais de détermination de la durée d'efficacité des liquides antigivrage sur ailes sur-refroidies devraient comporter des essais sur boîtes sur-refroidies en conditions de précipitations givrantes.

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LIST OF ACRONYMS

ARC	Aviation Research Corporation
AES	Atmospheric Environment Services (Canada)
APS	APS Aviation Inc.
CEF	Climatic Engineering Facility
C/FIMS	Contaminant/Fluid Integrity Monitoring System
ISO	International Standards Organization
SAE	Society of Automotive Engineers
TDC	Transportation Development Centre

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1. INTRODUCTION

At the request of the Transportation Development Centre of Transport Canada, APS Aviation Inc. undertook a study to validate that anti-icing fluid behaviour on sealed boxes used for measuring holdover times for the cold-soaked wing condition is representative of anti-icing fluid behaviour on actual cold-soaked wings in operation. Appendix A contains a detailed statement of work for this study.

The condition of cold-soaked wings is experienced by aircraft that land with fuel in wing tanks that has been chilled to very low temperatures at flight altitudes. Those aircraft designed with integral wing tanks which allow the fuel to wet the upper wing skin are of particular concern. In conditions of rain, drizzle or fog, clear ice may form on the wing upper surface, as well as underwing. Conditions of high humidity when condensation forms on wing surfaces may result in the formation of frost, or clear ice. This presents a particularly insidious hazard as it may occur while outside air temperatures are above freezing and thus be unexpected, typically producing a layer of clear ice film that is very difficult to identify. There is a substantial risk that a thick layer of ice may form, be dislodged during take-off, and ingested by rear-mounted engines.

A good deal of attention has been given to the problem, including implementing special operating procedures and system modifications to control fuel temperature. This is accomplished by managing fuel during flight, installation of heating units on the aircraft (to counteract fuel cooling during flight), regulated special inspections and aids to identify the existence of clear ice, and application of new anti-icing fluids with extended holdover times capable of protecting the wing during these conditions. This study pertains to the latter, and deals with the evaluation of fluid holdover times under this condition.

In preparation for the study, other research conducted on cold-soaked wings was reviewed and is referred to in the report. This includes a study on aircraft ground operations in Canadian winter weather (ARC report TP 12735E)(1)* which in addition to original data includes data on cold-soaked wings developed and provided by SAS. As well, McDonnell Douglas provided results from intensive flight tests that they had conducted on MD-80 aircraft to evaluate potential solutions (various fuel management procedures) to maintain fuel temperatures during flight. McDonnell Douglas also provided practical advice based on their test experience and detail on MD-80 wing surface wetting profiles for various fuel loads.

During the winter season 1994/95, APS Aviation performed an initial series of laboratory tests on sealed cold-soaked boxes to identify holdover times(2) and developed a methodology (3) based on an analytical approach to relate holdover times experienced on the test boxes to holdover times on aircraft wings. In the laboratory tests, sealed cold-soaked boxes of depth 15 and 7.5 cm were used. The analytical methodology recommended that boxes of depth 2.5 cm also be used in future trials.

The objectives of this study were:

- to conduct experiments to validate that the thermodynamic properties of the cold-soaked boxes are similar to actual cold-soaked wings; and
- to verify that fluid holdover times determined on cold-soaked boxes in a laboratory setting are applicable to aircraft wings. This necessitated testing both on service aircraft and on the sealed cold-soaked boxes.

The MD-80 aircraft was selected as the ideal test subject due to its wet wing design, and to the possibility of locating a flight of reasonably long duration (with maximum potential for fuel cooling) together with wing tanks sufficiently full at arrival to wet the upper surface. As well, it was planned to test the Canadair RJ aircraft. The RJ aircraft design includes a wet wing along with an integral fuel management system that continuously tops up the main tanks during flight.

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* Small superscripts in the text denote references cited at the end of the report.

Air Canada, Delta Airlines, American Airlines and USAir were contacted to seek their participation and all agreed subject to finding a suitable flight. Arrival flights at Dorval Airport, Montreal and Bradley International at Hartford, Connecticut were observed.

Preliminary cold-soaked box tests in ambient conditions were conducted at the APS Aviation test site at Dorval Airport, and tests in controlled conditions were conducted in the Climatic Engineering Facility of the National Research Council in Ottawa.

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2. METHODOLOGY

This section includes subsections which provide descriptions of the following: tests, test sites, equipment, test procedures, data forms, fluids, personnel and participants, and analysis methodology.

2.1 Description of Tests

2.1.1 Tests to Develop Wing Temperature Profiles

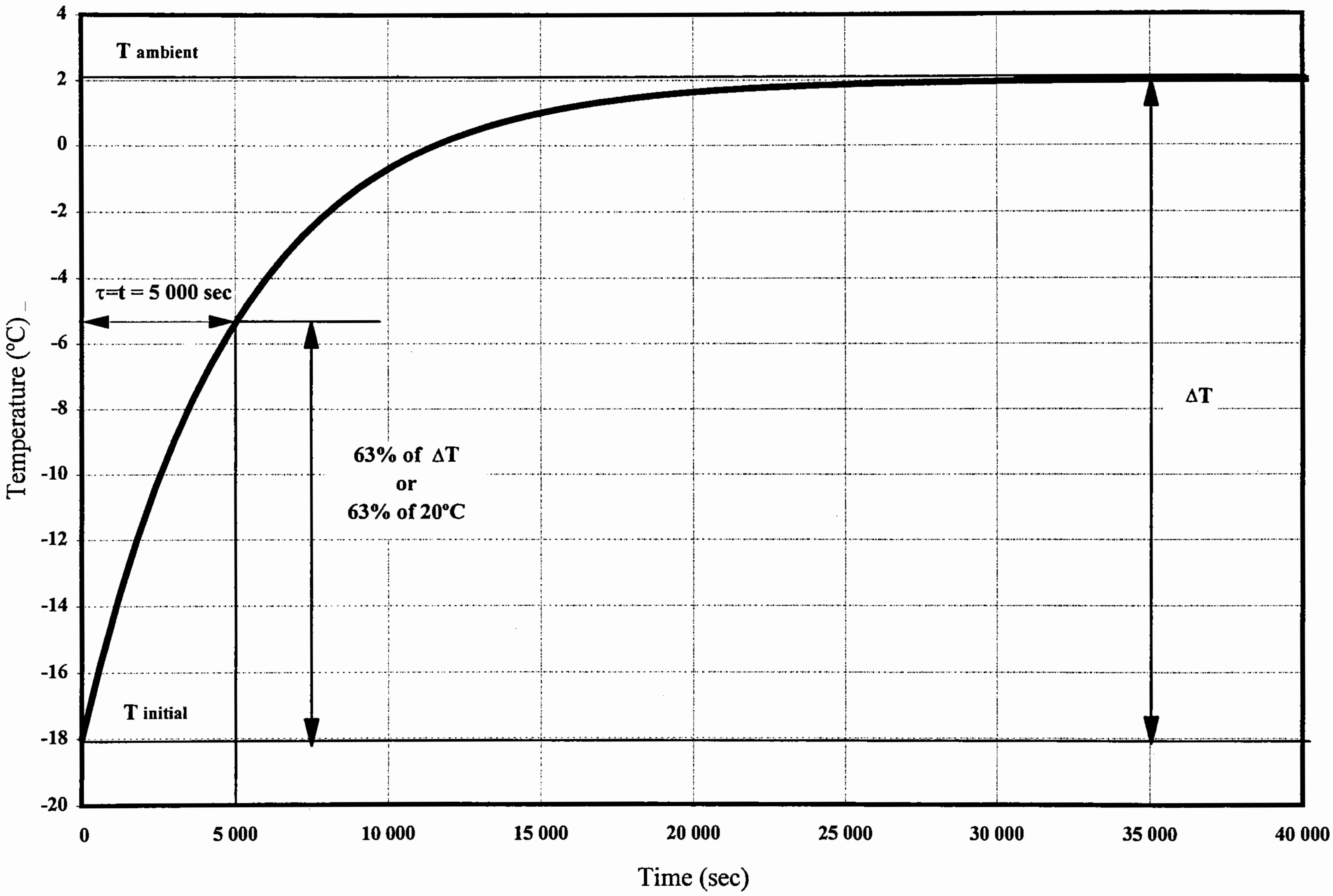
Two types of aircraft tests were planned. The first of these had the objective of developing a wing temperature profile for the cold-soaked wing. This involved progressively recording wing surface temperature and clock time as the wing warmed from its initial cold-soak temperature to ambient outside air temperature. Temperature and time could then be charted to develop a curve (temperature profile) illustrating the rate at which the wing surface temperature increased. For these tests it was not necessary to apply fluid and the tests were planned to be performed on aircraft gates at arrival. Data provided by McDonnell Douglas based on their cold-soak tests were reviewed as part of this activity.

Similar temperature profiles were measured for the various sized cold-soaked boxes.

Temperature profiles for aircraft wings and cold-soaked boxes were compared by calculating values for thermal time constants from experimental data for each test case. The report on methodology for simulating a cold-soaked wing(3) presented a detailed discussion on the concept of thermal time constant. The methodology proposed in that report was based largely on use of the time constant, and the report described its method of use both for theoretical and experimental analysis. Figure 2.1 provides an example of a temperature profile curve and the concept of the time constant. In this treatment a time constant is equivalent to the time taken for the

FIGURE 2.1

EXPLANATION OF TIME CONSTANT CONCEPT



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temperature differential (the difference between the test surface temperature and outside air temperature) to be reduced by 63%.

As signified by its name, the time constant is an unchanging value for each body regardless of its initial temperature, or the difference between its temperature and ambient air temperature. The following example shows the time constant for the body represented in Figure 2.1 (Condition 1) as being the same as the time constant for the same body under different temperature conditions (Condition 2).

Example:

	Condition 1	**Condition 2**
Outside Air Temperature	2°C	5°C
Initial Temp of test surface	-18°C	- 4°C
Temp differential	20°C	9°C
63% of differential	12.6°C	5.7°C
Time for surface to warm by above amount	83.3 min.	83.3 min.
Time constant = 83.3 minutes	(5 000 sec)	(5 000 sec)

Representative conditions for trials to develop a temperature profile for aircraft wings included an ambient air temperature of 0°C to +5°C with no precipitation and an aircraft wing surface temperature of -5°C to -10°C. The low end of this range was established based on reference to a survey of wing temperatures of aircraft in operation(1) which included data gathered in Canada and Europe, and is discussed in detail in Section 4.

2.1.2 Tests to Measure Fluid Holdover Times

The second planned type of aircraft test was designed to measure fluid holdover times during precipitation on cold-soaked wings of service aircraft. Desirable test conditions included an ambient air temperature of 0°C to +5°C with light to moderate rain and an aircraft wing surface temperature of -5°C to -10°C.

A good deal of effort and communication were directed toward locating flights that would serve as suitable test subjects. Search criteria included: an MD-80 or RJ aircraft; availability for testing during overnight layovers; inbound flight sufficiently long to promote cold-soaking; and ability to put procedures in place with the operator that could be initiated by the test team on the day selected for test. These procedures for the selected flight included advice to flight crews and ground crews regarding the test and its particular requirements, arrangement to board additional fuel at the departure airport sufficient to provide the condition of wing upper surface wetting at arrival, and suspension of any special fuel management procedures that the operator may have implemented to counteract cold-soaking.

Specification of the lower limit of main (wing) tank fuel that would wet the upper surface of the wing was made possible by reference to a wing top surface topography chart for DC-9-50 and MD-80 aircraft provided by McDonnell Douglas (Figure 2.2). That chart shows topographic profiles reflecting areas of the upper wing surface that are wetted by differing amounts of fuel. Upper wing wetting commences when the main tanks contain 2 943 kg of fuel (about 70 percent full) and the topographic lines for increased fuel load show the initial portion of the tank that is exposed to cold-soaking. This area is commonly referred to as the "cold corner" and is located at the rear corner at the inner end of the wing tank.

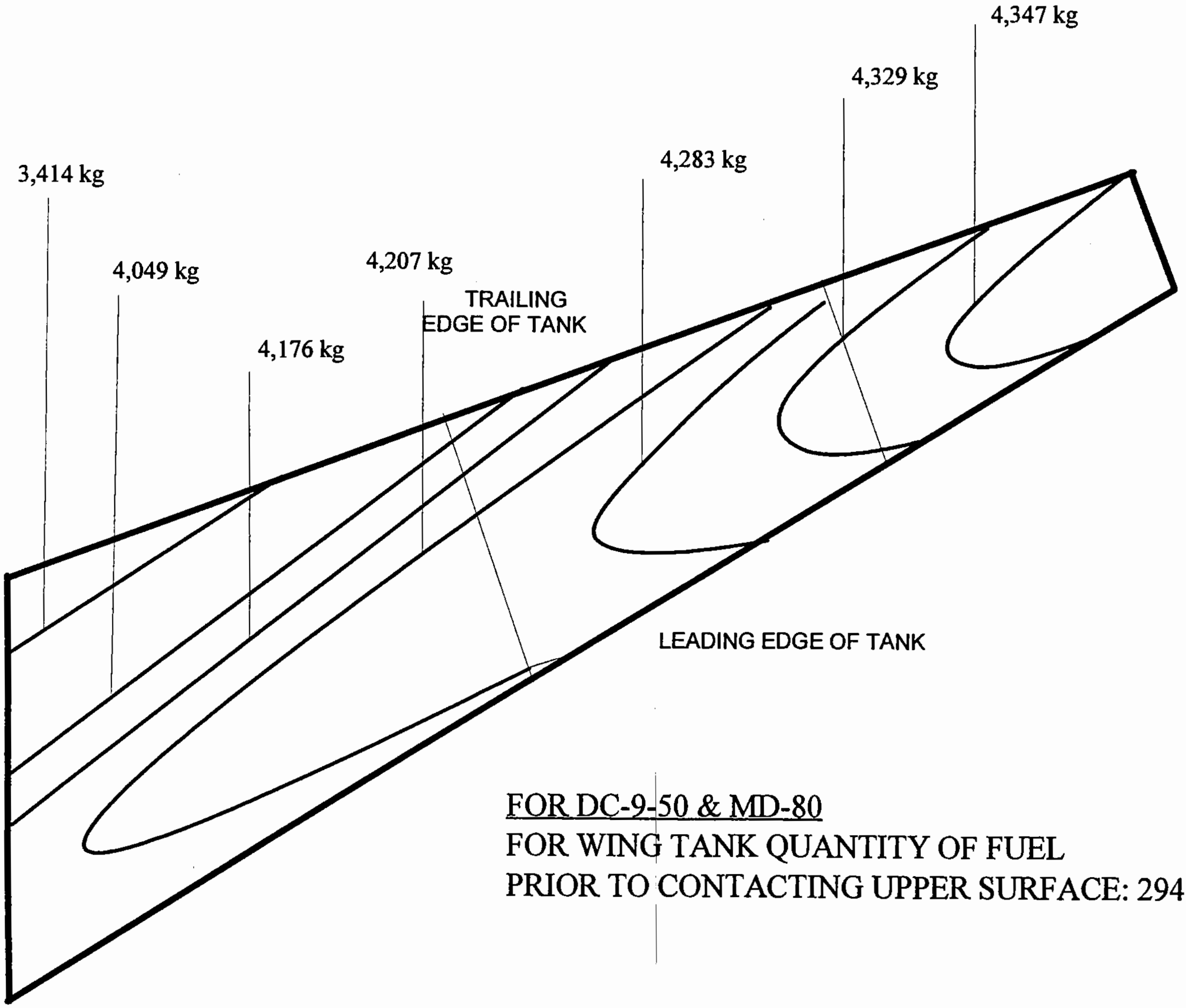
2.2 Test Sites

As a certain amount of test equipment was involved, Dorval Airport was considered the most efficient location for testing, thereby eliminating the need to transport test equipment and to develop the special arrangements that would be required to conduct tests at other airports. Air Canada agreed to make their deicing centre available to conduct fluid holdover time tests regardless of the participating airline, which further facilitated the test plan.

FIGURE 2.2

AREA OF WING SURFACE WETTED BY VARIOUS AMOUNTS OF FUEL

MAIN (WING) TANK DC-9-50 & MD-80



<u>FOR DC-9-50 & MD-80</u>
FOR WING TANK QUANTITY OF FUEL
PRIOR TO CONTACTING UPPER SURFACE: 2943 kg

SOURCE: McDONNELL DOUGLAS

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Air Canada, Delta Airlines, American Airlines and USAir were contacted to seek their participation, and potential flights were reviewed. A varied degree of testing, or in some cases checking inbound flights for cold-soaked condition, was performed with the participation of the first three carriers. USAir did not have a suitable flight at Dorval that met the test criteria.

After initial testing at Dorval it was found that none of the potential flights that had been identified offered satisfactory cold-soaked conditions for test purposes, and other locations were reviewed to locate flights that might serve as subjects for testing.

Discussions with Delta Airlines led to a review of potential flights at various points and an MD-80 flight was selected for test at Bradley International at Hartford, Connecticut. This flight held good promise with inbound flight duration of two hours.

Tests on cold-soaked boxes were conducted at the APS Aviation test site at Dorval Airport and in the Climatic Engineering Facility of the National Research Council in Ottawa.

2.3 Equipment

2.3.1 Aircraft Tests

A complete list of equipment is included in Appendix B, Experimental Program Rain on Cold-Soaked Wing Full-Scale Aircraft Trials.

Thermistor probes and data loggers were the principal measurement instruments. These were employed to track the temperature of the wing surface at pre-selected points over the full test duration. Thermistor probes were mounted with aluminum speed tape (Photo 2.1), or in some instances where the tape would not adhere, with a refrigerant putty (Photo 2.2). (Photos are provided at the end of this section.)

In addition, hand-held temperature probes were used to assess suitability of potential flights to serve as test subjects. Pole-mounted temperature probes as used by Aviation Research Corporation were used to collect initial data on wing surface temperatures immediately upon arrival, while thermistor probes were being mounted on the wing.

2.3.2 Cold-Soaked Box Tests

Cold-soaked boxes (Figure 2.3) designed for the 1994/95 study (3) which included boxes of 15, 7.5 and 2.5 cm depths were tested. Boxes were completely filled with glycol. An insulating jacket of 2.5 cm (1") insulating Styrofoam covering all walls and the underside was installed on each test box. Tests conducted outdoors made use of top plate covers to protect test surfaces until tests were initiated.

Thermistor probes and data loggers were used to measure temperature profiles on the surfaces of cold-soaked boxes. Photo 2.3 shows a data logger linked to a laptop PC for data display, and a set of cables on reels leading to thermistor probes. Photo 2.4 illustrates thermistor probes mounted on cold-soaked boxes. In these tests the probes were mounted with epoxy. This photo also provides a good view of the box construction showing the insulating blanket surrounding the box walls and underside. Photo 2.5 shows a flat plate stand with a full set of six boxes under test.

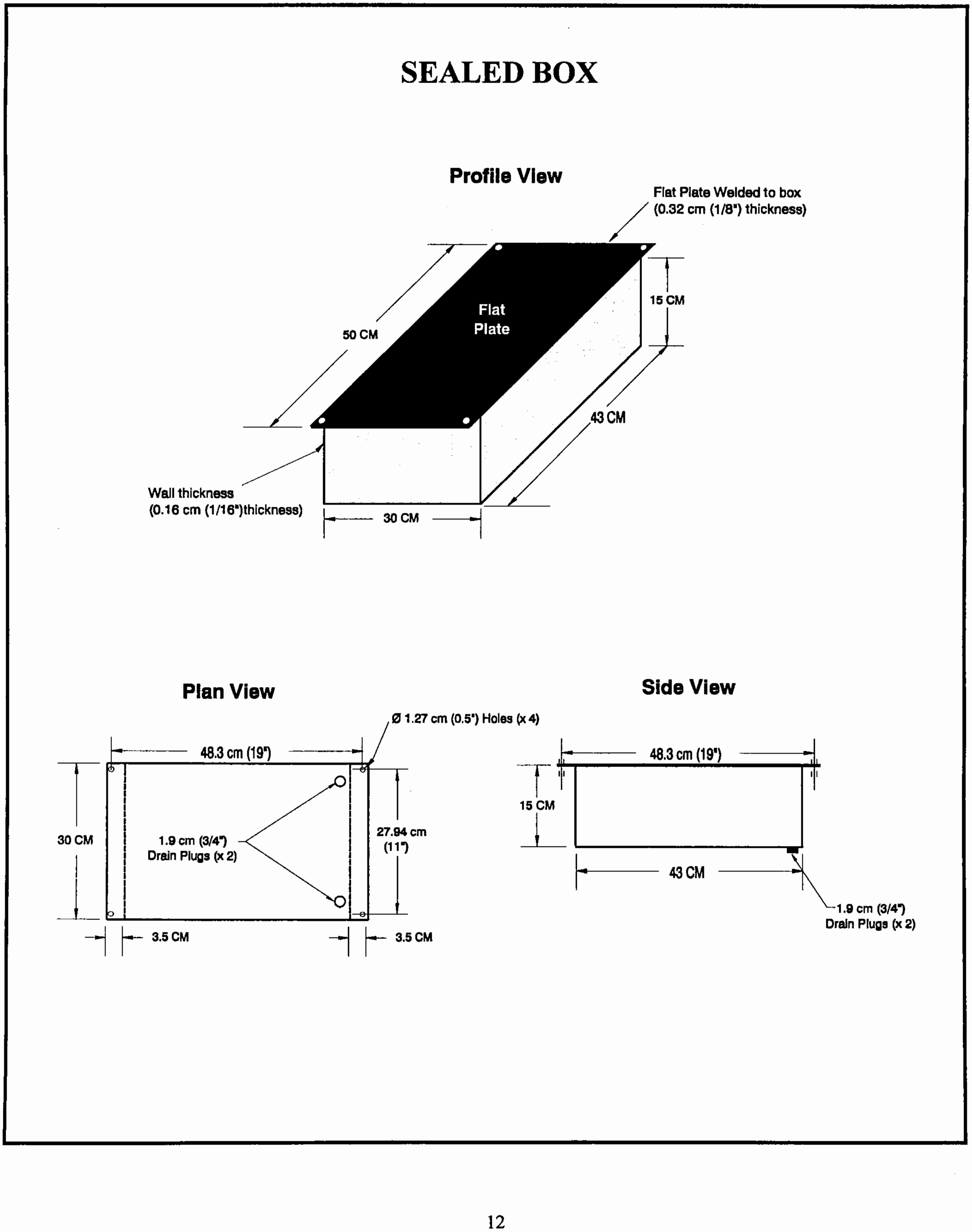
Tests conducted at the APS test site required a freezer in which filled boxes were placed for cold-soaking some time prior to the test.

Tests conducted at the NRC cold chamber used a liquid nitrogen bath (Photo 2.6) to cool the glycol which was then used to fill the cold-soaked boxes for test.

A complete list of equipment is included in Appendix C, Experimental Program to Measure Temperature Profiles of Cold-Soaked Boxes.

FIGURE 2.3

SCHEMATICS OF SEALED BOX
DEPTH OF 15 CM



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2.4 Test Procedures and Data Forms

2.4.1 Aircraft Trials

The test plan is shown in Table 2.1. The Experimental Program for these trials is included as Appendix B.

Weather forecasts were monitored seeking a period:

- For wing temperature profile tests - outside air temperatures of 0° to +5°C; with no precipitation; and
- For cold-soaked wing HOT tests - outside air temperatures of 0° to +5°C; with light to moderate rain.

As the winter season progressed, aircraft trials showed that those flights that had been selected for testing did not exhibit cold-soaked conditions suitable for testing. The test plan was reviewed and test condition specifications for data gathering to determine wing temperature profiles were revised to accommodate higher ambient temperatures while still ensuring an adequate temperature differential between wing and ambient air temperature to allow development of a temperature profile and enable valid calculation of the wing time constant. This led to a final attempt to measure wing time constants being conducted during warmer weather (Delta Airlines Test, July 18, 1996).

Arrangements were made with the participating airline to initiate special procedures on the day selected for test. These procedures included: advising personnel at the originating airport to board extra fuel sufficient to provide a wetted wing on arrival; advising flight crews regarding the test, the extra fuel being carried, and the need to override any special procedures in place to maintain fuel temperature while en route; advising ground personnel on their participation at airport of arrival to enable the test

TABLE 2.1

RAIN ON COLD-SOAKED WING FULL-SCALE AIRCRAFT TRIALS

TEST PLAN

WING TEMPERATURE PROFILE TESTS

RUN #	OCCASION #	WING	FLUID TYPE	A/C Type
1	1	Stbd	Nil	RJ
2	2	Port	Nil	MD-80

COLD-SOAKED WING HOT TESTS

RUN #	OCCASION #	WING	FLUID TYPE	A/C Type
3	3	Port	XL54	MD-80
4	3	Port	Ultra	MD-80
5	3	Port	Ultra	MD-80
6	4	Port	XL54	MD-80
7	4	Port	Ultra	MD-80
8	4	Port	Ultra	MD-80
9	5	Stbd	XL54	RJ
10	5	Stbd	Ultra	RJ
11	5	Stbd	Ultra	RJ

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team to gain access to the aircraft immediately on arrival so recording of wing temperatures and installation of thermistor probes could commence; and delaying refuelling until test completion.

For tests involving measurement of fluid holdover times, airline participation was arranged to tow the aircraft to and from the deicing pad, and to perform aircraft deicing/anti-icing, using their own vehicles and standard procedures.

Positions for installation of thermistor on the wing were specified on the wing plan form (Figures 2.4 and 2.5). The pattern of attachment points was selected to provide optimum discrimination of data. Because the wing surface temperature is influenced both by fuel wetting and by thermal conductivity of major structural components that are wetted by fuel, probes were located at structural component rivet lines where possible.

The General Test Data Form (Figure 2.6) was used to report weather conditions, aircraft type, on-board fuel data, and team member names.

The test plan procedure included installation of thermistor probes commencing immediately on flight arrival, while the aircraft was being off-loaded at the gate after arrival and, in the case of holdover tests, while awaiting for it to be towed to the deicing area. Prior to the test, thermistor probes and cables were coiled on individual racks to facilitate installation and allow immediate data capture as each was installed. Safety precautions included natural rubber overshoes for the man on the wing to prevent slipping, and a safety rope. Photo 2.7 gives a view of the test team installing probes on the wing of an MD-80, and Photo 2.8 shows an array of cables from installed probes to coils and loggers on the ramp under the wing. Photos 2.9 and 2.10 show probes installed on the wing surface.

FIGURE 2.4

DATA FORM FOR RAIN ON COLD-SOAKED WINGS TEMPERATURE PROFILE

REMEMBER TO SYNCHRONIZE TIME

Winter 95/96

LOCATION: YUL **DATE:** **RUN NUMBER:** **WING # :**

Initial Temperature Data with Hand-held Probes

1		2		3		4		5		6		7		8		9		10		11		12		13		14	
Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)

MD-80

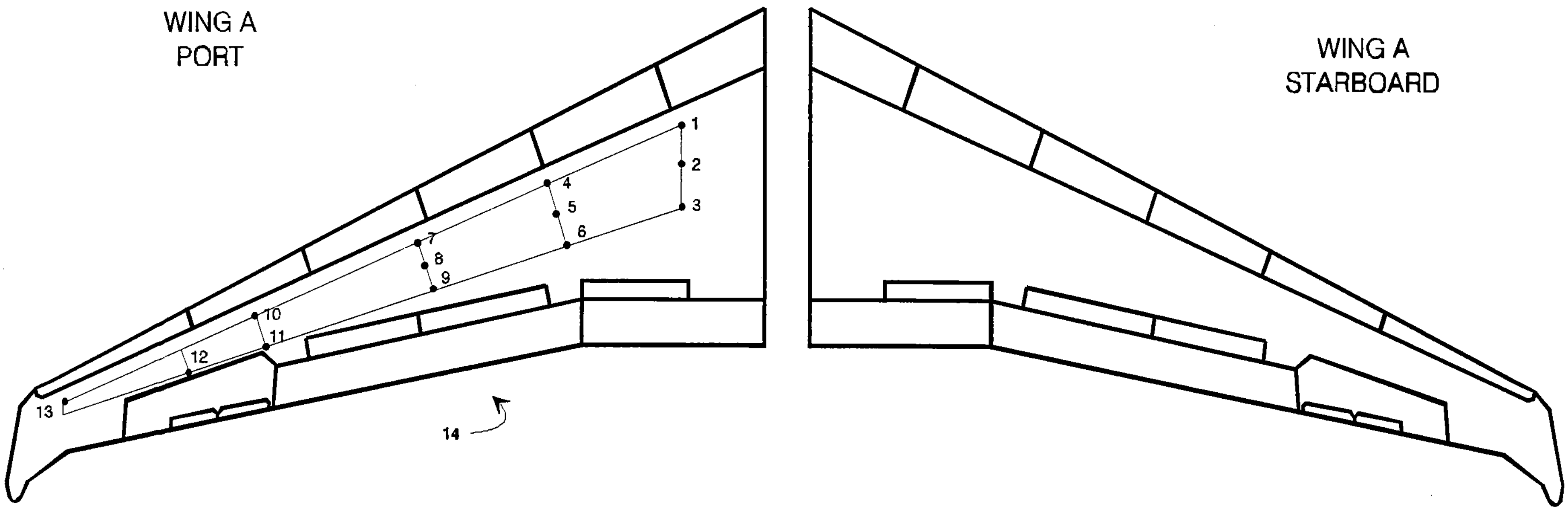

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FIGURE 2.5

REMEMBER TO SYNCHRONIZE TIME

DATA FORM FOR RAIN ON COLD-SOAKED WINGS TEMPERATURE PROFILE

Winter 95/9

LOCATION: YUL DATE: RUN NUMBER: WING # :

Initial Temperature Data with Hand-held Probes

1		2		3		4		5		6		7		8		9		10		11		12		13		14	
Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)

RJ

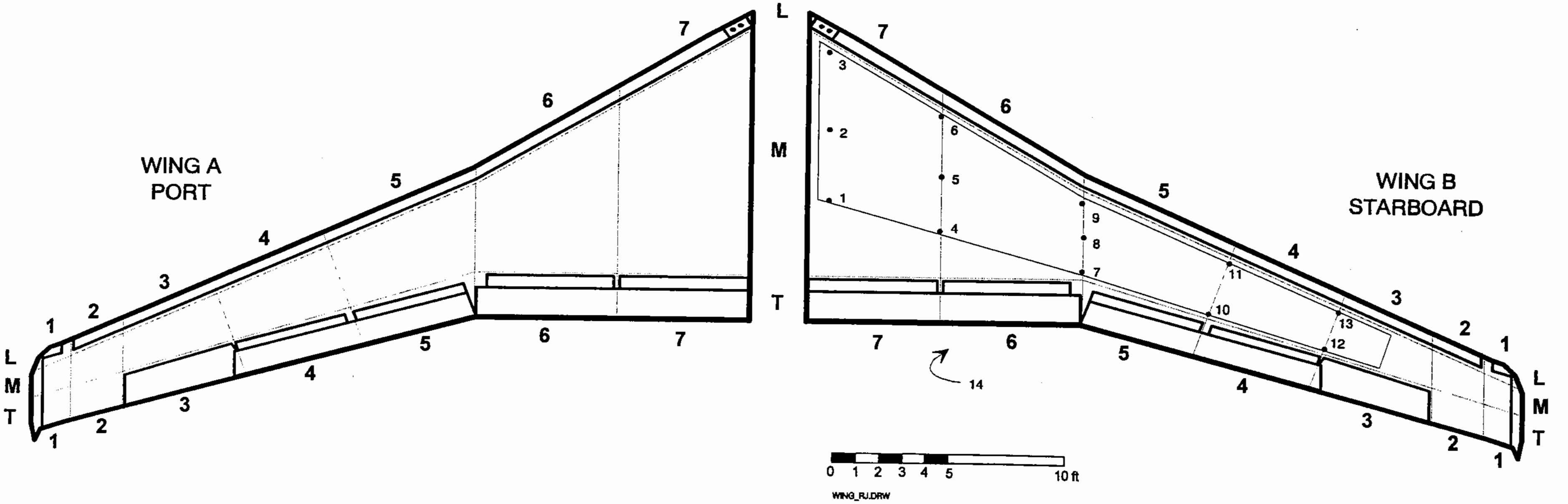

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FIGURE 2.6

GENERAL FORM

RAIN ON COLD-SOAKED WING FULL-SCALE AIRCRAFT TEST DATA

AIRPORT: YUL

AIRCRAFT TYPE: A320 DC-9 B-737 RJ BAe 146

EXACT LOCATION OF TEST: ______

AIRLINE: ______

DATE: ______

FIN #: ______

RUN #: ______ **a/c Direction:** ______ degrees

FUEL LOAD: ______ LB / KG

1st FLUID APPLICATION

Actual Start Time: ______ am / pm

Actual End Time: ______ am / pm

Start of Fluid Gauge: ______ L / gal

End of Fluid Gauge: ______ L / gal

Type of Fluid: ______

Truck #: ______

Fluid Temperature: ______

Fluid Nozzle Type: ______

2nd FLUID APPLICATION

Actual Start Time: ______ am / pm

Actual End Time: ______ am / pm

Start of Fluid Gauge: ______ L / gal

End of Fluid Gauge: ______ L / gal

Type of Fluid: ______

Truck #: ______

Fluid Temperature: ______

Fluid Nozzle Type: ______

Weather Conditions

OAT ______ ° C

Relative Humidity ______ %

Wind Speed ______ km/h

Wind Direction ______ degrees

Team Assignments

O1 ______

P1 ______

V1 ______

P2 ______

C1 ______

Airline Team

______ ______

______ ______

Observers

______ ______

While probe installation was in progress, wing skin surface temperatures were measured at the locations where thermistor probes were to be installed by use of the pole-mounted and hand-held temperature probes and recorded on the wing plan form (Figures 2.4 and 2.5). A record of the temperature of the underside of the wing was included to serve as an indication of fuel temperature.

For wing temperature profile tests, the remainder of the test involved the use of data loggers to record wing temperature as the wing warmed. These tests were performed on the bare wing without fluid, with the aircraft remaining at the arrival gate.

For fluid holdover tests, any ice already formed on the wing when the aircraft arrived at the deicing area was to be removed by following standard airline procedure with Type I fluid. The test fluid was then to be sprayed over the entire wing. Fluid failures were to be called by observers located on stairs at the wing edge and failure times indicated on data forms shown in Figures 2.7 and 2.8. This form was designed to record initial fluid thicknesses.

Standard flat plate fluid holdover time test procedures using plate pans were incorporated to measure rain intensity and quantity.

2.4.2 Cold-Soaked Box Tests

These tests were designed to record the temperature profiles of cold-soaked boxes of different depths (15, 7.5 and 2.5 cm deep). The boxes were insulated from ambient air except on the top plate surface, and filled with glycol. Two thermistor probes were installed on each box, at the 15 cm (6 inch) line corresponding to the position specified for laboratory cold-soak tests, and at the 22.5 cm (9 inch) line. For some tests, probes were installed within the 7.5 cm box, suspended between the upper and lower surfaces to measure the temperature of the fluid. Two data loggers connected to the probes logged temperature data over the entire test period, and when linked to

FIGURE 2.7

DATA FORM FOR RAIN ON COLD-SOAKED WINGS HOT TRIALS

REMEMBER TO SYNCHRONIZE TIME

Winter 95/96

LOCATION: YUL DATE: RUN NUMBER: WING # :

TIME OF FLUID APPLICATION: ____________ (hr:mm:ss)

FAILURES CALLED BY: __________________

COMMENTS:______________________

____

GRID AREA	FLUID THICKNESS (mil)		FLUID FAILURE TIME (MIN)	
	TIME	GAUGE	FIRST	100%
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				

DRAW FAILURE CONTOURS ACCORDING TO THE PROCEDURE

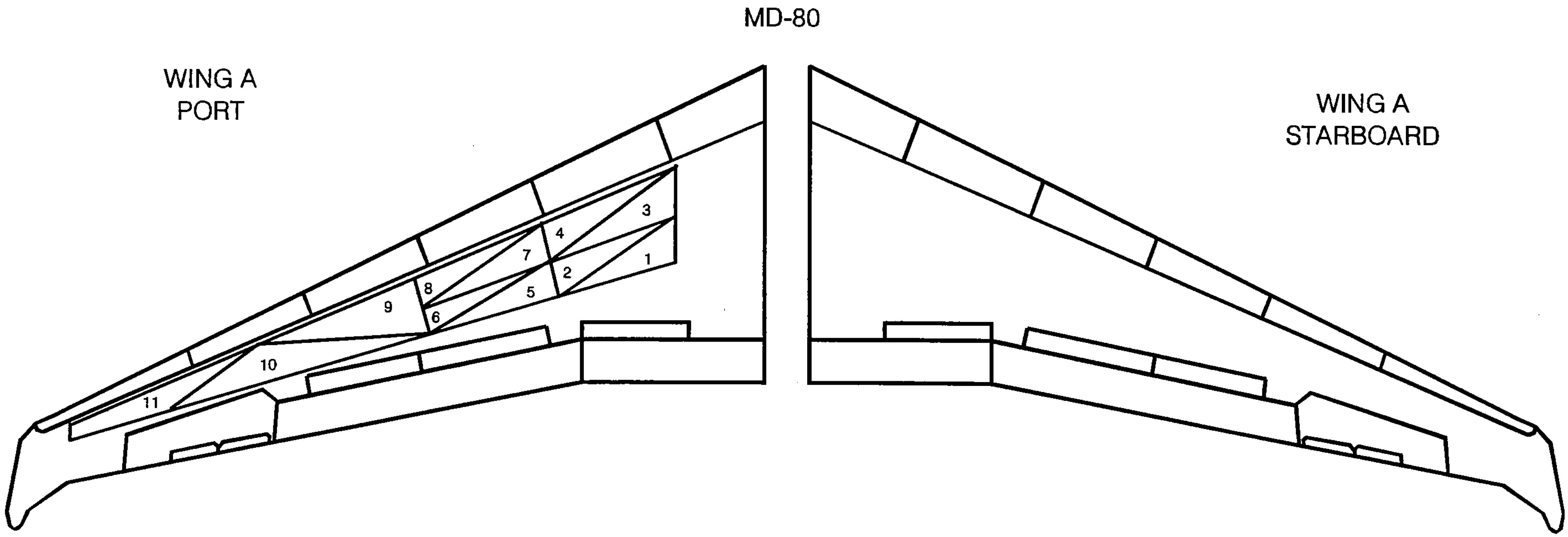

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FIGURE 2.8

DATA FORM FOR RAIN ON COLD-SOAKED WINGS HOT TRIALS

REMEMBER TO SYNCHRONIZE TIME

Winter 95/9

LOCATION: YUL **DATE:** **RUN NUMBER:** **WING #.:**

TIME OF FLUID APPLICATION:______________(hr:mm:ss)

FAILURES CALLED BY:______________________

COMMENTS:______________________

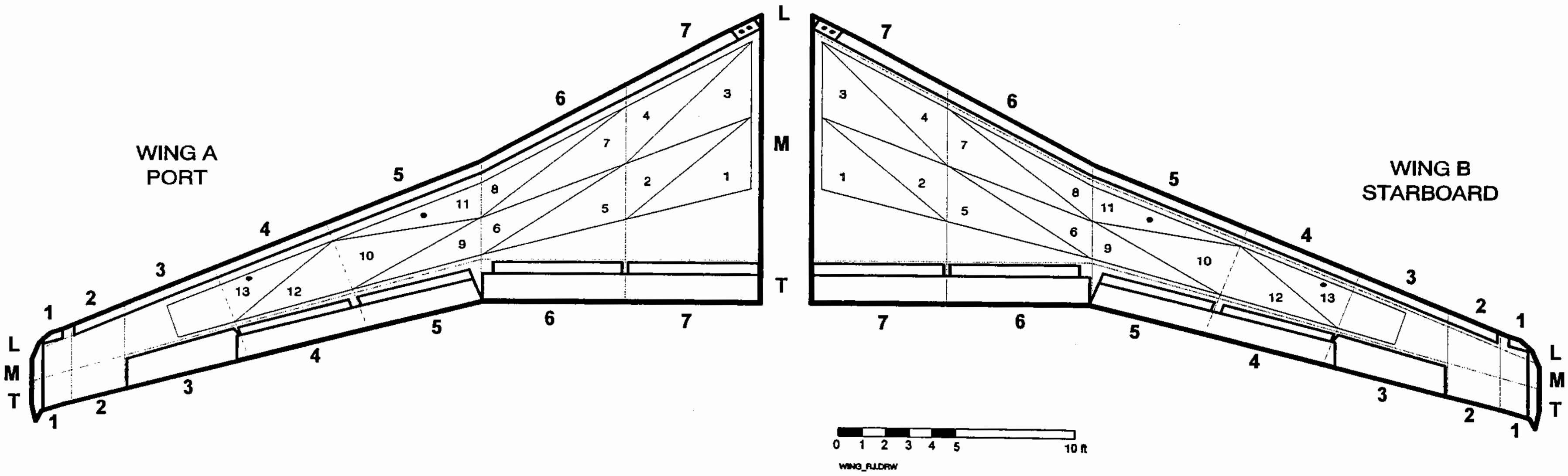
____

____

GRID	FLUID THICKNESS (mil)		FLUID FAILURE TIME (min)	
AREA	TIME	GAUGE	FIRST	100%
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				

DRAW FAILURE CONTOURS ACCORDING TO THE PROCEDURE

RJ



File: g:/cm1283/report/coldsoak/TPRF2_RJ.XLS Printed: 29/07/97 a laptop PC enabled temperatures to be monitored on a real-time basis. Prior to testing in the controlled conditions offered by the CEF facility, preliminary tests were conducted outdoors and inside the trailer at the APS test site.

2.4.2.1 Tests at APS Test Site

The boxes were placed in the freezer sufficiently long before testing to reach a common temperature of -25°C or lower. The data loggers were connected (located outside the freezer) and thermistor probe data was logged during the cooling period. Data sampling frequency was adjusted to enable data logging over this entire period.

Cold-soaked boxes were taken from the freezer for test, with probes and data logger still installed, and allowed to warm toward ambient temperature.

For initial tests, fluids as specified in the Test Plan (Appendix C, Attachment I) were poured on the box surfaces. Later tests were redesigned to include two boxes of each depth (2.5, 7.5 and 15 cm), of which one was tested with Ultra fluid applied and the other as a bare surface.

Outside air temperature data were recorded using a spare thermistor probe.

Tests continued and data was recorded typically for a 12-hour period, or until box temperatures reached outside air temperature.

2.4.2.2 Tests at NRC Cold Chamber

Tests to determine cold-soaked box temperature profiles were designed to include two boxes of each depth, of which one had Ultra fluid applied and the other was tested as a bare surface.

Each test commenced with the refilling of the cold-soaked boxes with glycol that had been cooled in the liquid nitrogen cooler. The boxes were then placed in the environmental facility. Ambient temperature was controlled at +2°C and tests were initiated when box surface temperatures reached -10°C thereby duplicating the conditions of concern experienced in actual operations. Tests were conducted in non-precipitation conditions.

Individual tests continued until surface temperatures reached or neared ambient temperature.

During later trials designed to determine fluid holdover times in cold-soaked conditions, cold-soaked box surface temperatures were again logged, this time under conditions of various types of precipitation.

2.5 Fluids

Fluids involved in these trials included UCAR Neat (100%) Type IV Ultra+ and UCAR Type I XL54.

2.6 Personnel and Participation

2.6.1 Aircraft Trials

Airline personnel were involved in special preparations for the tests as well as operating deicing vehicles and following their standard deicing procedures. APS Aviation staff coordinated the tests based on forecasted weather conditions, gathered test results and analysed the data.

Security escort staff were required for one test.

Individual task assignments are shown in Appendix B.

2.6.2 Cold-Soaked Box Tests

NRC staff operated the cold chamber in response to specified test conditions. APS staff conducted the tests, gathered and analysed test results.

2.7 Analysis Methodology

The objective of the temperature profile tests was to compare the thermodynamic performance of cold-soaked boxes to that of aircraft wings. Temperature data recorded by data loggers were downloaded to a PC and temperature profile curves for each probe measurement position were produced.

Additionally, temperature data were analysed to calculate the thermal time constant for each surface under study to serve as a standard criterion for comparing experimental results.

