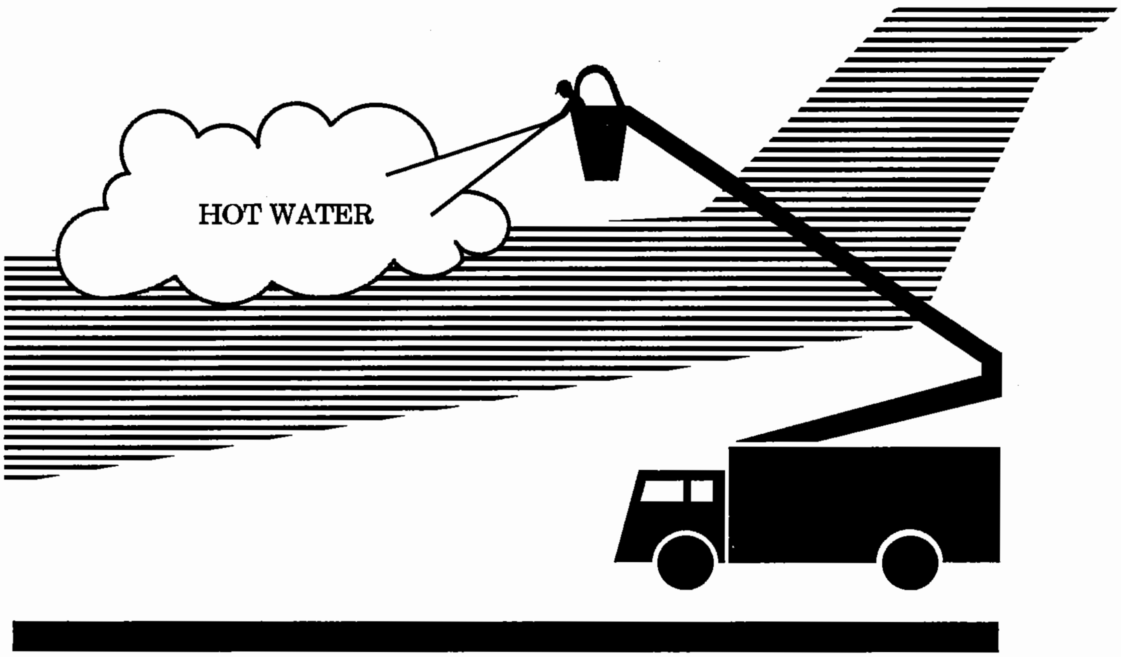
TP 12653E

Hot Water De-icing Trials for the 1994-1995 Winter



Prepared for

Dryden Commission Implementation Project
Transport Canada

by

APS AVIATION INC. APS

December 1995

TP 12653E
CM1222.001

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Peter Dawson, John D'Avirro

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

Un sommaire en français de ce rapport est inclus.

PREFACE

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

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

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

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

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

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

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

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

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

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

PREFACE

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

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

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

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

This report, TP 12653E, addresses the objective of determining the environmental limits for use of hot water as a de-icing fluid.

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

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See abstract

16. Abstract

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

The objective of this study was to develop data to assist in the determination of minimum environmental conditions under which hot water can be used for de-icing aircraft. Environmental and cost benefits associated with hot water de-icing are limited by an SAE-recommended -3°C minimum temperature limit for the process.

Data was collected during field hot water de-icing trials on overnighting aircraft at Dorval airport, and in laboratory tests at the NRC Cold Chamber in Ottawa. Data collected indicates that hot water de-icing is feasible at outside air temperatures below -3°C but that wind conditions must be taken into account.

Field and laboratory results suggest formulating a family of curves expressing lag time for the wing surface to reach 0°C following application of hot water as a function of outside air temperature and wind velocity. The establishment of a control chart based on these curves would provide a valuable tool to operators for determining acceptability of hot water de-icing under specific weather conditions, and could support the use of hot water as a de-icing agent under a much broader range of conditions than is currently reflected in the SAE Recommended Practice.

Further activities are recommended to gather additional data and to construct such a control chart.

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Voir résumé

16. Résumé

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

Le but de la présente recherche était de recueillir des données permettant de définir les conditions atmosphériques limites autorisant l'emploi d'eau chaude pour le dégivrage des aéronefs. Les avantages environnementaux et financiers de cette méthode se trouvent être contrecarrés par une recommandation de la SAE fixant à - 3 °C la température extérieure la plus basse autorisant la mise en oeuvre de cette méthode de dégivrage.

Des essais de dégivrage à l'eau chaude ont été menés à l'aéroport de Dorval (Montréal) sur des DC-9 d'Air Canada ayant passé la nuit à l'extérieur et dans la chambre froide du Conseil national de recherches à Ottawa. Les résultats montrent qu'il est admissible d'utiliser l'eau chaude pour le dégivrage des avions à une température de l'air extérieur inférieure à - 3 °C, à condition de tenir compte de la vitesse du vent.

Les essais sur le terrain et en laboratoire devraient permettre le traçage de courbes types montrant le temps ouvert à la pulvérisation d'antigivre sur les ailes - laps de temps entre l'arrosage à l'eau chaude et le retour au point de congélation - en fonction de la température de l'air extérieur et de la vitesse du vent. Ces courbes, une fois validées, permettraient aux exploitants de prendre des décisions éclairées concernant les opérations de dégivrage à l'eau chaude en fonction des conditions météorologiques observées. De plus, elles autoriseraient la mise en oeuvre de cette méthode dans des conditions beaucoup moins rigides que sous le régime actuel, à savoir la pratique recommandée par la SAE.

Il est recommandé de poursuivre les recherches afin de recueillir de plus amples informations permettant le traçage de ces courbes.

17. Mots clés Aéronefs, neige, antigivre, fluide, durée d'efficacité, dégivrage, glace, capteur, eau chaude	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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EXECUTIVE SUMMARY

At the request of the Dryden Commission Implementation Project (DCIP) of Transport Canada, APS Aviation Inc. undertook a study to establish lower temperature limits for application of hot water de-icing processes.

Hot water has been in use as an aircraft ground de-icing agent for many years and offers the significant benefits of reduced environmental impact and operating cost.

The standard process for hot water de-icing involves removal of snow or ice with hot water at a nozzle temperature of at least 60°C, followed by an overspray of anti-icing fluid applied before the water freezes. Application to aircraft wings may be in a single operation for each wing, or the wings may be de-iced in a series of panels. The applicable SAE Aerospace Recommended Practice ARP4737 suggests that a typical time to refreeze is 3 minutes and limits the use of hot water to conditions when outside air temperature (OAT) is not lower than -3°C.

The OAT restriction, established in response to voiced concerns by particular carriers, is the crux of the issue. While some carriers have experienced problems below -3°C, others have operated successfully with hot water to temperatures of -7°C and wish to continue enjoying the benefits of operating at these lower temperatures. Currently no scientific data on which to base an objective decision exists.

The objective of the study was to develop data to assist in the determination of minimum environmental conditions under which hot water can be used for de-icing.

Data Collection

Hot water de-icing trials on overnighting Air Canada DC-9 aircraft were conducted at the Air Canada de-icing centre at Dorval Airport, Montreal. Wing skin temperatures were sampled and logged continuously throughout the de-icing process by the use of thermistor probes mounted on the wing surfaces. Wing surfaces and cavities were observed for ice formation. Spraying was performed by Air Canada personnel.

The condition of the ramp surface was monitored to identify formation of any ice and related slipperiness resulting from the water spray.

The NRC Cold Chamber at Ottawa International Airport was used to evaluate the impact of specific variables on the de-icing process as applied to reference test panels. These variables included wind speed, temperature, fluid amounts, and thickness of flat plates used as test surfaces.

Results

The trials confirmed a procedure and appropriate equipment to be used to gather data to scientifically establish lower operational limits for hot water de-icing.

Test results indicated that hot water de-icing is feasible at outside air temperatures below -3°C, depending principally on wind and de-icing operator disciplines. A trial conducted at -9°C with a 7 kph wind resulted in a lag time available to the operator for overspray of 3.5 minutes.

Lack of suitable weather conditions and availability of aircraft and ground crew limited the number of tests.

Wind as simulated in a laboratory environment has a very major influence on lag time. For a fixed OAT, moving from a condition of zero wind to a wind of 26 kph reduces lag time by a factor of four.

Observations and measurements of ice formation on the ramp surface indicated that this should not be a significant problem for hot water de-icing operations utilizing off-gate dedicated de-icing pads.

Field and laboratory results suggest formulating a family of curves expressing lag time for the wing surface to reach 0°C following application of hot water as a function of OAT and wind velocity. The establishment of fully validated charts would provide a valuable tool to operators in determining acceptability of hot water de-icing under specific weather conditions, and could support the use of hot water as a de-icing agent under a much broader range of conditions than is currently reflected in the SAE Recommended Practice.

Recommendations

The following actions are recommended:

- Conduct further field tests to obtain more data under a wider range of weather conditions.

- Conduct further tests in the NRC Cold Chamber to gather data to complete the operational spectrum for different wind and temperature combinations.

- Construct an operations-decision model based on acquired data to assist in decision making on the use of hot water in actual operating conditions.

- Seek modification of the current SAE ARP4737 to extend the operational range.

SOMMAIRE

À la demande du Comité de mise en oeuvre de la Commission Dryden mis sur pied par Transports Canada, APS Aviation Inc. a lancé une étude visant à déterminer la température extérieure la plus basse autorisant l'emploi de l'eau chaude pour le dégivrage des avions au sol.

L'eau chaude sert depuis fort longtemps comme moyen de dégivrage au sol, car elle offre des gains intéressants sur les plans du coût d'exploitation et de l'impact sur l'environnement.

La méthode mise en oeuvre consiste à ôter la neige ou la glace avec de l'eau dont la température à la sortie de la buse est d'au moins 60 °C et à pulvériser un liquide antigivrage avant que l'eau n'ait le temps de geler. On peut procéder par nettoyage d'une aile au complet avant la pulvérisation ou par nettoyage et pulvérisation tronçon d'aile par tronçon d'aile. La pratique recommandée en l'occurrence par SAE Aerospace, celle portant le numéro ARP4737, indique que le temps ouvert à la pulvérisation d'antigivre avant que l'eau ne gèle de nouveau serait de 3 minutes, à condition que la température de l'air extérieur ne soit pas au-dessous de - 3 °C.

C'est cette limite de - 3 °C qui est au coeur du débat lancé par certains transporteurs aériens. Certains disent avoir buté contre des difficultés au-dessous de cette température limite, d'autres disent avoir pu opérer jusqu'à - 7 °C. Ces derniers souhaitent pouvoir continuer à bénéficier des avantages procurés par cette méthode. Il n'existe pour le moment aucune donnée permettant d'asseoir le débat sur une base scientifique objective.

La présente recherche avait pour but de recueillir des données permettant de définir la température extérieure la plus basse autorisant l'emploi de l'eau chaude pour le dégivrage des avions.

Saisie de données

Des essais de dégivrage à l'eau chaude ont été menés à l'aéroport de Dorval (Montréal) sur des DC-9 d'Air Canada ayant passé la nuit à l'extérieur. Des thermistances fixées au revêtement des ailes ont permis, tout au long de l'opération de dégivrage, de mesurer et d'enregistrer en continu la température du revêtement. On a également observé la formation de givre sur la surface des ailes et dans les espaces en creux. L'arrosage a été effectué par le personnel d'Air Canada.

On a observé le sol de l'aire de stationnement également afin de déceler, suite à cet arrosage, la formation de glace susceptible de rendre le sol glissant.

Par ailleurs, on s'est servi de la chambre froide que le Conseil national de recherches (CNR) exploite à l'aéroport international d'Ottawa pour observer l'effet de certaines variables sélectionnées sur le dégivrage de plaques planes servant de panneaux témoins, à savoir vitesse du vent, température, quantité de liquide utilisé et épaisseur des plaques planes.

Résultats

Les essais ont validé un mode opératoire ainsi que le matériel adéquat pour recueillir les données devant permettre d'asseoir sur une base scientifique la détermination des limites opérationnelles à l'emploi de l'eau chaude pour le dégivrage des avions.

Les résultats montrent qu'il est admissible d'utiliser l'eau chaude pour cet usage à une température de l'air extérieur inférieure à - 3 °C, à condition de tenir compte de la vitesse du vent et des méthodes de dégivrage mises en oeuvre. Un essai effectué à - 9 °C sous un vent soufflant à 7 km/h a donné un temps ouvert à la pulvérisation d'antigivre de trois minutes et demie.

Il a fallu limiter le nombre des essais à cause des conditions météorologiques peu propices et du nombre insuffisant d'avions et de personnel au sol.

Comme l'ont montré les essais climatiques en laboratoire, le vent joue un rôle déterminant dans le temps ouvert à la pulvérisation. À une température de l'air extérieur donnée, ce temps varie par un facteur de quatre entre une vitesse de vent nulle et de 26 km/h.

L'observation et la mesure de la formation de glace au sol ont montré que cela ne devrait pas constituer un obstacle important au dégivrage à l'eau chaude, si cette opération se déroulait dans un endroit dédié, à l'écart de l'aérogare.

Les essais sur le terrain et en laboratoire devraient permettre le traçage de courbes types montrant le temps ouvert à la pulvérisation d'antigivre sur les ailes - laps de temps entre l'arrosage à l'eau chaude et le retour au point de congélation - en fonction de la température de l'air extérieur et de la vitesse du vent. Ces courbes, une fois validées, permettraient aux exploitants de prendre des décisions éclairées concernant les opérations de dégivrage à l'eau chaude en fonction des conditions météorologiques observées; de plus, elles autoriseraient la mise en oeuvre de cette méthode dans des conditions beaucoup moins rigides que sous le régime actuel, à savoir la pratique recommandée par la SAE.

Recommandations

Les actions suivantes sont recommandées :

- Poursuivre les essais sur le terrain pour recueillir de plus amples informations dans une plage de conditions météorologiques plus étendue;

- Poursuivre les recherches dans la chambre froide du CNR pour couvrir toute la gamme des combinaisons de température et de vitesse du vent;

- Élaborer un modèle fondé sur les informations recueillies et destiné aux prises de décision concernant le dégivrage à l'eau chaude dans les conditions environnementales observées;

- Proposer que la pratique ARP4737 de la SAE soit modifiée afin d'élargir la plage des températures admissibles.

SECTION NUMBER			**PAGE NUMBER**

APPENDICES

FIGURE NUMBER | **PAGE NUMBER**

PHOTO NUMBER | **PAGE NUMBER**

LIST OF ACRONYMS

AES	Atmospheric Environment Services (Canada)
APS	APS Aviation Inc.
ARC	Aviation Research Corporation
ARP	Aerospace Recommended Practice
C/FIMS	Contaminant/Fluid Integrity Monitoring System
FAA	Federal Aviation Administration
ISO	International Standards Organization
NRC	National Research Council
OAT	Outside Air Temperature
SAE	Society of Automotive Engineers, Inc.
TDC	Transportation Development Centre
UCAR	Union Carbide
YUL	Dorval International Airport, Montreal

1. INTRODUCTION

1. INTRODUCTION

At the request of the Dryden Commission Implementation Project (DCIP) of Transport Canada, APS Aviation Inc. undertook a study to establish lower temperature limits for application of hot water de-icing processes. Appendix E, Para. 5.5, presents the detailed statement of work for this project.

Hot water has been in use as an aircraft ground de-icing agent for many years. Significant benefits are associated with use of water as a de-icing medium compared with commercial de-icing fluids, chief of which are low environmental impact and reduced operating costs.

Hot water de-icing as a standard process has enjoyed differing degrees of support and enthusiasm among airlines with some being strong proponents while others are apprehensive of its application in their operations.

The standard process for hot water de-icing involves removal of snow or ice with hot water at a nozzle temperature of at least 60°C, followed by an overspray of anti-icing fluid applied before the water freezes. The applicable SAE Aerospace Recommended Practice ARP4737 (Appendix A) states that anti-icing is to be applied before the water spray freezes, typically within three minutes. The delay in refreezing, referred to in this report as "lag time", is a result of the heat that has been transferred to the aircraft surface by the hot fluid. In practice the de-icing operator must monitor his own progress, ensuring that no surface area refreezes prior to application of the overspray. Three minutes from initial spray time is used as a guideline in monitoring surface refreezing, prior to applying an anti-icing overspray. De-icing a wing in discrete segments may be the result. Protection against refreezing of water in control surface cavities is vital.

1. INTRODUCTION

The SAE recommended practice limits the use of hot water to conditions when outside air temperature (OAT) is not lower than -3°C.

The OAT restriction, established in response to voiced concerns by particular carriers, is the crux of the issue. While some carriers have experienced problems below -3°C, others have used hot water as a de-icing fluid in conditions of ambient temperatures as low as -7°C and wish to continue enjoying the benefits of operating at these lower temperatures.

Variations in carrier processes may have an impact on the success of using hot water at lower temperatures:

- lower wing skin temperatures as a result of tankering of cold fuel;
- application of a heated versus cold anti-icing overspray; and
- ability to ensure consistently tight procedural disciplines related to use of hot water at lower temperatures.

Currently there exists no scientific data to enable an objective evaluation of the impact of outside air temperature on hot water de-icing processes. Neither does data exist for other related variables including wind and precipitation, both of which exert significant influence on de-icing effectiveness.

Carriers who have been particularly successful with hot water de-icing processes including operating at lower temperatures may have, intentionally or otherwise, benefitted from the operational judgement of field staff experienced in hot water de-icing who have learned which conditions give rise to rapid refreezing.

1. INTRODUCTION

To reach an informed decision on acceptable lower limits, a body of scientifically gathered data is required. This data would include the prevailing environmental conditions, the condition of hot water application, the temperature profile of the wing during actual de-icing operations, and the lag time from initial hot water spray until the wing surface again reaches the freezing point of water.

A method to gather this data was required, and subsequently, a model based on experimental data needed to be developed to indicate the maximum lag time available to the operator under existing weather conditions before the protective overspray should be applied. This initial study was designed to reflect operating conditions of ambient temperature and wind, but to exclude conditions of precipitation and also application of hot water to cold-soaked wings.

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2. METHODOLOGY

2.1 Test Sites

2.2 Equipment

2.3 Test Procedures and Data Forms

2.4 Fluids

2.5 Personnel and Participation

2.6 Analysis Methodology

2. METHODOLOGY

The methodology description is sub-divided into six sections which deal with test sites, test procedures and data forms, equipment, fluids, personnel and participants, and analysis methodology, respectively.

2.1 Test Sites

Hot water de-icing trials on actual aircraft were conducted at the Air Canada de-icing centre at Dorval Airport (Montreal). This enabled access to overnighting aircraft and to standard de-icing facilities and equipment as used by Air Canada. DC-9 aircraft were used for these trials, and de-icing performed by Air Canada de-icing personnel.

APS Aviation coordinated the tests on the basis of forecasted weather, seeking conditions in the range of -7 to -10°C with no precipitation.

Meteorological data was available from Environment Canada, gathered at a site in close proximity to the de-icing centre.

Standard flat plates[1] tested in the National Research Council (NRC) Cold Chamber at Ottawa were used to evaluate the impact of specific variables on the de-icing process. These variables included wind speed, ambient temperature, fluid amounts applied, and thickness of flat plates. The cold chamber facility enabled control of temperature as well as establishing a wind of pre-defined velocity over a flat plate stand.

[1] Standard flat plates as used for evaluating de-icing/anti-icing fluid.

2.2 Equipment

2.2.1 Aircraft Tests at Dorval De-icing Centre

During the procedural development stage it was realized that temperature profile data gathered via manually positioned temperature probes would be inadequate to enable a good understanding of the true nature of temperature gradient at a number of points on the wing surface.

Investigation into alternative approaches identified a combination of thermistor probes and temperature logger that would deliver the frequency, number and accuracy of temperature readings required, and provide reliability in the temperature conditions involved for testing. Low temperature type thermistor probes were selected that would give best resolution in the temperature ranges expected. Prior to field trials, accuracy of the probes was confirmed in an ice bath.

Two data loggers, each with capacity of seven external channels were purchased. The loggers were calibrated to record temperature readings at each of the probes, every 8 seconds. At this frequency rate, the logger had capacity for 10 hours of test data.

After some experimentation in installation, an installation procedure was settled on as described in Appendix B. Photos of a typical set-up of equipment at a DC-9 aircraft; probes positioned on the wing surface; an array of probe cables under the aircraft wing, and loggers mounted on a supporting back-board are shown in Photos 1, 2, 3 and 4.

