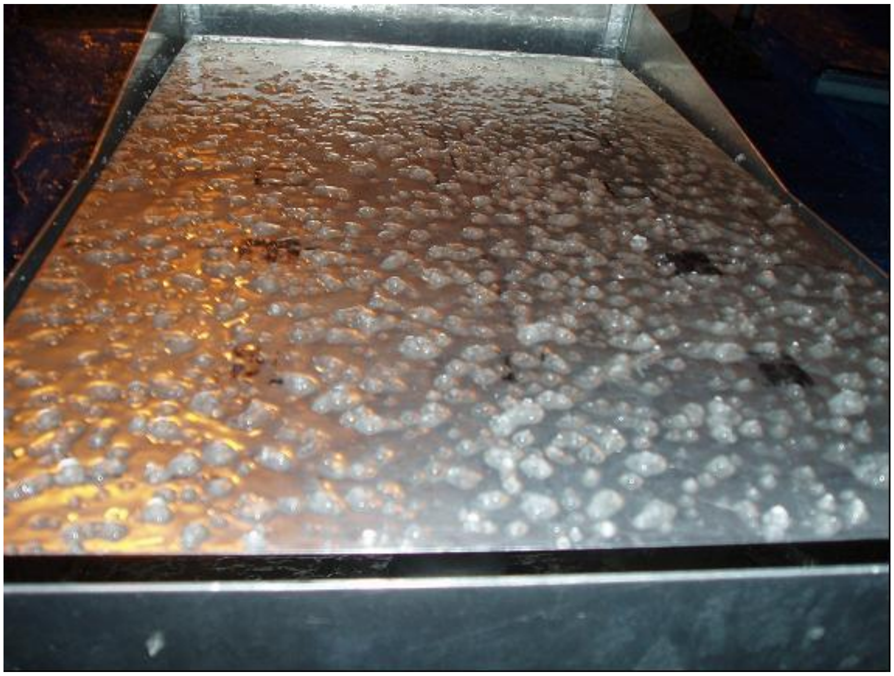
TP 14718E

Preliminary Endurance Time Testing in Simulated Ice Pellet Conditions



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In cooperation with

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Transport Canada

And

The Federal Aviation Administration
William J. Hughes Technical Center

Prepared by

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January 2006
Final Version 1.0

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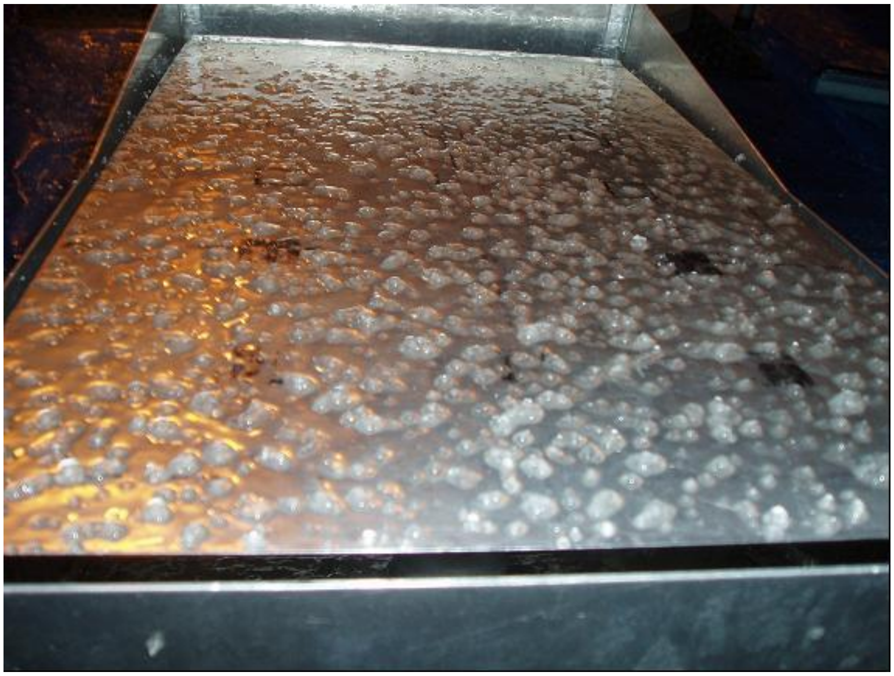

by

Marco Ruggi

January 2006
Final Version 1.0

The contents of this report reflect the views of APS Aviation Inc. and not necessarily the official view or opinions of the Transportation Development Centre of Transport Canada.

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

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PREFACE

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

- To develop holdover time data for all newly-qualified de/anti-icing fluids;
- To evaluate whether holdover times should be developed for ice pellet conditions;
- To examine the effect of heated fluids on Type II, III and IV fluid endurance times;
- To evaluate if it is appropriate to apply fluid with a -3°C buffer (fluid with a freeze point 3°C above the ambient temperature) for the 1st step of a two-step application;
- To evaluate weather data from previous winters to establish a range of conditions suitable for the evaluation of holdover time limits;
- To assist in the testing of flow of contaminated fluid from aircraft wings during takeoff;
- To validate the laboratory snow test protocol with Type II and IV fluids;
- To develop performance specifications for an integrated weather system that measures holdover time;
- To provide support for the development of a standard that evaluates remote on-ground ice detection systems;
- To conduct general and exploratory de/anti-icing research;
- To conduct endurance time tests on non-aluminum plates; and
- To conduct endurance time tests in frost on various test surfaces.

The research activities of the program conducted on behalf of Transport Canada during the winter of 2005-06 are documented in nine reports. The titles of the reports are as follows:

- TP 14712E Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2005-06 Winter;
- TP 14713E Aircraft Deicing Research in Natural and Simulated Ice Pellet Conditions;
- TP 14714E Evaluation of Fluid Freeze Points in First-Step Application of Type I Fluids;
- TP 14715E Winter Weather Impact on Holdover Time Table Format (1995-2006);
- TP 14716E Falcon 20 Trials To Examine Fluid Removed From Aircraft During Takeoff With Ice Pellets;
- TP 14717E Endurance Time Testing in Snow: Comparison of Indoor and Outdoor Data for 2005-06;
- TP 14718E Preliminary Endurance Time Testing in Simulated Ice Pellet Conditions;
- TP 14719E Aircraft Ground Icing General Research Activities During the 2005-06 Winter; and
- TP 14720E Effect of Heat on Fluid Endurance Times Using Composite Surfaces.

In addition, the following three interim reports are being prepared:

- *Implementation of Holdover Time Determination Systems (not for distribution)*;
- *Effect of Heat on Endurance Times of Anti-Icing Fluids; and*
- *Substantiation of Aircraft Ground Deicing Holdover Times in Frost Conditions.*

This report, TP 14718E, has the following objective:

- To investigate fluid endurance times in simulated ice pellet conditions.

The research described in this report is still ongoing.

PROGRAM ACKNOWLEDGEMENTS

This multi-year research program has been funded by the Civil Aviation Group, Transport Canada with support from the Federal Aviation Administration, William J. Hughes Technical Center, Atlantic City, NJ. This program could not have been accomplished without the participation of many organizations. APS would therefore like to thank the Transportation Development Centre of Transport Canada, the Federal Aviation Administration, National Research Council Canada, the Meteorological Service of Canada, and several fluid manufacturers.

APS would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data. This includes the following people: George Balaban, Katrina Bell, Kim Bendickson, Stephanie Bendickson, Nicolas Blais, Michael Chaput, Sami Chebil, John D'Avirro, Jan Goraczkowski, Chris McCormack, Rob Petermann, Marco Ruggi, Joey Tiano, Larry Turner, and David Youssef.

Special thanks are extended to Barry Myers, Frank Eyre and Yagusha Bodnar, who on behalf of the Transportation Development Centre, have participated, contributed and provided guidance in the preparation of these documents.

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Several research reports for testing of de/anti-icing technologies were produced for previous winters on behalf of Transport Canada. These are available from the Transportation Development Centre (TDC). This research project has been funded by the Civil Aviation Group of Transport Canada and the Federal Aviation Administration (FAA).

16. Abstract

The objective of this study was to investigate fluid endurance times in simulated ice pellet conditions. As testing was preliminary, the procedure for making and simulating the dispersal of ice pellets was investigated for the groundwork research conducted by APS at the PMG research facility during the summer of 2005. Testing was conducted in the PMG research facility cold chamber during simulated ice pellet precipitation conditions.

Data from the tests performed during the summer of 2005 were analysed. The preliminary calibration tests indicated that the procedure used to simulate ice pellet conditions generated results that were deemed acceptable according to the procedural requirements. Results also demonstrated that the simulated snowflake required a significantly shorter amount of time to fully dissolve in the deicing fluid in comparison to the simulated ice pellet.

While conducting endurance time testing on a standard test plate surface and on the airfoil, APS observers found it difficult to determine fluid failure; fluid contamination was observed after short periods of exposure to simulated ice pellet conditions, however it is unknown if this contamination would flow off a wing surface at aircraft rotation speeds. It was also observed that the fluid condition seemed to vary depending on the observer's angle of incidence and distance with respect to the objective. Adhesion to the airfoil was observed when conducting endurance time testing using a Type I heated fluid application.

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

Plusieurs rapports de recherche sur les essais de technologies de dégivrage et d'antigivrage ont été produits au cours d'hivers précédents pour le compte de Transports Canada. Ils sont disponibles au Centre de développement des transports (CDT). Le présent projet de recherche a été financé par le Groupe de l'Aviation civile de Transports Canada et la Federal Aviation Administration (FAA).

16. Résumé

La présente étude avait pour objectif d'examiner l'endurance des liquides dans des conditions de granules de glace simulés. Comme il s'agissait d'essais préliminaires, la procédure pour fabriquer et simuler la dissémination des granules de glace a été étudiée lors de travaux préparatoires de recherche effectués par APS au Centre de recherche PMG au cours de l'été 2005. Les essais ont été menés dans la chambre froide du Centre de recherche PMG dans des conditions de précipitation simulée de granules de glace.

Les données des essais effectués au cours de l'été 2005 ont été analysées. Les essais préliminaires de calibration ont démontré que la procédure utilisée pour simuler les conditions de granules de glace a donné des résultats considérés acceptables en fonction des exigences de procédure. Les résultats ont également démontré que les flocons de neige simulés prenaient nettement moins de temps à se dissoudre complètement dans le liquide de dégivrage, comparativement aux granules de glace simulés.

Au cours des essais d'endurance sur la surface d'une plaque d'essais standard et sur la voilure, les observateurs d'APS ont trouvé difficile l'identification de la défaillance du liquide ; de la contamination du liquide a été observée après de courtes périodes d'exposition aux conditions de granules de glace simulés, mais on ne sait pas si cette contamination s'écoulerait de la surface de l'aile aux vitesses de rotation des aéronefs. On a également observé que la condition du liquide semblait varier selon l'angle d'incidence de l'observateur et la distance de l'objectif. Au cours des essais d'endurance avec une application de liquide chauffé de Type I, on a noté de l'adhérence à la voilure.

17. Mots clés Dégivrage, intensité des chutes de neige, vidéo, visibilité, durée d'efficacité, assèchement	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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EXECUTIVE SUMMARY

Under contract to the Transportation Development Centre (TDC) of Transport Canada (TC), APS Aviation Inc. (APS) undertook a test program to investigate fluid endurance time in simulated ice pellet conditions. The exploratory groundwork research was conducted in conjunction with other projects to minimize expenditures.

Aircraft deicing operations during ice pellet conditions may occur, and although holdover times do not currently exist, aircraft may still be departing during ice pellet conditions following aircraft deicing. This has generated a need to investigate if fluid holdover times during ice pellet conditions should be provided for deicing operations.

As testing was preliminary, and the procedure for making and simulating the dispersal of ice pellets was still being investigated, the following six objectives were implemented for the groundwork research conducted by APS at the PMG research facility during the summer of 2005:

1. Determine the production time for making ice pellets;
2. Determine the size of the manufactured ice pellets;
3. Determine whether ice pellets can be stored overnight in below 0ºC conditions without bonding;
4. Determine the distribution of dispersed ice pellets using the automated pellet dispenser;
    a. Ice pellets were dispersed on a standard test plate used for endurance time testing; and
    b. Ice pellets were dispersed on an airfoil.
5. Determine the rate of precipitation produced by the dispersed ice pellets using the automated pellet dispenser; and
    a. The rate of precipitation was measured on a standard test plate used for endurance time testing; and
    b. The rate of precipitation was measured on the airfoil.
6. Conduct endurance time testing during simulated ice pellet conditions.
    a. Endurance time testing was conducted on a standard test plate used for endurance time testing; and
    b. Endurance time testing was conducted on the airfoil.

CONCLUSIONS

Data from the tests performed during the summer of 2005 were analysed. The preliminary calibration tests indicated that the procedure used to simulate ice pellet conditions generated results that were deemed acceptable according to the procedural requirements. Results also demonstrated that the simulated snowflake required a significantly shorter amount of time to fully dissolve in the deicing fluid in comparison to the simulated ice pellet.

While conducting endurance time testing on a standard test plate surface and on the airfoil, APS observers found it difficult to determine fluid failure. Fluid contamination was observed after short periods of exposure to simulated ice pellet conditions, but it is unknown if this contamination would flow-off a wing surface at aircraft rotation speeds. It was also observed that the fluid condition seemed to vary depending on the observer's angle of incidence and distance with respect to the objective. Adhesion to the airfoil was observed when conducting endurance time testing using a Type I heated fluid application.

SOMMAIRE

En vertu d'un contrat avec le Centre de développement des transports (CDT) de Transports Canada (TC), APS Aviation Inc. (APS) a entrepris un programme d'essais pour examiner l'endurance des liquides dans des conditions de granules de glace simulés. Les travaux exploratoires de recherche ont été menés conjointement avec d'autres projets afin de minimiser les coûts.

Le dégivrage d'aéronefs peut se faire dans des conditions de granules de glace et, bien que des durées d'efficacités ne soient pas encore en place, il est encore possible que des aéronefs décollent dans des conditions de granules de glace après le dégivrage. Cette situation a créé le besoin d'établir si des durées d'efficacité des liquides devraient être fournies pour le dégivrage dans des conditions de granules de glace.