Figure 2.9 presents an example of a typical temperature profile and its corresponding calculated temperature time constant. The formula(3) used for calculating the time constant was:

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

where J = time constant

t_1 = time at test start

t_2 = time at test end

T_1 = test surface temperature at test start

T_2 = test surface temperature at test end

T_0 = ambient temperature

$\Theta1 = T_0 - T_1$

$\Theta_2 = T_0 - T_2$

FIGURE 2.9

COLD-SOAKED BOX TEMPERATURE PROFILE
2.5 cm Box at 22.5 cm (9") Line - BARE
July 31, 1996 - CEF

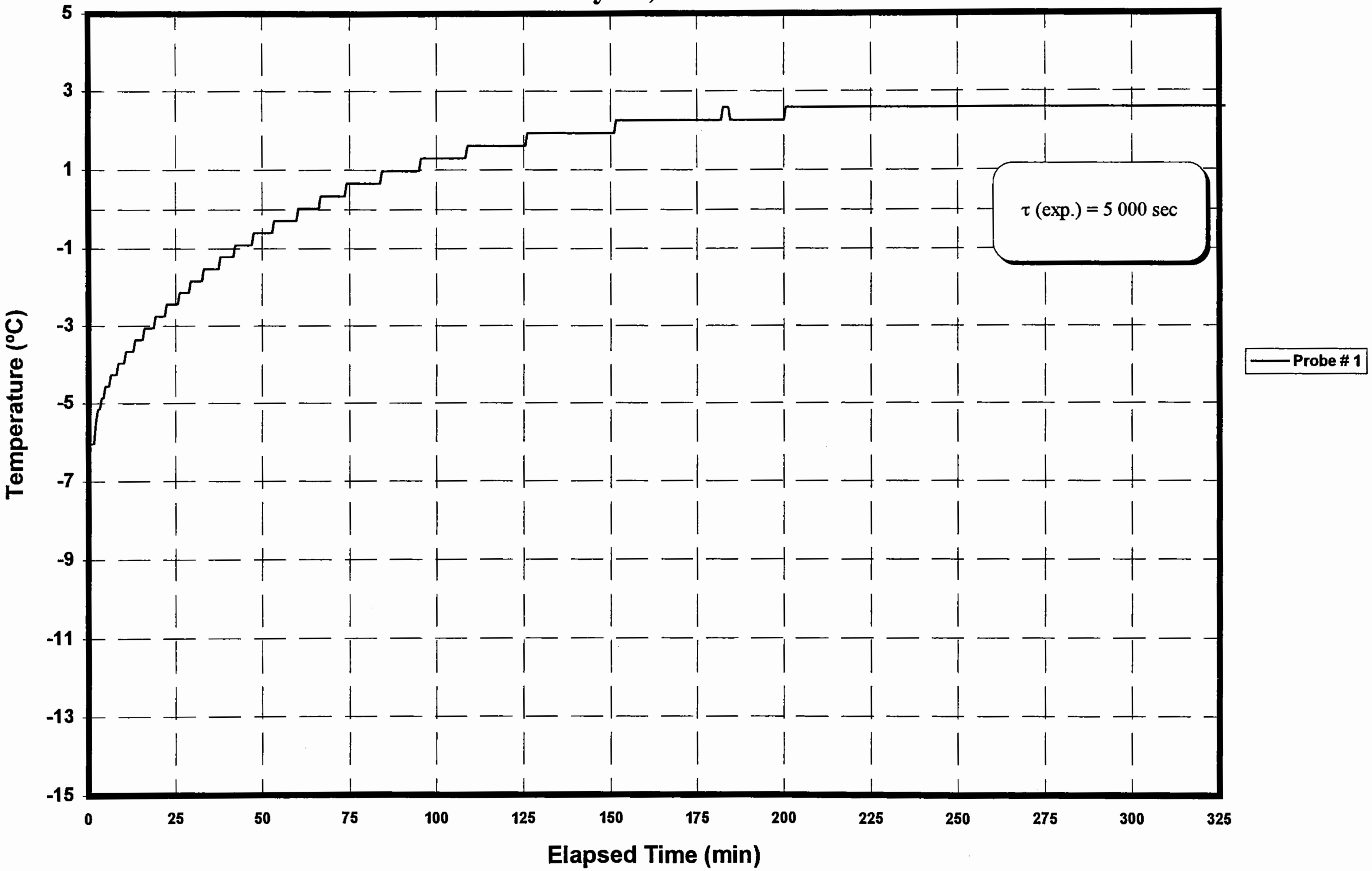


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Photo 2.1
Thermistor Probe Mounted on Wing with Aluminum Tape

Photo 2.2
Thermistor Probe Mounted on Underside of Wing with Refrigerant Putty

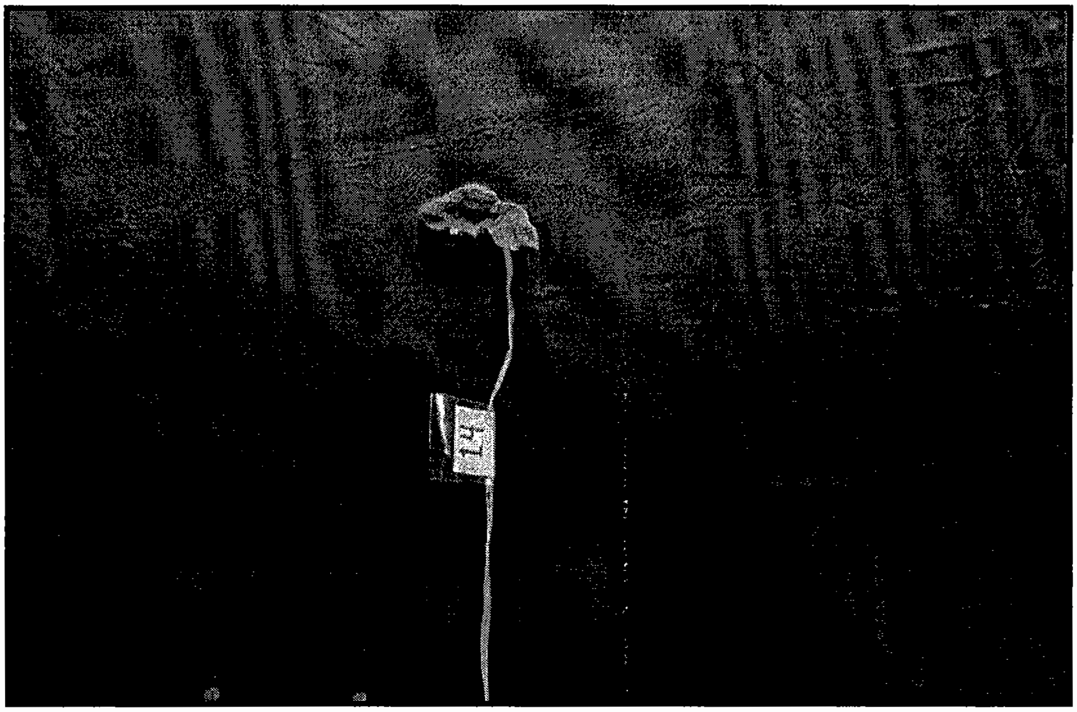


Photo 2.3
Data Logger, Laptop PC and Thermistor Probe Extension Cables

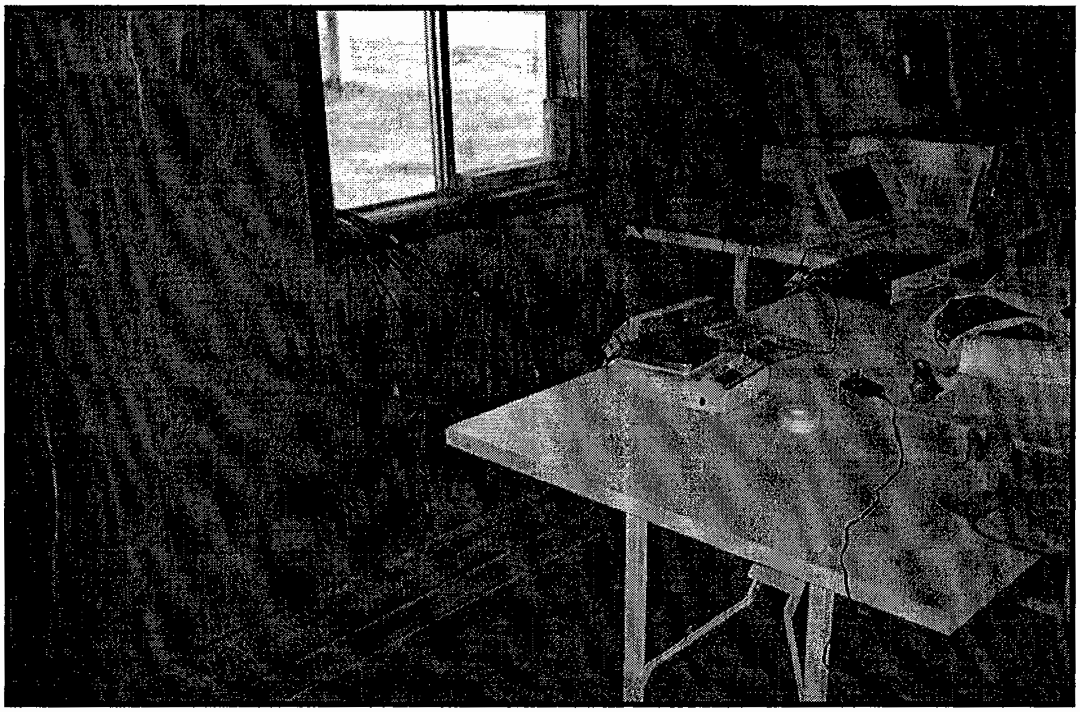


Photo 2.4
Thermistor Probes Mounted on Cold-Soaked Boxes

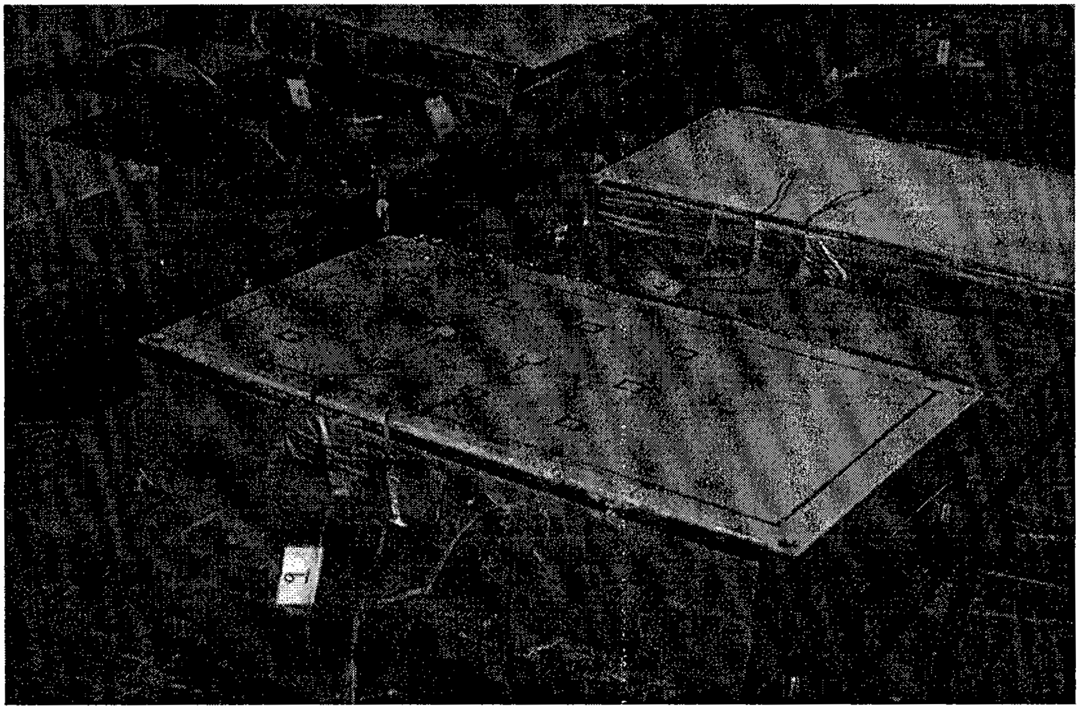


Photo 2.5
Flat Plate Stand with Six Cold-Soaked Boxes under Test

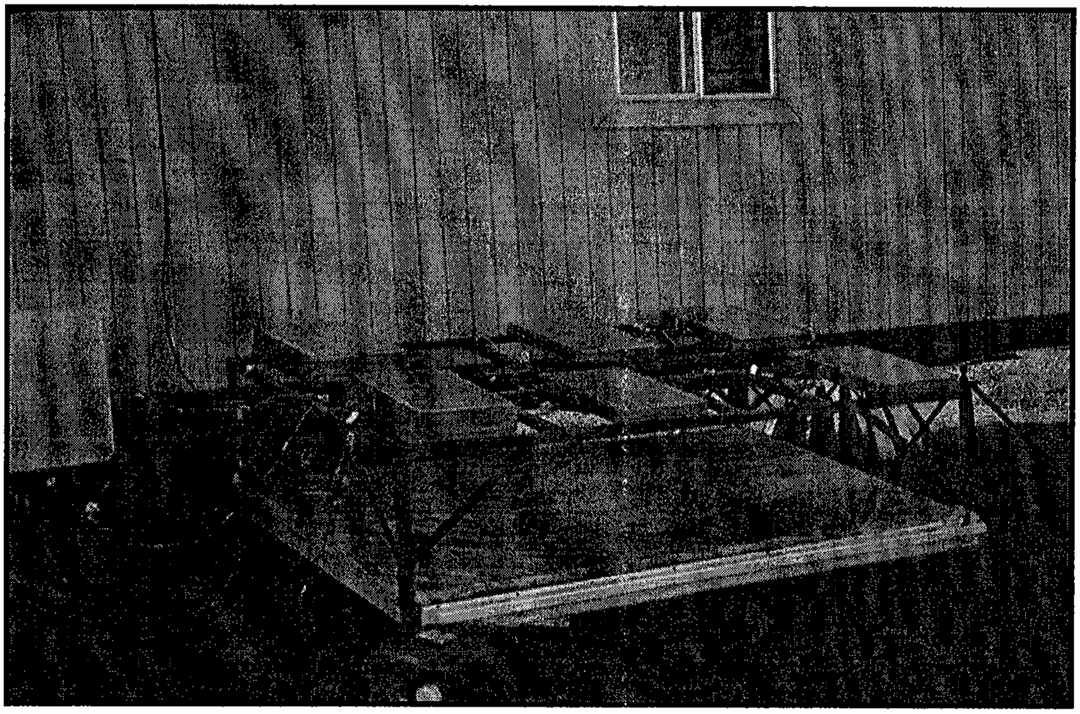


Photo 2.6
Liquid Nitrogen Bath used to Cool Glycol for Cold-Soaked Boxes at NRC Cold Chamber

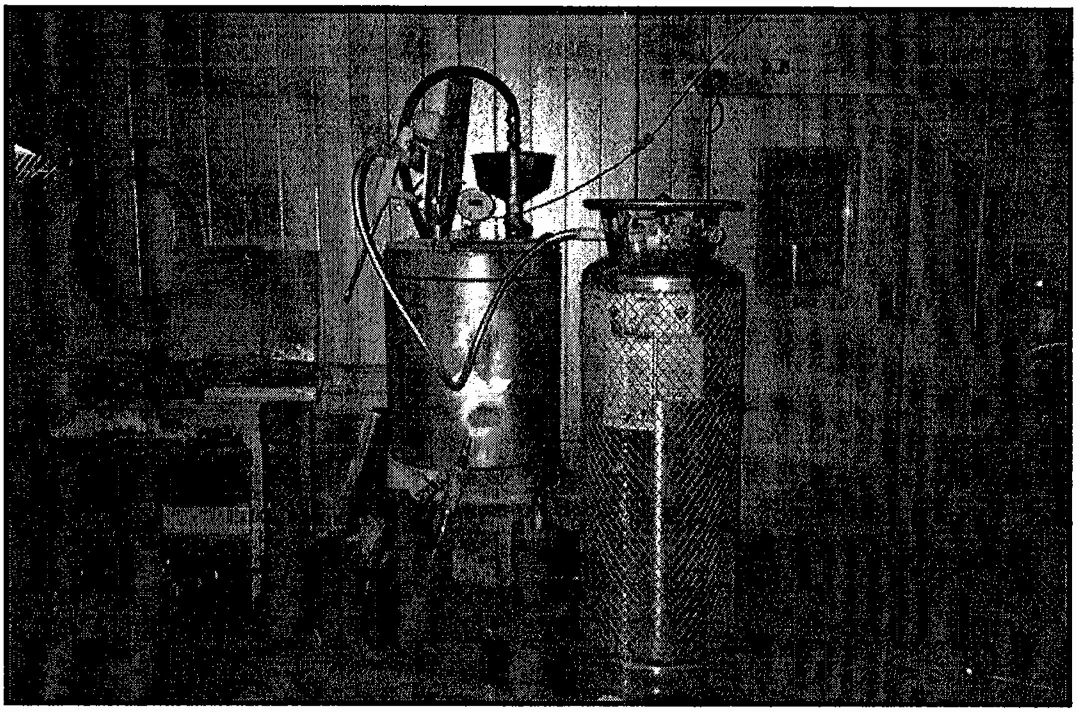


Photo 2.7
Installing Thermistor Probes on Wing of MD-80

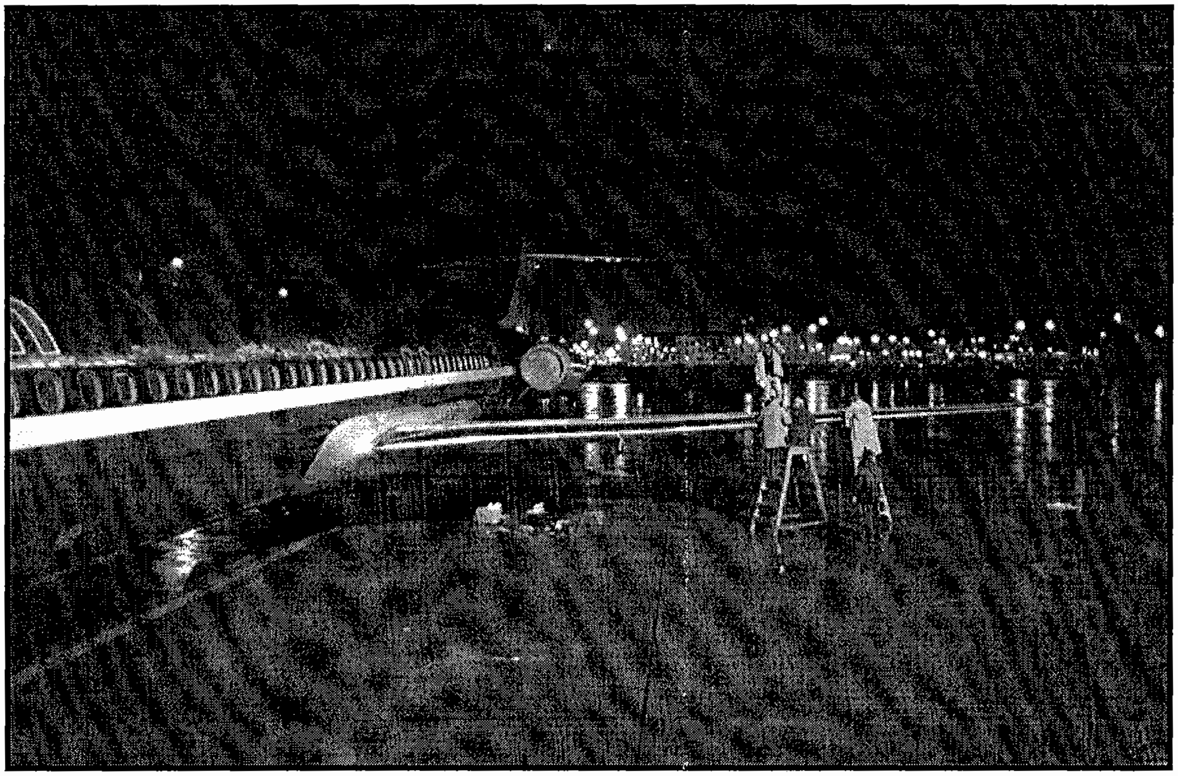


Photo 2.8
Thermistor Probe Cables and Data Logging Equipment for MD-80 Trial

Photo 2.9
Heater Blanket Installation, with Thermistor Probes Installed
American Airlines MD-80

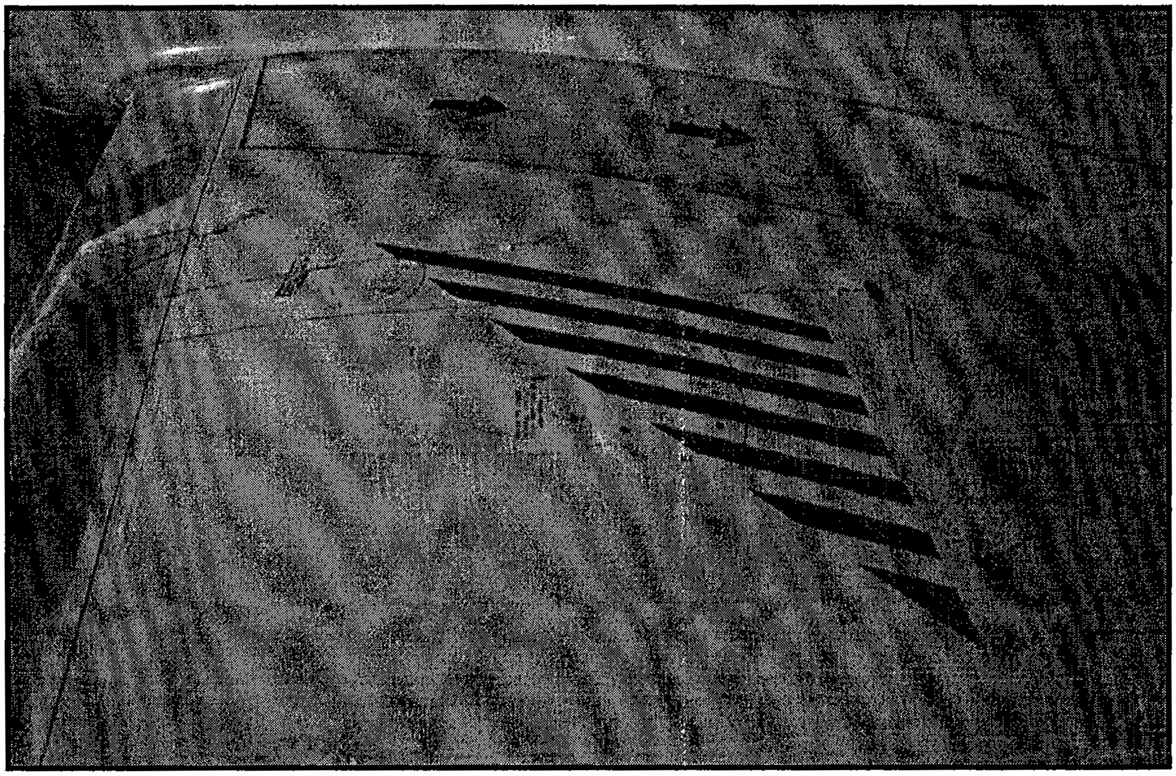
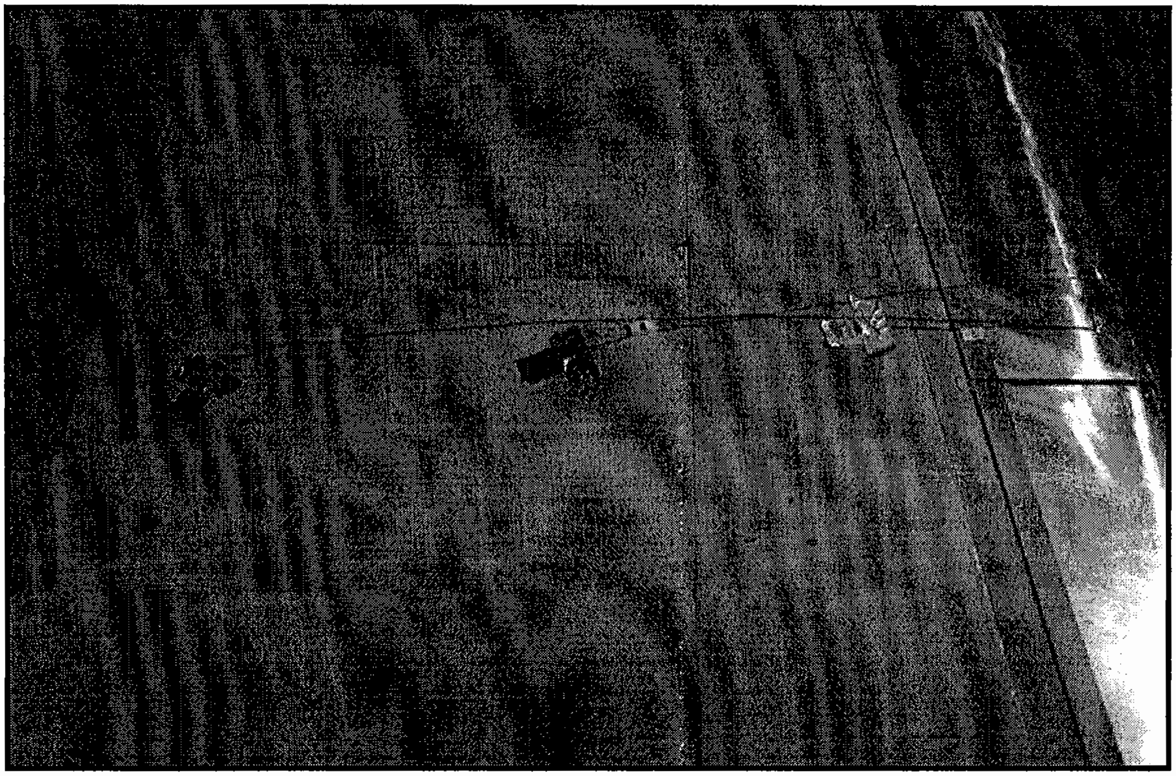


Photo 2.10
Thermistor Probe Installation
American Airlines MD-80



3. DESCRIPTION OF DATA AND OBSERVATIONS

3.1 Aircraft Trials

Preliminary tests to determine the suitability of potential full-scale test aircraft were performed upon arrival as reported in Table 3.1. A description of each trial follows.

3.1.1 Canadair RJ - Air Canada Flight 399 (April 11, 1996)

This flight operated between Washington and Montreal (Dorval). It arrived at the gate at 21:08 (9:08 pm). The duration of the flight was 92 minutes. The remaining fuel load in the wing tanks upon arrival was 2 160 kg (tanks full). The flight crew reported that the fuel temperatures registered on the aircraft instruments were -6°C at 11 6667 m (35 000 ft) and -4°C upon landing.

The outside ambient air temperature in Washington was 71°F (22°C) and in Montreal was 43.3°F (6.3°C).

Thermistor probes were immediately installed upon the aircraft's arrival at the gate. At the same time, a second team recorded wing temperatures using hand-held and pole-mounted temperature probes (see Figure 3.1).

Wing temperature measurements taken at 21:11 (three minutes after arrival at the gate), showed the skin temperatures on top of the wing at the inner end of the tank (points 1 and 2) to be 5.2 and 6.0°C, respectively. Under-wing temperature (point 14) taken at 21:25 hours was -0.5°C. The upper wing locations subsequently cooled to 2.6 and 5.2°C once the wing surface assumed steady-state heat transfer.

Installation of the thermistor probes took just under 20 minutes and logging commenced for each probe upon installation on the wing. Temperature profiles for each probe are shown in Figures 3.2 to 3.4.

TABLE 3.1

AIRCRAFT TRIALS - COLD-SOAKED WING

Airline	Aircraft Type	Airport Location	Date	Flight Duration (hrs)	Main Tank Load (kg)	OAT (°C)	Initial Wing Temp (°C)		Remarks
							Over Wing (Cold Corner)	Under Wing	
Air Canada	RJ	YUL	11 Apr, 1996	1.5	2 159**	6.3	5.2	-0.5	Halted test due to need to move aircraft
Delta Airlines	MD80	YUL	15 Apr, 1996	1.2		11.3		9.0	Cold-Soak assessment - no test
Delta Airlines	MD80	YUL	18 Apr, 1996	1.2		14.0	8.9	7.9	Cold-Soak assessment - no test
Comair	RJ	YUL	18 Apr, 1996	1.8		14.0	9.0	6.9	Cold-Soak assessment - no test
American Airlines	MD80	YUL	25 Apr, 1996	3.2	2 860	8.0	5.0	-3.0	Data logged for one hour
American Airlines	MD80	YUL	01 May, 96	1.3	2 500	12.5		0.3	Cold-Soak assessment - no test
Delta Airlines	MD80	BDL	18 Jul, 1996	2.0	3 000*	19.8	11.0	5.4	Temperature measured with hand held probe

* Wetted in cold corner

** Equivalent to full

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FIGURE 3.1

DATA FORM FOR RAIN ON COLD-SOAKED WINGS TEMPERATURE PROFILE

REMEMBER TO SYNCHRONIZE TIME

Winter 95/9

LOCATION: YUL **DATE:** 11 April, 1996 **RUN NUMBER:** AC399 **WING # :** Starboard

Initial Temperature Data with Hand-held Probes

1		2		3		4		5		6		7		8		9		10		11		12		13		14	
Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)
21:11	5.2	21:11	6.0	21:20	6.1	21:12	4.4	21:13	5.0	21:21	4.5	21:14	4.1	21:14	4.0	21:22	3.0	21:16	2.9	21:23	1.4	21:17	2.9	21:23	3.2	21:25	-0.5
21:30	2.6	21:30	5.2	21:34	5.8	21:28	4.2	21:29	5.0	21:34	4.9	21:27	4.7	21:28	4.1	21:33	3.9	21:27	3.1	21:32	2.4	21:26	3.5	21:32	3.6	21:34	-0.1

RJ

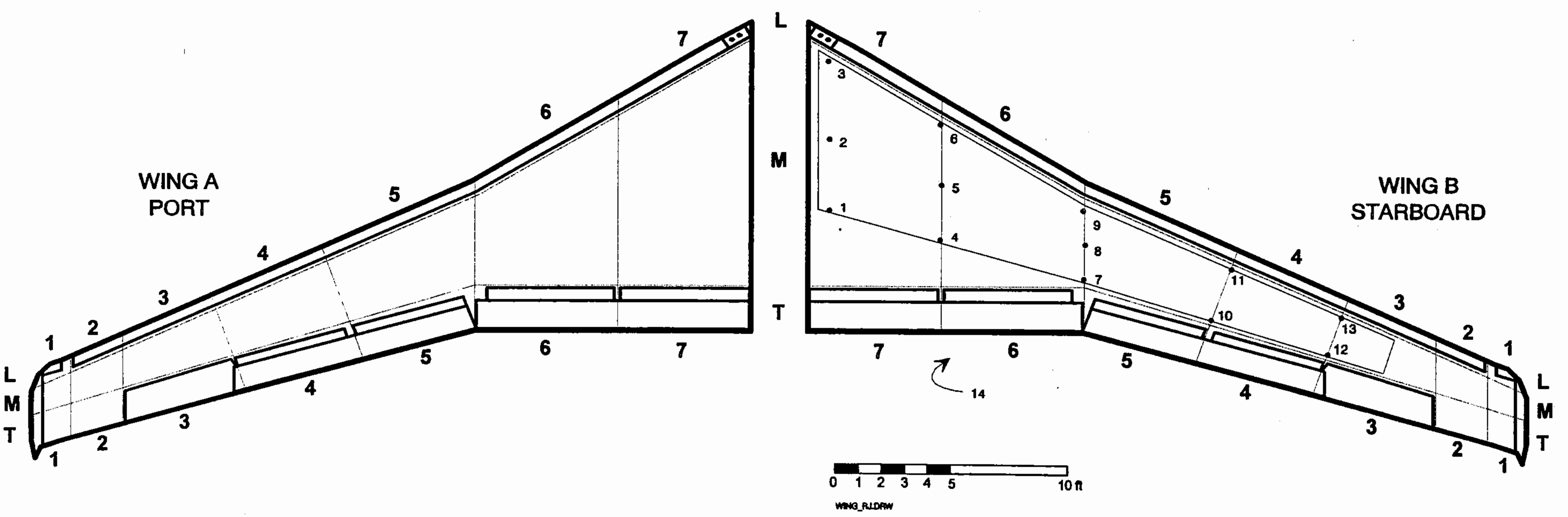

FIGURE 3.2

CANADAIR RJ COLD-SOAKED WING - TRAILING EDGE

April 11, 1996

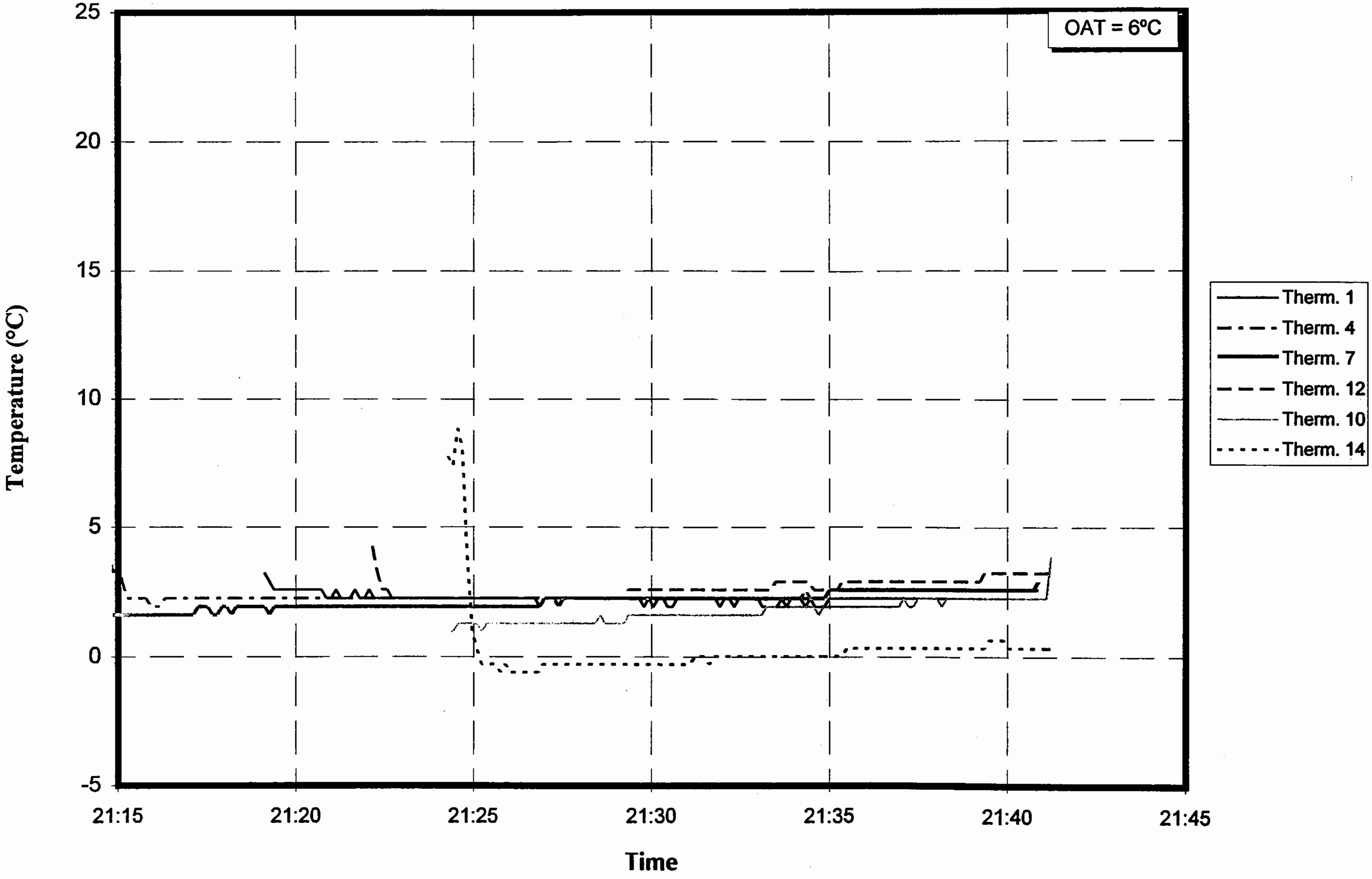

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FIGURE 3.3

CANADAIR RJ COLD-SOAKED WING - MIDDLE ROW

April 11, 1996

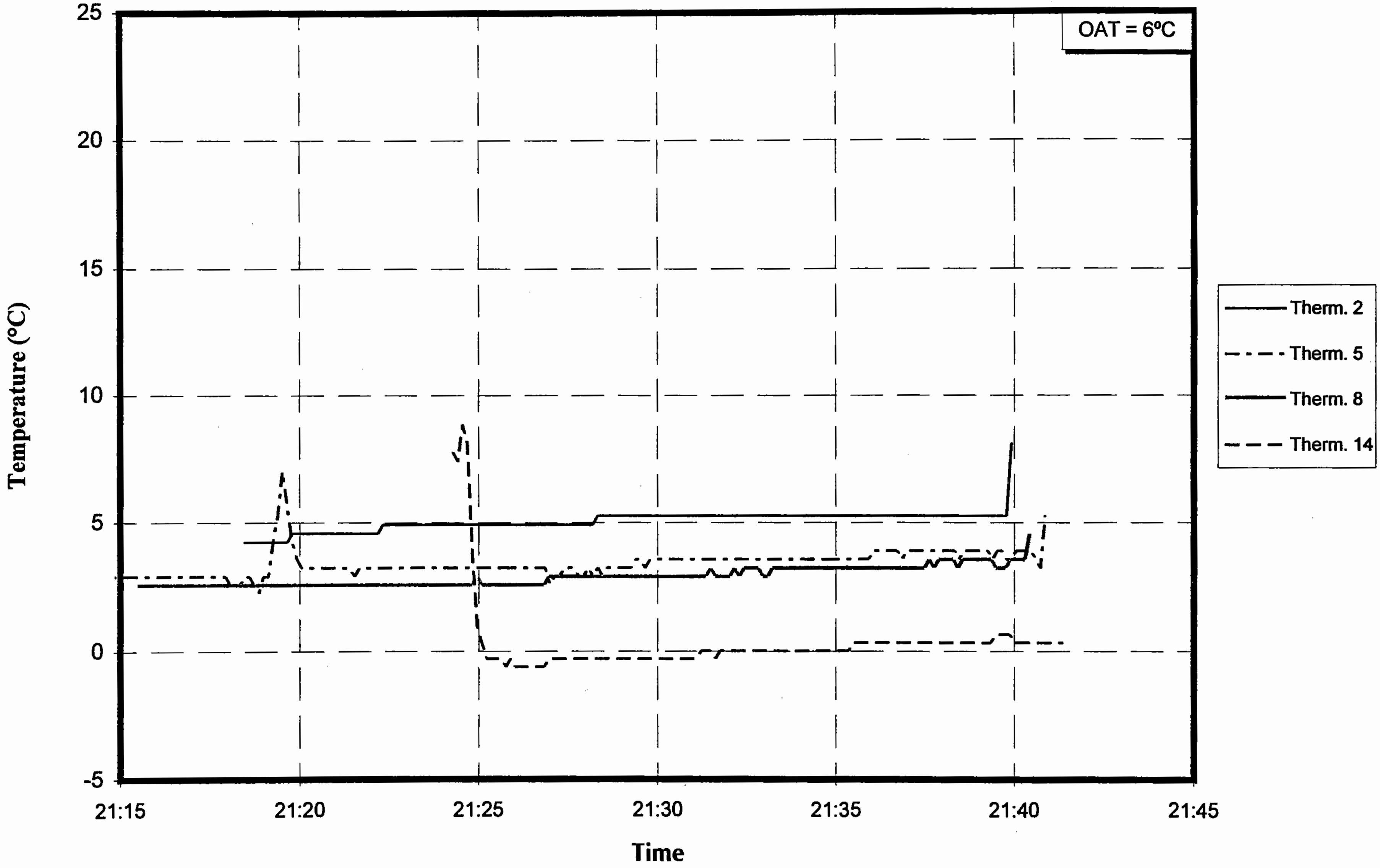

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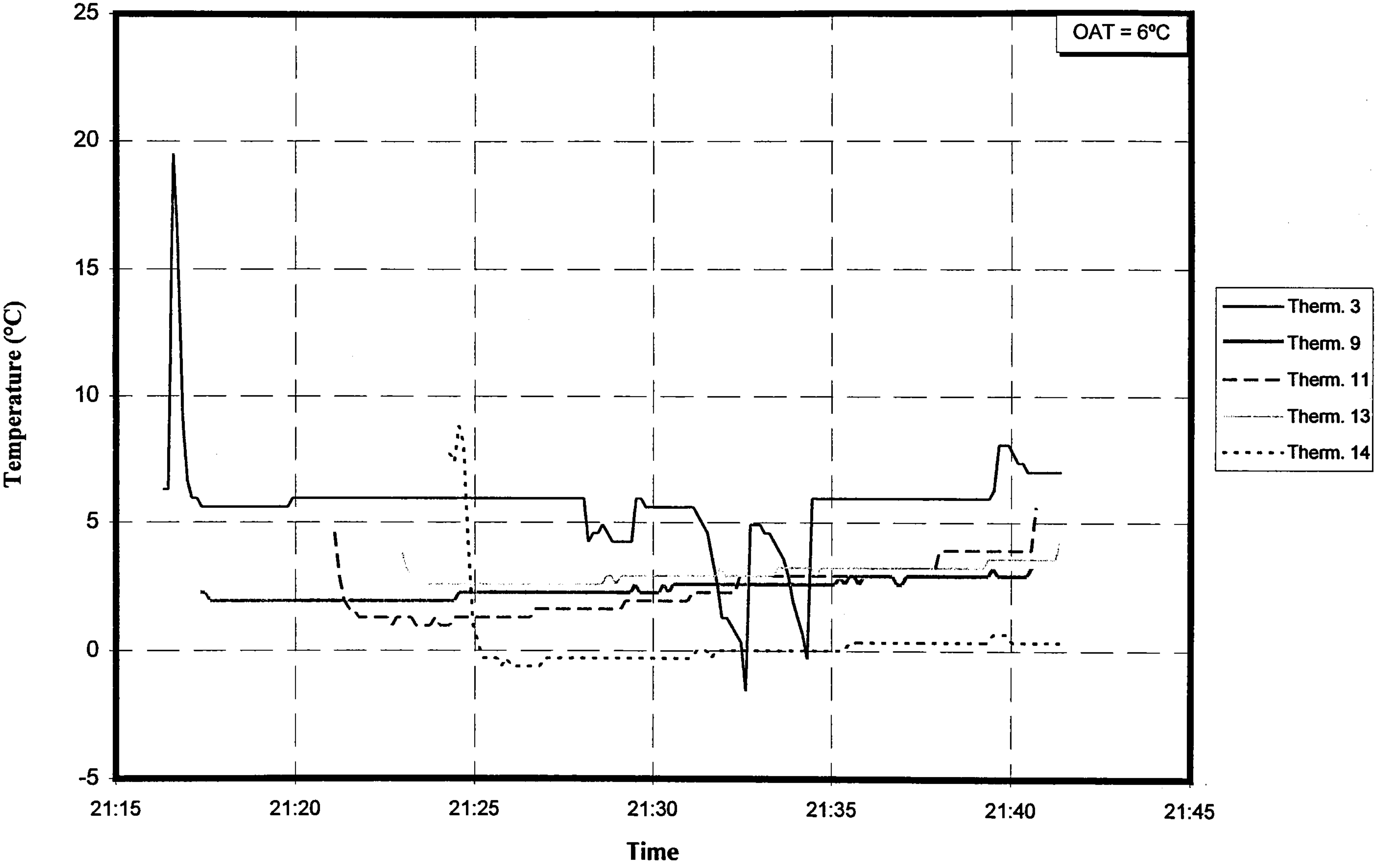
FIGURE 3.4

CANADAIR RJ COLD-SOAKED WING - LEADING EDGE

April 11, 1996



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Due to the need to relocate the aircraft to another gate, and because upper wing temperatures were already well above zero, recording was terminated at 21:42 hours, 34 minutes after arrival.

3.1.2 MD-80 - Delta Airlines (April 15 & 18, 1996)

Discussions with Delta Airlines identified that MD-80 flights arriving at Dorval Airport from Boston were potential subjects for cold-soak tests, and preliminary tests were conducted to measure wing temperatures upon arrival. The bottom wing surface temperatures were measured as an estimate of the fuel temperature, and the upper wing surface temperatures were measured at the cold point of the fuel tank (inner end, rear corner).

On two separate occasions (April 15 and April 18, 1996) MD-80 flights from Boston to Montreal were met by APS test personnel. The following temperatures were recorded:

15 April
Local outside ambient air temperature; 11.3°C.
Bottom wing surface temperature; 9°C.

18 April
Local outside ambient air temperature; 14°C.
Bottom wing surface temperature; 6.9°C.
Top wing surface temperature; 9.0°C.

Also, on April 18, a Canadair RJ arriving from Cincinnati (1.8 hours duration) was met;

Local outside ambient air temperature; 14°C.

Bottom wing surface temperature; 7.9°C.

Top wing surface temperature; 8.9°C.

Based on these measurements it was decided to seek a flight with longer inbound duration to produce cold-soak temperatures suitable for testing.

3.1.3 MD-80 - American Airlines Flight 479 (April 25, 1996)

This flight operated between Miami and Dorval, arriving at 23:09 after a flight duration of 3 hours 13 minutes. The fuel local in the wing tanks upon arrival was 2 860 kg, just under the 2 943 kg (at which wetting of the upper surfaces starts). Full passenger loads along with the cargo payload limited carriage of additional fuel. A one-hour delay at departure was experienced at Miami. The flight crew reported that outside air temperature en route was -46°C at 11 000 m (33 000 ft). The outside air temperature upon arrival was 8.0°C.

This aircraft was equipped with an electric heating blanket installed over the inner end of the main fuel tank, as can be seen in Photo 2.9, and as indicated in Figure 3.5. The flight crew reported that the heating blanket was not used en route. American Airlines MD-80 aircraft are equipped with self-operating fuel management system to counter cold-soaking of fuel en route. The system could not be de-activated for test purposes.

Thermistor probes were immediately installed upon arrival at the gate. Manual recording was not conducted for this test as full attention was given to thermistor probe installation and subsequent data recording.

On arrival, the underside of the wing had a layer of frost, which progressively thickened with time. The first measured temperature of the underside at about 23:20 indicated -3°C. The top of the wing did not experience any frost throughout the test

FIGURE 3.5

WING PLAN FORM SHOWING HEATER BLANKET INSTALLATION

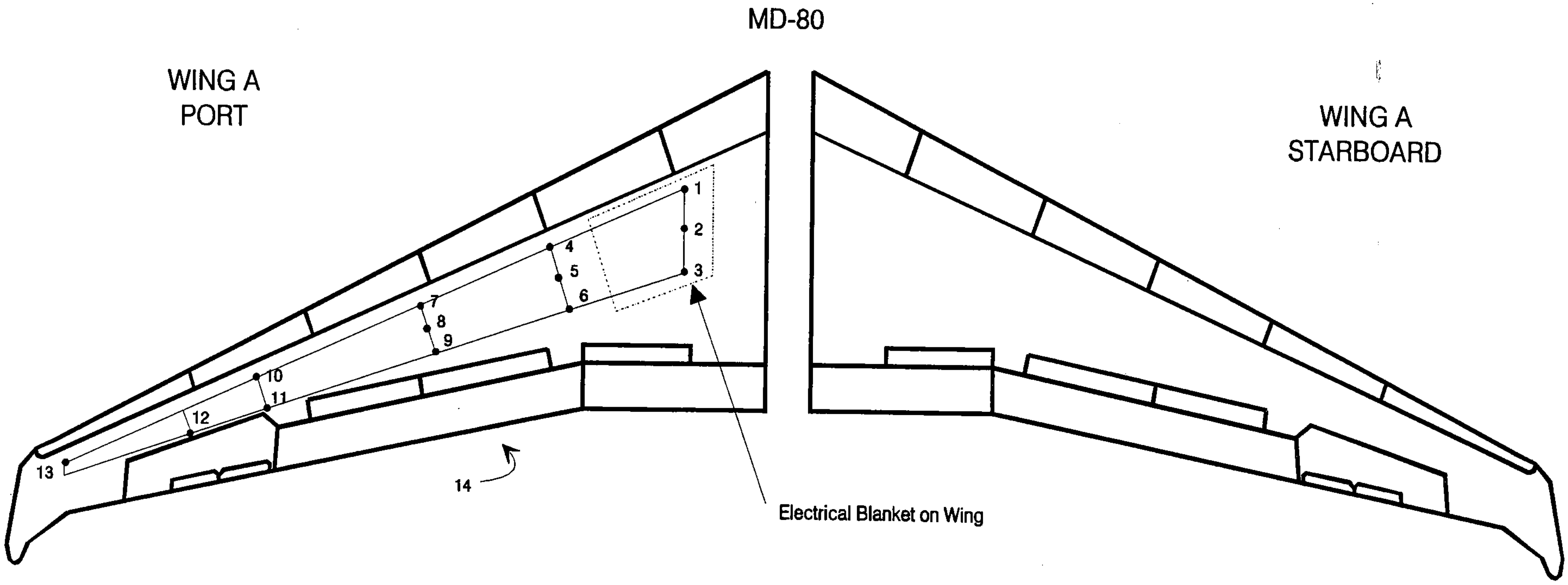
REMEMBER TO SYNCHRONIZE TIME

Winter 95/96

LOCATION: YUL **DATE:** **FLIGHT NUMBER:** **WING # :**

Initial Temperature Data with Hand-held Probes

1		2		3		4		5		6		7		8		9		10		11		12		13		14	
Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)



File: g:/cm1283/report/coldsoak/MD8_WPLN.XLS Printed: 29/07/97 but did experience condensation. The lowest temperature on the upper surface was +3 °C measured at position 6 (Figure 3.5) located at the rear of the fuel tank just outside the blanketed area.