PHOTO 1
EQUIPMENT SET-UP AT DC-9 AIRCRAFT

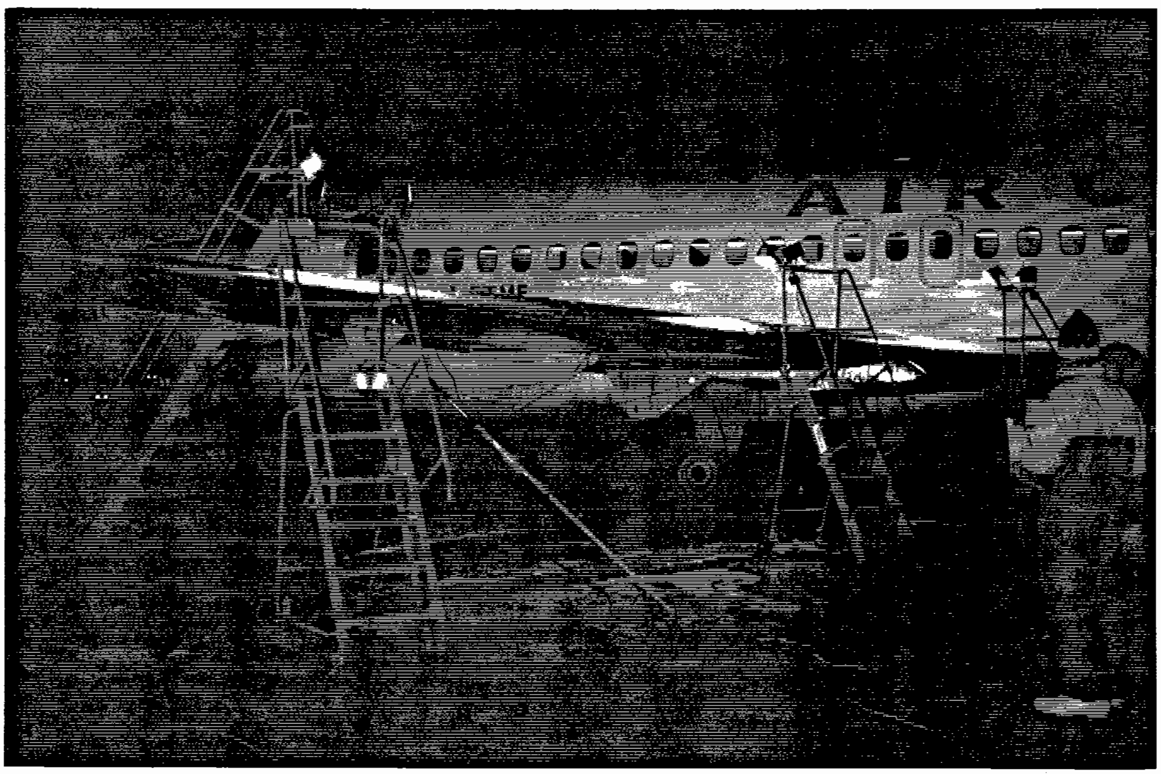


PHOTO 2
TYPICAL INSTALLATION OF THERMISTOR PROBES ON WING SURFACE

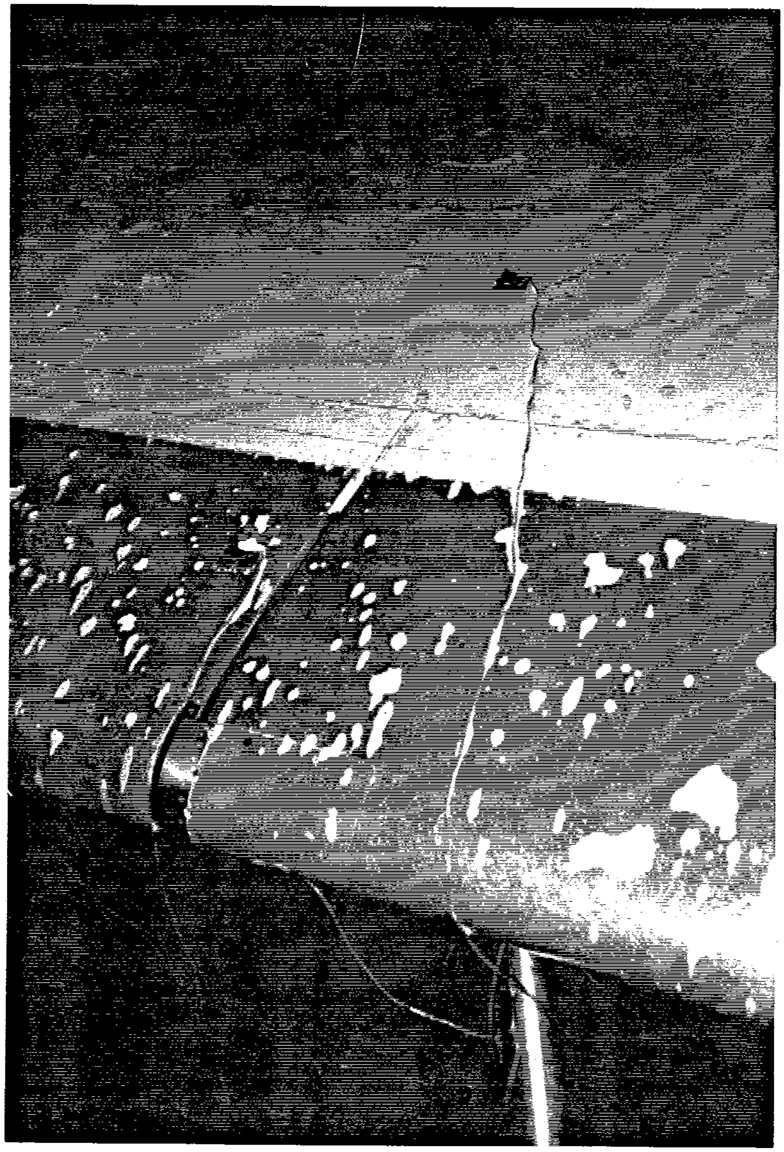


PHOTO 3
ARRAY OF PROBE CABLES UNDER AIRCRAFT WING

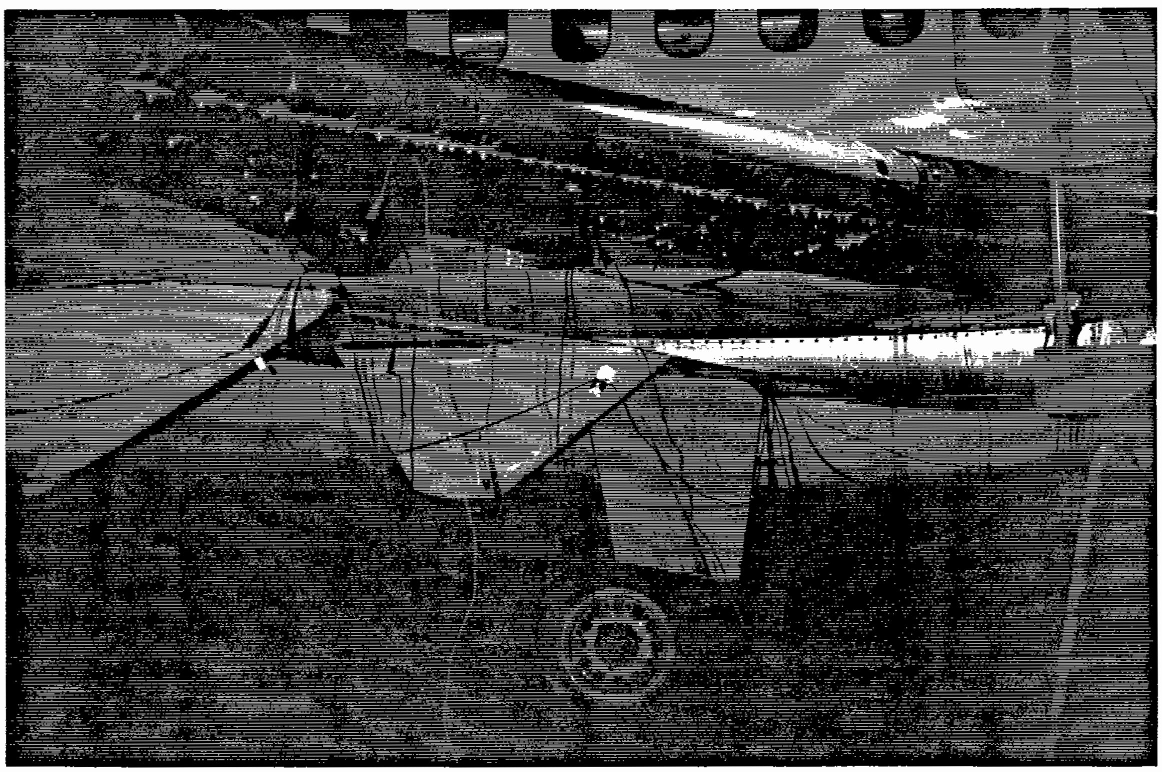
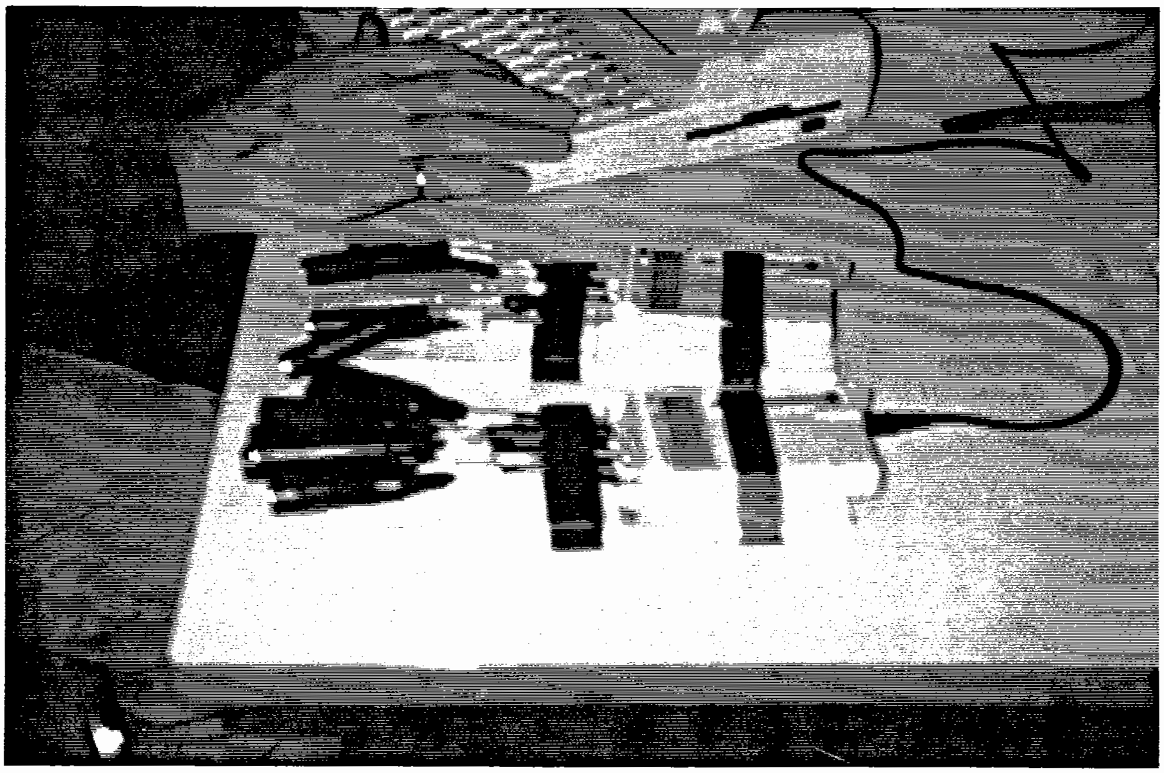


PHOTO 4
TEMPERATURE LOGGERS WITH CABLE TERMINALS AND BACK-BOARD



The rapid response of the instrumentation following application of hot water, as well as the sensitivity and precision as water in contact with the probe passes through phase change at freeze point, is illustrated in a typical temperature gradient curve shown in Figure 2.1. The two initial peaks of the curve at times 02:51:00 and 02:52:00, reflect a second application of heated fluid as the operator re-sprayed that particular area.

An equipment list is included in Appendix B.

2.2.2 Equipment at the NRC Cold Chamber

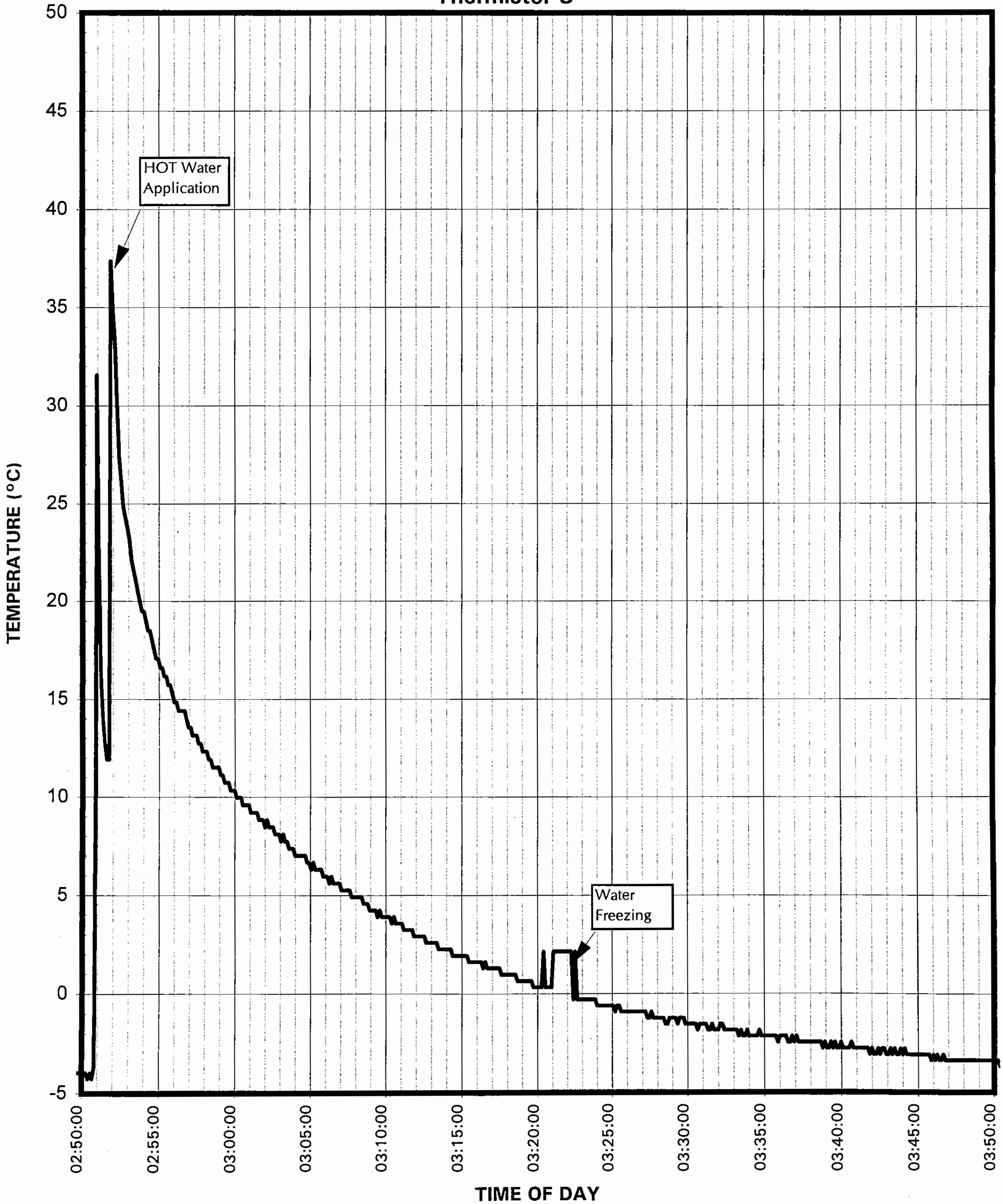
The cold chamber enabled temperature control to pre-determined levels. In addition, a large fan enabled winds to be established at various velocities through the simple expedient of changing fan distance from the test stand.

Photos of plates and heat sinks with thermistor probes installed, the fan set-up, and pouring technique are presented in Photos 5, 6 and 7.

Test instrumentation as used in field trials supplemented by an anemometer to measure wind velocity was used for these laboratory trials.

Placement of flat plates and heat sinks on the flat plate frame is shown in Figure 2.2.

Figure 2.1
SAMPLE WING TEMPERATURE PLOT
HOT WATER SKIN TEMPERATURE TEST@ YUL
Aircraft Wing (Starboard Side "B")
MAR 28, 1995, RUN #2
Thermistor 3



cm1222\analysis\hotwater\thermist\MR28R2S3.XLC

PHOTO 5
PLATES AND HEAT SINKS WITH THERMISTOR PROBES INSTALLED IN NRC COLD CHAMBER TESTS

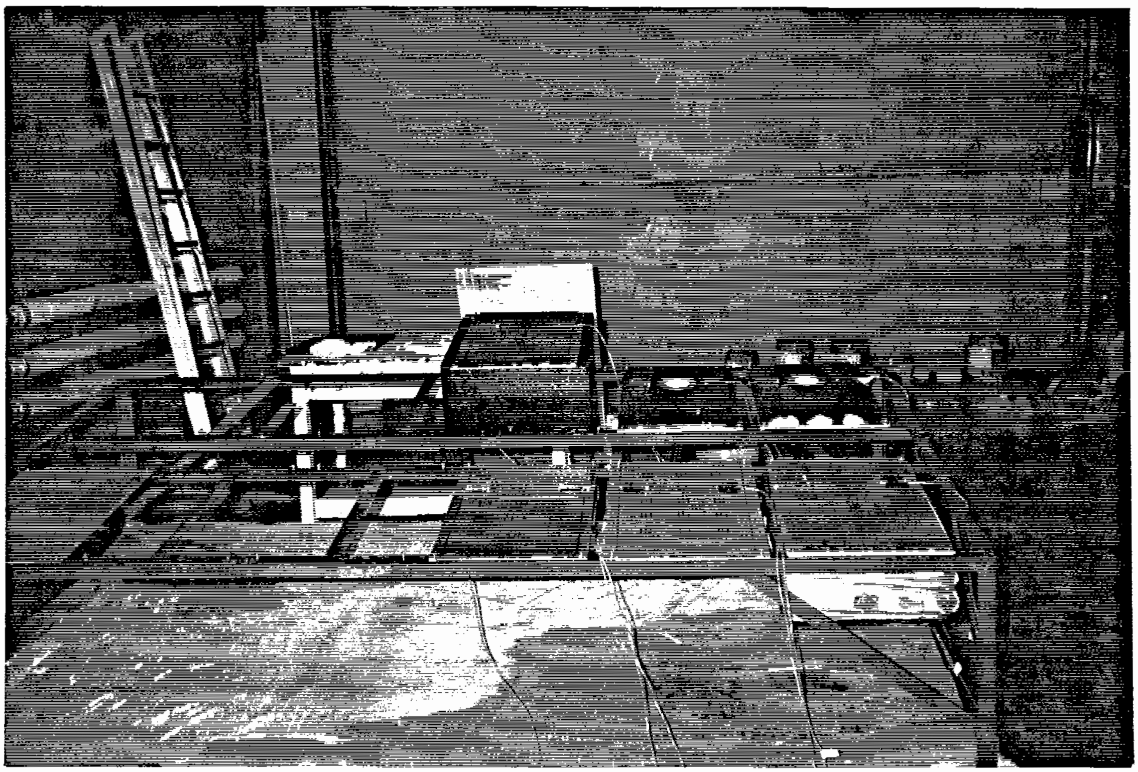


PHOTO 6
ELECTRIC FAN USED TO PROVIDE CONSTANT VELOCITY WIND IN NRC COLD CHAMBER

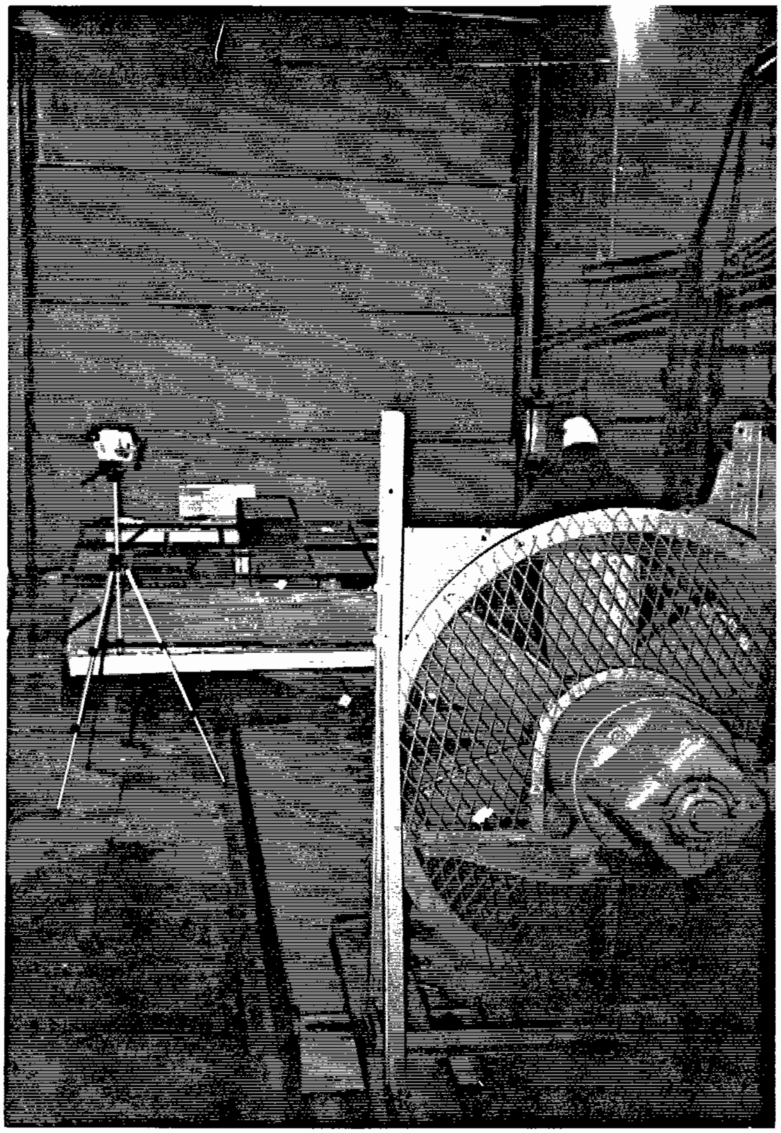


PHOTO 7
ILLUSTRATION OF POURING TECHNIQUE
IN NRC COLD CHAMBER TESTS

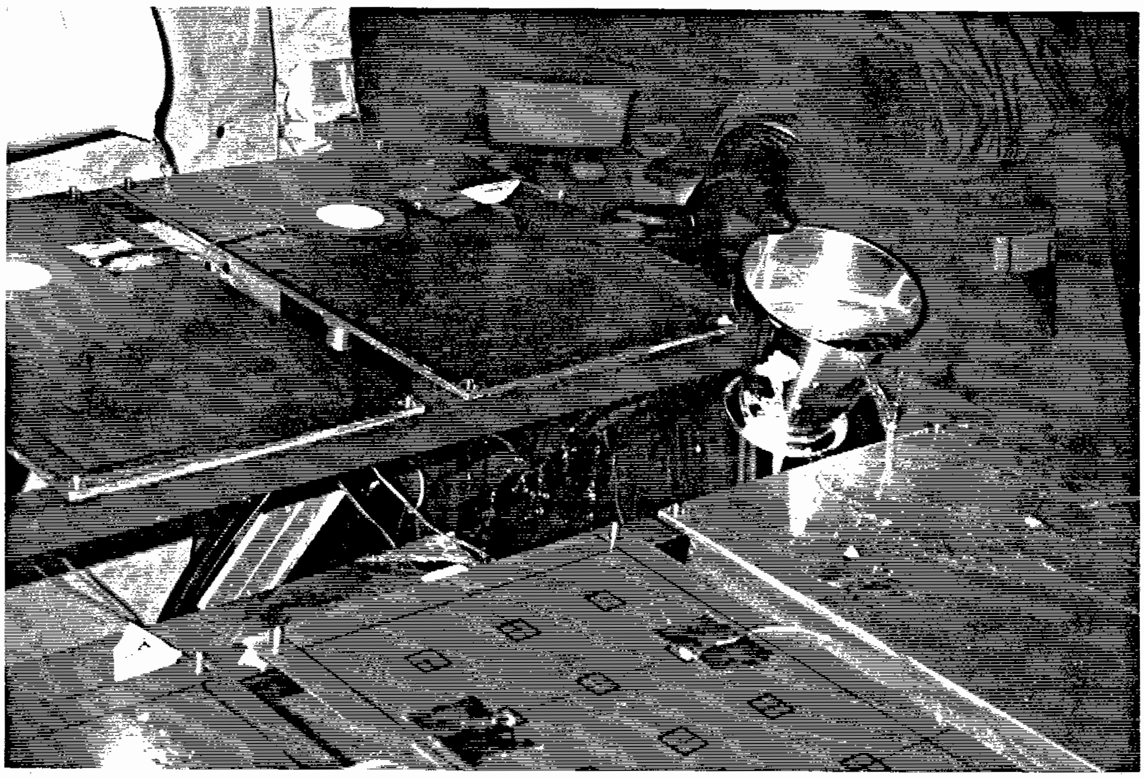
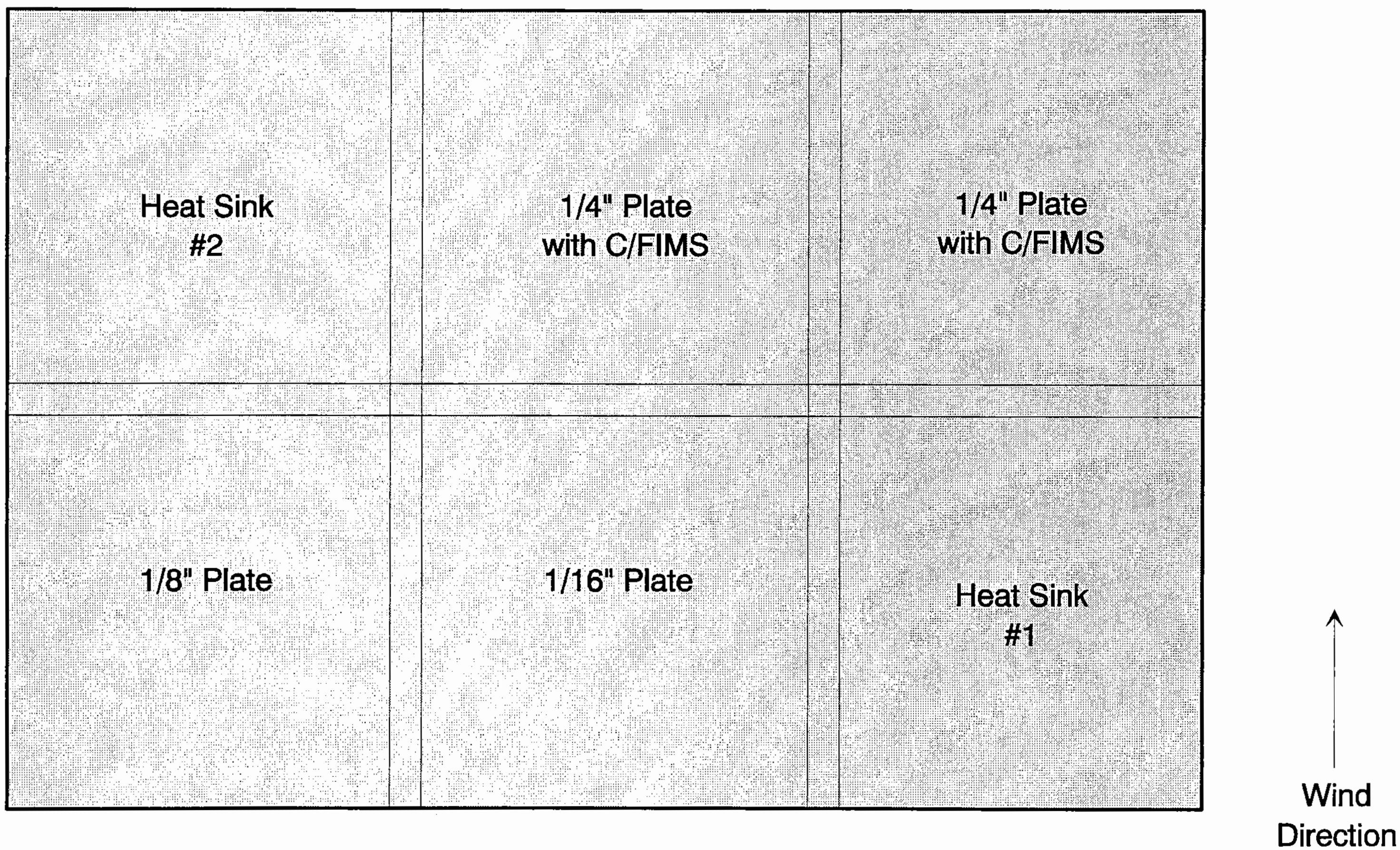


FIGURE 2.2
FLAT PLATE AND HEAT SINK PLACEMENT ON FLAT PLATE STAND



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2.2.3 Comparison of Temperature Measuring Devices

AlliedSignal C/FIMS sensors installed on flat plates were included in field and laboratory tests to provide a backup to the thermistor log as well as to provide a basis for comparison of the two instruments.

Manually positioned contact temperature probes as used by Aviation Research Corporation were utilized in initial field trials to enable an evaluation of their results versus the thermistor probes.

2.3 Test Procedures and Data Forms

2.3.1 Aircraft Trials

The aircraft trials were comprised of two types of tests:

- hot water spray without an overspray of anti-icing fluid to enable tracking of the wing surface temperature and condition as temperature decayed through the water freeze point;

- application of the current standard Air Canada hot water de-icing procedure which involves spraying hot water to de-ice followed by an anti-icing overspray of heated Type I fluid, and tracking of the wing surface temperature gradient resultant from that process.

A heat sink with a flat plate surface, and a flat plate with a C/FIMS sensor installed, were mounted on a flat plate stand near the aircraft and tested simultaneously with the objective of establishing a standard reference for on-going tests.

Care was taken to ensure that test water used for the aircraft trials was uncontaminated by any fluid remaining in de-icing vehicle tanks and lines, and storage tank refill lines.

Wing skin and heat sink temperatures were sampled and logged continuously throughout the de-icing process by the use of thermistor probes mounted on the surface. Temperature profiles developed from thermistor probe data were subsequently analyzed to determine elapsed time from time of application of hot water until surface temperature dropped to 0°C. Wing surface and cavities were monitored visually for ice formation following the fluid application, reflecting checks that are a standard element of aircraft inspections following de-icing.

Time was allowed between tests for the wing surface temperature to return to the pre-test condition.

The condition of the ramp surface was monitored visually to identify formation of any ice and to assess related slipperiness resultant from the water spray. Ramp surface temperatures were recorded and samples of fluid lifted from the ramp surface were measured for glycol concentration with a refractometer.

Hand-held contact temperature probes as used by Aviation Research Corporation were used to measure wing surface temperatures at the same points that thermistor probes were installed to compare results produced by the two instruments.

Complete details of test procedures including data collection forms are provided in Appendix B.

2.3.2 NRC Cold Chamber

Trials were conducted in the NRC Cold Chamber to investigate the influence of wind and temperature combinations on temperature gradient in a simulated hot water de-icing operation.

