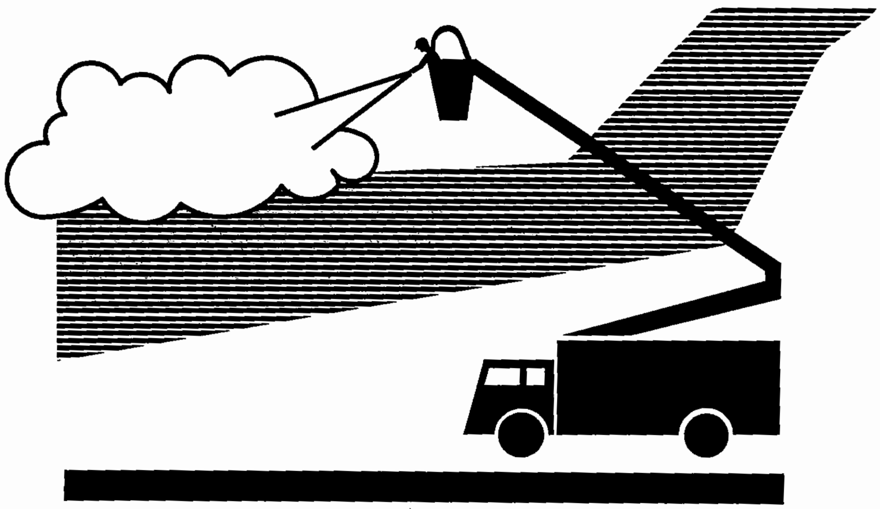
TP 12897E

Evaluation of Frost Formations at Very Cold Temperatures



Prepared for

Transportation Development Centre
on behalf of
Civil Aviation

Safety and Security
Transport Canada

by

APS AVIATION INC.

October 1996

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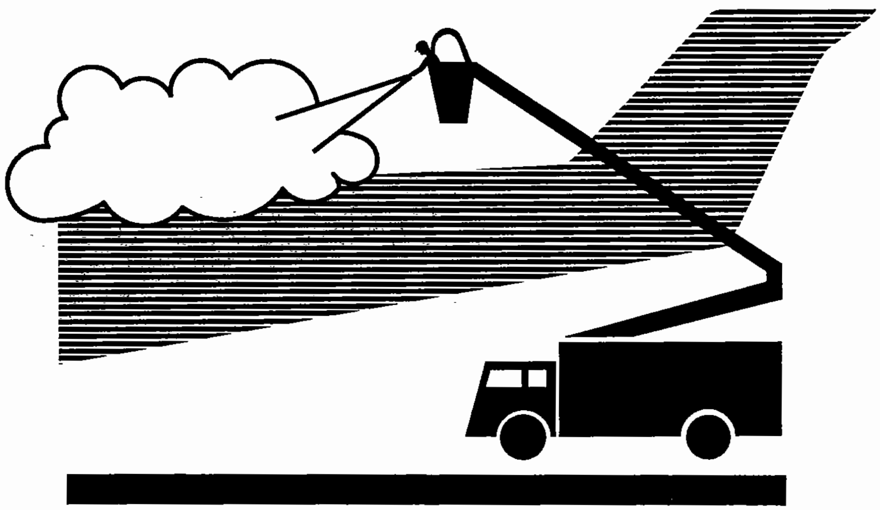

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The contents of this report reflect the views of APS Aviation Inc. and necessarily the official view or opinions of the Transportation Development Centre of Transport Canada.

DOCUMENT ORIGIN AND APPROVAL RECORD

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Un sommaire français se trouve avant la table des matières.

PREFACE

At the request of the Transportation Development Centre of Transport Canada, APS Aviation Inc. has undertaken a research program to further advance aircraft ground deicing/anti-icing technology. Specific objectives of the overall program were:

- To complete the substantiation of the existing Type I and Type II fluid SAE/ISO holdover time tables by conducting cold-soak tests and very low temperature tests;
- To determine the holdover time performance of the proposed Type IV fluids over the range of characteristic conditions and develop a generic Type IV holdover time table;
- To establish the precipitation, wind and temperature values that delimit the holdover times given in the tables;
- To validate that test data on Type IV fluid performance on flat plates used to establish the SAE holdover time tables is representative of Type IV fluid performance on service aircraft under conditions of natural freezing precipitation;
- To document the characteristics of frost deposits occurring naturally during very cold temperatures;
- To validate that fluid performance on cold-soaked boxes used for establishing holdover times is representative of fluid performance on a cold-soaked wing;
- To identify potential means of enhancing the visibility of failed wing surfaces from inside the aircraft; and
- To identify optimum wing locations to be used as representative surfaces by measuring the wet film thickness profiles of fluid application to aircraft wing surfaces.

PREFACE

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

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

This report, TP 12897E, addresses the objective of documenting the characteristics of frost deposits occurring naturally during very cold temperatures.

Funding for the research has come from the Civil Aviation Group, Transport Canada, with support from the Federal Aviation Administration. This program of research could not have been accomplished without the assistance of many organizations. APS would therefore like to thank the Transportation Development Centre, the Federal Aviation Administration, the National Research Council, Atmospheric Environment Services, Transport Canada and the fluid manufacturers for their contribution and assistance in the project. Special thanks are extended to Air Canada for provision of personnel and facilities and for their cooperation on the test program. The assistance and cooperation provided at Thompson, Manitoba, for this particular project by Calm Air International Ltd and Skyward Aviation Ltd were most valuable and much appreciated by APS. For this project, APS wishes to acknowledge the initiative and skill displayed by the project photographer.

Transport Canada | Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No. TP 12897E	2. Project No. 8879	3. Recipient's Catalogue No.
4. Title and Subtitle Evaluation of Frost Formations at Very Cold Temperatures		5. Publication Date October 1996
		6. Performing Organization Document No. CM1283.001
7. Author(s) Peter Dawson, John D'Avirro		8. Transport Canada File No. ZCD1455-14
9. Performing Organization Name and Address APS Aviation Inc. 1100 René Lévesque Blvd. West, Suite 1340 Montreal, Quebec H3B 4N4		10. PWGSC File No. XSD-5-01535
		11. PWGSC or Transport Canada Contract No. T8200-5-5542/001-XSD
12. Sponsoring Agency Name and Address Transportation Development Centre (TDC) 800 René Lévesque Blvd. West 6th Floor Montreal, Quebec H3B 1X9		13. Type of Publication and Period Covered Final
		14. Project Officer Barry Myers

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

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

16. Abstract

Removal of frost from wing surfaces at very cold ambient temperatures (-35°C and below) is a problem common to many operators in the North of Canada. Lack of facilities for application of deicing fluids and the low temperatures that can prohibit the use of fluids, preclude frost removal/prevention procedures used at lower latitudes.

The objective of the present study was to support recommended research from a previous study by providing photographic records and statistical data on the dimensional characteristics of natural frost formations typical of occurrence on aircraft wings at very cold temperatures; the effects of sweeping frosted surfaces were also recorded.

This report presents photographic documentation of naturally occurring frost deposits produced on test beds and operational aircraft wings. Sweeping appears to remove nearly all frost deposited (maximum observed was 1.5 mm deep) except for a thin layer (less than 0.1 mm) that can be seen on dark painted surfaces. Cleaning by sweeping was easiest on aluminium surfaces. Identifying frost residue was most difficult on white surfaces. The sweeping procedure typically left a small frost residue around rivets, joints, and any other irregularities in the wing surface.

17. Key Words Aircraft, anti-icing, deicing fluid, frost, holdover, plate, precipitation, temperature	18. Distribution Statement Limited number of copies available from the Transportation Development Centre

19. Security Classification (of this publication)	20. Security Classification (of this page)	21. Declassification (date)	22. No. of Pages	23. Price
Unclassified	Unclassified	—	xiv, 47, apps	—

CDT/TDC 79-005
Rev. 96

Canada

Transports Canada | Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada TP 12897E	2. N° de l'étude 8879	3. N° de catalogue du destinataire
4. Titre et sous-titre Evaluation of Frost Formations at Very Cold Temperatures		5. Date de la publication Octobre 1996 6. N° de document de l'organisme exécutant CM1283.001
7. Auteur(s) Peter Dawson, John D'Avirro		8. N° de dossier - Transports Canada ZCD1455-14
9. Nom et adresse de l'organisme exécutant APS Aviation Inc. 1100, boul. René-Lévesque Ouest Bureau 1340 Montréal, Québec H3B 4N4		10. N° de dossier - TPSGC XSD-5-01535 11. N° de contrat - TPSGC ou Transports Canada T8200-5-5542/001-XSD
12. Nom et adresse de l'organisme parrain Centre de développement des transports (CDT) 800, boul. René-Lévesque Ouest 6e étage Montréal (Québec) H3B 1X9		13. Genre de publication et période visée Final 14. Agent de projet Barry Myers

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

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

16. Résumé

Le problème aigu du dégivrage des ailes d'un avion par temps très froid (à partir de - 35° C) est commun à plusieurs exploitants dans les régions nordiques du Canada. L'absence de hangars où pourrait s'effectuer l'arrosage des ailes avec un liquide dégivrant et les températures extrêmes rendent impossible l'utilisation des liquides dégivrants et antigivre ainsi que des procédés en usage dans les régions plus au sud.

Donnant suite aux recommandations formulées par une étude antérieure, la présente étude avait pour objet d'appuyer celle-ci par des documents photographiques et des données statistiques sur les caractéristiques dimensionnelles des formations de givre sur les ailes d'aéronefs par temps très froid et d'approfondir l'effet de la technique du balayage effectué sur diverses surfaces.

Dans le rapport est présentée une série de documents photographiques montrant des surfaces givrées naturellement : éprouvettes et ailes d'aéronefs en exploitation. Il a été observé que le balayage enlevait les formations de givre presque complètement (épaisseur maximale observée : 1,5 mm) et ne laissait qu'une couche extrêmement mince (inférieure à 0,1 mm) visible sur les parties recouvertes d'une peinture foncée. Les surfaces en aluminium étaient les plus faciles à balayer. Le plus difficile était d'observer le givre résiduel sur les surfaces blanches. Le givre résiduel se manifestait surtout autour des discontinuités de l'aile : rivets, joints à recouvrement, et autres.

17. Mots clés Aéronefs, antigivre, dégivrage, givre, durée d'efficacité, plaques planes, précipitations, température	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

19. Classification de sécurité (de cette publication) Non classifiée	20. Classification de sécurité (de cette page) Non classifiée	21. Déclassification (date) —	22. Nombre de pages xiv, 47, ann.	23. Prix —

CDT/TDC 79-005
Rev. 96

Canada

EXECUTIVE SUMMARY

Removal of frost from wing surfaces at very cold ambient temperatures (-35°C and below) is a problem common to many operators in the North of Canada. Hangars are not always available, installation of wing covers is not a complete solution and use of deicing fluids can be prohibitive in the very cold temperatures experienced.

In the 1994/1995 winter season, recognizing that a practical and economical solution would benefit a great number of operators, Transport Canada requested APS Aviation to evaluate the suitability of hot blown air as a frost removal agent. The results of that study, published in Transport Canada Report TP 12655E, *Forced Air Deicing Trials for the 1994/95 Winter*, indicated that using existing ground heaters as a source of hot air, and fitting them with well designed nozzles to deliver the hot air to the wing surface, could be a feasible and economical solution, if particular operational concerns could be overcome. The study recommended that research be conducted to evaluate: a) frost removal by manual sweeping; b) defrosting only the forward portion of the wing using blown hot air; and if warranted by the results of the research of a) and b); c) development of a fully engineered nozzle to optimize defrosting with heated air.

The objective of the present study was to support the recommended research by providing photographic records and statistical data on the dimensional characteristics of natural frost formations typical of occurrence on aircraft wings at very cold temperatures and to demonstrate the effects of sweeping on several test surfaces.

The report presents a series of documented photographs of naturally occurring frost, both on a test bed and on wings of operating aircraft at Thompson Airport. Where possible, a quantitative analysis of dimensions of frost formations and degree of surface coverage was performed and is included. Photographs include both undisturbed natural frost, and the residue remaining after sweeping.

Sweeping appears to remove nearly all frost deposited (maximum observed was 1.5 mm) except for a thin layer (less than 0.1 mm) that can be seen on the darker surfaces. Cleaning by sweeping was easiest on the aluminium surface. Identifying frost residue was most difficult on the white surface. The sweeping procedure typically left a small frost residue around rivets, joints, and any other irregularities in the wing surface.

Photographic evidence indicates that the characteristics of frost formations vary greatly and, under similar environmental conditions, depend heavily on the test surfaces employed. This aspect may need to be addressed in attempts to reproduce frost synthetically for laboratory and/or wind tunnel testing. The varied nature of the frost formations observed did not appear to influence the ability to remove frost by sweeping.

It is recommended that the information on frost characteristics presented in this report be used:

- To assist research to evaluate the acceptability of removing frost by sweeping;
- To assist research to evaluate the acceptability of defrosting only the forward part of the wing; and
- To evaluate suitability of current methods of simulating frost in wind tunnel experiments.

It is further recommended that a similar approach be followed to characterize frost deposits experienced at moderate and cold temperatures in Southern Canada, and at moderate temperatures at Thompson, Manitoba.

SOMMAIRE

Le problème aigu du dégivrage des ailes d'un avion par temps très froid (à partir de - 35° C) est commun à plusieurs exploitants dans les régions nordiques du Canada. Les mises sous hangar ne sont pas toujours possibles, la protection des ailes est une solution incomplète et le coût des liquides dégivrants à ces températures extrêmes peut s'avérer rédhibitoire.

Devant la nécessité de trouver une solution à la fois pratique et économique profitant à nombre d'exploitants, Transports Canada a confié à APS Aviation Inc. pour l'hiver de 1994-1995 le mandat d'approfondir l'utilité du soufflage d'air chaud comme moyen de dégivrage. L'étude portant le numéro TP 12655E intitulée *Forced Air Deicing Trials for the 1994/1995 Winter* a montré que le soufflage d'air chaud était dans certains cas à la fois pratique et économique, à condition d'utiliser les générateurs d'air chaud existants et de les munir d'une tuyère appropriée. L'étude a débouché sur la recommandation de mener des recherches sur : a) le dégivrage par balayage des ailes; b) le dégivrage de la partie avant de l'aile par soufflage d'air chaud et, sous réserve de résultats encourageants, c) une tuyère permettant d'optimiser le soufflage par air chaud.

La présente étude avait pour objet d'appuyer les recherches préconisées par des documents photographiques et des données statistiques sur les caractéristiques dimensionnelles des formations de givre sur les ailes d'aéronefs par temps très froid et d'approfondir l'effet de la technique du balayage effectué sur diverses surfaces.

Dans le rapport est présentée une série de documents photographiques montrant des surfaces givrées naturellement, éprouvettes et ailes d'aéronefs en exploitation à l'aéroport de Thompson, accompagnés chaque fois que cela était possible d'une analyse indiquant les caractéristiques dimensionnelles des formations de givre : taille, forme et distribution. Les photographies montraient ces formations d'abord à l'état naturel puis après balayage.

Il a été observé que le balayage enlevait les formations de givre presque complètement (épaisseur maximale observée : 1,5 mm) et ne laissait qu'une couche extrêmement mince (inférieure à 0,1 mm)

visible sur les parties les plus foncées de l'aile. Les surfaces en aluminium étaient les plus faciles à balayer. Le plus difficile était d'observer le givre résiduel sur les surfaces blanches. Le givre résiduel se manifestait surtout autour des discontinuités de l'aile : rivets, joints à recouvrement et autres.

Les documents photographiques montrent que les caractéristiques des formations de givre varient beaucoup et que, dans des conditions environnementales comparables, elles dépendent avant tout de la nature de la surface sur laquelle le givre se dépose. Il serait utile d'approfondir cet aspect des choses dans le but de déterminer s'il serait possible de reproduire en laboratoire et (ou) dans une soufflerie, les conditions propices à la formation de givre. Peu importe la nature des formations de givre observées, elle ne semblait pas s'opposer à la technique de dégivrage par balayage.

Il est recommandé de se servir des résultats obtenus de la présente étude pour :

- guider la recherche sur les possibilités de dégivrage offertes par le balayage;
- guider la recherche visant à vérifier s'il serait suffisant de ne dégivrer que la partie avant de l'aile;
- évaluer l'adéquation des méthodes en vigueur pour l'obtention de givre en soufflerie.

Il est également recommandé d'utiliser cette même démarche dans le but d'étudier les caractéristiques des formations de givre sous des climats modérés ou froids (régions du sud du Canada) et moyennement froids (Thompson, Manitoba).

TABLE OF CONTENTS

SECTION NUMBER	PAGE NUMBER

LIST OF ACRONYMS

APS	APS Aviation Inc.
C/FIMS	Contaminant/Fluid Integrity Monitoring System
ISO	International Standards Organization
SAE	Society of Automotive Engineers
TDC	Transportation Development Centre

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1. INTRODUCTION

Removal of frost from wing surfaces at very cold ambient temperatures (-35°C and below) is a problem common to many operators in the North.

Aspects of the operation combined with extreme low temperatures preclude frost removal/prevention procedures that are standard approaches elsewhere:

- At these temperature extremes, application of de-icing fluids is not practical as the fluid freeze points (with the required 10°C buffer) have been approached or surpassed (Note: The need for the 10°C buffer for Type I fluid in the condition of frost with no further precipitation was discussed at the SAE G-12 General Meeting Jun 20-24, 1996, Denver. Agreement was reached that the buffer is not required in that particular condition, and the intent is to indicate such in future editions of SAE Holdover Time Tables. This will provide some relief by allowing approved use of Type I fluid in temperature conditions down to the actual freeze point of the fluid.);

- Prevention of frost formation by hangaring aircraft is not always possible;

- Wing covers have been extensively tested but do not offer a complete solution, being difficult and, in some situations, dangerous to install and remove. In addition, frost sometimes forms underneath the wing cover;

- Removal of frost crystals through sweeping (commonly referred to as the "sweep to shine" method) results in a surface that is considerably smoother than the undisturbed frost, but does leave behind a thin film adhering to the wing.