Temperature profiles for each probe are shown in Figures 3.6 to 3.8. Thermal time constant values were calculated for probe locations 4, 5, and 6 as these were outside the area blanketed by the heating unit. The average time constant value for these points was 27 000 seconds.

The test was terminated after about one hour at which point the wing was not considered to be cold-soaked.

3.1.4 MD-80 - American Airlines Flight 1634 (May 1, 1996)

This flight operated from Los Angeles via Chicago to Montreal. The flight duration on the last 80-minute leg of the journey identified this craft as a potential test. Its pay load status allowed for higher fuel loads to be carried.

A preliminary test was conducted to measure wing temperatures on arrival. Bottom wing surface temperatures were measured as an estimate of the fuel temperature. Top wing surface temperatures were not measured.

May 1
Local ambient air temperature; 12.5 °C.
Bottom wing surface temperature; 0.3 °C.

Fuel loads in the main tanks were 2 500 kg (insufficient to wet the upper surface). The heating blanket had been used briefly during descent, and turned off upon landing.

FIGURE 3.6

MD-80 COLD-SOAKED WING - LEADING EDGE

April 25, 1996

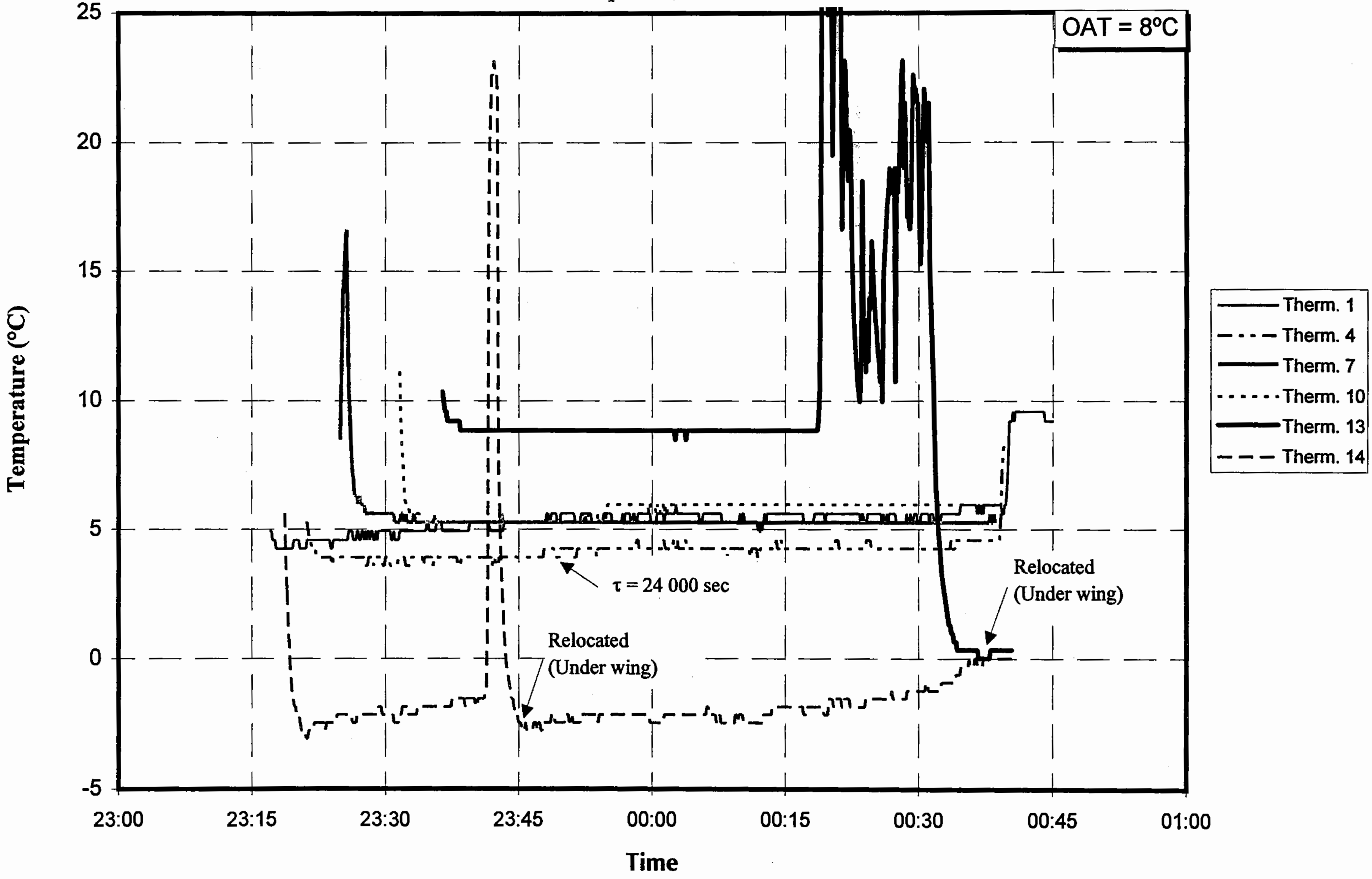


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FIGURE 3.7

MD-80 COLD-SOAKED WING - MIDDLE ROW

April 25, 1996

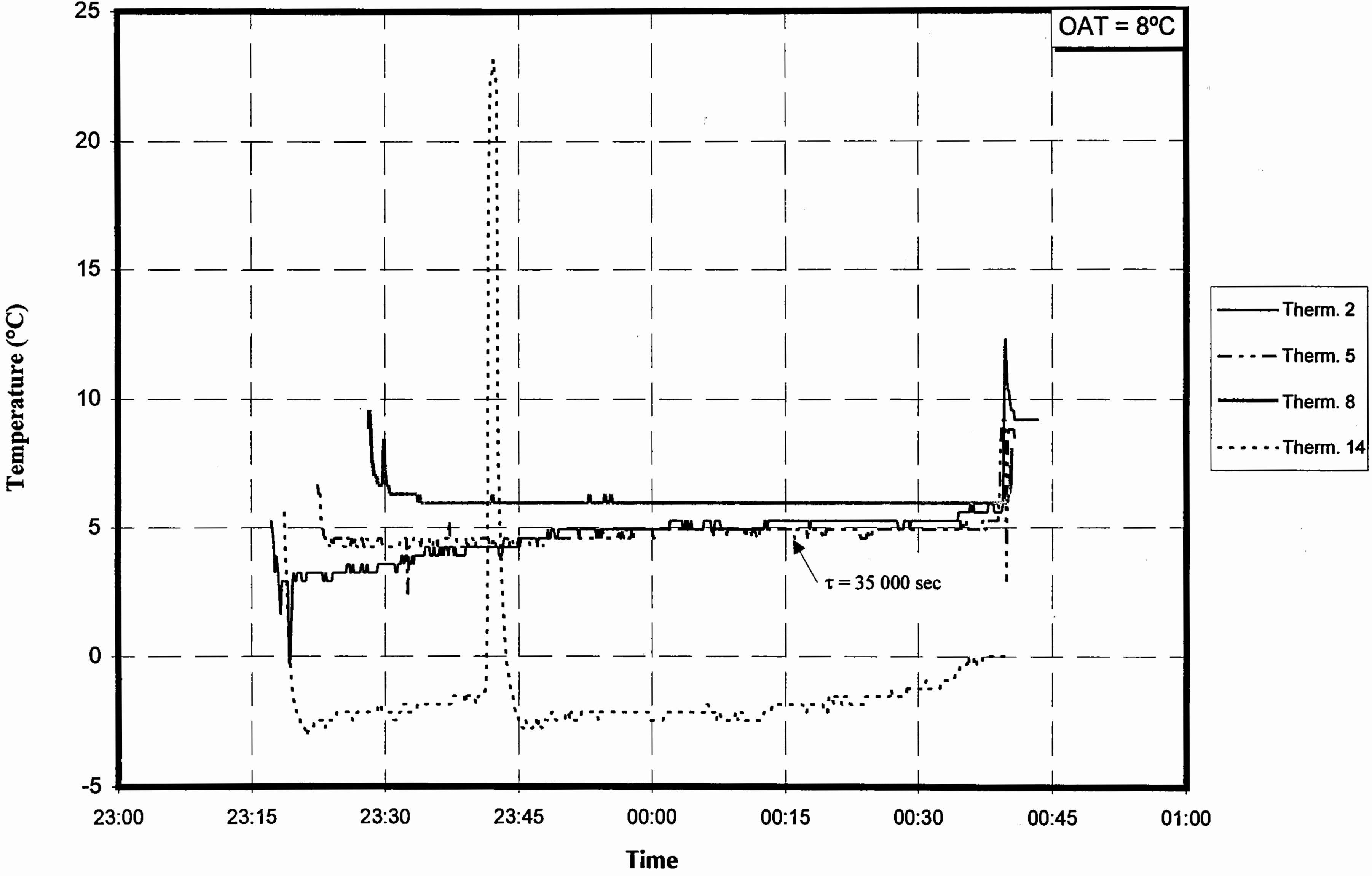

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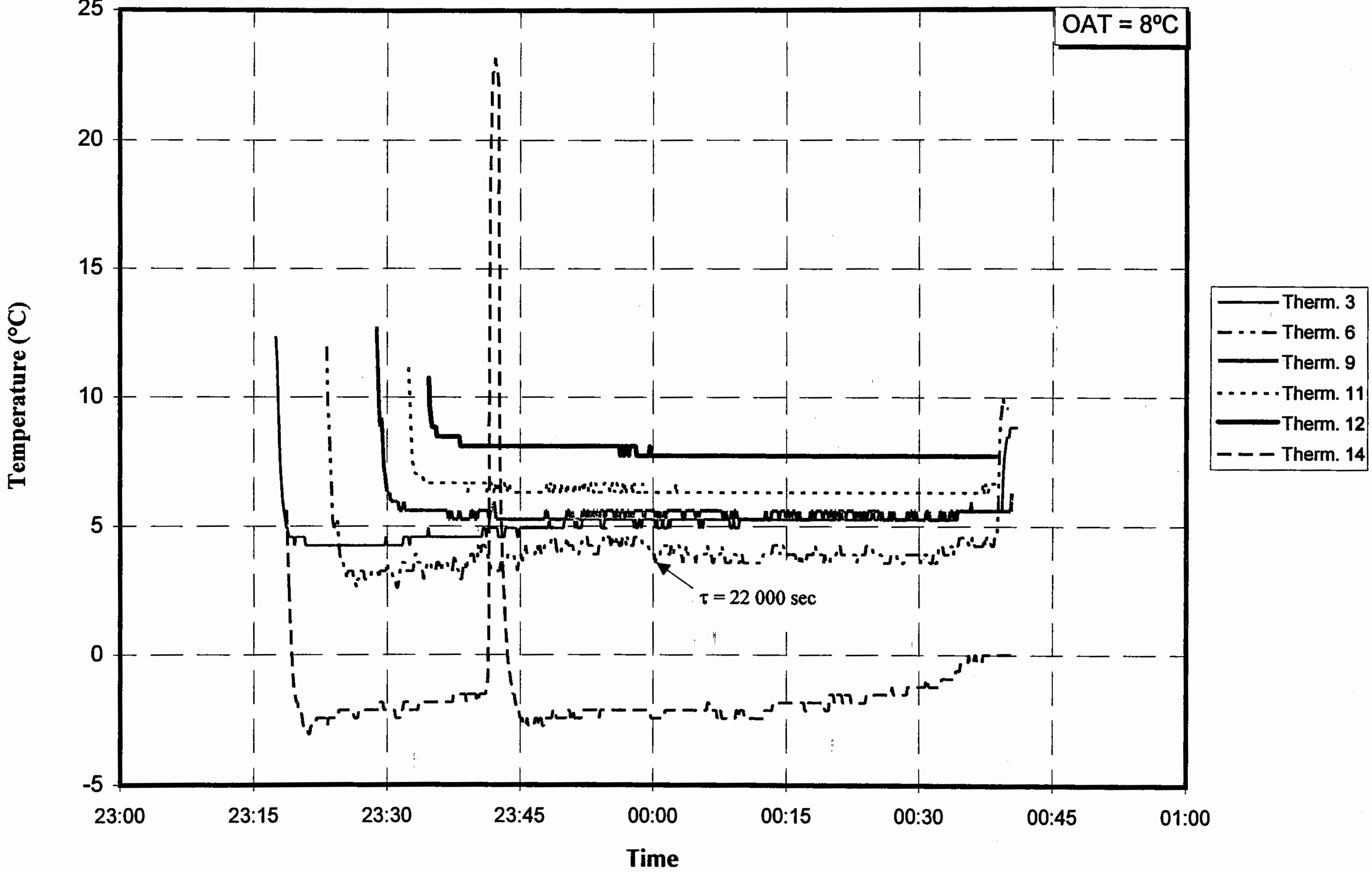
FIGURE 3.8

MD-80 COLD-SOAKED WING - TRAILING EDGE

April 25, 1996



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3.1.5 MD-80 - Delta Airlines Flight 1582 (July 17/18, 1996)

This flight which terminated Bradley International Airport (Hartford, Connecticut) was selected as a potential test subject based on the following factors: flight duration (inbound flight leg two hours); ability of the Delta operation to suspend their alternate fuel burn program for the flight; ability to carry additional fuel to cause wetting of the wing on arrival; and absence of heating blankets on Delta aircraft (which reduce heat exchange from wing surfaces). The size of the operation at Bradley was conducive to uncomplicated arrangements for access to the operation and testing.

A preliminary check was conducted to determine wing temperatures on arrival, with a plan to conduct a full-scale test with full test crew if appropriate.

The test flight arrived at 00:23 on July 18, 1996 following a flight of two-hours duration from Atlanta. Temperature measurements on the top wing surface at the inner end of the main fuel tank and bottom wing surface commenced on arrival and continued for about one hour (Figure 3.9). The lowest top wing surface temperature, at the cold corner of the wing, was measured to be 11.0°C and the initial bottom wing surface temperature recorded was 5.4°C.

The outside air temperature was 20°C giving a 9 degree temperature differential between the upper wing and ambient.

The flight crew reported en route fuel temperature of 6 to 7°C at altitude of 11 000 m (33 000 ft). Alternate fuel burn was not employed en route. Main tank fuel loads on arrival were 3 000 kg, slightly over the limit where fuel wetting of the upper surface begins. It was learned that a temporary embargo on fuel tankering instituted by Delta prevented additional fuel from being boarded. Time constant values based on this data for the "cold corners" (location 3) averaged 26 500 seconds.

FIGURE 3.9

DATA FORM FOR RAIN ON COLD-SOAKED WINGS TEMPERATURE PROFILE

REMEMBER TO SYNCHRONIZE TIME

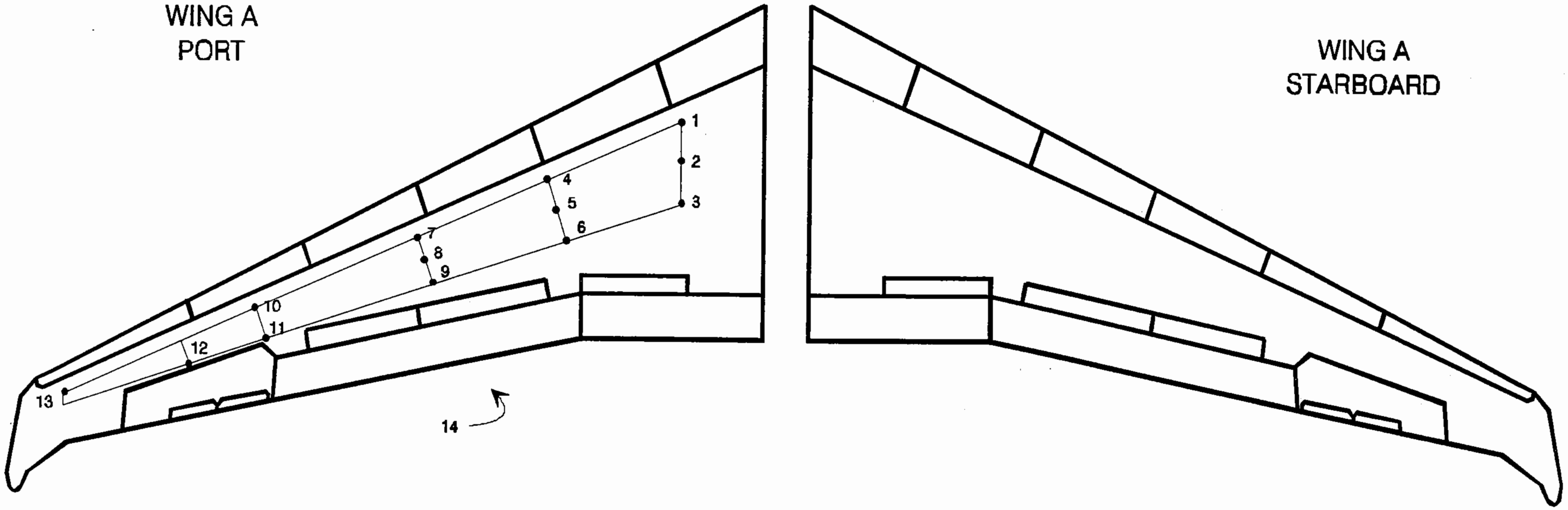
Winter 95/96

LOCATION: BDL **DATE:** 17-18 July 1996 **FLIGHT NUMBER:** 1582 / 17 Jul, 1996 **WING # :**

Initial Temperature Data with Hand-held Probes

	1		2		3		4		5		6		7		8		9		10		11		12		13		14	
	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)
PORT	00:29	13.0		12.2		11.0		17.0		12.3		11.0															00:27	5.4
	00:41	14.4		13.2		11.9	00:45	13.4		13.9		12.3															00:48	6.1
	01:09	13.7		13.8		12.2	01:11	12.8		14.0		12.5															01:13	6.3
	01:33	13.2		13.8		12.5	01:35	13.3		14.6		12.5															01:32	7.1
STBD	00:52			13.4		11.1	00:53	13.4		14.3		12.5															00:50	6.6
	01:16			13.4		11.5	01:17	13.7		14.6		12.5															01:14	6.8
	01:39			13.3		11.9	01:40	13.5		14.0		12.9															01:37	7.9

MD-80



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Based on observed wing temperatures and the temporary embargo on tankering extra fuel, it was decided to not proceed with a full-scale test.

3.2 Data from McDonnell Douglas Wing Clear Ice Trials; October 1989, Anchorage, Alaska

McDonnell Douglas conducted a series of trials in 1989 designed to quantify the causes of wing clear icing and to evaluate proposed solutions. An MD-80 aircraft was modified for the test with thermocouples installed at a number of locations on the wing skin and at locations immersed in the fuel within the tanks. Temperature data were logged for each thermocouple location during tests which included both flight and ground phases. Other data logged included flight parameters.

Data from the ground phase of the test (after arrival) included the fuel load, temperature, and ambient weather conditions. Comments were recorded regarding formation of ice in each case.

Trials were conducted using Anchorage Alaska as a base. These flights terminated at various airports in Alaska where suitable temperature and precipitation conditions to cause clear ice to form were sought. Various schemes to counter cold-soaking of fuel were tested.

The data logged during the ground phase of the trials were of interest to this study as it corresponded to the conditions sought for APS aircraft trials. It was considered to be an excellent potential source of supplemental data to determine wing temperature profiles during cold-soaked conditions.

Discussions with McDonnell Douglas led to provision of test data to be used as appropriate for the purposes of this study. Table 3.2 provides a summary of all the flight tests performed by McDonnell Douglas in this series.

TABLE 3.2

SUMMARY OF FLIGHT TESTS

McDONNELL DOUGLAS, OCTOBER 1989

Flight #	**Date**	**Flight Duration (hr:min)**	**Fuel Quantity (lbs)**		**Comments (Temp/dew (°F), Location, etc)**
			Mains	**Centre**	
46	10-18	2:05			Checkout flight, Yuma
47	10-19	5:05	2 750 / 2 750	50	Ferry, Yuma - Anchorage
48	10-20	1:25	9 750 / 9 600	10 800	31°F, Anc - Anc
49	10-21	1:50	6 100 / 6 100	8 750	45/39, Anc-Juneau
50	10-21	2:55	5 150 / 5 150	3 950	33/13, Jun-Anc, Xfer
51	10-22	3:05	9 850 / 9 850	1 400	43/34, Anc-Jun, Heating
52	10-22	1:45	3 500 / 3 500	850	24/13, Jun-Anc
53	10-23	3:55	9 450 / 9 450	0	45/29, Anc-Cold Bay, Xfer
54	10-23	1:15	9 600 / 9 750	2 900	27/26, CBD-Anc
55	10-25	4:55	6 200 / 6 300	5 550	39/39, Anc-Sitka
56	10-25	1:35	9 700 / 9 800	2 400	29/17, Sit-Anc, Heating
57	10-26	2:30	7 850 / 7 850	14 550	36/30, Anc-Kodiak, Drizzle, Mod icing
58	10-26	0:35	4 250 / 4 100	14 850	Kod-Anc, ferry
59	10-27	2:25	9 850 / 9 850	3 750	37/32, anc-Cordova, Drizzle, Mod icing
60	10-27	0:30	9 700 / 9 600	3 200	Cdv-Anc, Ferry
61	10-28	2:45	7 550 / 7 450	7 550	40/39, Anc-Cdv, Rain, Heavy ice, Transfer
62	10-28	1:30	5 850 / 5 850	5 900	31/30, Cdv-Anc

Source: McDonnell Douglas

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A wing plan showing detailed locations of each thermocouple installation was provided which enabled selection of those locations (on the top and bottom wing surfaces) that corresponded to APS test requirements. All points selected for measurements were located at the inner end of the main fuel tank (Figure 3.10).

Printed data sheets for each test included progressive temperature values for each datum point logged against clock time at five-minute intervals. Wing surface temperature values typically changed very rapidly during and immediately following the landing phase, and these data were excluded from consideration. This period of instability is illustrated in Figure 3.11 which charts wing skin temperature values during the different phases of the flight (in flight, landing, and on ground). Wing skin temperature can be seen to progressively cool during the flight phase, warm rapidly during landing, and then recool a lesser degree following landing (effect of cold fuel in tanks). After a period, (in this case about 15 minutes) a state of thermal equilibrium is reached following which the wing surface temperature progressively warms under the influence of warmer outside air temperature.

The latter stage is the period of interest for this study. A range of data was selected for the ground phase of the operation commencing at the time that wing surface temperature values reached a state of equilibrium, and continuing to the time when the provided test description indicated that external influences (test routines) were to be applied, or to the end of reported data.

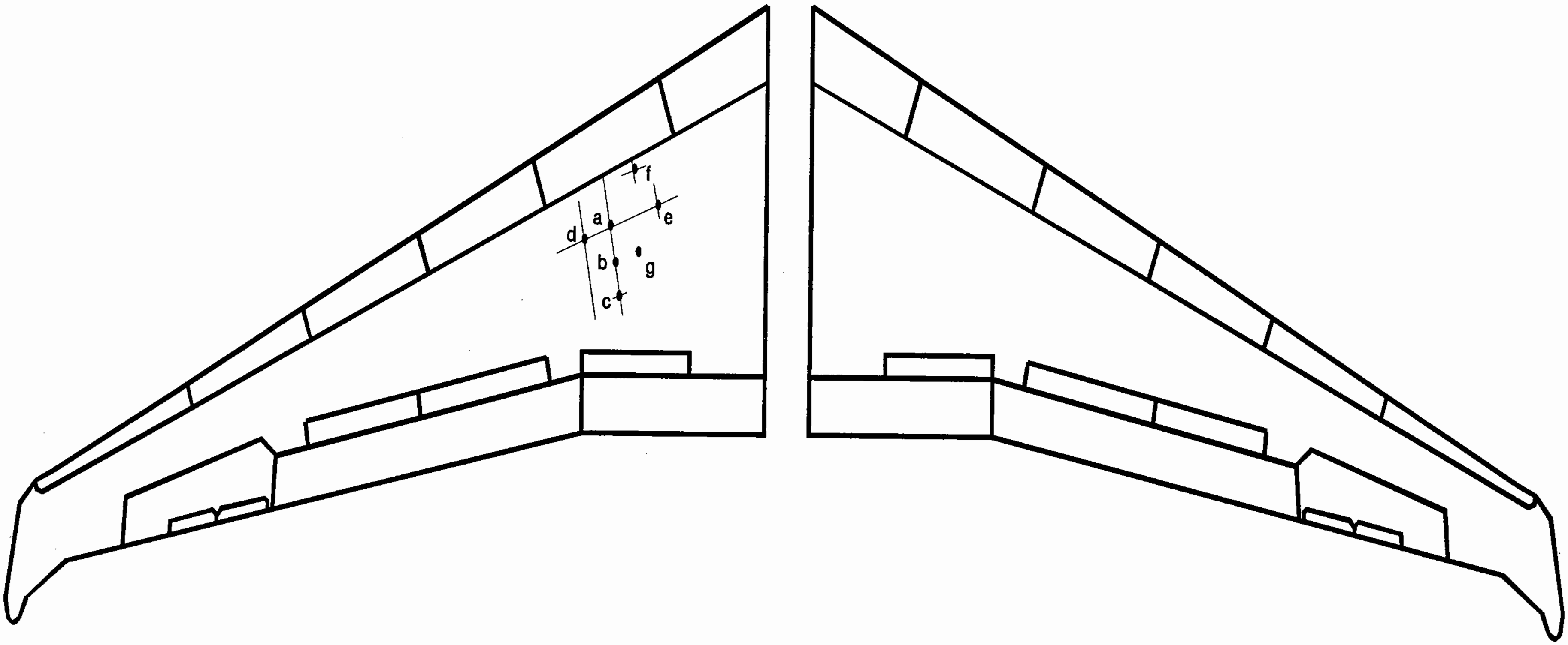
Selection of either the port or the starboard wing was guided by the planned tests descriptions provided by McDonnell Douglas.

Temperature data for thermocouple locations of interest were retrieved for the test period selected, and entered into a PC spread sheet for analysis. As was the case for APS aircraft and cold-soaked box data analysis, this involved plotting the data to present temperature profile curves as well as calculating thermal time constant values for each location.

FIGURE 3.10

THERMOCOUPLE LOCATIONS ON MD-80 WING

McDONNELL DOUGLAS WING CLEAR ICE TRIALS



a) 281 470
b) 281 471
c) 281 472
d) 281 473
e) 281 474
f) 281 475
g) 281 444

Source: McDonnell Douglas

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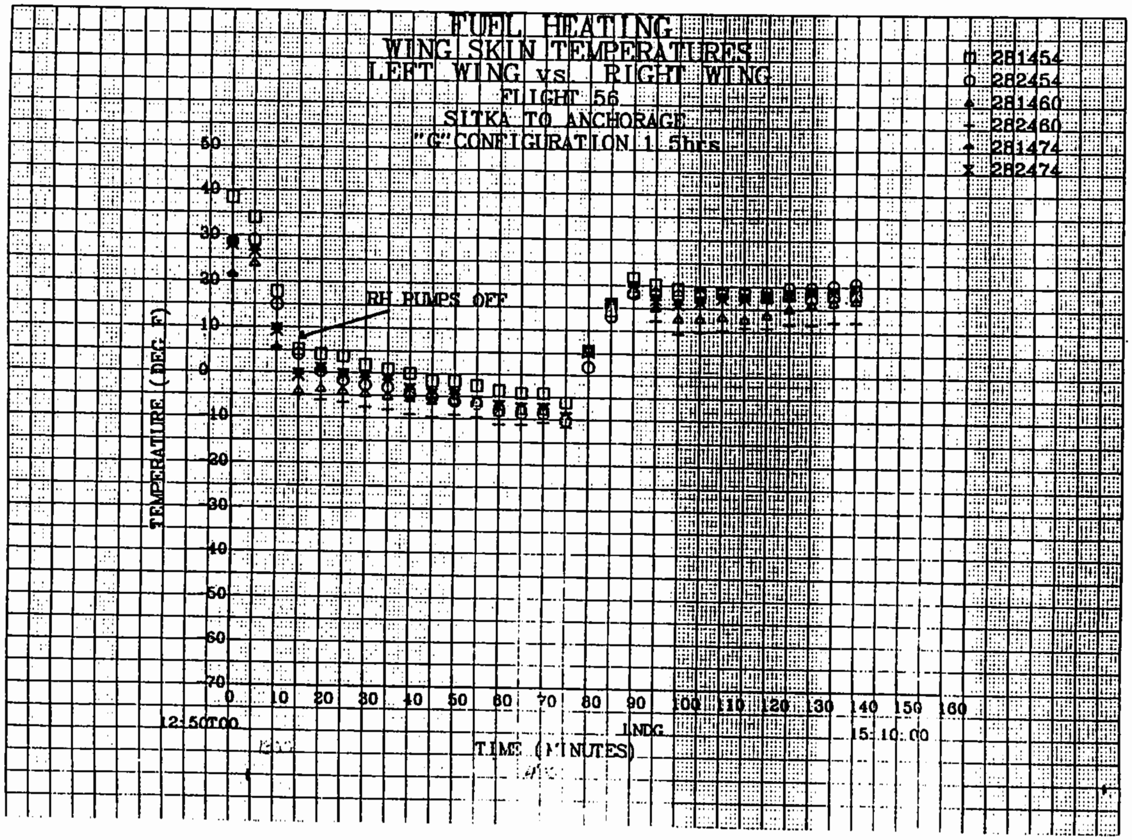
FIGURE 3.11

TEMPERATURE PROFILE FOR MD-80 FLIGHT



SOURCE: McDONNELL DOUGLAS

On examination it was seen that not all trial data were suitable for inclusion in this study. This is due primarily to the influence on wing temperatures of the different fuel temperature maintenance schemes being evaluated. Ultimately, three trials were judged to be appropriate for inclusion, referred to in Table 3.2 as Flight numbers 55, 56 and 59.

3.2.1 McDonnell Douglas Cold-Soaked Trials Selected for Supplemental Data

Figures 3.12 to 3.14 present temperature data for selected points on the wing surface.

These charts plot the temperature at each thermocouple location as a function of time. The chart header shows fuel on board and ambient temperature. (Figure 3.12 has fewer measurement locations shown as two points of interest were not included in the data base).

The results from trial data are listed in Table 3.3.

TABLE 3.3

SELECTED MCDONNELL DOUGLAS COLD-SOAK TEST RESULTS

Flt #	**Ambient Temp. (°C)**	**Fuel (kg)**	**Precipitation**	**Initial Wing Temp.* (°C)**	**Time Constant (seconds)**	**Comment**
55	3.9	2 820	Dry	-7.4	1,400	Upper surface not wetted
56	-1.7	4 410	Dry	-8.4	15,400	Full tank, wing completely wetted
59	2.8	4 480	Drizzle	-11.8	4,000	Full tank, wing completely wetted, clear ice formed

---

* At location 28X471, initial temperature value in range of data selected.

FIGURE 3.12

FLIGHT 55 WING SKIN TEMPERATURE - OCTOBER 25, 1989

FUEL: Main 2818/2864 kg, Centre 2523 kg

OAT= 3.9 °C

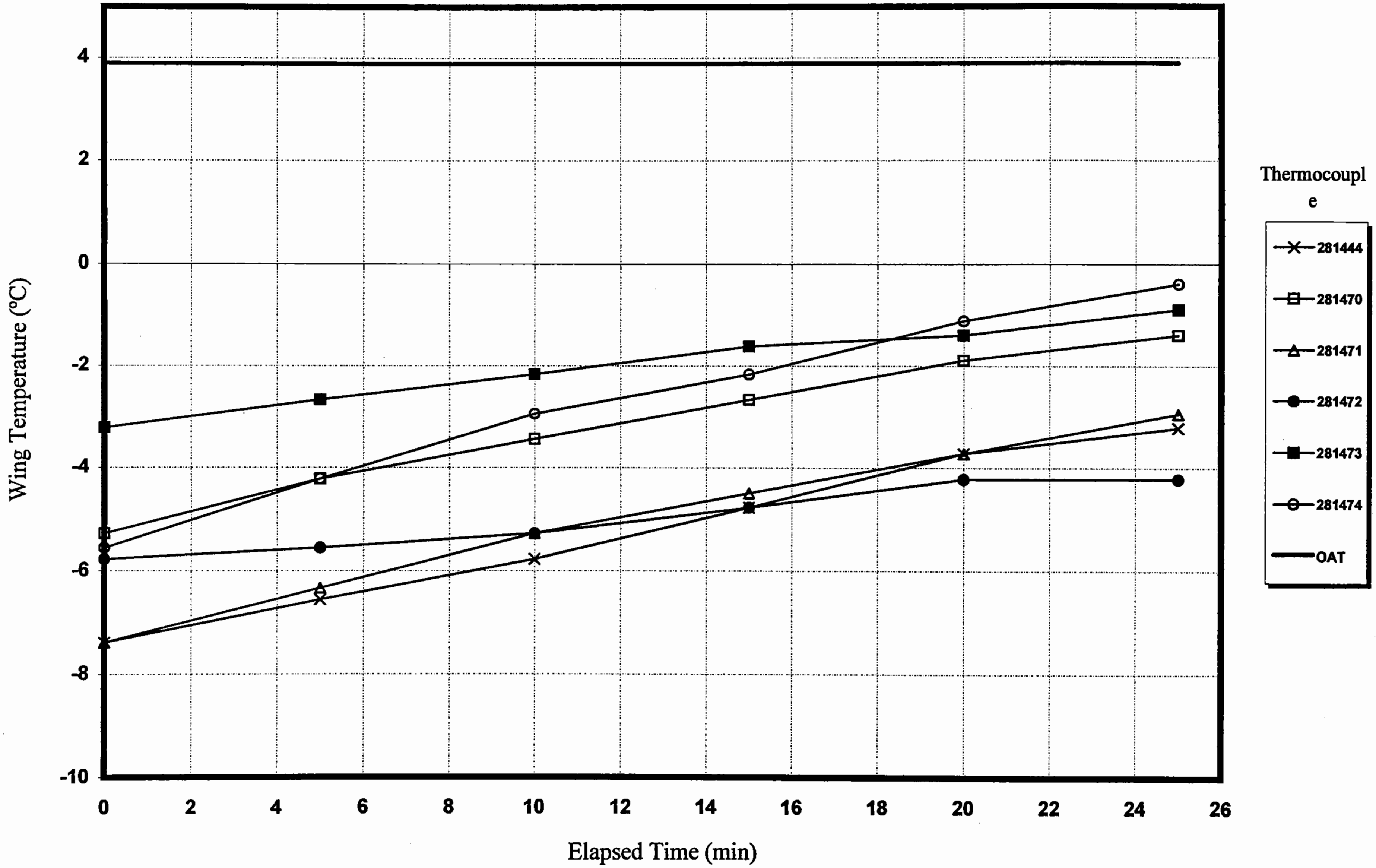


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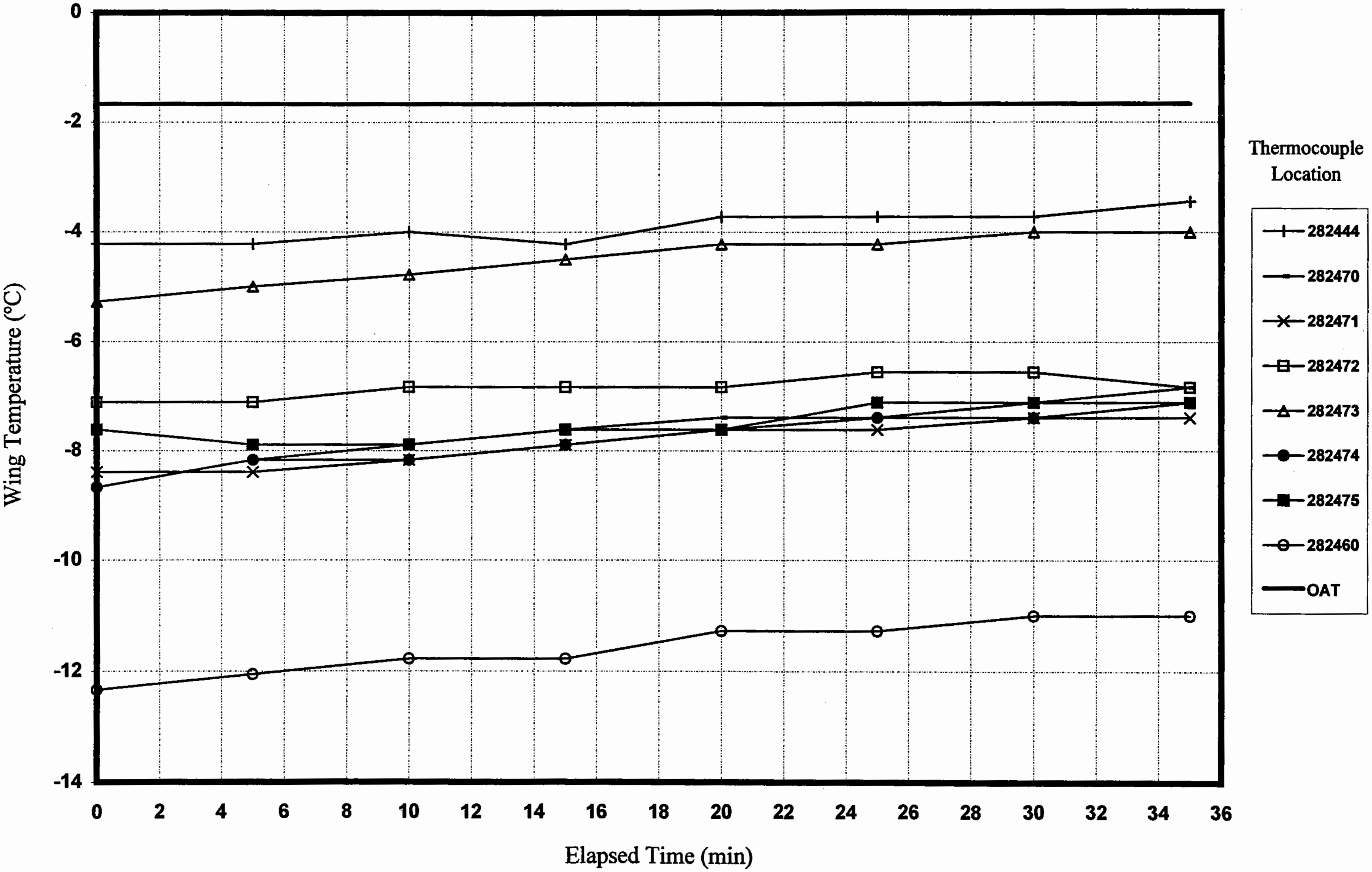
FIGURE 3.13

FLIGHT 56 WING SKIN TEMPERATURE - OCTOBER 25, 1989

FUEL: Main 4410/4455 kg, Centre 1090 kg

OAT= -1.7 ºC



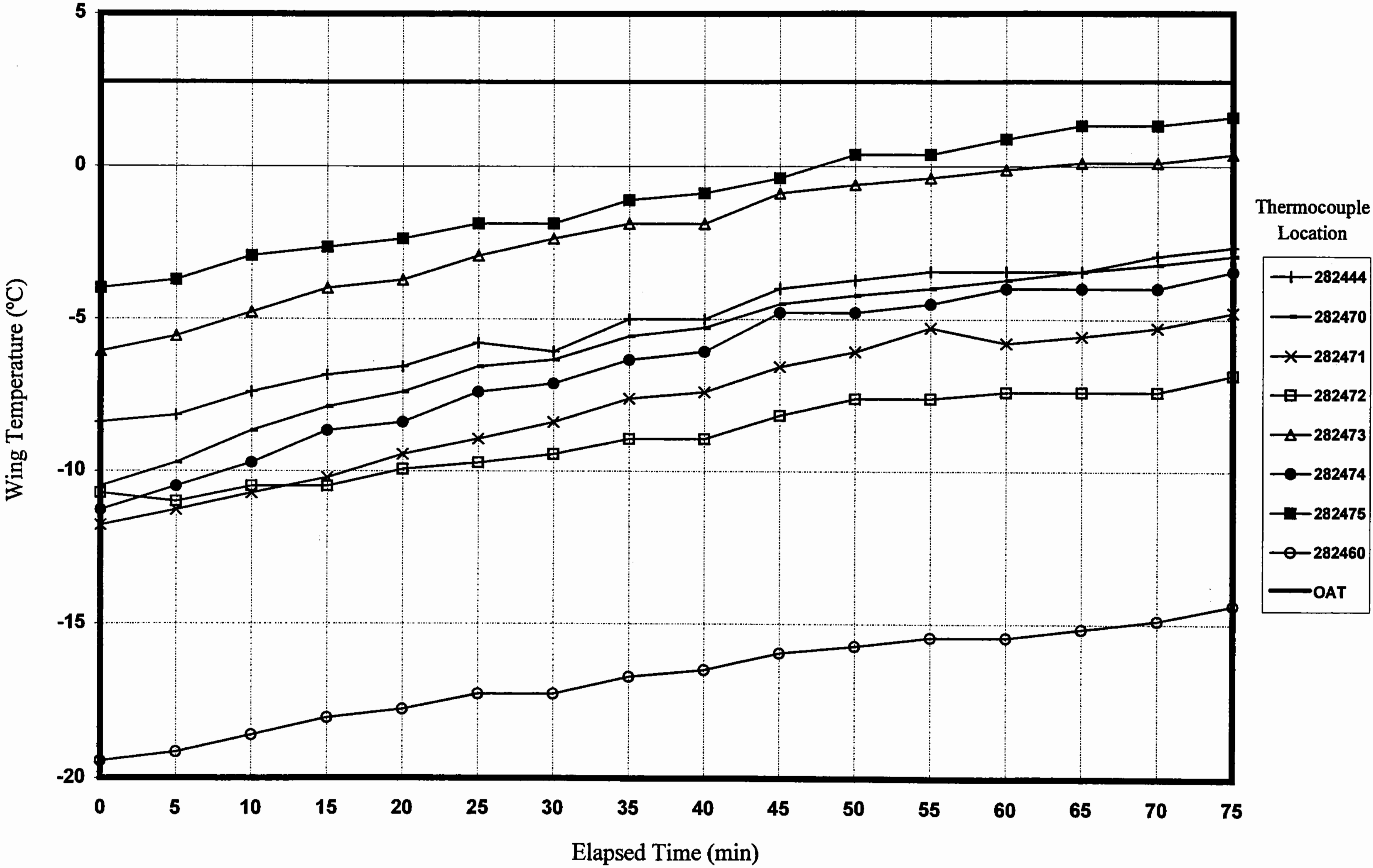
File:g:\cm1283\report\coldsoak\MD_SKIN2.XLS
At: F56_chart
Printed:20/03/97

FIGURE 3.14

FLIGHT 59 WING SKIN TEMPERATURE - OCTOBER 27, 1989

FUEL: Main 4477/4477 kg, Centre 1705 kg

OAT= 2.8 ºC



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3.2.2 Discussion on Results from McDonnell Douglas Trials

Flight 55 trial data produced a time constant value of 1 400 seconds. Such a low value reflects the conditions of this case where the upper surface of the wing was not wetted and the wing fuel tank was only 30 percent full. Heat transfer between the fuel and upper wing skin would be via a large cavity of air over the fuel and structural ribs and stringers partly immersed in the fuel.

The trial on Flight 56 involved full wing tanks and completely wetted upper wing skin under no precipitation. The same fuel quantity condition applied to the trial on Flight 59, but here drizzle was falling on the wings.

Very different values for time constants result from the data; 4.3 hours for Flight 56 versus 1.1 hours for Flight 59. Disregarding the influence of other factors such as wind, at least part of this difference in value must be attributable to heat transfer by the drizzle falling on the wing surface.

3.3 Cold-Soaked Box Trials

Preliminary cold-soaked box tests in ambient conditions were conducted at the APS Aviation test site at Dorval Airport, and tests in controlled conditions were conducted in the Climatic Engineering Facility of the National Research Council in Ottawa.

3.3.1 Preliminary Tests at the APS Test Site

Initial trials involved four 2.5 cm and two 7.5 cm boxes tested in accordance with the plan shown in Table 3.4. A typical test result is shown in Figure 3.15 which illustrates temperature profile curves for each of the boxes under typical test conditions to protect and insulate the test surface. As each box was removed from the freezer an insulating cover was installed.