Flat plates of varying thicknesses and heat sink properties were tested to evaluate the impact of plate thickness on temperature decay time following hot fluid application. Flat plates tested included two plates at 6.4 mm (¼") thick, each having a C/FIMS sensor installed, one plate at 3.2 mm (⅛") thick and one plate at 1.6 mm (1/16") thick (Figure 2.2).

In addition to the initial proposal to test flat plates, two sealed box heat sinks of 15 cm depth (Figure 2.4) were introduced to more closely simulate an aircraft wing with cold fuel in tanks. The actual heat sink unit used in field tests at the Dorval de-icing centre was included for consistency.

Two thermistor probes were installed on each test surface (Figure 2.3), and linked to the temperature logger. Temperature profiles were subsequently developed from this data and analysed to determine the elapsed time from point of hot fluid application until plate temperature reached 0°C.

FIGURE 2.3

LOCATION OF THERMISTOR PROBES ON FLAT PLATES

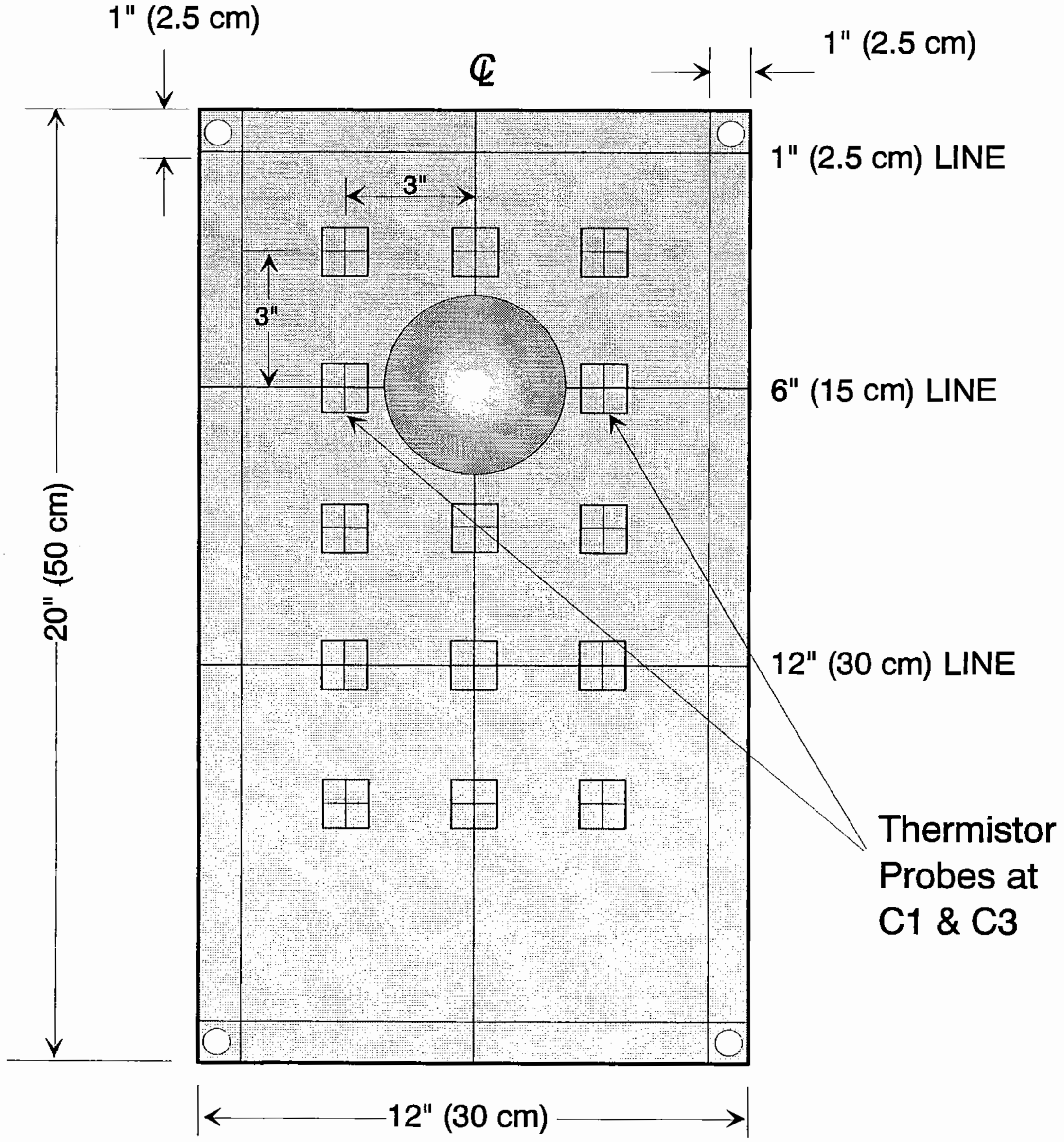

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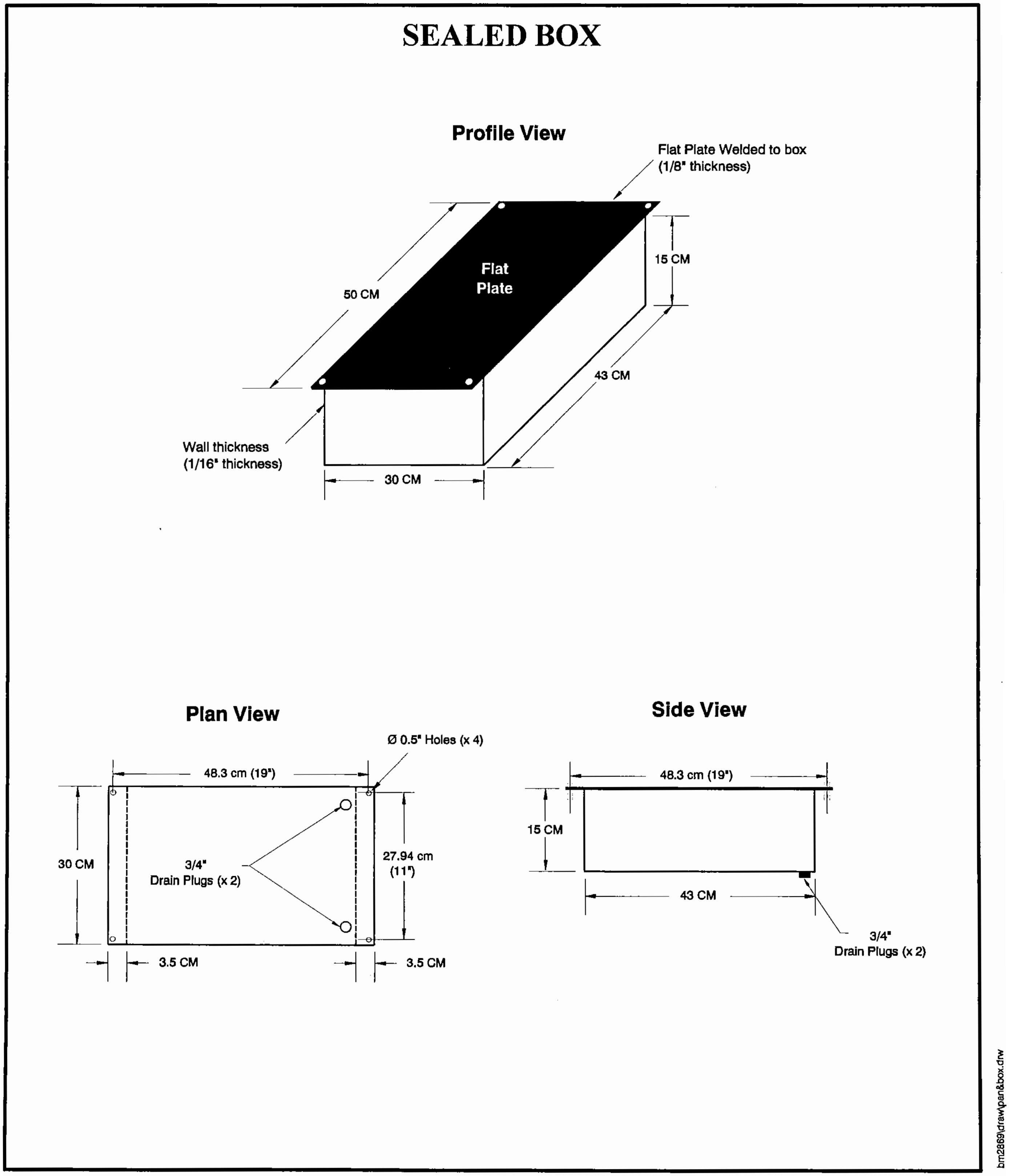
FIGURE 2.4
SCHEMATICS OF SEALED BOX
DEPTH OF 15 CM



The cold chamber temperature, with plates in position, was established at -5°C and sufficient time allowed for equipment to reach that temperature.

Winds were simulated by use of a large fan and different velocities were controlled by varying set-up distance from the test stand to the fan. Measuring wind velocity with an anemometer at several points across the flat plate frame confirmed that uniform flow was being generated.

Type I de-icing fluid was used in lieu of water to enable pre-wetting of plates with the objective of achieving an even flow of fluid over the plate. The fluid was poured in such a manner as to ensure that the full quantity of fluid flowed over the plate, as opposed to the standard method used in fluid qualification tests of pouring at the plate edge to counter boundary effects.

A standard fluid quantity was calculated to represent an amount typically sprayed in a hot water operation. From aircraft tests at Dorval this was calculated to be 0.5 litres for an area equivalent to the flat plate surface. In the aircraft tests early failures typically occurred on flight control surfaces having a gap at their forward edge. The effect of this gap was that upstream fluid was prevented from flowing down over the control surface, and the only fluid having an influence on the control surface temperature was that fluid which was sprayed directly upon it. This observation justified application of the calculated fluid quantity without an adjustment for fluid flow-down. Fluid was heated to 74°C (165°F) or as close as achievable for each consecutive test. Temperature of the heated fluid was logged by use of a spare thermistor probe.

Tests consisted of two steps at each wind setting. The first step consisted of pouring the standard volume of heated Type I fluid over each test surface with the exception that double the standard volume was poured over one of the two 6.4 mm (1/4") plates. Time was taken to allow the plates to cool to or near ambient, then a second step was conducted pouring fluid volumes double the amount of the first step. Again the plates were allowed to cool to ambient, and then the wind velocity was adjusted to a new value and the two-step tests repeated.

Elapsed time from point of hot fluid application until the plate surface temperature dropped to 0°C was calculated for each combination of plate thickness, fluid volume poured, wind velocity and temperature.

Because Type I fluid was used in these tests in lieu of hot water, a trial using hot water was conducted as a control to indicate any measurable difference in results between water and Type I fluid.

Details of test procedures including data collection sheets are provided in Appendix C.

2.4 Fluids

2.4.1 Aircraft Tests at Dorval De-icing Centre

To avoid contamination of hot water, vehicle tanks and lines were flushed prior to filling for test.

Type I fluid (UCAR XL 54) heated to 160°F was used as an anti-icing overspray in those tests reflecting the complete procedure of de-icing with hot water and anti-icing with Type I fluid.

2.4.2 NRC Cold Chamber

UCAR's Type I fluid mixed to a 29% concentration to provide a fluid freezing point at 10°C below ambient (-5°C) was used in lieu of hot water for these trials. Pure water was used in one set of trials to provide a comparison of results to the Type I fluid.

2.5 Personnel and Participation

2.5.1 Aircraft Tests at Dorval De-icing Centre

Air Canada staff operated airline de-icing vehicles and followed their standard spraying procedures for these tests. The tests were coordinated by APS Aviation staff based on forecasted weather conditions. Test results were gathered and analysed by APS Aviation.

Individual task assignments are shown in Appendix B.

2.5.2 NRC Cold Chamber

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

2.6 Analysis Methodology

Data analysis was performed in two stages. Initial analysis was performed in preparation for presentations to the SAE G-12 Committee meetings held in May '95 in Montreal and Amsterdam. Subsequently further analysis was performed for the present report.

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3. DESCRIPTION OF DATA AND OBSERVATIONS

3.1 Aircraft Tests Dorval De-icing Centre

3.2 NRC Cold Chamber

3.3 Comparison of Temperature Measuring Devices

3. DESCRIPTION OF DATA AND OBSERVATIONS

3.1 Aircraft Tests Dorval De-icing Centre

Tests were conducted with a DC-9 aircraft on three occasions with the following weather conditions experienced;

	Average OAT °C	Wind kph
March 28 '95	-3	6
April 05 '95	-13	28
April 07 '95	-9	7

On each of these occasions several tests of a repetitive nature were conducted to eliminate any possible impact of variance in spraying pattern or technique and to verify repeatability of results. A single data point was selected to represent results of each of the three test conditions. The data point selected was the shortest lag time (the most conservative) of all temperature gradient curves developed.

Trials to establish the temperature gradient of the wing surface following application of hot water without the Type I overspray were conducted on the starboard wing, while simultaneous tests of the complete procedure employing the hot fluid overspray were conducted on the port wing. Following spraying, time was taken for the wing surface temperature to cool to ambient temperature. Any ice formed during tests on the starboard wing was removed as part of the subsequent test. Figure 2.1 in Section 2.2 illustrates typical temperature gradient curves, while Appendix D contains the temperature gradient curves for the remaining tests.

The physical linkage of thermistor probe cables to the logger initially presented some problems of intermittent interruptions or outright broken leads. The inherent lack of robustness of the logger connector design was compensated for in later tests by attaching components to a back-board support which resolved the problem to a major extent, enabling complete data to be collected from all probes.

Results for different probe attachment points showed a significant variance in temperature gradient and elapsed time from point of fluid application to point when wing temperature fell to 0°C. Areas such as spoiler panels and flaps showed the fastest temperature decay. This was supported by visual observation of ice formation on these surfaces.

The charted thermistor results illustrate the high degree of influence of spray technique on results. Tests where the de-icing operator sprayed hot water starting from the wing tip and progressing to the wing root, and then worked his way out again to the wing tip, show up in the results. Points that were sprayed twice clearly show a double peak in temperature rise, and tend to indicate a higher level of heat transfer to the wing surface, thus extending the temperature decay time. Probe points that were not sprayed directly, but were reached by fluid flowing from nearby, clearly show the effect of heat loss already experienced by the fluid.

Testing the purity of the applied water showed that in fact a very small degree of contamination existed, probably a carry-over from previous fluid in the tanks and lines. The contamination present resulted in freeze values of -1°C.

Meteorological data including OAT and wind velocity was provided from AES measurement, taken at their Dorval Airport site. It should be noted that wind velocity is measured at a point 10 meters above ground level.

3.2 NRC Cold Chamber

Data gathered during these trials consisted of temperature data logged from thermistor probes, supported by supplemental data of environmental conditions. The results are shown in Figures 3.1, 3.2 and 3.3 on following pages.

3.3 Comparison of Temperature Measuring Devices

Comparison of the thermistor/logger combination to the C/FIMS sensor readout showed that the latter instrument did not respond as quickly to large temperature changes, but did reflect consistent results in stable or slowly changing temperature conditions. Figure 3.3 illustrates a typical comparison.

The hand-held temperature probe delivered point readings similar to the thermistor/logger combination as shown in Figure 3.4. The challenge of manually collecting readings in conditions of rapidly changing temperature is illustrated in the first few minutes following hot water application, where a few seconds lag in recording time can result in a significant difference in the temperature recorded.

Taking temperature samples with the hand-held probe while the wing was being de-iced was not practical. Taking samples with a frequency high enough to establish a true temperature profile for a number of points on the wing surface would be difficult.

FIGURE 3.1

EFFECT OF WIND SPEED, VOLUME POURED & PLATE THICKNESS ON LAG TIME TO FREEZE POINT

Tests Conducted @ National Research Council Climatic Engineering Facility

APRIL 12, 1995

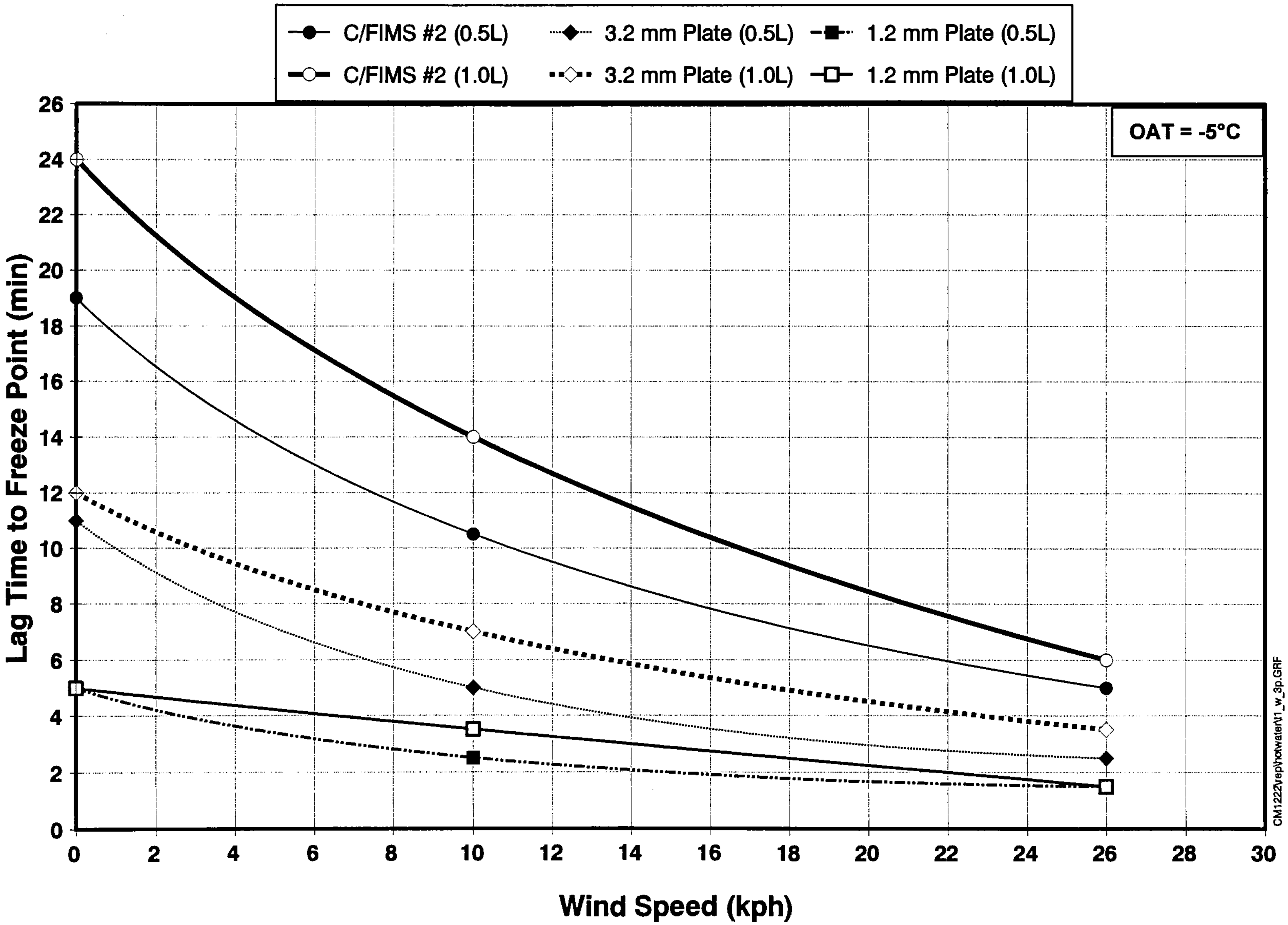


FIGURE 3.2
LAG TIME OF TYPE I FLUID vs HOT WATER
TESTS CONDUCTED @ CEF
APRIL 12, 1995

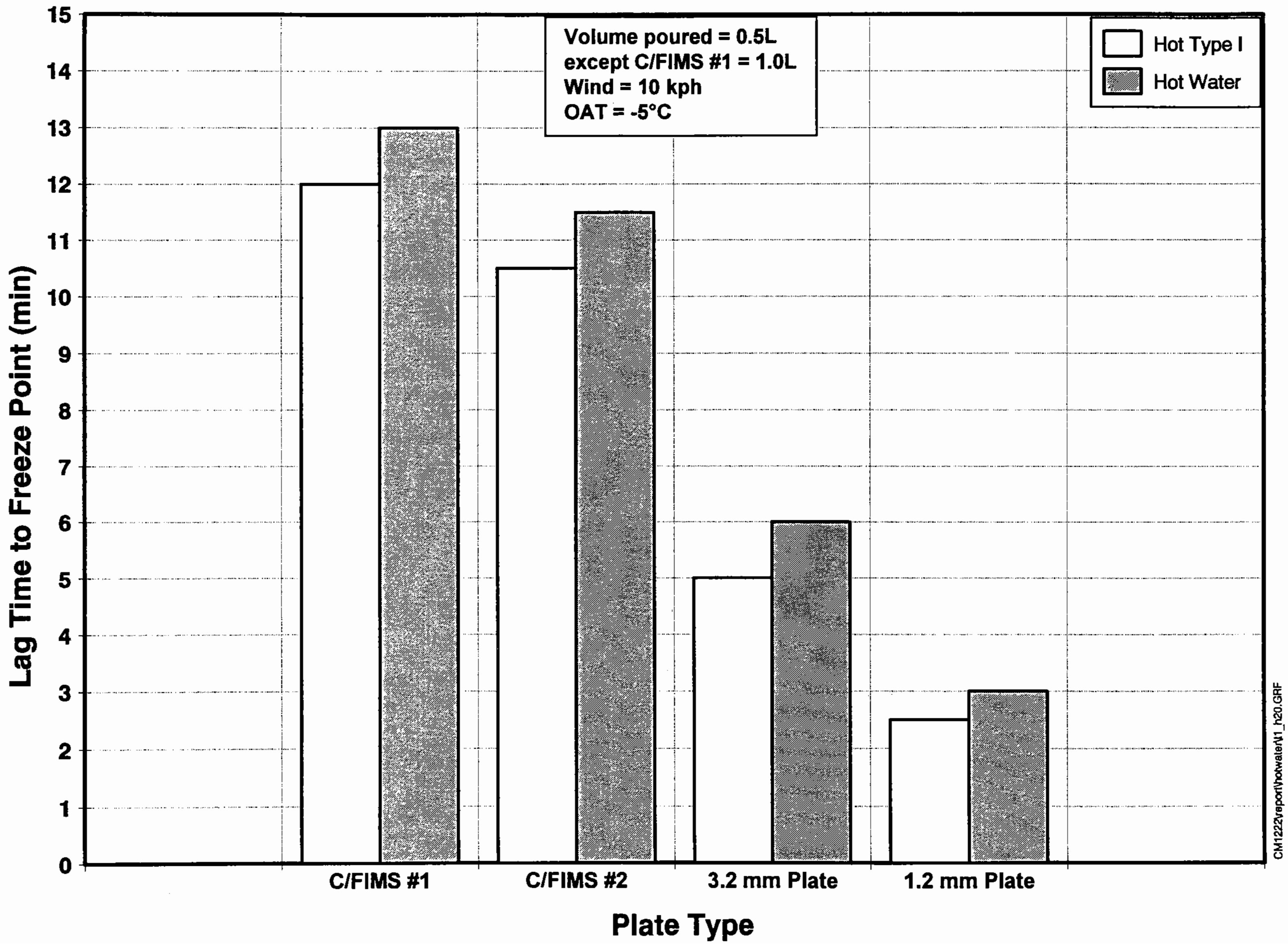


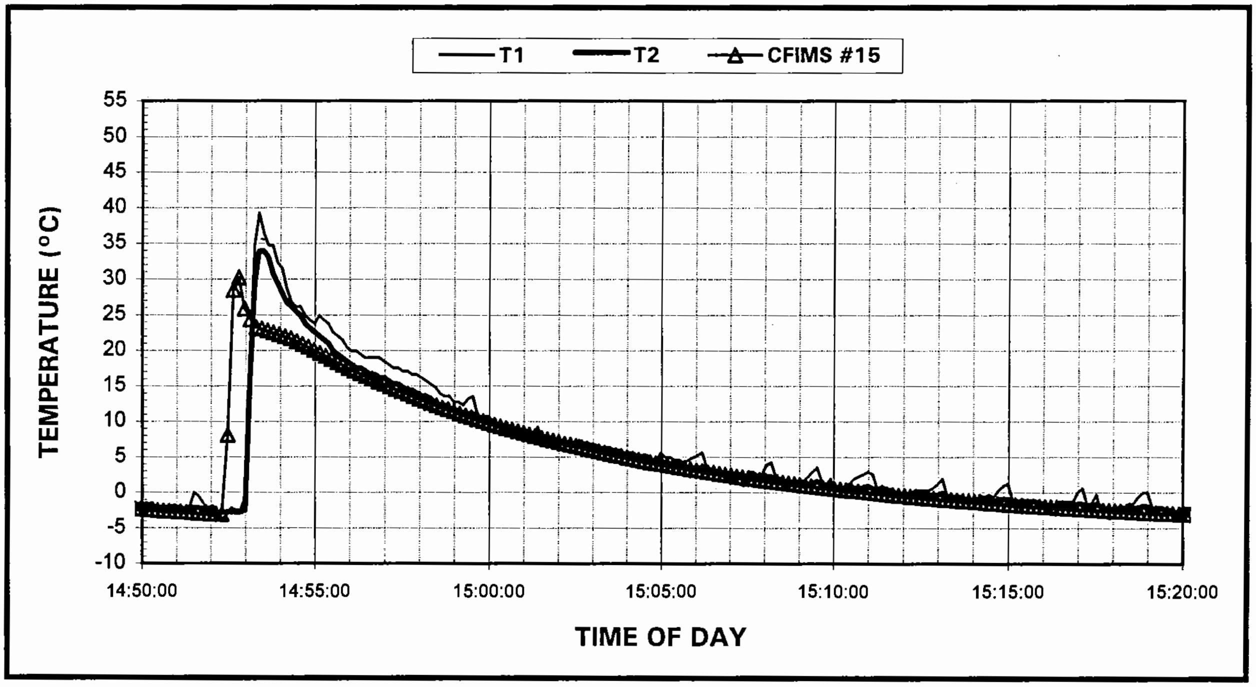
FIGURE 3.3

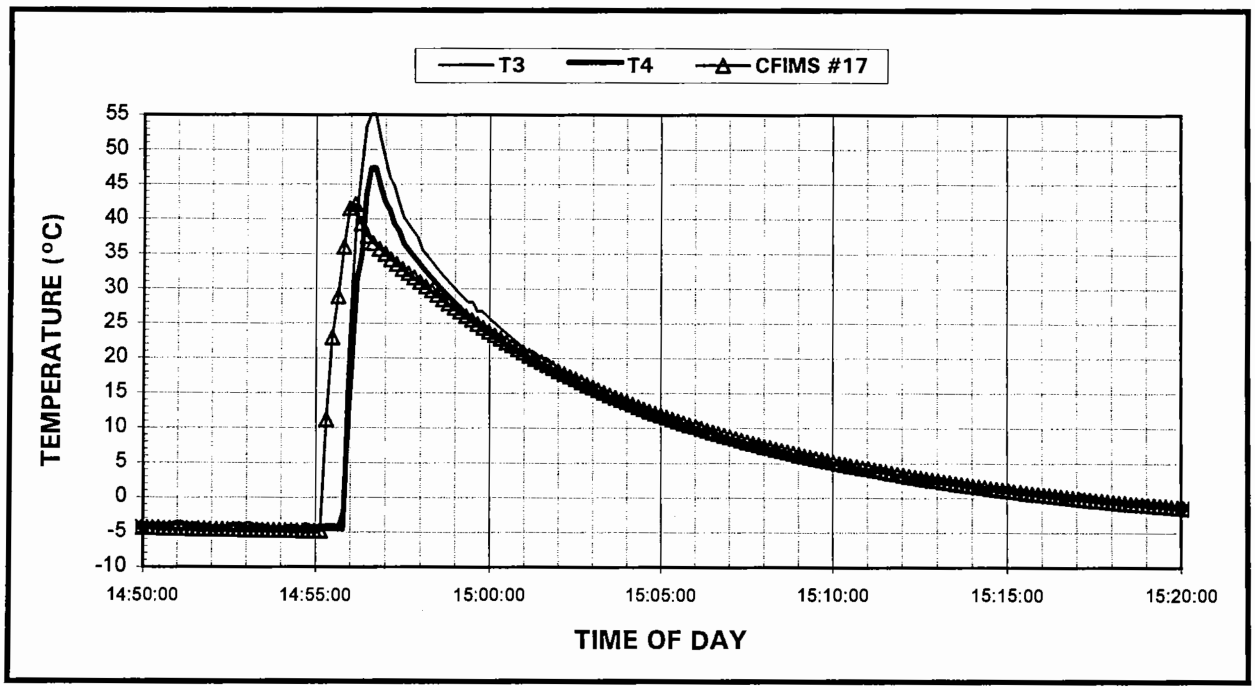
COMPARISON OF C/FIMS TEMPERATURE LOG TO THERMISTOR LOG

NRC COLD CHAMBER - OTTAWA

Port Side Logger

April 12, 1995, Run #2





rep\hotwater\AP12R2.XLS, Run #2 (Therm)