Puisqu'il s'agissait d'essais préliminaires et que la procédure pour fabriquer et simuler la dissémination des granules de glace était encore à l'étude, les six objectifs suivants ont été mis en place pour les travaux préparatoires de recherche effectués par APS au Centre de recherche PMG au cours de l'été 2005 :

1. Identifier le temps de fabrication de granules de glace ;
2. Établir la dimension des granules de glace fabriqués ;
3. Déterminer si les granules de glace peuvent être entreposés de nuit sous 0ºC, sans qu'ils ne se fusionnent ;
4. Établir la diffusion des granules de glace dispersés à l'aide du distributeur de granules automatique ;
    a. Les granules de glace ont été dispersés sur une plaque d'essai standard utilisée pour les essais d'endurance ; et
    b. Des granules de glace ont été dispersés sur une voilure.
5. Établir le taux de précipitation produit par les granules de glace dispersés à l'aide du distributeur de granules automatique ; et
    a. Le taux de précipitation a été mesuré sur une plaque d'essais standard utilisée pour les essais d'endurance ; et
    b. Le taux de précipitation a été mesuré sur la voilure.
6. Mener des essais d'endurance dans des conditions de granules de glace simulés.
    a. Des essais d'endurance ont été menés sur une plaque d'essais standard utilisée pour les essais d'endurance ; et
    b. Des essais d'endurance ont été menés sur une voilure.

CONCLUSIONS

Les données des essais effectués au cours de l'été 2005 ont été analysées. Les essais préliminaires de calibration ont démontré que la procédure employée pour simuler des conditions de granules de glace a produit des résultats jugés acceptables en fonction des exigences en matière de procédures. Les résultats ont également démontré que les flocons de neige simulés nécessitent une période de temps nettement inférieure pour se dissoudre complètement dans le liquide de dégivrage, comparativement aux granules de glace simulés.

Au cours des essais d'endurance sur une plaque d'essais standard et sur la voilure, les observateurs d'APS ont trouvé difficile l'identification de la défaillance du liquide. De la contamination du liquide a été observée après de courtes périodes d'exposition aux conditions de granules de glace simulés, mais on ne sait pas si cette contamination s'écoulerait de la surface de l'aile aux vitesses de rotation des aéronefs. On a également observé que la condition du liquide semblait varier selon l'angle d'incidence de l'observateur et la distance de l'objectif. Au cours des essais d'endurance avec une application de liquide chauffé de Type I, on a noté de l'adhérence à la voilure.

CONTENTS Page

LIST OF APPENDICES

LIST OF FIGURES Page

LIST OF TABLES Page

LIST OF PHOTOS Page

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GLOSSARY

APS	APS Aviation Inc.
EG	Ethylene Glycol
FAA	Federal Aviation Administration
HOT	Holdover Time
MSC	Meteorological Service of Canada
NRC	National Research Council (Canada)
OAT	Outside Air Temperature
TC	Transport Canada
TDC	Transportation Development Centre

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1. INTRODUCTION

Under winter precipitation conditions, aircraft are cleaned with a freezing point depressant fluid and protected against further accumulation by an additional application of such a fluid, possibly thickened to extend the protection time. Aircraft ground deicing had, until recently, never been researched and there is still little understanding of the hazard and of what can be done to reduce the risks posed by the operation of aircraft in winter precipitation conditions. This "winter operations contaminated aircraft – ground" program of research is aimed at overcoming this lack of knowledge.

Over the past several years, the Transportation Development Centre (TDC), Transport Canada (TC) has managed and conducted de/anti-icing related tests at various sites in Canada; it has also coordinated worldwide testing and evaluation of evolving technologies related to de/anti-icing operations with the co-operation of the US Federal Aviation Administration (FAA), the National Research Council (Canada) (NRC), Meteorological Service of Canada (MSC), several major airlines, and deicing fluid manufacturers. TDC is continuing its research, development, testing and evaluation program.

Under contract to TDC, with financial support from the FAA, APS Aviation Inc. (APS) undertook a test program to investigate fluid endurance time in simulated ice pellet conditions. The exploratory groundwork research was conducted in conjunction with other projects to minimize expenditures.

1.1 Background

Aircraft deicing operations during ice pellet conditions may occur, and although holdover times do not currently exist, aircraft may still be departing during ice pellet conditions following aircraft deicing. This has generated a need to investigate if fluid holdover times during ice pellet conditions should be provided for deicing operations.

1.2 Objectives

The primary objective of this project is the following:

- To determine fluid endurance times during ice pellet conditions.

As testing is preliminary, and the procedure for making and simulating the dispersal of ice pellets is still being investigated, the following six objectives were implemented for the groundwork research conducted by APS at the PMG research facility:

1. Determine the production time for making ice pellets;
2. Determine the size of the manufactured ice pellets;
3. Determine whether ice pellets can be stored overnight in below 0ºC conditions without bonding;
4. Determine the distribution of dispersed ice pellets using the automated pellet dispenser;
   a) Ice pellets dispersed on a standard test plate used for endurance time testing; and
   b) Ice pellets dispersed on an airfoil.
5. Determine the rate of precipitation produced by the dispersed ice pellets using the automated pellet dispenser; and
   a) The rate of precipitation should be measured on a standard test plate used for endurance time testing; and
   b) The rate of precipitation should be measured on the airfoil.
6. Conduct endurance time testing during simulated ice pellet conditions.
   a) Endurance time testing should be conducted on a standard test plate used for endurance time testing; and
   b) Endurance time testing should be conducted on the airfoil.

1.3 Report Format

The following list provides short descriptions of the main sections of this report:

a) Section 2 provides a description of the methodology used to carry out the tests;
b) Section 3 presents the procedural feasibility for producing simulated ice pellets precipitation conditions (Objectives 1 to 5);
c) Section 4 presents the data collected, through macroscopic video, of simulated ice pellets and simulated snowflakes dissolving in de/anti-icing fluid;
d) Section 5 presents the endurance time data that were collected during simulated ice pellet precipitation conditions on a standard test plate and on an airfoil (Objective 6);
e) Section 6 presents the "Far vs. Near – Pilots Perspective" data that were collected during simulated ice pellet precipitation conditions on the airfoil;
f) Section 7 presents the conclusions; and
g) Section 8 presents the recommendations.

2. METHODOLOGY

This section describes the overall approach, test parameters and experimental procedures followed in this project.

APS measurement instruments and test equipment are calibrated and verified on an annual basis. This calibration is carried out according to a calibration plan derived from approved ISO 9001:2000 standards and developed internally by APS.

2.1 PMG Research Facility

Testing to satisfy the objectives described in Section 1.2 was carried out at the PMG Research Facility. Testing was conducted in conjunction with other test programs to reduce costs. APS personnel conducted the exploratory research.

2.2 Description of Test Procedures

Endurance time tests were conducted using various fluids at the PMG Research Facility. Testing was conducted following the application methods described below.

2.2.1 Endurance Time Test on Standard Test Plate

Endurance time testing was conducted using a standard plate sitting in the "NCAR Bucket" (Photo 2.1). The bucket was placed on a weigh scale (Photo 2.2) and the weight was manually recorded to monitor the rate of precipitation. One litre of fluid was applied to the test plate for each endurance time test (Photo 2.3). The "Ice Pellet Pitcher" (Photo 2.4) was positioned approximately 1.2 meters away from, and 1.2 meters above the test plate. Fluid failure was recorded. Fluid Brix was measured during selected tests using a brixometer (Photo 2.5).

2.2.2 Endurance Time Test on the Airfoil

Endurance time testing was conducted using the airfoil (Photo 2.6). To calculate the rate of precipitation during the endurance time test, three bins measuring 10 X 10 cm were positioned on the airfoil and were weighed prior to and after the endurance time test (Photo 2.7). Approximately 5 L of fluid was applied to the airfoil for each endurance time test (Photo 2.8). The "Ice Pellet Pitcher" (Photo 2.4) was positioned approximately 1.2 meters away from and 1.2 meters above the test plate.

Fluid failure was recorded. Fluid Brix was measured during selected tests using a brixometer (Photo 2.5).

2.3 Data Forms

Two data forms were required for the comparative fluid endurance time testing in simulated ice pellet conditions:

a) Data form for documenting fluid endurance time and rate of simulated precipitation; and
b) Data form for documenting fluid failure observations on the airfoil.

The data forms are provided in Appendix A.

2.4 Equipment

The test equipment for standard holdover time (HOT) testing was used to conduct endurance time testing. Sections 2.4.1 to 2.4.8 briefly describe the equipment used.

2.4.1 Standard Test Plate Surface

Fluid endurance time testing was conducted using a standard aluminum test plate. A schematic of the test plate is shown in Figure 2.1.

2.4.2 NCAR Bucket

Fluid endurance time testing was conducted using a standard aluminum test plate sitting inside a self-contained bucket (NCAR Bucket) which collected any fluid run off from the plate. The NCAR bucket was placed on a weigh scale to measure the rate of precipitation. A photo of the test plate is shown in Photo 2.1.

2.4.3 Weigh Scale

A weigh scale, with a precision of 0.1 g, was used to measure the rate of simulated ice pellet precipitation. The scale was zeroed prior to each endurance time test.

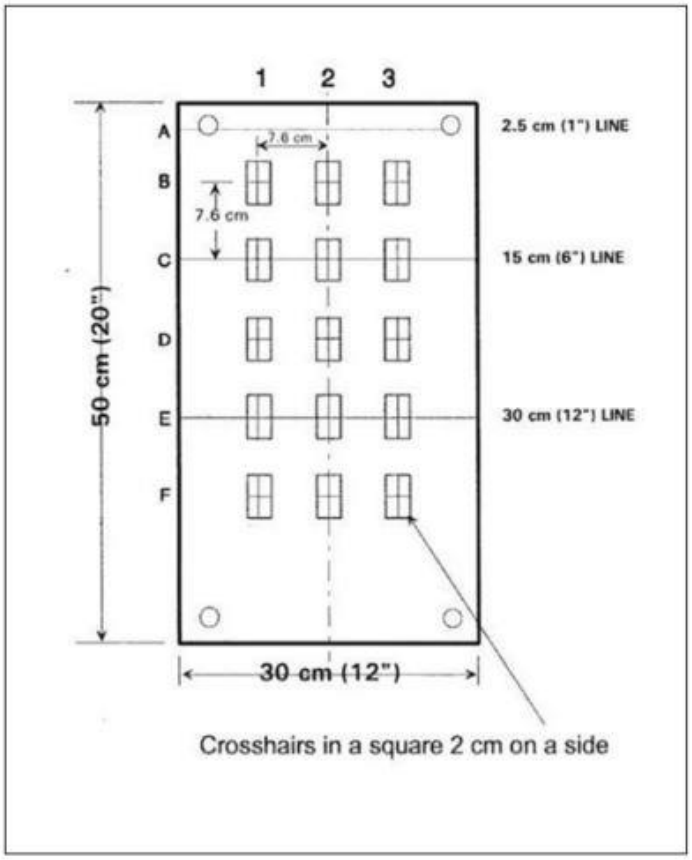

Figure 2.1: Schematic of Standard Holdover Time Test Plate

2.4.4 Airfoil

Fluid endurance time testing was conducted using the airfoil (Photo 2.6).

2.4.5 Rate Bins

Aluminum bins were used to measure the distribution of simulated ice pellets on the test plate and on the airfoil. Aluminum bins were also used to measure the rate of simulated ice pellet precipitation on the airfoil. The collection area of each bin measured 1 dm^2. The bins were weighed prior to and following each test.

2.4.6 Brixometer

Brix measurements were taken using a hand-held brixometer (Photo 2.5). Brix measurements provided data relevant to the fluid concentration; measuring Brix monitors fluid dilution.

2.4.7 Ice Pellet Pitcher

The simulated ice pellets were distributed over the test surface using the ice pellet pitcher. The ice pellet pitcher consisted of a motor-driven modified hand-held fertilizer dispenser. The rate of precipitation was controlled with the speed of rotation of the motor, as well as with the size of the opening of the dispenser reservoir drop feeder.

2.4.8 Composite Tile Surfaces for Making Ice Pellets

Composite tile surfaces (Photo 2.9) were treated with a water sealant to allow water to bead on the surface. The composite tile surfaces, measuring 0.1 m², were cooled to below 0ºC and sprayed with warm distilled water using a hand-held spray bottle(Photo 2.10). An adjustable nozzle on the hand-held spray bottle was used to create a fine water mist, which allowed for the proper formation of water droplets on the surface. The sprayed composite tiles were placed in a holding rack (Photo 2.11) to allow the water droplets to freeze; frozen water droplets formed the ice pellets used for testing. The ice pellets were dislodged from the surface using a plastic putty knife (Photo 2.12). Photo 2.13 shows the setup used for the ice pellet production station.

2.5 Fluids

Table 2.1 provides information concerning the various fluids utilised for endurance time testing in simulated ice pellet conditions.