TABLE 3.4

FIELD TESTS - COLD-SOAKED BOXES
TEST PLAN

RUN #	FLUID Type	COLD-SOAK Box Type	PRECIPITATION	PROBE #		
				External		Internal
				15 cm	22.5 cm	
1	Dry	2.5 cm	Dry	3	4	
2	Type I (cold)	2.5 cm	Dry	7	8	
3	Type IV	2.5 cm	Dry	1	2	
4	Hot Water	2.5 cm	Dry	5	6	
5	Dry	7.5 cm	Dry	9	10	13
6	Type IV	7.5 cm	Dry	11	12	

Notes: Boxes precooled to -25°C approximately.
Hot water temperature 82°C approximately (150°F).
Fluid quantities 1.5L per plate.
Hot water - 0.5 L
Probe 14 - air temperature

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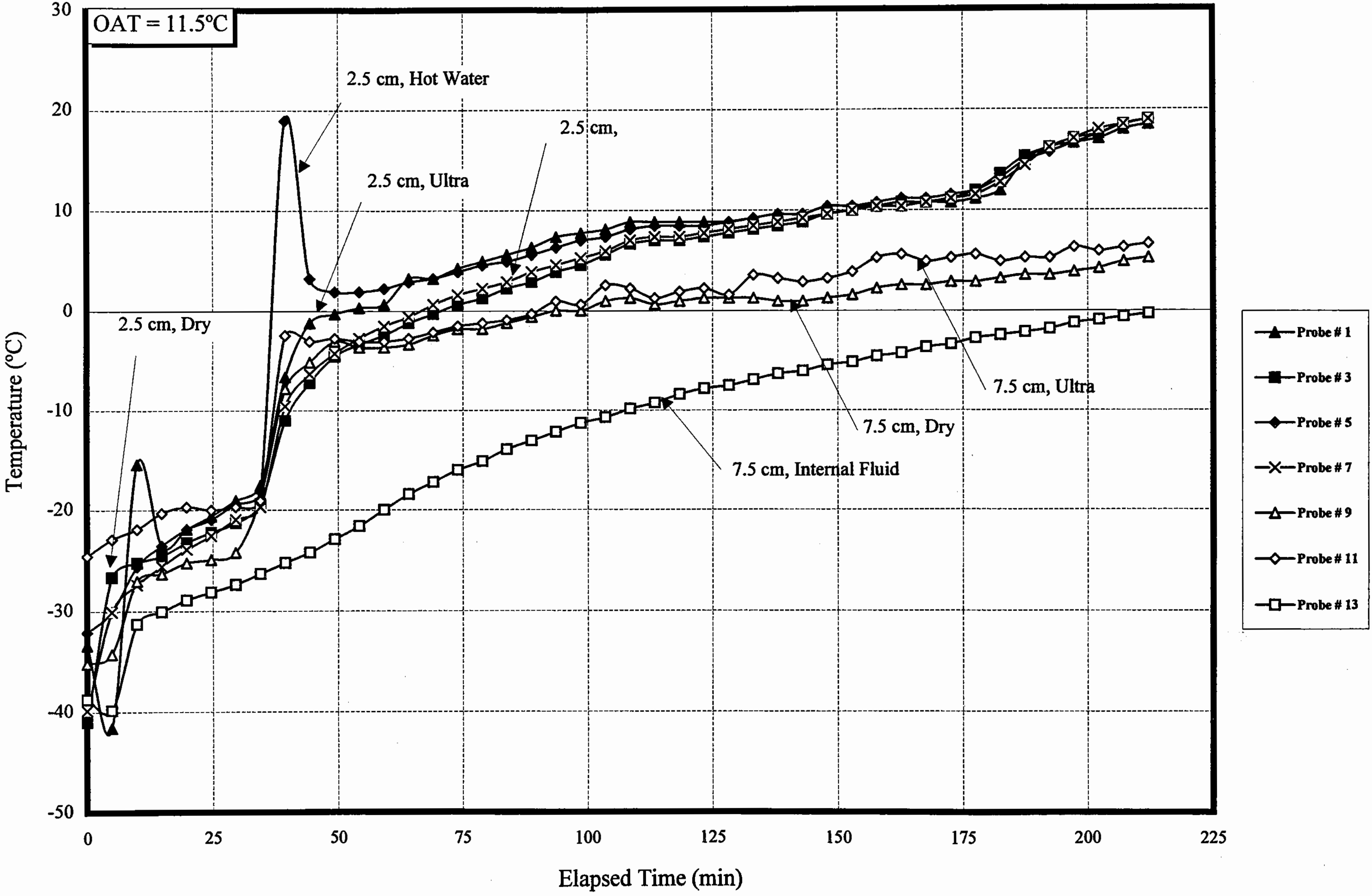
FIGURE 3.15

FIELD TESTS - COLD-SOAKED BOXES AT 15 CM (6") LINE
OUTDOORS - APS SITE - MAY 14, 1996



File:g:\cm1283\report\coldsoak\BOX_COOL.XLS
At: MAY14 (CHART)
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The initial part of the data curves shows temperature increase as the covered boxes are removed from the freezer and moved outside to the stand situated in the shadow of the test site trailer. At 35 minutes into the test, the insulating covers were removed and fluids were applied, reflected by the sharp increase in surface temperatures shown. Some crossover of temperature profiles for different boxes occurs as they are subjected to application of different fluids. A period of stabilization of surface temperatures then occurred, followed by a period of progressive warming toward ambient temperature. The two boxes of 7.5 cm depth are seen to warm at a slower rate than the 1.5 cm boxes. The progressive warming of internal fluid is shown on the bottom curve.

At 182 minutes into the test, the sun began shining on the lower rank of the test stand where the 2.5 cm boxes were located, as reflected by increasing temperatures on those boxes.

To calculate time constants, data were used from the stabilized portion of the curve following fluid application. For this test example, Figure 3.16 shows temperature profile curves based on the data during the period from 64 minutes to 172 minutes, and reports the calculated time constant values for each curve.

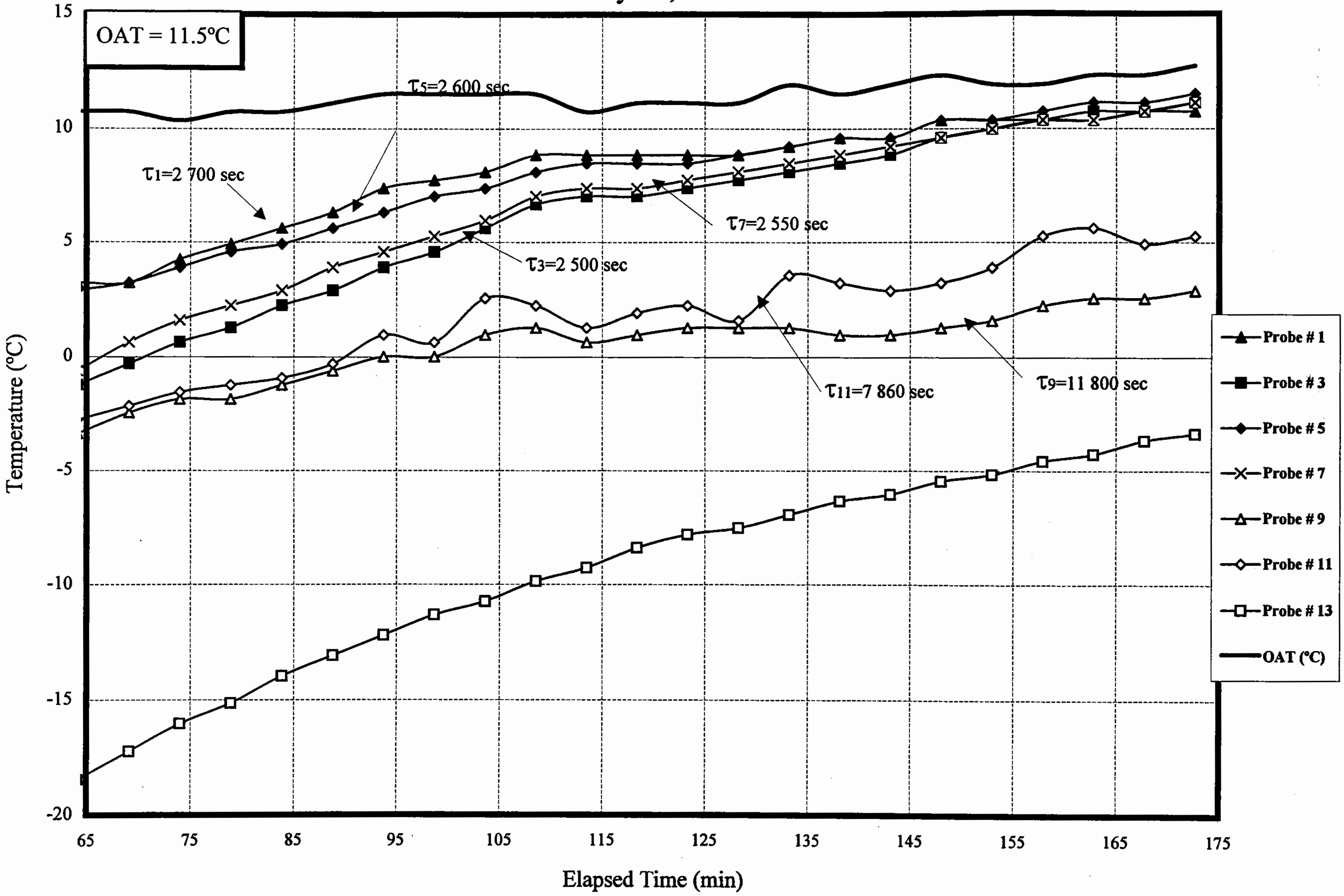
In this series of outdoor tests the time constant values calculated for each test condition varied significantly from day to day. This variation was believed to be associated with climatic conditions such as wind, cloud cover and radiant heating. To counteract this, a test set-up was established inside the test site trailer and several tests were conducted. The tests were initiated at sundown to avoid heat transfer by solar radiation during the day, and allowed to run overnight.

Figure 3.17 provides results from one such test conducted on June 10, 1996. In this test four boxes were used; two each of the 2.5 and 7.5 cm depth, with one tested dry and the other covered with Type IV Ultra fluid. The top line displays ambient

FIGURE 3.16

FIELD TESTS - COLD-SOAKED BOXES - DETAIL

May 14, 1996



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At: MAY14 @ 6"
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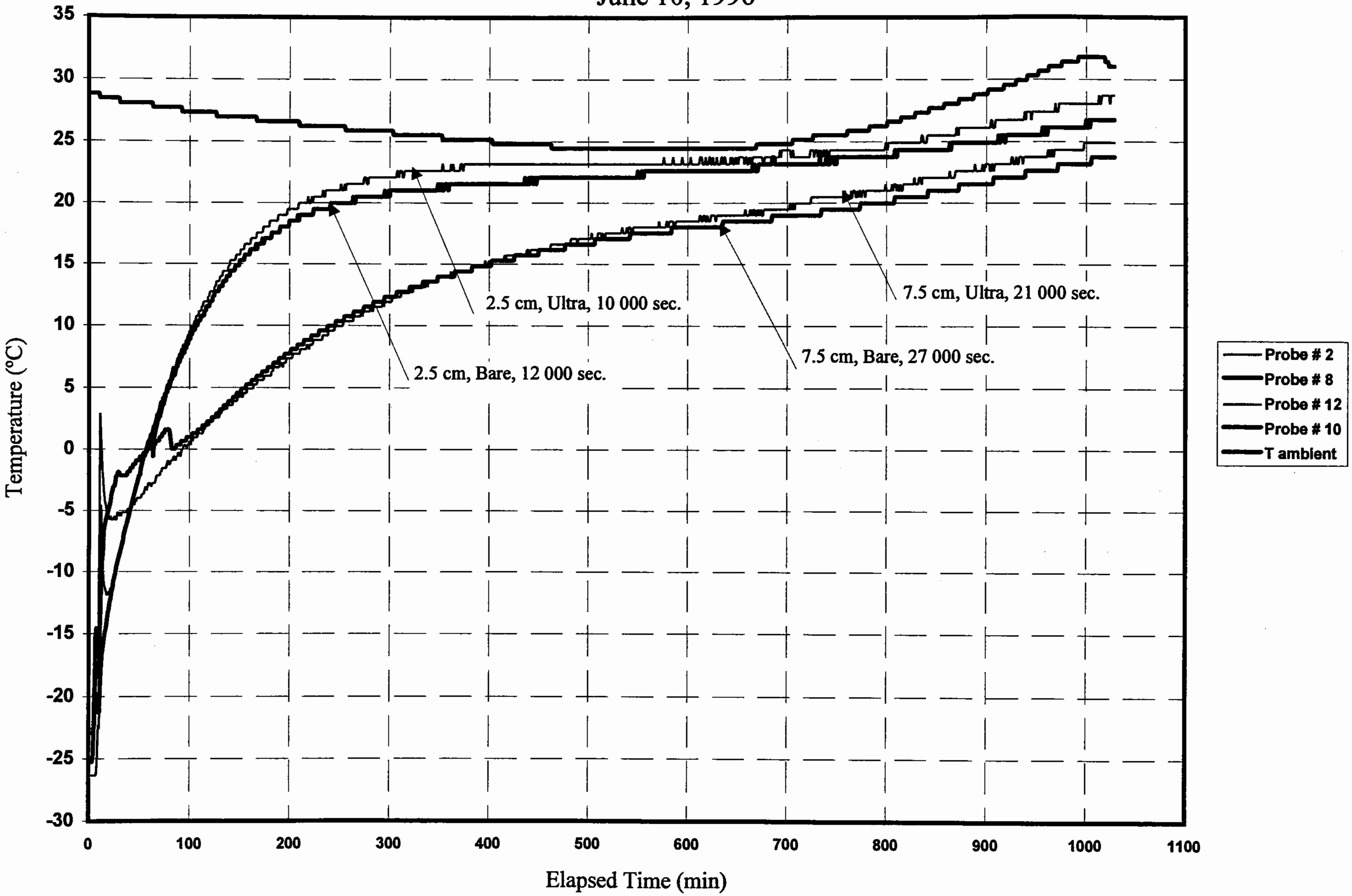
FIGURE 3.17

AES SITE COLD-SOAKED BOXES AT 22.5 CM (9") LINE

June 10, 1996



File:g:\cm1283\report\coldsoak\JUN10_AN.XLS
At: 9" line
Printed:97-7-30

temperature which can be seen to decrease gradually from an initial value of 28°C to 24°C overnight, and then increase rapidly starting at sunrise the following morning. For the purposes of calculating time constants, data were selected for the period ranging from 100 minutes to 600 minutes. The value for ambient temperature was taken as the mean over this period.

3.3.2 Trials at the NRC CEF Facility

Trials to measure time constant values of cold-soaked boxes were conducted on June 25 and 26, and again in the period July 29 to August 2, 1996.

These trials were repeated several times to establish the reproducibility of the data as represented by calculated time constant values.

All trials consisted of the following set-up, conducted at +2°C OAT with no precipitation.

Box Size (cm)	Box Surface
2.5	Bare
2.5	Type IV Ultra+
7.5	Bare
7.5	Type IV Ultra+
15	Bare
15	Type IV Ultra+

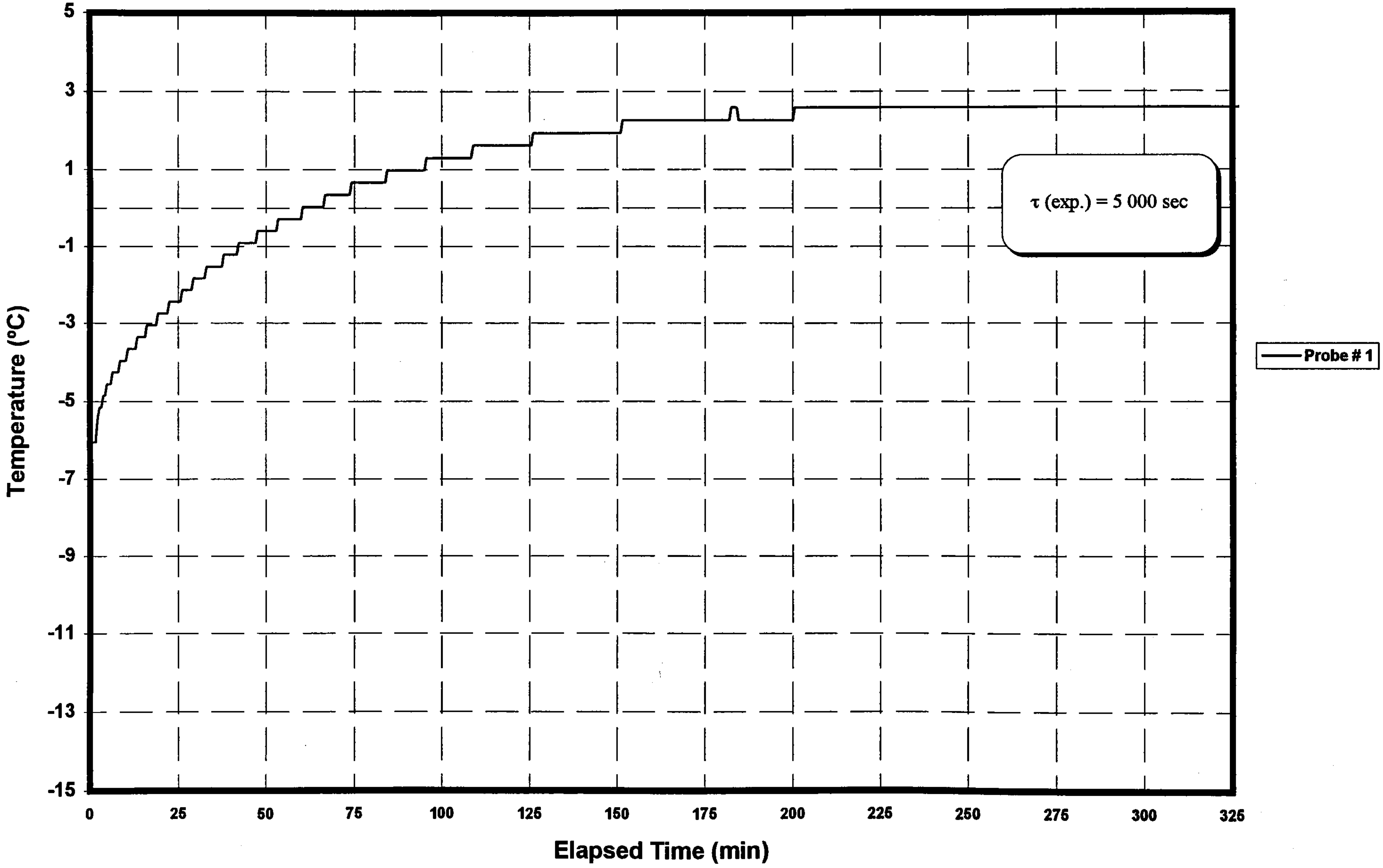
A typical test result is presented in Figure 3.18 showing the temperature profile as the surface warms up, and the calculated time constant for the curve.

FIGURE 3.18

COLD-SOAKED BOX TEMPERATURE PROFILE - NRC CEF

2.5 cm Box at 22.5 cm (9") Line - BARE

July 31, 1996



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At: 2.5_CHT BARE (2)
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4. ANALYSIS AND DISCUSSION

4.1 Establishing Temperature Parameters for Trials

Independent variables for these trials included parameters both for outside air temperatures and for skin surface temperature for test aircraft wings and cold-soaked boxes.

4.1.1 Outside Air Temperature (OAT)

The nature of the problem caused by cold-soaked wings lies with the temperature of the wing surface being significantly lower than that of outside air, and of fluids on the wing freezing (or failing) earlier than would be expected based on the value of the OAT. This situation is not limited to conditions of outside air temperatures above freezing, and SAE ARP4737 application guidelines (which are based on outside air temperatures) for deicing and anti-icing fluids include a caution that aircraft skin temperature and OAT may differ.

Because the objective of the study specified the precipitation conditions of concern to be rain or drizzle, an outside air temperature range of 0°C to 5°C was established for the aircraft trials, and 2°C for trials in the cold chamber.

4.1.2 Skin Surface Temperature

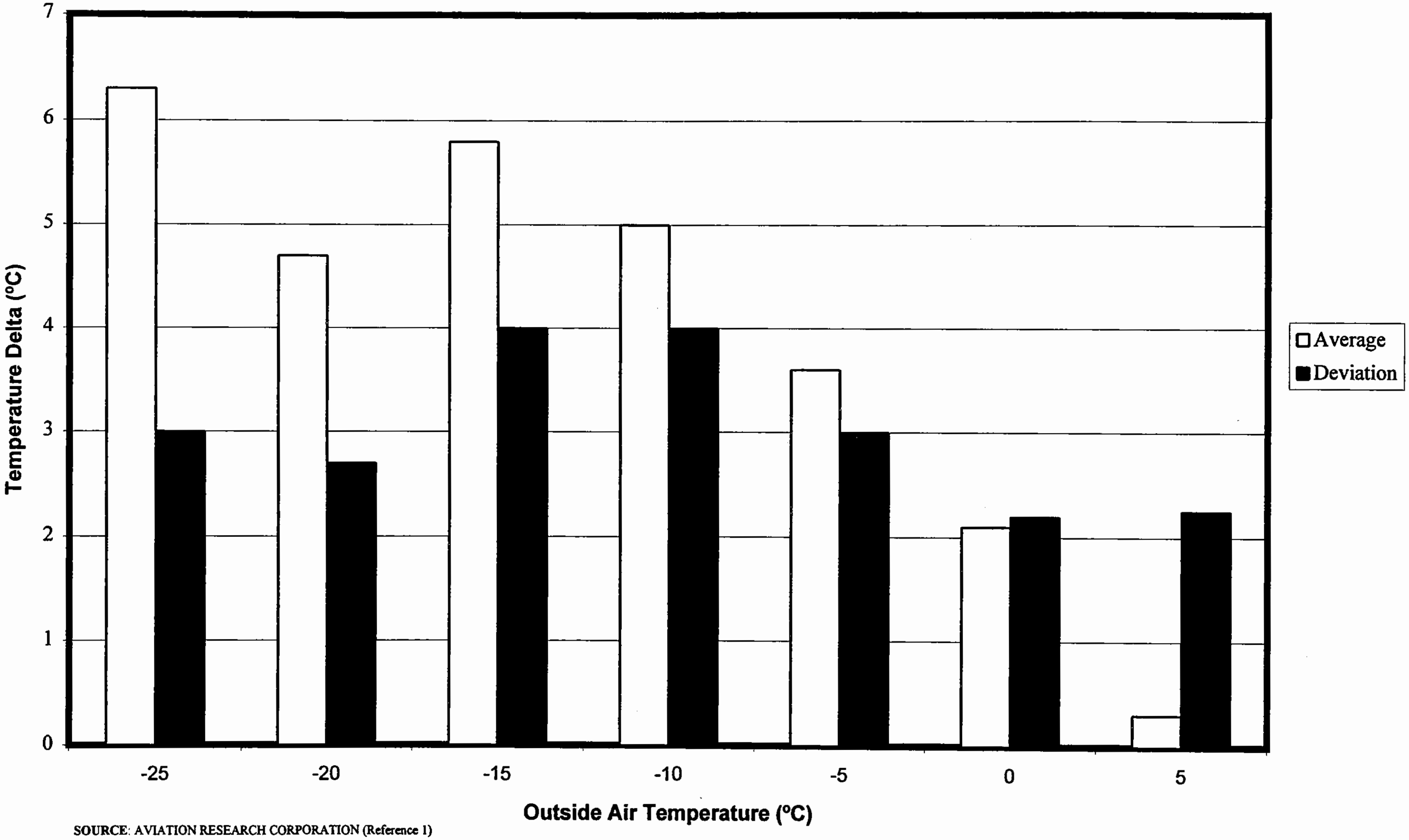
The temperature range to represent cold-soaked wings was established from a review of data collected in a survey to determine typical values of wing skin temperatures(1) and from direct communication with Scandinavian Airlines.

The wing temperature survey was conducted at a number of airport locations in North America and Europe, and included a variety of aircraft types. The survey report presented wing temperature values in the form of bar charts (see example Figure 4.1). These charts are included in this report and are located in Appendix G.

FIGURE 4.1

TEMPERATURE DIFFERENTIAL AS FUNCTION OF OUTSIDE AIR TEMPERATURE

(All Aircraft, All Airports)



SOURCE: AVIATION RESEARCH CORPORATION (Reference 1)

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Values for temperature differential between wing skin and outside air, and the calculated standard deviation of survey data are plotted for various ranges of outside air temperature.

In analysing the data presented in the report, specific charts were selected. For North American surveys, charts were selected which represented the average of all aircraft sampled including results from measurements in Winnipeg (to represent a cold location) and results from tests on the DC-9 aircraft (to represent an aircraft with wet wing). For surveys in Europe, charts representing the right-hand wing (at arrival), and both the right-hand and left-hand wings (following refueling) were selected. Analysis of temperature values taken from these charts is presented in Table 4.1. The lowest wing temperature based on the survey values in the table is calculated to be -4.5 °C.

Communications with SAS led to a description of a test envelope (Figure 4.2) which would reflect the SAS experience of cold-soaked wing temperatures. This envelope reflects a range of cold-soaked wing temperatures possible during OAT conditions below 0 °C as well as above. For the purpose of this test the lowest wing temperature value (-9 °C) at the freeze point was of interest.

It was decided that a test range for surface skin temperature with a lower limit of -10 °C would be appropriate and would encompass all possible values. In reality this lower limit is the most severe condition, and any future tests should consider skin temperatures around -5 °C.

4.2 Aircraft Trials

A number of attempts to identify MD-80 flights arriving at Dorval Airport that would serve as suitable subjects for cold-soaked testing proved unsuccessful, with upper wing temperatures on arrival consistently found to be well above 0°C. Success was hampered by the limited number of operators of MD-80 aircraft at Dorval, and the small number of

TABLE 4.1

WING TEMPERATURE VALUES FROM COLD-SOAKED WING SURVEY

Appendix #	OAT (°C)		ΔT (°C) (Average)	T (°C)[1] Average	Standard Deviation (σ)	Minimum T(°C)[2] (based on 3σ)
	Range	Range Mid-Point				
G-1		0 5	2.1 0.2	2.1 5.2	2.2 2.2	-4.5 -1.4
G-2		0 5	0.4 0	0.4 5	0.8 0	-2 5
G-3		0 5	2.8 -0.6	2.8 4.4	1.7 2	-2.3 -1.6
G-4	0 - 5 5 - 10	2.5 7.5	-1 -3	1.5 4.5	2 2.2	-4.5 -2.1
G-5	0 - 5 5 - 10	2.5 7.5	-2.5 -3	0 4.5	0.5 0.7	-1.5 2.4
G-6	0 - 5 5 - 10	2.5 7.5	-2.7 -3.3	-0.2 -4.2	0.5 0.7	-1.7 2.1

(1) T (Average) = Range Mid-Point + Δ T

(2) Minimum T = T (Average) - 3 (Standard Deviation)

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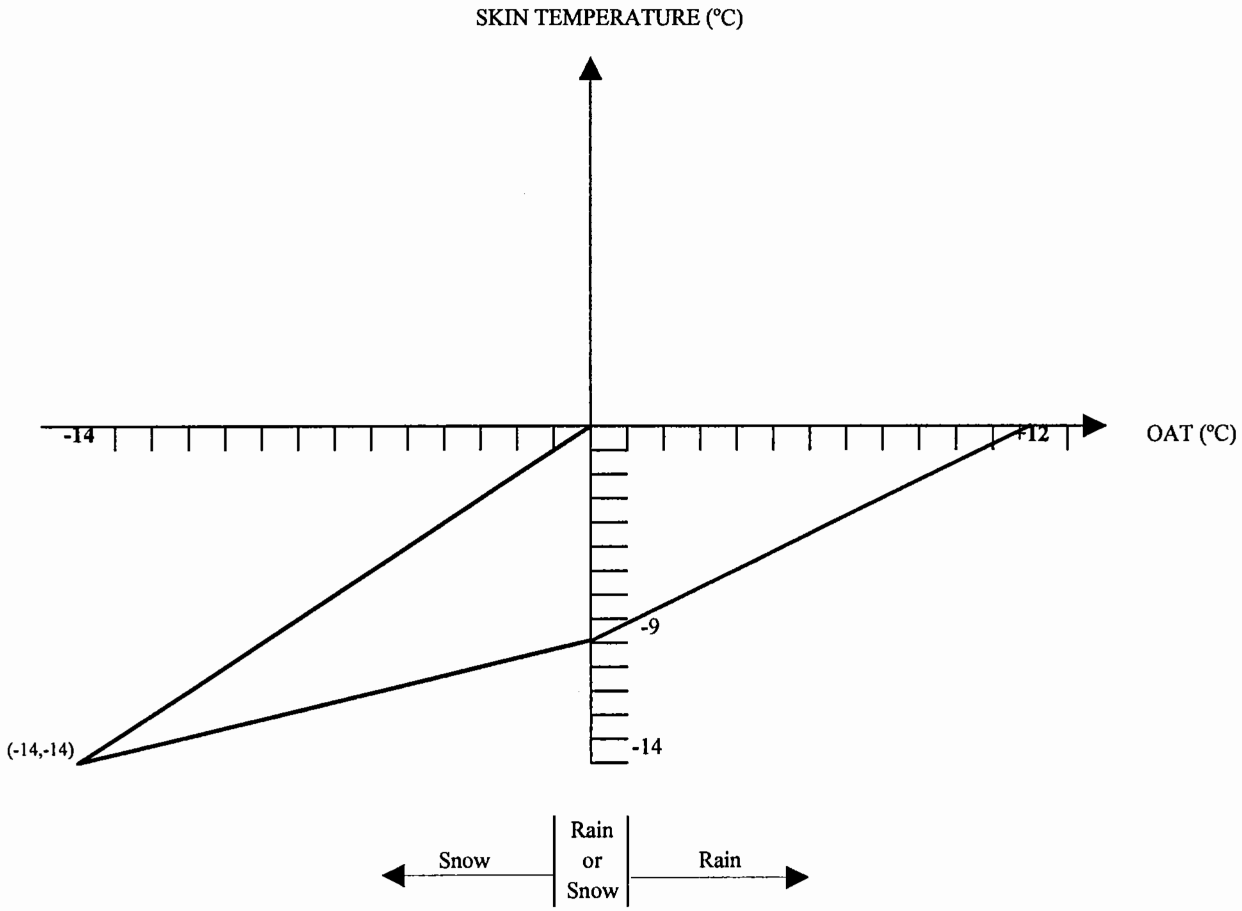
Printed: 97-7-30

FIGURE 4.2

SUGGESTED TEST ENVELOPE
SCANDINAVIAN AIRLINES



Source: Scandinavian Airlines

flights that had sufficient duration to experience cold-soaking. In some instances, special arrangements to encourage cold-soaking on inbound flights could not be fully implemented. Although operation of installed heater blankets on wings could be suspended, the insulating effect of the blanket still existed. In one case, the fuel management process designed to hinder cold-soaking could not be manually overridden.

In a final attempt to measure a wing temperature profile, a test was conducted at Bradley International Airport at Hartford, Connecticut with an inbound flight of sufficient duration (2 hrs).

The problems in locating a flight with wing temperatures suitable for testing is perhaps typical of the fleeting nature of the cold-soaked wing condition.

The lack of suitable test subjects (aircraft with cold-soaked wings) resulted in collection of only a limited amount of data to address the first objective of this study (to develop a wing temperature profile for the cold-soaked wing), and made it impossible to conduct tests to evaluate fluid holdover times on cold-soaked wings.

A summary of results shown in Table 4.2 includes data from two test events initiated with the expectation that the aircraft would arrive with wings in a cold-soaked condition, as well as data from selected tests in the McDonnell Douglas series of Wing Icing Tests.

4.2.1 American Airlines MD-80 Trial

The test on the American Airlines MD-80 on April 25, 1996 found the coldest upper wing surface temperature following stabilization after landing to be 3.0°C with outside air temperature at 8.0°C. Wing temperatures upon arrival were influenced by operation of the fuel management system during the flight, and by the insulating effect of the heating blanket even though it was not activated. The wing tank fuel load upon arrival was just under the amount at which wetting of the upper surface commences

TABLE 4.2

AIRCRAFT TRIALS - TEMPERATURE PROFILE

Airline	A/C Type	Date	Main Tank Load (kg)*	OAT (°C)	Initial Measure of Wing Temp (°C)		Precipitation	Time Constant (Seconds)
					Over Wing (Cold Corner)	Under Wing		
American Airlines	MD-80	25 April, 1996	2 860	8.0	5.0	-3.0	Dry	27 000
Delta Airlines	MD-80	18 July, 1996	3 000	19.8	11.0	5.4	Dry	26 500
MD Trial (55)	MD-80	25 October, 1989	2 820	3.9	-7.4	Not Provided	Dry	1 400
MD Trial (56)	MD-80	27 October, 1989	4 410	-1.7	-8.4**	-12.3	Dry	15 400
MD Trial (59)	MD-80	25 October, 1989	4 480	2.8	-11.8**	-19.4	Drizzle	4 000

* Wetting of MD-80 upper wing surface commences at 2 943 kg

** Taken at position 281 471 (Figure 3.10)

(2 860 kg vs. 2 943 kg). The flight crew had determined that boarding of additional fuel was limited by payload.

Wing temperature data were recorded over a 1 hour, 20-minute duration. The time constant value was calculated on data collected from thermistor' attached at points outside the blanketed area. The value (27 000 seconds) was influenced by the fact that the wing was not wetted and by the insulating effect of the heating blanket over the inner end of the wing tank.

4.2.2 Delta Airlines MD-80 Trial

The test on the Delta Airlines MD-80, July 18, 1996 was a preliminary trial to determine if suitable conditions existed for a full-scale test. As discussed in Section 2.4.1, this test was initiated on the premise that a time constant value for a wetted wing can be calculated if a sufficient temperature differential between wing and ambient temperature exists, regardless of the absolute value of the ambient temperature which was expected to be warm. A wing surface temperature somewhat below 0°C was desired following the 2-hour flight.

The test flight arrived with fuel in wing tanks just above the point at which wetting commences (3 000 kg vs. 2 943 kg), additional fuel boarding having been constrained by a Delta Airlines temporary embargo on fuel tankering. Top wing surface temperature was 11 °C with ambient temperature at 19.8 °C.

Wing surface temperatures were measured over a one-hour period using a hand-held temperature probe. The time constant value (26 500 seconds) calculated on collected was influenced by the top wing surface not being significantly wetted. Due to the limitation on fuel tankering, and the initial wing temperature being considerably above 0 °C, it was decided to not continue with a full-scale test.

4.2.3 Air Canada Canadair RJ Trial

This test on the Canadair RJ was conducted with Air Canada on April 11, 1996. The special arrangements put in place for the flight resulted in the aircraft arriving with full wing tanks (2 160 kg) and a good report on flight conditions by the flight crew.

With full wing tanks for the complete duration of the flight (about 1.5 hours), it was expected that some degree of cold-soaking would be experienced. The results of wing temperature measurements showed that only a minor degree of cold-soaking resulted, with temperatures measured at different points on the wing ranging from 2 to 5°C, as compared to ambient outside air temperature of 6.3°C.

Due to the small degree of cold-soaking (insufficient for the purpose of calculation of thermal time constant values) and the operator need to move the aircraft, the test was terminated after 25 minutes.

4.2.4 McDonnell Douglas - Wing Icing Tests

Trial 55 was conducted with wing tanks only 30 percent full and with upper wing surfaces unwetted by fuel. The low time constant value calculated (1 400 seconds) reflects this condition in which heat transfer between the cold fuel and the upper wing skin is insulated by the large cavity of air over the fuel.

The test conditions reported for trials 56 and 59 were ideal for the purpose of this study. Tests were conducted with full wing tanks which would result in wetting of the complete upper wing skin. Outside air temperature was near 0°C and upper wing skin temperature was near -10°C. Test 56 was conducted with no precipitation; test 59 was conducted under drizzle and resulted in ice formation on the wing surface.

Time constants calculated for tests 56 and 59 were 15 400 seconds and 4 000 seconds, respectively. As would be expected, the time constant value in the precipitation condition was less than during the dry condition, indicating that the drizzle warms up the wing upper surface faster. The influence of other factors such as wind is not known.

These values compare to the theoretical value calculated in the 1994/95 study (3) for the Canadair RJ aircraft wing with Type IV Ultra applied, in a no precipitation condition, of 6 000 seconds.

4.3 Cold-Soaked Box Trials

4.3.1 Preliminary Trials at the APS Test Site

These preliminary tests were conducted in advance of planned tests at the NRC cold chamber facility and results are presented in Appendix D. Test results provided data with a wide range of scatter despite attempts to control external influences on the rate of heat transfer as measured on box surfaces. As well, the impact on results of the high ambient air temperature during the tests could not be quantified. Data from this series of tests were set aside in favor of later test data developed in the controlled laboratory conditions offered by the NRC cold chamber facility.

4.3.2 Trials at the NRC Cold Chamber Facility

Table 4.3 presents a summary of calculated time constant values for cold-soaked box temperature profile tests conducted at the NRC CEF facility. These tests were conducted under conditions of no precipitation, with ambient air temperatures as reported. Initial box surface temperatures were established at -10°C. Even under these controlled conditions a good deal of spread in calculated time constant values was observed. Temperature profile curves resulting from these tests are presented in Appendix E.

TABLE 4.3

COLD-SOAKED BOX TEMPERATURE PROFILE TESTS

TIME CONSTANT (Seconds)

TEST LOCATION	**NRC - CEF**						
AMB. TEMP.	**+2°C**	**+3°C**	**+2°C**	**+2°C**	**+2°C**	**+2°C**	**+2°C**
BOX SIZE (cm)	**June 25, 1996**	**June 26, 1996**	**July 29, 1996**	**July 30, 1996**	**July 31, 1996**	**Aug 1, 1996**	**Aug 2, 1996**
2.5 ***BARE***	N/A	7 000	3 000	5 000	5 000	3 500	5 000
2.5 ***ULTRA+***	N/A	4 000	6 000	5 000	3 000	4 000	3 000
7.5 ***BARE***	13 000	16 000	13 000	8 000	12 000	11 000	21 000
7.5 ***ULTRA+***	6 000	17 000	13 000	17 000	N/A	N/A	17 000
15 ***BARE***	25 000	26 000	13 000	22 000	20 000	33 000	33 000
15 ***ULTRA+***	21 000	33 000	27 000	22 000	N/A	33 000	N/A

Note: No Precipitation

During separate trials designed to measure the holdover times for cold-soaked conditions(4), also conducted at this facility, temperature profiles of the cold-soak test box surfaces were measured. These trials were conducted under rain conditions with rates established to represent drizzle, light, moderate and heavy rain. Different types of fluids at various concentrations were applied. Box surface temperature and ambient air temperature were controlled to the values described for the earlier trials. Appendix F presents data for relevant tests, including calculated time constant values.

The results from both of these test series are presented in Table 4.4. The time constant values shown in columns headed "Time Constant Trials" are mean values from repeated tests after removing high and low values. Time constant values shown under "HOT Trials" are mean values of all repeated tests.

Examination of the results reveals the following trends:

1) In nearly all cases an increase in precipitation rate is accompanied by a decrease in time constant value. This reflects the observation made on the McDonnell Douglas data.

   In practical terms, this means that the wing surface (represented here by the box) would warm up faster under heavy rain conditions than under drizzle. This is not unexpected and echoes experience during actual operations wherein continued exposure to heavy rain tends to resolve the problem of wing ice formation, eventually washing off any ice that has already formed on the wing. If this has already occurred by the time of push back or on arrival at the deicing centre, then no further action is required.

TABLE 4.4

COLD-SOAKED BOXES TIME CONSTANT VALUES

(Seconds)

Box	No Precipitation			Drizzle (HOT TRIALS - CEF)[2]				Light Rain (HOT TRIALS - CEF)[2]			
Size	Theoretical Calculation	CEF Time Constant Trials[1]		TYPE I UCAR ADF		Ultra+		TYPE I UCAR ADF		Ultra+	
(cm)	Propylene Glycol	Bare	Ultra+ (100%)	Diluted	XL54	75%	100%	Diluted	XL54	75%	100%
2.5	2 700	4 600	4 000	600	1 700	No Test	4 000	300	500	2 200	2 700
7.5	8 000	13 000	15 700	400	3 300	8 500	9 000	200	500	2 600	9 600
15	16 000	25 200	27 300								

[1] From Table 4.3; mean values calculated after removing high and low values

[2] From Appendix F

4.4 Comparison of Wing and Cold-Soaked Box Time Constants

From the limited data available for aircraft wing time constant calculations, the results from the McDonnell Douglas trials appear to be the most useful. For the condition of bare surface and no precipitation, the wing time constant value of 15 400 seconds compares reasonably well to mean values developed for the three sizes of cold-soaked boxes, which range from 4 600 to 25 200 seconds.

Figure 4.3 presents in chart form, time constant values determined experimentally for the MD-80 aircraft wing and cold-soaked boxes, as well as theoretical values for the Canadair RJ wing, and cold-soaked boxes. The set of cold-soaked box sizes tested appears to deliver a range of time constants that encompass time constant values expected from actual aircraft wings.

The difference in time constant values among the different size boxes requires examination to determine influence on fluid holdover times.

4.5 Significance of Size of Cold-Soaked Box

In evaluating the significance of the different size of box and the time constant for each, the results of fluid holdover time trials on boxes for rain on cold-soaked wings(4) were examined.

Figure 4.4 presents holdover time values for neat Type IV fluid plotted against different precipitation rates of rain. A regression curve to predict holdover time (with precipitation rate as the single independent variable) has been calculated and drawn for each box size. These lines have a high degree of correlation to the individual point values as indicated by the reported coefficient of correlation (r) values. The line for the 15 cm box is influenced by the absence of data points for higher precipitation rates, and is not valid in the region of moderate and heavy rates of rain.

FIGURE 4.3

COMPARISON OF TIME CONSTANT VALUES

AIRCRAFT WINGS AND COLD-SOAKED BOXES

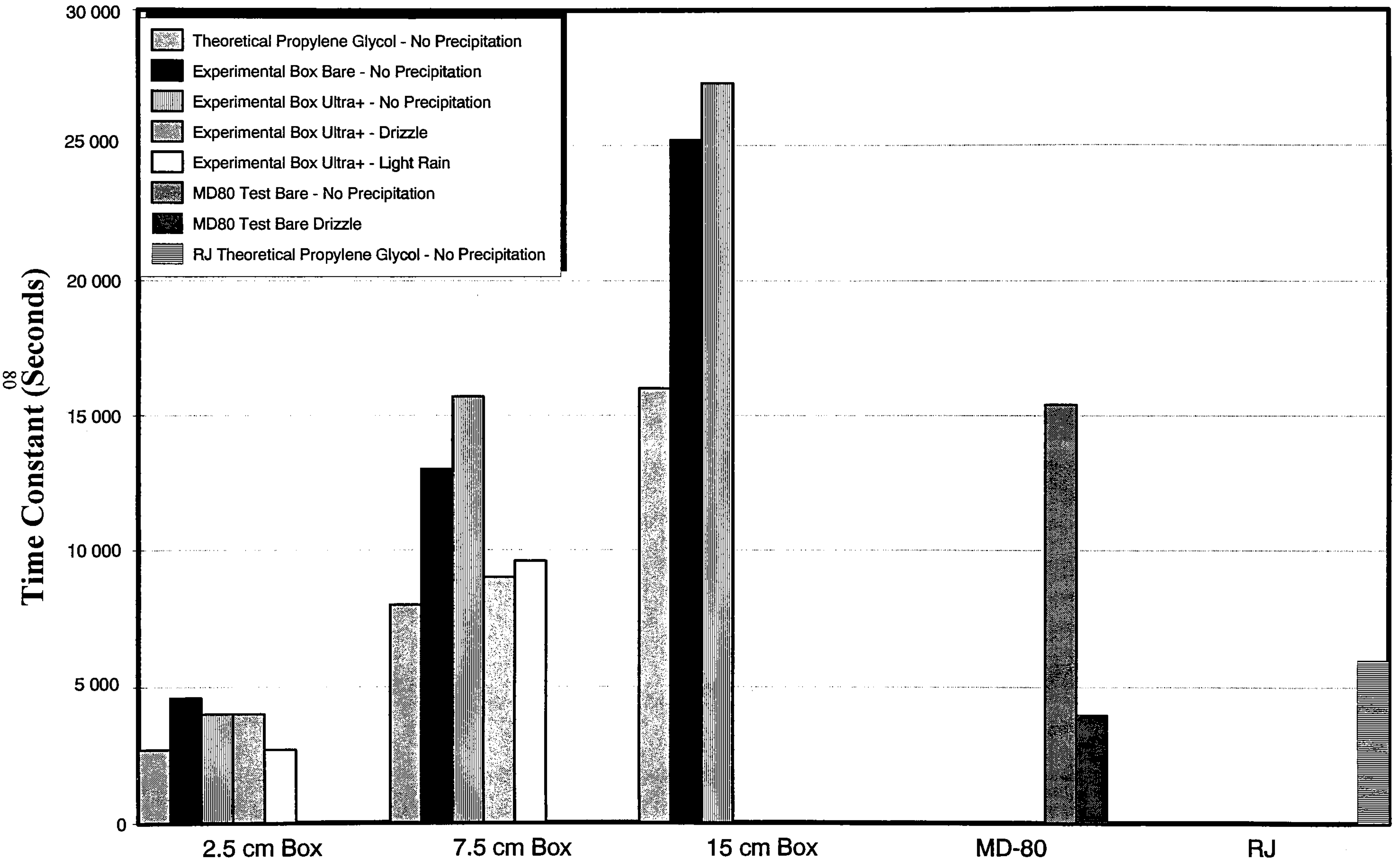


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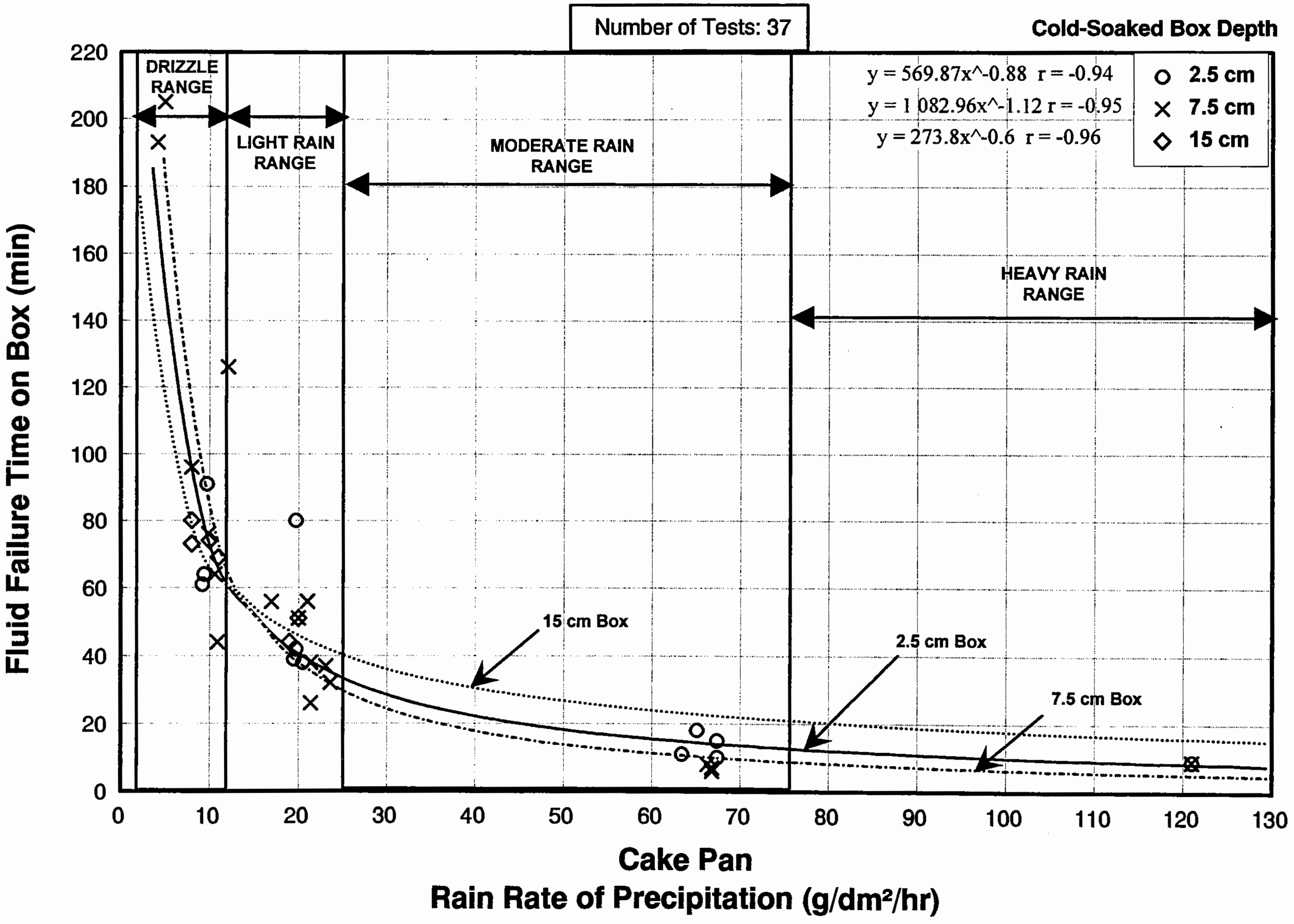
FIGURE 4.4

EFFECT OF BOX SIZE AND RATE OF PRECIPITATION ON FAILURE TIME

TYPE IV NEAT

RAIN ON COLD-SOAKED SURFACE

1995 - 1996



From these lines it can be seen that the size of box does have some degree of influence on holdover time at a fixed value of rate of precipitation. However, when the range of rates encompassed within the definition of any one category of precipitation is considered, it is seen that HOT values within each of those categories are influenced much more by rates of rain than by box size.