In the 1994/95 winter season, recognizing that a practical and economical solution would benefit a great number of operators, Transport Canada requested APS Aviation to evaluate the suitability of hot blown air as a frost removal agent. Study objectives included examining the use of existing ground heaters modified as necessary to deliver hot air to the wing, to avoid costs of new equipment should this approach prove acceptable. The results of that study were published in Transport Canada Report TP 12655E, "Forced Air Deicing Trials for the 1994/95 Winter".

Study results indicated that using existing ground heaters as a source of hot air, and fitting them with well designed nozzles to deliver the hot air to the wing surface, could be a feasible and economical solution. Operational concerns identified during trials using modified equipment included the slow rate at which frost was removed, the large size and awkward physical handling characteristics of the test air nozzle, and the need to operate from the top of the wing.

The study recommended further activities:

(a) Research to evaluate the acceptability of removing frost by sweeping;

(b) Research to evaluate the acceptability of defrosting only the forward part of the wing; and

(c) Depending on the results of the foregoing, development of a properly engineered nozzle to facilitate defrosting with heated air.

The objective of the present study was to support the recommended research by providing photographic records and statistical data on the dimensional characteristics of natural frost formations typical of occurrence on aircraft wings at very cold temperatures. Undisturbed frost deposits and the residue remaining after removal of frost by sweeping were investigated.

2. METHODOLOGY

2.1 Test Sites

This activity was conducted at Thompson, Manitoba (where the 1994/95 hot air frost removal trials had been conducted).

2.2 Personnel and Participation

A local professional photographer, Mr. Harv Sawatzky, was commissioned. Arrangements were made to allow him to gain access to aircraft during frost conditions of interest, and to develop an experimental test bed of aluminum plates to supplement aircraft photography. APS provided guidelines on the required types of images and climatic conditions.

A series of photographs of naturally occurring frost formations were produced. The substrates included a bed of test plates and wings of operational aircraft.

Local firms Calm Air International Ltd. and Skyward Aviation Ltd. actively participated and cooperated: Calm Air provided samples of aircraft materials to serve as test surfaces on the test bed, and provided local advice; Skyward Aviation made their aircraft available for early morning photographic sessions following nights when frost occurred at very cold temperatures.

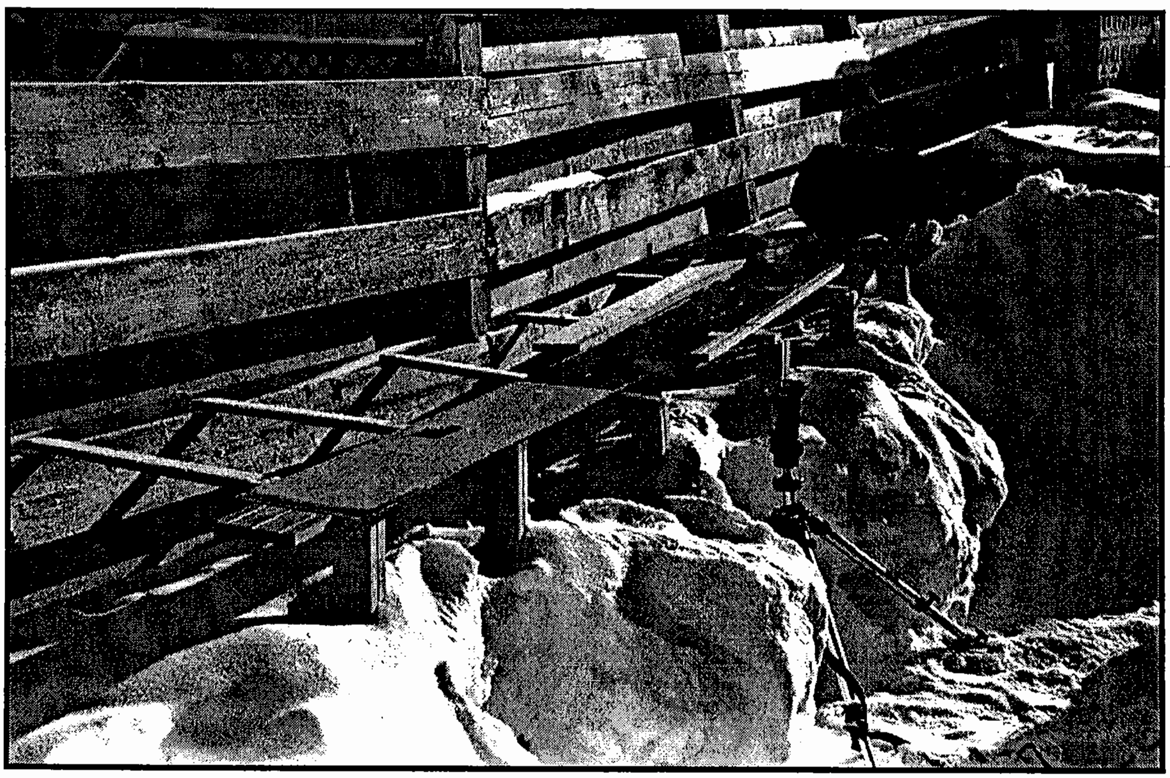
2.3 Equipment

The photographer provided all photographic equipment necessary and constructed an outdoor test bed (Photo 1) to provide suitable surfaces for natural frost growth and related photography.

Photo 1

Photographic Set-up Showing Sheets of

Aircraft Material for Frost Growth



The test bed consisted of sheets of aircraft wing surface materials provided locally by Calm Air. These included:

- A bare aluminum surface;
- A painted aluminum surface with dark blue and white sections; and
- A propeller spinner cone fabricated of metal thicker than that of the other samples.

Test surfaces were sequentially cleaned of all residues and grease with paint thinner, soapy water and a damp cloth.

Access to operating aircraft which had overnighted at Thompson Airport was arranged.

A metal ruler with metric gradations down to 0.5 mm was used for perspective in the photos.

A stiff straw broom typical of the type of broom used by operators to remove snow from aircraft wings was used to sweep frost from test surfaces to represent the "sweep to shine" procedure.

2.4 Methodology

The photographer tracked local weather with the airport weather office and initiated photo sessions accordingly. Photographic sessions took place in the early morning, and photographic records included temperature at the time of each session, as well as documentation from the Thompson Weather Office providing environmental conditions on an hourly basis for the preceding night.

Five separate photo sessions took place at temperatures of -28° to -36°C.

The resulting photographs, taken at both overhead and profile angles, depict frost deposits in close-up images. In each image, a scale with fine gradations was included to provide a perspective of the size, shape and distribution of individual frost formations. Detailed documentation associated with each photograph was maintained. It includes a description of the test conditions and the subject test surface as well as any observations made by the photographer.

Following photography of undisturbed frost, the frost was swept with a broom and the surface was again photographed to record remaining frost residue.

3. DESCRIPTION OF DOCUMENTATION AND ANALYSIS METHODOLOGY

3.1 Frost Photography Sessions

Photographic sessions were conducted as follows:

		Session Temp.(°C)	Dew Point (°C)
February 27, 1996	06:30 - 08:00 hrs	-28	-34
March 02, 1996	06:30 - 09:30 hrs	-30	-35
March 03, 1996	08:00 - 09:00 hrs	-30	-34
March 04, 1996	07:00 - 08:30 hrs	-36	-42
March 05, 1996	07:00 - 08:30 hrs	-36	-41

One hundred and sixty-eight photos of frost in various states were produced. Two perspectives of frost in close-up were captured. Edge shots of frost on test bed surfaces showed frost profiles, illustrating height of frost formations, as well as providing examples of frontal cross-sectional shape. Overhead shots of frost on test bed and aircraft surfaces illustrated the degree of frost coverage of the surface, as well as the size and shape of individual frost formations.

Surfaces were photographed with frost in its natural state, and again after removal of as much frost as possible by sweeping.

The great variation in dimensions of frost formations in any photo, as well as the irregular shapes of formations, led to the development of a statistical approach to description of the frost characteristics in selected photos of interest.

3.2 Frost in Profile

The height of frost deposits on the surface was the attribute of interest and an attempt was made to provide statistical measures of height. The approach used was to overlay a grid on transparent film over the photo of interest, lining up a grid line with the substrate surface. Height of frost in each grid column including those columns where no frost was present was noted by counting the number of grid squares covered by frost (Figure 3.1). The resultant values for all grid columns were treated statistically to determine the mean height and the range of values. Confidence intervals were calculated to 95% confidence levels. Grid size was scaled against the ruler gradations (mm) included in each photo.

It should be noted that the plate edge view of frost in profile included formations of frost set back slightly from the edge, in addition to frost formations at the very edge of the plate. The skyline that resulted from this is not a true representation of frost profile along a straight line on the surface, but does allow an analysis of representative heights of frost formations.

3.3 Frost Distribution in Plan Form

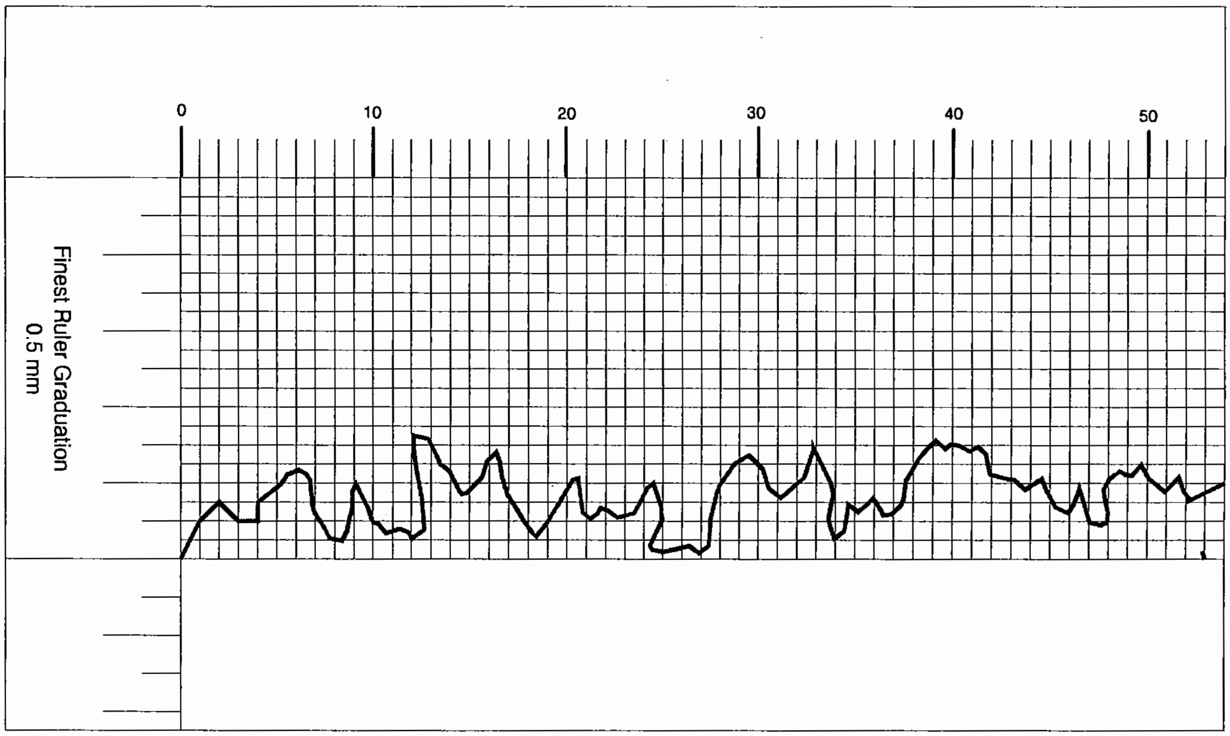
The size (area) of individual frost formations and the percentage of test surface area covered with frost deposits versus the percentage uncovered were taken as the parameters of interest.

The measurement procedure first required the photos to be blown up to page size. A sampling approach utilizing a transparency of an indexed grid overlaid on the photo was then followed (see Figure 3.2). In this approach, the transparent grid was overlaid on the photo, and grid squares were then sampled at random using a table of random numbers.

To determine the size of frost formations, each grid square that was selected at random was examined to determine whether it contained frost. If frost was present, then that specific individual frost formation was examined in total, and its total area estimated in terms of total of grid squares covered. The resultant values were then analyzed to provide a statistical

FIGURE 3.1

MEASUREMENT OF FROST HEIGHT



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Examine each grid column and record the height of frost using grid lines as dimensions.

Example: Frost heights in each grid columns from left to right

1.0
2.5
2.5
2.0
3.5
etc.

Values are converted to mm by scaling the grid against the ruler gradations shown in each photo, and then processed to calculate a statistical estimate of the mean height of frost, with confidence interval.

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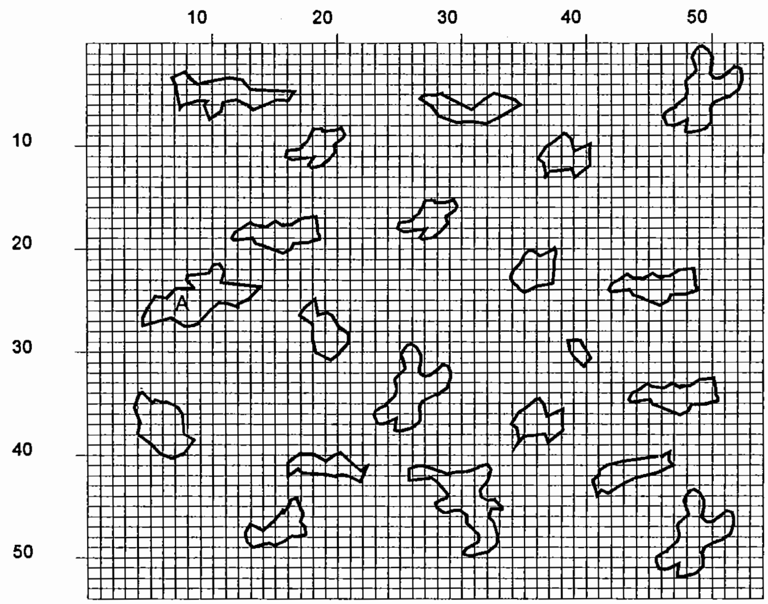
Figure 3.2

Measurement of Size of Frost Formations and Calculation of

Percentage of Surface Area Covered by Frost



A. Measurement of Size of Frost Formations

Formations are selected at random using a table of random numbers. Example: random number 0925 (column 09, row 25) hits formation "A" shown in the example. The number of grid squares (say 22) covered by formation "A" are counted and recorded. This process is repeated for further random samples. All sample values are converted to mm^2 by scaling the grid against the ruler gradations shown in each photo, and results are then processed to calculate a statistical estimate of the mean size, with confidence interval, of frost formations in that photo.

B. Calculation of Percentage of Surface Area Covered by Frost

Grid squares are selected at random using a table of random numbers. Each selected grid square is examined to estimate the percentage of its area that is covered by frost. Example:

Random Number Selected	*Area Covered %*
0915	0
0824	100
0926	50
1826	100
3634	25
etc.	etc.

The sample estimated percentages are then processed to calculate a statistical estimate of the true percentage covered, with confidence interval.

estimate of size and variance of frost formations.

To measure surface area covered by frost, a similar approach was used. Randomly selected grid squares were examined for presence of frost, and values representing the percentage of frost present in the selected grid square were assigned. Again, the resultant values were analyzed to provide a statistical estimate of percentage of surface area covered by frost.

The detail in some photos did not allow this approach to be followed, and in those cases, an estimate of dimensions and surface coverage was developed by visually selecting and measuring frost formations that appeared to be representative of the entire test surface.

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4. ANALYSIS, OBSERVATION AND DISCUSSION

This section discusses particular sets of photos which have been selected to illustrate points of interest. These photos are included at the end of this section. It includes the results of statistical analysis of frost in selected photos, along with some discussion on frost characteristics portrayed in the photo, including any associated observations recorded by the photographer during the actual sessions.

4.1 Frost on Dark Blue Painted Surface, March 2, 1996 (Photos 2, 3, and 4)

This set portrays both the edge view and plan view of frost deposits. Surface coverage in Photo 3 was estimated to be 36%. Photo 4 includes a large area with no frost deposit, which reduced surface coverage to 16% for the total area displayed. Small points of frost can be seen in otherwise bare areas between the larger frost formations.

Estimates of frost formation dimensions (reported in each photo) are mean height 0.8 mm; mean size 2.5 mm^2. Size varied from 0.1 to 8.7 mm^2.

4.2 Dark Blue Painted Surface Following Sweeping, March 2, 1996 (Photos 5 and 6)

These photos illustrate the result of removal of frost by sweeping. The residue as seen on the edge view is too small to measure. Similarly on the plan view, the residue is seen as a thin film on the surface. Loose particles can be seen in both views.

4.3 Frost on White Painted Surface, March 2, 1996 (Photos 7 and 8)

Height of frost formations measured on the edge view of this plate (Photo 8) ranges from 0.6 to 1.5 mm with a mean height of 1.0 mm.

The plan view shows sharp individual formations not occurring in clusters as is seen in other photos. The shadows cast by individual frost formations make it difficult to assess surface area covered, but provide a good perspective of shape and height of frost in profile. Surface area coverage is estimated to be 50%. Frost formations range in size from 0.3 to 7.0 mm^2.