Table 2.1: Fluids Used for Endurance Time Testing

Fluid Type	Fluid Name	Viscosity Information
I	UCAR ADF XL54	N/A
IV	Octagon MaxFlo	5540 mPa.s
IV	Dow UCAR ADF/AAFULTRA +	Sample From Aeromag

Photo 2.1: NCAR Bucket and Standard Aluminum Test Plate

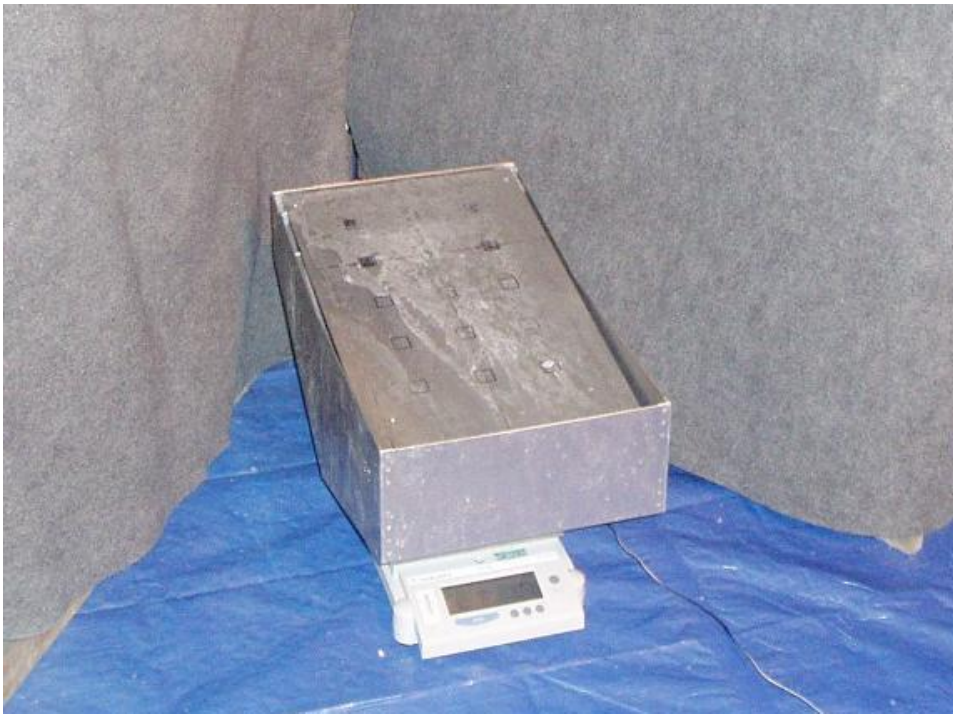

Photo 2.2: Weigh Scale Used to Measure Rate of Precipitation

Photo 2.3: Fluid Application to Standard Aluminum Test Plate in NCAR Bucket

Photo 2.4: Ice Pellet Pitcher Used to Simulate Ice Pellet Precipitation Conditions

Photo 2.5: Hand-Held Brixometer

Photo 2.6: Airfoil Used for Endurance Time Testing

Photo 2.7: Location of Bins Used to Calculate Rate of Precipitation

Photo 2.8: Fluid Application to Airfoil

Photo 2.9: Composite Tile Surface Used to Produce Ice Pellets

Photo 2.10: Hand-Held Spray Bottle Used to Spray Composite Tile Surfaces

Photo 2.11: Holding Rack Used for Composite Surface Tiles

Photo 2.12: Plastic Putty Knife Used to Scrape Ice Pellets From Composite Tiles

Photo 2.13: Setup for Ice Pellet Production Station

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3. PROCEDURAL FEASABILITY

Preliminary testing to verify the feasibility of producing and dispensing simulated ice pellets on an aluminum test plate surface and on the airfoil was conducted at the PMG research facility. The cold chamber was cooled to -5ºC. This section describes the procedural conclusions relating to Objectives 1 to 5 described in Section 1.2; each numbered subsection corresponds to the objective described in Section 1.2.

1. Determine the production time for making ice pellets;
2. Determine the size of the manufactured ice pellets;
3. Determine whether ice pellets can be stored overnight in below 0ºC conditions without bonding;
4. Determine the distribution of dispersed ice pellets using the automated pellet dispenser; and
    a. Ice pellets should be dispersed on a standard test plate used for endurance time testing; and
    b. Ice pellets should be dispersed on the airfoil.
5. Determine the rate of precipitation produced by the dispersed ice pellets using the automated pellet dispenser.
    a. The rate of precipitation should be measured on a standard test plate used for endurance time testing; and
    b. The rate of precipitation should be measured on the airfoil.

3.1 Production Time for Making Ice Pellets

Approximately 4 kg of ice pellets, smaller than 5 mm in diameter, were manufactured during each test session. Each test session lasted approximately 6 hours. Two members of the APS staff were in charge of manufacturing the ice pellets.

3.2 Size Distribution of the Simulated Ice Pellets

The manufactured ice pellets varied in size. The ice pellets were sifted through a screen to remove any ice pellets with a diameter greater than 5 mm. Ice pellets with a diameter greater than 5 mm were discarded. Due to the sifting process used, a small percentage of ice pellets with diameter greater than 5 mm still remained in the samples. A size distribution of the simulated ice pellets was calculated to obtain the mean volume diameter. The mean volume diameter was calculated for two samples (Photo 3.1 and Photo 3.2). Figure 3.1 to Figure 3.4 demonstrate the results obtained. It should be noted that the simulated ice pellets had a flattened side resulting from freezing on the composite tile surface. The mean volume diameter was calculated assuming the ice pellet measured in the photo was spherical.