In a further examination of significance of box size, a multiple regression to predict holdover time was calculated based on the data collected during the same (neat Type IV) series of tests. This calculation included the following as initial independent variables: the three different sizes of boxes; the different fluid brands tested; the mean skin temperature over the test duration; and the rate of precipitation.

A series of iterations was performed, progressively excluding those potential independent variables having a statistically insignificant and least degree of influence on the outcome. In this process, the size of box was the first factor to be eliminated, followed by the brand of Type IV fluid. The final regression formula (Table 4.5) included only rate of precipitation (r) and temperature of box surface (k) as independent variables. A multiple regression coefficient (R^2 value) of 0.90 resulted, indicating an acceptable least squares fit.

Figure 4.5 presents regression lines resulting from the multiple regression drawn at box surface temperatures of -5 and -10°C, compared to the previous regression line for the 7.5 cm box.

The conclusion of this analysis is that the influence of box size is insignificant when compared to the impact the rate of precipitation exerts on holdover times within each category of precipitation. When light rain and drizzle are combined for the purpose of SAE holdover time tables, the influence of box size (for the box sizes tested) diminishes even further and becomes irrelevant. Testing on boxes in other types of precipitation should include a range of box sizes to enable a similar analysis of the sensitivity of holdover time to box size.

TABLE 4.5

MULTIPLE REGRESSION - TYPE IV NEAT

Regression Statistics	
Multiple R	0.951793219
R Square	0.905910332
Adjusted R Square	0.900375646
Standard Error	0.12577482
Observations	37

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	5.178567092	2.5892835	163.678712	3.54987E-18
Residual	34	0.537856385	0.0158193		
Total	36	5.716423477			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.000%*	*Upper 95.000%*
Intercept	-6.086633014	2.953304081	-2.060957	0.04702212	-12.08846507	-0.084800956	-12.08846507	-0.084800956
Log r	-0.918915347	0.059307482	-15.49409	5.6449E-17	-1.039442572	-0.798388122	-1.039442572	-0.798388122
K	0.033348682	0.010980749	3.0370135	0.00456533	0.01103313	0.055664234	0.01103313	0.055664234

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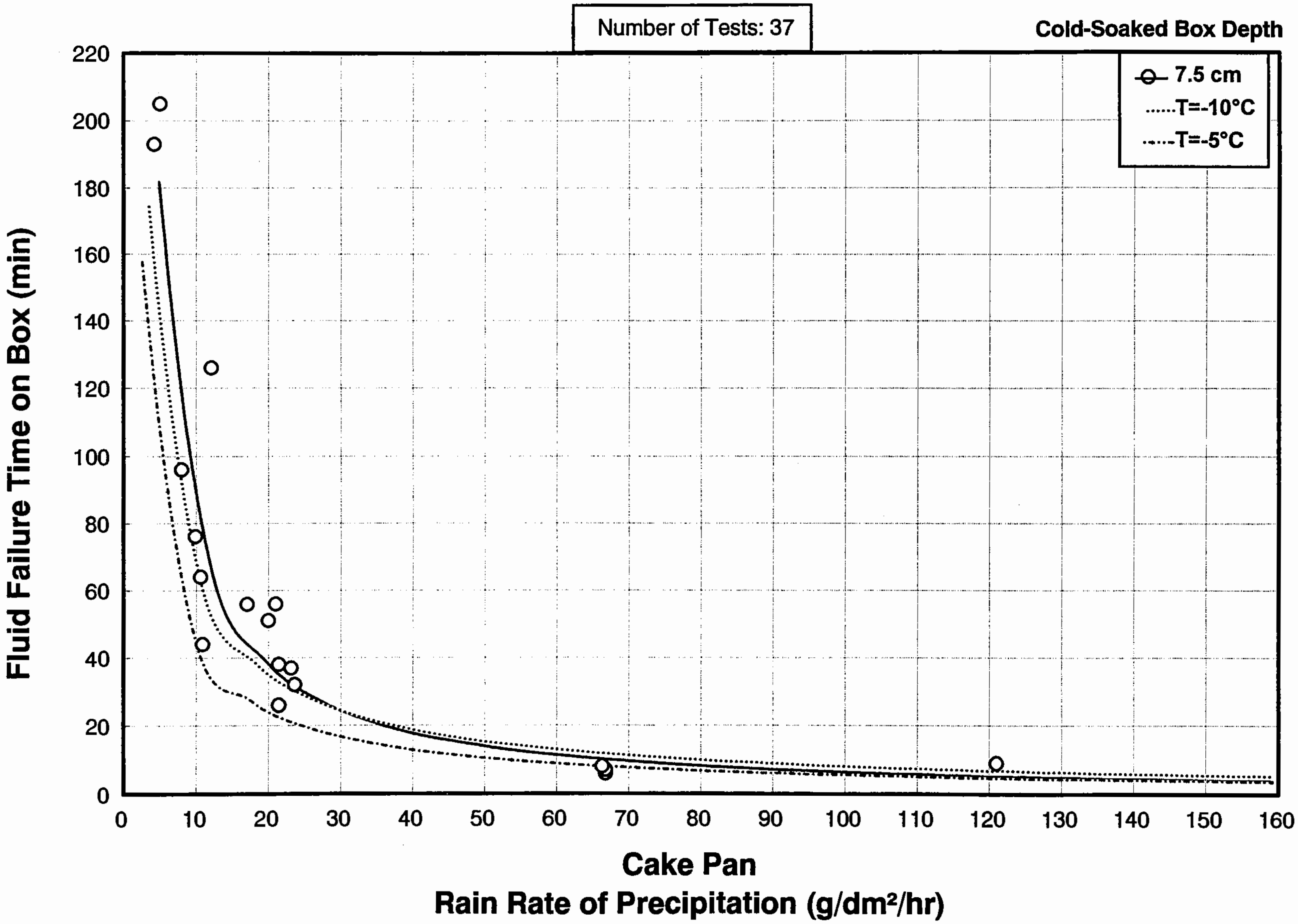
At: Regression

FIGURE 4.5

EFFECT OF BOX SURFACE TEMPERATURE AND RATE OF PRECIPITATION ON FAILURE TIME
TYPE IV NEAT
RAIN ON COLD-SOAKED SURFACE
1995 - 1996



In summary, the cold-soaked boxes do provide an acceptable representation of a cold-soaked wing for the purpose of determining fluid holdover times. There does not appear to be any reason for restricting this to the condition of rain, and the extension of box use to fluid testing in conditions of freezing precipitation appears to be valid.

4.6 General

Although fluid holdover times on cold-soaked wings could not be evaluated in this study (due to the difficulty in locating a suitable aircraft) some comments on the subject are worth mentioning.

In a study to evaluate fluid thickness on aircraft wings (5), it was determined that the greatest film thickness was formed on the top part of the wing where the slope is most shallow, with typical thickness values (for Type IV Ultra fluid) ranging from 2.0 to 3.5 mm. These thickness values were substantially greater than those observed during trials on flat plate (values between 1 and 2 mm). The area of the wing surface where fluid remains thickest is that same area that is of concern for the cold-soaking condition as it lies directly over the fuel tanks. The implication of this observation is that fluid holdover times on aircraft wings would be expected to be longer than holdover times measured on flat plates, as a result of the greater film thickness.

The difficulty in finding a flight to serve as a test subject (an arriving aircraft with cold-soaked wings), highlighted the fact that existence of the condition is dependent on very specific circumstances. In the search for a suitable flight, it was noted that a number of fixes to prevent the condition have been implemented, including heater blankets on wings, and fuel management procedures and systems to discourage cold-soaking. The operation of some of these was suspended to encourage cold-soaking for test purposes; however even this premeditated action, along with tankering of extra fuel, still failed to produce a subject suitable for testing. This reflects the findings of the wing temperature survey at North American locations(1) which failed to find evidence of significantly cold-soaked wing conditions.

Efforts to define a unique thermal time constant value for each cold-soaked box were frustrated as repeated tests produced considerable variation in values. It is expected that the same kind of variation would be encountered with repeated attempts to measure time constant values for aircraft wings. Variability in time constant values is believed to be influenced by a number of factors including fuel (or internal fluid) volume, wind, and thermal radiation from external sources.

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5. CONCLUSIONS

From this analysis it is concluded that:

- The thermodynamic properties of the cold-soaked boxes designed to enable laboratory evaluation of fluid holdover times for the condition of rain on cold-soaked wings do provide an acceptable representation of thermodynamic properties of the actual wing.

  A good deal of scatter was experienced in measured cold-soaked box time constant values. It is believed that this variability is probably also true for actual aircraft wings and that a good deal of variability in time constant values would be observed in wing measurements.

- The influence of box size on fluid holdover times is not important when compared to the influence of precipitation rate.

- Rain on the surface of the cold-soaked body causes it to warm more rapidly than in a dry condition, producing a shorter time constant. Increased rates of precipitation accelerate the rate of warming and change the time constant.

- The cold-soaked boxes may find a useful application in tests to determine fluid holdover times in conditions of freezing precipitation, providing a means of evaluating the impact of a cold-soaked surface on holdover times as compared to the standard approach of testing on a flat plate at ambient temperature.

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6. RECOMMENDATIONS

It is recommended that:

- Cold-soaked boxes be accepted as satisfactory representations of cold-soaked wings for the purpose of laboratory trials to evaluate fluid holdover times.

- Future fluid holdover time trials conducted during conditions of freezing precipitation should include tests on cold-soaked boxes to determine the impact of a cold-soaked wing on fluid holdover times in those conditions.

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REFERENCES

1. *Aircraft Ground Operations in Canadian Winter Weather: Taxi Times, Wing Temperatures and Hot De-Icing,* Aviation Research Corporation, Montreal, April 1996, TP 12735E, 128.

2. D'Avirro, J., Boutanios, Z., *Aircraft Ground De/anti-icing Fluid Holdover Time Field Testing Program for the 1994-1995 Winter*, APS Aviation Inc., Montreal, December 1995, TP 12654E, 180.

3. Boutanios, Z., D'Avirro, J., *Methodology for Simulating a Cold-Soaked Wing,* APS Aviation Inc., Montreal, December 1995, TP 12678E, 40.

4. D'Avirro, J., *Aircraft Ground De/anti-icing Fluid Holdover Time Field Testing Program for the 1995-1996 Winter*, APS Aviation Inc., Montreal, December 1996, TP 12698E, 163.

5. Dawson, P., D'Avirro, J., *Evaluation of Fluid Thickness to Locate Representative Surfaces*, APS Aviation Inc., Montreal, October 1996, TP 12900E, 109.

APPENDIX A

TERMS OF REFERENCE - WORK STATEMENT

TRANSPORTATION DEVELOPMENT CENTRE

WORK STATEMENT
(revised* November 96)

AIRCRAFT AND FLUID HOLDOVER TIME TESTS FOR WINTER 95/96
(Short Title: Winter Tests 95/96)

1 INTRODUCTION

In the last decade, a number of fatal aircraft accidents have occurred in the winter at take-off during periods of precipitation that could contaminate aerodynamic surfaces; in several of these accidents the effectiveness of aircraft ground anti-icing has been suspect. Of particular importance to Canada was the crash of an Air Ontario F-28 at Dryden, Ontario on 10th March 1989, which led to a Commission of Inquiry led by Justice Moshansky.

The deicing fluids used on aircraft were originally expected to provide protection for the surfaces during only brief taxi and take-off periods. As traffic demand has grown, operations under more extreme weather conditions have increased, and traffic congestion on the airports has introduced lengthy line-ups for take off with the accompanying longer anti-icing protection requirement. This led to the development of the Type II anti-icing fluids for the jet aircraft and the Type III fluids for turboprops, both of which provide longer protection time (known as Holdover Time) following application. The times given in the official Holdover Time Tables were originally established by the Association of European Airlines (AEA) based on assumptions of fluid properties, and anecdotal data all related to operations in the European environment. These tables are published by the AEA, the Society of Automotive Engineers (SAE) and the International Standards Organization (ISO).

In a series of meetings on holdover time sponsored by the SAE Committee on Aircraft Ground Anti-icing involving the major airlines, aircraft manufacturers and anti-icing fluid producers, a program for field testing Type II fluids to establish holdover times in representative weather conditions was proposed. TDC took the lead in accepting to coordinate these activities for the 90/91 winter season with the participation of a number of carriers, deicing fluid manufacturers, the University of Quebec at Chicoutimi (UQAC), the National Research Council (NRC), and the Federal Aviation Administration (FAA). TDC undertook to prepare the test procedures and analyze and distribute all test results.

During the 90/91 season the methods of testing were developed and Type II and Type III fluids were tested. The Type II fluid results indicated that the times in the holdover tables were excessively long under normal winter snow conditions in North America. This led to the introduction of a range of time values for each condition (except frost) in the AEA/SAE/ISO tables, the original AEA value being retained for the high time and a new lower time from the TDC tests for the "worst" conditions.

For the 91/92 winter season TDC tests were made on Type III fluids exclusively because of the importance of this fluid to commuter operators.

With the release of the recommendations of the Dryden Inquiry in March, 1992 and the setting up of the Dryden Commission Implementation Project Office (DCIP), even greater support for these holdover tests was generated in Canada. Almost simultaneously the La Guardia crash of a F-28, also in March 1992 spurred the FAA to introduce Holdover Time regulations and to request that the SAE Committee on Aircraft Ground Deicing spearhead work on establishing holdover guidelines. This led to the formation of the holdover time working group, co-chaired by DCIP and FAA/ARC. Building on the earlier work initiated by TDC for the 90/91 and 91/92 winter seasons, a major test program was initiated to substantiate the existing holdover time tables. DCIP undertook to coordinate the expanded test program as part of its fulfilment of the recommendations of the Dryden Commission.

The 92/93 series of outdoor winter tests were in Montreal and involved revision of the test protocol, tests in both natural and artificial snow on flat plates, on simulated wings and on wing leading edges, and used a sensor to confirm fluid failure criteria. Type I, Type II and Type III fluids were tested. Simulated frosting, freezing fog and freezing rain conditions were tested at the NRC facilities in Ottawa. As a result of these tests large parts of the Type I and Type II tables were substantiated

For the 93/94 testing season, efforts were aimed at continuing the substantiation of the holdover tables and mostly involved testing diluted Type II fluids. All natural snow tests were made at Dorval, freezing fog at the NRC Helicopter Icing Facility and Freezing drizzle and freezing rain at the NRC Cold Environment Facility (CEF). In addition to the Instrumar sensor the RVSI remote sensor was also used to assist in collecting data. UCAR provided a new long lasting Type II fluid for preliminary testing.

An important effort was made in the 94/95 season to verify that the flat plate data were representative of aircraft wings. Air Canada cooperated with DCIP by making aircraft and limited ground support staff available at night to facilitate the correlation testing of flat plates with performance of fluids on aircraft. The new UCAR ULTRA fluid was extensive tested and resulted in a new TC/FAA holdover table providing 50% longer holdover times for use during the 95/96 winter season. Additional testing was undertaken to evaluate the suitability of hot air for de-icing as an alternative to heated de-icing fluids at low (e.g. -30^{0}C and below) ambient temperatures. wet snow. Tests were also performed to assess the potential for extending the use of hot water for de-icing from the current -3^{0}C limitation down to -7^{0}C or lower, where past experience has shown it feasible.

The winter 94/95 season testing was very restricted by the paucity of snow conditions and therefore much of the planned testing was not completed. Substantiation of the Type I and Type II tables needs certain special conditions hard to find in the field such as low temperatures with precipitation, and rain or other precipitation on cold soaked surfaces. The development of ULTRA by Union Carbide has stimulated all the manufacturers to produce new long lasting anti-icing fluids that will be defined as Type IV; all these fluids will contribute to the definition of the performance requirements for a generic Type IV. 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. The few aircraft tests made to validate the flat plate tests were inconclusive and more such tests are needed. The testing with hot water and with hot air for special deicing conditions have not been completed. All these areas are the subjects for the further research that is planned for the 95/96 winter.

2 PROGRAM OBJECTIVE (MCR 16)

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

3 PROGRAM SUB-OBJECTIVES

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

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

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

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

4 PROJECT OBJECTIVES

4.1 To complete the substantiation of the existing Type I and Type II SAE holdover time Tables by conducting cold soak tests and very low temperature tests.

4.2 To determine the holdover time performance of the proposed Type IV fluids over the range of characteristic conditions and create a generic Type IV holdover time table.

4.3 To establish the precipitation, wind and temperature values that delimit the holdover times given in the tables.

4.4 To validate that flat plate test data used to establish the SAE Type IV holdover time tables is representative of Type IV performance on service aircraft. under conditions of natural freezing precipitation.

4.5 To evaluate hot air de-icing as an alternative to heated de-icing fluids for frost removal at low ambient temperatures.

4.6 To undertake special tests of Type IV fluids in comparison with a Type II fluid at high rates of precipitation.

5. DETAILED STATEMENT OF WORK

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

5.1 Substantiation of Type I and Type II Tables

5.1A Laboratory "Cold soak" Test Program

Tests will be conducted at the Climatic Engineering Facility (CEF), of the National Research Council, Ottawa. APS will supply all necessary equipment and fluids for the conduct of the tests. Laboratory test should be performed after the field tests so that some temperatures can be chosen to match the field tests.

5.1.1 Develop an experimental plan to conduct tests, analyze results and prepare a report to provide values given for the SAE/ISO Holdover Time Tables for Type I. Type II and Type IV fluids using cold soaked boxes to simulate cold soaked wing conditions for a range of precipitation rates above and below freezing.
5.1.2 Include tests at +2°C and -7°C and at temperatures corresponding to selected field tests and cover a range of box temperatures from 0°C to -15°C and a range of precipitation rates, simulating rain, freezing drizzle and snow. These rates should be determined in consultation with personnel from AES and NRC. APS will use their own cold box designs.
5.1.3 Present the test plan to TDC Project Office for review Comment and approval.
5.1.4 Schedule tests with NRC and give advance notice of all intended tests to the TDC project officer.
5.1.5 Conduct tests in the NRC cold chamber using flat plates as benchmark
5.1.6 Analyze results from cold boxes and compare with the flat plate results

5.1B *Field "Cold soak" Test Program*

Conduct full scale aircraft cold soak experiments with the cooperation of local airlines. Use thermistors to measure temperatures on cold soak box and aircraft wing.

5.1C **Low Temperature Test**

Test Type I and Type II fluids on flat plates to establish holdover times at the lowest temperatures encountered in the winter. These test will be similar to those in the program of Type IV testing and will run concurrently with the Type IV tests

5.2 Program of Type IV

This program will test new "long-life" Type IV fluids over the entire range of conditions covered by the HOT Tables and will include outside testing under conditions of natural precipitation, and laboratory testing in the NRC CEF for tests involving freezing fog, freezing drizzle and light freezing rain.

5.2.1 Develop a program to test samples of the new Type IV fluids to establish holdover times over the full range of HOT table conditions.
5.2.2 Obtain samples from producers of qualified Type IV fluids
5.2.3 Establish a test site for the conduct of outside tests at Montreal, Dorval Airport

5.2.4 Arrange for support services and appropriate facilities.
5.2.5 Recruit and train local personnel .
5.2.6 Repair and replace TDC supplied equipment used for testing in previous years as necessary.
5.2.7 In consultation with TDC, devise a method to evaluate the precipitation type in order to assess the effects of wet and dry snow on visibility in precipitation.
5.2.8 Install an ETI precipitation gauge at Dorval to study its correlation with the READAC gauge and the plate pans.
5.2.9 Acquire data from the READAC station at Dorval on a minute-by-minute basis.
5.2.10 Give advance notice of all intended tests to the TDC project officer.
5.2.11 Conduct tests during periods of freezing precipitation concurrent with HOT Table substantiation tests of conventional fluids. For Type I,II and IV fluids, frequent testing should be conducted under natural precipitation conditions when temperatures are below -14°C.
5.2.12 Coordinate scheduling of the indoor tests with the NRC.
5.2.13 Install Instrumar's C/FIMS on at least one plate, if available RVSI's and SPAR remote sensor will be set up to view the stand holding six standard test plates. All sensors will be used for both the chamber tests and all the field tests where feasible. Determine fluid failure by visual observation
5.2.14 Conduct tests with simulated freezing fog, freezing drizzle and light freezing rain in the NRC CEF facility, Ottawa, supplying the necessary materials and equipment for tests.
5.2.15 Conduct ancillary tests at Dorval and the NRC Chamber to study the effect of HOT's of successive application of new and conventional Type II fluids on clear and contaminated Type I's.
5.2.16 Collect visibility data during periods of freezing precipitation at Dorval and correlated with concurrent meteorological data, including precipitation rate, precipitation type, temperature, wind velocity and direction as appropriate.
5.2.17 Present program results and plans for completion for a "mid-term" review to be called by TDC.
5.2.18 Video tape the tests for archival purposes
5.2.19 Test results will be collected, analyzed and a report produced.

5.3 Weather

The significance of weather conditions in the holdover time tables needs to be defined the high time value represents "light"" conditions and the shortest time is the boundary for a "heavy" condition. Some evaluation of these terms shall be developed on the basis of existing and current data.

5.3.1 Review weather conditions for test data from all years and all sites for the cases where failure time lay outside the range in the tables for Type I and Type II fluids
5.3.2 Study extreme weather conditions during the 1995/96 winter tests at Dorval using a Type 1 fluid to evaluate "Light" conditions and a Type II to evaluate "heavy" conditions
5.3.3 Analyze the data with respect to the parameters of experimental site, weather conditions, fluid type and fluid manufacturer to establish relationships between weather parameters and holdover time values
5.3.4 Recommend caution statements to go into the holdover time tables
5.3.5 Recommend revisions to the fluid performance tests.

5.4 Performance of Ultra Fluids on Flat Plates Versus Aircraft Surfaces

This test program will be conducted at Dorval International Airport, using aircraft made available by an airline, and, subject to weather conditions, will include three (3) all night test sessions. In general, aircraft will be made available for testing outside regular service hours, i.e. available between 23:00 hrs. and 06:00 hrs. Tests will be conducted to verify that fluid failures on the flat plates used to develop HOT guidelines for the new fluid occurred before failure on the aircraft wings. Depending on the site selected for these tests, it is expected that Air Canada will be providing ancillary equipment and services as stipulated in their agreement with Transport Canada for the 1994/95 winter; this equipment will include lighting fixtures as necessary, observation platforms, vehicles, storage facilities, office facilities and personnel rest accommodation. Additional tests, if required, may be requested subject to agreement by all parties involved.

5.4.1 Develop an experimental program for concurrent comparison testing of fluids under conditions of natural freezing precipitation on flat plates and on aircraft.

5.4.2 ***Prepare the following test plan features, plans and procedures:***

a) A detailed statement of work for each of the participants;

b) A specific test plan, for review by all parties, which will include as a minimum:

- Schedule and sequence of activities;
- Detailed list of responsibilities;
- Complete equipment list;
- List of data, measurements and observations to be recorded; and
- Test procedures.

c) Activities including:

- Visual and Instrumented Data Logging;
- Monitoring and recording environmental conditions, including:
  - Air temperature,
  - Wing surface temperature at selected locations,
  - Wind velocity and direction, and
  - Precipitation type and rate;
- Record of aircraft and plate orientation to the wind; and
- Use of instrumentation to determine the condition of the fluid.

d) Acquisition of data from the tests will address:

- Identification of fluid failure criteria;
- Location of first point of fluid failure on the wing, and subsequent failure progression;
- Correlation of fluid failure time to environmental conditions;
- Correlation of fluid failure times on flat plates and aircraft; and
- Behaviour of fluid on the "representative" surface.

5.4.3 Present the experimental programs for review and approval by the TDC project officer.

5.4.4 Arrange (with the cooperation of TDC) for deicing equipment and aircraft representative of those in common use by airlines in Canada to be made available for the tests .

5.4.5 Present the approved program to the airline involved prior to the start of field tests.

5.4.6 Recruit and train local personnel who will conduct test work.

5.4.7 Provide all equipment and all other instrumentation necessary for conduct of tests and recording of data.

5.4.8 Arrange for the provision of fluids by UCAR for spraying an aircraft.

5.4.9 Secure necessary approvals and passes for personnel and vehicle access for operation on airport airside property

5.4.10 Schedule tests on the basis of forecast significant-duration night-time periods of freezing precipitation;

5.4.11 Provide advance notice to Air Canada of the desired test set-up, including aircraft orientation with respect to the forecast wind direction, sequence of fluid applications, and any additional services requested.

5.4.12 Confirm that the de-icing equipment used for the tests is equipped with a nozzle suitable for the application of Ultra fluids. Application of fluids will be by airline personnel.

5.4.13 Arrange for spray application during the initial tests to be observed by the fluid manufacturer's representative for endorsement.

5.4.14 Orient the aircraft with leading edge into the wind on two occasions and trailing edge into the wind on the third occasion.

5.4.15 Conduct tests of Type II Ultra plus fluid on standard flat plates and aircraft, using Ultra on the plates as a benchmark fluid along with a standard Type II when available.

5.4.16 Record the progression of fluid failure on the wing over the series of tests conducted.

5.4.17 Videotape records of all tests will be made.

5.4.18 Return any equipment obtained from airlines for use during the tests to its original condition at the end of the test program.

5.4.19 Assemble and analyze all results

5.5 Frost Removal

Frost alleviation and removal by "sweep and shine" and hot air shall be explored.

5.5.1 Sweep and Shine

Tests shall be conducted at very low temperatures to evaluate the efficacy of sweep and shine. Micromeasurements of frost shall be made prior to tests and following various amounts of sweeping. Numbers of crystals per area will be noted along with their height and shape to indicate roughness level

5.5.2 Hot Air

Successful application of hot air for frost removal is dependent on provision of a well designed air application tool; one that is user friendly and will provide speedy and effective results. provision will be made to evaluate prototype equipment in conjunction with an airline and a manufacturer.

5.6 Wing Surface Visibility Study

Examine various options to enhance visibility of failed wing surfaces from inside the cabin and flight deck and make recommendations.

5.7 Representative Surfaces Guidelines Study

5.7.1 Study the optimum locations for representative surfaces on specific test aircraft wings.

5.7.2 Develop generic guidelines for defining the optimum locations for representative surfaces on any aircraft and for installation of wing contamination sensors.

5.8 *Heavy Precipitation Type IV Tests*

Using the NRC CEF, test all qualified Type IV fluids at 100% concentration along with a standard Type II fluid as a benchmark at simulated high precipitation rates of 25gm/dm2/hr and at low temperatures close to -7C.

5.9 Presentations of test program results

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

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

5.10 Reporting

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

5.10.1 Substantiation of HoldOver Time Tables

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

5.10.2 Reporting of Other Testing

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

APPENDIX B

EXPERIMENTAL PROGRAM

RAIN ON COLD-SOAKED WING FULL-SCALE AIRCRAFT TRIALS

EXPERIMENTAL PROGRAM
RAIN ON COLD SOAKED WING FULL-SCALE AIRCRAFT TRIALS

Winter 1995/96
Version 1.1

This document provides the detailed procedures and equipment required for the conduct of rain on cold soaked wing full-scale aircraft trials for the 1995/96 winter season.

1. OBJECTIVE

To verify values determined in laboratory experiments for fluid holdover times in conditions simulating rain on cold soaked wings, and to verify the thermal time constants used for scaling the laboratory cold soak boxes to the wing.

2. TEST REQUIREMENTS

APS will coordinate a series of tests at Dorval airport, or at other airports if necessary. Tests will be planned and coordinated on the basis of forecasted weather conditions and aircraft availability.

Two types of tests will be conducted. The first of these (**wing temperature profile test**) has the objective of developing a wing temperature profile for the cold soaked wing, recording the rise in wing surface temperature over time. This data will be used to support rain on cold soaked wing experiments in a laboratory setting utilizing sealed cold-soak boxes to represent the wing. Test conditions for this test include an ambient outside temperature of 0°C to +5°C. with no precipitation. This test does not involve application of de-icing fluid. Data made available by McDonnell Douglas based on similar experiments will be analyzed in conjunction with results of this test.

The second type of test has the objective of measuring fluid holdover times (**cold soaked wing HOT test**) on cold soaked wings of a full-scale aircraft. Test conditions for this test type include an ambient outside temperature of 0°C to +5°C. with light to moderate rain. Type I and Type IV fluids will be tested. Results of this test will be analyzed together with the results of laboratory trials to provide substantiated HOT table values.

Current APS Aviation staff will be utilized during tests as necessary.

Arrangements will be made with an airline for aircraft, staff, and de-icing equipment availability.

Aircraft with sufficient quantities of cold soaked fuel in the wing tanks to represent typical cold soaked wing situations are required. Typical wing surface temperatures sought are -10° to -15°C. The DC-9/MD80 family of aircraft are favoured subjects for trial, due to fuel tank design which causes the wing to be susceptible to cold soaking. Other aircraft types will be considered as test subjects depending on participating airline, aircraft availability, and whether the proposed aircraft is susceptible to cold soak wing surface conditions.

Arrangements will be made with the participating airline to support aircraft arrival with sufficient cold soaked fuel on-board to develop a cold soaked wing for test purposes. The duration of the inbound flight and the quantity of fuel boarded at origin are considerations.

Test aircraft will need to be made available for tests as soon as possible after arrival to take full advantage of fuel temperatures which have been cold soaked during flight.

Conducting wing temperature tests (which do not involve application of fluids) at the arrival gate may be appropriate. For cold soaked wing HOT tests, speedy handling of the aircraft on arrival, and towing to the de-icing area will require co-ordination. Access to the aircraft at the gate will be needed to allow installing temperature probes on the wing (on the side not interfering with ramp operations) immediately after arrival.

Both test types will involve installation of thermistor temperature probes at pre-selected points on the upper and lower wing surface to provide data to develop a wing surface temperature profile over time during the tests.

Cold soaked wing HOT tests will involve deicing the wing, and applying the test fluid over the cold soaked area of the wing surface. The trial will record time duration until fluid failure occurs. Event times will be recorded. Actual amount and rate of precipitation will be measured for each test. Thickness of the anti-icing fluid film as applied will be recorded.

Fluids to be tested are XL54 and Ultra.

Other data recorded will include ambient meteorological conditions, data on fluid sprayed, and visual observations of the condition of the fluid on the wing.

Conduct of the trial will be photographed and video taped to demonstrate the test set-up and procedures, and fluid condition at failure.

3. EQUIPMENT

Equipment to be employed is described in Attachment II.

4. PERSONNEL

Five personnel are required for temperature profile tests; six for HOT tests. A description of the responsibilities and duties of each person is provided as guidelines in Attachment III.

5. PROCEDURE

The test procedure is included in Attachment IV.

6. DATA FORMS

The data forms are listed below:

Figure 2	General Form
Figure 3	Data Form - Wing Temperature Profile
Figure 4	Data form - Rain on Cold soaked Wings HOT Trials
Figure 5	Meteo/Plate Data Form

ATTACHMENT I

RAIN ON COLD-SOAKED WING FULL-SCALE AIRCRAFT TRIALS
TEST PLAN

WING TEMPERATURE PROFILE TESTS

RUN #	OCCASION #	WING	FLUID TYPE	A/C Type
1	1	Stbd	Nil	RJ
2	2	Port	Nil	MD-80

COLD-SOAKED WING HOT TESTS

RUN #	OCCASION #	WING	FLUID TYPE	A/C Type
3	3	Port	XL54	MD-80
4	3	Port	Ultra	MD-80
5	3	Port	Ultra	MD-80
6	4	Port	XL54	MD-80
7	4	Port	Ultra	MD-80
8	4	Port	Ultra	MD-80
9	5	Stbd	XL54	RJ
10	5	Stbd	Ultra	RJ
11	5	Stbd	Ultra	RJ

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14/11/96

ATTACHMENT II

RAIN ON COLD-SOAKED WING TRIALS

TEST EQUIPMENT CHECKLIST

TASK	***Montreal***	
	Resp.	**Status**
Logistics for Every Test		
Passes		
Call Personnel (JD, PD, ZB, GT, ML, MH, ER, JFB, JM)		
Advise Airlines (Personnel, A/C Orientation, Equip)		
Monitor Forecast		
Test Equipment		
Supply of AA cells		
Video Cameras X 2 + 15 batteries + 2 chargers		
Thickness Gauges - 4 hand held, 2 mounted on poles		
General Data Forms		
Aircraft Wing Forms		
Compass		
Tape measure		
Clipboards X 4		
Space pens and pencils X 6		
Paper Towels		
Electrical Extension Chords x 8 minimum		
Lighting x 6 single black & 3 double yellow poles		
Tools		
Flashlights		
Cloth wipers for gauges		
Cotton gloves (mechanics type)		
Stop watches		
Pylons		
Laser Pointers		
Storage bins for small equipment		
Temperature Probe x 2 (pole mounted)		
Thermometer (digital hand held)		
Protective clothing (pants + coats)		
Glass thermometer		
Refractometer + brixometer		
Methyl Alcohol		
Plate Pans x 3		
Scale		
Thermistor kit including: 1. thermistor probes 2. temperature loggers 3. data cables 4. laptop PC x 2 5. aluminum tape 6. rubber tape 7. Putty/Gel		
Whistle		
Still camera		
Rolling Stairs x 6		
OTHER TEST EQUIPMENT (1)		
XL 54 Fluids for wings (UCAR)		
Ultra Fluids for wings (UCAR)		
Spray vehicle for XL54 x1 (A/L)		
Spray vehicle for Ultra x1 (A/L)		
Test Aircraft		
Storage Facilities (A/L)		
Fluid Collection Facilities		
Electrical Power (A/L)		
Airline Personnel		

(1) To be provided by others

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ATTACHMENT III

RAIN ON COLD SOAKED WING FULL-SCALE AIRCRAFT TRIALS
RESPONSIBILITIES/DUTIES OF TEST PERSONNEL

Refer to Figure 1 for position of equipment and personnel. Refer to the test procedure Attachment IV for more detail.

WING TEMPERATURE PROFILE TESTS

Observers L1, T1

- Collect temperature readings using pole mounted probes during initial period until thermistor probes are installed and operational.
- Install thermistor probes at locations designated on the wing plan form Figure 4). This will require one person working from the de-icing vehicle bucket.
- Dismantle thermistor probes at end of test ensuring that all traces of tape are removed.
- Replace equipment to storage locations at end of test.

Observer O1

- Obtain following data and record on the General Data Form; aircraft and fuel load, weather conditions.
- Manage the data logger equipment: clear previous data prior to test; synchronize time; ensure initial and ongoing integrity of logger and thermistor probe installation by monitoring "real time" display; download data to PC following test completion.
- Identify and record on wing plan form cold soak area expected from fuel on-board quantity.
- Note on wing plan the locations for installation of thermistor probes.
- Note and record information specified on the general data form.
- Assist team coordinator.

Test Coordinator

- Team leader.
- Responsible for test area and test team.
- Authority on test procedures and conditions.
- Coordinate activities of APS team and airline personnel.
- Responsible for deciding when tests will be conducted based on weather condition observations and forecasts. Coordinate with airline contact.
- Alert team personnel to conduct the tests.
- Assign tasks to team personnel. Provide briefings as needed.
- Review data forms at test completion for completeness and accuracy.
- Ensure all clocks and video are synchronized.
- Ensure proper documentation of video tapes.
- Monitor test procedure in progress to ensure proper application.
- Call end of test based on temperature stabilizing.
- Ensure that the site is returned to original condition. Final site inspection to ensure no objects left at the site that could cause FOD.

Video Operator

- Ensure proper lighting.
- Mobile.
- Understanding of test objectives and procedures.
- Video aircraft test set-up including installation of thermistor probes to indicate measurement locations, and any temperature sampling using hand held probes.
- Take still photos showing instruments, setup, measurements, etc.

COLD SOAKED WING HOT TESTS

Observers L1, T1

- Collect temperature readings using pole mounted probes during initial period that aircraft is at gate, and at de-icing centre; until thermistor probes are installed and operational.

- Setup rolling stairs, lights and cables.

- Install thermistor probes at locations designated on the wing plan form Figure 4). This will require one person working from the de-icing vehicle bucket.

- Dismantle thermistor probes at end of test ensuring that all traces of tape are removed.

- Replace the rolling stairs, lights and cables and other equipment to storage locations at end of test.

- During the test, be located on the stairs at the assigned position.

- Measure and record initial fluid thickness at each probe point.

- Monitor fluid condition for failure; record failure event times and observations.

Observer R1

- Responsible to manage rain collection plate pan and record results using Meteo/Plate Pan Data Form (Figure 5). Three plate pans will be required.

- Assist in setting up and dismantling test.

Observer O1

- Obtain fluid samples; measure and record brixometer readings.

- Manage the data logger equipment: clear previous data prior to test; synchronize time; ensure initial and ongoing integrity of logger and thermistor probe installation by monitoring "real time" display; download data to PC following test completion.

- Note and record information required on the general data form.

- Assist team coordinator.

Test Coordinator

- Team leader.
- Responsible for test area and test team.
- Authority on test procedures and conditions.
- Coordinate activities of APS team and airline personnel.
- Responsible for deciding when tests will be conducted based on weather condition observations and forecasts. Coordinate with airline contact.
- Alert team personnel to conduct the tests.
- Assign tasks to team personnel. Provide briefings as needed.
- Review data forms at test completion for completeness and accuracy.
- Ensure all clocks and video are synchronized.
- Ensure proper documentation of video tapes, and of fluid samples.
- Monitor test procedure in progress to ensure proper application.
- Call end of test based on fluid failure.
- Ensure that the site is returned to original condition. Final site inspection to ensure no objects left at the site that could cause FOD.

Video Operator

- Install PVC tubes on stairs with duct tape.
- Ensure proper lighting.
- Mobile.
- Understanding of test objectives and procedures.
- Video aircraft test set-up including installation of thermistor probes to indicate measurement locations. Videotape fluid application procedure, and fluid thickness measurement process.
- Videotape and photograph fluid failure condition.
- Take still photos showing instruments, setup, measurements, etc.

ATTACHMENT IV

RAIN ON COLD SOAKED WING FULL-SCALE AIRCRAFT TRIALS

TEST PROCEDURE

1. Preparation

Wing fuel tank characteristics for the test aircraft types will be examined and discussed with the participating airline to determine on-board fuel quantity required to produce a cold soaked wing surface area for test purposes.

Procedures will be developed to identify specific inbound flights for test purposes and to arrange for a sufficient quantity of fuel to be boarded at origin on the day of test.

As on-board fuel will start to gain temperature at arrival, access to the aircraft as soon as possible after arrival is important. Ways of speeding up access will be examined with the airline, and a procedure will be developed that minimizes delay to test initiation following arrival.

A procedure to delay re-fuelling until test completion will be instituted.

Locations on the wing where thermistor probes will be installed will be pre-defined and specified on the wing plan form. The pattern of attachment point locations will be selected to provide optimum discrimination of data. As the wing surface temperature will be influenced both by fuel wetting and by thermal conductivity of major structural components that are immersed in fuel, probes will be located at structural component rivet lines where possible.

2. Pre-Test Set-Up

Monitor weather forecasts seeking a period;

- for wing temperature profile tests - temperatures of 0° to +5°C; with no precipitation,
- for cold soaked wing HOT tests - temperatures of 0° to +5°C; with light to moderate rain.

Discuss with airline contacts 48 hours prior to intended test, ensuring understanding of which type of test is being proposed. Confirm on day of test. Confirmation will trigger events in the airline to board additional fuel to produce the cold soaked wing.

Advise all involved including TDC Project Officers.

For cold soaked wing HOT tests;
- Locate aircraft at the de-icing centre
- Arrange for de-icing vehicle with heated Type I and cold Ultra fluids.

Brief all involved on the objectives of the trials, the data and observations to be gathered, and the roles and tasks of each participant.

Technicians will be instructed on equipment use.

The video recording technician will be briefed on the type of detail desired.

Synchronize time on stopwatches, video cameras and temperature loggers.

Clear data logger of previous data.

Check video equipment for functioning.

WING TEMPERATURE PROFILE TESTS

3. Test Procedure

Record data on the General Test Data Form reporting on weather conditions, aircraft and on board fuel data and team member names.

These tests may be conducted at the gate in order to eliminate delays following flight arrival. Normally the ramp area at the port wing area is free from ground operations activities, and will be the wing selected for test.

If there is a delay in access to the wing, record the wing skin surface temperatures in the expected cold soaked area using the hand held temperature probes mounted on poles. Also record the temperature of the underside of the wing to serve as an indication of fuel temperature.

Install thermistor probes on the upper wing surface in accordance with the wing plan form (Figure 4). Install a probe on the underside of the wing to serve as an indication of fuel temperature. Installation of probes on the wing will require access from a deicing truck bucket.

Monitor the temperature probe readings, and wait for the surface temperature to reach OAT.

Video tape and photograph the installation procedure, and the locations of probe attachment.

4. End of Test

The test will be terminated when the wing skin temperature reaches ambient OAT.

Download data from the data loggers to the laptop PC.

Collect all data forms, voice and video tapes.

Ensure data form is completed for end of test and other data.

5. Post Test

Dismantle thermistor probes from the wing, ensuring that all traces of tape are removed.

Restore test area to pre-test condition.

COLD SOAKED WING HOT TESTS

6. Test Procedure

Record data on the General Test Data Form reporting on weather conditions, aircraft and on board fuel data and team member names.

While the aircraft is being off-loaded at the gate after arrival and while awaiting for it to be moved to the de-icing area, begin installing thermistor probes in accordance with the wing plan form (Figure 4). While this is in progress, measure wing skin surface temperatures at the locations where thermistor probes are to be installed by use of the hand held temperature probes mounted on poles, and record on the data form (Figure 3). Indicate the locations sampled. Include a record of the temperature of the underside of the wing to serve as an indication of fuel temperature.

When the aircraft has been towed to the de-icing area, finalize installation of probes, including on the underside of the wing to serve as an indication of fuel temperature. Installation of probes at the mid-chord point of the wing will require access from a deicing truck bucket.

If ice has already started to form on the wing, de-ice with Type I fluid.

Follow flat plate fluid holdover test procedures using plate pans to measure rain intensity and quantity.

Spray the test fluid over the entire wing.

Position stairs with lights at locations where they can quickly be moved to the wing for monitoring fluid failure.

Record the thickness of fluid film at each of the temperature probe installations, and record on data form (Figure 4).

Monitor the fluid for signs of failure following standard failure criteria described in "Flat Plate Fluid HOT Trials" ; record failure events. Note observations on nature of failure.

Include observations from within the cabin to determine visibility of failure from that location.

Monitor and note any ice formation on the underside of the wing.

Collect samples of fluid from the wing surface following onset of fluid failure.

Video tape and photograph the installation procedure, and the locations of probe attachment.

7. End of Test

Each test run will be terminated when the test fluid fails.

Ensure data form is completed for end of test and other data.

At the end of all testing, download data from the data loggers to the laptop PC.

Collect all data forms, voice and video tapes.

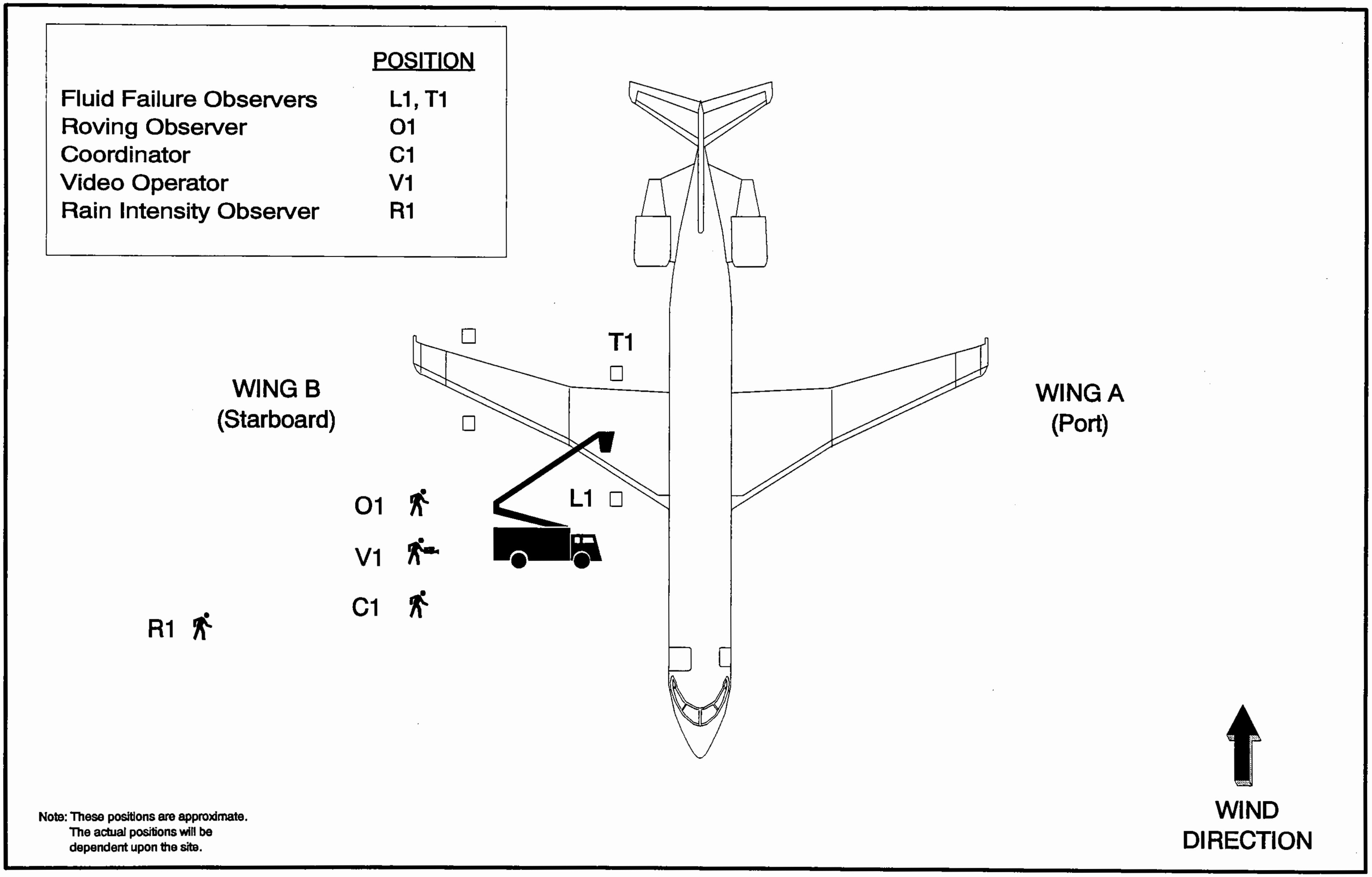
8. Post Test

Dismantle thermistor probes from the wing, ensuring that all traces of tape are removed.