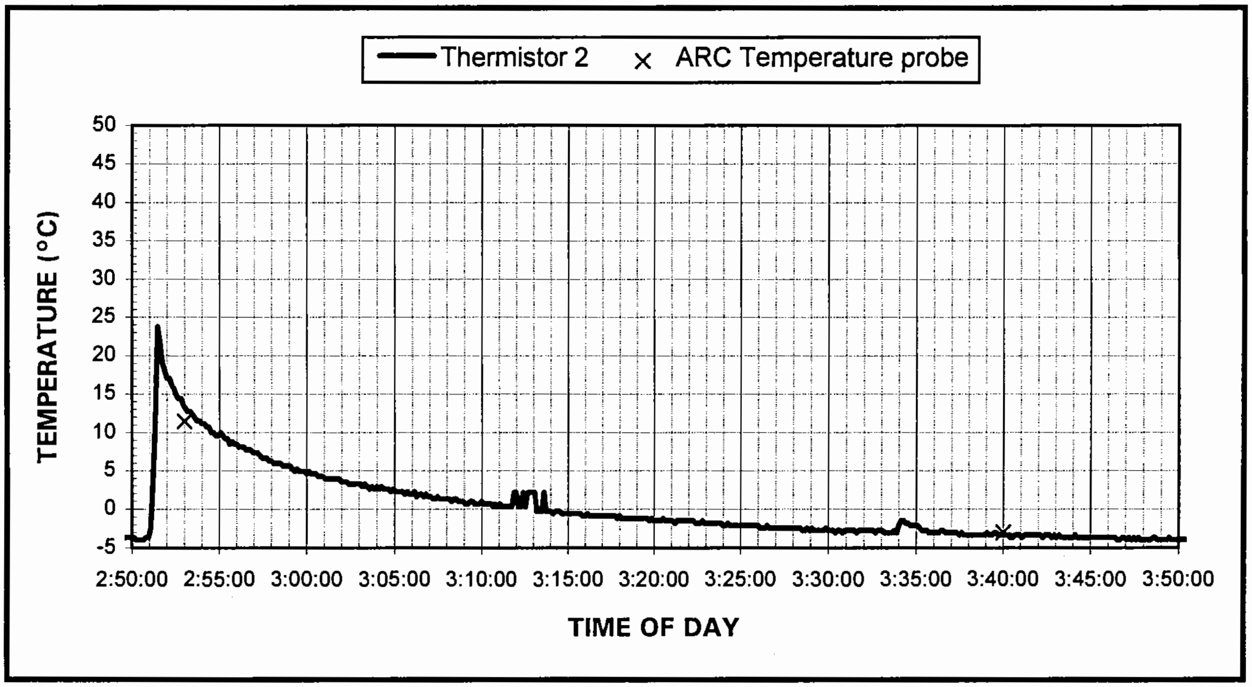
FIGURE 3.4

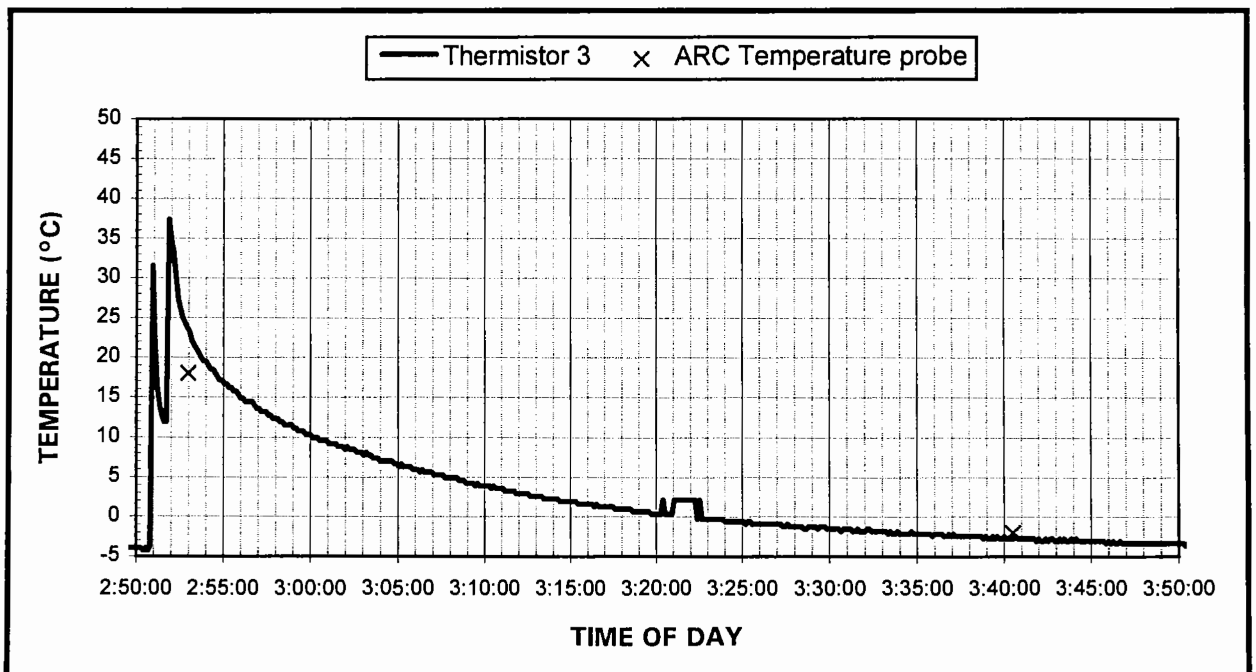
COMPARISON OF ARC TEMPERATURE PROBES TO THERMISTOR LOG

AIRCRAFT TESTS - DORVAL DEICING CENTRE

Aircraft Wing (Starboard Side "B")

March 28, 1995, RUN #2





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4. OBSERVATION AND ANALYSIS

4.1 Cold Chamber Tests

4.2 Aircraft Tests at Dorval De-icing Centre

4. OBSERVATION AND ANALYSIS

This section presents an analysis of the study data which was collected both at the NRC Cold Chamber and Dorval Airport, Montreal.

4.1 Cold Chamber Tests

These tests were designed to indicate the impact of specific variables on the time for surface temperature to decay to 0°C following hot fluid application. These variables were:

- wind velocity;
- plate thickness;
- volume of fluid applied.

Test results are shown on Figure 3.1. The tests indicate that the time for temperature to drop to 0°C is decreased by a factor of four in a 26 kph wind as compared to calm conditions.

The thicker plates have a longer lag time, reflecting their greater capacity to absorb heat from fluid.

The impact of volume of fluid poured is illustrated showing that additional lag time is achieved in the case of thicker plates, but that little or no benefit is achieved from the addition of greater volume in the case of thin plates. This reflects the observations in the field trials where aircraft wing panels such as spoiler panels showed the fastest temperature drop and were observed to freeze up earliest.

Comparison of temperature lag times resultant from pouring hot water versus hot Type I are shown on Figure 3.2. The longer lag times resultant from water reflect the greater heat transfer capacity of water as compared to Type I.

The cold chamber tests showed that the heat sink boxes gave unrealistically long lag times, however flat plates appeared to be appropriate representations of aircraft wing surfaces. The data, although limited, shows that the lag times resulting from field trials at -3°C and -9°C in winds of 6 and 7 kph were in a range of values corresponding to lag times produced on flat plates, in particular the 3.2 mm thick plate, in the laboratory at -5°C. Further work is required to determine the plate thickness that best simulates those wing flight control surfaces where early failure was experienced in field tests.

4.2 Aircraft Tests at Dorval De-icing Centre

4.2.1 Temperature Decay Time

The objective of these tests was to determine the lag time available to the de-icing operator following the application of hot water until an overspray of anti-icing fluid is required ice (ie wing surface temperature reached 0°C), under various environmental conditions.

On each of the test nights, several tests of a repetitive nature were conducted to ensure reliability and repeatability of measured results. As well, temperatures were measured and logged at a number of points on the wing surface. This resulted in a number of temperature gradient curves which indicated the time elapsed (lag time) from the point of hot water application until wing surface temperature cooled to 0°C. The lag time selected as representative for the test condition was that which was most critical (shortest) among all the temperature gradient curves developed. Lag time was calculated as the interval from the time that the temperature gradient curve rose through 0°C as a result of the hot water spray, until it descended through 0°C during cooling.

Analysis of the data for the three test conditions yielded lag times as follows:

	OAT °C	Wind kph	Lag Time to 0°C minutes
March 28 '95	-3	6	17
April 05 '95	-13	28	0.5
April 07 '95	-9	7	3.5

These values are represented on the following chart (Figure 4.1), which illustrates their values relative to the current SAE Recommended Practice (Appendix A).

The tests of March 28 and April 7 yielded lag times, that is time available to the operator to apply an overspray of anti-icing fluid, that would be operationally acceptable in actual practice. Examination of wing cavities did not identify ice formation problems during these tests.

These values illustrate the effect of wind as well as temperature and suggest the existence of a family of curves expressing the relationship of lag time, OAT, and wind velocity. Such a family is hypothesized in Figure 4.2. Also shown are the lag times developed in related studies

FIGURE 4.1
HOT WATER DE-ICING TRIALS
MAR - APR 1995

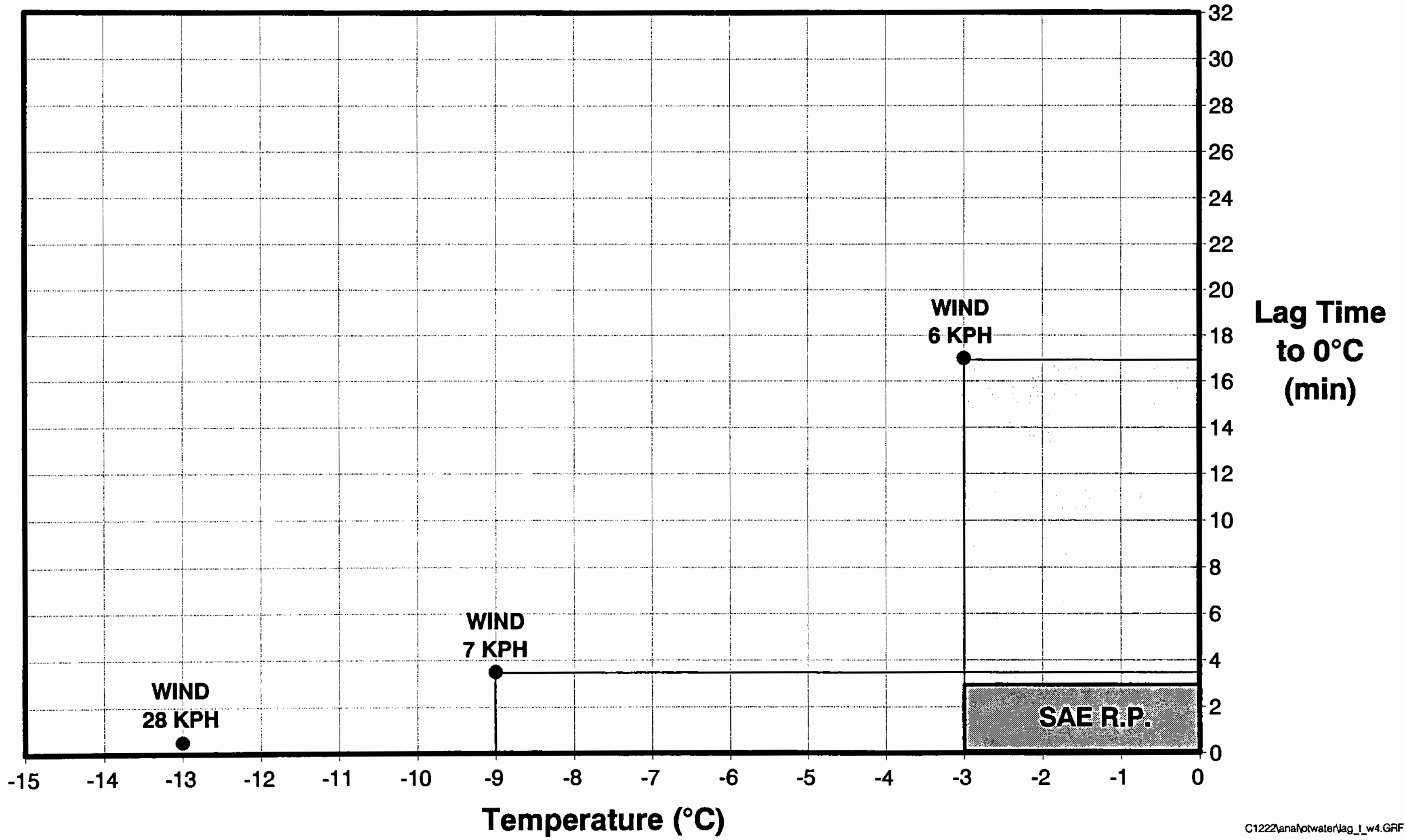
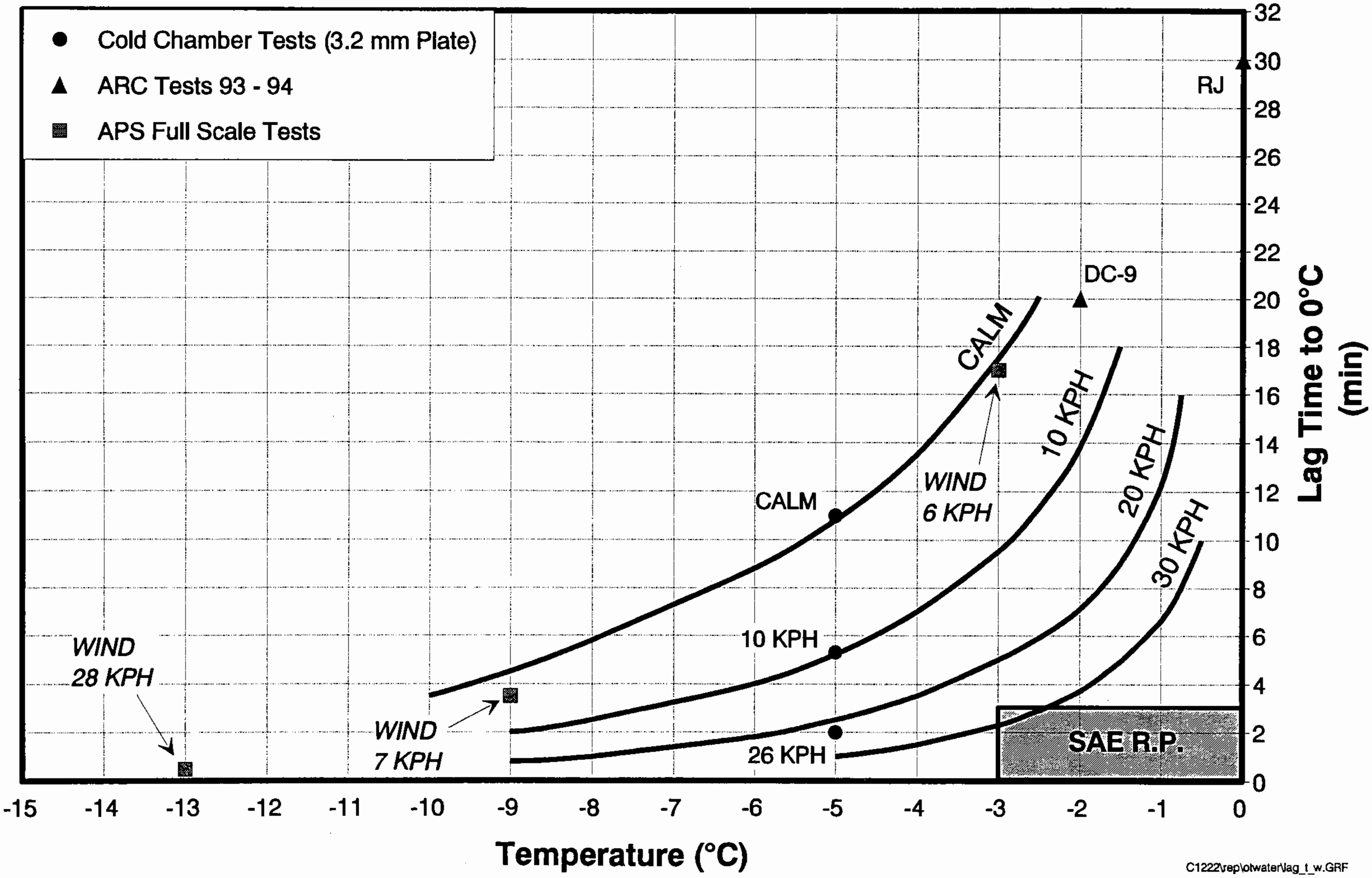


FIGURE 4.2
HYPOTHETICAL CURVES RELATING WIND SPEED WITH LAG TIME TO FREEZE POINT
HOT WATER DE-ICING TRIALS
MAR - APR 1995



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including the NRC Cold Chamber trials, and 1994 ARC Wing Surface Temperature Gradient Study[2] performed under light wind conditions. The establishment of a fully validated chart similar to Figure 4.2 would provide a valuable tool to operators in determining acceptability of hot water de-icing under specific weather conditions, and could enable the water use of hot water as a de-icing agent under a much broader range of conditions than is currently recommended.

It was noted in the field trials that the hot water in use was contaminated with a very weak concentration of Type I de-icing fluid resulting in a depressed freeze point to -1°C. This raises a point concerning the utility of applying weak concentrations as a substitute for pure hot water in this process, thereby gaining a substantial factor of safety at a low cost, or alternatively extending the range of conditions under which the hot water process might be applied. The wing temperature profiles show that even a 1°C drop in freezing point is equivalent to a significant increase in the effective lag time. This could have the added benefit of enabling and encouraging the use of recycled fluid recovered from de-icing areas, at the weak concentrations of recovery but purified through a filtration process. A side benefit of this would be the reduction of disposal costs of recovered fluid.

Although these trials were limited to DC-9 aircraft, the early failures occurred on control surfaces common to all aircraft and for this reason it is believed that test results can be extended to other aircraft types. Aircraft and flight control panels manufactured with composite materials may give different results and should be tested.

2 1994 ARC Wing Surface Temperature Gradient Study.

4.2.2 Impact on Ramp Condition

A supplemental objective of the study was to establish an understanding of ice formation on the ramp and impact on ramp surface slipperiness, ie. safety implication.

This objective was approached through observation of any ice formation during field trials, measurement of ramp surface temperature before and after the spray operation and measurement of concentration of fluid samples taken from the ramp surface following anti-icing overspray.

	OAT °C	Wind kph	Ramp Surface Temp. °C	Condition Ice Formation
March 28 '95	-3	6	+1 to +3	no ice formation
April 05 '95	-13	28	-8 to -10	ice build-up on ramp under leading and trailing edges
April 07 '95	-9	7	-2 to -4	slush, no hard ice

In these trials the ramp surface temperatures generally were several degrees warmer than OAT. Heat transfer from fluid to ramp resulted in a temporary elevation of temperatures.

Fluid samples taken from ramp surface following overspray of anti-icing fluid gave BRIX readings varying from 15 to 24, indicating ramp fluid freeze points of -12 to -20°C. These samples were limited in number, and further samples may have shown lower BRIX readings.

Formation of ice to the degree noted in these trial conditions indicate that operations in dedicated de-icing areas should not normally pose a safety issue. Hot water de-icing on gate could result in conditions impacting upon personnel involved in aircraft servicing and handling activities, however gate de-icing is becoming less and less a standard mode of operation.

The fluid drainage pattern of the de-icing centre served to drain away the expended water. No special drainage requirements were identified. It may be noted that fluids recovered from the spray site following hot water de-icing will further dilute recovered fluids from previous operations utilizing Type I de-icing fluids.

5. CONCLUSIONS

5. CONCLUSIONS

These trials established a procedure and appropriate equipment to gather data that may be used to scientifically establish lower operational limits for hot water de-icing. Thermistor probes mounted on the wing surface produced accurate data on wing surface temperature as it moved rapidly through a wide range of temperatures following hot fluid application. Data loggers configured to record data at 10 second intervals enabled development of reliable temperature profiles that indicated elapsed time for specific points on the wing surface to reach 0°C following the application of hot fluid.

Results indicate that hot water de-icing is feasible at outside air temperatures below -3°C, dependent on other conditions such as wind and operator disciplines. A trial conducted at -9°C with a 7 kph wind resulted in a lag time available to the operator of 3.5 minutes, representing the time available from initial application of hot water until application of an anti-icing overspray is required.

Although these trials were limited to DC-9 aircraft, the early failures occurred on control surfaces common to all aircraft and for this reason it is believed that test results can be extended to other aircraft types. Aircraft and flight control panels manufactured with composite materials may give different results and should be tested.

Wind has a very major impact on lag time. Tests in a laboratory environment showed that for a fixed OAT, moving from a condition of zero wind to a wind of velocity 26 kph has the effect of reducing lag time by a factor of four. This observation supports the statements of experienced operators who indicate that a cautious approach is necessary even at more moderate temperatures during conditions of high wind.

Cold chamber tests showed that heat sink boxes produced unrealistically long lag times and that the range of thicknesses of flat plates as tested were appropriate. Further work is required to determine the thickness of plate that best simulates those wing surfaces where earliest failure was experienced during field tests.

The measured wing temperature gradients suggest the existence of a family of curves expressing the relationship of OAT and wind velocity with the lag time for the wing surface to reach 0°C following application of hot water. Charts showing a family of hypothetical curves are presented. Curves are overlaid with data points resultant from aircraft and NRC Cold Chamber trials, and from the 1994 ARC Wing Surface Temperature Gradient Study. The establishment of expanded and validated charts would provide a valuable tool to operators to determine acceptability of hot water de-icing under specific weather conditions, and could support the use of hot water as a de-icing agent under a much broader range of conditions than is currently reflected in the SAE Recommended Practice.

Tests at the NRC Cold Chamber showed that application of increased volumes of hot water has an extending influence on lag times on thicker panels, but does not extend lag time on thinner panels. Specific locations on the aircraft wing such as control surface panels experienced the most rapid drop in temperature and a tendency to refreeze earliest.

Laboratory results indicated that water has a greater capacity than Type I fluid for transferring heat to the aircraft surface.

Observations and measurements of ice formation on the ramp surface indicated that this should not be a deterrent to hot water de-icing operations located at off-gate dedicated de-icing pads with adequate drainage.

Comparison of the thermistor/logger combination to the C/FIMS sensor readout showed that the latter instrument did not respond as quickly to large temperature changes, but did reflect consistent results in stable or slowly changing temperature conditions.

The hand-held temperature probe delivered point readings similar to the thermistor/logger combination.

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6. RECOMMENDATIONS FOR FURTHER DEVELOPMENT

6. RECOMMENDATIONS FOR FURTHER DEVELOPMENT

This section outlines the direction and scope for future testing.

- Conduct further field trials in conjunction with Air Canada under specific trial environmental conditions that will complement data gathered to date. Design and utilize these trials to correlate results on critical wing surfaces to results on flat plates of various thicknesses with the objective of facilitating subsequent laboratory trials.