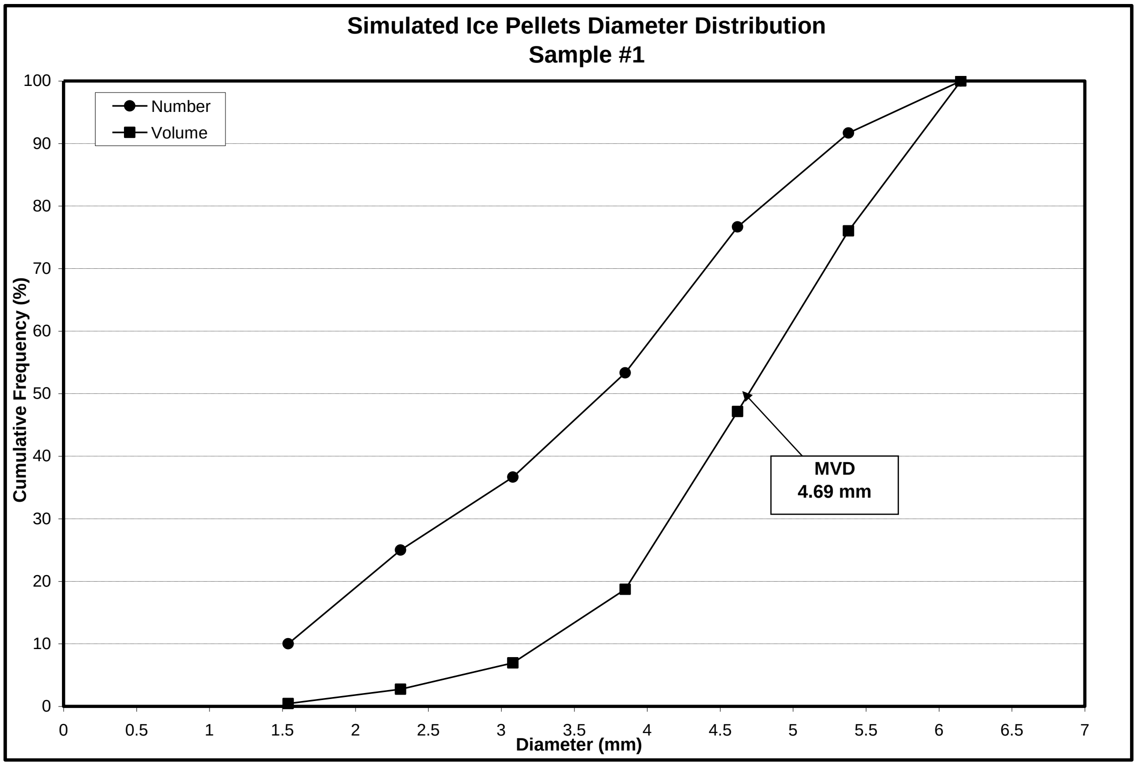


Figure 3.1: Sample #1 - Linear Representation of Size Distribution

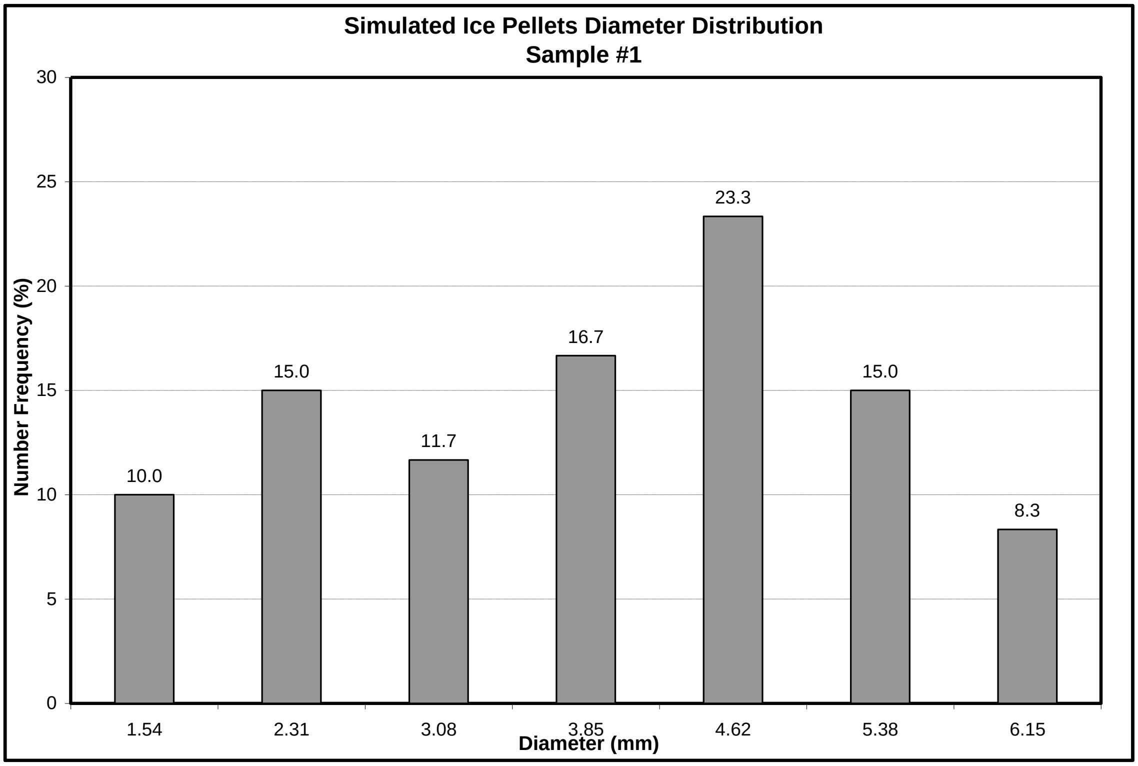


Figure 3.2: Sample #1 – Histogram Representation of Size Distribution

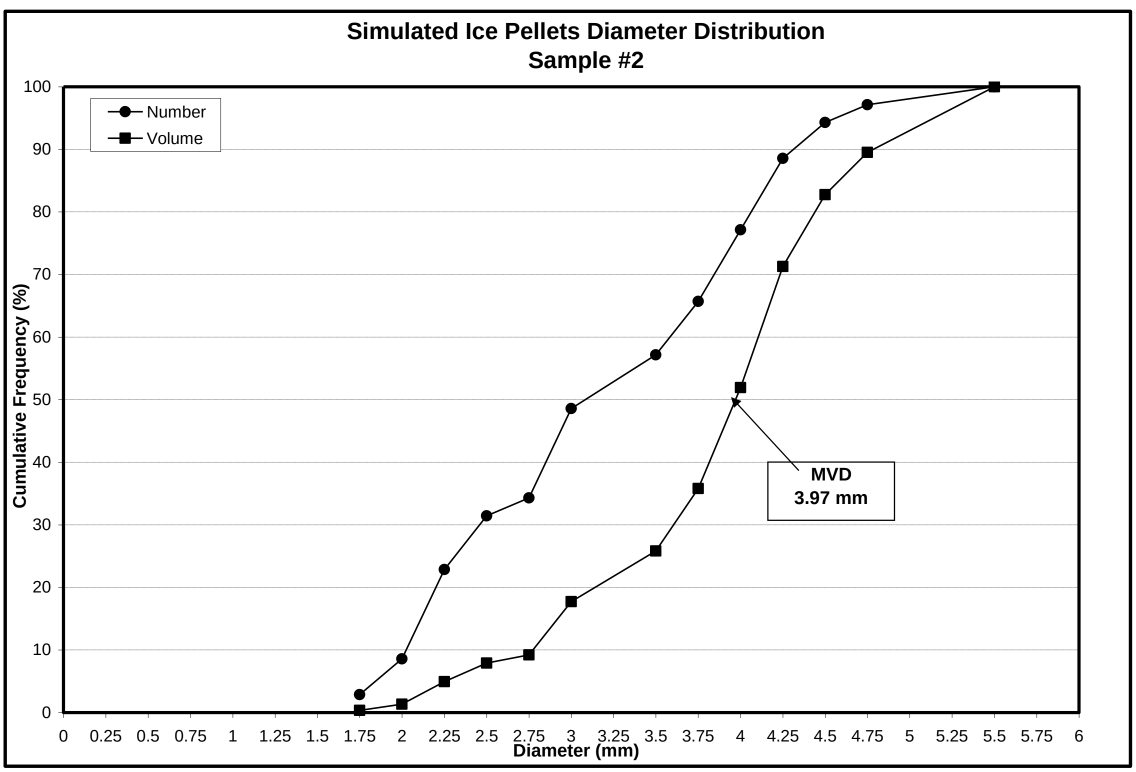


Figure 3.3: Sample #2 - Linear Representation of Size Distribution

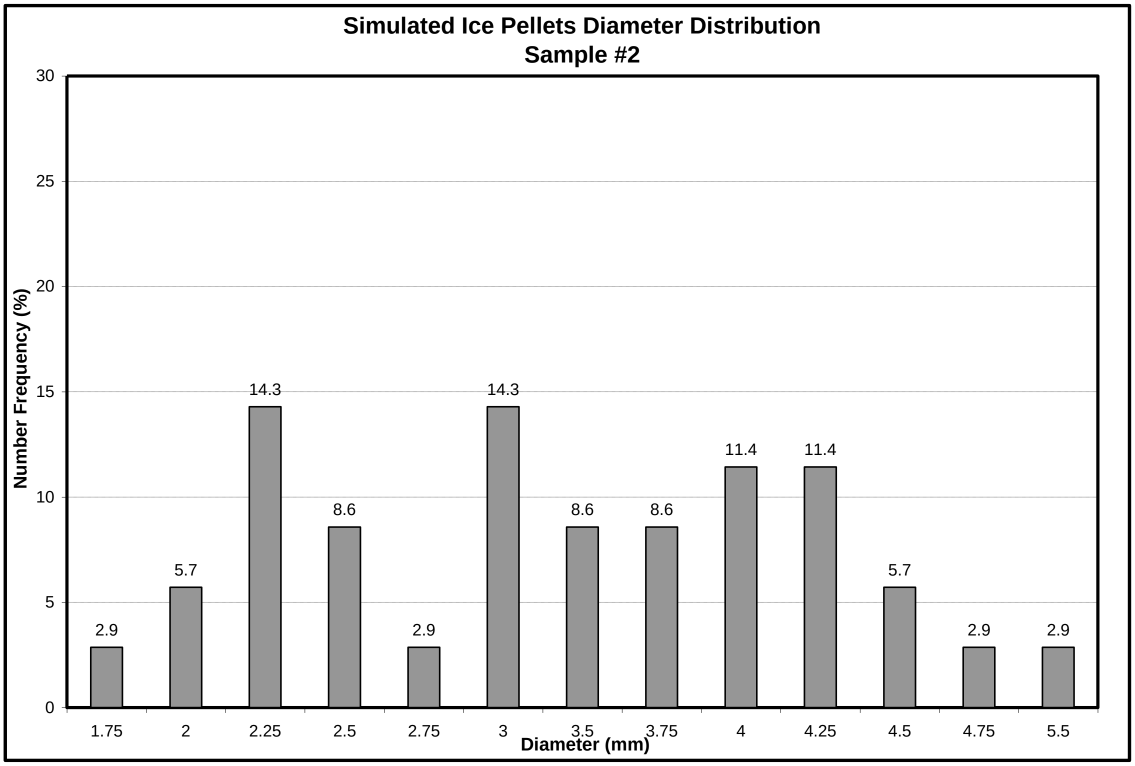


Figure 3.4: Sample #2 – Histogram Representation of Size Distribution

3.3 Overnight Storage of Simulated Ice Pellets in Below 0°C Conditions

It was observed that overnight storage of the simulated ice pellets was feasible considering minimum temperature differentials in the ambient temperature of the ice pellets. The PMG research facility chamber was cooled to -5°C for testing purposes. After testing ended, the cooling units were shut and the chamber would return to room temperature overnight. To avoid having the simulated ice pellets melt overnight, the insulated cooler containing the ice pellets was placed inside a freezer cooled to -10°C. The ice pellets were retrieved from the freezer only when the chamber was again cooled to -5°C the following morning.

To avoid having the ice pellets stick together, the ice pellets could not be transferred through locations with largely different ambient temperatures. Transferring the ice pellets from a cold condition to a warmer condition would create condensation on the surface of the ice pellet, which would then freeze and cause the ice pellets to adhere to each other. This was avoided by maintaining the ice pellets in an environment with constant temperature.

3.4 Distribution Using the Ice Pellet Dispenser

3.4.1 Distribution Measured on a Standard Test Plate

The distribution of dispersed ice pellets using the automated pellet dispenser was measured on a standard test plate. Fifteen bins were placed over the test plate covering the entire test surface; their locations relative to the 7.5, 15, and 22.5 cm lines on the plate are shown in Figure 3.5. The bins were weighed prior to, and after dispersing the ice pellets. Table 3.1 demonstrates the results obtained. The distribution of ice pellets was deemed acceptable based on the results obtained.

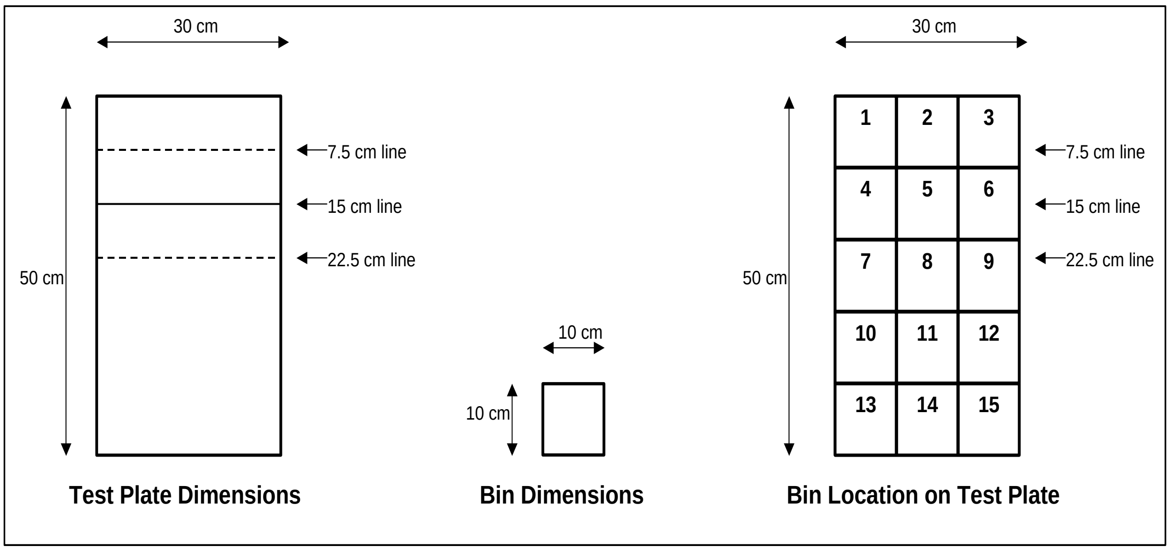


Figure 3.5: Location of Bins on Test Plate for Distribution Tests

3.4.2 Distribution Measured on the Airfoil

The distribution of dispersed ice pellets using the automated pellet dispenser was measured on the airfoil. Five bins were placed on the airfoil in select locations and are demonstrated in Figure 3.6. The bins were weighed prior to, and after dispersing the ice pellets. Table 3.2 demonstrates the results obtained. The distribution of ice pellets was deemed reasonable based on the results obtained.

Table 3.1: Distribution of Ice Pellets on Standard Test Plate

Bin #	Empty Bin (g)	Bin With Pellets (g)	Total Weight of Ice Pellets (g)	Difference in Weight from Average (g)
1	79	80.8	1.8	0.2
2	83	84.7	1.7	0.1
3	83.2	84.4	1.2	-0.4
4	79.3	80.8	1.5	-0.1
5	84.6	86.4	1.8	0.2
6	83.1	84.7	1.6	0.0
7	85.4	87.1	1.7	0.1
8	84	85.8	1.8	0.2
9	84.7	86.2	1.5	-0.1
10	87.9	89.7	1.8	0.2
11	83	84.7	1.7	0.1
12	85	86.5	1.5	-0.1
13	86.4	87.8	1.4	-0.2
14	80.6	82.5	1.9	0.3
15	85.2	86.5	1.3	-0.3

Average Weight (g)	**1.6**
Standard Deviation (g)	**0.2**

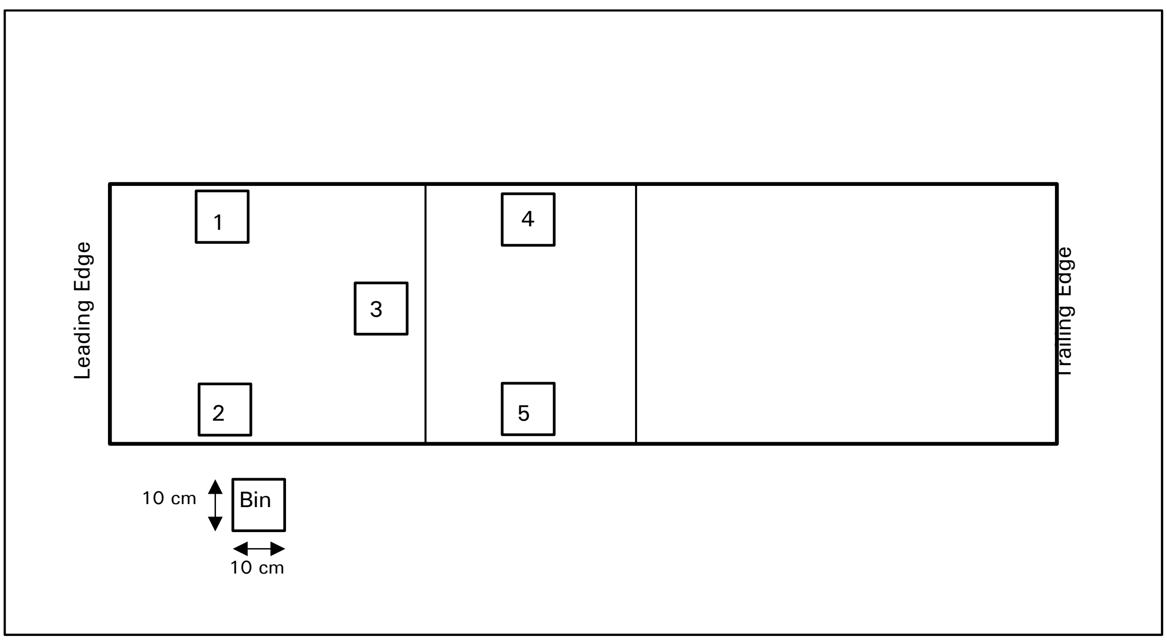


Figure 3.6: Location of Bins on the Airfoil for Distribution Tests

Table 3.2: Distribution of Ice Pellets the Airfoil

Bin #	Empty Bin (g)	Bin With Pellets (g)	Total Weight of Ice Pellets (g)	Difference in Weight from Average (g)
1	79.4	82.0	2.6	0.0
2	83.4	87.5	4.1	1.5
3	83.9	87.2	3.3	0.7
4	84.5	85.6	1.1	-1.5
5	85.1	87.1	2.0	-0.6

Average Weight (g)	**2.6**
Standard Deviation (g)	**1.2**

3.5 Simulated Rate of Precipitation Using the Ice Pellet Dispenser

3.5.1 Simulated Rate of Precipitation on a Standard Test Plate

The rate of precipitation produced by the dispersed ice pellets using the automated pellet dispenser was measured on a standard test plate. The rate of precipitation was controlled with the speed of rotation of the motor, as well as with the size of the opening of the dispenser reservoir drop feeder. The "NCAR bucket", a self-containing support exactly sized for a standard aluminum test plate, was used for endurance time testing. The "NCAR bucket" was placed on a weigh scale, and collected any fluid falling from the test plate. The rate of precipitation was determined by the difference in weight recorded by the weigh scale. Depending on the particular test, the rate of precipitation produced by the ice pellet dispenser ranged from less than 4 g/dm²/h for some tests, to greater than 100 g/dm²/h for other tests.

3.5.2 Simulated Rate of Precipitation on the Airfoil

The rate of precipitation produced by the dispersed ice pellets using the automated pellet dispenser was measured on the airfoil. The rate of precipitation was controlled with the speed of rotation of the motor, as well as with the size of the opening of the dispenser reservoir drop feeder. For endurance time testing, three bins were placed on the airfoil in select locations that are seen in Figure 3.7. The bins were weighed prior to, and after dispensing the ice pellets in order to calculate the rate of precipitation. It should be noted that due to the large surface of the airfoil, the leading edge generally experienced a greater rate of precipitation in comparison to the trailing edge.

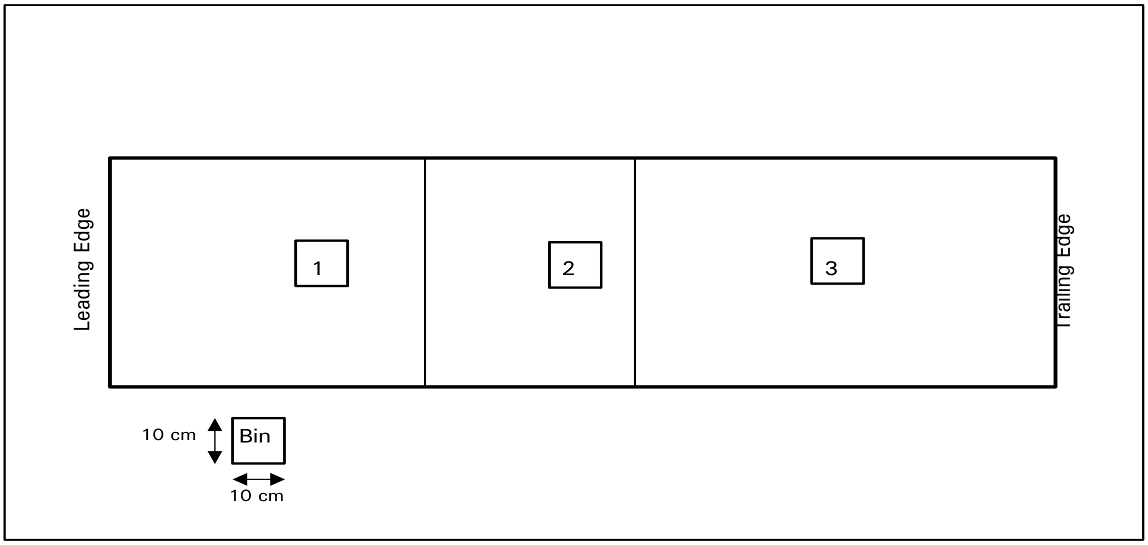
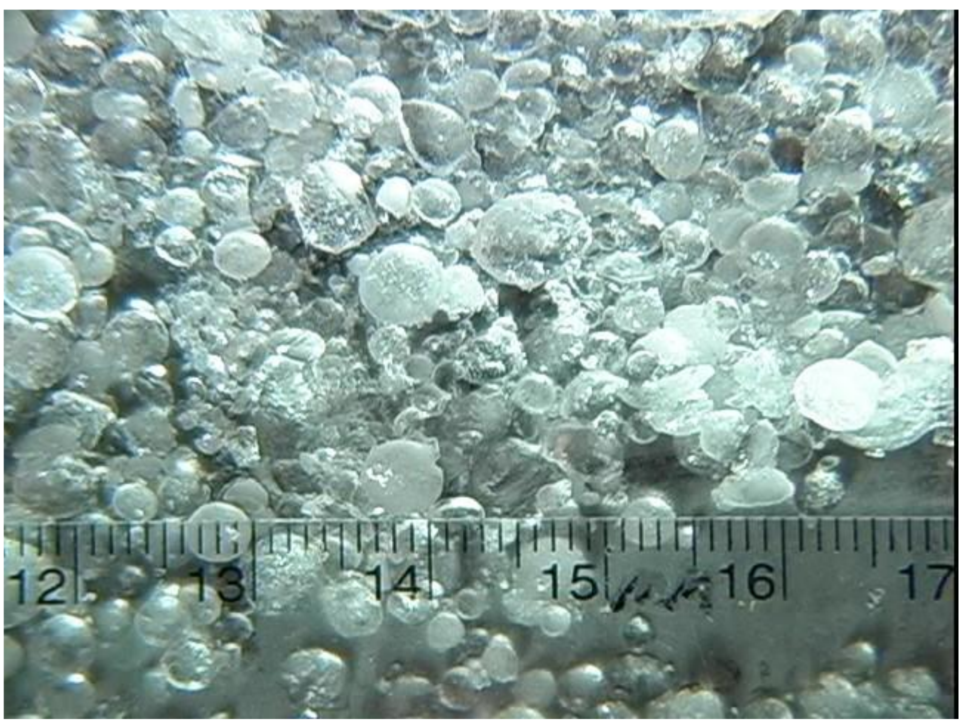


Figure 3.7: Location of Bins on the Airfoil for Endurance Time Tests

Photo 3.1: Photo Demonstrating Ice Pellet Size Distribution – Sample #1

Photo 3.2: Photo Demonstrating Ice Pellet Size Distribution – Sample #2



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4. ICE PRECIPITATION DISSOLVING IN DEICING FLUID

Video documentation of simulated ice precipitation dissolving in deicing fluid was obtained to determine any differences in the rate of decay. This section describes the data collected.