Restore test area to pre-test condition.

FIGURE 1

POSITION OF EQUIPMENT AND PERSONNEL
RAIN ON COLD SOAKED WING HOT TRIALS



	POSITION
Fluid Failure Observers	L1, T1
Roving Observer	O1
Coordinator	C1
Video Operator	V1
Rain Intensity Observer	R1

Note: These positions are approximate.
The actual positions will be
dependent upon the site.

G:\BM2980\PROCEDUR\COLDSOAK\YULSETUP.DRW

FIGURE 2

GENERAL FORM
RAIN ON COLD-SOAKED WING FULL SCALE AIRCRAFT

AIRPORT: YUL

AIRCRAFT TYPE: A320 DC-9 B-737 RJ BAe 146

EXACT LOCATION OF TEST: ______

AIRLINE: ______

DATE: ______

FIN #: ______

RUN #: ______ **a/c Direction:** ______ degrees

FUEL LOAD: ______ LB / KG

1st FLUID APPLICATION

Actual Start Time: ______ am / pm

Actual End Time: ______ am / pm

Start of Fluid Gauge: ______ L / gal

End of Fluid Gauge: ______ L / gal

Type of Fluid: ______

Truck #: ______

Fluid Temperature: ______

Fluid Nozzle Type: ______

2nd FLUID APPLICATION

Actual Start Time: ______ am / pm

Actual End Time: ______ am / pm

Start of Fluid Gauge: ______ L / gal

End of Fluid Gauge: ______ L / gal

Type of Fluid: ______

Truck #: ______

Fluid Temperature: ______

Fluid Nozzle Type: ______

Weather Conditions

OAT ______ ° C

Relative Humidity ______ %

Wind Speed ______ km/h

Wind Direction ______ degrees

Team Assignments

O1 ______

P1 ______

V1 ______

P2 ______

C1 ______

Airline Team

______ ______

______ ______

Observers

______ ______

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FIGURE 3

REMEMBER TO SYNCHRONIZE TIME

DATA FORM FOR RAIN ON COLD-SOAKED WINGS TEMPERATURE PROFILE

Winter 95/96

LOCATION: YUL **DATE:** **RUN NUMBER:** **WING # :**

Initial Temperature Data with hand Held Probes

1		2		3		4		5		6		7		8		9		10		11		12		13		14	
Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)

RJ

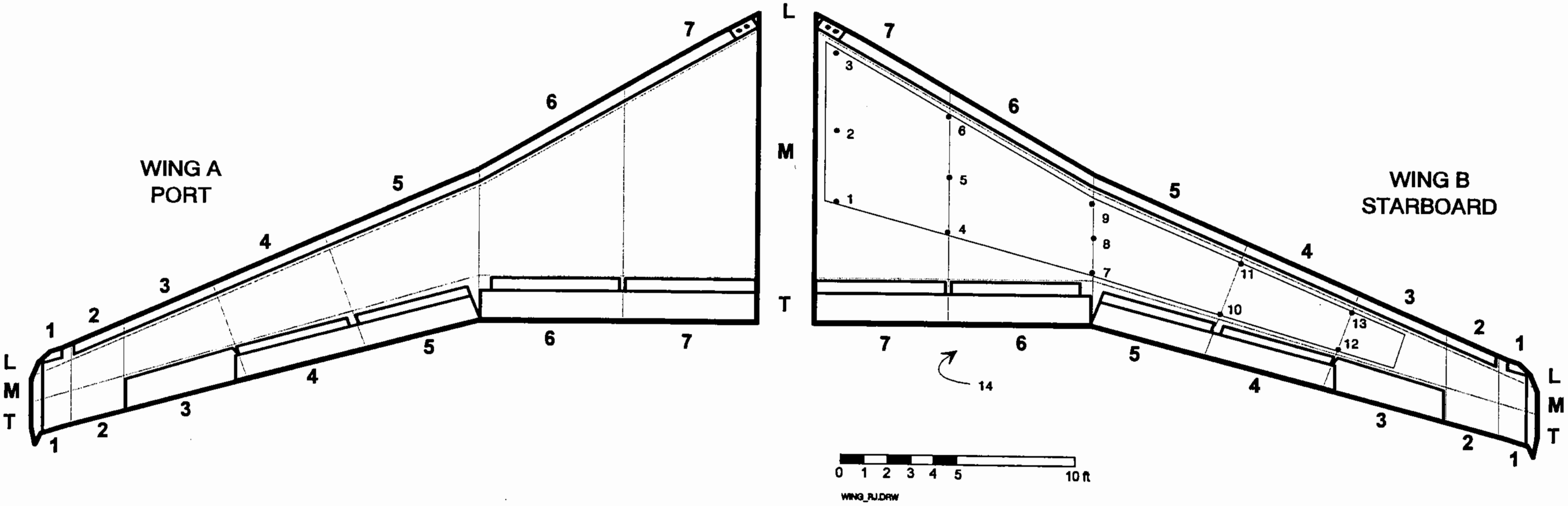

FIGURE 3

DATA FORM FOR RAIN ON COLD-SOAKED WINGS TEMPERATURE PROFILE

REMEMBER TO SYNCHRONIZE TIME

Winter 95/96

LOCATION: YUL **DATE:** **RUN NUMBER:** **WING # :**

Initial Temperature Data with hand Held Probes

1		2		3		4		5		6		7		8		9		10		11		12		13		14	
Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)	Time (hh:mm)	Temp. (°C)

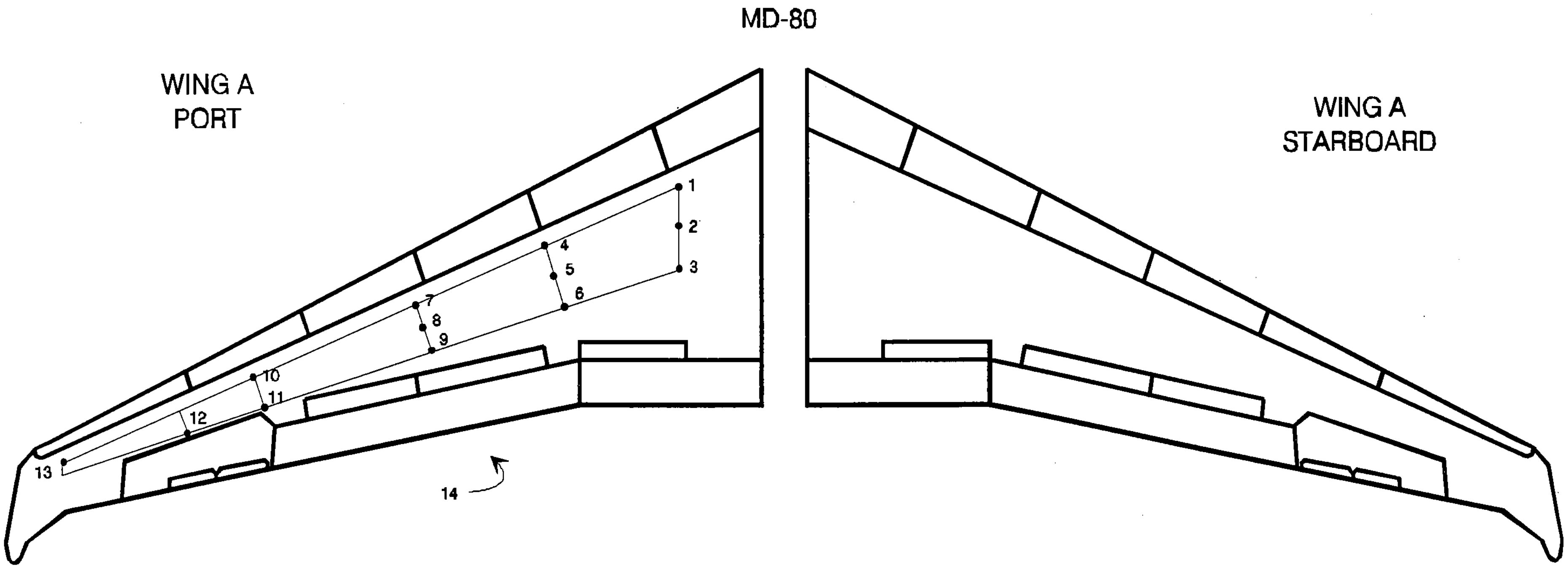

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FIGURE 4

DATA FORM FOR RAIN ON COLD-SOAKED WINGS HOT TRIALS

REMEMBER TO SYNCHRONIZE TIME

Winter 95/96

LOCATION: YUL **DATE:** **RUN NUMBER:** **WING # :**

TIME OF FLUID APPLICATION:_______________ (hr:mm:ss)

FAILURES CALLED BY:________________________

COMMENTS:____________________

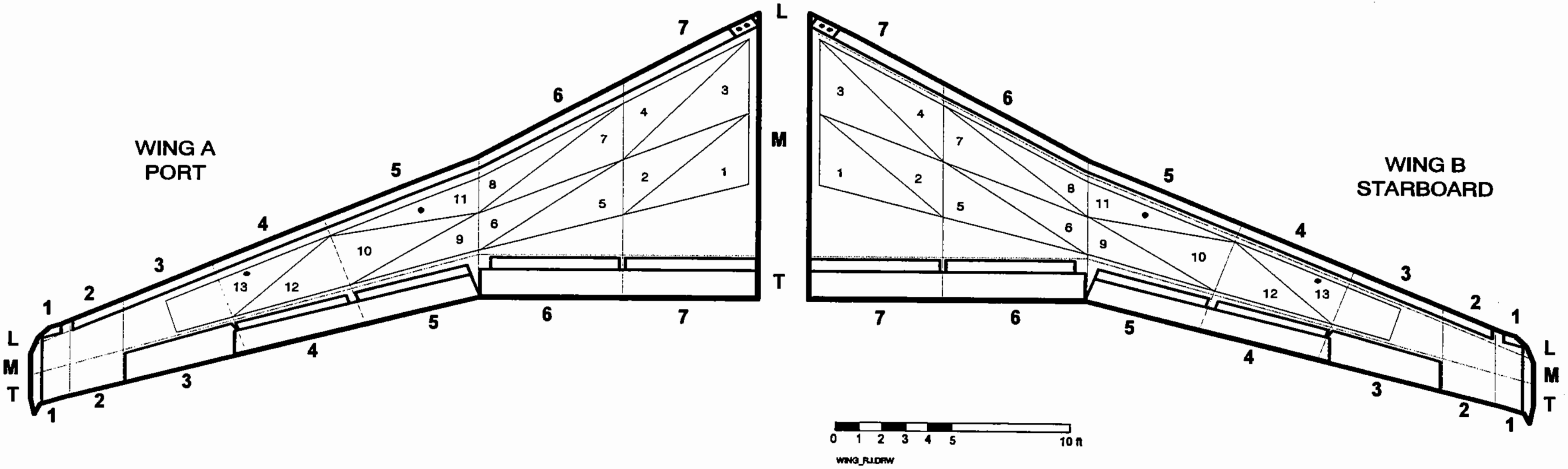
____

____

GRID	FLUID THICKNESS (mil)		FLUID FAILURE TIME (min)	
AREA	TIME	GAUGE	FIRST	100%
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				

DRAW FAILURE CONTOURS ACCORDING TO THE PROCEDURE

RJ



File: g:/cm1283/procedur/full_scl/coldsoak/TPRF2_RJ.XLS Printed: 18/03/96

FIGURE 4

DATA FORM FOR RAIN ON COLD-SOAKED WINGS HOT TRIALS

REMEMBER TO SYNCHRONIZE TIME

Winter 95/96

LOCATION: YUL **DATE:** **RUN NUMBER:** **WING # :**

TIME OF FLUID APPLICATION: ____________ **(hr:mm:ss)**

FAILURES CALLED BY: ___________________

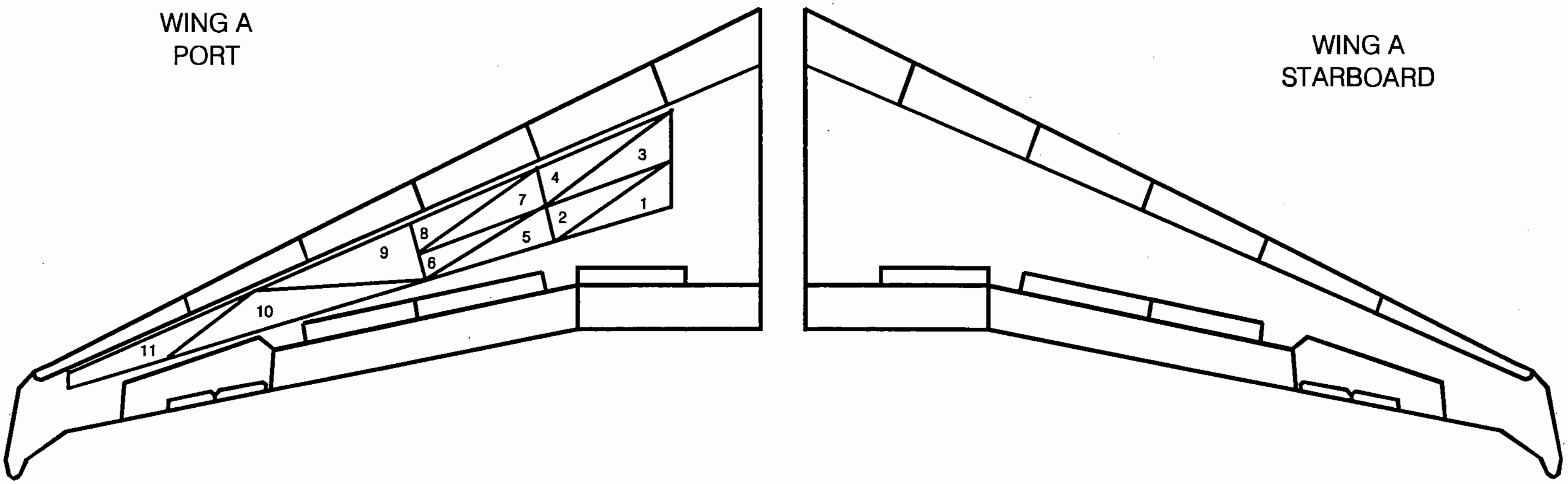
COMMENTS:_______________________

____

GRID AREA	FLUID THICKNESS (mil)		FLUID FAILURE TIME (MIN)	
	TIME	GAUGE	FIRST	100%
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				

DRAW FAILURE CONTOURS ACCORDING TO THE PROCEDURE

MD-80



File: g:/cm1283/procedur/full_scl/coldsoak/V2-2MD80.XLS Printed: 22/04/96

FIGURE 5

METEO/PLATE PAN DATA FORM

REMEMBER TO SYNCHRONIZE TIME WITH AES - USE REAL TIME

VERSION 3.0

Winter 95/96

LOCATION:

DATE:

PLAN # (see Attachment I):

RUN # :

STAND # :

RVSI VIDEO CASSETTE #:

Real Time After Fluid Applied to Plates U and X: am / pm

VIDEO CAMERA (PANNING) CASSETTE #:

HAND HELD VIDEO CASSETTE #:

PLATE PAN WEIGHT MEASUREMENTS *

PAN #	t TIME BEFORE (hr:min)	t TIME AFTER (hr:min)	w WEIGHT BEFORE (grams)	w WEIGHT AFTER (grams)	COMPUTE RATE (Δw*4/ Δt) (g/dm^2/h)

*measurements every 15 min. and at failure time of each test panel.

METEO OBSERVATIONS **

TIME (hr:min)	TYPE (Fig. 4) ZR, ZL,S, SG IP, IC, BS, SP	AMOUNT + +, +, -, --	CLASSIF. (See Fig. 3)	Visibility (day only)	If SNOW, WET or DRY	TEMP °C	WIND SPEED	WIND DIR.

**observations at beginning, end, and every 15 min. intervals. Additional observations when there are significant changes.

COMMENTS :

	PRINT	SIGN
WRITTEN & PERFORMED BY :		
VIDEO BY :		
TEST SITE LEADER :		

File:g:\cm1283\procedur\coldsoak\METEO.XLS
Meteo & Pan

APPENDIX C

EXPERIMENTAL PROGRAM TO MEASURE TEMPERATURE PROFILES OF COLD-SOAKED BOXES

EXPERIMENTAL PROGRAM TO MEASURE TEMPERATURE PROFILES OF COLD-SOAK BOXES

Winter 1995/96
Version 1.1

This document provides the detailed procedures and equipment required for the conduct of trials to evaluate the effect of rain, in combination with different de-icing fluids, on temperature profiles of cold-soak boxes.

1. OBJECTIVE

To measure the effect of rain on the temperature profile of cold-soak boxes.
To measure the effect of de-icing fluids on the temperature profile of cold-soak boxes.

2. TEST REQUIREMENTS

APS will conduct tests at the Dorval Airport AES Test Site.

Tests will be designed to record the temperature profiles of two designs of cold- soak boxes (7.5 cm and 2.5 cm. deep). The boxes will be insulated from ambient air except on the top plate surface, and filled with fluid. Two thermistor probes will be installed on each box, at the 6 inch line corresponding to the position specified for laboratory cold-soak tests, and at the 15 inch line. The boxes will be placed in the freezer at least four days before test with the objective of achieving a common temperature of -25°C or lower. The data loggers will be connected (located outside the freezer) and thermistor probe data will be logged during the cooling period. Data sampling frequency will be adjusted to enable data logging over this entire period.

Test variables will be precipitation conditions and test fluids. One test will be conducted in dry conditions and one in conditions of light rain. Test outside air temperatures will be in the range of 0° to +5°C.

Logger data will be saved prior to removing boxes from the freezer, and data sampling frequency adjusted to 8 seconds.

Cold-soak boxes will be taken from the freezer for test, with probes and data logger still installed, and placed on the flat plate test stands.

Fluids as specified in the Test Plan (Attachment I) will be poured on the plates. A procedure will be followed to ensure the same box is used for each designated fluid in the two tests.

Rate of precipitation will be measured following the standard test process.

Temperature data will be recorded using data logger.

Tests will run until box temperatures reach outside air temperature.

3. EQUIPMENT

Equipment for this test is listed in Attachment II.

4. PERSONNEL

Two personnel are required to conduct these tests.

5. PROCEDURE

The procedure is as described above under "TEST REQUIREMENTS".

6. DATA FORMS

The data form required is:

- Figure 1 Meteo/Plate Data Form

ATTACHMENT I

FIELD TESTS - COLD-SOAK BOXES

TEST PLAN

RUN #	FLUID Type	COLD-SOAK Box Type	PRECIPITATION	PROBE #	
				6"	15"
1	Dry	2.5 cm	Dry		
2	Type I (cold)	2.5 cm	Dry		
3	Type IV	2.5 cm	Dry		
4	Hot Water	2.5 cm	Dry		
5	Dry	7.5 cm	Dry		
6	Type I (cold)	7.5 cm	Dry		
7	Type IV	7.5 cm	Dry		
8	Dry	2.5 cm	Light Rain		
9	Type I	2.5 cm	Light Rain		
10	Type IV	2.5 cm	Light Rain		
11	Hot Water	2.5 cm	Light Rain		
12	Dry	7.5 cm	Light Rain		
13	Type I	7.5 cm	Light Rain		
14	Type IV	7.5 cm	Light Rain		

Notes: Boxes precooled to -25°C approximately.
Hot water temperature 82°C approximately (150°F).
Fluid quantities 1.5L plate.

File:g:/bm2980/procedur/coldsoak/TPLAN1.XLS
1996-04-23 09:35

ATTACHMENT II

FIELD TESTS - COLD-SOAK BOXES

TEST EQUIPMENT CHECKLIST

TASK	***NRC Cold Chamber***	
	Resp.	**Status**
Logistics for Every Test		
Test Equipment		
Stand x 1		
Still Photo Camera		
Weigh Scale		
Precipitation rate Data Forms		
Cake Pans x 2		
Type I Fluids		
Type IV Fluids		
Paper Towels		
Rubber squeegees		
Plastic Refills for Fluids and funnels		
Electrical Extension Cords		
Lighting x 2		
Tools		
Insulated cold-soak boxes 2.5 cm x 4		
Insulated cold-soak boxes 7.5 cm x 4		
Coolant Fluid		
Storage bins for small equipment		
Thermistor Probes & logger kit		
Putty for Thermistors		
Protective clothing		
Tie wraps		
Tags (Labels) for Fluid designation on stand		
Sprayer		
2.0 Litre Containers		
Electric Kettle		
Freezer Chest		

FIGURE 5

METEO/PLATE PAN DATA FORM

REMEMBER TO SYNCHRONIZE TIME WITH AES - USE REAL TIME

VERSION 3.0 Winter 95/96

LOCATION: **DATE:** **PLAN #** (see Attachment I): **RUN # :** **STAND # :**

RVSI VIDEO CASSETTE #: **Real Time After Fluid Applied to Plates U and X:** **am / pm**

VIDEO CAMERA (PANNING) CASSETTE #: **HAND HELD VIDEO CASSETTE #:**

PLATE PAN WEIGHT MEASUREMENTS *

PAN #	t TIME BEFORE (hr:min)	t TIME AFTER (hr:min)	w WEIGHT BEFORE (grams)	w WEIGHT AFTER (grams)	COMPUTE RATE (Δw*4/ Δt) ($g/dm^2/h$)

*measurements every 15 min. and at failure time of each test panel.

METEO OBSERVATIONS **

TIME (hr:min)	TYPE (Fig. 4) ZR, ZL,S, SG IP, IC, BS, SP	AMOUNT ++, +, - , --	CLASSIF. (See Fig. 3)	Visibility (day only)	If SNOW, WET or DRY	TEMP °C	WIND SPEED	WIND DIR.

**observations at beginning, end, and every 15 min. intervals. Additional observations when there are significant changes.

COMMENTS : ______________________________

____

____

____

____

____

____

____

	PRINT	SIGN
WRITTEN & PERFORMED BY :		
VIDEO BY :		
TEST SITE LEADER :		

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Meteo & Pan

APPENDIX D

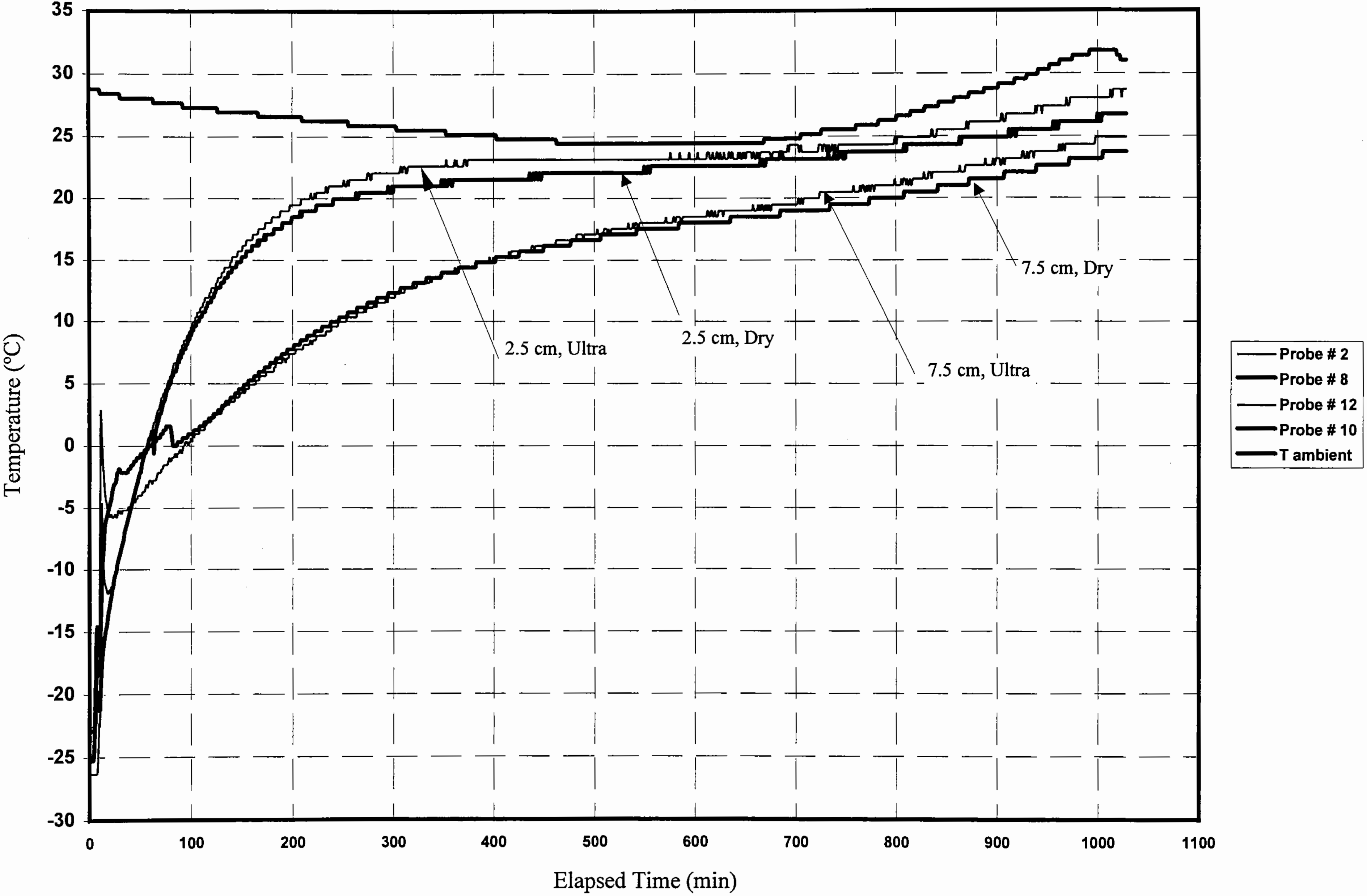
COLD-SOAKED BOX TRIALS AT APS SITE

JUNE 1996

FIGURE D.1

APS SITE COLD SOAK BOXES @ 9" LINE

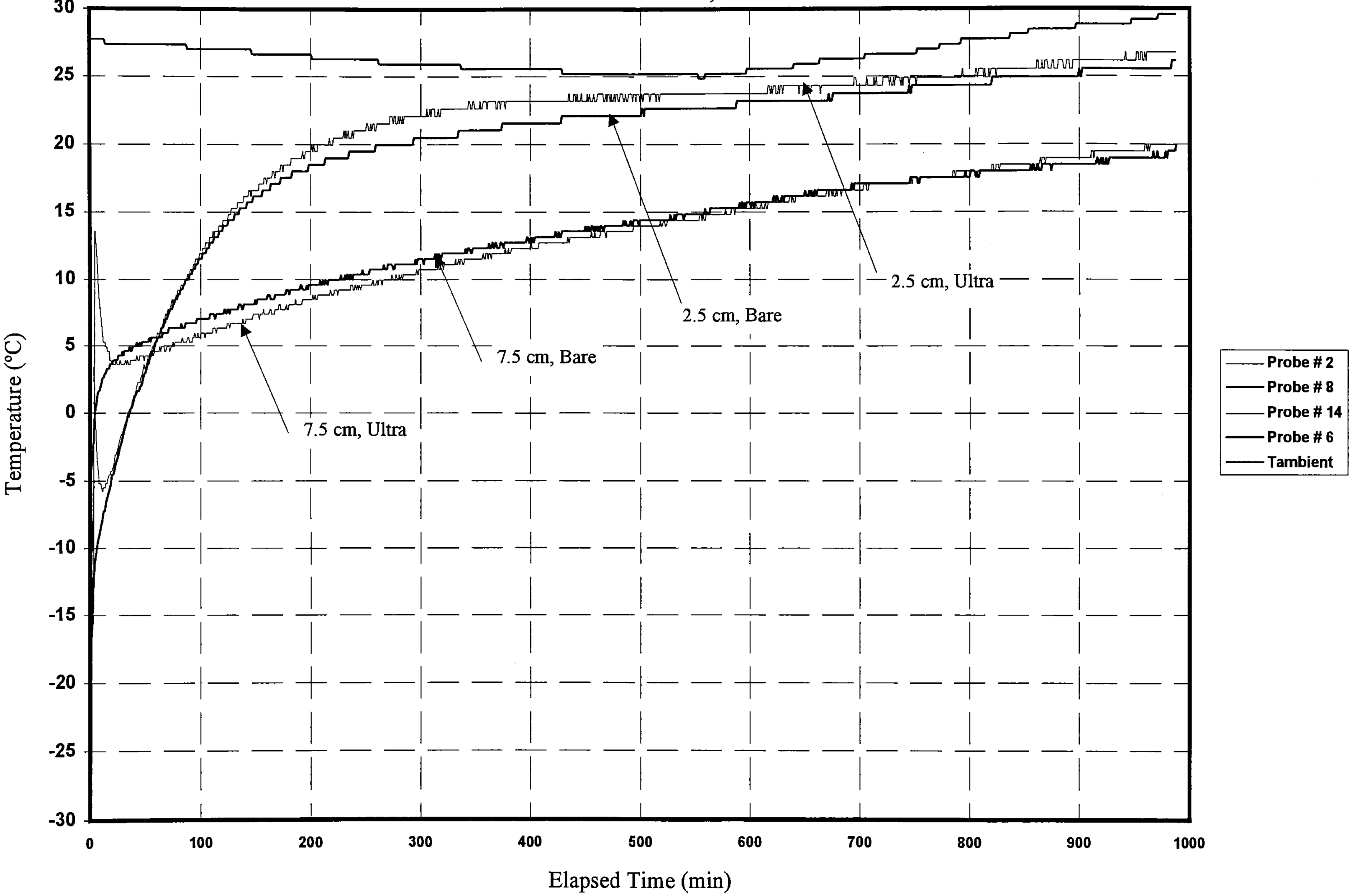
June 10, 1996



File:g:\cm1283\analysis\coldsoak\emp_prf\JUN10_AN.XLS
At: 9" line
Printed:23/01/97

FIGURE D.2

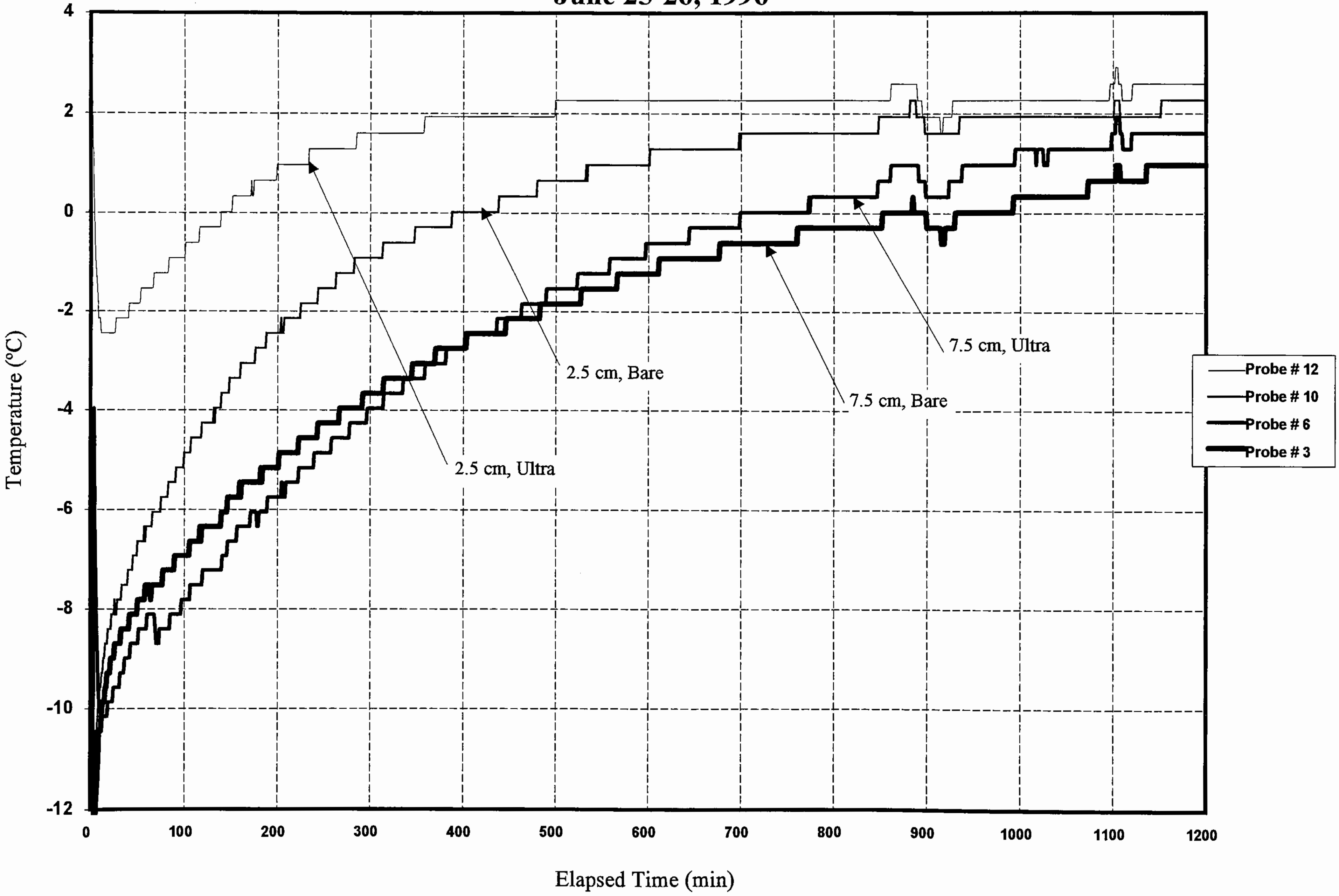
APS SITE COLD SOAK BOXES @ 9" LINE
June 19-20, 1996



File:g:\cm1283\analysis\coldsoak\tmp_prf\JUN20_AN.XLS
At: 9" Line
Printed:23/01/97

FIGURE D.3

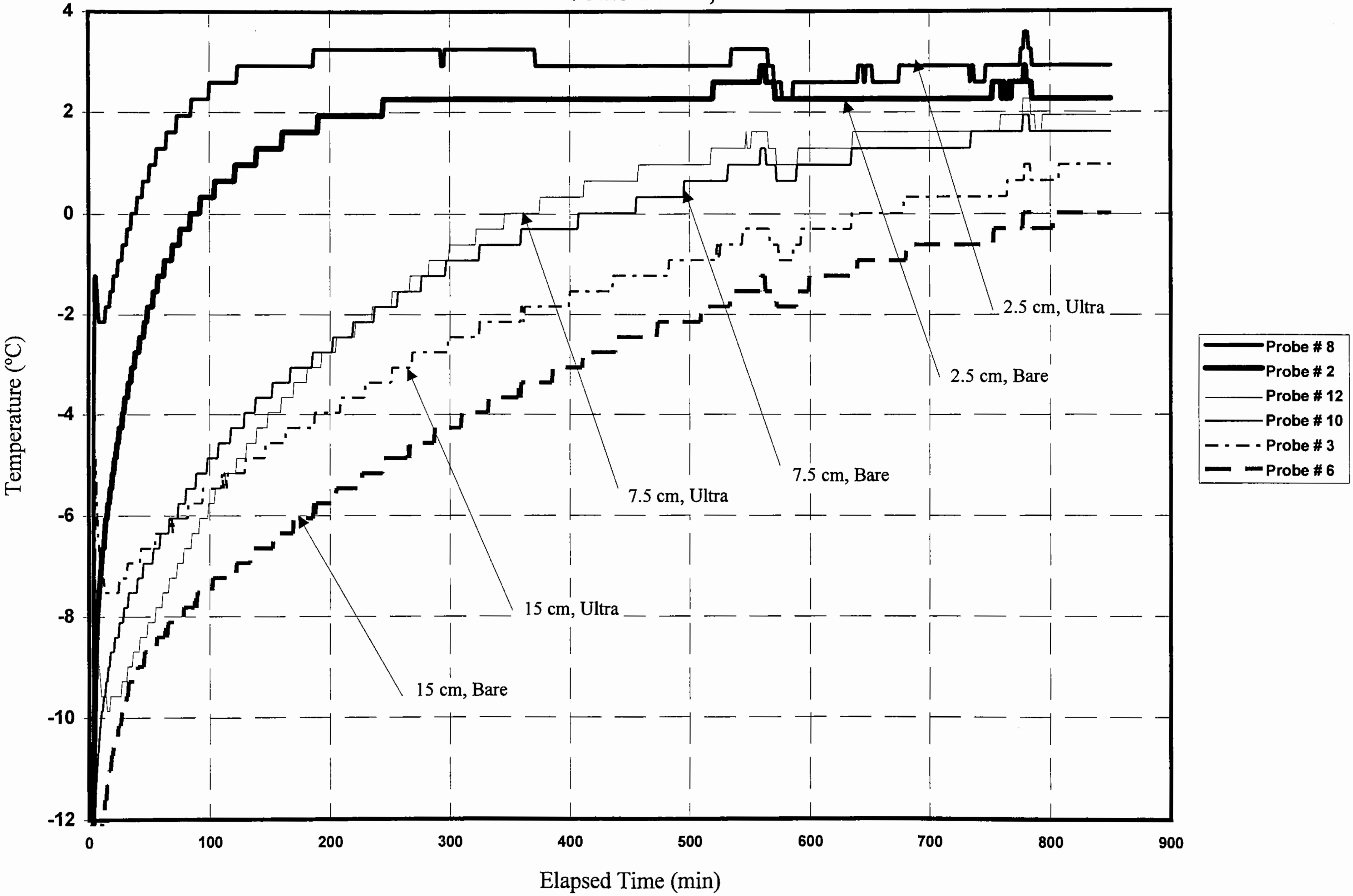
APS SITE COLD SOAK BOXES @ 9" LINE
June 25-26, 1996



File:g:\cm1283\analysis\coldsoak\tmp_prfJN25A_AN.XLS
At: 9" Line
Printed:23/01/97

FIGURE D.4

APS SITE COLD SOAK BOXES @ 9" LINE
June 26-27, 1996



File:g:\cm1283\analysis\coldsoak\tmp_prf\JN26B_AN.XLS
At: 9" Line
Printed:23/01/97

APPENDIX E

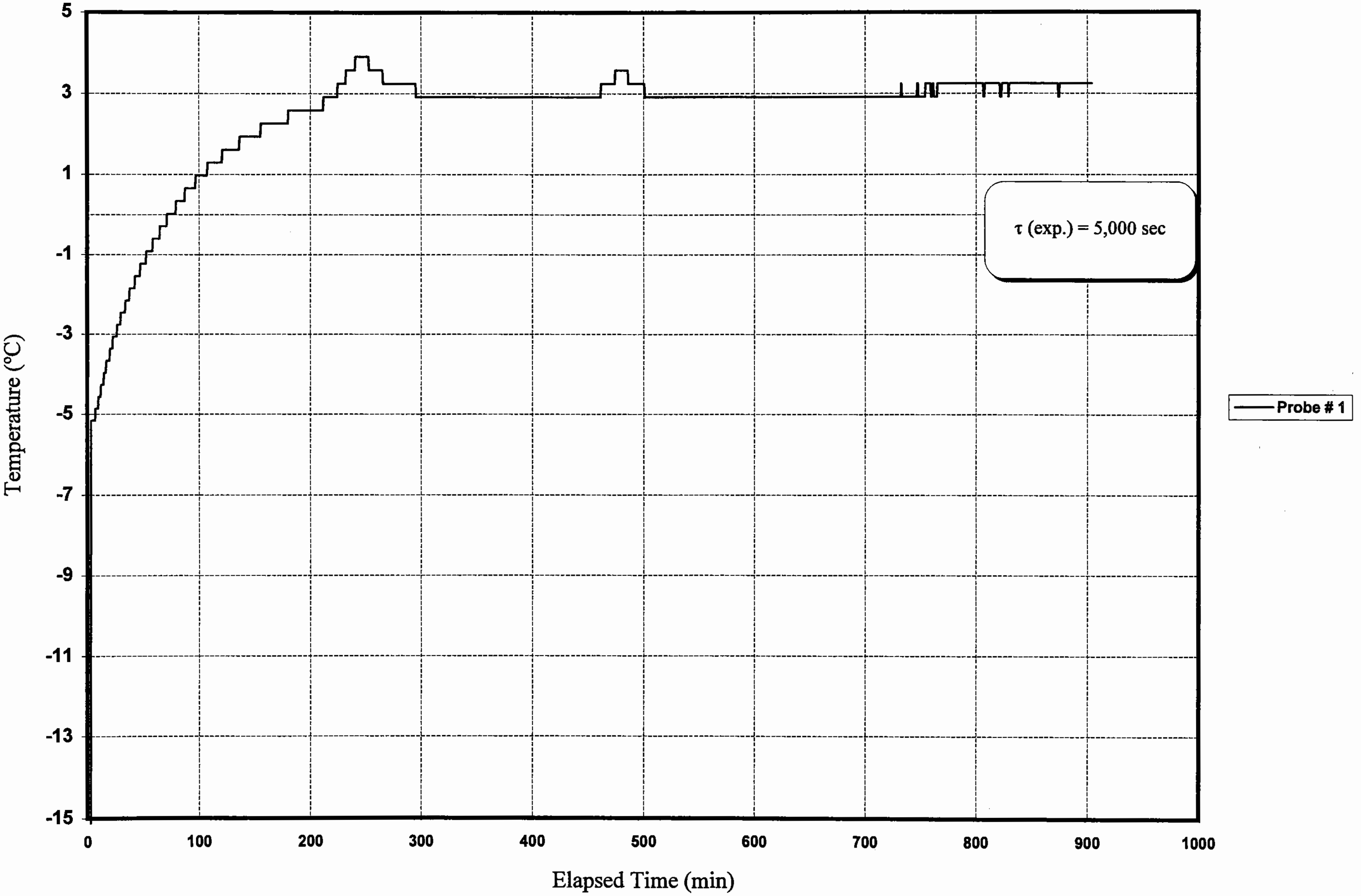
COLD-SOAKED BOX TRIALS AT CEF COLD CHAMBER

JULY 30 - AUGUST 2, 1996

FIGURE E.1

CEF COLD CHAMBER COLD SOAK BOXES @ 9" LINE

2.5 cm Box - BARE, July 30, 1996

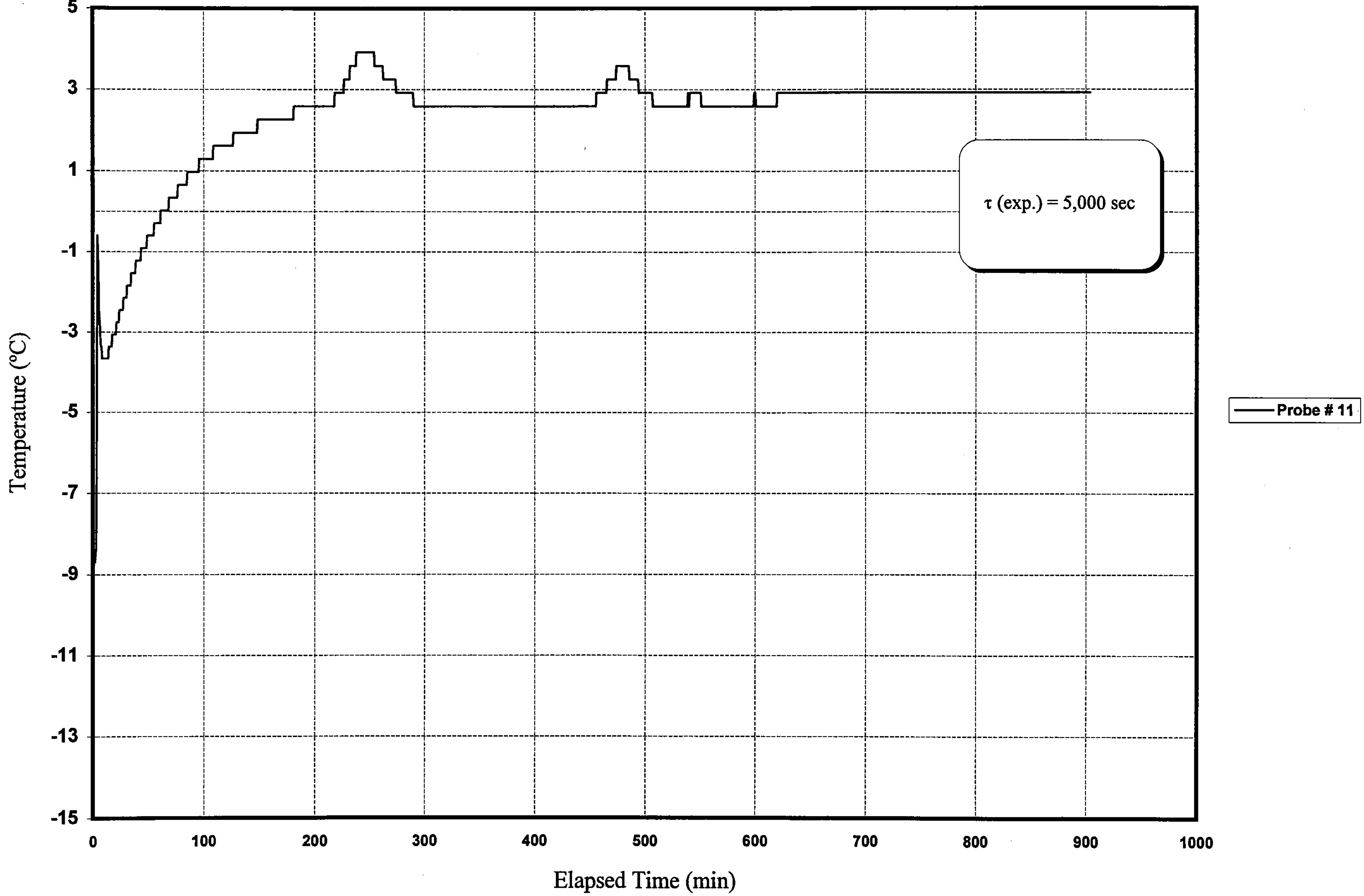


File:g:\cm1283\analysis\coldsoak\temp_prf\JUL30_AN.XLS
At: 2.5_CHT BARE
Printed:23/01/97