- Conduct further tests in the NRC Cold Chamber to gather data to complete the operational spectrum for wind and temperature combinations.

- Construct an operations decision model based on acquired data to assist in decision making on the use of hot water in actual operating conditions. Seek modification of SAE ARP4737 to lower limits from the present -3°C minimum.

- Explore the use of highly diluted concentrations of Type I de-icing fluid as an alternative to hot water to develop an understanding of the further range of weather conditions that might be safely considered under this process. This could have the added benefit of enabling and encouraging the use of recycled fluid recovered from de-icing areas, at the weak concentrations of recovery but purified through a filtration process. A side benefit of this would be the reduction of disposal costs of recovered fluid, as no "fresh" fluids, water in this case, would be added to the reservoir of recovered fluids.

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APPENDIX A

SAE ARP4737

GUIDELINE FOR APPLICATION OF HOT WATER

TABLE 1 - Guideline for Application of SAE Type I Fluid Mixture (Minimum Concentration) as a Function of OAT

OAT °C	OAT °F	1 Step Procedure see para. 6.3.3.1 Deicing/Anti-icing	2 Step Procedure (see para. 6.3.3.2) 1st Step Deicing	2 Step Procedure (see para. 6.3.3.2) 2nd Step Anti-Icing*
-3 and above	27 and above	FP of heated** fluid mixture should be at least 10°C(18°F) below OAT	Water heated to 60°C(140°F) minimum at the nozzle, or a heated mix of fluid and water	FP of fluid mixture shall be at least 10°C(18°F) below actual OAT
below -3	below 27		FP of heated fluid mixture shall not be more than 3°C(5°F) above actual OAT	

°C Degrees Celsius
°F Degrees Fahrenheit
OAT Outside Air Temperature
FP Freezing Point

Heated Fluid - Fluid temperature not less than 60°C(140°F) at the nozzle is desirable.

* To be applied before 1st Step fluid freezes, typically within 3 minutes (see para. 6.3.3.2)
** Clean aircraft may be anti-iced with cold fluid

CAUTION: AIRCRAFT SKIN TEMPERATURE AND OAT MAY DIFFER

6.3.2 Aircraft Related Limits: The application of deicing/anti-icing fluid shall be in accordance with the requirements of the airframe/engine manufacturers.

6.3.3 Procedure Precautions:

6.3.3.1 One Step Deicing/Anti-Icing: It is performed with an anti-icing fluid (see 3.2.2). The correct fluid concentration is chosen with regard to desired holdover time, dictated by OAT and weather conditions.

6.3.3.2 Two Step Deicing/Anti-Icing: The first step is performed with deicing fluid (see 3.2.1). The correct deicing fluid mixture is chosen with regard to OAT. The second step is performed with anti-icing fluid (see 3.2.2). This fluid and its concentration are chosen with regard to desired holdover time, which is dictated by OAT and weather conditions. The second step shall be performed before first step fluid freezes (typically within 3 min); if necessary area by area. If freezing has occurred on the critical areas of the aircraft, step 1 shall be repeated.

6.3.3.3 With regard to holdover time provided by the applied fluid, the objective is that it be equal to or greater than the estimated time from start of anti-icing to start of takeoff based on existing weather conditions.

6.3.3.4 Aircraft shall be treated symmetrically, that is, left hand and right hand side shall receive the same and complete treatment.

CAUTION: Aerodynamic problems could result if this requirement is not met.

6.3.3.5 Engines are normally shut down but may be running during deicing/anti-icing operations. Main engines shall be slow running and air-conditioning and/or APU air selected OFF, or as recommended by the airframe and engine manufacturer.

6.3.3.6 Do not spray deicing/anti-icing fluids directly onto hot brakes, wheels, exhausts, or thrust reversers.

6.3.3.7 Deicing/anti-icing fluid shall not be directed into the orifices of pitot heads, static vents, or directly onto airstream direction detectors probes/angle of attack airflow sensors.

6.3.3.8 All reasonable precautions shall be taken to minimize fluid entry into engines, other intakes/outlets, and control surface cavities. See relevant manuals.

6.3.3.9 Do not direct fluid onto flight deck or cabin windows as this can cause cracking of acrylic or penetration of the window sealing.

6.3.3.10 All doors and windows shall be closed to prevent:

a. Floor areas being contaminated with slippery fluids
b. Upholstery becoming soiled

APPENDIX B

TEST PROCEDURES AND EQUIPMENT LIST

EXPERIMENTAL PROGRAM
HOT WATER DE-ICING TRIALS
1994 - 1995 De-icing / Season

1. OBJECTIVE

To develop data to assist in the determination of minimum ambient air temperature conditions under which hot water can be used for de-icing.

2. TEST REQUIREMENTS

As the opportunity to piggy-back on Air Canada hot water trials has been delayed due to an airline decision to postpone these until October 1995, APS will coordinate a series of tests at the APS test site at the YUL de-icing centre. Primary attention will be given to establishing temperature gradients of wing skin surfaces during the process of hot water de-icing.

Air Canada aircraft will be used and the Air Canada standard de-icing procedure followed by airline personnel.

Current APS staff will be utilized during tests as necessary.

Tests will be planned and coordinated on the basis of forecasted weather conditions, seeking conditions in the range of -7 to -10°C with no precipitation.

Data recorded in addition to the wing skin temperature gradient will include ambient meteorological conditions, data on fluid sprayed, and visual observations of wing surface condition. Ramp surface icing conditions will be monitored and ground surface temperatures recorded. A video record of the tests will be maintained. A heat sink will be tested simultaneously to establish a standard reference for temperature gradient during hot water de-icing.

Test results will be collected, analyzed and reported.

3. EQUIPMENT

Equipment requirements are shown in Attachment A.

4. PERSONNEL

Up to five APS staff will be required. Assignments will be in accordance with the guideline Attachment D. Air Canada staff will position the aircraft, prepare trucks for water spraying and follow their standard hot water de-icing procedures, including inspection of cavities for ice formation.

5. PROCEDURE

The test procedure is shown as Attachment B.

6. DATA FORMS

Data form Attachment E is planned. Temperature data is collected by means of thermistor probes and data logger.

ATTACHMENT A

Test Equipment - Hot Water Tests

Aircraft located at de-icing site, with ground support.

De-icing trucks x 2 (to freeze up the a/c with spray of undiluted cold water and to conduct hot water de-icing with spray of undiluted hot water and overspray of hot Type I fluid).

Stairs.

Stand to mount heat sink, filled with fluid.

Heat sink.

C/FIMS sensor and associated equipment.

Temperature logger kit.

ARC Temperature probe and voice recorder.

Video camera and support equipment.

Flood lights for stairs.

Extension cords for flood lights.

Extension cord to PC in aircraft cabin.

Stop watches.

Flash lights.

Rain wear.

Glass thermometer for fluid temperatures.

Refractometer.

ATTACHMENT B

Test Procedure - Hot Water De-icing Trials

Background

These tests will involve first icing up an aircraft and flat plates including the heat sink box, and then removing the ice following the standard hot water procedure. Care will need to be taken to ensure test water is uncontaminated by any fluid remaining in truck tanks and lines, and refill lines.

Wing skin and heat sink temperatures will be sampled and logged continuously throughout this process via thermistor probes mounted on the wing surface. Wing surface and cavities will be examined for ice deposits following the de-icing procedure.

The condition of the ramp surface will be monitored to identify presence of ice formation and related slipperiness as a result of the de-icing process. Ramp surface temperatures will be recorded and samples of fluid taken from the ramp surface will be tested for strength with a refractometer.

As with other aircraft tests, plans will assume aircraft availability only after daily operations, in the period 2300 - 0600.

Pre test set-up

Monitor weather forecasts seeking a period with temperatures in the range of -7 to -10°C with no precipitation.

Discuss with Air Canada 48 hours prior to day of intended test, to decide on tests and to enable flushing of truck tanks prior to filling with water for test.

Advise all involved including Frank Eyre and Tony Manzo.

Ensure heat sink is stored outdoors to enable it to obtain ambient temperature.

Empty truck tanks of contents and flush to remove remaining fluid.

Board uncontaminated water and overspray fluid into one truck and heat to normal temperature.

ATTACHMENT B (Contd)

Board uncontaminated cold water in the second truck and maintain at cold temperature.

Locate aircraft (DC-9 preferred) at the de-icing centre.

Position heat sink in test stand near parked aircraft.

Install and check C/FIMS equipment for functioning.

Position stairs with flood lights at wing to enable installation of probes.

Synchronize time on stopwatches, video camera, PC for C/FIMS and PC for temperature logger.

Check video equipment for functioning.

Install probes on wing and on heat sink, following the probe installation procedure Attachment C. Attempt to locate extensions in such a way that the PC may be located in aircraft cabin and remain interfaced with logger, to allow continuous monitoring of real-time readings of all probes during the test. Electrical power to PC will be required for this.

Remove stairs from wing area.

Spray wing and plates including the heat sink in the flat plate frame with cold water and await freezing.

Test Procedure

Conduct standard de-icing procedure on the aircraft wing and on the plates including the heat sink mounted in the flat plate frame.

Monitor real-time temperature readings from probes.

Record aircraft and ramp surface data as described on data forms supplied.

Relocate stairs with lights beside wing to enable inspection of surface and cavities.

ATTACHMENT B (Contd)

Inspect wing surface and cavities for ice formation and record.

Inspect ramp surface for ice and slipperiness and record.

Video tape the entire process, capturing close-up shots of the wing surface in the iced condition and following de-icing.

Down load temperature logger data to PC for subsequent analysis.

Post test

Remove probe installation. Ensure all tape removed. Rain wear will be required as protection when reaching probes on wing surface.

ATTACHMENT C

Thermistor Probe Installation and Logger Operation

Mounting Probes and Leads on Aircraft Wings

Using aluminum speed tape, tape probes to designated points shown on data sheet. Place the tape so that about one-half of the probe disc protrudes from the tape edge. This tape edge should be aligned with the slope of the wing to prevent pooling of fluid about the probe disc.

Attach probe extension leads as required and protect terminal junction point from fluid by wrapping with black tape.

Attach leads to underside of wing with tape to support weight of leads and prevent from whipping when sprayed, as well as to prevent fluid from running back along the leads to the junction point.

Logger Set-up

Using PC interface, set up parameters for test: activate channels and set read rate. Note memory time available at selected read rate. Clear memory of past data.

Locate appropriate location to store logger during test; protected from fluid spray and accidental harm, eg. wheel well.

Attach leads to logger and check integrity of all channels to ensure readings are being gathered.

Mark probe installation points on the data form and indicate probe (channel) numbers.

Detach PC and remove from scene.

Protect logger and terminal box junctions in plastic bag and secure to selected point with black tape.

Logger Retrieval

Detach logger from leads, and take it to PC for downloading data.

Download data to PC as soon as possible to avoid accidental over-running logger memory time span and overwriting of data.

ATTACHMENT C (contd)

Probe and Extension Lead Retrieval

Detach all taped points from aircraft surface ensuring all tape is removed. Rain wear will be required as protection when reaching for probes on wing surface.

Dry each probe and its lead by holding in one hand and wiping toward the plug. Take care not to stretch the lead covering. Form into loose loops and replace in plastic storage bag.

Similarly, dry and store all extension leads.

ATTACHMENT D
HOT WATER DE-ICING TESTS - DORVAL AIRPORT
TASK ASSIGNMENTS

ACTIVITY	ASSIGNMENT	DETAILS
1- Prepare de-icing trucks for trials; flush systems, board water and Type I.	AC	
2- Ensure heat sink located outdoors well before test to attain ambient temperature.	APS	man #4
3- Pre-test briefing; task assignments; sync watches, camera, PCs.	APS	man #1
4- Position aircraft and ground support.	AC	DC9 preferred
5- Position flat plate frame with heat sink and C/FIMS near aircraft.	APS	men #1, 2, & 4
6- Link C/FIMS PC to sensor and check for functionality.	APS	man #3
7- Position stairs with flood lights/extension cords for probe installation (one in rear and two in front of wing).	APS	men #1, 2, &4
8- Install probes on aircraft and on heat sink as per procedure. Run extension cord for PC in cabin.	APS	men #1, 2, &4
9- Prepare for Video-taping; tape probe set-up configuration.	APS	man #5
10- Spray Cold Water on aircraft and on plates; await freezing.	AC	

ATTACHMENT D (contd)
HOT WATER DE-ICING TESTS - DORVAL AIRPORT
TASK ASSIGNMENTS

ACTIVITY	ASSIGNMENT	DETAILS
Collect Data		
11- Conduct Hot Water de-icing with overspray on a/c and plates	AC	
12- Monitor real time temperatures and download logger data.	APS	man #1
13- Collect and test fluid samples taken from ramp surface.		man #2
14- Complete aircraft data form: record wing areas progressively de-iced and associated spray times, amounts/temperatures of fluids sprayed.		man #3
15- Collect temperatures using ARC temperature probe from wing and ramp surface according to positions shown on data form.		man #4
16- Video-tape set-up, de-icing procedure, wing and ramp surface condition before during and after test.	APS	man #5 video eqpt
17- Visual inspection of results, wing surface and cavities.	AC APS DCIP	Record on data forms
18- Dismantle probe installation and clean up site.	APS	All

HOT WATER DE-ICING TRIALS

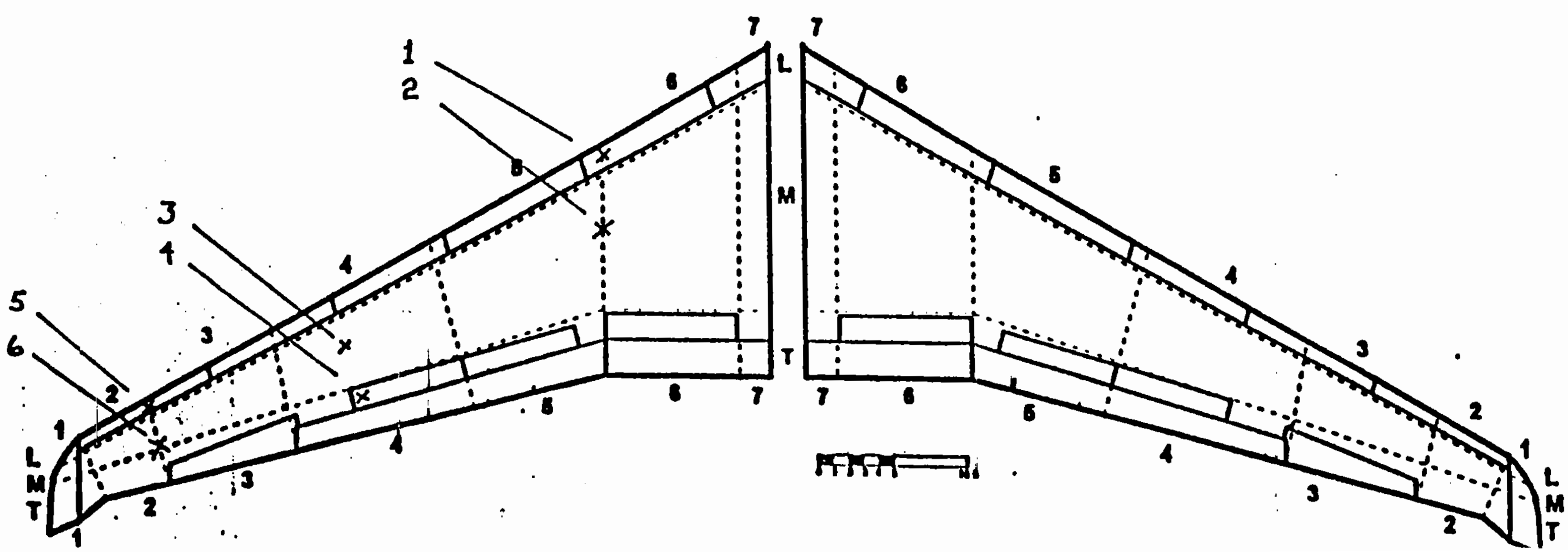
Location ________ Date/Time __________ A/C type/fin # DC-9 /____ Fuel in wing ___________

WX Conditions; OAT ____°C Rel Hum ____% Wind Speed _______ Wind Dir'n _________

Tank Gauges	Initial	Final	Temp °C	Overspray Fluid Type
Hot Water	_____ Litres	______ L	_____ °C	
Overspray	_____ L	______ L	_____ °C	__________

Wing Area Sprayed	Time of Hot Water Application Initial	Time of Hot Water Application Final	Time of Overspray Application Initial	Time of Overspray Application Final	Final Wing Condition
A	________	________	________	________	______________________________
B	________	________	________	________	______________________________
C	________	________	________	________	______________________________
D	________	________	________	________	______________________________
Sink	________	________	________	________	______________________________

Note: 1 Sketch and label progressive spray areas on new wing plan form for each wing.



HOT WATER DE-ICING TRIALS

Location _______ Date/Time _________ A/C type/fin # DC-9 /____

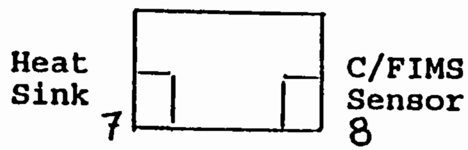
TEMPERATURE RECORDING POINTS FOR MANUAL TEMPERATURE PROBE

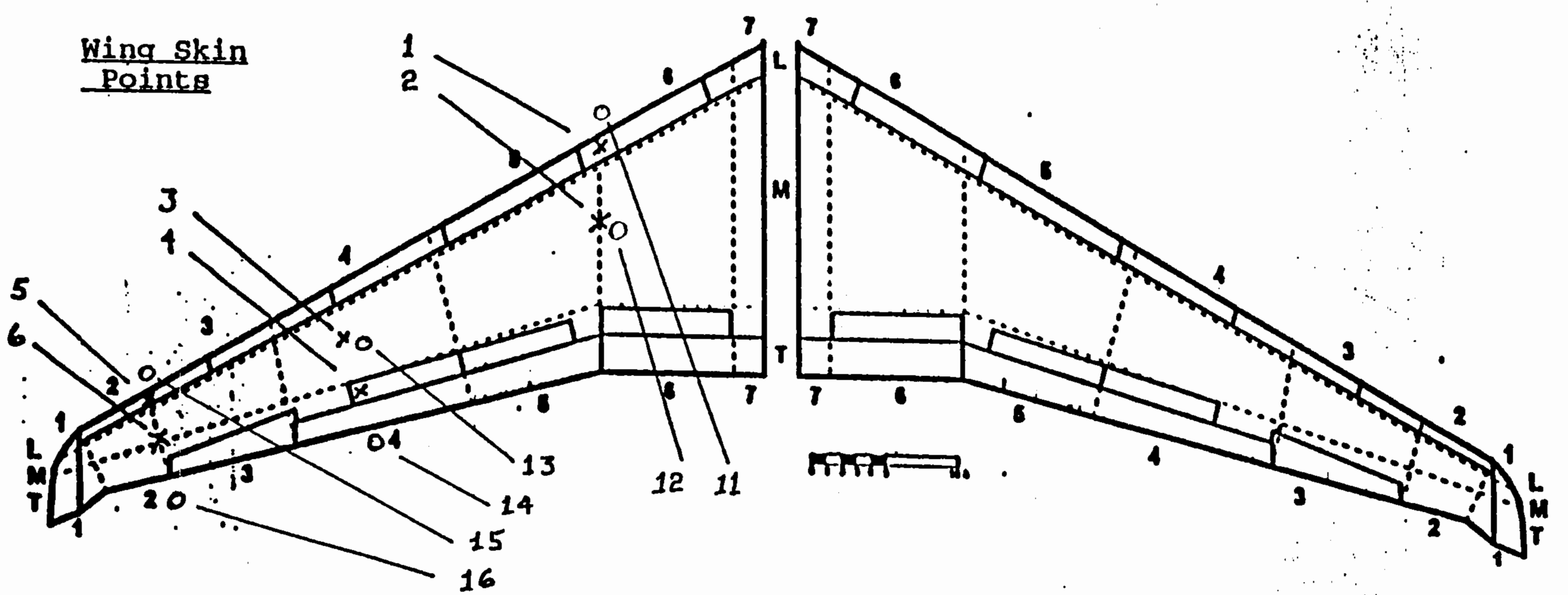
Note:

1 Progressively record temperatures according to sequence shown.

2 At completion of de-icing, examine ramp surface at recording points for any degree of icing or slipperiness, and record comments directly on the data form at each location.

Flat Plate Frame





Ramp Surface Points

APPENDIX C
NATIONAL RESEARCH COUNCIL
COLD CHAMBER TRIALS

CONTROLLED WING TEMPERATURE EXPERIMENTS NRC Ottawa, 12 Apr 95

Equipment

Six plates as follows;
¼" plates with C/FIMS sensors installed x 2
Plate 1/8"
Plate 1/16"
Heat sink # 1 (from Dorval field trials)
Heat sink # 2

Type I fluid with 10°C freeze point protection below ambient
Pitchers
Anemometer
Fans

Temperature logger kit

Set-up Procedure

- Install plates on frame. Install thermistors on plates, two per plate at 6" line. Record installation pattern.

- Establish cold chamber temperature at -5°C and allow sufficient time for test equipment to reach ambient temperature.

- Heat fluid to 165°F (74°C).

- Set up fans to blow over plates, delivering a common velocity over all plates. Check with anemometer to confirm. Tests will require air velocities of about 10 knots and 20 knots.

Test Procedure

- Establish ambient conditions before each test as per test sheet.
- Wet plates prior to pouring with cold Type I.
- Pour amounts of heated fluid on plates as per test sheet. Pour carefully to ensure all fluid flows down plate.
- Measure and record wind at each plate.
- Record time of each test.
- Collect plate temperature gradients on a continuous basis on temperature logger.

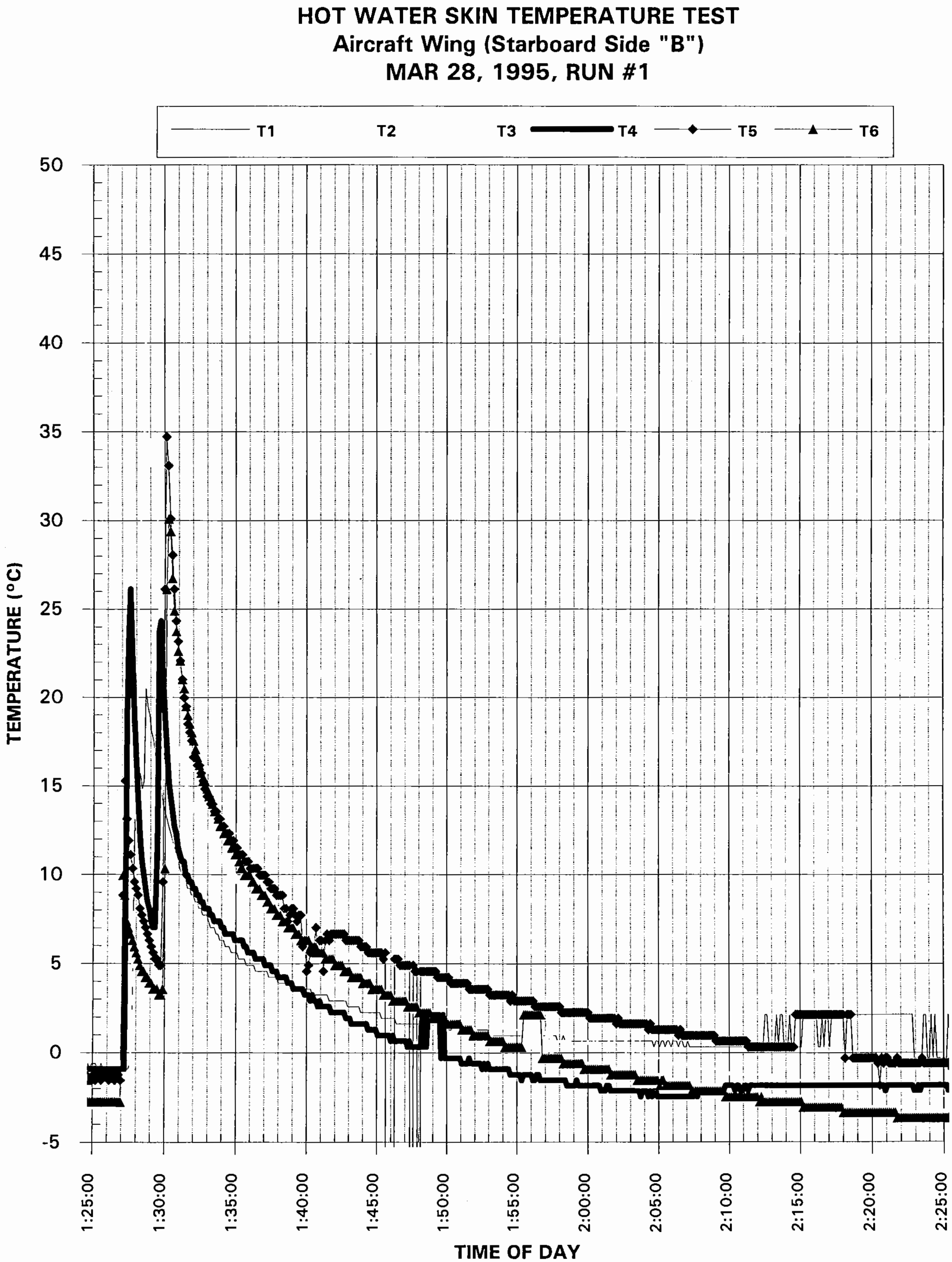
Controlled Wing Temperature Experiments NRC Ottawa 12 April 1995

PLATE	1 Fluid	2 Fluid	5 Fluid	6 Fluid	3 Fluid	4 Fluid	7 Hot Water
6.4mm C/FIMS 1 time to 0°C	0.5 L	1.0 L	0.5 L	1.0 L	0.5 L	1.0 L	0.5 L
6.4mm C/FIMS 2 time to 0°C	1.0 L	2.0 L	1.0 L	2.0 L	1.0 L	2.0 L	1.0 L
Plate 3.2mm time to 0°C	0.5 L	1.0 L	0.5 L	1.0 L	0.5 L	1.0 L	0.5 L
Plate 1.0mm time to 0°C	0.5 L	1.0 L	0.5 L	1.0 L	0.5 L	1.0 L	0.5 L
Heat Sink 1 time to 0°C	0.5 L	1.0 L	0.5 L	1.0 L	0.5 L	1.0 L	0.5 L
Heat Sink 2 time to 0°C	0.5 L	1.0 L	0.5 L	1.0 L	0.5 L	1.0 L	0.5 L
Wind Kph	0	0	10	10	26	26	10

Fluid temp = 165°F
Wet all plates with cold Type I before pouring.
Base amount of fluid = 0.5 Litre
Allow plates to cool to ambient before next test.