Ice on the plate is the result of melting and refreezing on the previous day.

4.4 White Painted Surface Following Sweeping, March 2, 1996 (Photo 9)

After sweeping, frost is no longer visible in the photograph. The photographer commented on the difficulty of seeing frost residue remaining on the white surface as compared to the previously described blue surface.

4.5 Frost on Aluminum Surface, March 2, 1996 (Photo 10)

Frost formation on the aluminum surface was quite different from that on the previous painted surfaces. Relatively large very irregular shaped clusters of frost occurred, composed of smaller patches and small open areas. Larger open areas between clusters show small pin points of frost. About 30% of the surface in area is covered with frost.

Size of clusters is difficult to quantify due to the difficulty in determining where one cluster stops and another begins; however, size is estimated to vary from very small particles (2 mm^2) to large patches (900 mm^2).

4.6 Aluminum Surface Following Sweeping, March 2, 1996 (Photo 11)

Following sweeping, the aluminum surface showed almost no frost remaining. The photographer commented that less effort was required to clean the aluminum surface as compared to the other painted test surfaces.

4.7 Frost on Aluminum Surface, March 3, 1996 (Photos 12 and 13)

The edge view provides an excellent illustration of frost growth and allowed measurement of height of frost crystals (mean height 0.4 mm).

The shapes of the crystals seen in the plan form are very consistent in shape and distribution. Surface coverage is about 21% and mean size of frost formations is 0.8 mm^2.

These frost deposits may be compared to those shown in Photo 10, having been deposited on the same bare aluminum surface at the same (-30°C) temperature. The frost formations have taken very different shapes and distribution in the two cases.

4.8 Frost on Dark Blue Painted Surface, March 3, 1996 (Photos 14 and 15)

This is the same day as the previous photo. A light layer of snow that fell during the night has accumulated over the frost deposits on this surface, whereas none accumulated on the aluminum surface.

The edge view is an image of frost overlaid with a fine layer of snow. Frost deposits can be seen on the underside of the plate. In the plan view the frost is hidden by the snow.

4.9 Dark Blue Painted Surface Following Sweeping, March 3, 1996 (Photos 16 and 17)

The edge view very clearly shows that little frost remains after sweeping. The frost on the underside of the plate is typical of the initial frost on the upper surface.

Fresh snowflakes have fallen on the surfaces shown in both the plan and the profile view.

4.10 Frost on Spinner Cone, March 3, 1996 (Photos 18 and 19)

The height of frost deposits shown in the edge view range from 0.4 to 0.8 mm.

The frost deposits shown in the plan view are composed of a main core with one or more tails fanning out from this core. The core sizes appear to range from 0.1 to 0.2 mm^2, and the lengths of the tails range from 1.0 to 2.0 mm. The surface area is about 40% covered. Crystals of fresh snow can be seen in the photos.

4.11 Frost on Dark Blue Painted Surface, March 4, 1996 (Photos 20, 21 and 22)

These edge views provide a good presentation of frost in profile. The height ranges from 0.5 to 2.0 mm and the mean height is estimated at 0.7 mm.

Surface coverage is about 19% and formations average 0.3 mm^2 in area, ranging from 0.1 to 0.9 mm^2.

Points of very fine frost can be seen in the open areas.

4.12 Dark Blue Painted Surface Following Sweeping, March 4, 1996 (Photos 23 and 24)

After sweeping very little frost can be identified. The small spots on the plan view are snow crystals that have fallen after sweeping.

4.13 Frost on White Painted Surface, March 4, 1996 (Photos 25 and 26)

As noted by the photographer, frost on a white surface is difficult to see. Size of frost formations range from 0.05 to 0.4 mm^2 with a mean of 0.1 mm^2. Distribution over the surface is quite consistent; surface coverage is about 15%. From the original Photo 25, height was estimated to range from 1.0 to 1.5 mm.

4.14 Frost on Aluminum Surface Before and After Sweeping, March 4, 1996 (Photos 27, 28 and 29)

Photos 27 and 28 present frost deposits in their natural state and Photo 29 illustrates the result of sweeping. The small white specks are snow crystals (as seen on the ruler). From the original of Photo 27, frost height was estimated to range from 0.2 to 0.4 mm. Surface coverage was estimated to be 15 to 20% and size ranged from 0.5 to 3.0 mm^2.

4.15 Frost on Cessna 310R Wing, March 5, 1996 (Photos 30, 31 and 32)

Photos 30 and 31 show frost on the aircraft before and after sweeping. Some frost remains on the vortex generator following sweeping, although the wing surface appears clean. It was noted that the sweeping procedure typically leaves a small frost residue around rivets, joints, and any other irregularities in the wing surface.

Photo 32 shows frost on this aircraft in detail. Coverage is estimated to be 100% with individual formations ranging in size from 0.1 to 0.5 mm^2.

Photo 2

Edge View of Frost on Dark Blue Painted Surface

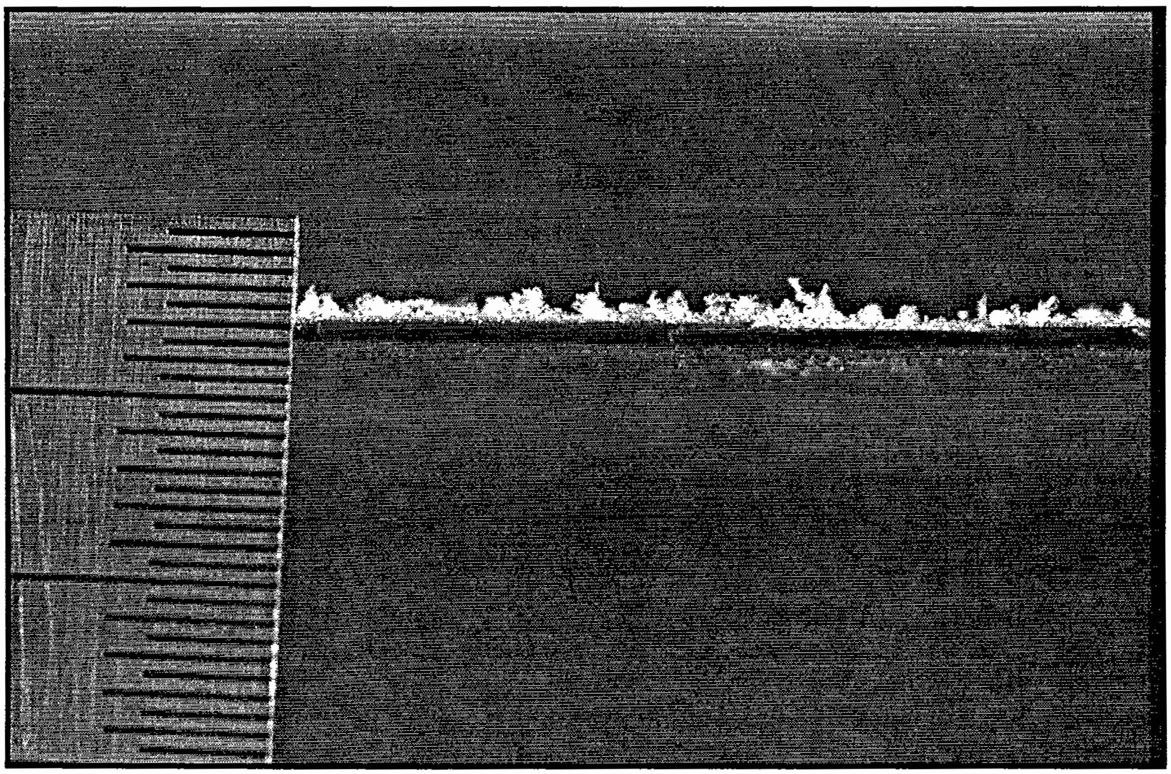


Image no 31 - Set 2 - Negative strip 8269

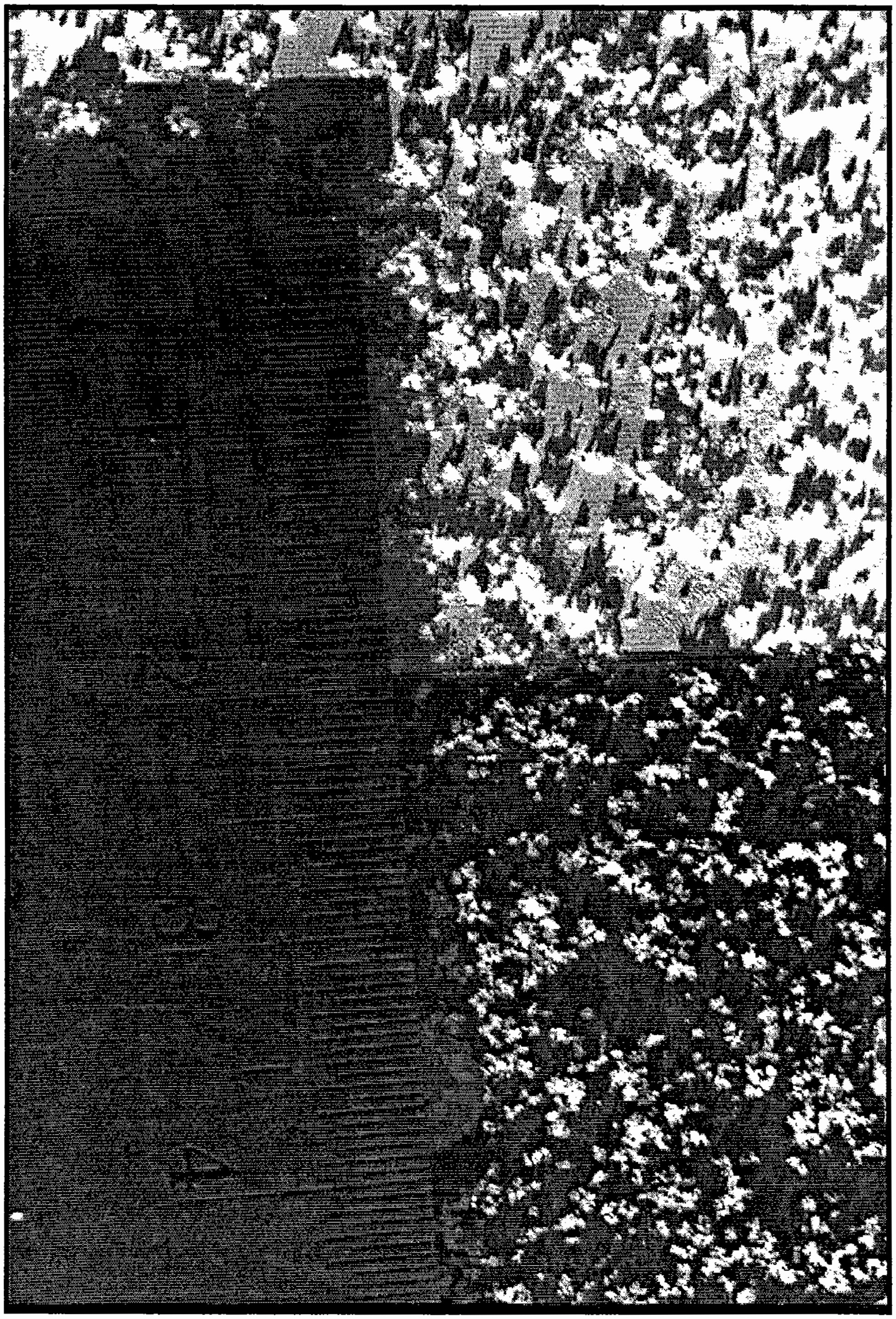
March 2, 1996 Temperature: -30°C

Time: 06:30 - 09:30

Mean Height 0.8 mm ± 0.1

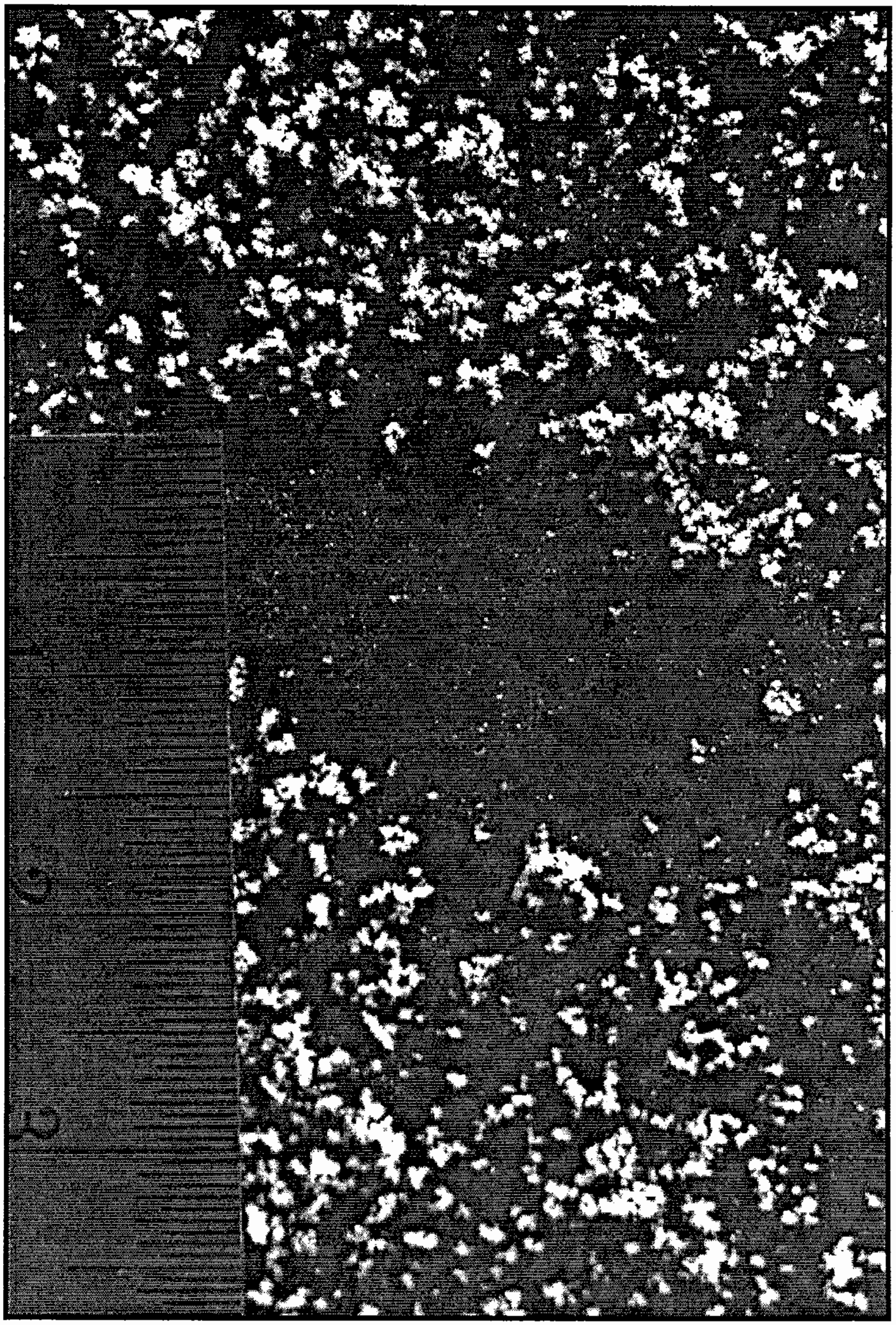
Height Range: 0.3 to 1.5 mm

Photo 3
Painted Surface: Dark Blue and White (Image no 33/Set 2 - Negative strip 8269)



March 2, 1996 Temp. -30°C Time: 06:30 - 09:30
Surface Coverage: 36% ± 12% Size Mean: 2.5mm^2 ± 1.6 Size Range: 0.1 to 8.7 mm^2

Photo 4
Dark Blue Painted Surface (Image no 32/Set 2 - Negative strip 8269)



March 2, 1996	Temp. -30°C	Time: 06:30 - 09:30
Surface Coverage: 16% ± 10%	Size Mean: 2.2 mm^2 ± 1.3	Size Range: 0.1 to 4.3 mm^2

Photo 5
Edge View - Dark Blue Painted Surface after Sweeping and Wiping
(Image no 27 - Set 3/Negative strip 8271)