FIGURE E.2

CEF COLD CHAMBER COLD SOAK BOXES @ 9" LINE

2.5 cm Box - ULTRA, July 30, 1996

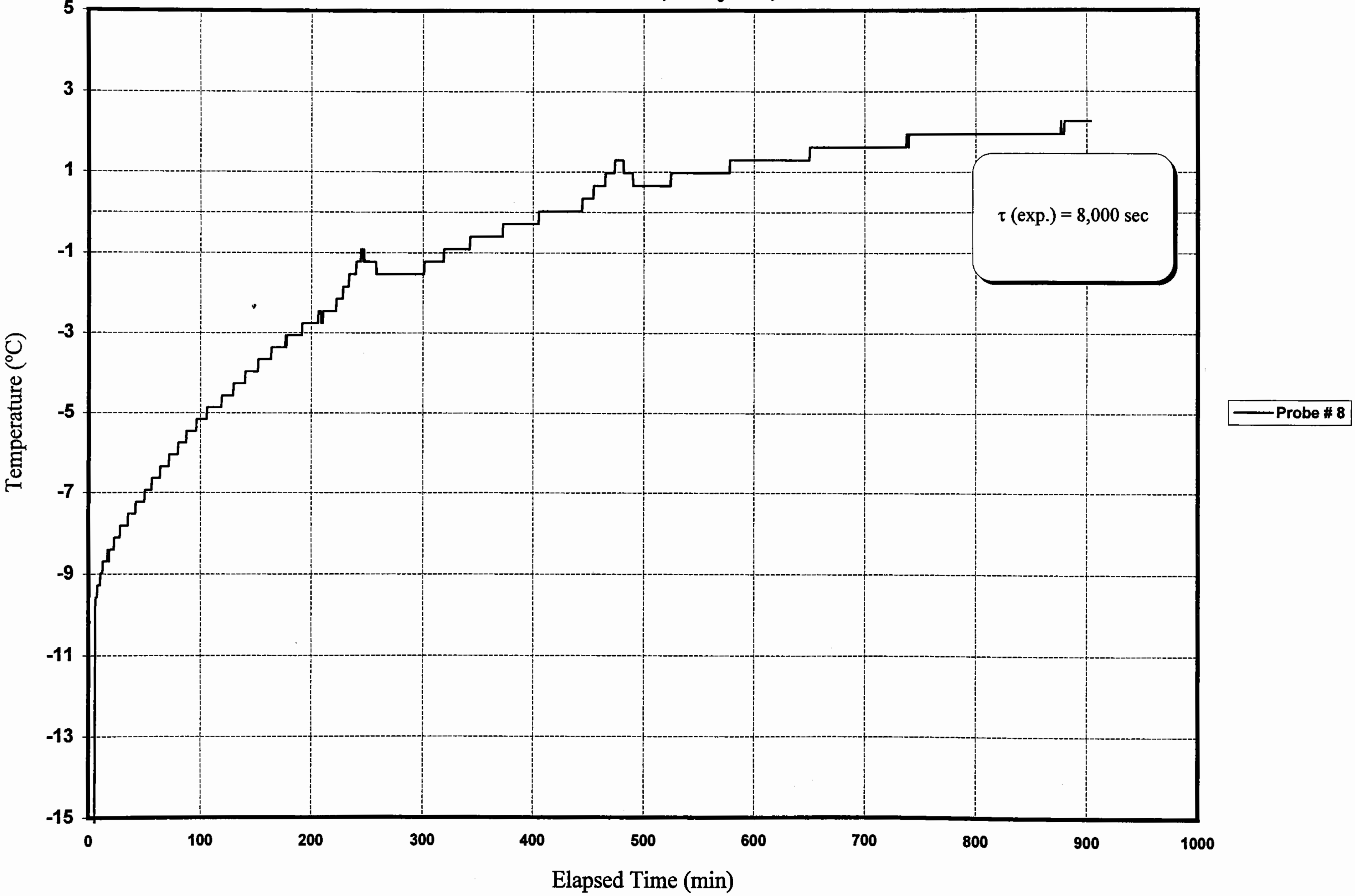


File:g:\cm1283\analysis\coldsoak\temp_prf\JUL30_AN.XLS
At: 2.5_CHT ULTRA
Printed:23/01/97

FIGURE E.3

CEF COLD CHAMBER COLD SOAK BOXES @ 9" LINE

7.5 cm Box - BARE, July 30, 1996

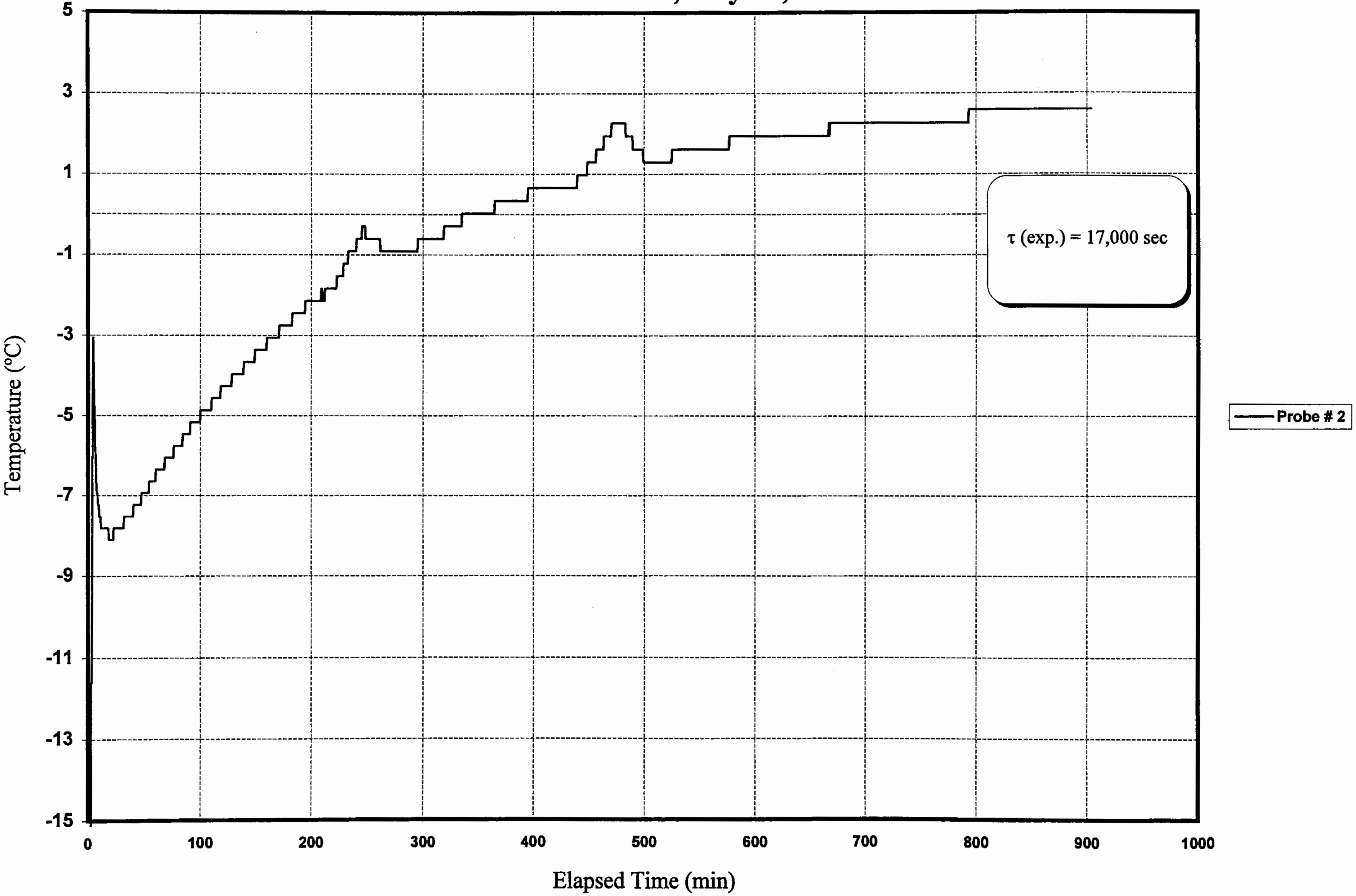


File:g:\cm1283\analysis\coldsoak\temp_prf\JUL30_AN.XLS
At: 7.5_CHT BARE
Printed:23/01/97

FIGURE E.4

CEF COLD CHAMBER COLD SOAK BOXES @ 9" LINE

7.5 cm Box - ULTRA, July 30, 1996

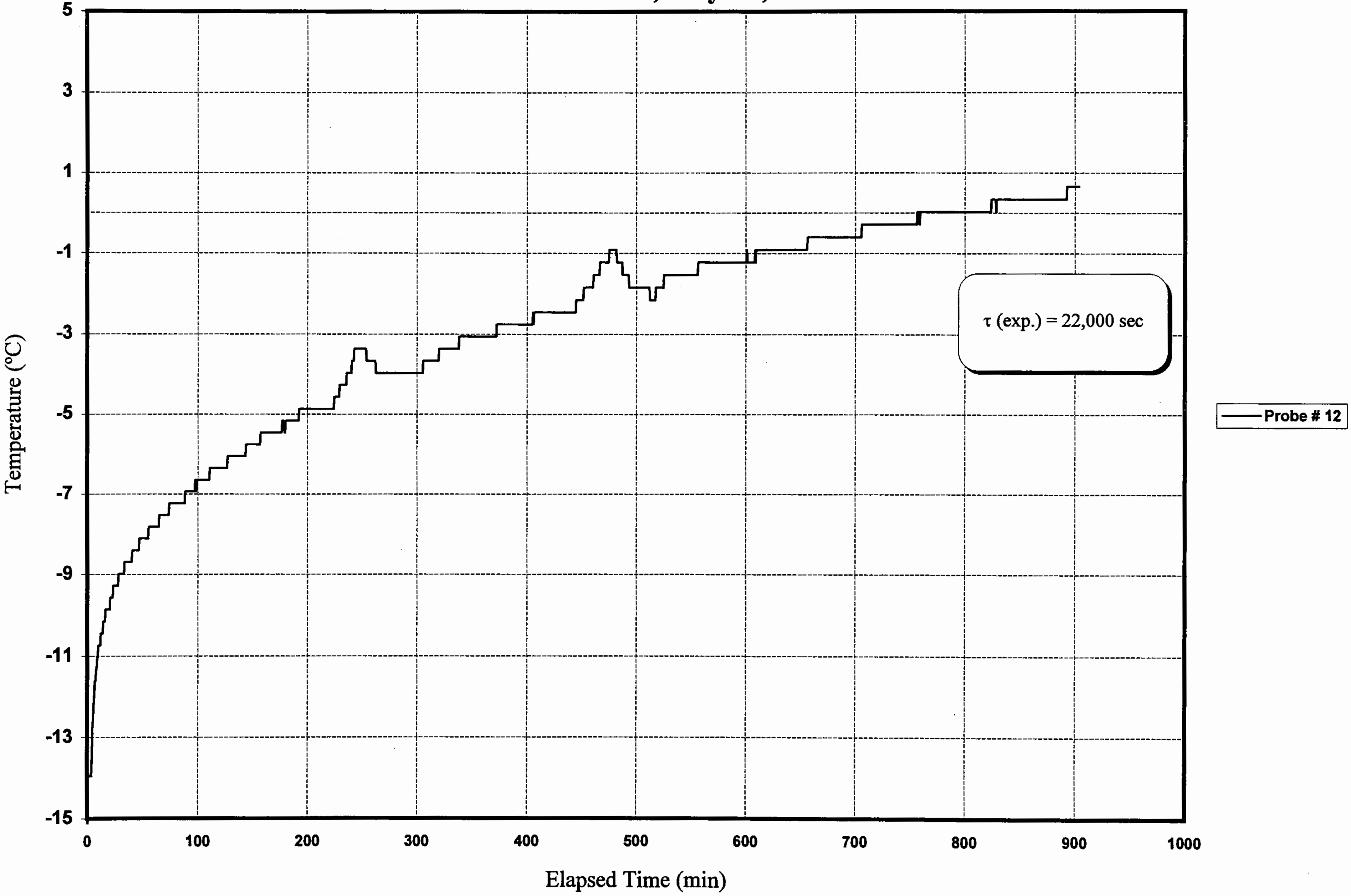


File:g:\cm1283\analysis\coldsoak\temp_prf\JUL30_AN.XLS
At: 7.5_CHT ULTRA
Printed:23/01/97

FIGURE E.5

CEF COLD CHAMBER COLD SOAK BOXES @ 9" LINE

15 cm Box - BARE, July 30, 1996



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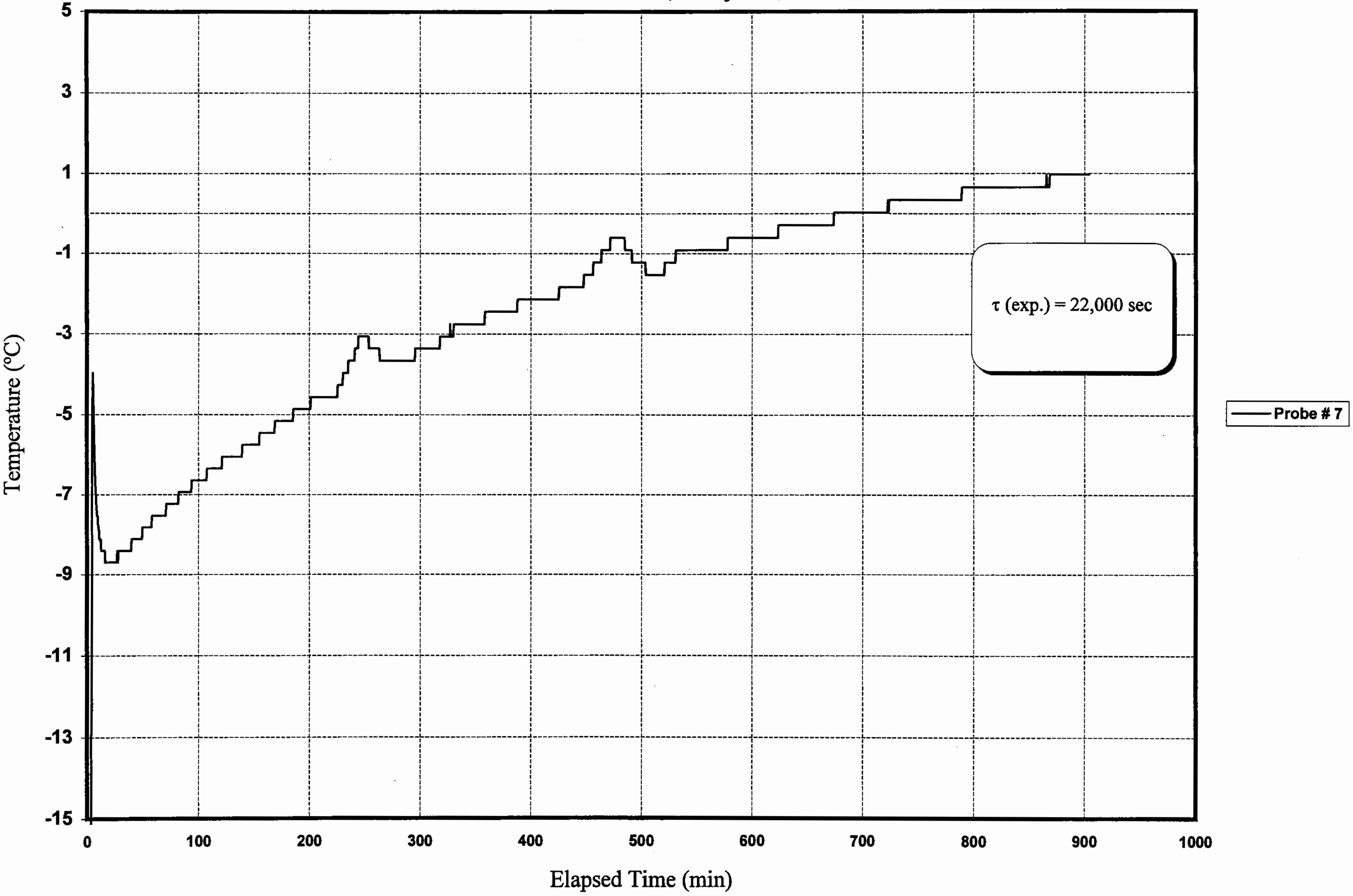
At: 15_CHT BARE
Printed:23/01/97

FIGURE E.6

CEF COLD CHAMBER COLD SOAK BOXES @ 9" LINE

15 cm Box - ULTRA, July 30, 1996

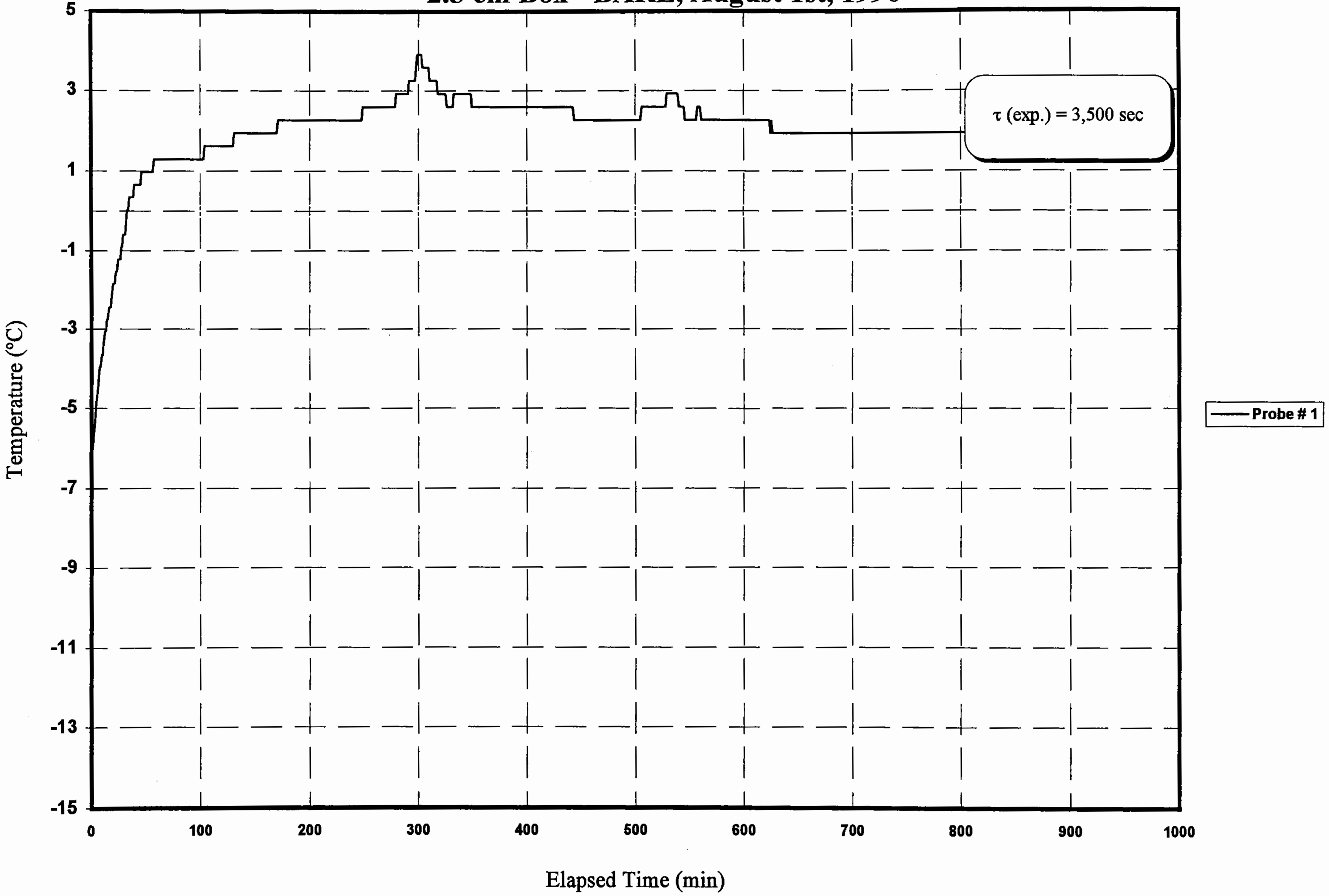


File:g:\cm1283\analysis\coldsoak\temp_prf\JUL30_AN.XLS
At: 15_CHT ULTRA
Printed:23/01/97

FIGURE E.7

CEF COLD CHAMBER COLD SOAK BOXES @ 9" LINE

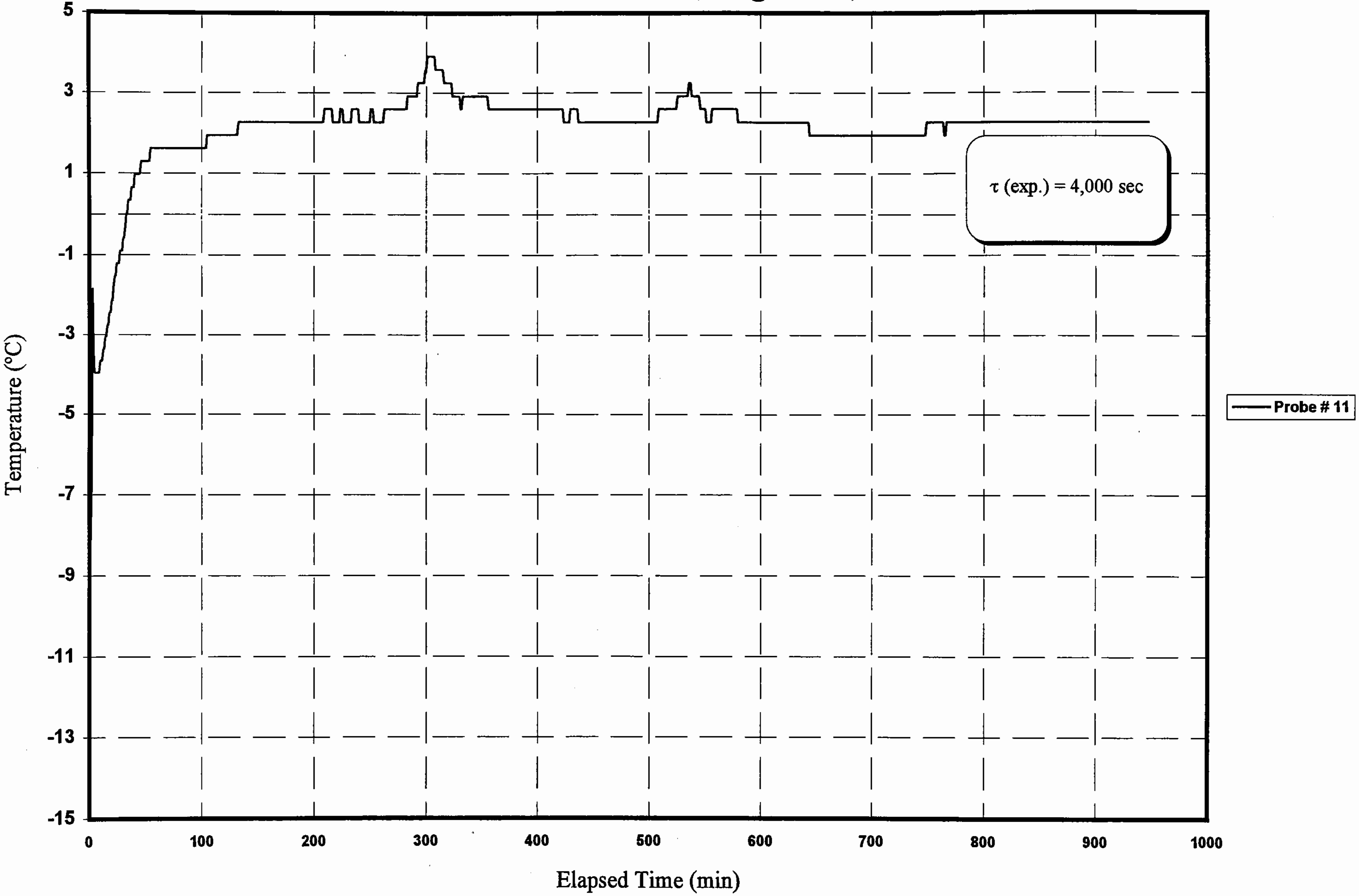
2.5 cm Box - BARE, August 1st, 1996



File:g:\cm1283\analysis\coldsoak\temp_prf\AUG01_AN.XLS
At: 2.5_CHT BARE
Printed:23/01/97

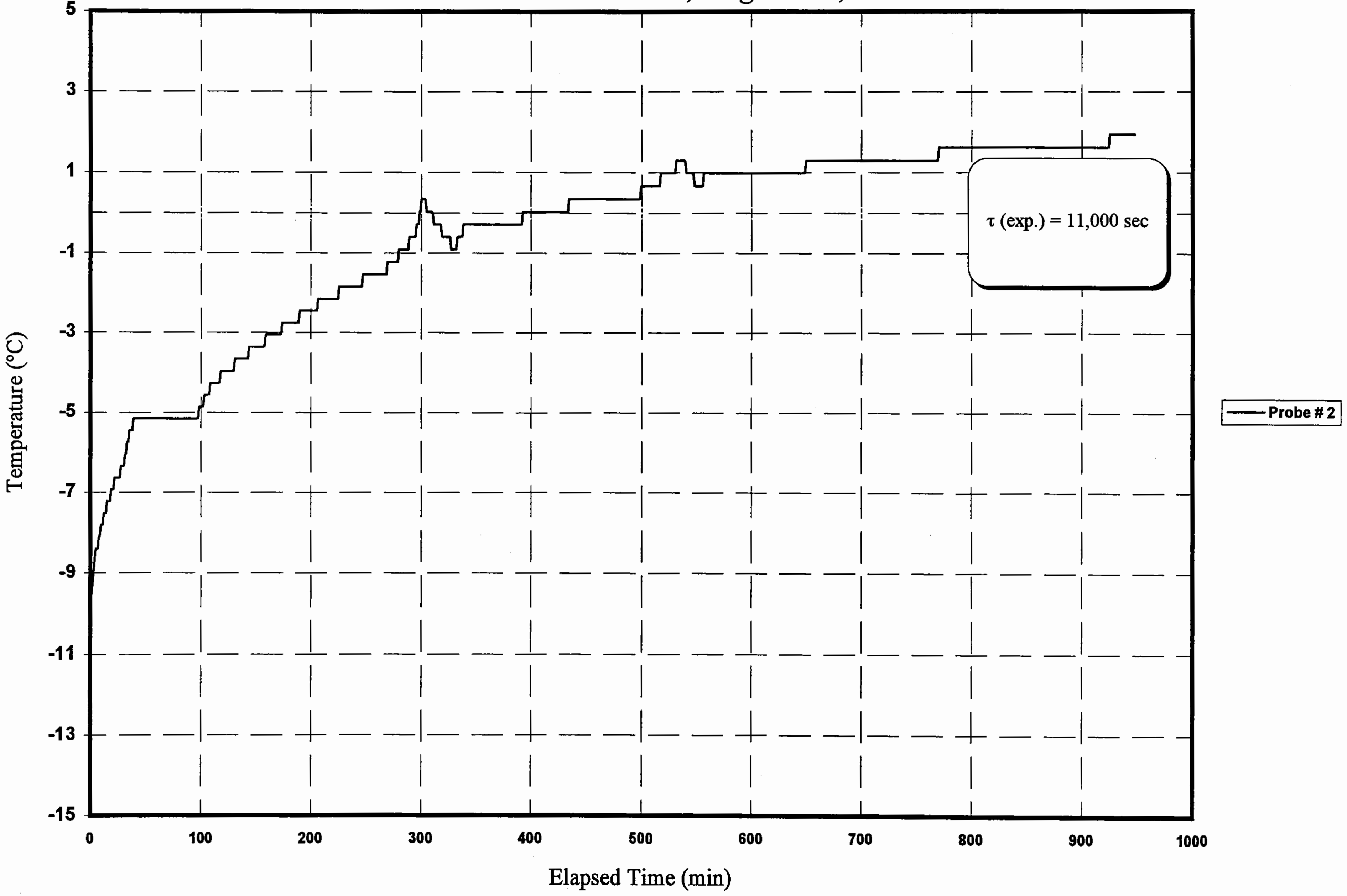
FIGURE E.8

CEF COLD CHAMBER COLD SOAK BOXES @ 9" LINE
2.5 cm Box - ULTRA, August 1st, 1996



File:g:\cm1283\analysis\coldsoak\temp_prf\AUG01_AN.XLS
At: 2.5_CHT ULTRA
Printed:23/01/97

FIGURE E.9

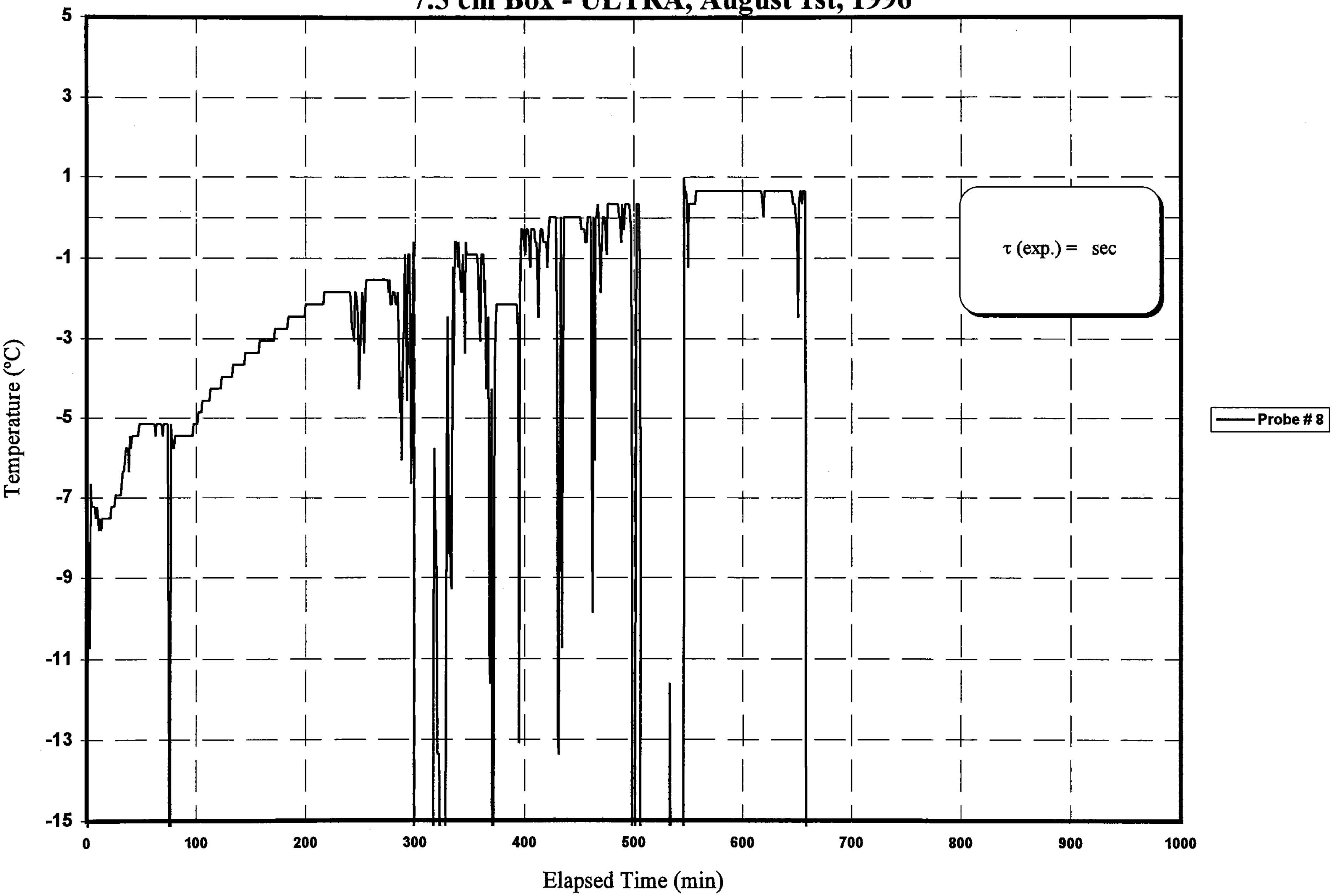


File:g:\cm1283\analysis\coldsoak\temp_prf\AUG01_AN.XLS
At: 7.5_CHT BARE
Printed:23/01/97

FIGURE E.10

CEF COLD CHAMBER COLD SOAK BOXES @ 9" LINE

7.5 cm Box - ULTRA, August 1st, 1996

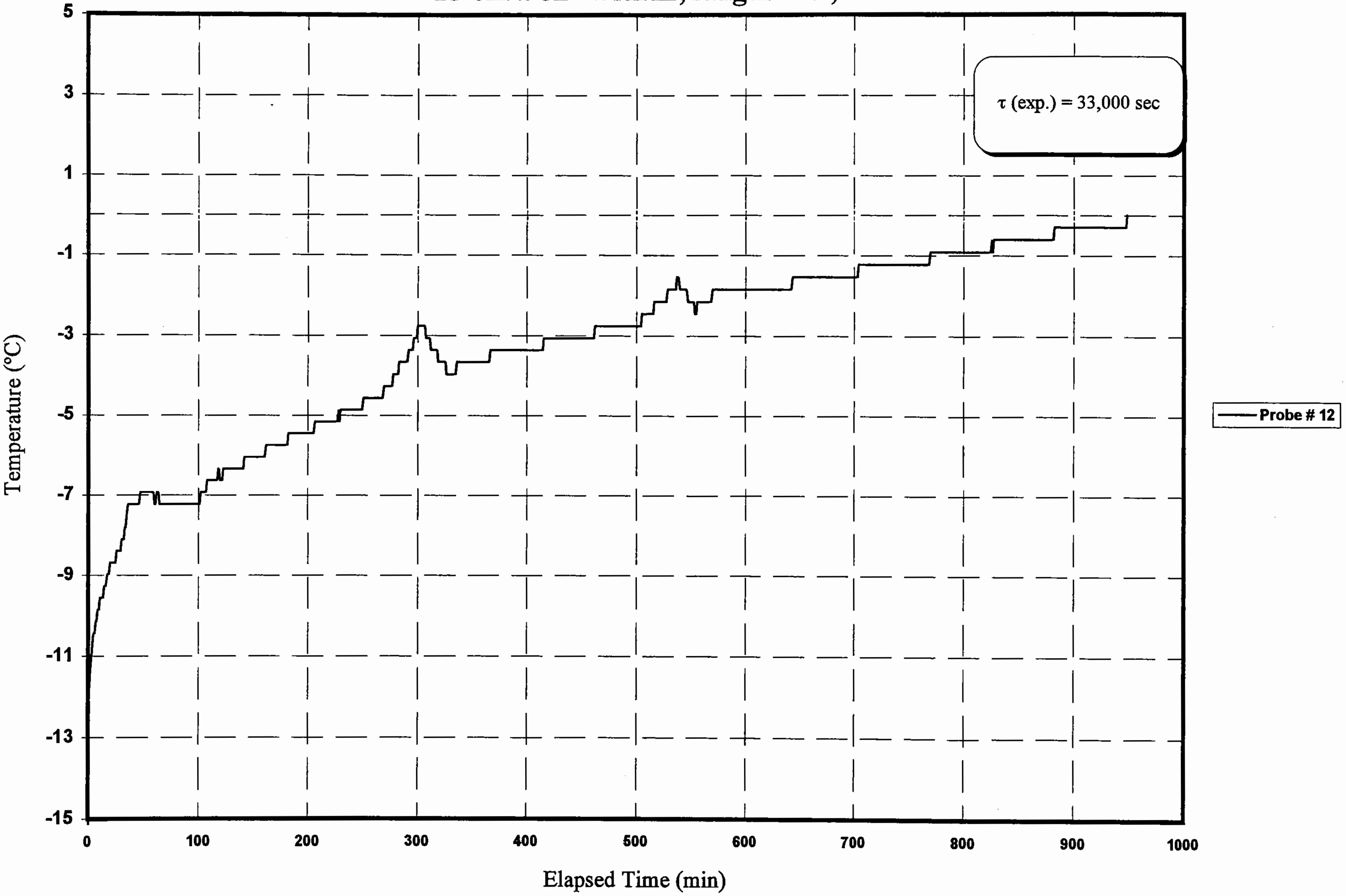


File:g:\cm1283\analysis\coldsoak\temp_prf\AUG01_AN.XLS
At: 7.5_CHT ULTRA
Printed:23/01/97

FIGURE E.11

CEF COLD CHAMBER COLD SOAK BOXES @ 9" LINE

15 cm Box - BARE, August 1st, 1996

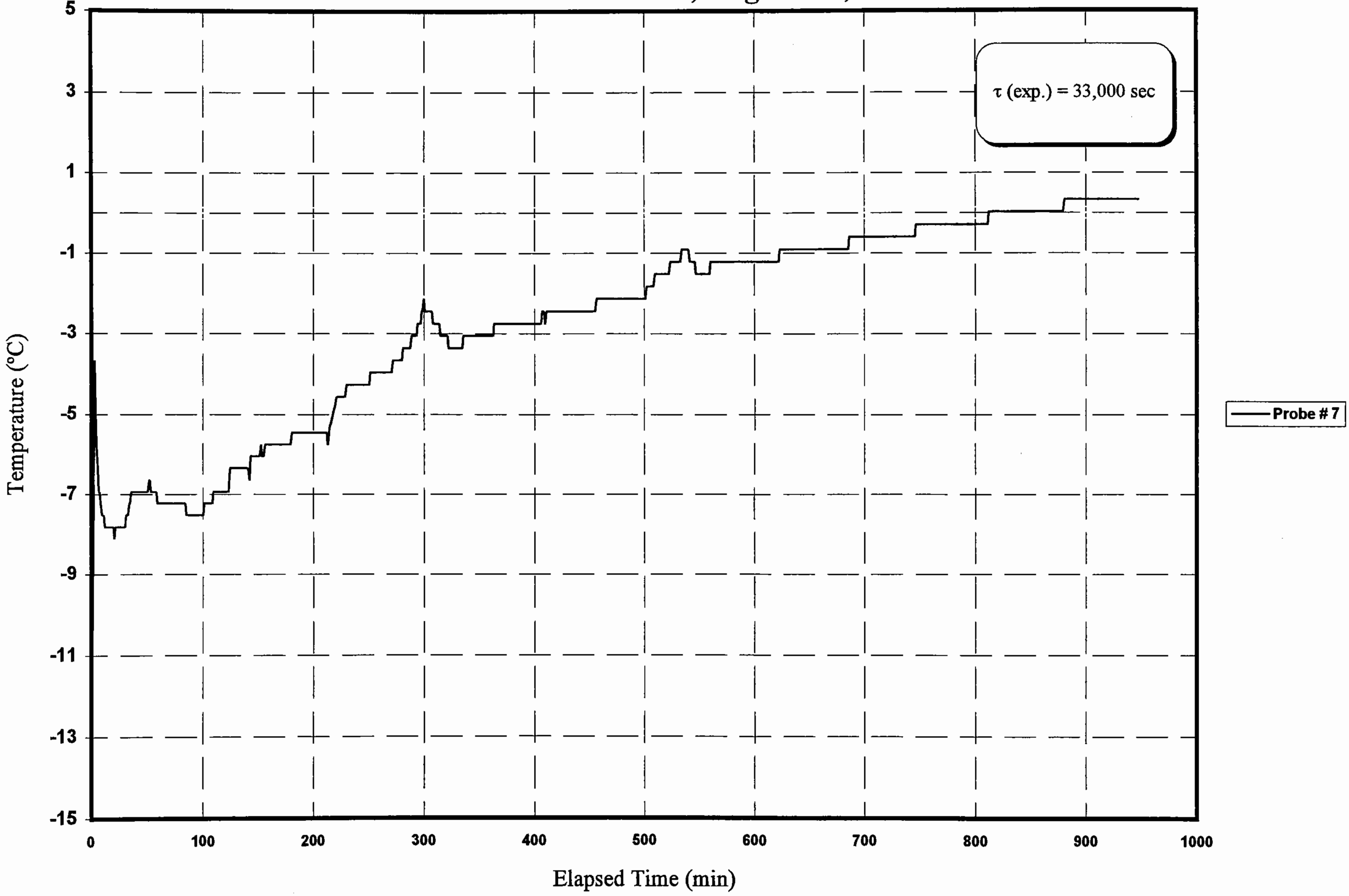


File:g:\cm1283\analysis\coldsoak\temp_prf\AUG01_AN.XLS
At: 15_CHT BARE
Printed:23/01/97

FIGURE E.12

CEF COLD CHAMBER COLD SOAK BOXES @ 9" LINE

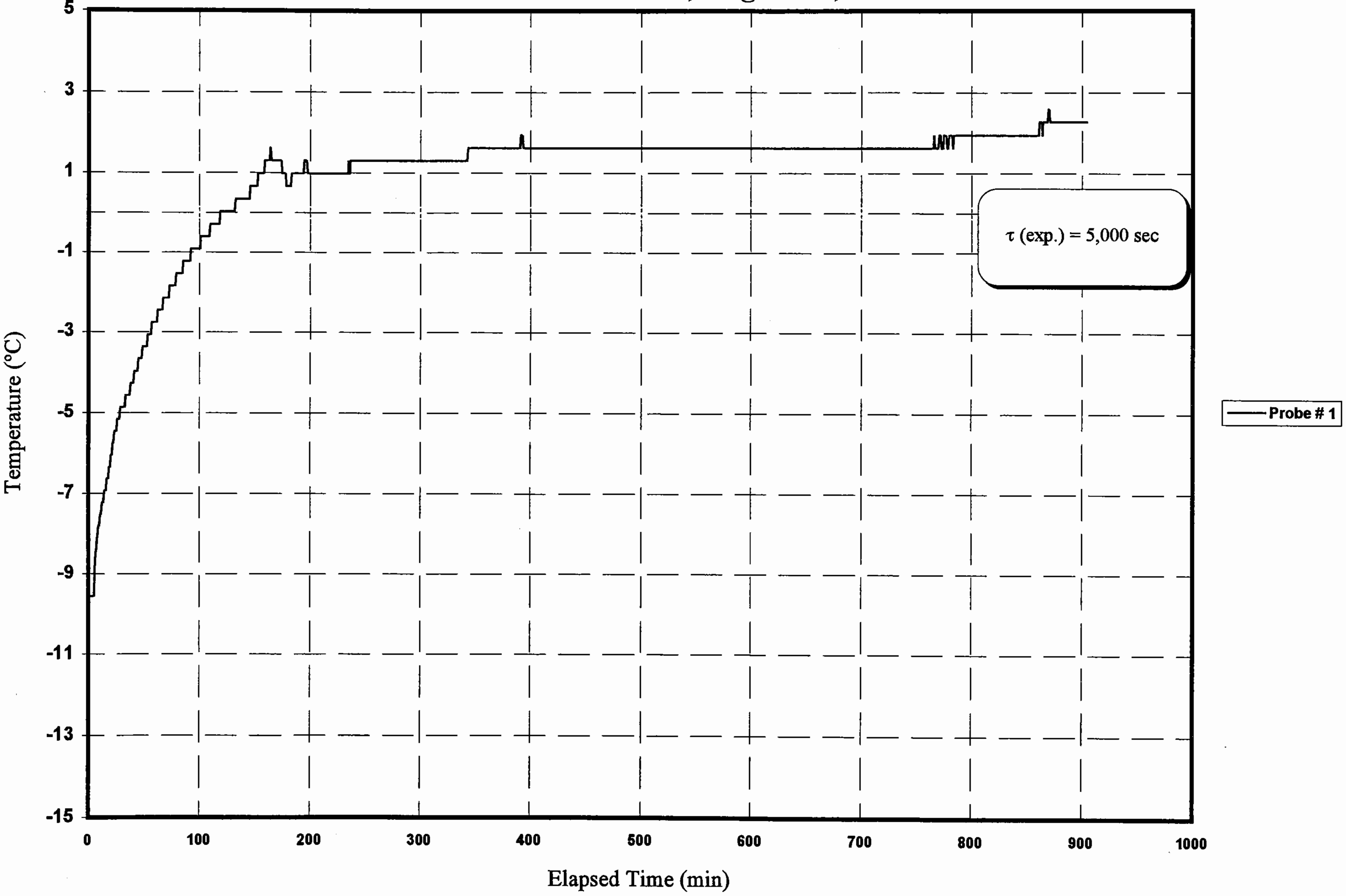
15 cm Box - ULTRA, August 1st, 1996



File:g:\cm1283\analysis\coldsoak\temp_prf\AUG01_AN.XLS
At: 15_CHT ULTRA
Printed:23/01/97

FIGURE E.13

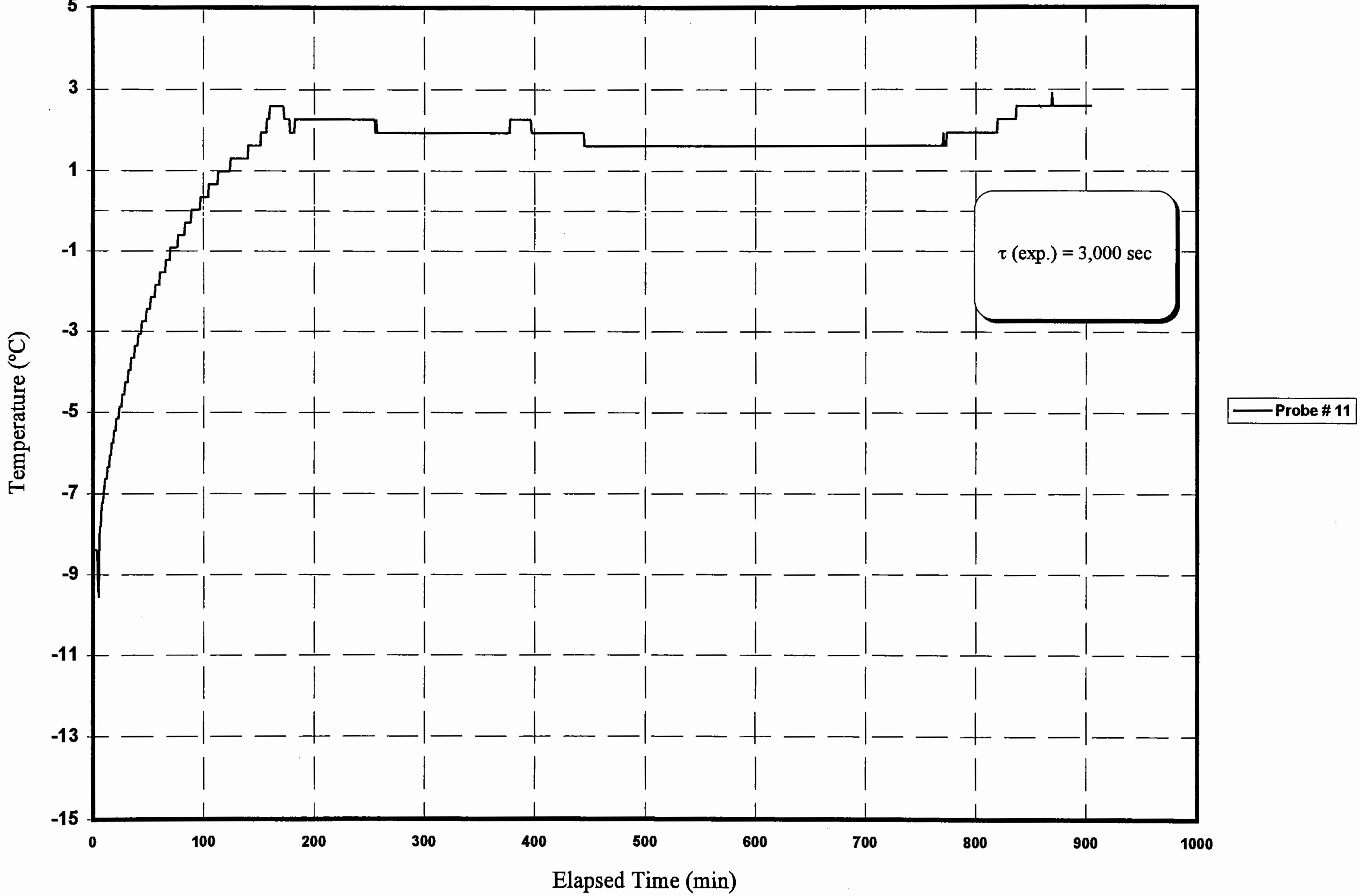
CEF COLD CHAMBER COLD SOAK BOXES @ 9" LINE
2.5 cm Box - BARE, August 02, 1996