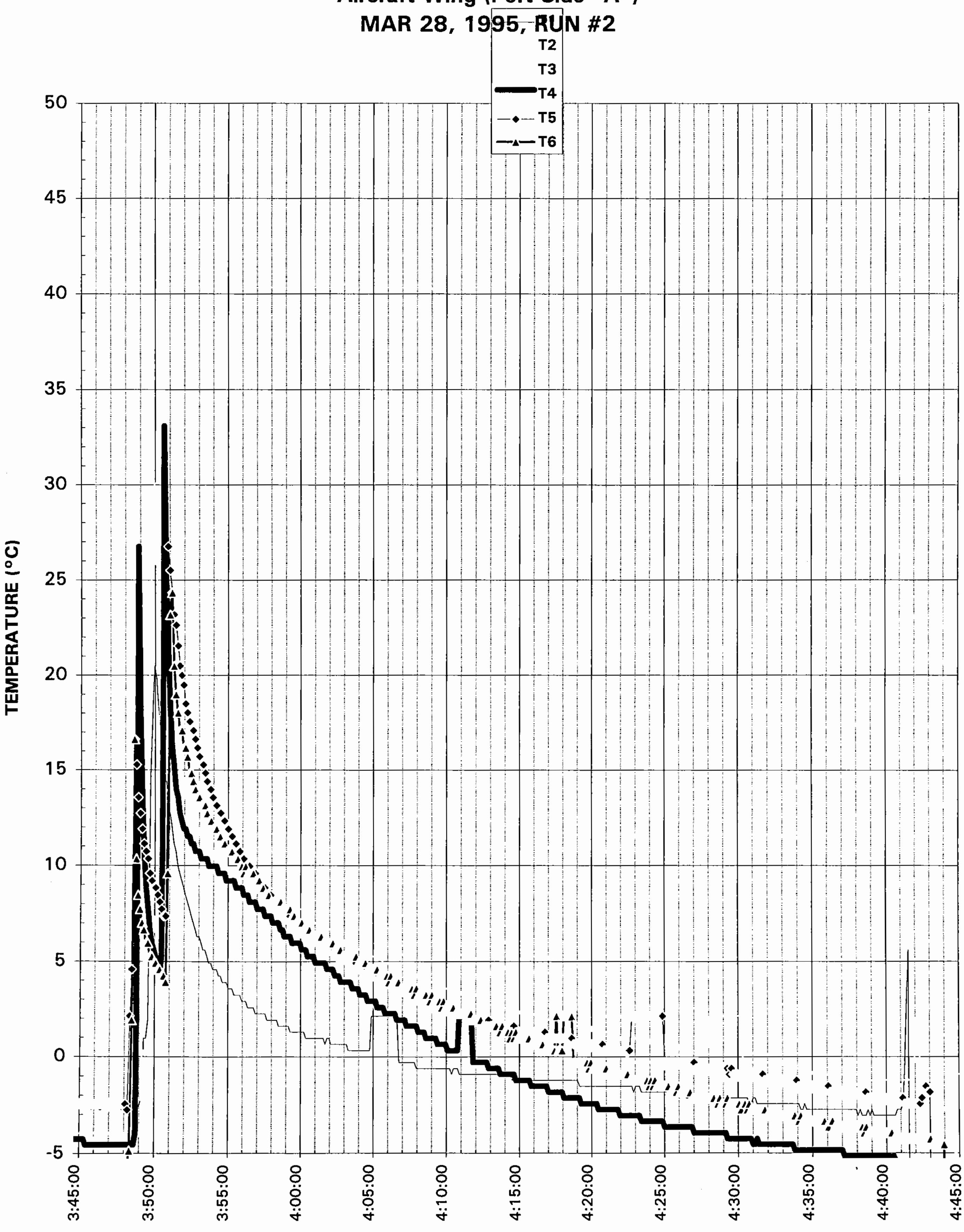
APPENDIX D
WING TEMPERATURE PROFILES
FROM AIRCRAFT TRIALS

March 28, 1995
April 5, 1995
April 7, 1995


HOT WATER SKIN TEMPERATURE TEST
Aircraft Wing (Starboard Side "B")
MAR 28, 1995, RUN #1
T1
T2
T3
T4
T5
T6
TEMPERATURE (°C)
50
45
40
35
30
25
20
15
10
5
0
-5
1:25:00
1:30:00
1:35:00
1:40:00
1:45:00
1:50:00
1:55:00
2:00:00
2:05:00
2:10:00
2:15:00
2:20:00
2:25:00
TIME OF DAY

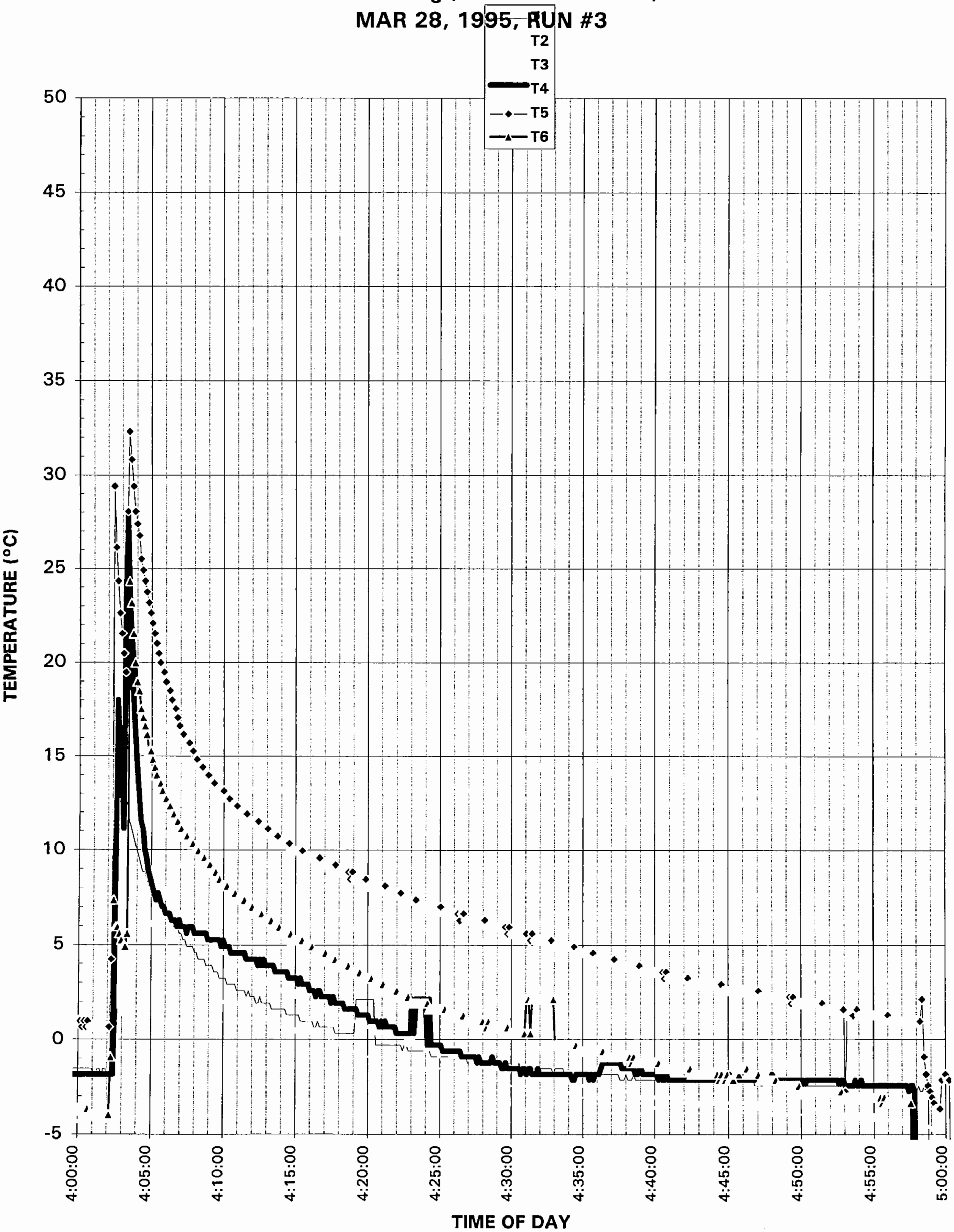
MR28BR1.XLC

HOT WATER SKIN TEMPERATURE TEST
Aircraft Wing (Port Side "A")
MAR 28, 1995, RUN #2

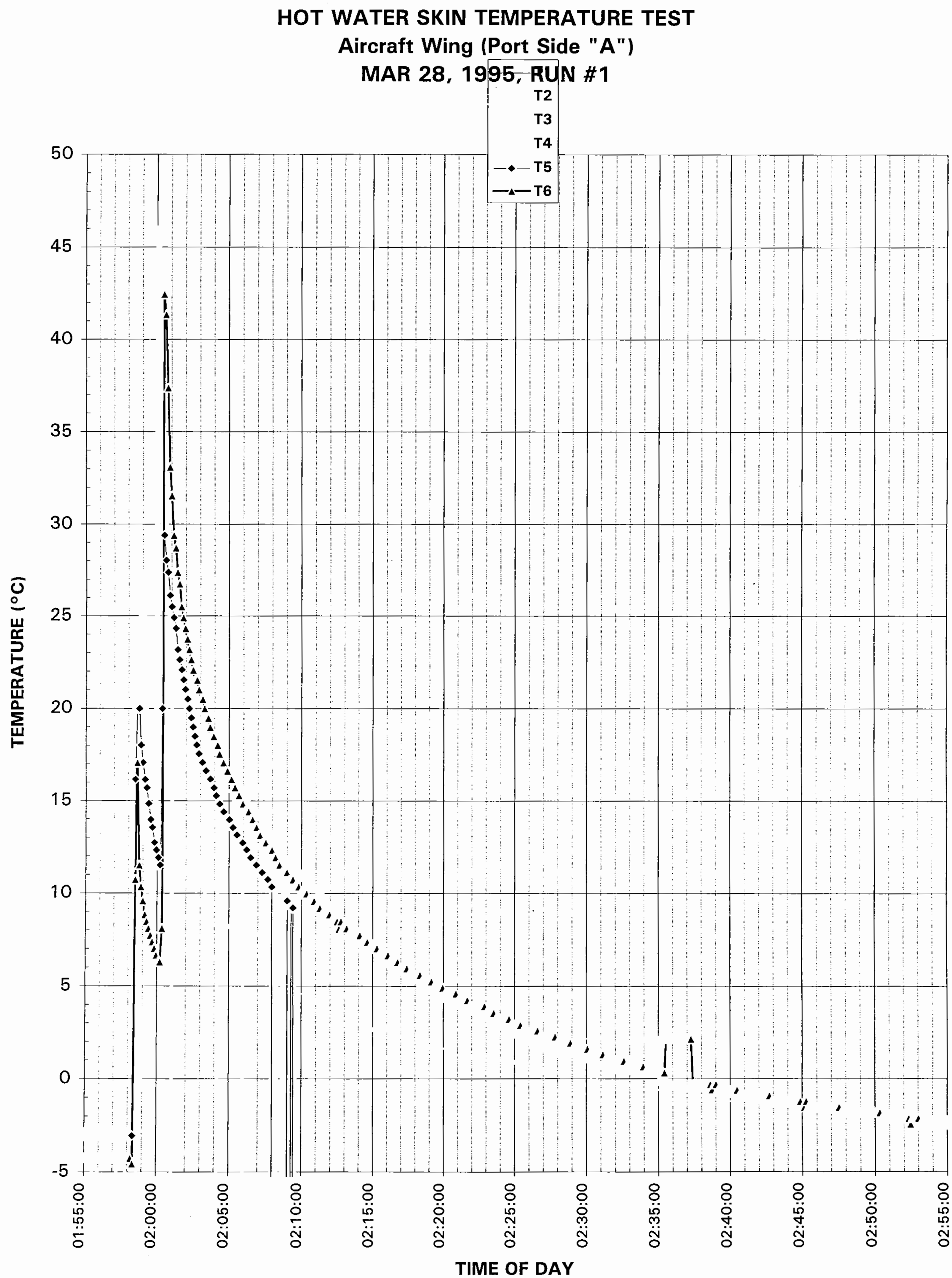


MR28WAR2.XLC

HOT WATER SKIN TEMPERATURE TEST
Aircraft Wing (Starboard Side "B")
MAR 28, 1995, RUN #3

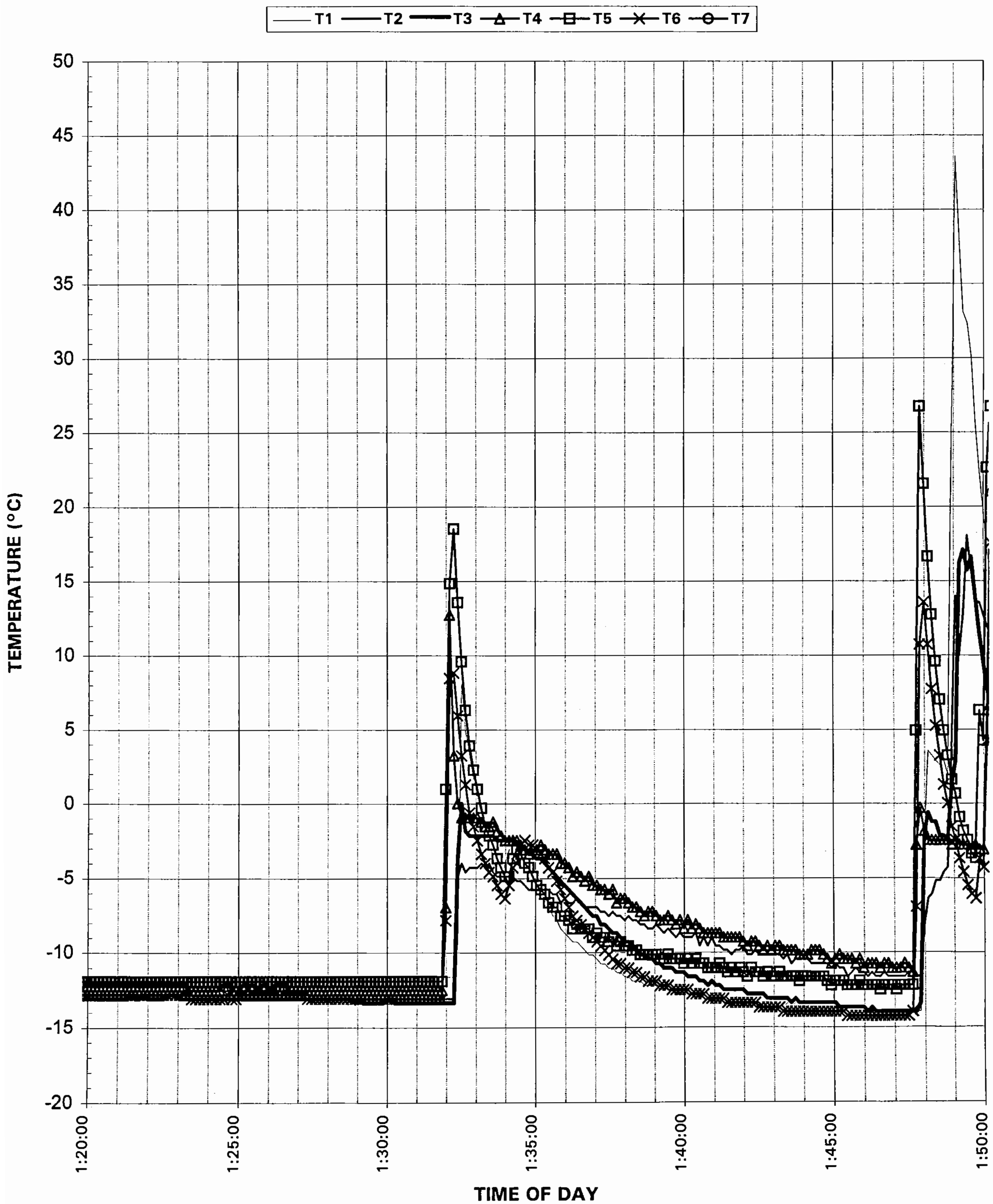


MR28BR3.XLC



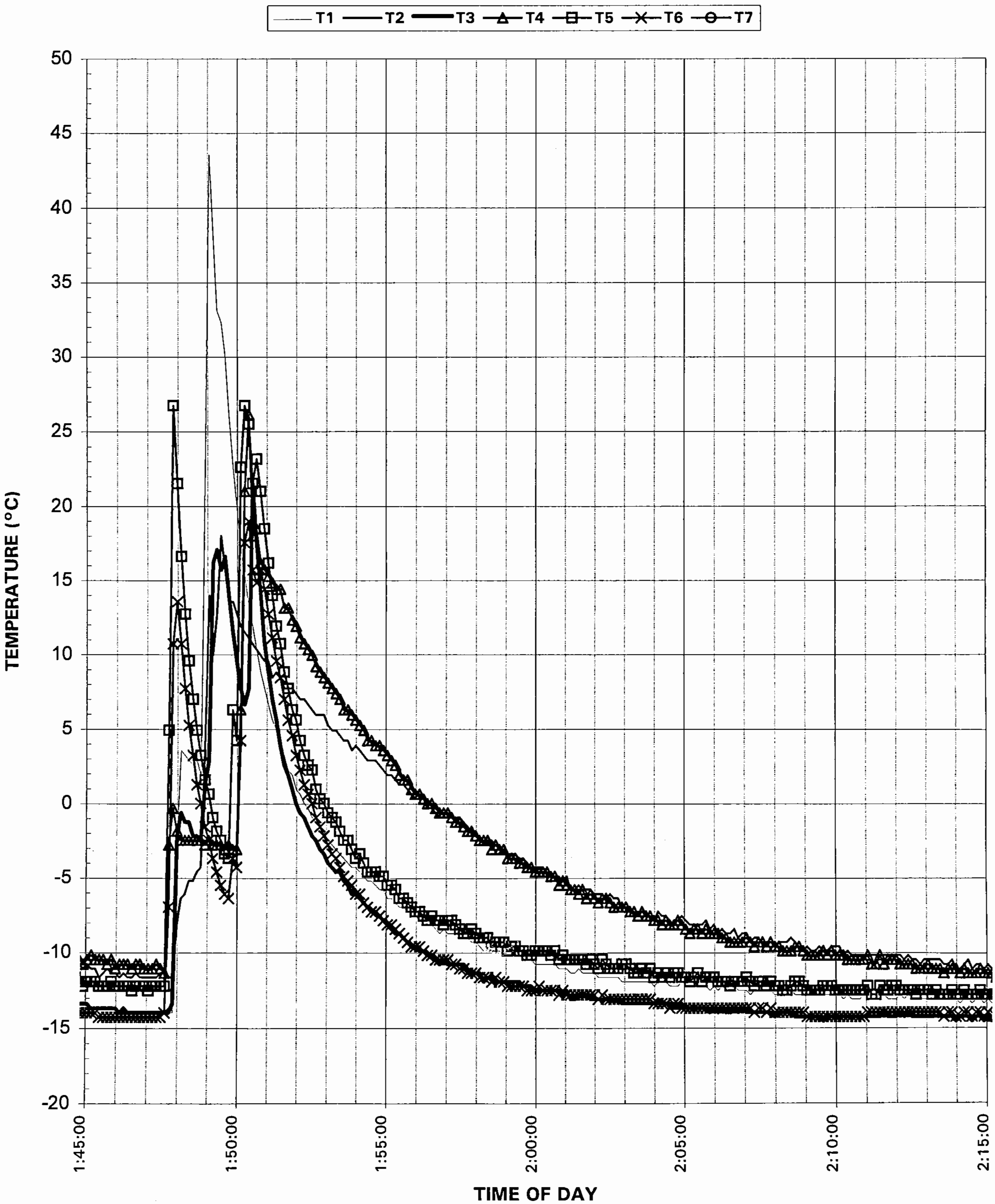
MR28WAR1.XLC

HOT WATER SKIN TEMPERATURE TEST @ YUL
Port Side
April 05, 1995, Run #1



AP05R1P.XLC

HOT WATER SKIN TEMPERATURE TEST @ YUL
Port Side
April 05, 1995, Run #2



AP05R2P.XLC

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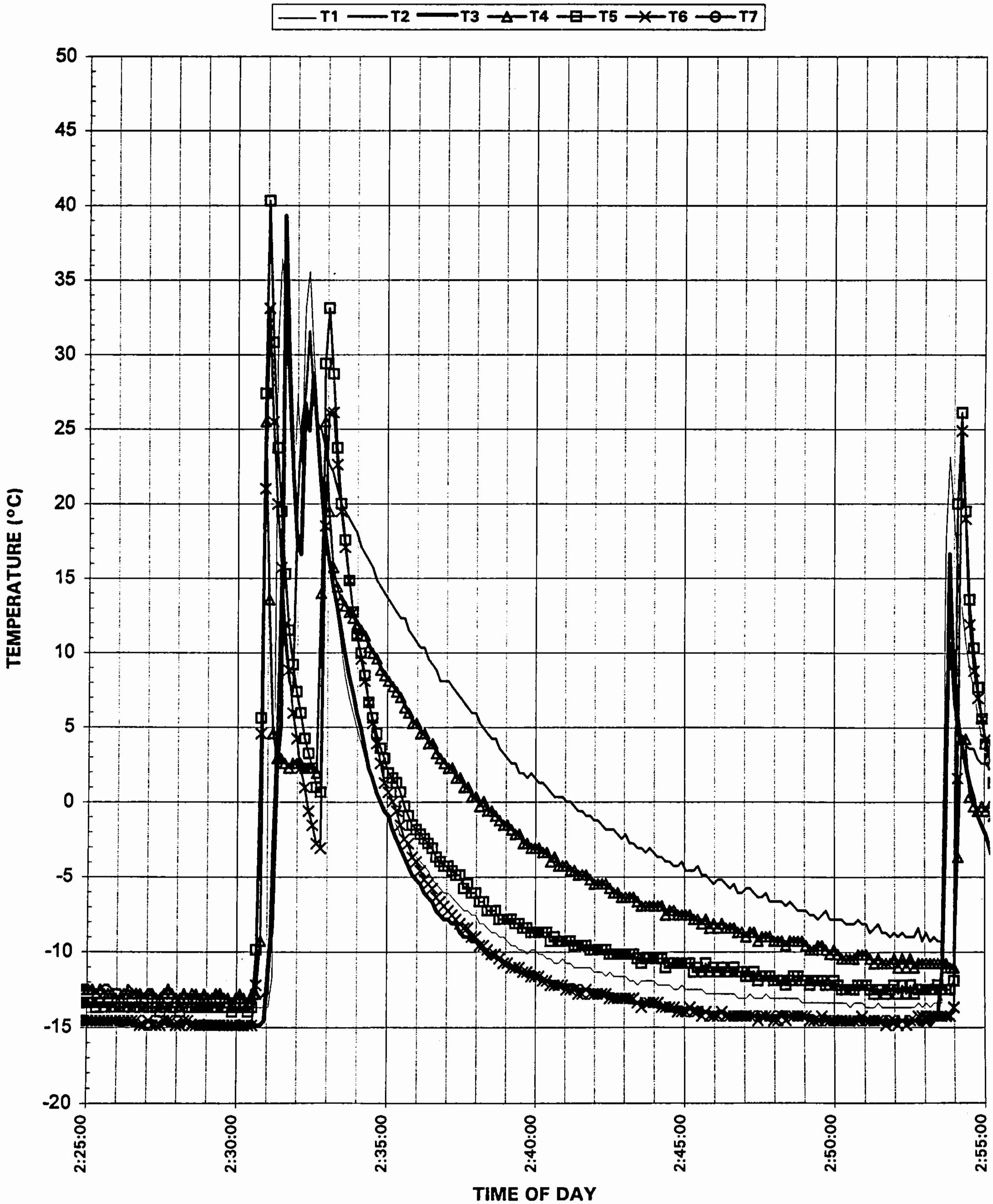
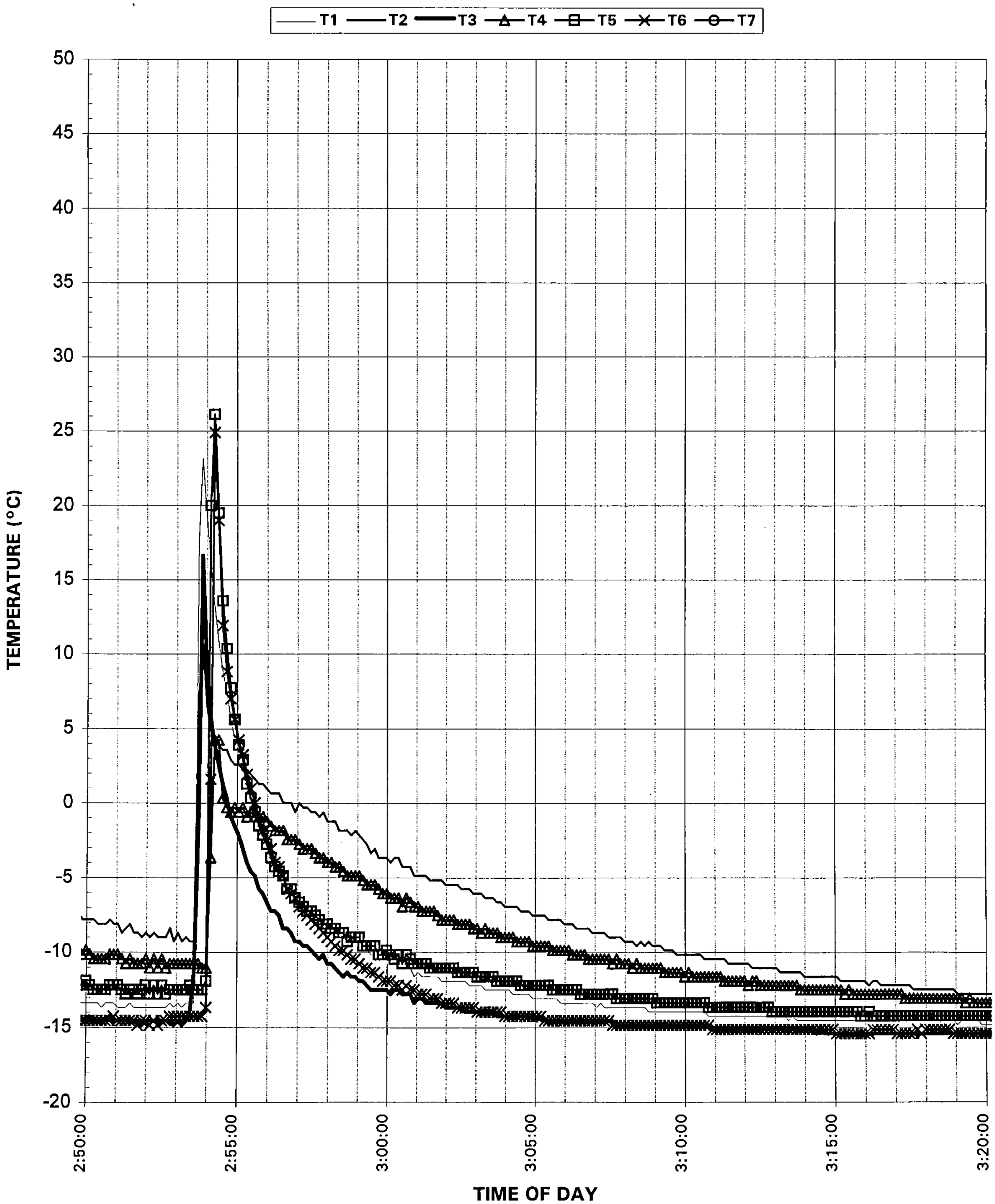
Port Side
April 05, 1995, Run #3