4.1 Background

At the request of TC, APS coordinated the production of several short videos documenting the details of a snowflake and an ice pellet melting in a deicing fluid bath. The videos served as a tool to explore the properties of ice precipitation dissolving in a deicing fluid bath during set intervals of time.

4.2 Objectives

- To document the details of a snowflake dissolving in different dilutions of deicing fluid; and
- To document the details of an ice pellet dissolving in different dilutions of deicing fluid.

4.3 Setup - Macro Filming

The setup required a macro lens camera to document the melting of a simulated snowflake and a simulated ice pellet in a deicing fluid bath. The camera was setup to video a 1 dm^2 area. The time stamped videos produced were later edited to provide still images of predetermined times during each test. Figure 4.1 demonstrates the side view of the setup.

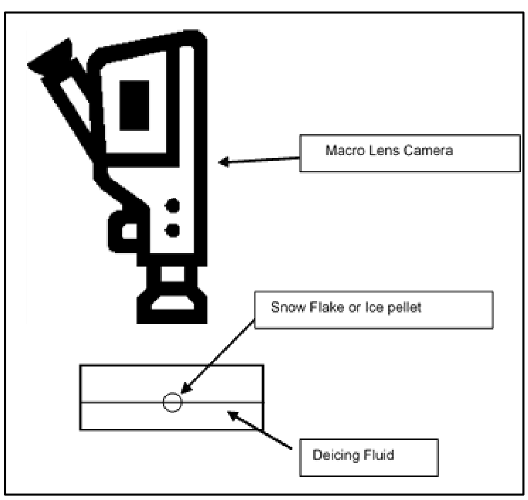

Figure 4.1: Side View of Macro Lens Setup

4.4 Log of Tests – Ice Precipitation Dissolving in Deicing Fluid

To facilitate the understanding of the data collected, a log was created for the series of tests conducted by APS at the PMG research facility. The log presented in Table 4.1 provides relevant information for each test conducted, as well as the final values recorded. Each row contains data specific to one test. It should be noted that the outside air temperature (OAT) was -5°C during all the tests conducted. The following is a brief description of the column headings for the test logs:

Test No.: Exclusive number identifying each test.

Precipitation: Simulated ice precipitation placed in deicing fluid bath (i.e. ice pellet or snowflake).

Start Time: Start time for the test recorded in local time.

End Time: End time for the test recorded in local time.

Total Time: Total time for the test recorded in minutes.

Fluid Name: Manufacturer brand name specific for each aircraft deicing fluid.

Fluid Type: Aircraft deicing fluid type.

Dilution Brix: Aircraft deicing fluid Brix measured prior to the start of the test.

Table 4.1: Data Log – Ice Precipitation Dissolving in Deicing Fluid

Test #	Precipitation	Start Time (Local)	End Time (Local)	Total Time (min)	Fluid Name	Fluid Type	Dilution Brix
1	Ice Pellet	0:00:21	--	Did Not Melt	Type I EG	1	10.5
2	Ice Pellet	0:20:27	0:39:40	19:13	Type I EG	1	20.25
3	Ice Pellet	0:40:32	0:54:55	14:23	Type I EG	1	32
4	Ice Pellet	0:58:40	1:16:12	17:32	Type IV EG (Neat)	4	41
5	Snowflake	1:18:42	1:20:24	01:42	Type I EG	1	10.5
6	Snowflake	1:20:30	1:21:15	00:45	Type I EG	1	20.5
7	Snowflake	1:21:52	1:22:04	00:12	Type I EG	1	32
8	Snowflake	1:22:16	1:22:27	00:11	Type IV EG (Neat)	4	41
9	Ice Pellet	1:24:24	--	Did Not Melt	Type I EG	1	10.5
10	Ice Pellet	0:00:06	0:21:16	21:10	Type I EG	1	15
11	Ice Pellet	0:21:42	0:33:23	11:41	Type I EG	1	25
12	Ice Pellet	0:33:57	0:57:13	23:16	Type IV EG (Neat)	4	41
13	Ice Pellet	0:57:29	1:09:42	12:13	Type IV EG (50/50)	4	25
14	Ice Pellet	1:09:57	1:22:52	12:55	Type IV EG (75/25)	4	32
15	Snowflake	1:24:06	1:24:14	00:08	Type IV EG (Neat)	4	41
16	Snowflake	1:24:44	1:24:59	00:15	Type IV EG (50/50)	4	25
17	Snowflake	1:25:19	1:25:30	00:11	Type IV EG (75/25)	4	32
18	Snowflake	1:25:49	1:26:30	00:41	Type I EG	1	15
19	Snowflake	1:26:43	1:26:58	00:15	Type I EG	1	25

Video documentation of the ice precipitation dissolving in deicing fluid was taken during each test. A select number of representative photos were extracted from each test video. Appendix B includes the photo documentation for each of the nineteen tests conducted. For example, in Appendix B, Test #1 included five photos demonstrating the size of the ice pellet at specified intervals following the start time of the test; the test time elapsed is denoted by Δt: h:mm:ss.

4.5 Ice Precipitation Rate of Decay in Deicing Fluid

To facilitate the analysis of the data collected, the tests conducted were divided into the following groups:

- Simulated Ice Pellet Dissolving in Type I Fluid;
- Simulated Ice Pellet Dissolving in Type IV Fluid;
- Simulated Snowflake Dissolving in Type I Fluid; and
- Simulated Snowflake Dissolving in Type IV Fluid.

For each grouping, the data collected was plotted. Figure 4.2 to Figure 4.5 demonstrate the fluid dilution versus the total time it took for the ice precipitation to dissolve. A regression analysis of the data for each grouping was performed, and the resulting regression curve was superimposed on the data set.