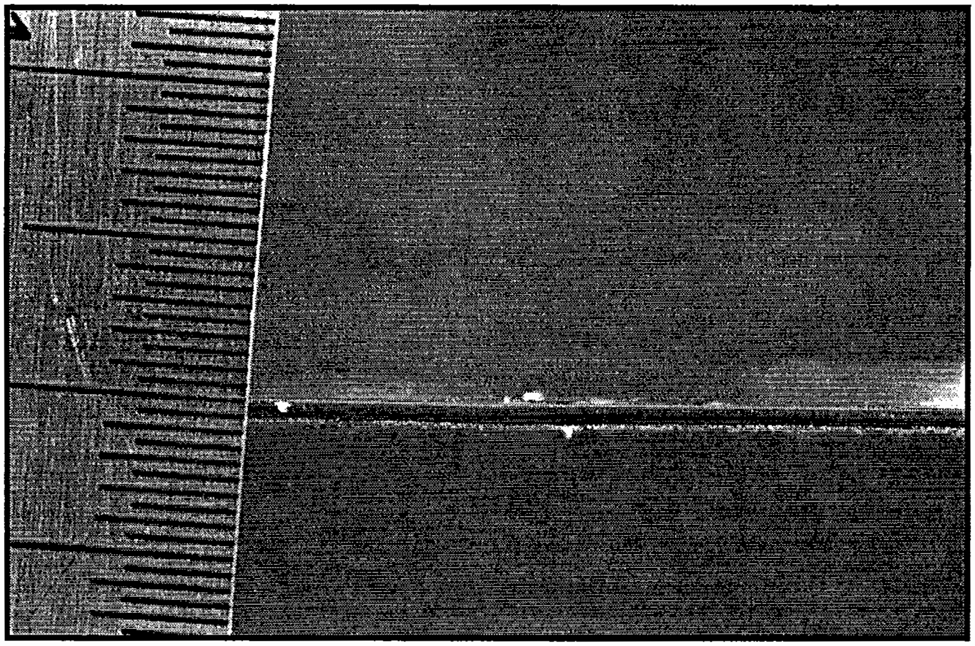
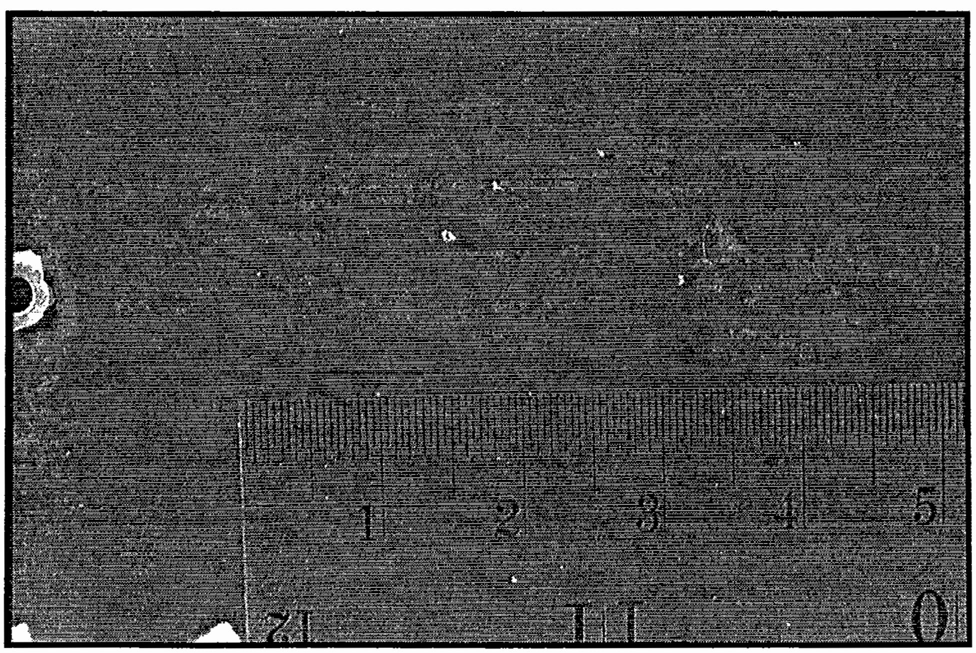
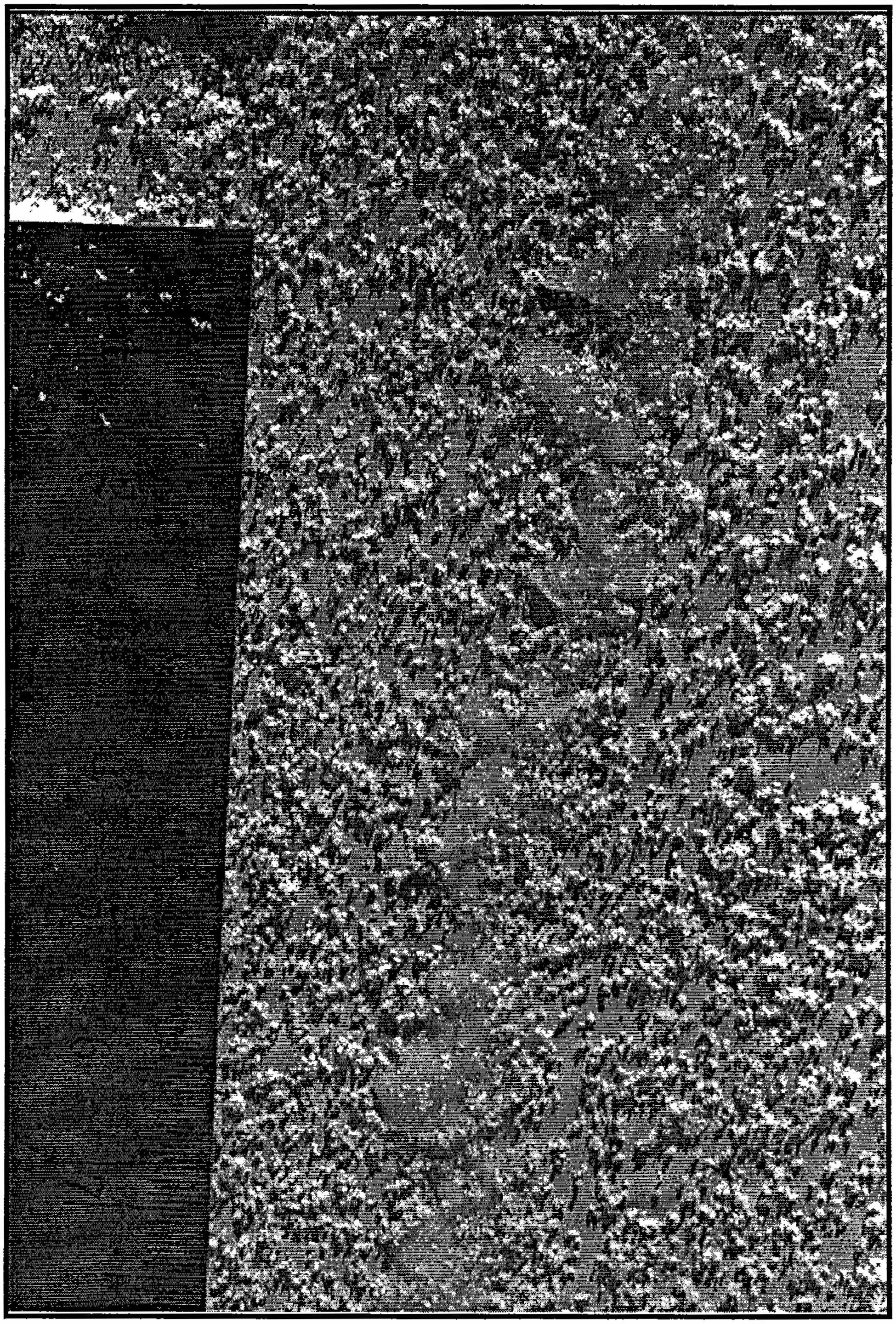


Photo 6
Plan View - Dark Blue Painted Surface after Sweeping and Wiping
(Image no 15 - Set 3/Negative strip 8271)



March 2, 1996 Temp: -30°C Time: 06:30 - 09:30

Photo 7
Frost on White Surface (Image no 4/Set 3 - Negative strip 8271)



March 2, 1996	Temp. -30°C	Time: 06:30 - 09:30
Surface Coverage: Approx. 50%	Size of Frost Formations:	Range 0.3 to 7.0mm^2

Photo 8

Edge View of Frost on White Painted Surface

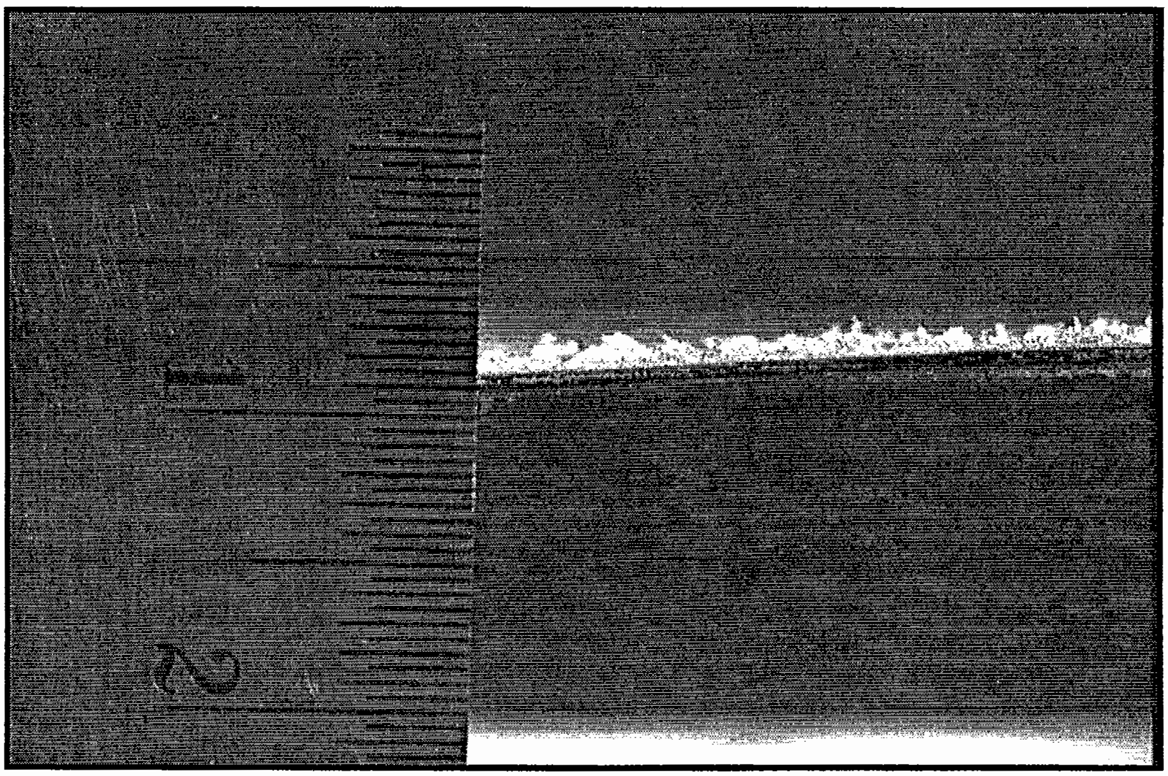


Image no 0 - Set 3 Negative strip 8271

March 2, 1996 Temperature: -30°C

Time: 06:30 - 09:30

Mean Height: 1.0 ± 0.1 mm

Height Range: 0.6 to 1.5 mm

Photo 9

White Painted Surface Following Sweeping

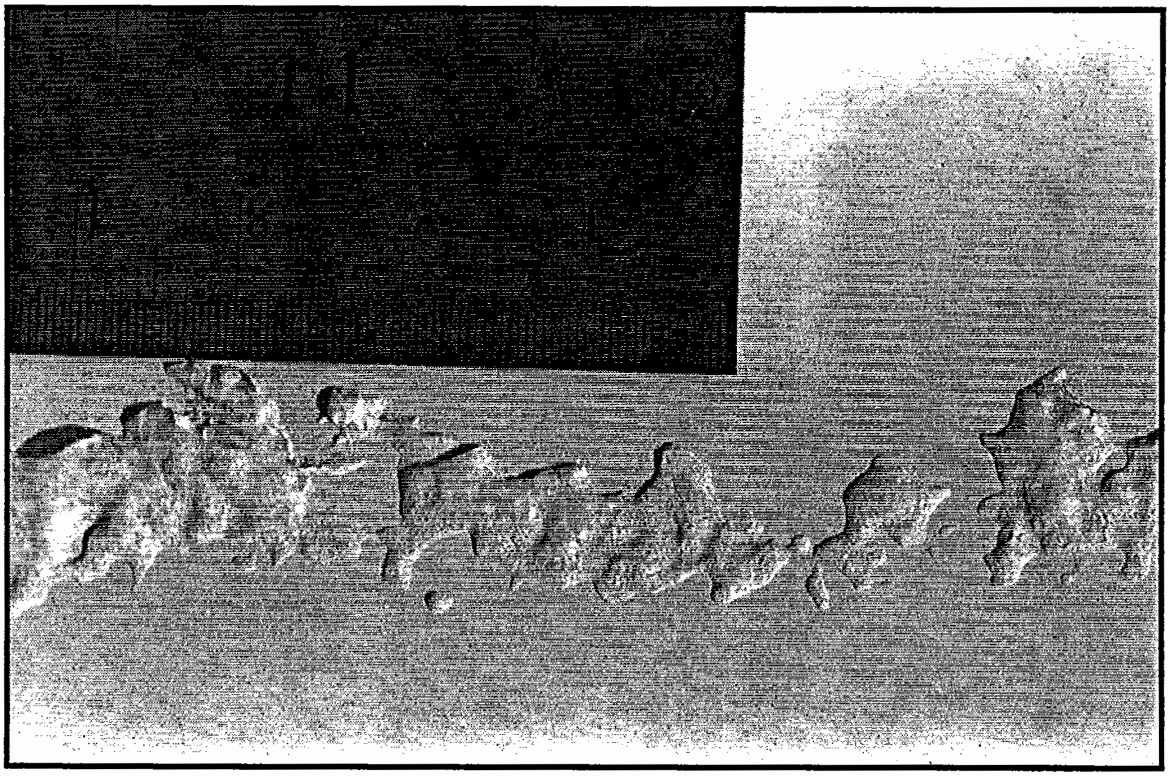
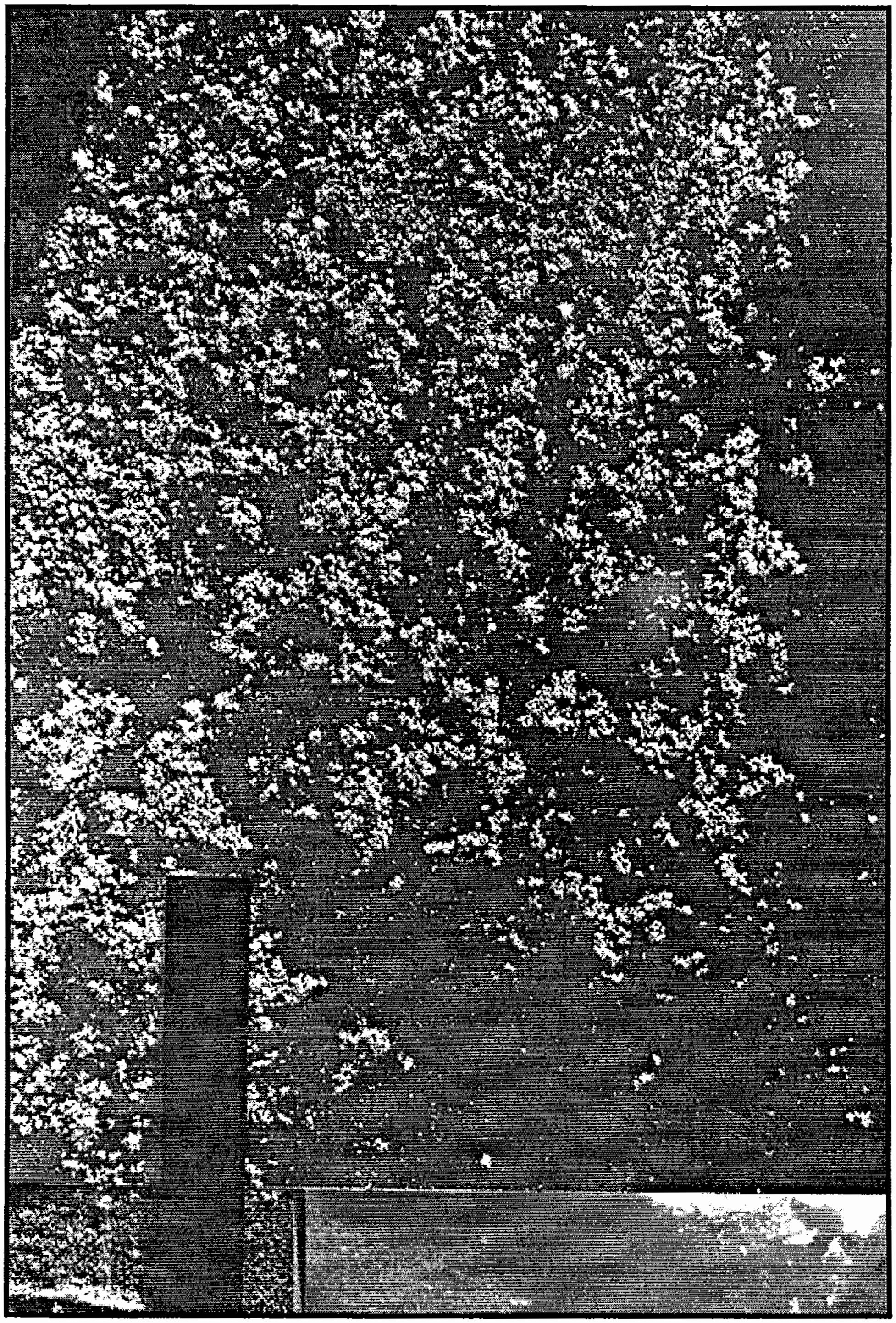


Image no 18 - Set 3	Negative strip 8271
March 2, 1996	Temperature: -30°C
Time:	06:30 - 09:30

Photo 10
Frost on Bare Aluminum Surface (Image no 6/Set 3 - Negative strip 8271)



March 2, 1996 | Temp. -30°C | Time: 06:30 - 09:30
Surface Coverage: 30% ± 12 | Size Range: 2 to 900 mm^2