HOT WATER SKIN TEMPERATURE TEST @ YUL
Port Side
April 05, 1995, Run #4



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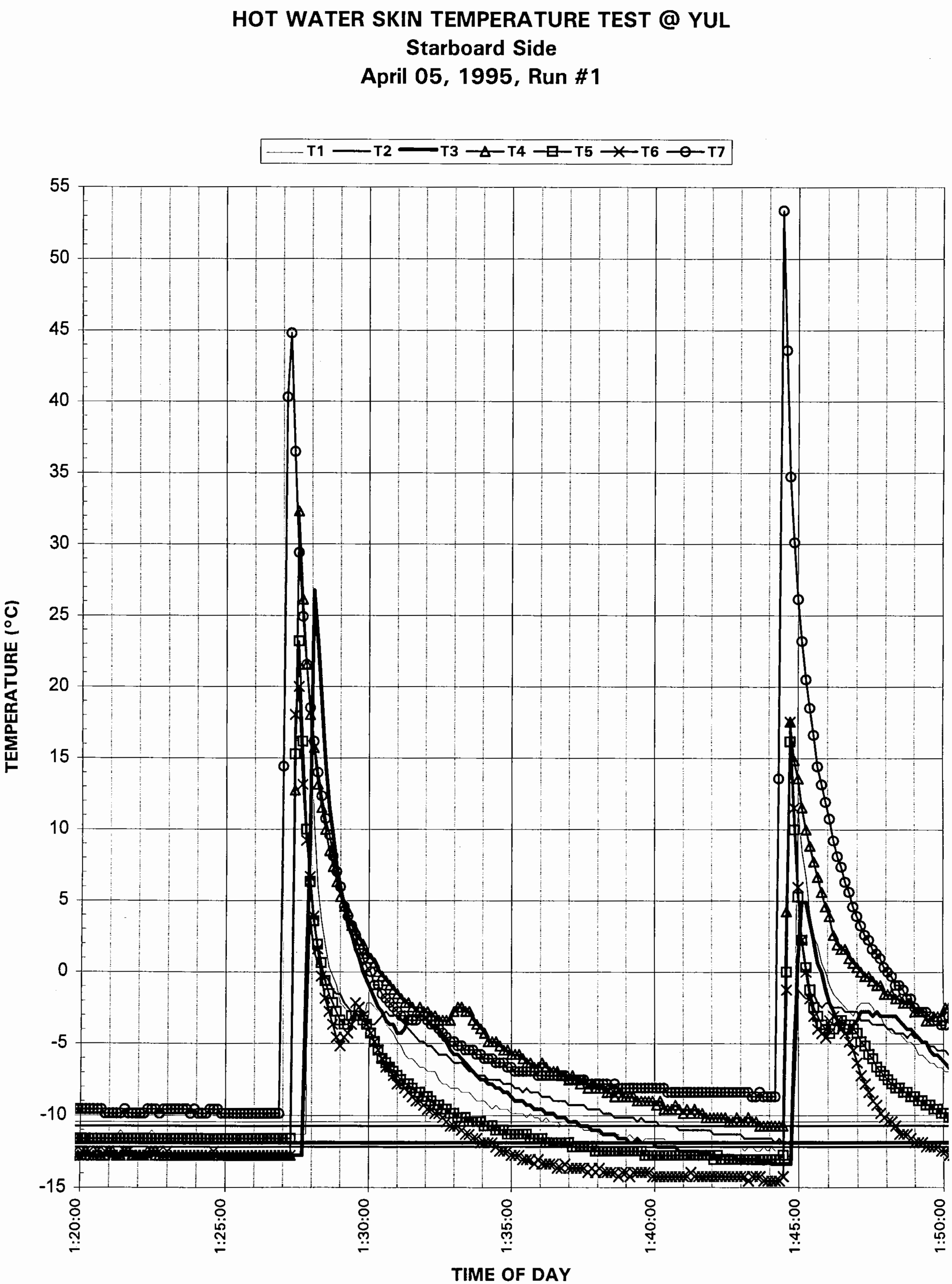
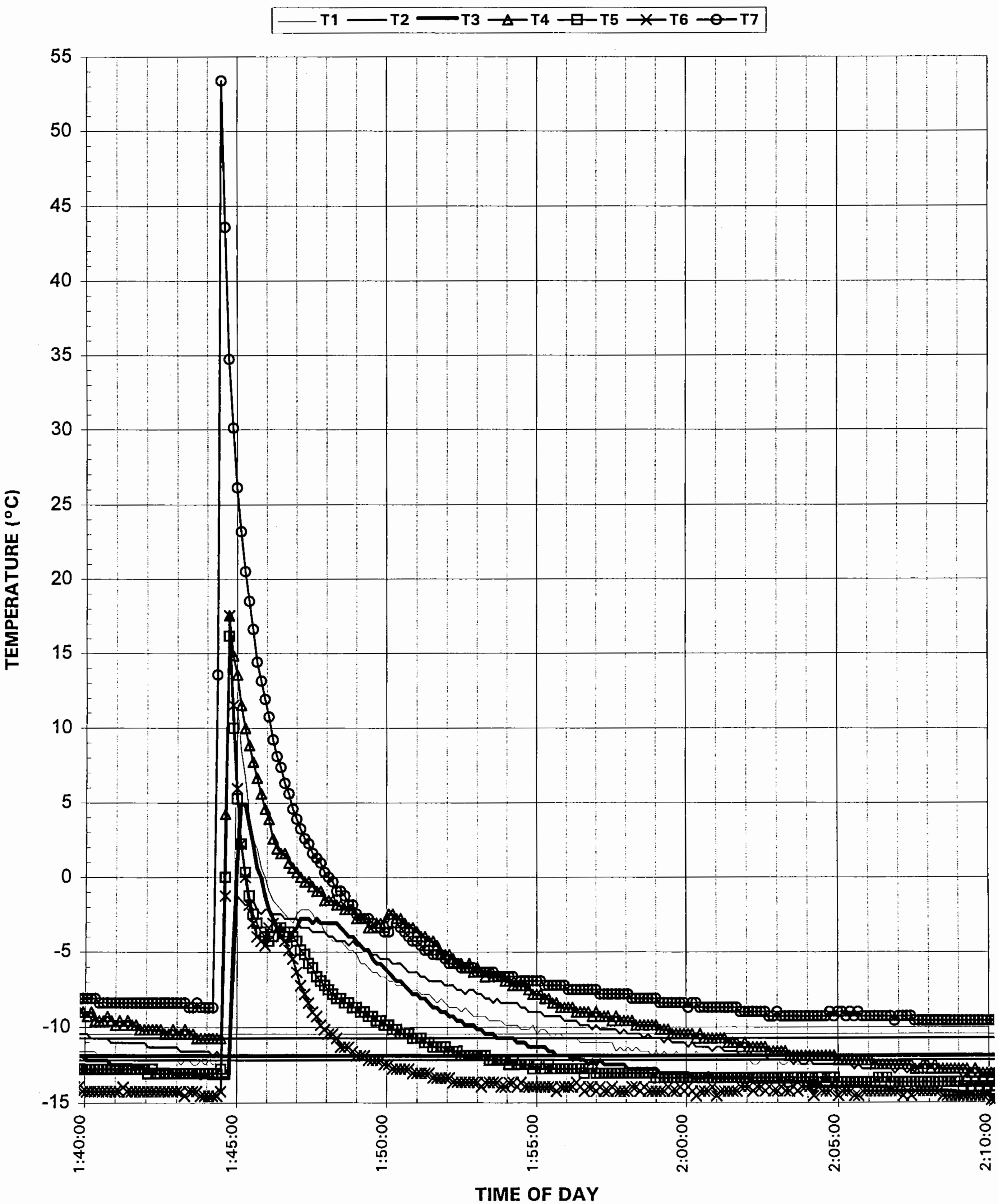

HOT WATER SKIN TEMPERATURE TEST @ YUL
Starboard Side
April 05, 1995, Run #1
T1
T2
T3
T4
T5
T6
T7
TEMPERATURE (°C)
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
1:20:00
1:25:00
1:30:00
1:35:00
1:40:00
1:45:00
1:50:00
TIME OF DAY

AP05R1S.XLC

HOT WATER SKIN TEMPERATURE TEST @ YUL
Starboard Side
April 05, 1995, Run #2



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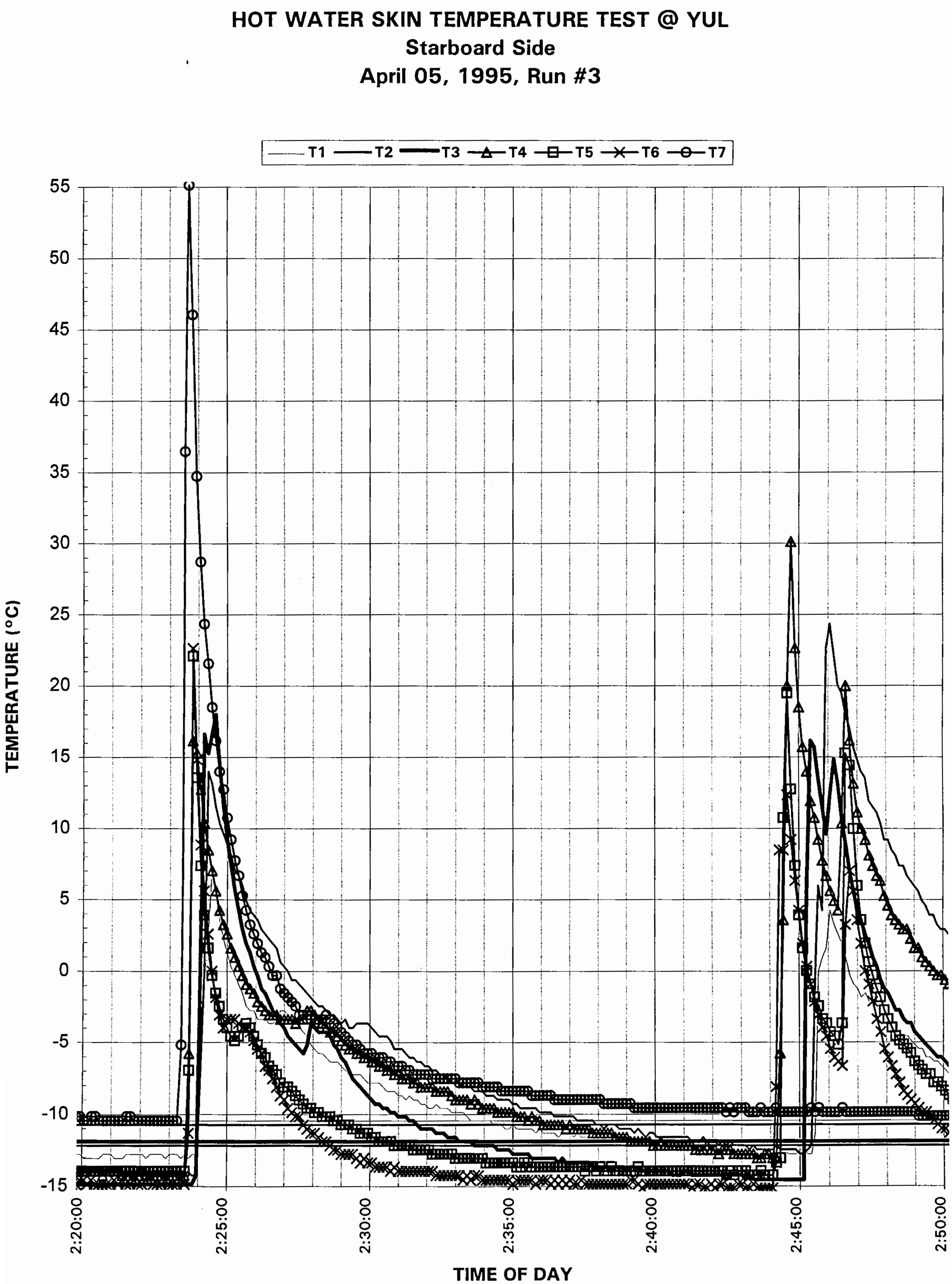
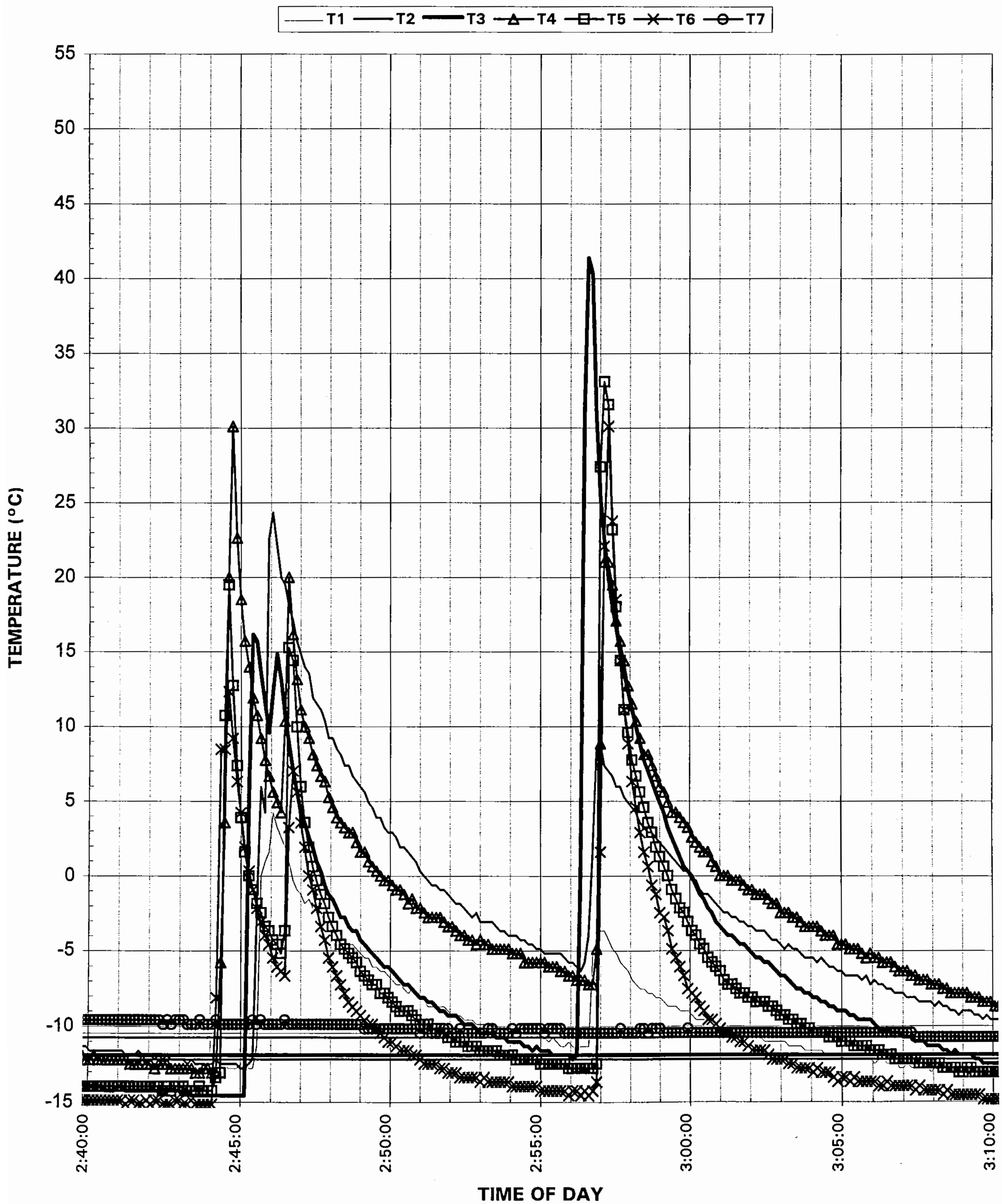

HOT WATER SKIN TEMPERATURE TEST @ YUL
Starboard Side
April 05, 1995, Run #3
T1
T2
T3
T4
T5
T6
T7
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
TEMPERATURE (°C)
2:20:00
2:25:00
2:30:00
2:35:00
2:40:00
2:45:00
2:50:00
TIME OF DAY

AP05R3S.XLC

HOT WATER SKIN TEMPERATURE TEST @ YUL
Starboard Side
April 05, 1995, Run #4



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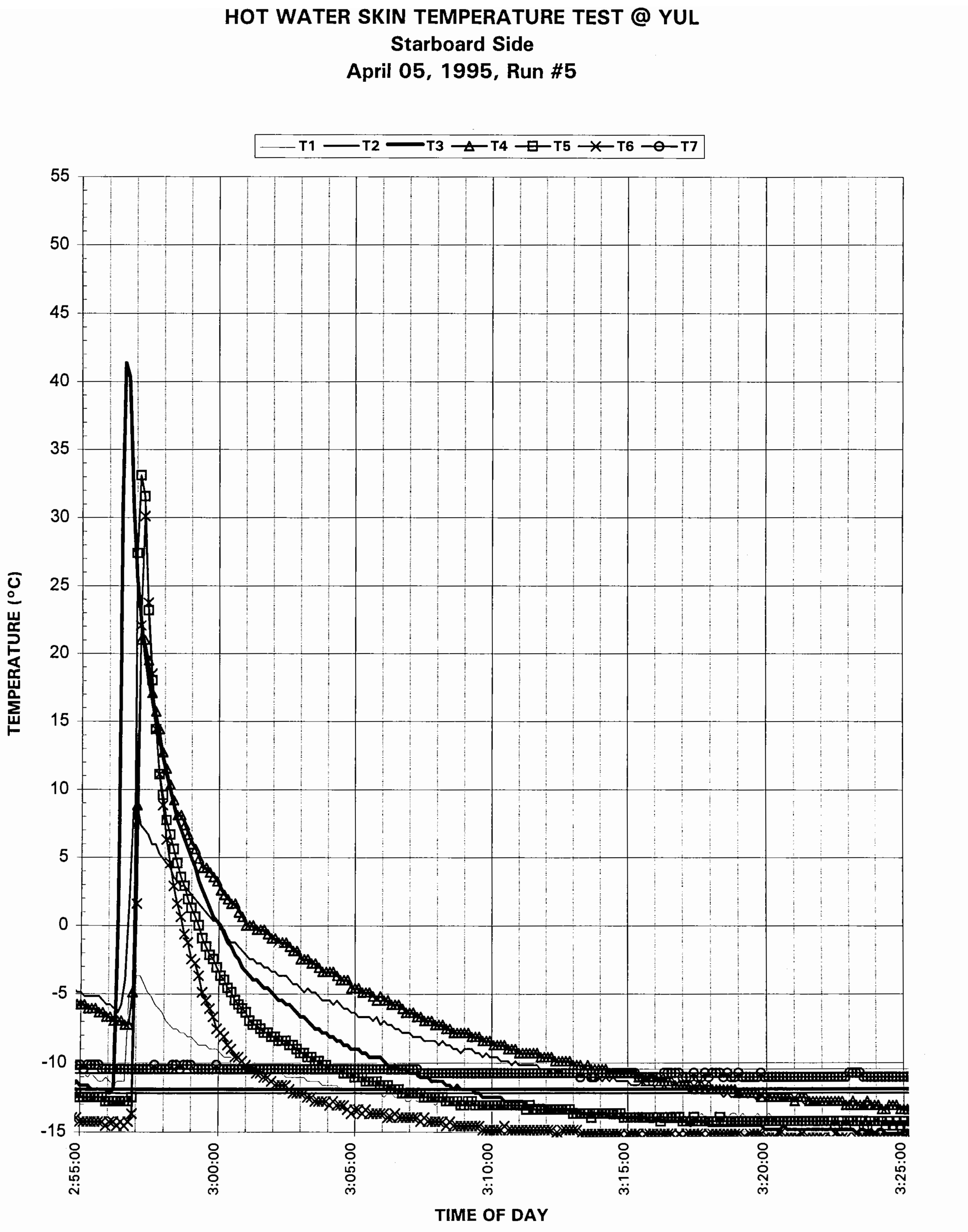
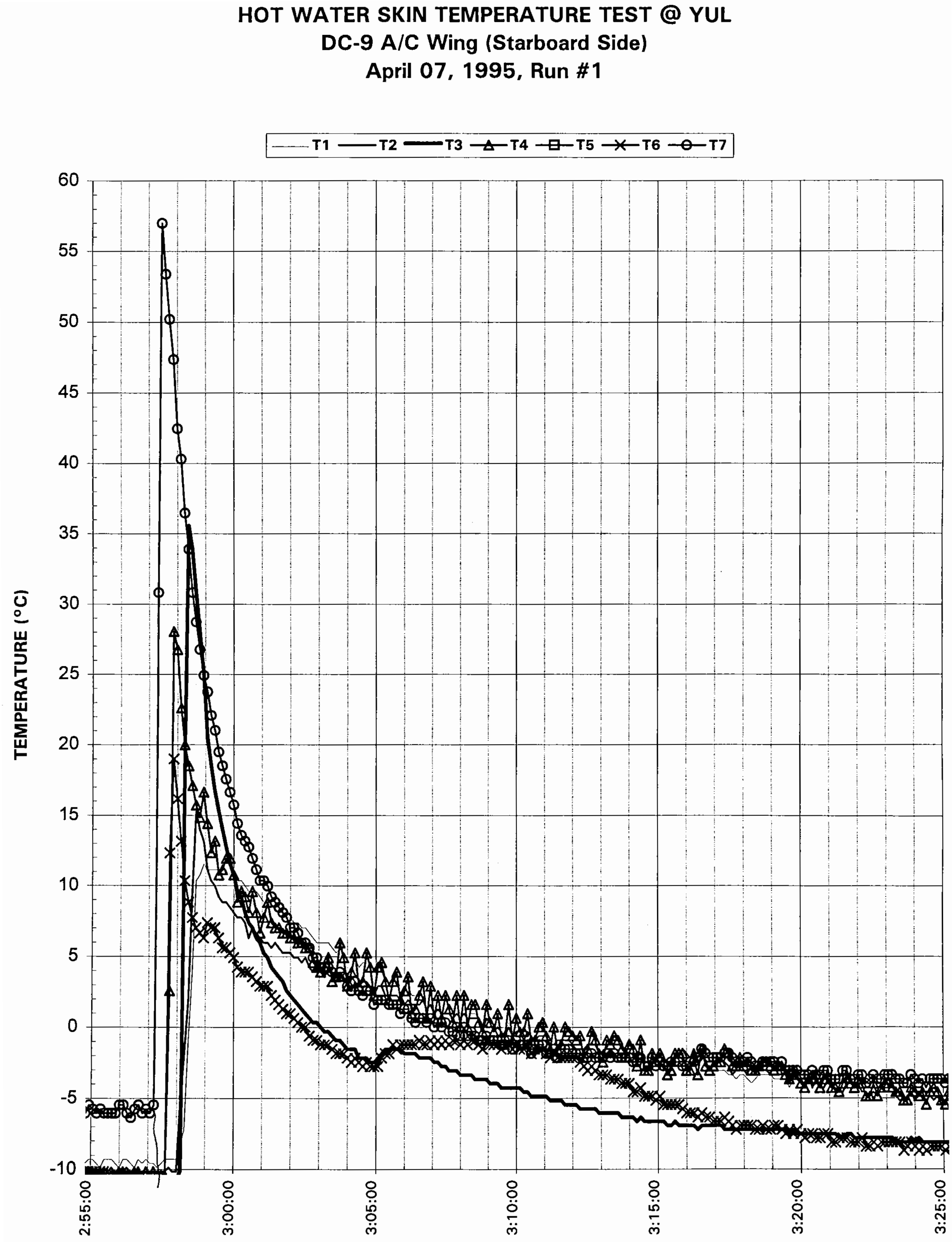
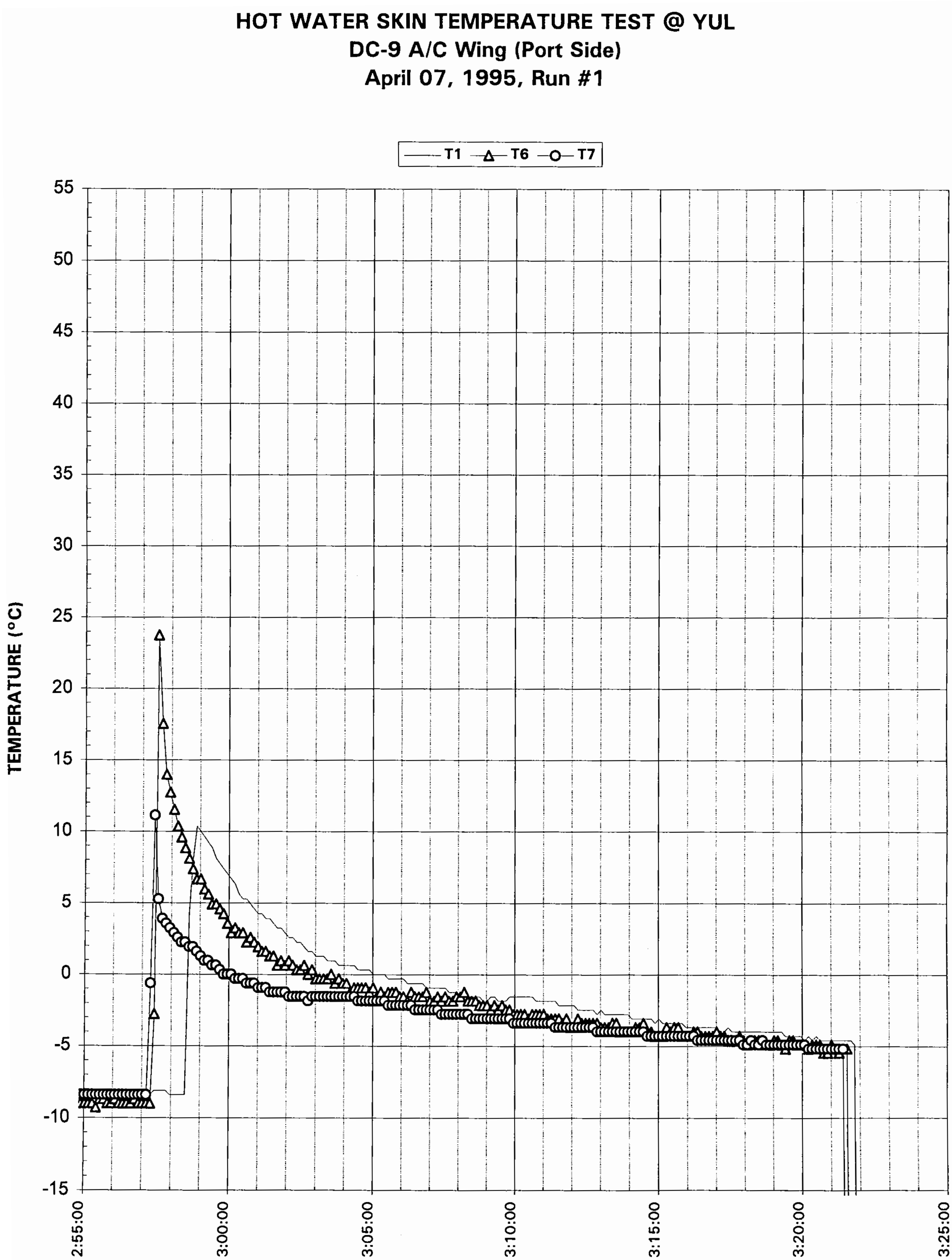