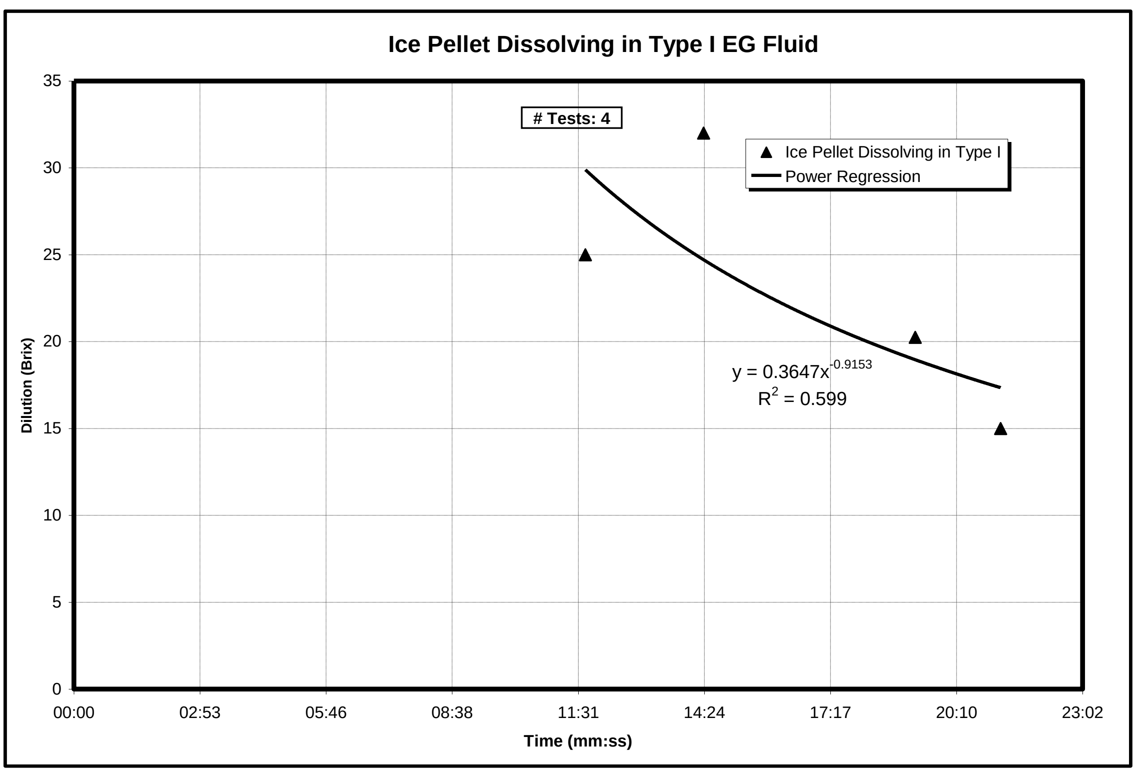

Figure 4.2: Simulated Ice Pellet Dissolving in Type I EG Fluid

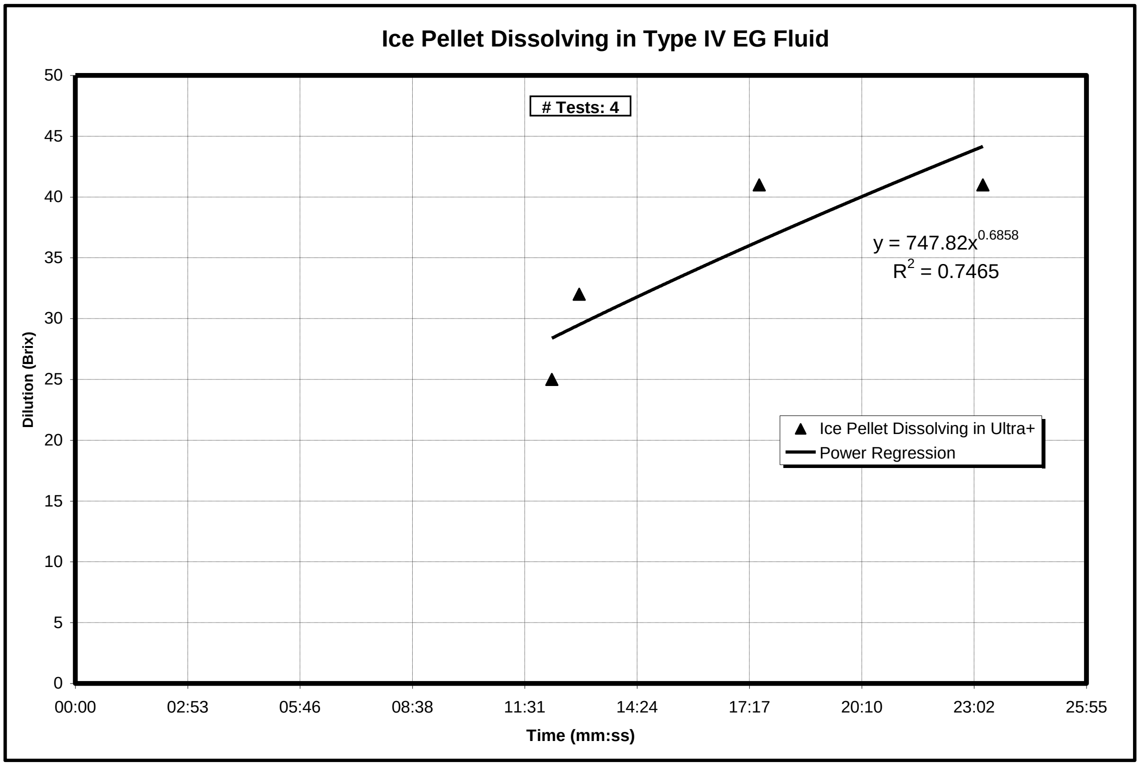

Figure 4.3: Ice Pellet Dissolving in Type IV EG Fluid

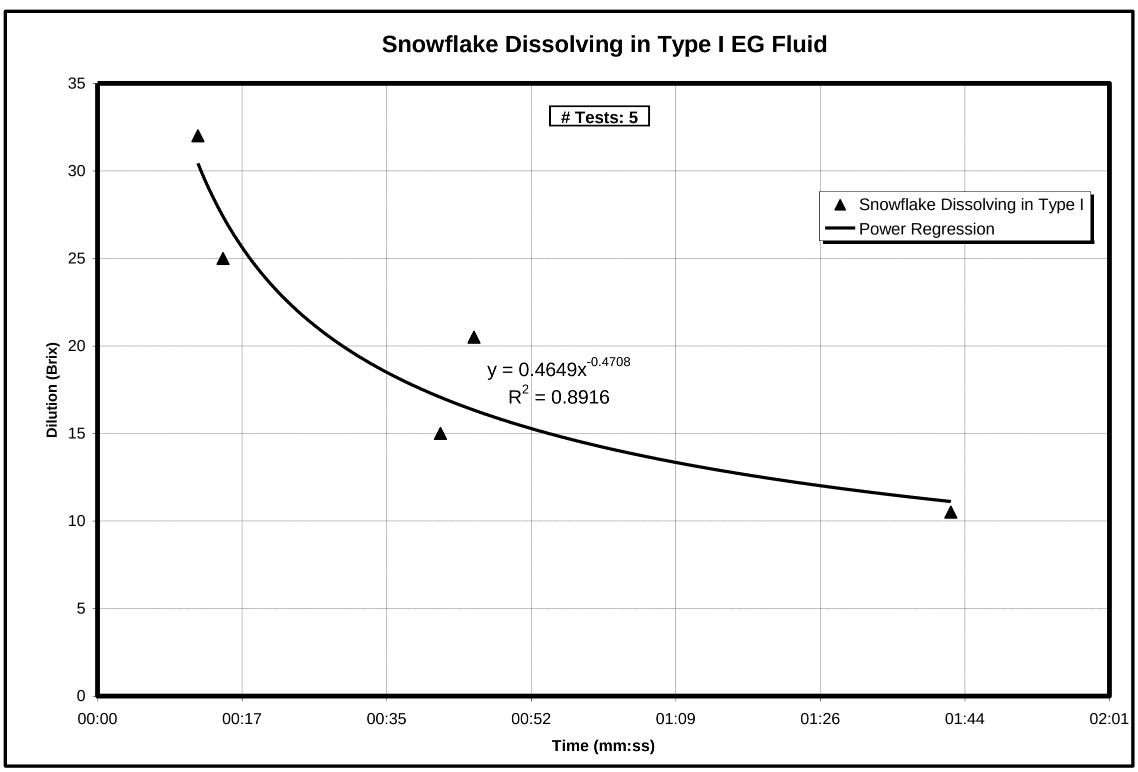

Figure 4.4: Simulated Snowflake Dissolving in Type I Fluid

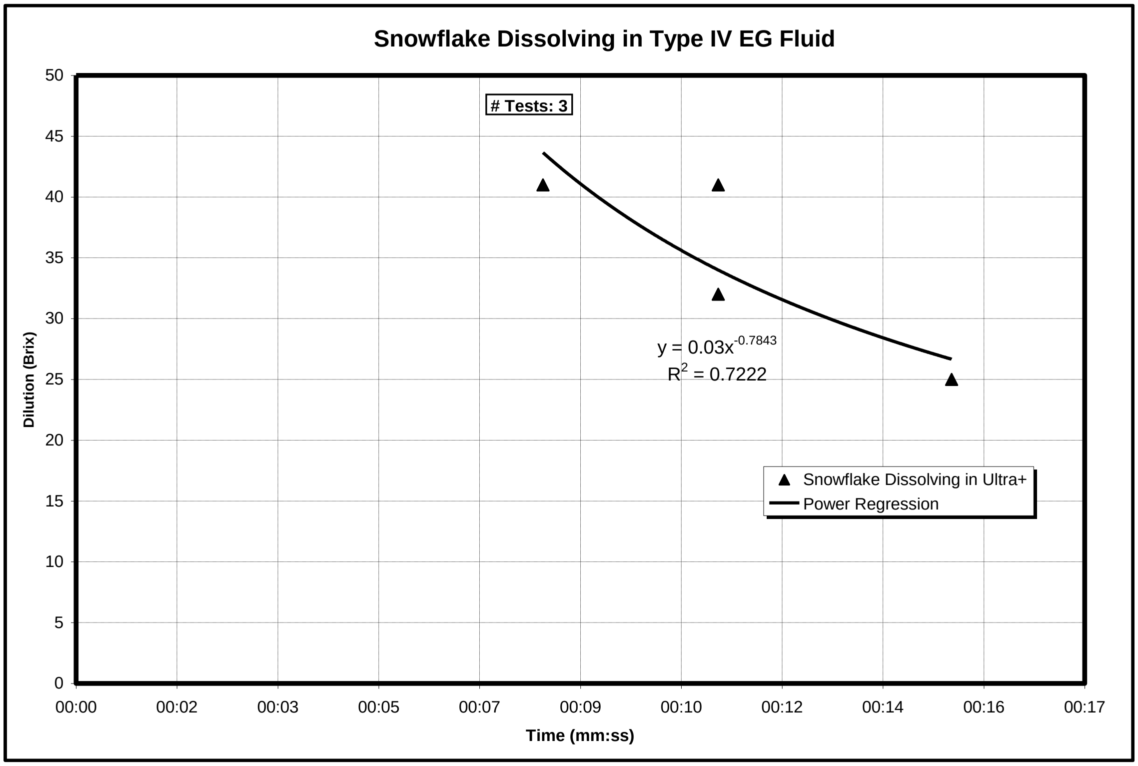

Figure 4.5: Simulated Snowflake Dissolving in Type IV Fluid

Based on the results, the simulated snowflake required a significantly shorter amount of time to fully dissolve in the deicing fluid in comparison to the simulated ice pellet. It should be noted that this testing was conducted to visually demonstrate a single snowflake and a single ice pellet dissolving in deicing fluid, and that the mass of the snowflake was less than that of the ice pellet. It was also observed that the time for the ice precipitation to fully dissolve generally increased as the fluid dilution decreased. Additional data is required to validate the results obtained.

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5. ENDURANCE TIME TESTING

Endurance time testing was conducted during simulated ice pellets conditions on flat plates and on the airfoil. This section describes the data collected and observations documented by the APS research team.

5.1 Log of Tests

To facilitate the accessibility of the data collected, a log was created for the series of tests conducted by APS at the PMG research facility. The log presented in Table 5.1 provides relevant information for each of the endurance time tests conducted, as well as final values recorded. Each row contains data specific to one test. The following is a brief description of the column headings for the test logs:

Test No.:	Exclusive number identifying each test.
Start Time:	Start time for the test recorded in local time.
End Time:	End time for the test recorded in local time.
Total Time:	Total time for the test recorded in minutes.
Test Surface:	Test surface used for the specific test (i.e. test plate or airfoil).
Fluid Name:	Manufacturer brand name specific for each aircraft deicing fluid.
Fluid Dilution:	Aircraft deicing fluid glycol concentration.
Fluid Type:	Aircraft deicing fluid type.
Fluid Temp:	Aircraft deicing fluid temperature prior to application, measured in degrees Celsius.
OAT:	Outside ambient temperature of the PMG research facility chamber, measured in degrees Celsius.
Average Rate of Precipitation:	Average precipitation rate, measured in g/dm²/h, collected by the NCAR bucket for plate test tests, or measured by the three 1 dm² bins placed on the airfoil for the airfoil tests.
Initial Brix:	Fluid Brix measured prior to applying the fluid on the test plate.
Final Brix (Fluid Only):	Fluid Brix measured at the end of the test. The fluid sample did not include any solid precipitation.

Final Brix (Fluid and Pellet Mix): Fluid Brix measured at the end of the test. A sample including fluid and solid precipitation was extracted from the test plate. The sample was melted to create a homogeneous solution. The measured Brix of the homogenous solution was recorded.

Approx. Snow HOT: Snow holdover time, corresponding to the average rate of precipitation during the test, specific to the deicing fluid used, used as a comparative guideline.

Photo Doc.: Designates an endurance time test during which photo documentation was taken at set intervals throughout the test.

5.2 Photo Documentation of Endurance Time Testing on Flat Plates and on the Airfoil

Photos of the test plate were taken at random intervals during the endurance time testing. Photos were taken using a hand-held digital camera from different angles and perspectives. The objective was to obtain photo documentation of the fluid condition while exposed to simulated ice pellet conditions for random time intervals and precipitation rates. Due to the large number of photos taken during each test, a select number of representative photos were chosen for each test. Appendix C includes the photo documentation for each of the eight tests conducted on flat plates. Appendix D includes the photo documentation for each of the three tests conducted on the airfoil. For example, in Appendix C, Test #3 includes five photos demonstrating the condition of the test surface at specified intervals following the start time of the test; the test time elapsed is denoted by Δt: h:mm:ss. Each test included in Appendix C and D includes five or eleven photos taken during the test.

5.3 APS Observations – Endurance Time Testing on Flat Plates

While conducting endurance time tests on flat plates, APS observers found it difficult to determine fluid failure. It was observed that the fluid condition seemed to vary depending on the angle of incidence of the observer's line of sight. As a comparative guideline, the snow holdover times for the specific fluids were included in the test log. APS recommended that fluid failure during ice pellet conditions be characterized to further conduct endurance time testing. Each endurance time test was stopped when the fluid condition was considered to be severe.

5.4 Video Documentation of Endurance Time Testing on the Airfoil

Testing was conducted primarily to demonstrate different pilot perspectives of fluid failure. Video documentation of the airfoil was taken during endurance time testing using two cameras; details of the procedure are included in Section 6.3. Still images were extracted from the videos created. A select number of representative photos were chosen for each camera perspective and were included in Appendix E. Appendix E contains two sets of photos (from the two different camera perspectives) specific to a test. For example, Test #9 includes five photos demonstrating the condition of the test surface from a near perspective, and five photos demonstrating the condition of the test surface from a far perspective. Each pair of near and far photos were taken at similar time intervals for comparative purposes; the test time elapsed is denoted by Δt: h:mm:ss.

5.5 APS Observations – Endurance Time Testing on the Airfoil

Adhesion to the airfoil was observed when conducting endurance time testing using a Type I heated fluid application. The documented observations while conducting endurance time testing on the airfoil will be discussed in Section 6; testing on the airfoil was conducted primarily to demonstrate different pilot perspectives of fluid failure.

Table 5.1: Data Log – Endurance Time Testing

Test #	Start Time (Local)	End Time (Local)	Total Time (min.)	Test Surface	Fluid Name	Fluid Dilution	Fluid Type	Fluid Temp (ºC)	OAT (ºC)	Average Rate of Precip. (g/dm²/h) Plate			Initial Brix	Final Brix (Fluid Only)	Final Brix (Fluid and Pellet Mix)	Approx. Snow HOT (min.)	Photo Doc.
										Bin 1	Bin 2	Bin 3					
1	1:55:10 PM	2:50:00 PM	54.8	Plate	Type IV PG	Neat	4	-5	-5	19.6			36	N/A	N/A	52	
2	1:34:00 PM	2:13:00 PM	39.0	Plate	Type IV PG	Neat	4	-5	-5	22.5			36	N/A	N/A	46	
3	2:33:00 PM	2:36:00 PM	3.0	Plate	Type IV PG	50/50	4	-5	-5	118.7			20	14.25	7	2	X
4	2:50:00 PM	2:56:00 PM	6.0	Plate	Type IV PG	50/50	4	-5	-5	62.7			20	14.25	5	3	X
5	4:04:30 PM	4:20:00 PM	15.5	Plate	Type IV PG	50/50	4	-5	-5	13.4			20	14	11	12	X
6	9:59:00 AM	10:48:00 AM	49.0	Plate	Type IV PG	75/25	4	-5	-5	9.4			29.75	21.25	16	56	X
7	1:23:00 PM	1:44:00 PM	20.0	Plate	Type IV EG	Neat	4	-5	-5	33.0			41	17	6.5	30	X
8	2:25:00 PM	2:40:00 PM	15.0	Plate	Type IV PG	50/50	4	-5	-5	15.5			19	18	10.5	10	X
9	12:31:00 PM	12:38:30 PM	7.5	Airfoil	Type IV PG	50/50	4	-5	-5	29.7	11.2	1.0	19	NA	NA	N/A	X
10	4:31:00 PM	4:55:00 PM	24.0	Airfoil	Type IV PG	50/50	4	-5	-5	24.0	12.8	7.8	19	NA	NA	N/A	X
11	10:00:00 AM	10:10:00 AM	10.0	Airfoil	Type I EG	10º Buffer	1	Warm	-5	25.8	15.6	6.6	41	NA	NA	N/A	X

6. FAR VS. NEAR-PILOTS PERSPECTIVE

Endurance time testing was conducted on the airfoil to determine any differences in fluid condition assessment based on an observer's position and perspective. This section describes the data collected and observations documented by the APS research team.

6.1 Background

At the request of TC, APS coordinated the preliminary production of an educational video documenting simultaneous videos of an airfoil subjected to simulated ice pellet precipitation conditions. Focus was directed towards accurately representing the human observer's view of an airfoil subjected to simulated ice pellet precipitation conditions.

Similar testing will be conducted during the winter of 2005-06 using high definition video cameras. These videos will be made available to pilots, and possibly to airlines, ground deicing crews, and other individuals and/or companies involved in ground de/anti-icing with the goal of improving flight safety.

6.2 Objective

To document simultaneous perspectives representing close in and pilot views of an airfoil subjected to ice pellet precipitation conditions.

6.3 Setup - Simultaneous Filming

The setup required two video cameras to document simultaneous perspectives representing a close-up and distant observer's view of an airfoil subjected to ice pellet precipitation conditions. The two cameras were set up at varying distances. The time stamped videos produced were later edited to provide still images of predetermined times during each test. In accordance with the video documentation of the endurance time test, APS observers were stationed at different locations in the PMG chamber, and their observations, with respect to fluid condition, were documented at set intervals throughout the test. The time stamped videos were later edited to provide still images of predetermined times during each test. Figure 6.1 illustrates the plan view of the setup and the location of the APS observers.