Photo 11

Bare Aluminum Surface Following Sweeping

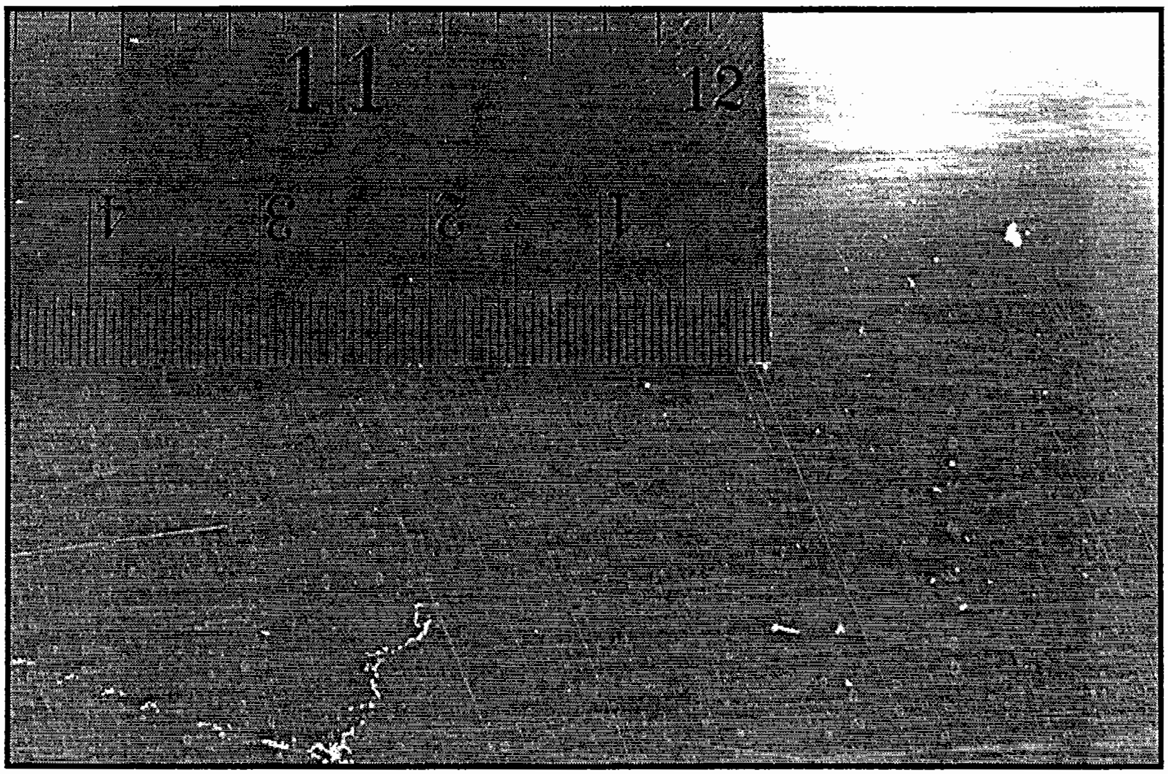


Image no 22 - Set 3	Negative strip 8271
March 2, 1996	Temperature: -30°C
Time:	06:30 - 09:30

Photo 12

Edge View of Frost on Bare Aluminum Surface

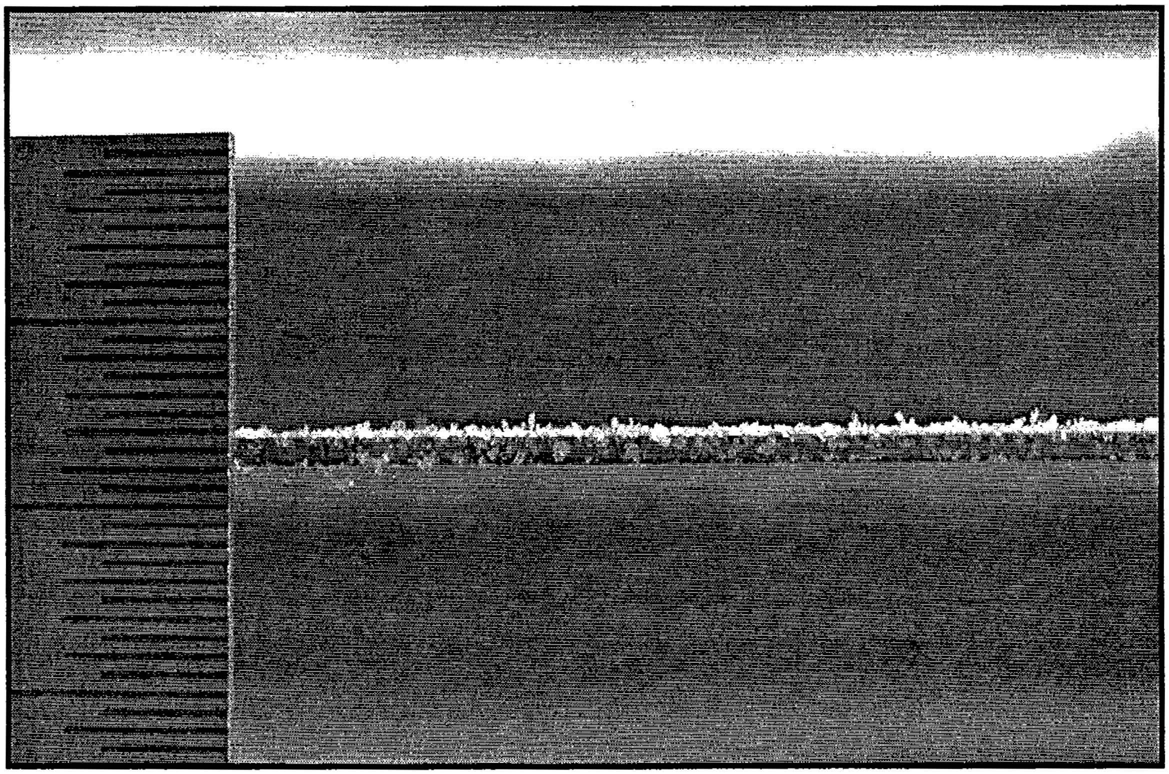


Image no 1-2 - Set 4 Negative strip 8268

March 3, 1996 Temp -30°C - Time: 08:00 - 09:00

Mean Height: 0.4 mm ± 0.1

Height Range: 0.3 to 0.8 mm

Photo 13

Frost on Bare Aluminum Surface

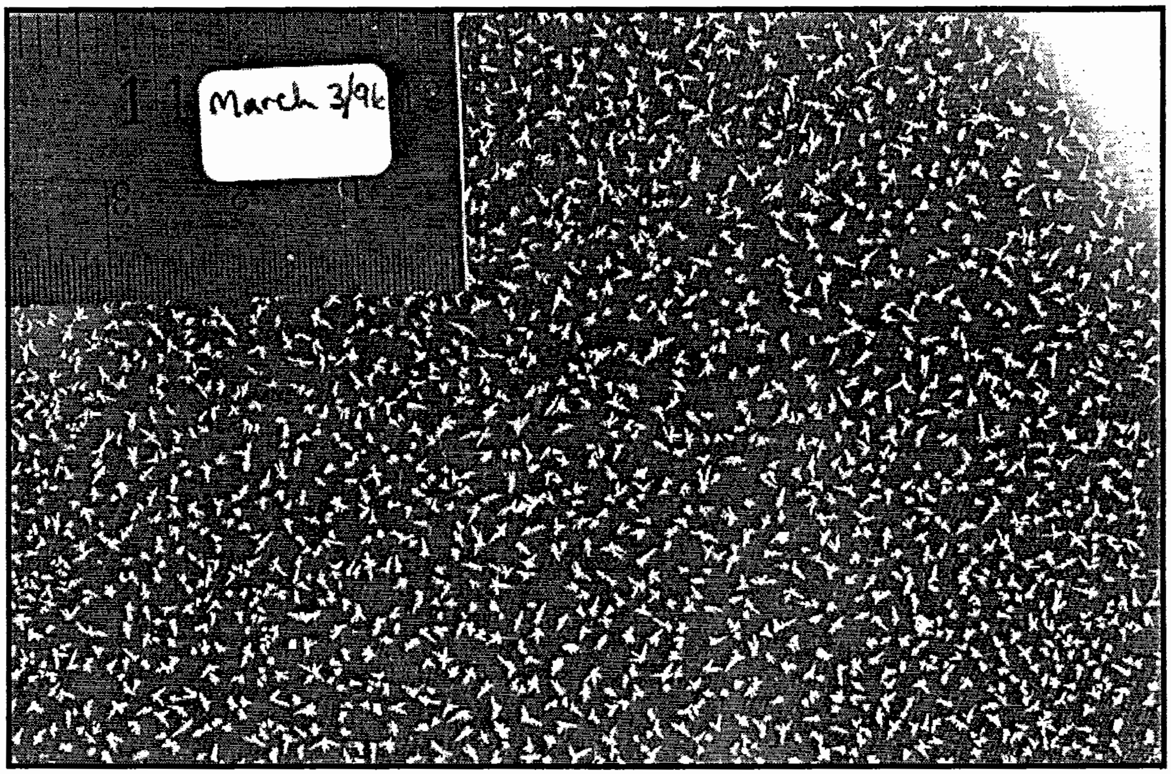


Image no 32 - Set 3	Negative strip 8271
March 3, 1996	Temperature: -30°C
Time:	08:00 - 09:00
Surface Coverage:	21% ± 8
Size of Frost Formations:	Mean 0.8 mm^2 ± 0.1
	Range 0.2 to 1.2 mm^2

Photo 14
Edge View of Frost with Snow Deposit on Dark Blue Painted Surface
(Image no 0 - Set 4/Negative strip 8268)

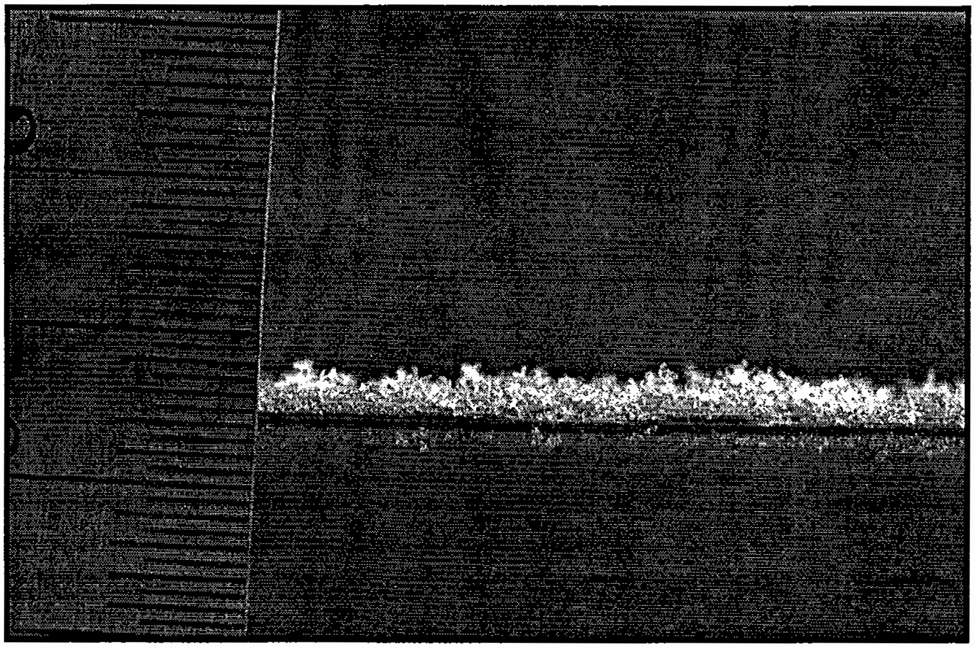
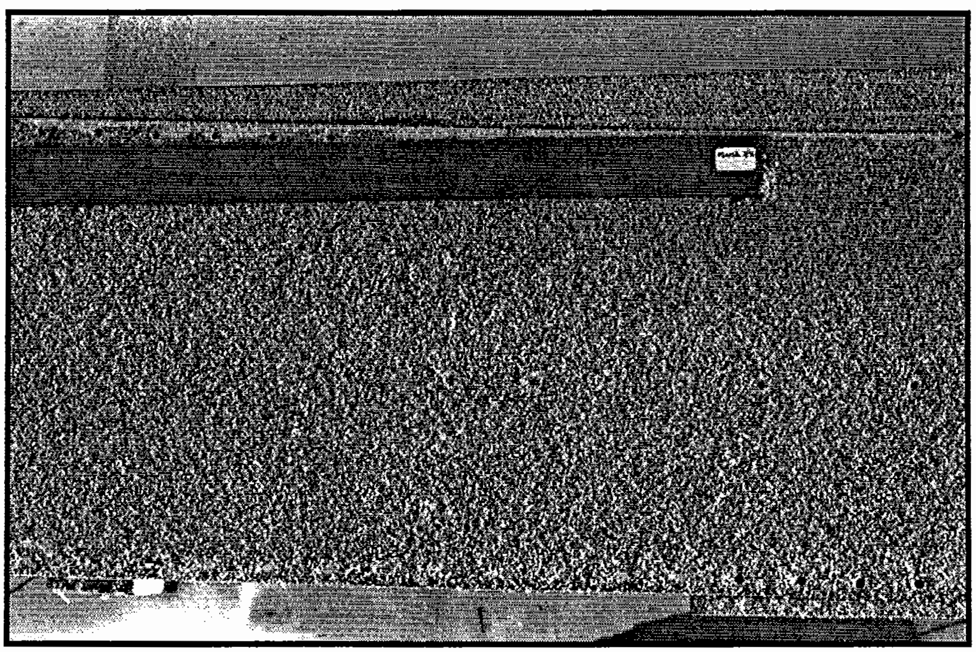


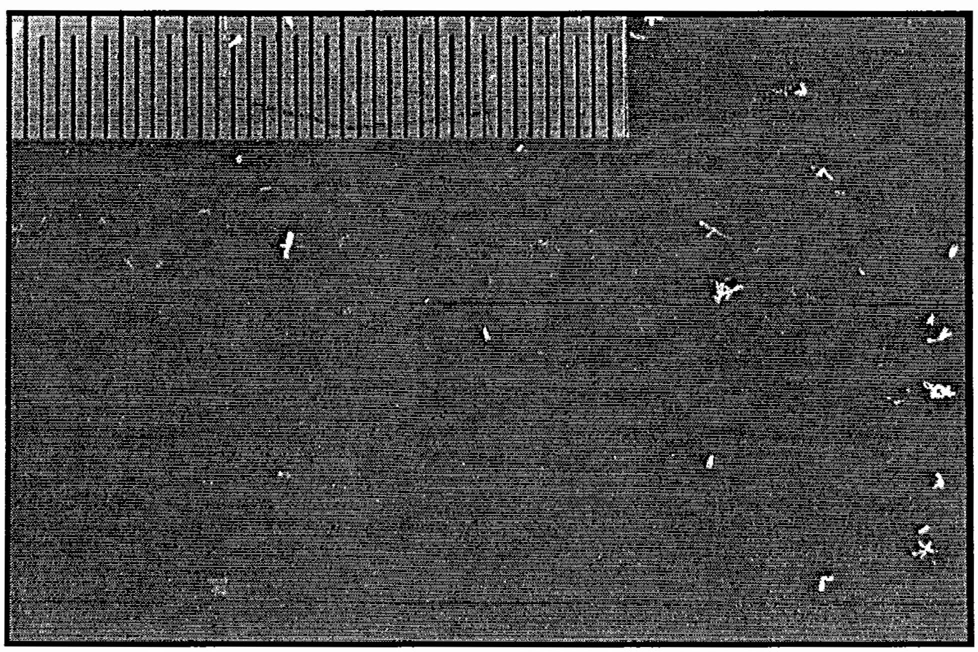
Photo 15
Dark Blue Painted Surface (Image no 30 - Set 3/Negative strip 8271)



March 3, 1996 Temperature: -30°C Time: 08:00 - 09:00

Photo 16
Edge View of Dark Blue Painted Surface after Sweeping and Wiping
(Image no 20 - Set 4/Negative strip 8268)

Photo 17
Close-up - View of the Frost Remaining on Dark Blue Painted Surface After Sweeping and Wiping (Image no 23 - Set 4/Negative strip 8268)