HOT WATER SKIN TEMPERATURE TEST @ YUL
Starboard Side
April 05, 1995, Run #5
T1
T2
T3
T4
T5
T6
T7
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
TEMPERATURE (°C)
2:55:00
3:00:00
3:05:00
3:10:00
3:15:00
3:20:00
3:25:00
TIME OF DAY

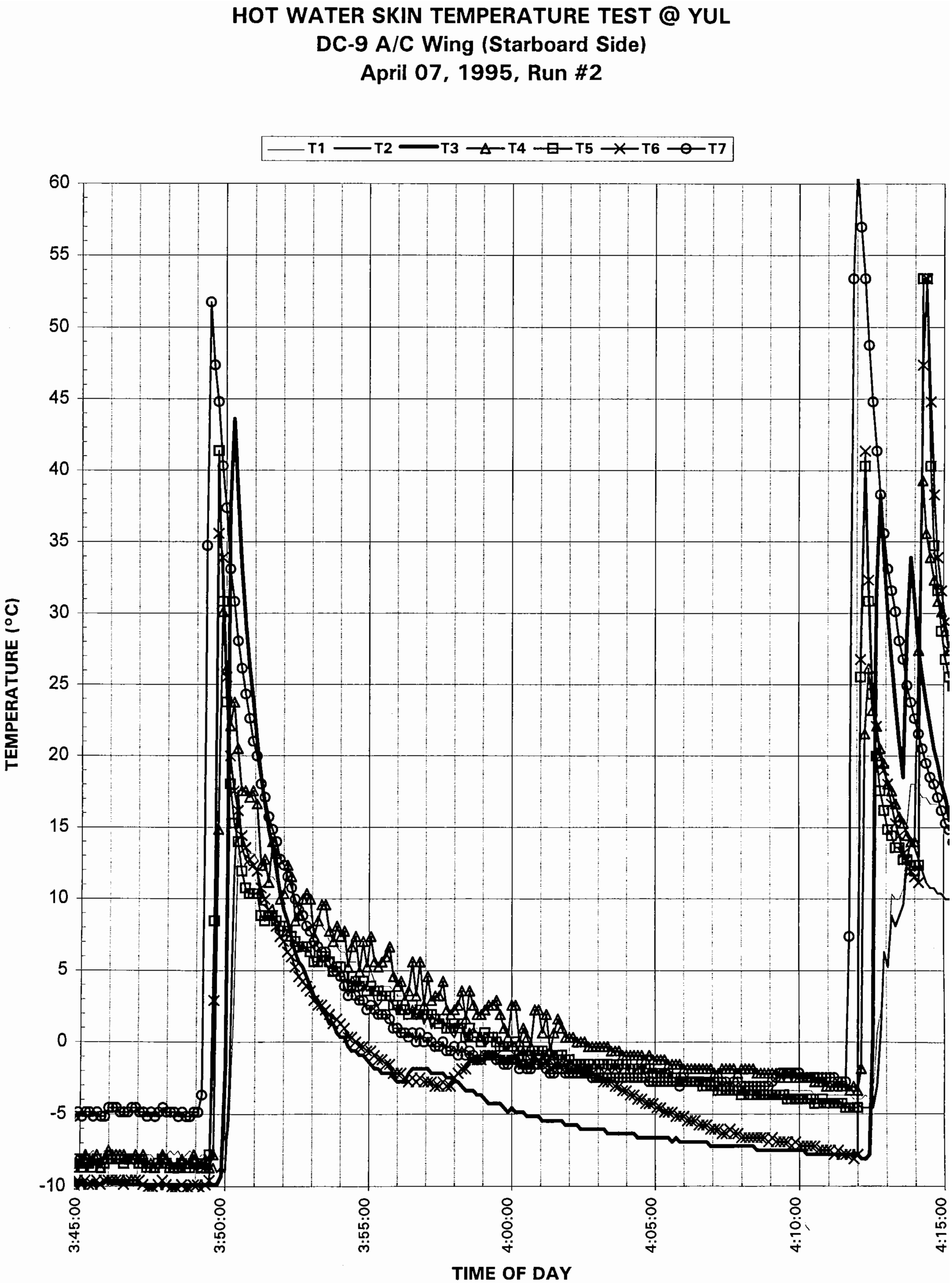
AP05R5S.XLC


HOT WATER SKIN TEMPERATURE TEST @ YUL
DC-9 A/C Wing (Starboard Side)
April 07, 1995, Run #1
T1
T2
T3
T4
T5
T6
T7
TEMPERATURE (°C)
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
2:55:00
3:00:00
3:05:00
3:10:00
3:15:00
3:20:00
3:25:00
TIME OF DAY

AP07R1S.XLC


HOT WATER SKIN TEMPERATURE TEST @ YUL
DC-9 A/C Wing (Port Side)
April 07, 1995, Run #1
T1
T6
T7
TEMPERATURE (°C)
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
2:55:00
3:00:00
3:05:00
3:10:00
3:15:00
3:20:00
3:25:00
TIME OF DAY

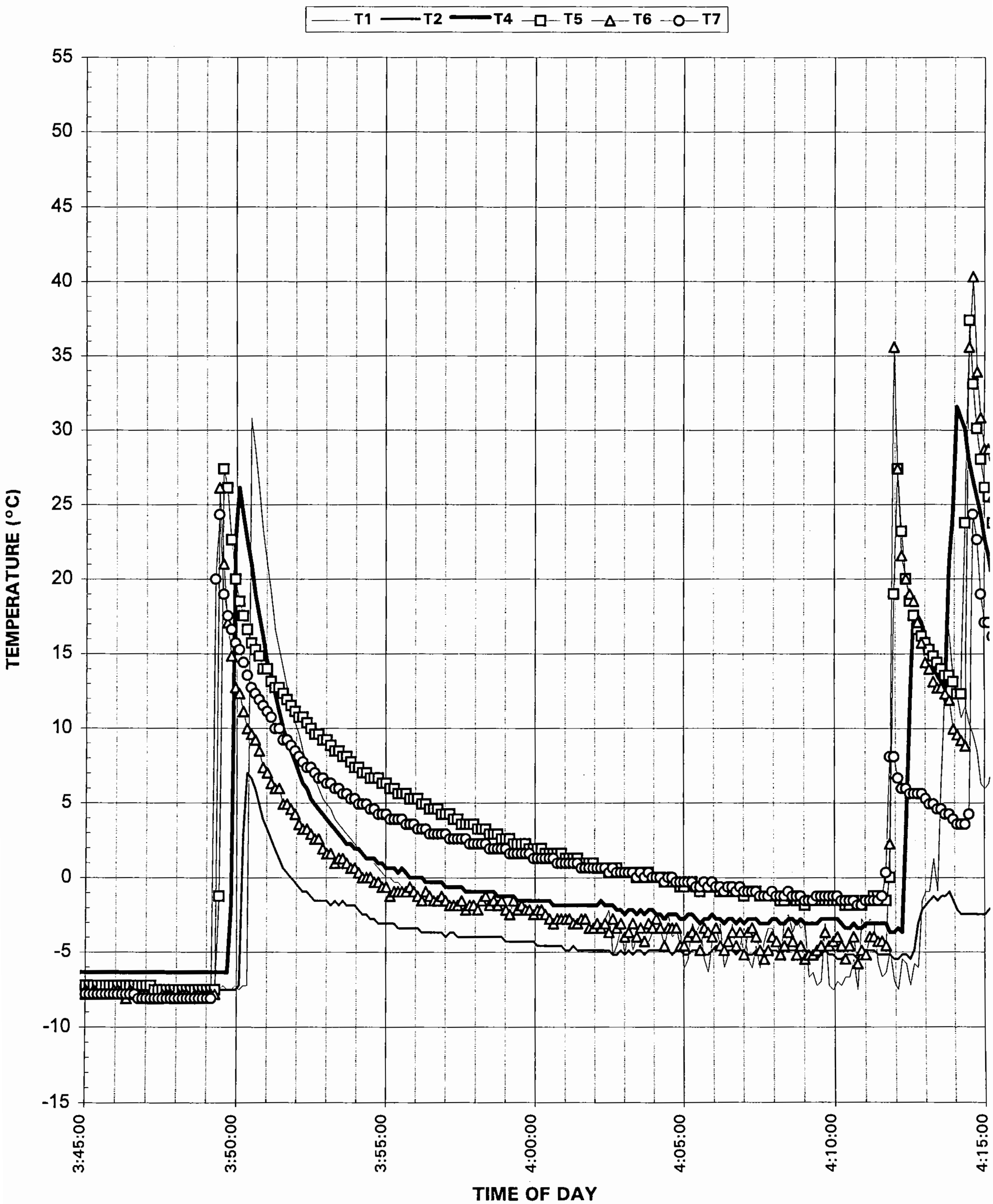
AP07R1P.XLC



HOT WATER SKIN TEMPERATURE TEST @ YUL
DC-9 A/C Wing (Starboard Side)
April 07, 1995, Run #2
T1
T2
T3
T4
T5
T6
T7
TEMPERATURE (°C)
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
3:45:00
3:50:00
3:55:00
4:00:00
4:05:00
4:10:00
4:15:00
TIME OF DAY

AP07R2S.XLC

HOT WATER SKIN TEMPERATURE TEST @ YUL
DC-9 A/C Wing (Port Side)
April 07, 1995, Run #2



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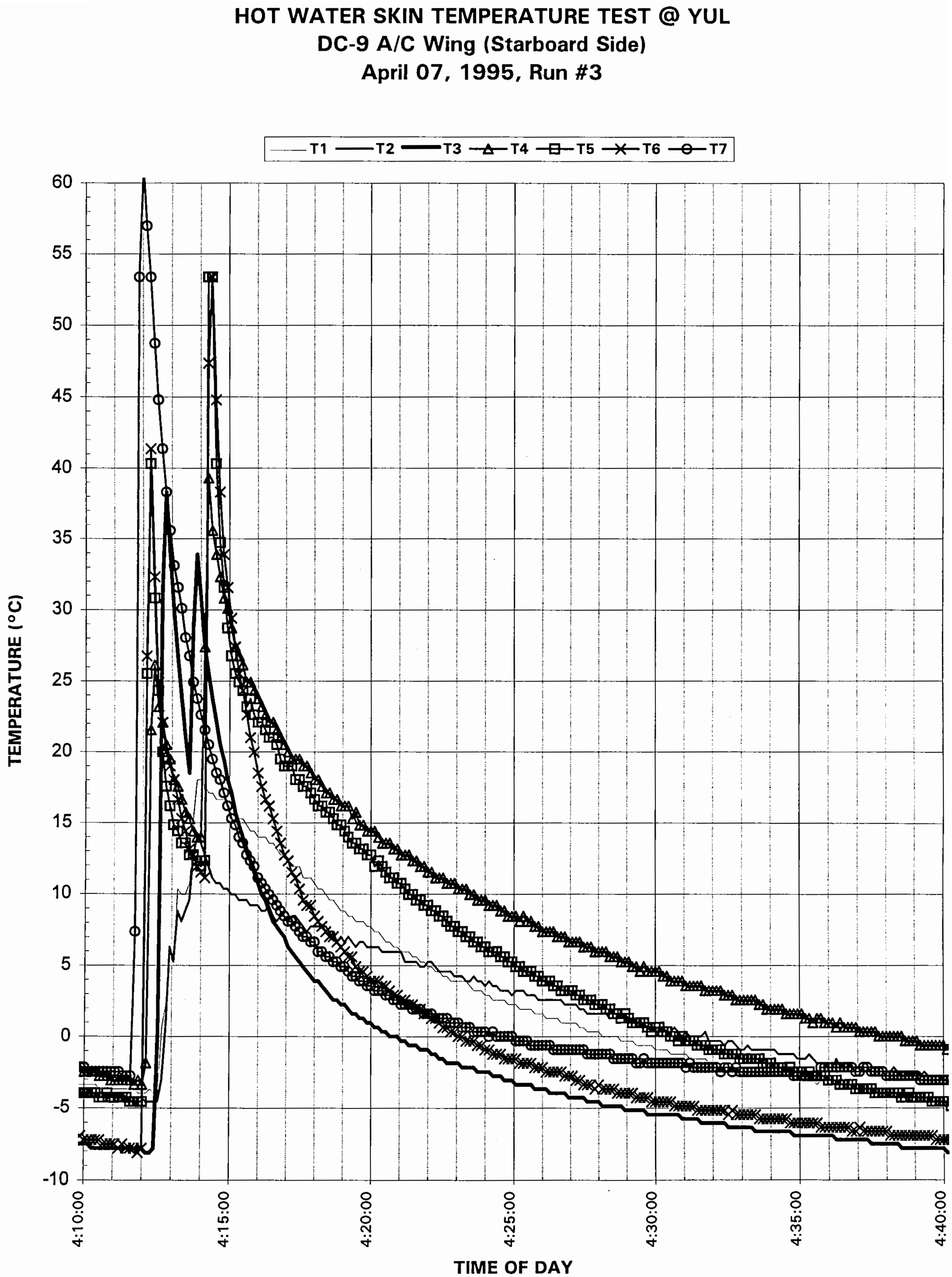
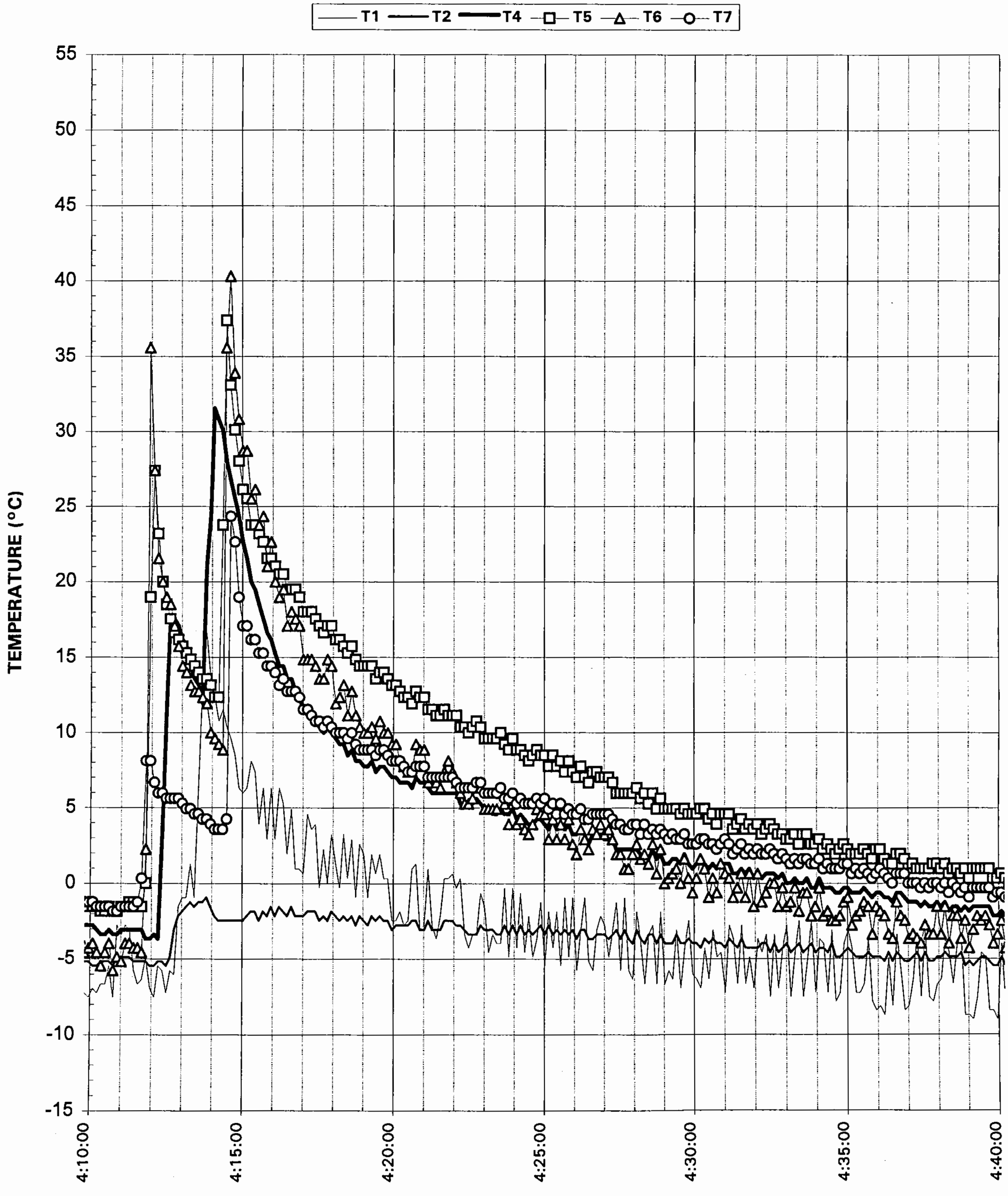

HOT WATER SKIN TEMPERATURE TEST @ YUL
DC-9 A/C Wing (Starboard Side)
April 07, 1995, Run #3
T1 T2 T3 T4 T5 T6 T7
TEMPERATURE (°C)
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
4:10:00
4:15:00
4:20:00
4:25:00
4:30:00
4:35:00
4:40:00
TIME OF DAY

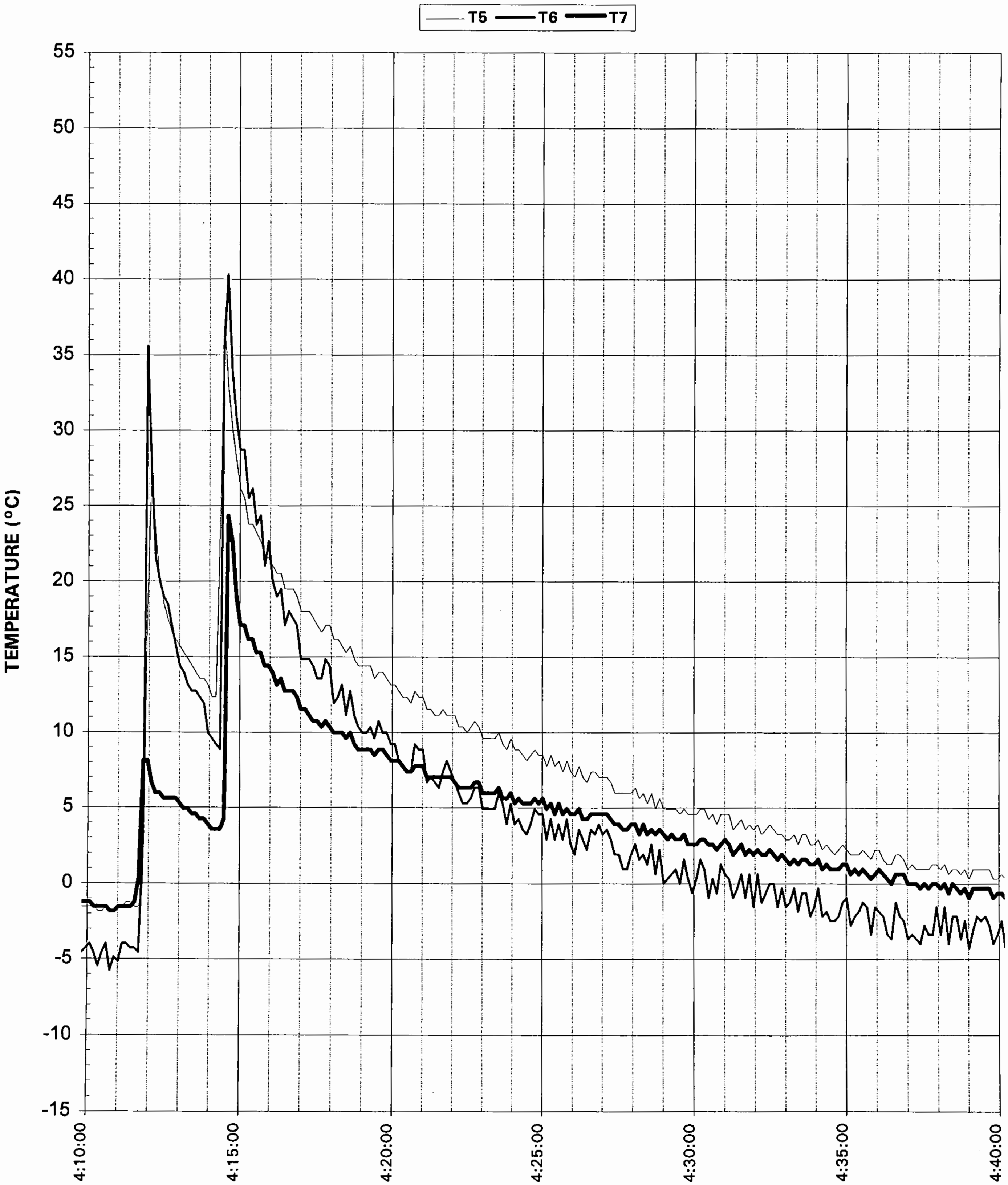
AP07R3S.XLC

HOT WATER SKIN TEMPERATURE TEST @ YUL
DC-9 A/C Wing (Port Side)
April 07, 1995, Run #3



AP07R3P.XLC

HOT WATER SKIN TEMPERATURE TEST @ YUL
DC-9 A/C Wing (Port Side)
April 07, 1995, Run #3



AP07R3P.XLC

APPENDIX E

TERMS OF REFERENCE - WORK STATEMENT

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WORK STATEMENT

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

1 INTRODUCTION

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

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

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

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

DCIP plans to take advantage of these offers to undertake the outstanding Holdover Time work, and with crew and equipment mobilized, to 'piggy-back' additional tests:

To evaluate the suitability of hot air for de-icing as an alternative to heated de-icing fluids at low (e.g. -30°C and below) ambient temperatures. The hot air temperature must not exceed 85°C; time to de-ice, avoidance of re-freezing, and operational economics are factors to be considered. Similarly forced air will also be considered for removal of cold dry snow, and for 'warm' wet snow.

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

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

2 PROGRAM OBJECTIVE (MCR 16)

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

3 PROGRAM SUB-OBJECTIVES

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

4 PROJECT OBJECTIVES

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

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

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

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

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

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

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

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

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

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

5. DETAILED STATEMENT OF WORK

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

5.1 "Cold soak' Test Program

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

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

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

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

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

5.2 Substantiation of HOT Tables

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

5.3.9 Videotape records of all tests shall be made.

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

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

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

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

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

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

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

5.5 Hot Water as a de-icing agent

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

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

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

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

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

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

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

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

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

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

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

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

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

5.8 Presentations of test program results

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

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

5.9 Reporting

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

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

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