File:g:\cm1283analysis\coldsoak\temp_prf\AUG02_AN.XLS
At: 2.5_CHT BARE
Printed:23/01/97

FIGURE E.14

CEF COLD CHAMBER COLD SOAK BOXES @ 9" LINE
2.5 cm Box - ULTRA, August 02, 1996

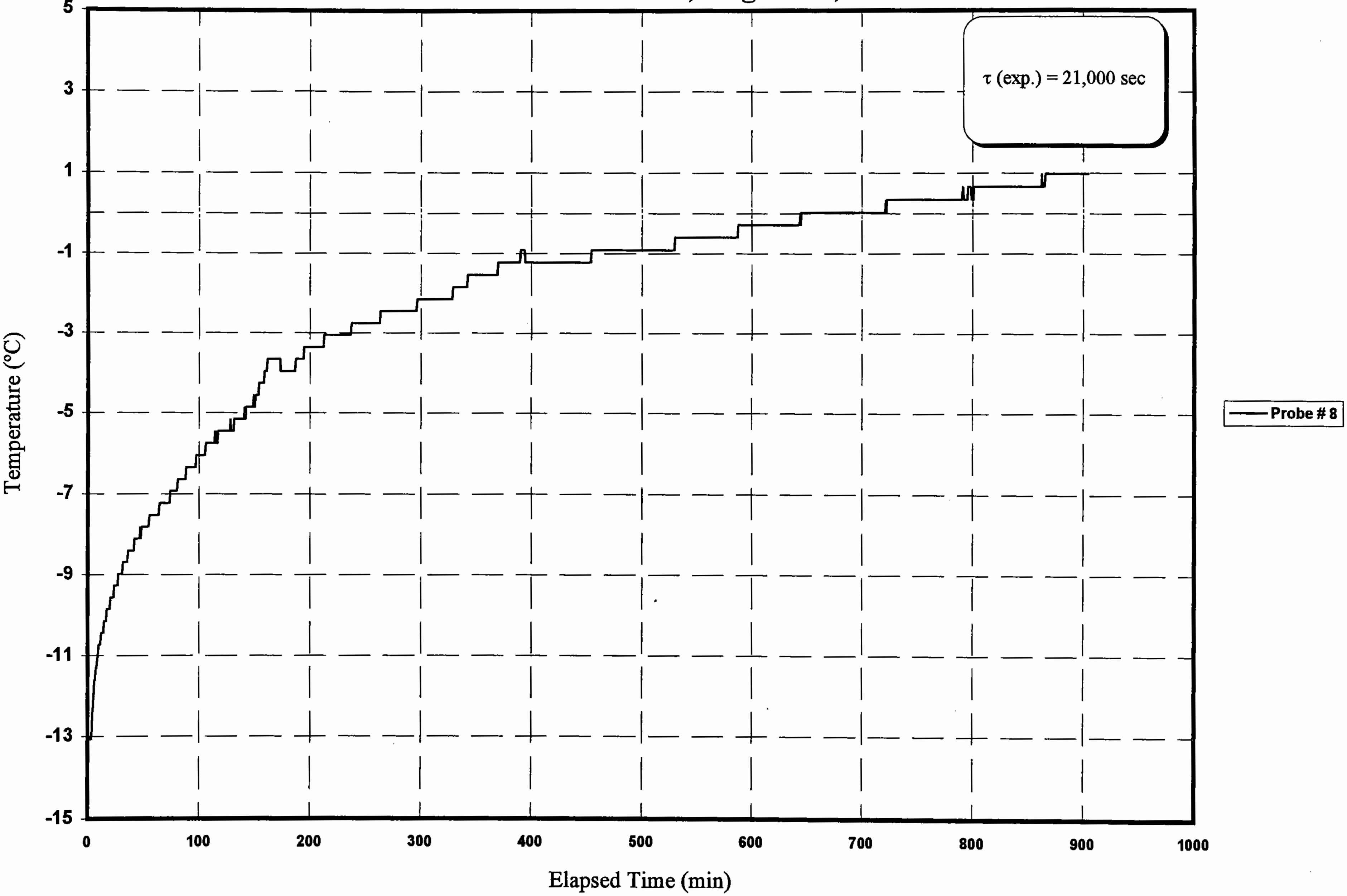


File:g:\cm1283\analysis\coldsoak\temp_prf\AUG02_AN.XLS
At: 2.5_CHT ULTRA
Printed:23/01/97

FIGURE E.15

CEF COLD CHAMBER COLD SOAK BOXES @ 9" LINE

7.5 cm Box - BARE, August 02, 1996

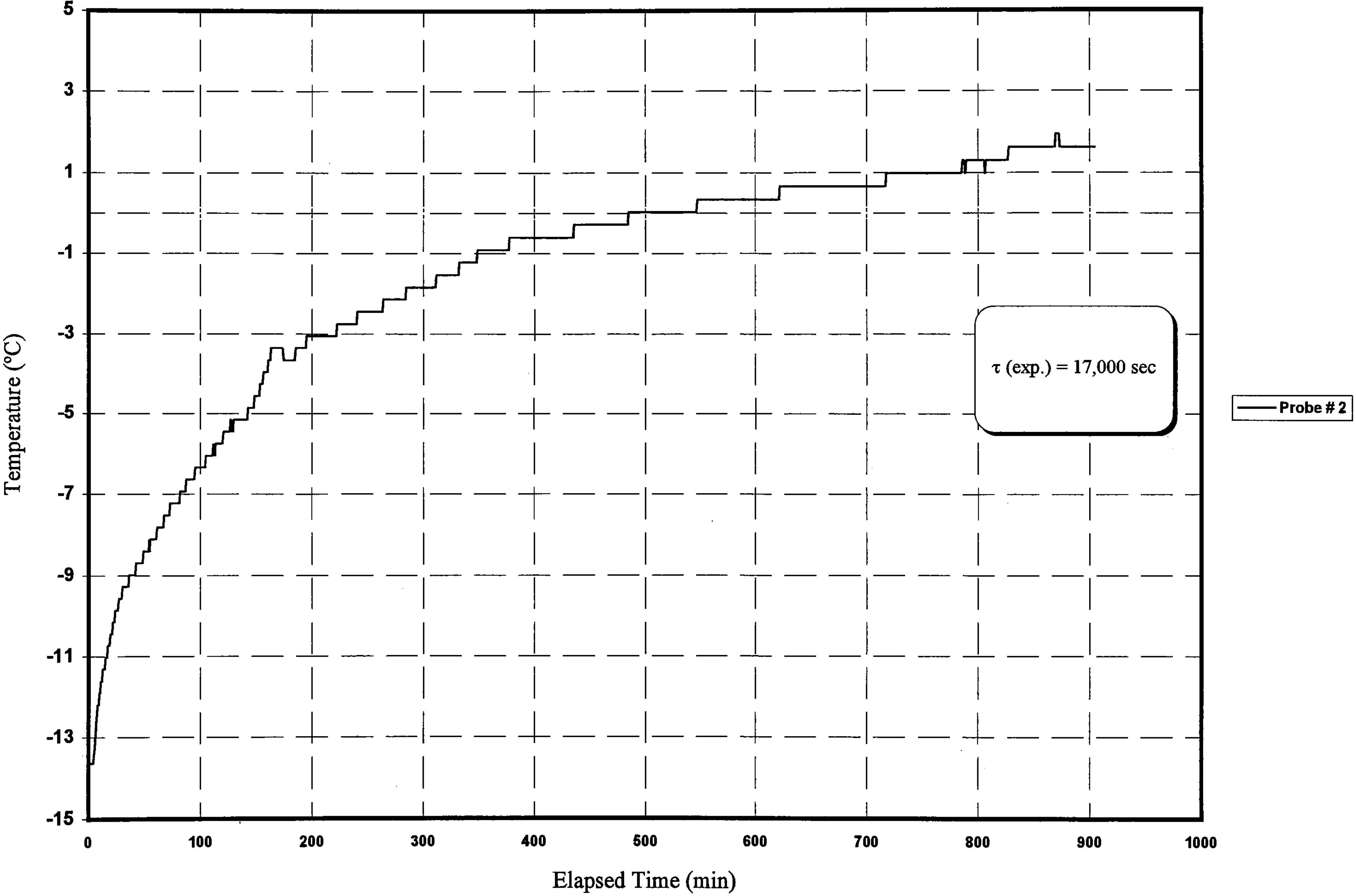


File:g:\cm1283\procedur\coldsoak\boxes\AUG02_AN.XLS
At: 7.5_CHT BARE
Printed:23/01/97

FIGURE E.16

CEF COLD CHAMBER COLD SOAK BOXES @ 9" LINE

7.5 cm Box - ULTRA, August 02, 1996

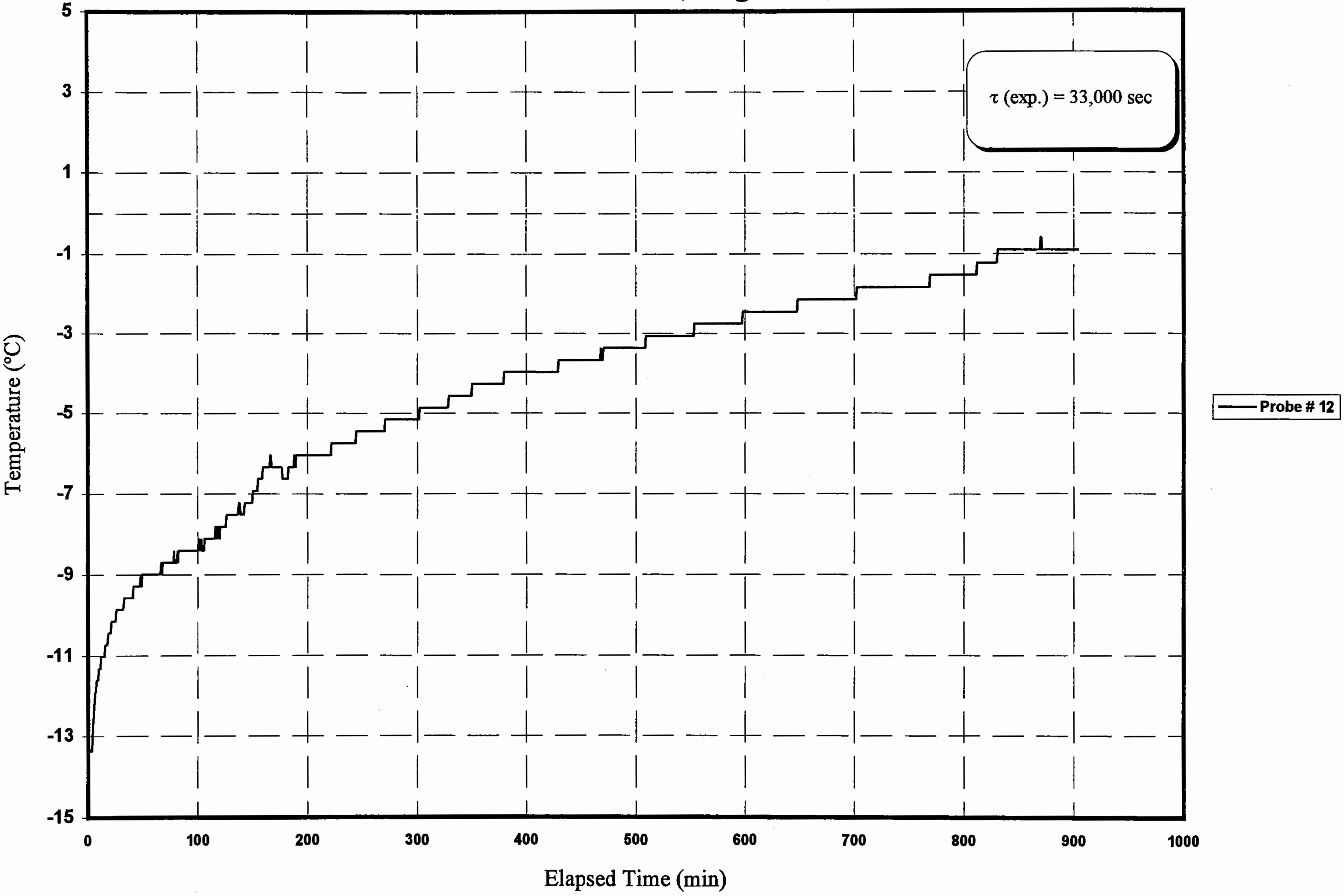


File:g:\cm1283\analysis\coldsoak\temp_prf\AUG02_AN.XLS
At: 7.5_CHT ULTRA
Printed:23/01/97

FIGURE E.17

CEF COLD CHAMBER COLD SOAK BOXES @ 9" LINE

15 cm Box - BARE, August 02, 1996



File:g:\cm1283\analysis\coldsoak\temp_prf\AUG02_AN.XLS
At: 15_CHT BARE
Printed:23/01/97

APPENDIX F

EXTRACT OF COLD-SOAKED DATA AT CEF FOR 1995/1996 TEST SEASON

APPENDIX F

EXTRACT OF COLD SOAK DATA @ CEF FOR 1995/96 TEST SEASON

report published (year)	form no.	test no.	date	run no.	start time	end time	contamin time	fld dil	fld type	fld type	Box Size [cm]	BOX [all time] [min]	Avg Rate of pans (Shield) [g/dm^2/hr]	Precip. Type	initial skin temp [C]	final skin temp [C]	average skin temp [C]	ambient temp [C]	Time Constant τ
1996	1	1	Aug-06-96	1	12:44:00	14:15:00	14:02:00	100%	4	C-100	2.5	91	9.7	drizzle	-10.0	-0.5	-5.3	2.7	3,947
1996	1	2	Aug-06-96	1	12:47:00	14:03:00	13:40:00	100%	4	C-100	7.5	76	9.9	drizzle	-10.0	-2.5	-6.3	2.3	4,873
1996	1	3	Aug-06-96	1	12:49:00	14:55:00	14:10:00	100%	4	C-102	7.5	126	12.1	drizzle	-10.0	-1.0	-5.5	2.7	6,101
1996	1	4	Aug-06-96	1	12:53:00	13:57:00	13:38:00	100%	4	C-107	7.5	64	10.6	drizzle	-10.0	-3.0	-6.5	2.3	4,583
1996	2	5	Aug-06-96	3	16:12:00	16:39:00	16:26:00	75%	4b	C-700	7.5	27	9.8	drizzle	-10.0	-7.5	-8.8	4.4	8,473
1996	2	6	Aug-06-96	3	16:10:00	16:42:00	16:24:00	75%	4b	C-707	7.5	32	10.8	drizzle	-10.0	-6.5	-8.3	4.4	6,887
1996	2	7	Aug-06-96	3	16:14:00	17:10:00	16:37:00	75%	4b	C-702	7.5	56	9.1	drizzle	-10.0	-5.0	-7.5	4.9	8,229
1996	3	8	Aug-07-96	2	10:32:00	11:33:00	10:45:00	100%	4	C-107	2.5	61	9.2	drizzle	-11.0	-3.0	-7.0	1.0	3,319
1996	3	9	Aug-07-96	2	10:42:00	11:46:00	11:36:00	100%	4	C-107	2.5	64	9.4	drizzle	-10.0	-2.0	-6.0	1.0	2,973
1996	3	10	Aug-07-96	2	10:16:00	13:29:00	12:06:00	100%	4	C-102	7.5	193	4.2	drizzle	-11.0	-5.0	-8.0	1.0	16,734
1996	4	13	Aug-07-96	4	14:19:00	15:22:00	14:50:00	100%	2	A-205	2.5	63	5.4	drizzle	-10.0	-2.5	-6.3	1.3	3,481
1996	4	14	Aug-07-96	4	13:44:00	14:17:00	13:59:00	100%	2	A-201	2.5	33	10.8	drizzle	-10.0	-5.5	-7.8	1.3	3,884
1996	4	15	Aug-07-96	4	13:18:00	14:07:00	13:43:00	100%	2	A-205	2.5	49	9.3	drizzle	-10.0	-4.0	-7.0	1.3	3,871
1996	4	16	Aug-07-96	4	14:12:00	15:06:00	14:31:00	100%	2	A-201	7.5	54	2.5	drizzle	-10.0	-7.0	-8.5	1.3	10,465
1996	4	18	Aug-07-96	4	14:16:00	14:41:00	14:30:00	100%	2	A-201	7.5	25	9.8	drizzle	-9.0	-7.0	-8.0	1.3	6,932
1996	5	19	Aug-07-96	5	11:50:00	13:08:00	12:02:00	75%	4b	C-702	2.5	78	9.2	drizzle	-11.0	-3.0	-7.0	1.1	4,304
1996	5	20	Aug-07-96	5	12:10:00	12:49:00	N/A	75%	4b	C-707	2.5	39	9.4	drizzle	-10.0	-4.0	-7.0	1.0	2,982
1996	6	23	Aug-07-96	5	11:17:00	12:01:00	11:45:00	100%	4	C-100	7.5	44	10.9	drizzle	-10.0	-8.0	-9.0	1.0	13,103
1996	7	24	Aug-07-96	5	13:49:00	14:19:00	14:00:00	100%	2	A-205	7.5	30	9.3	drizzle	-10.0	-8.5	-9.3	1.3	12,587
1996	8	25	Aug-07-96	5	15:27:00	16:18:00	15:50:00	75%	2b	A-212	2.5	51	5.4	drizzle	-8.5	-4.0	-6.3	1.3	4,972
1996	8	26	Aug-07-96	5	14:59:00	15:30:00	15:15:00	75%	2b	A-501	2.5	31	10.8	drizzle	-10.0	-6.0	-8.0	1.4	4,305
1996	8	27	Aug-07-96	5	14:49:00	15:24:00	15:16:00	75%	2b	A-212	2.5	35	9.3	drizzle	-10.0	-4.0	-7.0	1.4	2,804
1996	8	28	Aug-07-96	5	15:32:00	16:25:00	15:51:00	75%	2b	A-501	7.5	53	2.5	drizzle	-10.0	-6.0	-8.0	1.3	7,287
1996	8	29	Aug-07-96	5	15:09:00	15:34:00	N/A	75%	2b	A-212	7.5	25	9.3	drizzle	-9.0	-7.0	-8.0	1.3	6,969
1996	9	31	Aug-07-96	6	16:29:00	16:38:00	16:35:00	57%	1	B-213	2.5	9	5.4	drizzle	-10.0	-7.0	-8.5	1.7	1,827
1996	9	32	Aug-07-96	6	16:29:00	16:37:00	16:36:00	71%	1	B-214	2.5	8	10.8	drizzle	-10.0	-5.0	-7.5	1.7	863
1996	9	33	Aug-07-96	6	15:54:00	16:01:00	15:59:00	57%	1	B-213	2.5	7	9.3	drizzle	-10.0	-7.5	-8.8	1.1	1,644
1996	9	34	Aug-07-96	6	15:46:00	15:51:00	15:49:00	57%	1	B-213	7.5	5	9.3	drizzle	-9.0	-7.5	-8.3	1.1	1,865
1996	9	35	Aug-07-96	6	15:41:00	15:48:00	15:46:00	71%	1	B-214	7.5	7	9.8	drizzle	-10.0	-7.5	-8.8	1.2	1,656
1996	10	36	Aug-07-96	6	16:01:00	16:08:00	16:05:00	57%	1	B-213	2.5	7	10.8	drizzle	-5.0	-4.5	-4.8	1.2	5,020
1996	10	37	Aug-07-96	6	16:15:00	16:21:00	16:19:00	57%	1	B-213	7.5	6	9.8	drizzle	-5.0	-4.5	-4.8	1.8	4,686
1996	11	38	Aug-07-96	7	16:56:00	17:01:00	N/A	21%	1a	B-253	2.5	5	5.4	drizzle	-10.0	-6.0	-8.0	1.6	711
1996	11	39	Aug-07-96	7	17:03:00	17:06:00	N/A	27%	1a	B-254	2.5	3	10.8	drizzle	-10.0	-2.0	-6.0	1.6	155
1996	11	40	Aug-07-96	7	16:55:00	16:58:00	16:57:00	21%	1a	B-253	2.5	3	9.3	drizzle	-10.0	-6.0	-8.0	1.7	428
1996	11	42	Aug-07-96	7	16:52:00	16:55:00	16:54:00	21%	1a	B-253	7.5	3	9.3	drizzle	-10.0	-6.0	-8.0	1.7	429
1996	11	43	Aug-07-96	7	17:08:00	17:11:00	17:10:00	27%	1a	B-254	7.5	3	9.8	drizzle	-10.0	-7.0	-8.5	1.6	602
1996	12	44	Aug-07-96	7	16:40:00	16:46:00	16:45:00	21%	1a	B-253	2.5	6	10.8	drizzle	-5.0	-2.0	-3.5	1.7	610
1996	12	45	Aug-07-96	7	17:14:00	17:18:00	17:16:00	27%	1a	B-254	7.5	4	9.8	drizzle	-5.0	-4.0	-4.5	1.6	1,462
1996	13	46	Aug-08-96	8	09:40:00	10:22:00	N/A	100%	4	C-100	2.5	42	19.7	light rain	-10.0	-3.0	-6.5	1.4	2,666
1996	13	47	Aug-08-96	8	09:38:00	10:16:00	09:48:00	100%	4	C-107	2.5	38	20.5	light rain	-10.0	-4.0	-7.0	1.5	3,076
1996	13	48	Aug-08-96	8	09:33:00	10:53:00	10:09:00	100%	4	C-102	2.5	80	19.7	light rain	-9.0		-4.5	1.4	2,430
1996	13	49	Aug-08-96	8	09:36:00	10:15:00	09:45:00	100%	4	C-107	2.5	39	19.5	light rain	-10.0	-3.0	-6.5	1.5	2,481
1996	13	50	Aug-08-96	8	09:43:00	10:21:00	09:58:00	100%	4	C-100	7.5	38	21.4	light rain	-10.0	-8.0	-9.0	1.5	11,888
1996	13	52	Aug-08-96	8	10:19:00	10:51:00	10:31:00	100%	4	C-102	7.5	32	23.6	light rain	-10.0	-8.0	-9.0	1.4	9,991
1996	14	54	Aug-08-96	8	10:29:00	10:55:00	10:39:00	100%	4	C-107	7.5	26	21.4	light rain	-10.0	-4.0	-7.0	1.5	2,105
1996	14	55	Aug-08-96	8	10:47:00	11:24:00	11:17:00	100%	4	C-100	7.5	37	23.1	light rain	-10.0	-7.0	-8.5	1.4	7,288
1996	15	57	Aug-08-96	9	11:15:00	11:36:00	11:30:00	75%	4b	C-700	2.5	21	19.7	light rain	-10.0	-5.0	-7.5	1.4	2,193
1996	15	58	Aug-08-96	9	11:34:00	12:00:00	11:50:00	75%	4b	C-707	2.5	26	20.5	light rain	-11.0	-3.0	-7.0	1.5	1,521
1996	15	60	Aug-08-96	9	11:44:00	12:12:00	11:55:00	75%	4b	C-707	2.5	28	19.5	light rain	-10.0	-4.0	-7.0	1.5	2,266
1996	15	61	Aug-08-96	9	11:24:00	11:40:00	11:34:00	75%	4b	C-707	7.5	16	21.4	light rain	-9.0	-8.0	-8.5	1.5	9,551
1996	15	62	Aug-08-96	9	11:46:00	12:02:00	N/A	75%	4b	C-700	7.5	16	23.1	light rain	-9.0	-5.0	-7.0	1.5	1,997
1996	15	64	Aug-08-96	9	11:20:00	11:36:00	11:26:00	75%	4b	C-700	7.5	16	22.9	light rain	-10.0	-7.0	-8.5	1.4	3,146
1996	16	65	Aug-08-96	10	12:04:00	12:35:00	12:15:00	100%	2	A-205	2.5	31	19.7	light rain	-10.0	-4.0	-7.0	1.5	2,510
1996	16	66	Aug-08-96	10	12:22:00	12:39:00	12:31:00	100%	2	A-201	2.5	17	20.5	light rain	-10.0	-5.0	-7.5	1.5	1,784
1996	16	67	Aug-08-96	10	12:16:00	12:37:00	12:25:00	75%	2b	A-212	2.5	21	19.7	light rain	-10.0	-6.0	-8.0	1.5	2,941
1996	16	68	Aug-08-96	10	12:19:00	12:37:00	12:33:00	75%	2b	A-501	2.5	18	19.5	light rain	-10.0	-5.0	-7.5	1.5	1,884
1996	16	69	Aug-08-96	10	11:53:00	12:12:00	12:03:00	100%	2	A-201	7.5	19	21.4	light rain	-8.0	-5.0	-6.5	1.5	2,989
1996	16	70	Aug-08-96	10	12:12:00	12:33:00	12:20:00	100%	2	A-205	7.5	21	23.1	light rain	-10.0	-6.0	-8.0	1.5	2,934
1996	16	72	Aug-08-96	10	12:10:00	12:24:00	12:18:00	75%	2b	A-501	7.5	14	22.9	light rain	-10.0	-7.0	-8.5	1.5	2,785
1996	17	73	Aug-08-96	11	13:15:00	13:19:00	13:18:00	57%	1	B-213	2.5	4	19.7	light rain	-10.0	-6.0	-8.0	1.6	569
1996	17	74	Aug-08-96	11	13:16:00	13:21:00	13:20:00	63%	1	B-221	2.5	5	20.6	light rain	-10.0	-5.0	-7.5	1.6	533
1996	17	75	Aug-08-96	11	13:28:00	13:31:00	13:30:00	21%	1a	B-253	2.5	3	22.2	light rain	-10.0	-3.0	-6.5	1.6	194
1996	17	76	Aug-08-96	11	13:17:00	13:20:00	13:19:00	25%	1a	B-251	2.5	3	19.5	light rain	-10.0	-4.0	-7.0	1.6	248
1996	17	77	Aug-08-96	11	13:07:00	13:11:00	13:09:00	63%	1	B-221	7.5	4	21.4	light rain	-10.0	-7.0	-8.5	1.8	818

File:g:\cm1283\reports\coldsoak\956_BOX.XLS
Printed:14/01/97

APPENDIX G

EXCERPTS FROM WING TEMPERATURE SURVEY
REFERENCE (1)

FIGURE G.1

TEMPERATURE DIFFERENTIAL AS FUNCTION OF OUTSIDE AIR TEMPERATURE

(All Aircraft, All Airports)

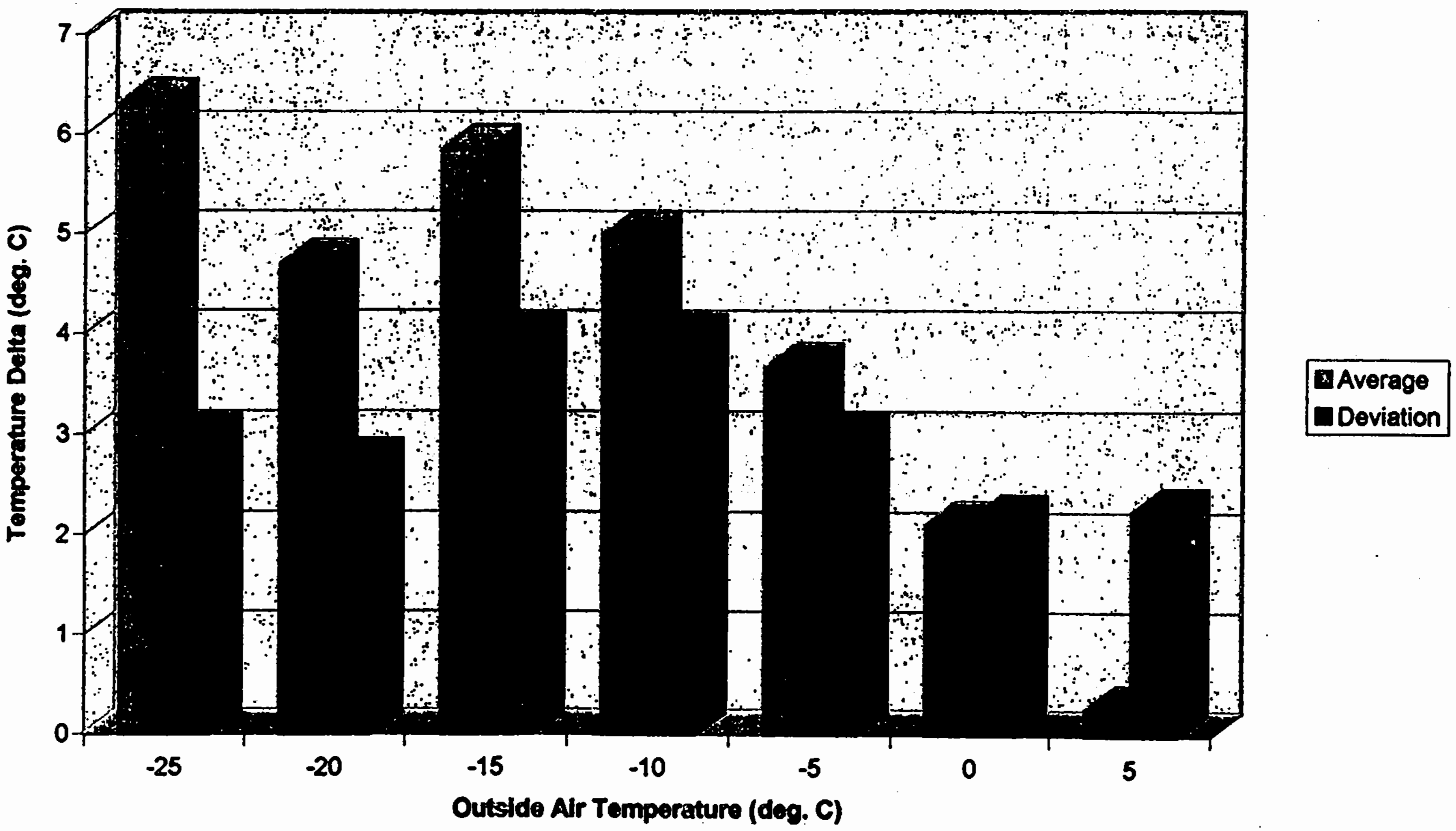


FIGURE G.2

TEMPERATURE DIFFERENTIAL AS FUNCTION OF OUTSIDE AIR TEMPERATURE (All Aircraft, YWG)

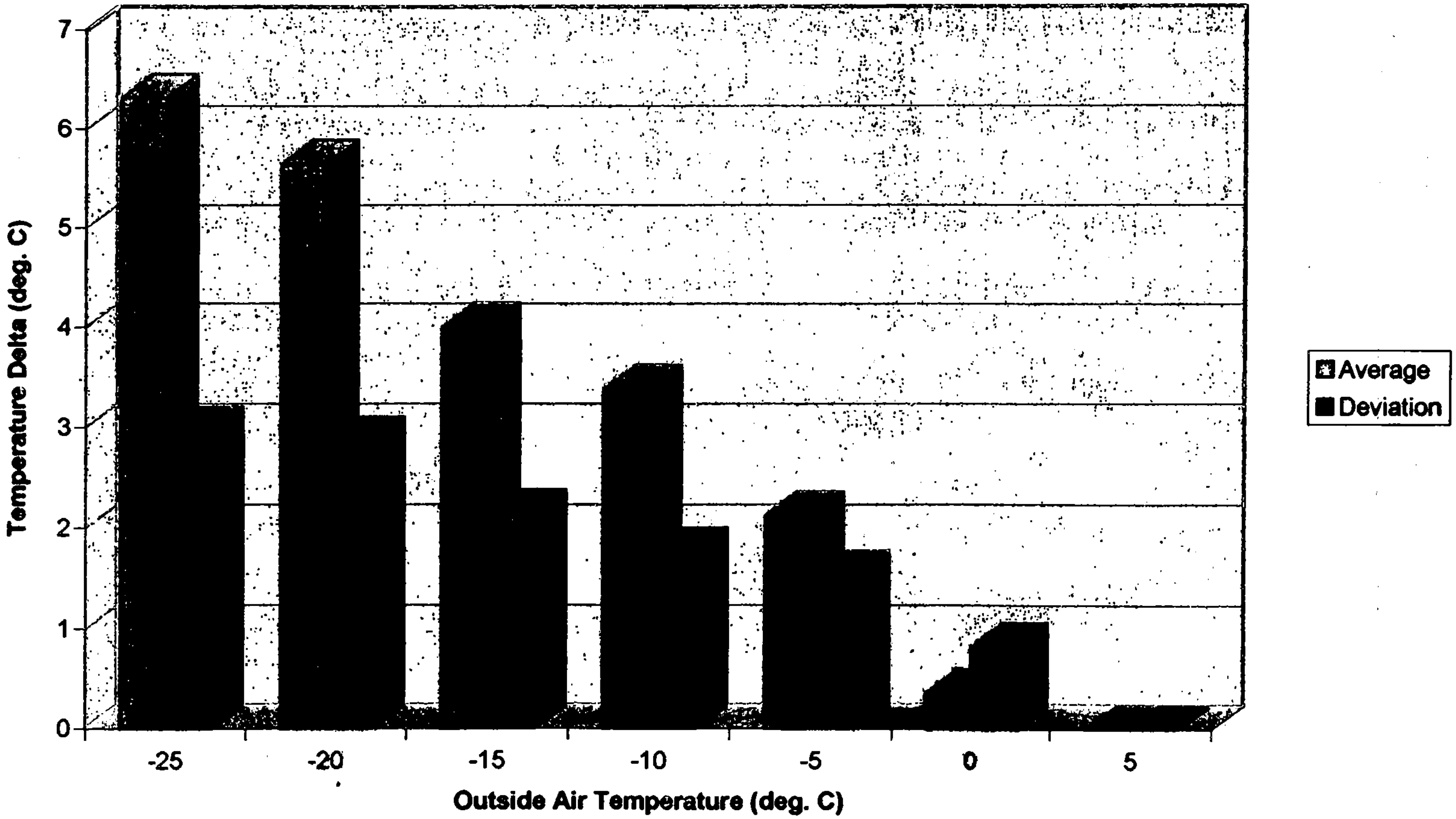


FIGURE G.3

TEMPERATURE DIFFERENTIAL AS FUNCTION OF OUTSIDE AIR TEMPERATURE (DC9, All Airports)

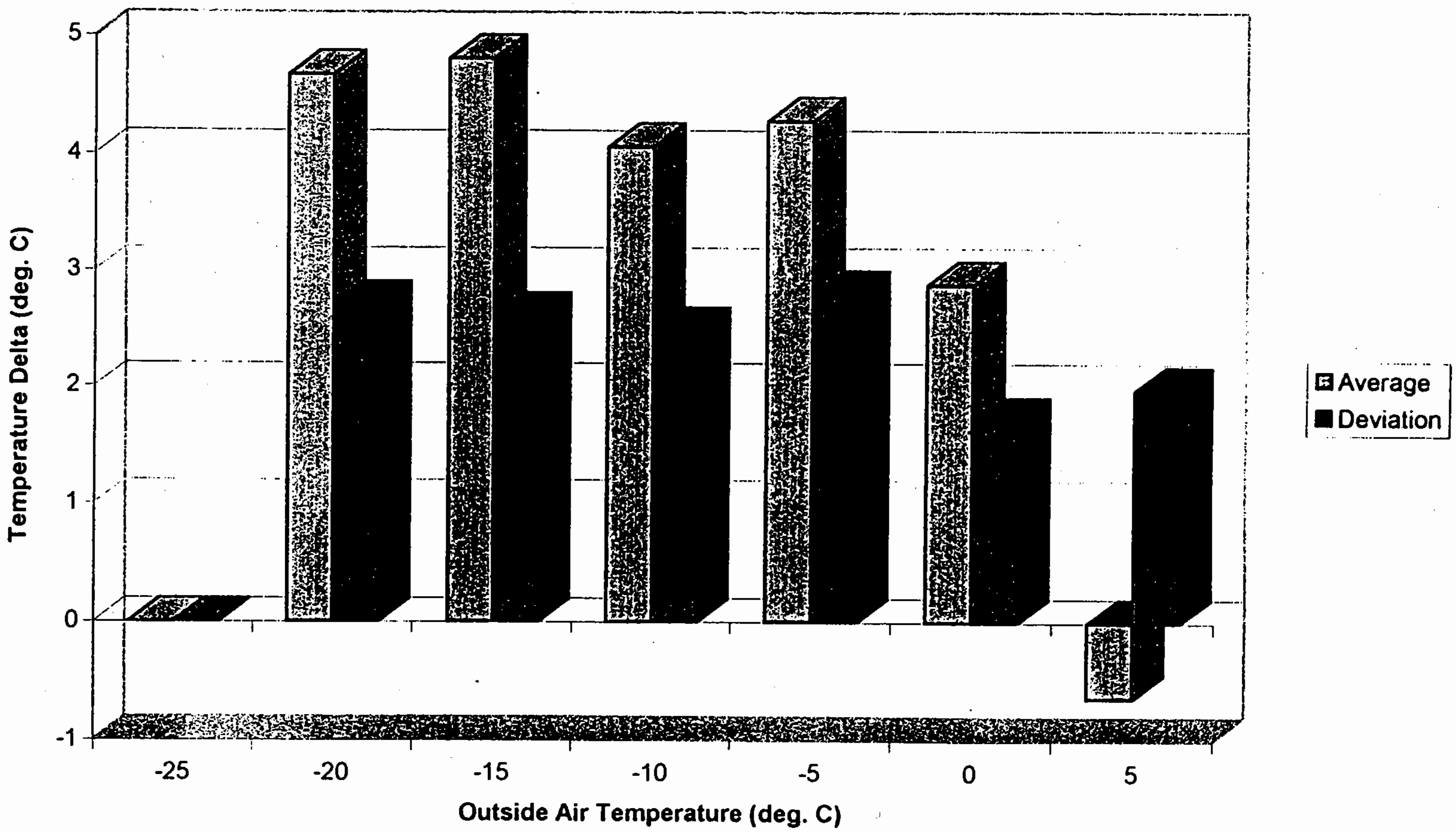


FIGURE G.4

EUROPEAN DATA
TEMPERATURE DIFFERENTIAL AS FUNCTION OF OUTSIDE AIR TEMPERATURE
(R/H Wing. At Arrival)

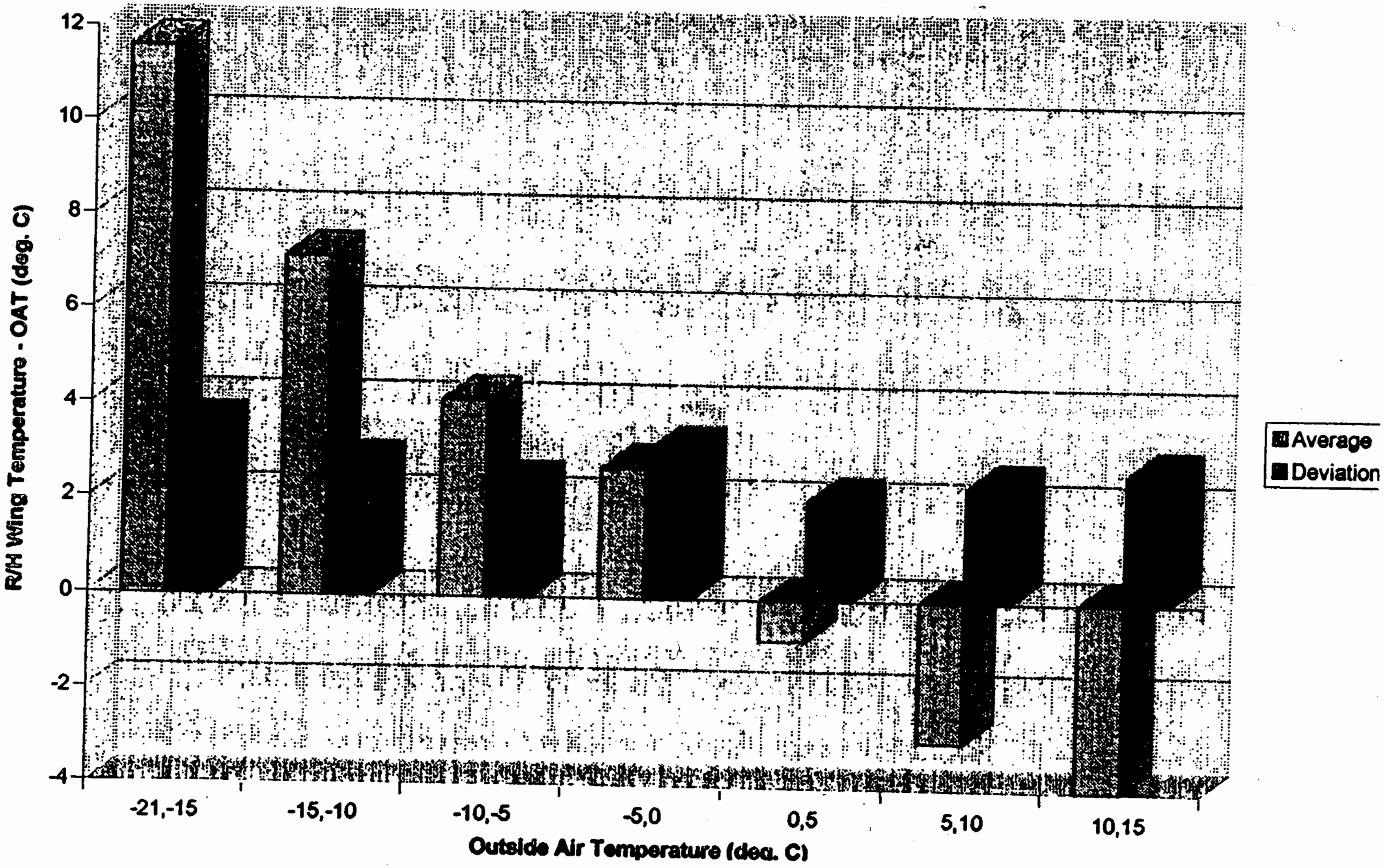


FIGURE G.5

EUROPEAN DATA
TEMPERATURE DIFFERENTIAL AS FUNCTION OF OUTSIDE AIR TEMPERATURE
(Left Wing, Point 2)

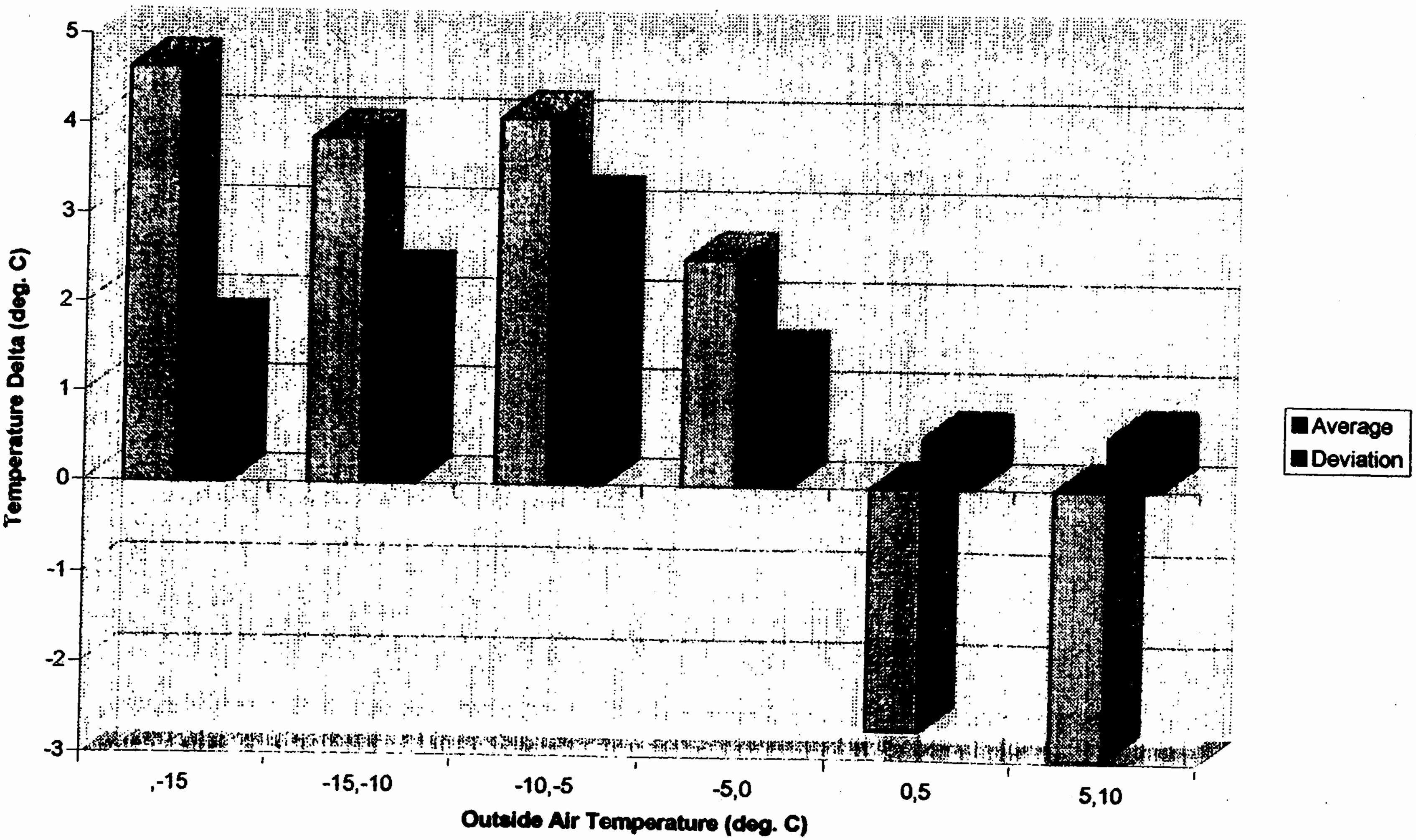


FIGURE G.6

EUROPEAN DATA
TEMPERATURE DIFFERENTIAL AS FUNCTION OF OUTSIDE AIR TEMPERATURE
(Right Wing, Point 2)