March 3, 1996 Temperature: -30°C Time: 08:00 - 09:00

Photo 18

Spinner Cone Edge View

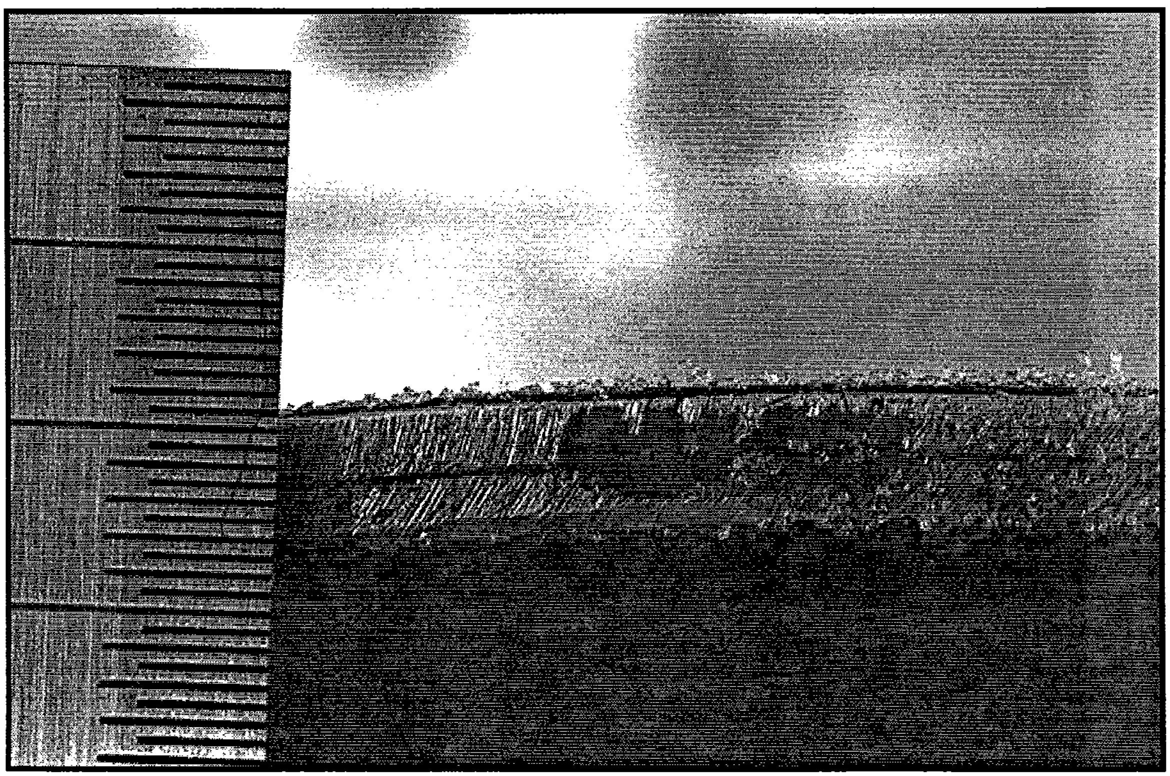
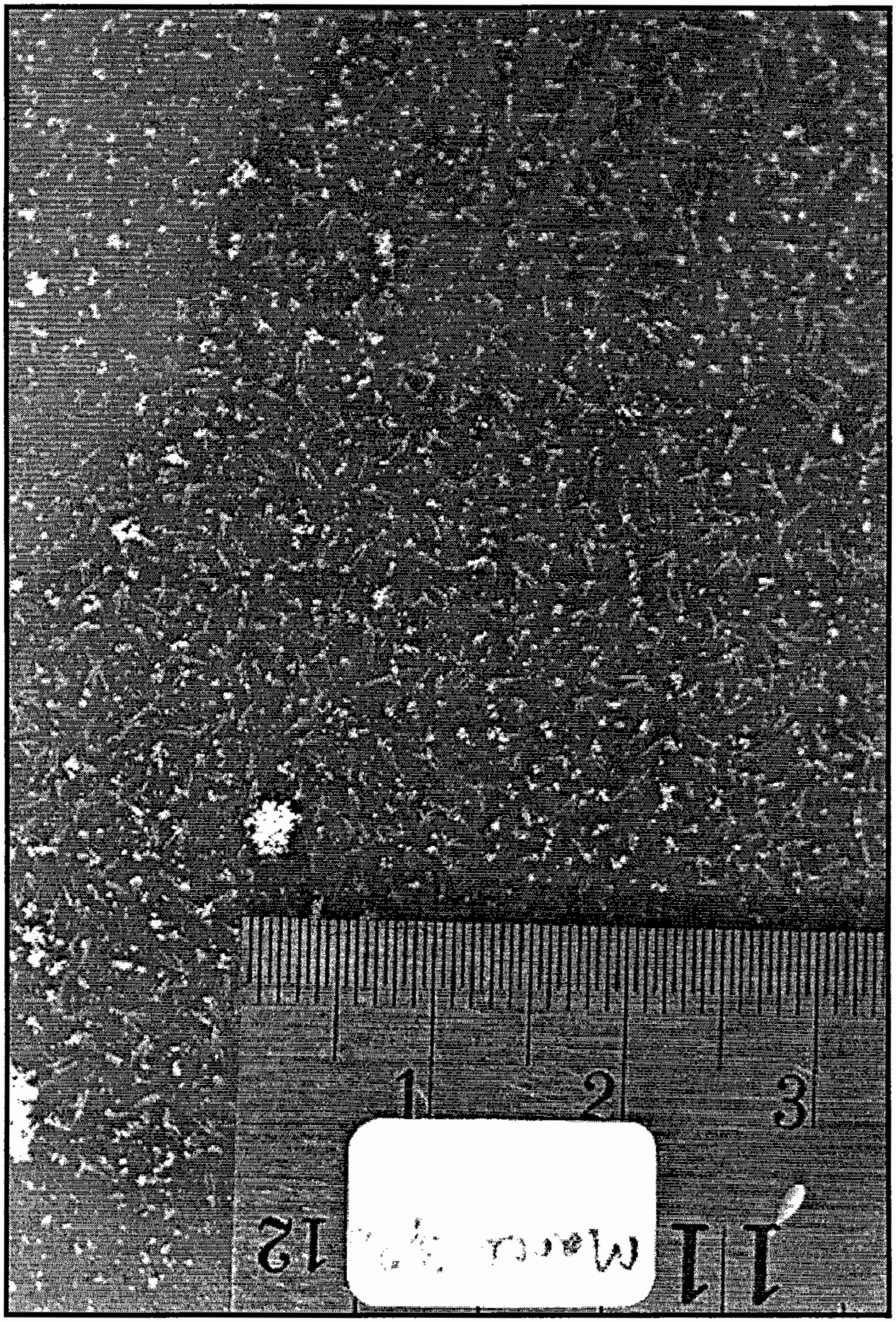


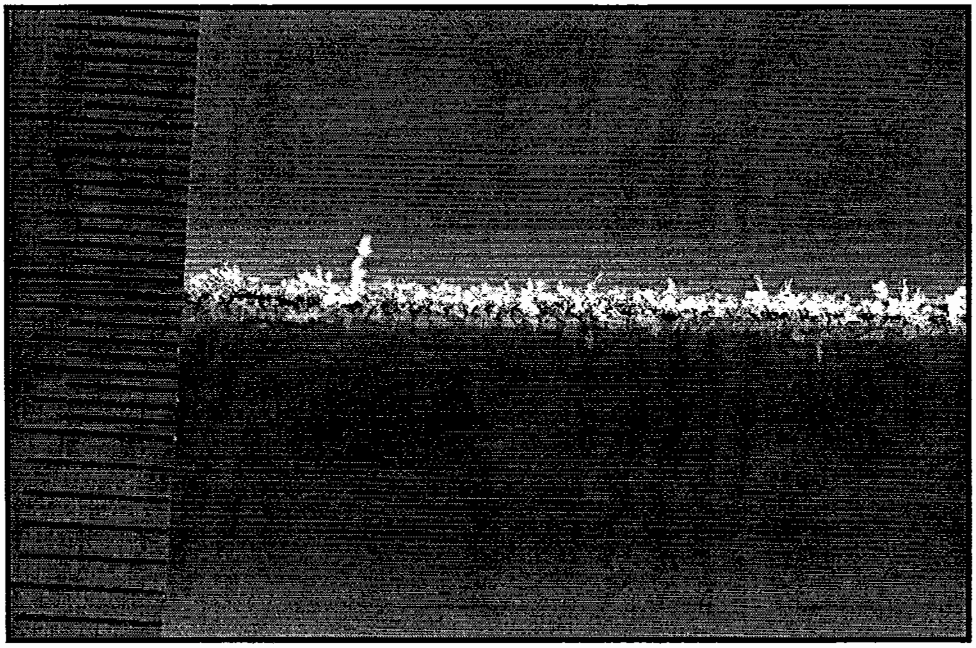
Image no 6 - Set 4	Negative strip 8268
March 3, 1996	Temperature: -30°C
Time: 08:00 - 09:00	Height range: 0.4 to 0.8 mm

Photo 19
Spinner Cone Side View (Image no 5/Set 4 - Negative strip 8268)



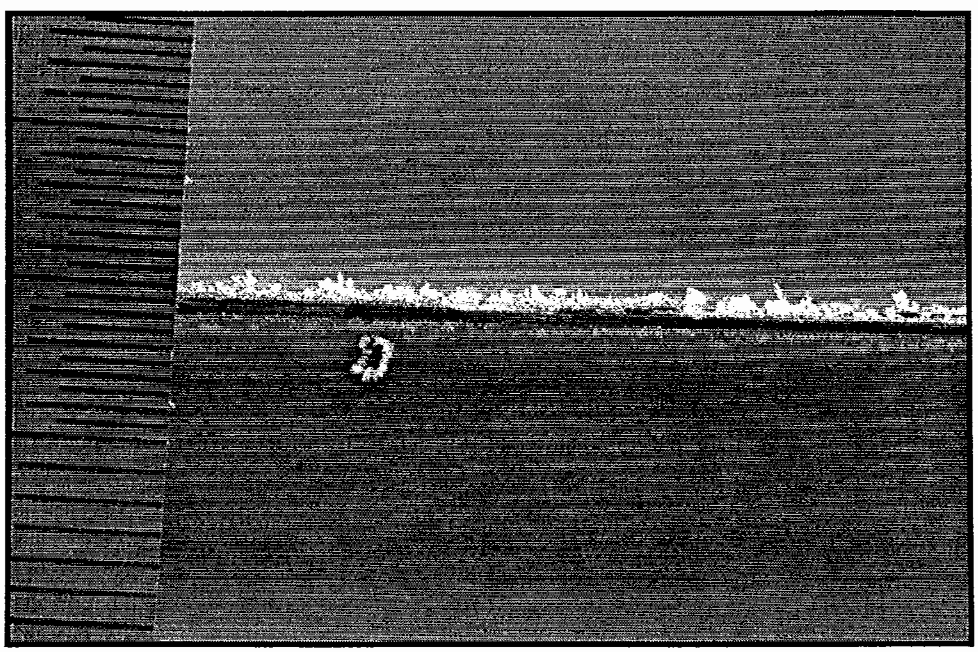
March 3, 1996	Temp. -30°C	Time: 08:00 - 09:00
Surface Coverage: Approx. 40%	Size of Frost Formations:	Core 0.1 to 0.2 mm^2
		Tail 1 to 2 mm long

Photo 20
Edge Detail on Dark Blue Painted Surface (Image no blank - Set 5/Negative strip 8270)



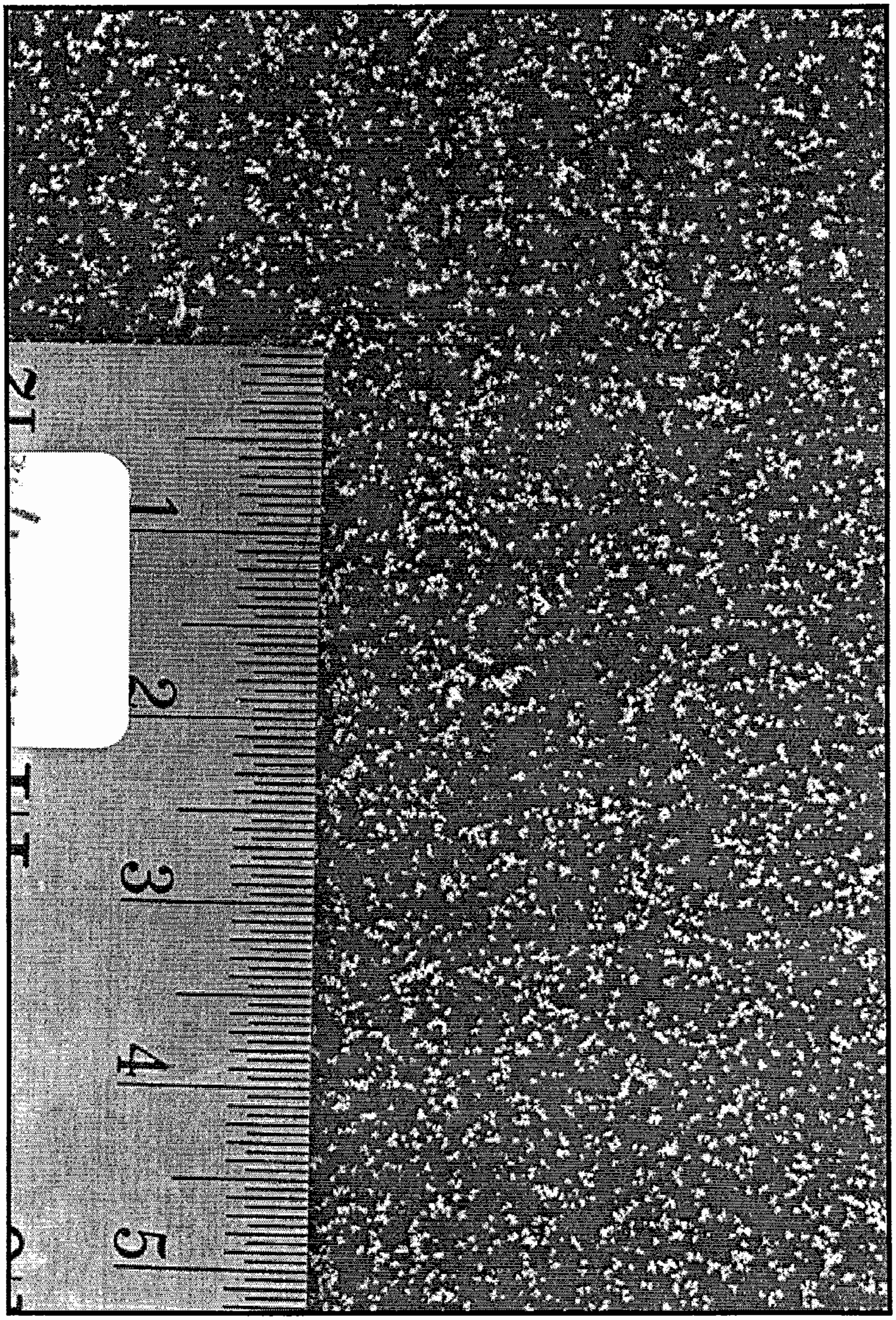
March 4, 1996 Temp: -36°C Time: 07:00 - 08:30 Mean height: 0.7 mm ± 0.2 Range: 0.5 to 2.0 mm

Photo 21
Edge Detail on Dark Blue Painted Surface with Edge Scraped Clean
(Image no 0 - Set 5 Negative Strip 8270)



March 5, 1996 Temperature: -37 to -35°C Time: 07:00 - 08:30

Photo 22
Frost on Dark Blue Painted Surface (Image no 33/Set 4 - Negative strip 8268)



March 4, 1996	Temp. -30°C	Time: 07:00 - 08:30
Surface Coverage: 19% ± 10	Size of Frost Formations:	Mean 0.3 $mm^2 \pm 0.2$
		Range 0.1 to 0.9 mm^2

Photo 23

Edge Detail on Dark Blue Painted Surface (same plate as previous photo) following Sweeping and Wiping

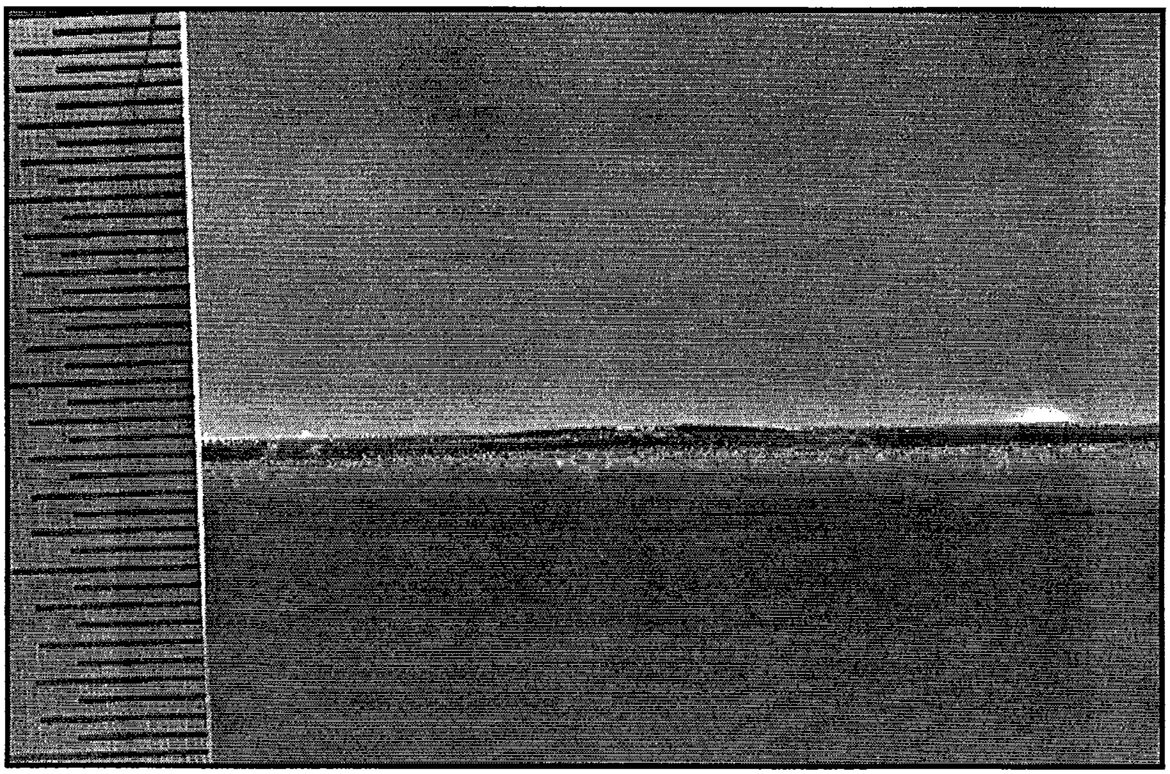


Image no 10 - Set 5	Negative Strip 8270
March 4, 1996	Temperature: -36°C
Time:	07:00 - 08:30
Average height:	0.1 mm (estimate as too small to measure in photo)

Photo 24

Frost Detail on Dark Blue Painted Surface (same plate as previous photo) following Sweeping and Wiping