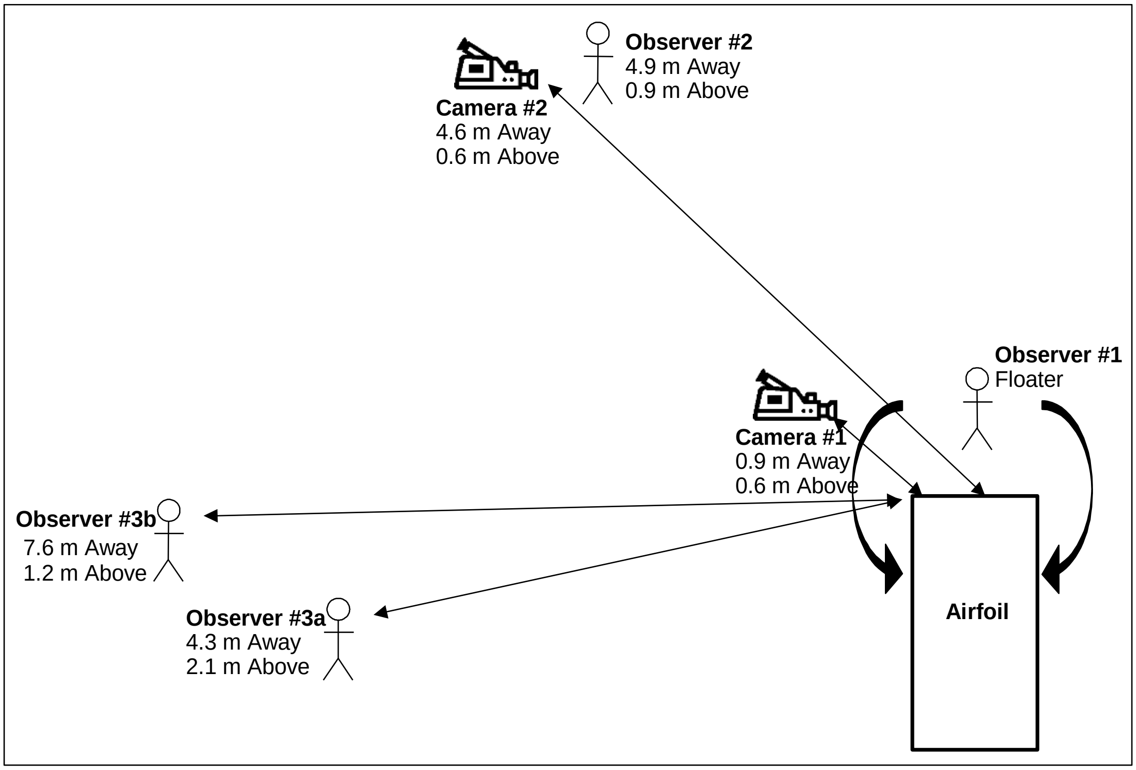

Figure 6.1: Simultaneous Filming Setup and APS Observer Positions

6.4 Video Documentation of Endurance Time Testing on the Airfoil

Testing was conducted primarily to demonstrate different pilot perspectives of fluid contamination. Video documentation of the airfoil was taken during endurance time testing using two cameras. Still images were extracted from the videos created. A select number of representative photos were chosen for each camera perspective for each test and were included in Appendix E. Pertinent test information is included in Table 5.1.

6.5 Observations – Endurance Time Testing on the Airfoil

In accordance with the video documentation of the endurance time test, observers were stationed at different locations in the PMG chamber. Observations, with respect to fluid condition, were recorded at set intervals for the duration of each test. Observers approximated the percentage of the airfoil surface covered by expended deicing fluid for each of the recorded observations. Three observers participated in each test (observer 3a, and observer 3b represent one observer changing locations during each test). The documented observations are included in Table 6.1 to Table 6.3.

Table 6.1: Test # 9 Observations – Simulated Ice Pellet Endurance Time Test on the Airfoil

Simulated Ice Pellet Endurance Time Tests on Airfoil
Test #9 (August 30, 2005)
Octagon Maxflo (50/50)

Time (min)	% Airfoil Failed			
	Observer 1	**Observer 2**	**Observer 3a**	**Observer 3b**
	Obs. Position: Baseline Failure **Distance from Airfoil:** N/A **Height:** N/A	**Obs. Position:** Camera #2 **Dist. from Airfoil:** 4.9 m **Height:** 0.9 m	**Obs. Position:** Staircase **Dist. from Airfoil:** 4.3 m **Height:** 2.1 m	**Obs. Position:** Platform **Dist. from Airfoil:** 25 ft **Height:** 4 ft
1	0	5	0	--
2	0	5	10	--
3	0	10	--	50 **(Failed)**
4	5 to 10	15	20	--
6	33 **(Failed)**	25	--	100
7	--	33 **(Failed)**	50 **(Failed)**	--

Table 6.2: Test # 10 Observations – Simulated Ice Pellet Endurance Time Test on the Airfoil

Simulated Ice Pellet Endurance Time Tests on Airfoil
Test #10 (August 30, 2005)
Octagon Maxflo (50/50)

Time (min)	% Airfoil Failed			
	Observer 1	**Observer 2**	**Observer 3a**	**Observer 3b**
	Obs. Position: Baseline Failure **Distance from Airfoil:** N/A **Height:** N/A	**Obs. Position:** Camera #2 **Dist. from Airfoil:** 4.9 m **Height:** 0.9 m	**Obs. Position:** Staircase **Dist. from Airfoil:** 4.3 m **Height: 2.1 m**	**Obs. Position:** Platform **Dist. from Airfoil:** 7.6 m **Height:** 1.2 m
1	0	0	0	0
2	0	0	1	--
4	2 to 5	5	5	--
5	--	10	5	--
6	3	12	10	10
7	--	15	--	--
8	4 to 5	17	15	--
9	--	17	15	10
10	5	20	15	--
11	--	23	15	--
13	--	25	20	--
14	7	--	20	--
15	--	27	--	50 **(Failed)**
16	--	--	20	
17	--	30	--	
18	10	--	25	
19	--	33 **(Failed)**	--	
20	14	--	50 **(Failed)**	
21	--	36	--	
22	--	37	--	
23	--	--	75	
24	18	--	75	

Table 6.3: Test # 11 Observations – Simulated Ice Pellet Endurance Time Test on the Airfoil

Simulated Ice Pellet Endurance Time Tests on Airfoil
Test #11 (August 31, 2005)
EG UCAR Type I (10 º Buffer)

Time (min)	% Airfoil Failed			
	Observer 1	**Observer 2**	**Observer 3a**	**Observer 3b**
	Obs. Position: Baseline Failure **Distance from Airfoil:** N/A **Height:** N/A	**Obs. Position:** Camera #2 **Dist. from Airfoil:** 4.9 m **Height:** 0.9 m	**Obs. Position:** Staircase **Dist. from Airfoil:** 4.3 m **Height:** 2.1 m	**Obs. Position:** Platform **Dist. from Airfoil:** 7.6 m **Height: 1.2 m**
0.5	0	0	0	0
1.0	0	0	0	0
1.5	0	0	5	5
2.0	0	0	5	--
2.5	0	0	--	8
3.0	--	5	10	--
3.5	--	10	--	10
4.0	1	10	15	--
4.5	--	15	--	15
5.0	5	20	30	--
5.5	--	22	--	30
6.0	20	25	50 **(Failed)**	--
6.5	50 **(Failed)**	27	--	50 **(Failed)**
7.0	70	30	60	--
7.5	--	33 **(Failed)**	--	60
8.0	--	40	65	--
8.5	--	50	--	60
9.0	100	55	75	--
9.5		60	--	80
10.0		65	90	

It was observed that the fluid condition seemed to vary based on the observer's position with respect to the airfoil. The further away the observer was located, the more difficult it was for the observer to distinguish whether the deicing fluid had expended. In addition, without a standardized method to visually determine fluid failure, APS observers found it difficult to assess the fluid condition.

7. CONCLUSIONS

The preliminary conclusions drawn from the tests performed at the PMG research facility are described in this section. These conclusions are preliminary in that the procedure to conduct endurance time testing in simulated ice pellet conditions is still in development.

7.1 Procedural Feasibility

Preliminary calibration tests indicated that the procedure used to simulate ice pellet conditions generated results that were deemed acceptable according to the procedural requirements.

7.2 Endurance Time Testing in Simulated Ice Pellet Conditions

While conducting endurance time testing on a standard test plate surface and on the airfoil, APS observers found it difficult to determine fluid failure. Fluid contamination was observed after short periods of exposure to simulated ice pellet conditions. However, it is unknown if this contamination would flow-off a wing surface at aircraft rotation speeds. It was observed that the fluid condition seemed to vary depending on the observer's sight-line angle of incidence. Each endurance time test was stopped when the fluid condition was severe.

7.3 Far vs. Near-Pilots Perspective

It was observed that the fluid condition seemed to vary based on the observer's position with respect to the airfoil. The farther away the observer was located, the more difficult it was for the observer to distinguish whether the deicing fluid had expended. In addition, without a standardized method to visually determine fluid failure, APS observers found it difficult to assess the fluid condition.

7.4 Ice Precipitation Dissolving in Deicing Fluid

Results demonstrated that the simulated snowflake required a significantly shorter amount of time to fully dissolve in the deicing fluid in comparison to the simulated ice pellet. It was also observed that the time for the ice precipitation to fully dissolve generally increased as the fluid dilution decreased.

7.5 Adhesion on Aluminum Surfaces

Adhesion to the airfoil was observed when conducting endurance time testing using a Type I heated fluid application. With Type IV fluid applied at -5°C, the ice pellets did not adhere to the aluminum test surfaces. However, it is not known whether the contamination would be removed during a takeoff run.

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8. RECOMMENDATIONS

8.1 Procedural Enhancements

It is recommended that natural ice pellet endurance time data be collected to validate the results obtained using simulated ice pellets. It is also recommended that a sample of natural ice pellets be photographed to document the size distribution and shape of the ice pellets to validate the dimensions of the simulated ice pellets produced by APS.

8.2 Endurance Time Testing in Simulated Ice Pellet Conditions

It is recommended that fluid failure during ice pellet conditions be characterized. Comparative testing in simulated snow and ice pellet conditions should be conducted to document fluid Brix values at select intervals throughout the endurance time test. Documenting fluid Brix will demonstrate the fluid dilution process during the endurance time test and may provide a better outlook on how to characterize fluid failure during ice pellet conditions.

8.3 Far vs. Near-Pilots Perspective

It is recommended that video documentation of an airfoil subject to ice pellet conditions be acquired using a high definition video camera. Different camera positions should be explored to find a camera perspective which best represents a pilot's perspective of an aircraft wing.

8.4 Ice Precipitation Dissolving in Deicing Fluid

Testing should be continued using different dilutions of the fluid previously tested. Comparative testing should also be conducted using equal masses of simulated snow and simulated ice pellets.

8.5 Adhesion on Aluminum Surfaces

Testing should be conducted using heated Type II and Type IV to verify if these conditions can cause adhesion on aluminum test surfaces during ice pellet conditions. Mixed precipitation testing (simulated freezing rain and ice pellet conditions) should also be conducted at temperatures close to 0°C.

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APPENDIX A

DATA FORMS

Fluid Endurance Time and Rate of Precipitation Data Form - Simulated Ice Pellet Conditions

Date:	
Run #:	

Fluid Name:	
Fluid Dilution:	
Test Surface:	

Time	Weight	Time	Weight	Time	Weight

Time	Brix	Thickness
Initial		

HOT	
Avg Rate	

M:\Groups\CM1892 (TC-Deicing 04-05)\Data\Ice Pellets PMG\Ice Pellets\Procedures

Fluid Failure Observation Data Form - Simulated Ice Pellet Conditions on Airfoil

Observation Position	
Distance from Airfoil	
Height (eye level to top of Airfoil)	

Time	% Airfoil Failed	Picture Taken (Y/N)	Observations

- Approximately ten observations should be recorded per test.
- The time interval between observations can be approximated by taking The expected HOT of the fluid being tested and dividing by ten.
- A final observation should be recorded once fluid failure has been confirmed.

M:\Groups\CM1892 (TC-Deicing 04-05)\Data\Ice Pellets PMG\Ice Pellets\Procedures

APPENDIX B

ICE PRECIPITATION DISSOLVING IN DEICING FLUID

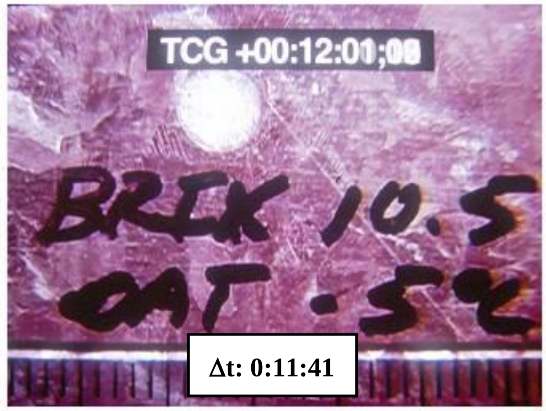
Ice Pellet Dissolving in Deicing Fluid

TEST # 1

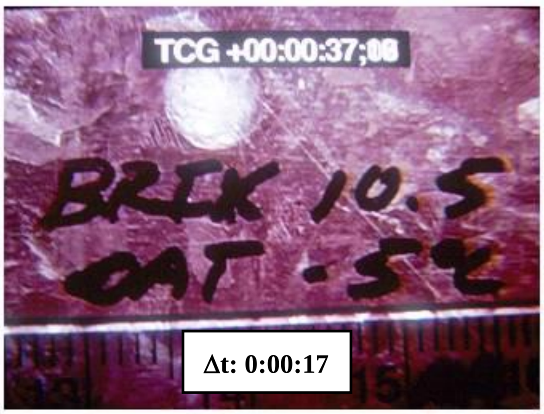
Type I EG

Total Time to Dissolve: Did not Melt

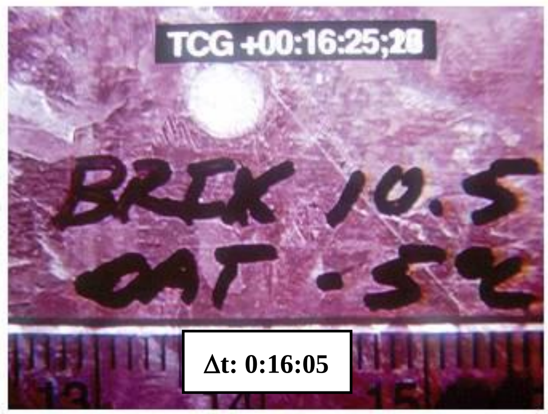
Start Time: 0:00:21
End Time: _:_:_
Initial Brix: 10.5