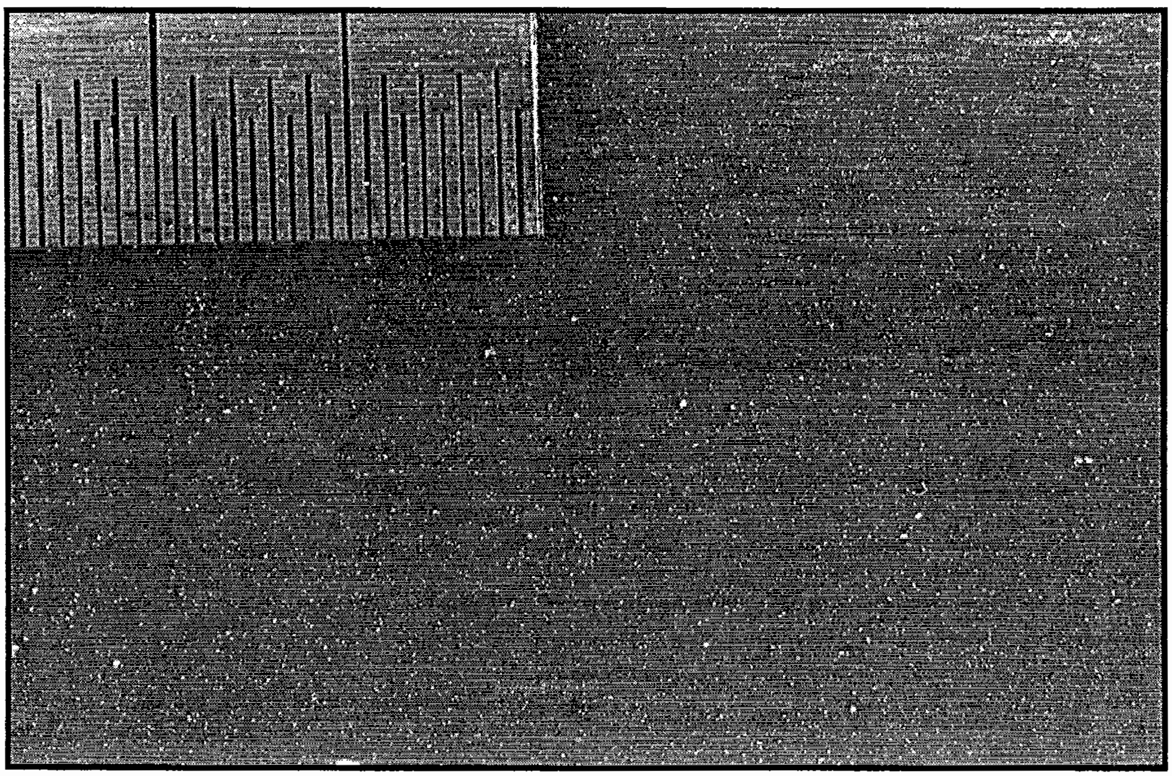


Image no 5 - Set 5	Negative strip 8270
March 4, 1996	Temperature: -36°C
Time:	07:00 - 08:30

The small spots are crystals that have formed after sweeping and wiping.

Photo 25

Frost on White Painted Surface

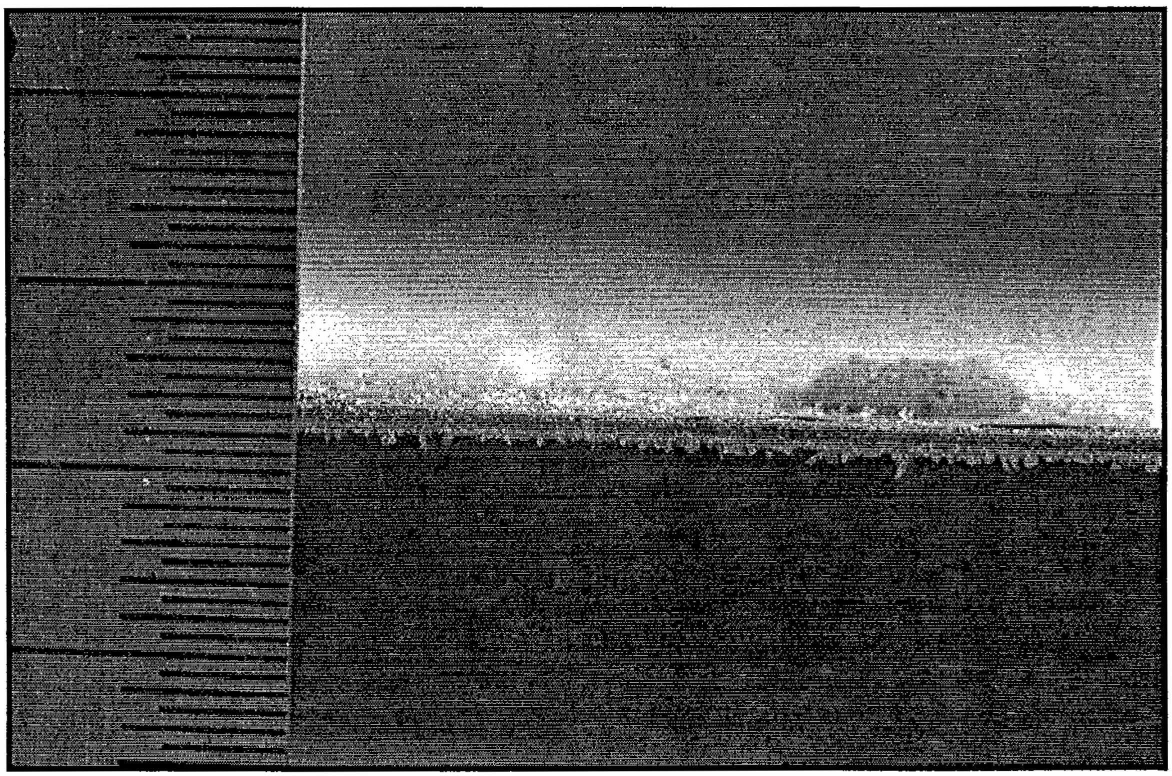
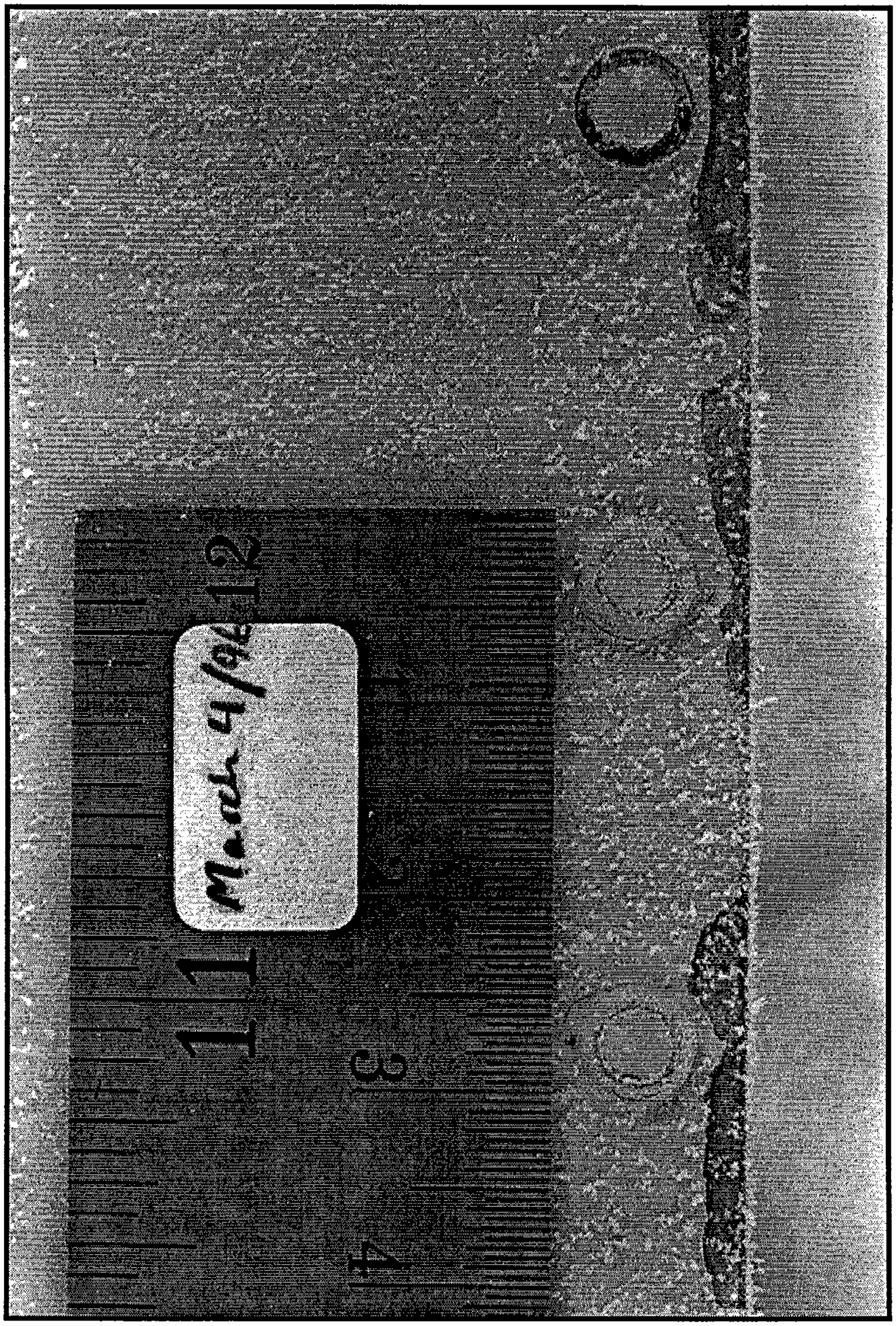


Image no 35 - Set 4	Negative strip 8268
March 4, 1996	Temperature: -36°C
Time:	07:00 - 08:30
Height Range:	1 to 1.5 mm

Photo 26
Overhead View - Frost around Rivet Holes on White Painted Surface
(Image no 32/ Set 4 - Negative strip 8268)



March 4, 1996
Surface Coverage: 15%

Temp. -30°C
Size of Frost Formations:

Time: 07:00 - 08:30
Mean 0.1 mm^2
Range 0.05 to 0.4 mm^2

Photo 27

Edge Detail - Frost on Bare Aluminum Surface

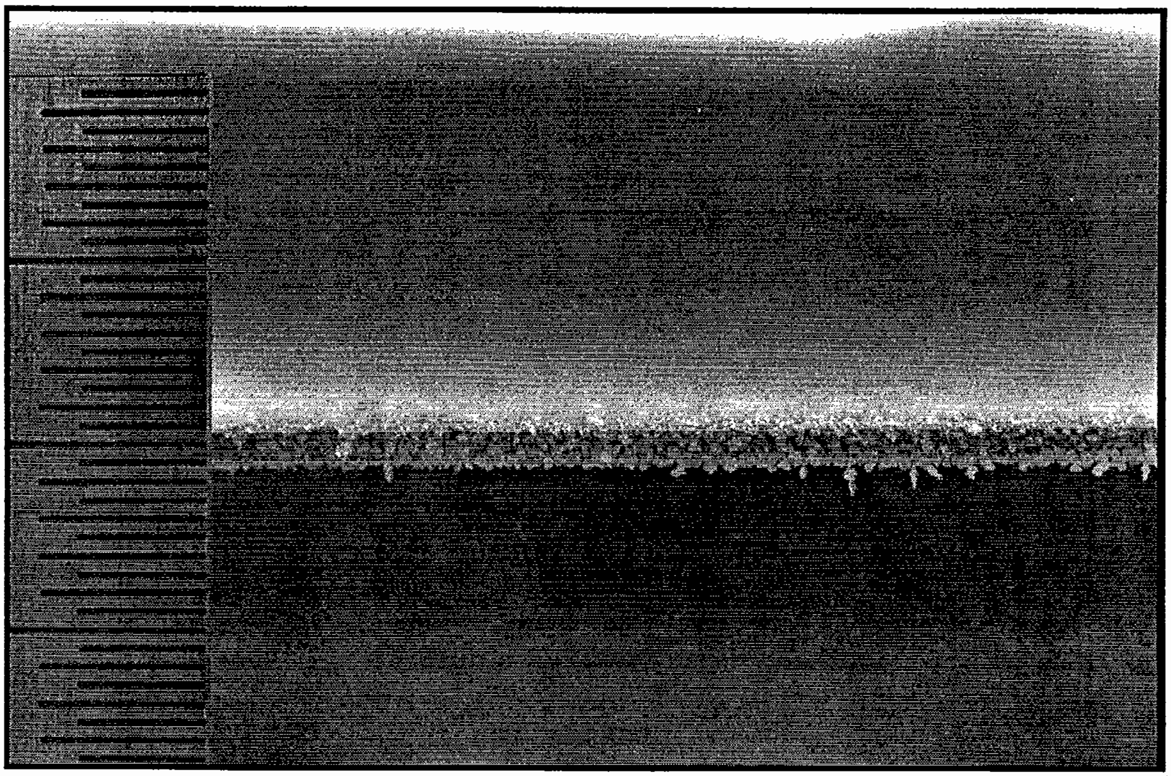
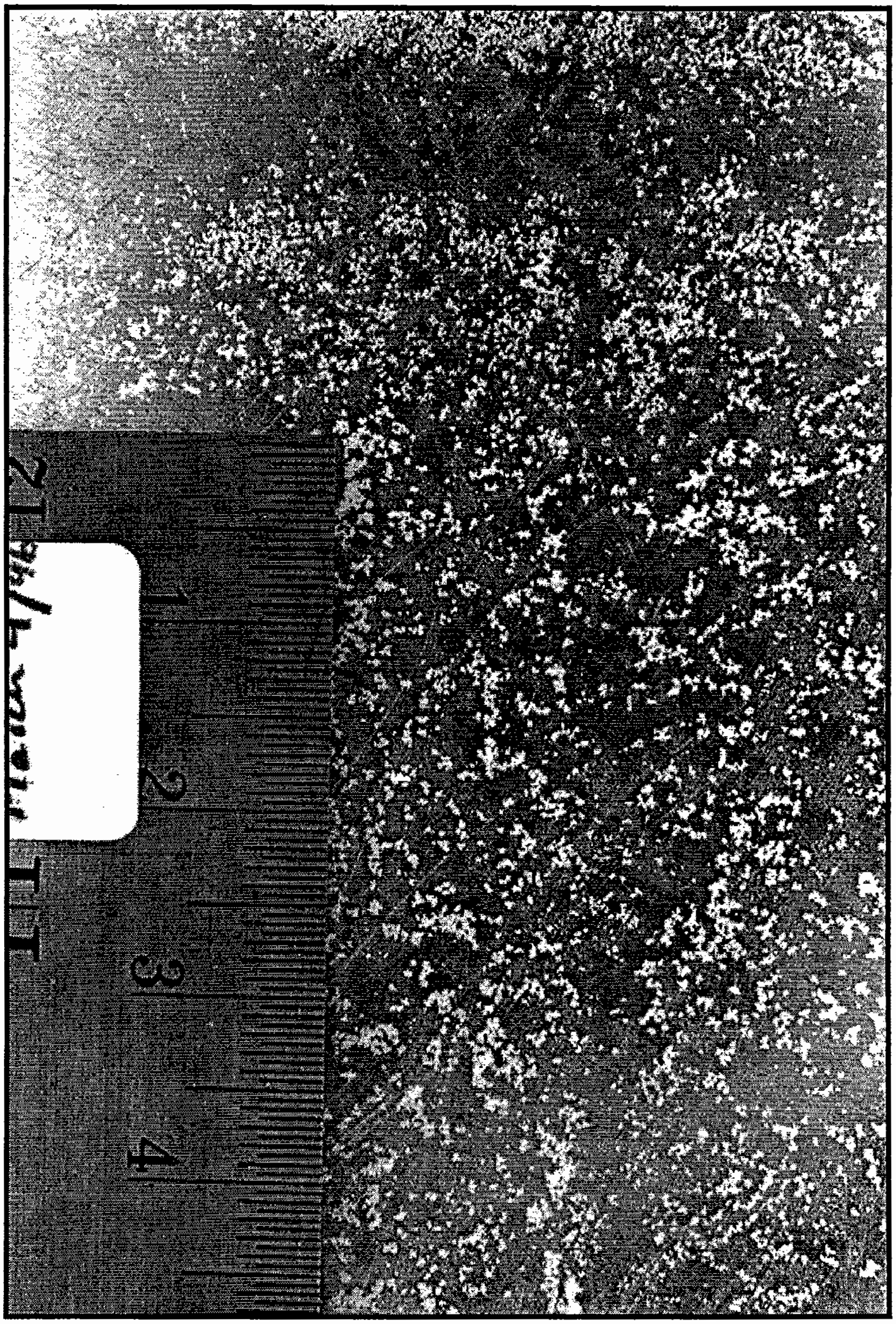


Image no 1 - Set 5	Negative strip 8270
March 4, 1996	Temperature: -36°C
Time:	07:00 - 08:30
Height Range:	0.2 to 0.4 mm

Photo 28

Frost on Aluminum Surface (Image no 34/ Set 4 - Negative strip 8268)



March 4, 1996	Temp. -30°C	Time: 07:00 - 08:30
Surface Coverage: 15 to 20%	Size of Frost Formations:	Range 0.5 to 3.0 mm^2

Photo 29

Frost on Aluminum Surface after Sweeping and Wiping

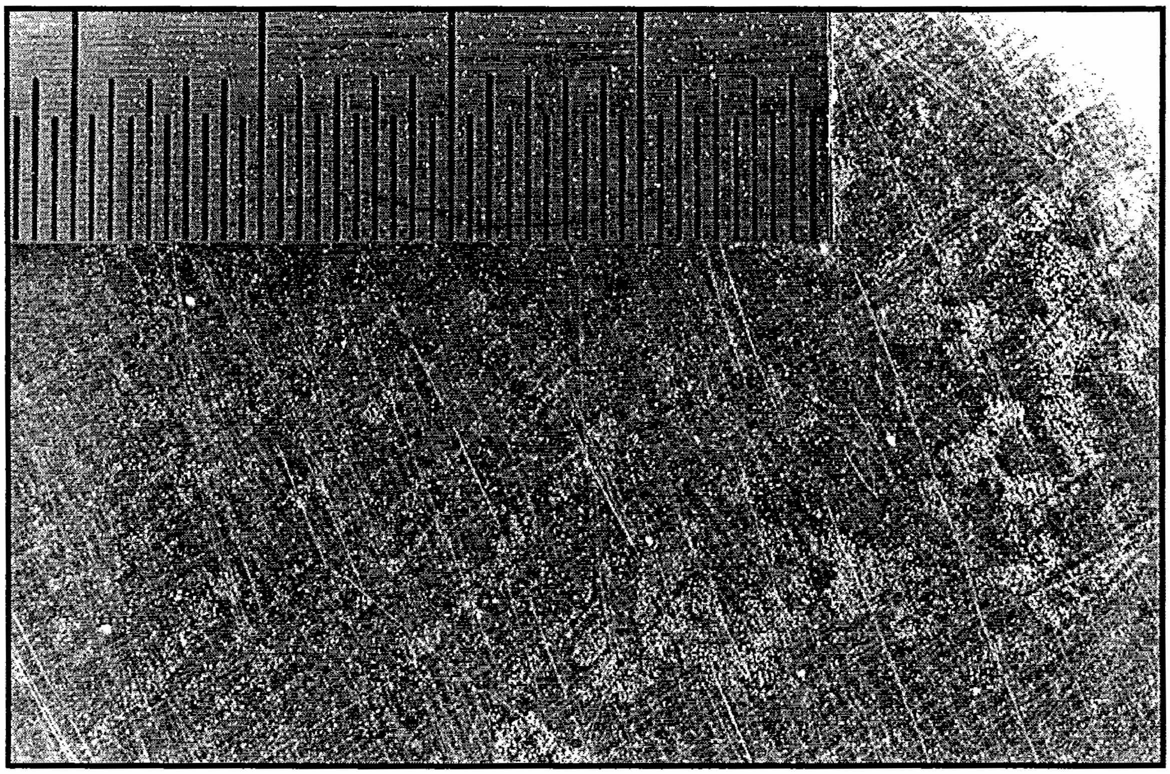


Image no 8 - Set 5	Negative strip 8270
March 4, 1996	Temperature: -36°C
Time:	07:00 - 08:30

Photo 30
Cessna 310R Frost Build-up by the Vortex Generators (Image no 28 - Set 5/Negative strip 8270)

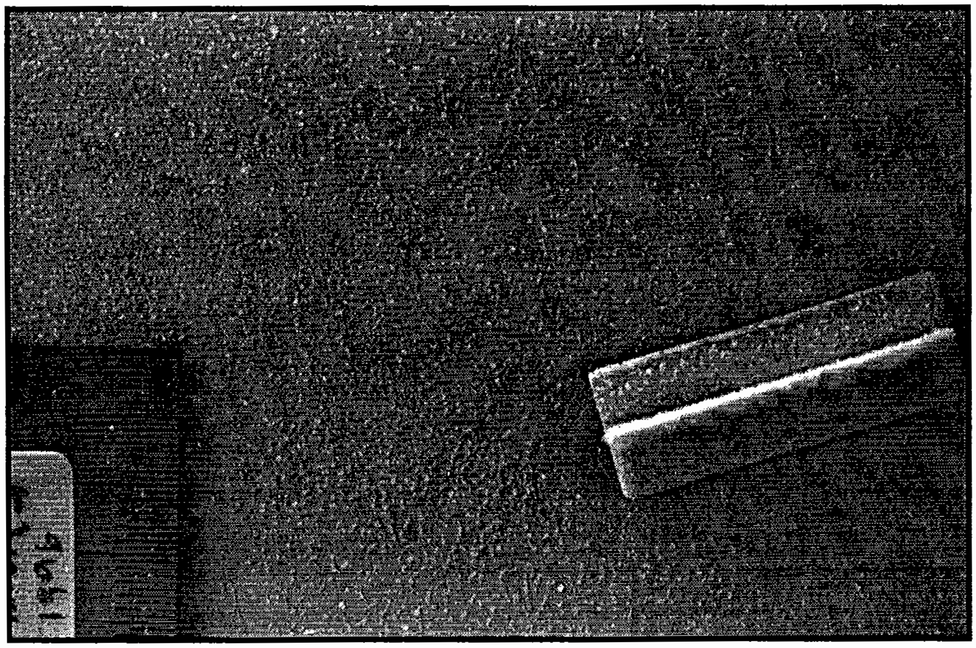
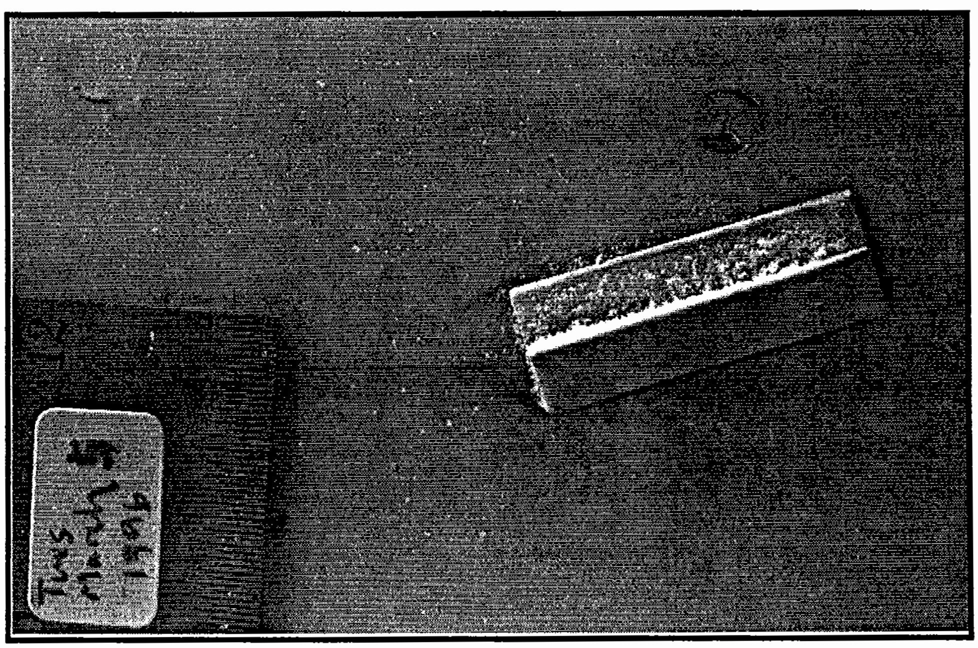


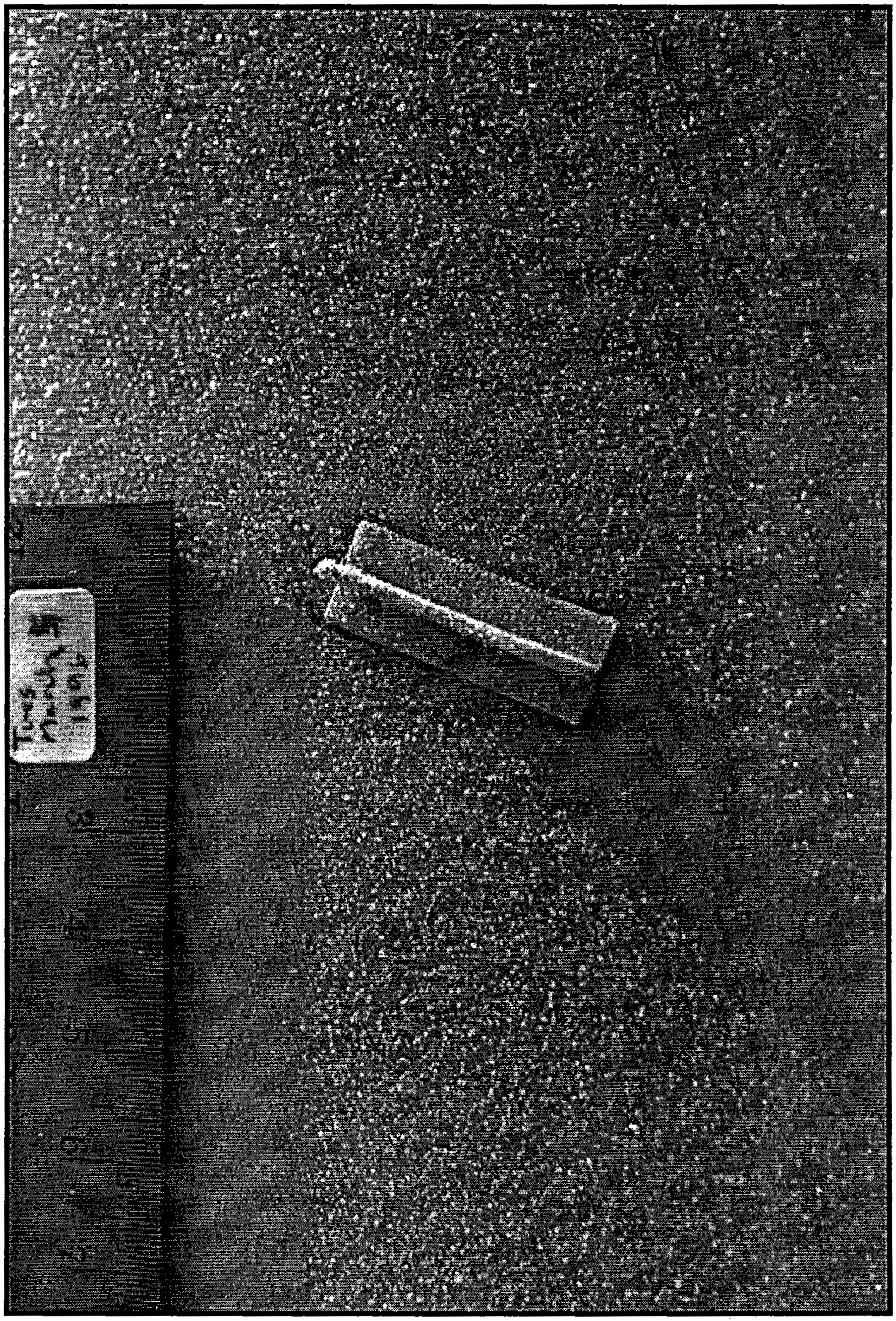
Photo 31
Same Location After Sweeping (Image no 30 - Set 5/Negative strip 8270)



March 5, 1996 Temperature: -37 to -35°C Time: 07:00 - 08:30

Photo 32

Cessna 310R Frost Build-up by the Vortex Generators (Image no 31/Set 5 - Negative strip 8270)



March 5, 1996	Temp. -37 to -35°C	Time: 07:00 - 08:30
Size Range: 0.1 to 0.5 mm^2	Surface Coverage: 100%	

5. CONCLUSIONS

A documented set of photographs of frost formations deposited in natural conditions in very cold weather has been presented. Where possible, a quantitative analysis of dimensions of frost formations and degree of surface coverage is included. A complete set of original photographs has been provided to the Transportation Development Centre.

Sweeping appears to remove nearly all frost deposited (maximum observed was 1.5 mm prior to sweeping) except for a thin layer (less than 0.1 mm) that can be seen on the darker surfaces. The aluminum surface was easiest to clean by sweeping, while the white surface offered the most difficulty in identifying residue frost. The sweeping procedure typically leaves a small frost residue around rivets, joints, and any other irregularities in the wing surface.

Photographic results indicated that the characteristics and nature of frost formations vary greatly among the surfaces used, even under the same environmental conditions. This may need to be addressed in any attempts to reproduce frost artificially for laboratory or wind tunnel testing. The differing nature of frost formations did not appear to influence the ability to remove frost by sweeping.

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6. RECOMMENDATIONS

It is recommended that the information on frost characteristics presented in this report be used:

- To assist research to evaluate the acceptability of removing frost by sweeping;
- To assist research to evaluate the acceptability of defrosting only the forward part of the wing; and
- To evaluate the suitability of current methods of simulating frost in wind tunnel experiments.

It is further recommended that a similar approach be followed to characterize frost deposits experienced at moderate and cold temperatures in Southern Canada, and at moderate temperatures at Thompson, Manitoba.

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APPENDIX

TERMS OF REFERENCE - WORK STATEMENT

TRANSPORTATION DEVELOPMENT CENTRE

WORK STATEMENT
(revised* November 96)

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

1 INTRODUCTION

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

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

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

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

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

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

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

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

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

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

2 PROGRAM OBJECTIVE (MCR 16)

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

3 PROGRAM SUB-OBJECTIVES

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

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

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

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

4 PROJECT OBJECTIVES

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

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

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

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

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

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

5. DETAILED STATEMENT OF WORK

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

5.1 Substantiation of Type I and Type II Tables

5.1A Laboratory "Cold soak" Test Program

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

5.1.1 Develop an experimental plan to conduct tests, analyze results and prepare a report to provide values given for the SAE/ISO Holdover Time Tables for Type I. Type II and Type IV fluids using cold soaked boxes to simulate cold soaked wing conditions for a range of precipitation rates above and below freezing.

5.1.2 Include tests at +2°C and -7°C and at temperatures corresponding to selected field tests and cover a range of box temperatures from 0°C to -15°C and a range of precipitation rates, simulating rain, freezing drizzle and snow. These rates should be determined in consultation with personnel from AES and NRC. APS will use their own cold box designs.

5.1.3 Present the test plan to TDC Project Office for review Comment and approval.

5.1.4 Schedule tests with NRC and give advance notice of all intended tests to the TDC project officer.

5.1.5 Conduct tests in the NRC cold chamber using flat plates as benchmark

5.1.6 Analyze results from cold boxes and compare with the flat plate results

5.1B ***Field "Cold soak" Test Program***

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

5.1C **Low Temperature Test**

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

5.2 Program of Type IV

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

5.2.1 Develop a program to test samples of the new Type IV fluids to establish holdover times over the full range of HOT table conditions.

5.2.2 Obtain samples from producers of qualified Type IV fluids

5.2.3 Establish a test site for the conduct of outside tests at Montreal, Dorval Airport

5.2.4 Arrange for support services and appropriate facilities.

5.2.5 Recruit and train local personnel .

5.2.6 Repair and replace TDC supplied equipment used for testing in previous years as necessary.

5.2.7 In consultation with TDC, devise a method to evaluate the precipitation type in order to assess the effects of wet and dry snow on visibility in precipitation.

5.2.8 Install an ETI precipitation gauge at Dorval to study its correlation with the READAC gauge and the plate pans.

5.2.9 Acquire data from the READAC station at Dorval on a minute-by-minute basis.

5.2.10 Give advance notice of all intended tests to the TDC project officer.

5.2.11 Conduct tests during periods of freezing precipitation concurrent with HOT Table substantiation tests of conventional fluids. For Type I,II and IV fluids, frequent testing should be conducted under natural precipitation conditions when temperatures are below -14°C.

5.2.12 Coordinate scheduling of the indoor tests with the NRC.

5.2.13 Install Instrumar's C/FIMS on at least one plate, if available RVSI's and SPAR remote sensor will be set up to view the stand holding six standard test plates. All sensors will be used for both the chamber tests and all the field tests where feasible. Determine fluid failure by visual observation

5.2.14 Conduct tests with simulated freezing fog, freezing drizzle and light freezing rain in the NRC CEF facility, Ottawa, supplying the necessary materials and equipment for tests.

5.2.15 Conduct ancillary tests at Dorval and the NRC Chamber to study the effect of HOT's of successive application of new and conventional Type II fluids on clear and contaminated Type I's.

5.2.16 Collect visibility data during periods of freezing precipitation at Dorval and correlated with concurrent meteorological data, including precipitation rate, precipitation type, temperature, wind velocity and direction as appropriate.

5.2.17 Present program results and plans for completion for a "mid-term" review to be called by TDC.

5.2.18 Video tape the tests for archival purposes

5.2.19 Test results will be collected, analyzed and a report produced.

5.3 Weather

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

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

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

5.4.1 Develop an experimental program for concurrent comparison testing of fluids under conditions of natural freezing precipitation on flat plates and on aircraft.
5.4.2 ***Prepare the following test plan features, plans and procedures:***
a) A detailed statement of work for each of the participants;
b) A specific test plan, for review by all parties, which will include as a minimum:
- Schedule and sequence of activities;
- Detailed list of responsibilities;
- Complete equipment list;
- List of data, measurements and observations to be recorded; and
- Test procedures.

c) Activities including:

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

d) Acquisition of data from the tests will address:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

5.4.17 Videotape records of all tests will be made.

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

5.4.19 Assemble and analyze all results

5.5 Frost Removal

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

5.5.1 Sweep and Shine

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

5.5.2 Hot Air

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

5.6 Wing Surface Visibility Study

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

5.7 Representative Surfaces Guidelines Study

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

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

5.8 *Heavy Precipitation Type IV Tests*

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

5.9 Presentations of test program results

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

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

5.10 Reporting

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

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

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