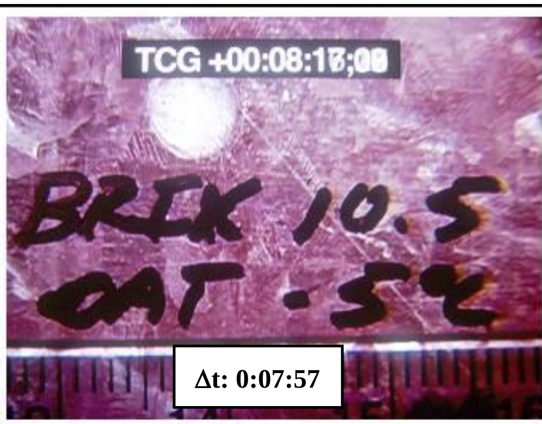
Δt: 0:11:41



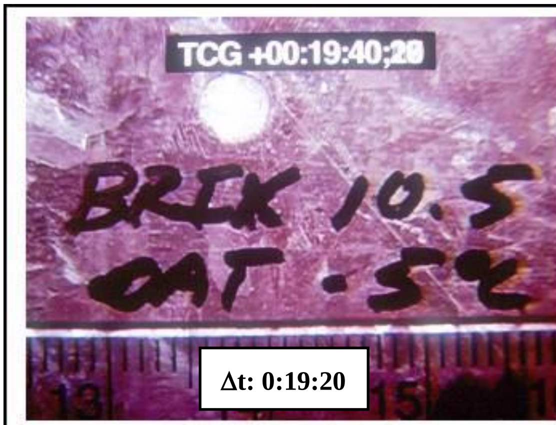
Δt: 0:00:17



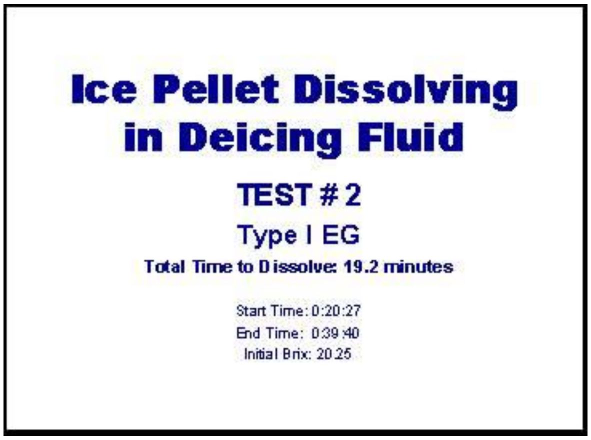
Δt: 0:16:05

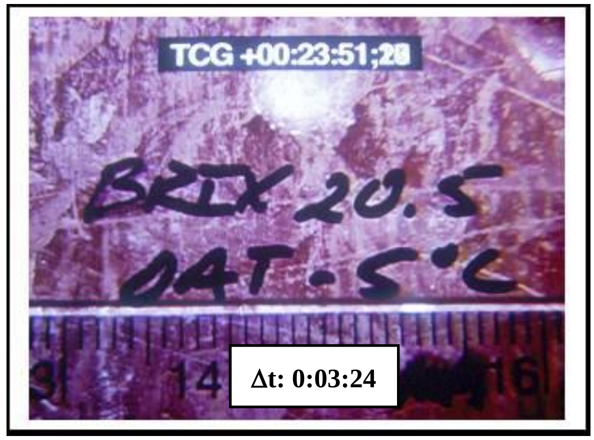


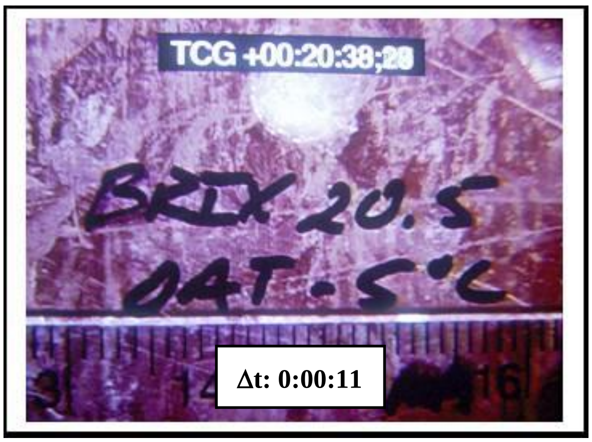
Δt: 0:07:57

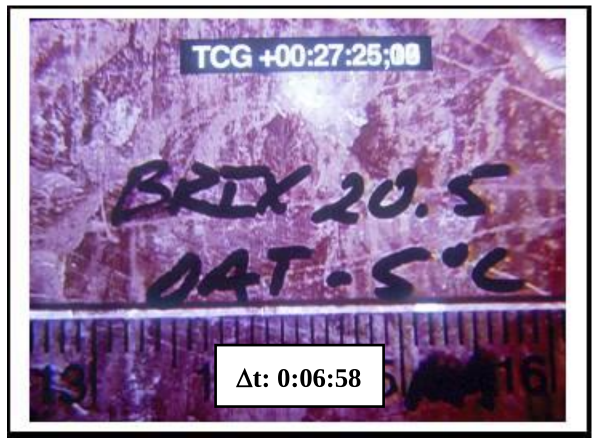


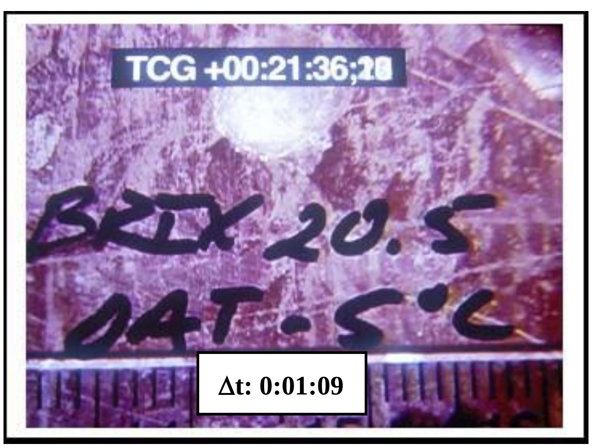
Δt: 0:19:20


Ice Pellet Dissolving
in Deicing Fluid
TEST # 2
Type I EG
Total Time to Dissolve: 19.2 minutes
Start Time: 0:20:27
End Time: 0:39:40
Initial Brix: 20.25


TCG +00:23:51;28
BRIX 20.5
OAT -5°C
Δt: 0:03:24


TCG +00:20:38;28
BRIX 20.5
OAT -5°C
Δt: 0:00:11


TCG +00:27:25;00
BRIX 20.5
OAT -5°C
Δt: 0:06:58


TCG +00:21:36;28
BRIX 20.5
OAT -5°C
Δt: 0:01:09


TCG +00:39:37;28
BRIX 20.5
OAT -5°C
Δt: 0:19:10

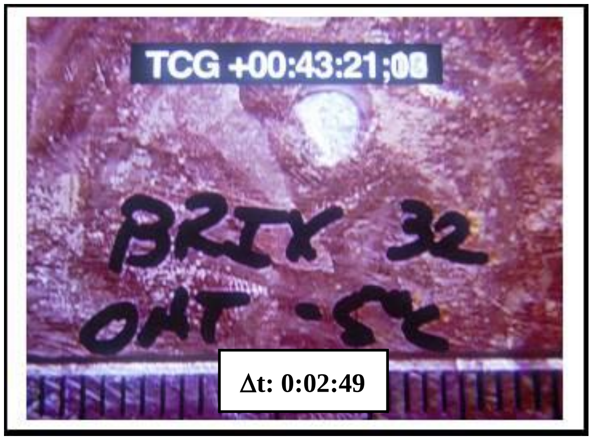
Ice Pellet Dissolving in Deicing Fluid

TEST # 3

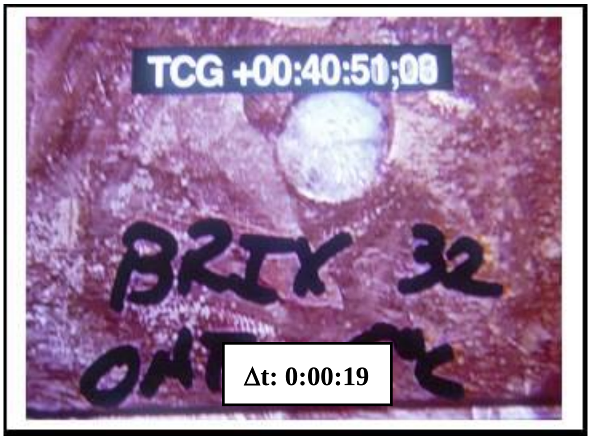
Type I EG

Total Time to Dissolve: 14.3 minutes

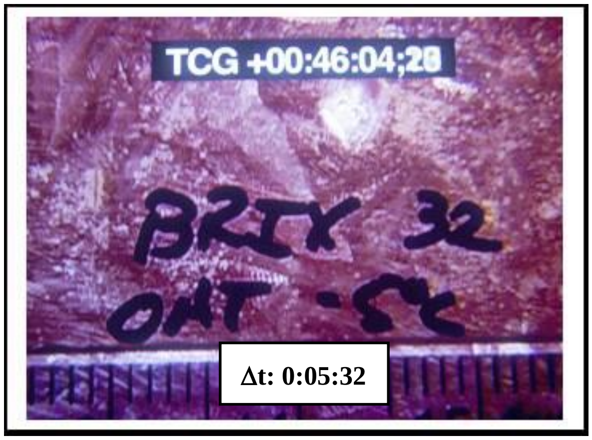
Start Time: 0:40:32
End Time: 0:54:55
Initial Brix: 32



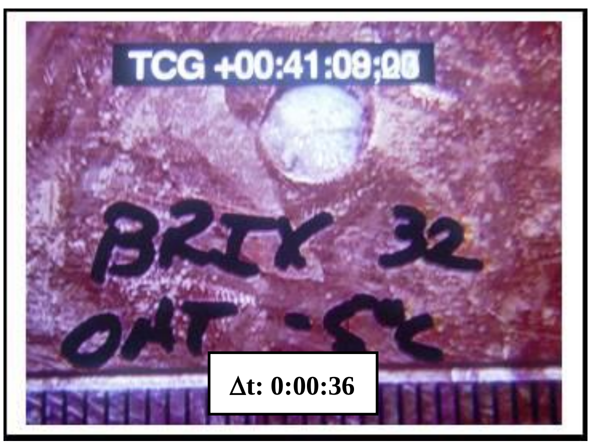
Δt: 0:02:49



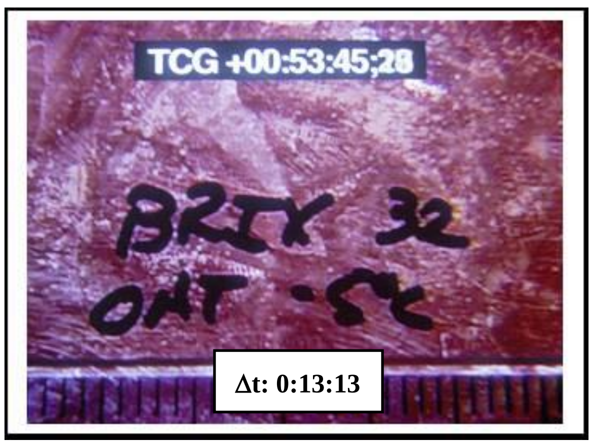
Δt: 0:00:19



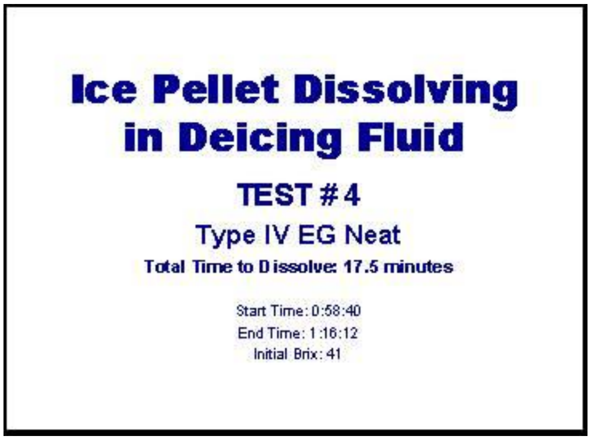
Δt: 0:05:32



Δt: 0:00:36

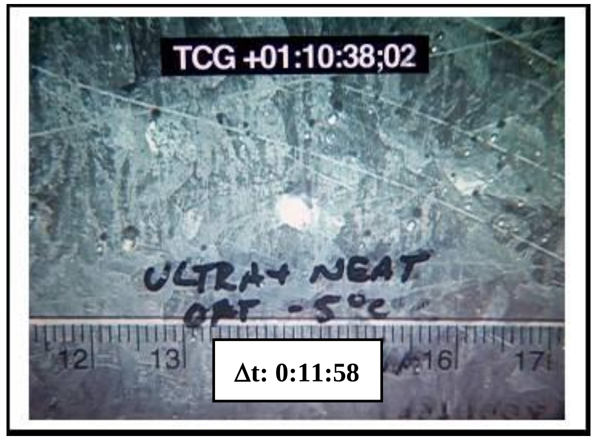


Δt: 0:13:13

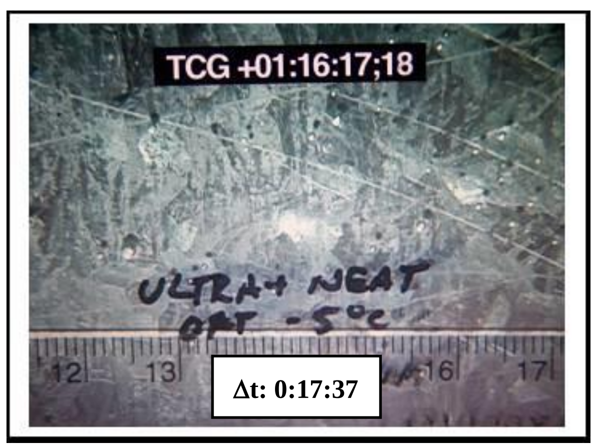

Ice Pellet Dissolving
in Deicing Fluid
TEST # 4
Type IV EG Neat
Total Time to Dissolve: 17.5 minutes
Start Time: 0:58:40
End Time: 1:16:12
Initial Brix: 41


TCG +00:58:48;07
12 13 16 17
Δt: 0:00:08


TCG +01:05:02;22
12 13 16 17
Δt: 0:06:22


TCG +01:10:38;02
12 13 16 17
Δt: 0:11:58


TCG +01:14:37;15
12 13 16 17
Δt: 0:15:57


TCG +01:16:17;18
12 13 16 17
Δt: 0:17:37

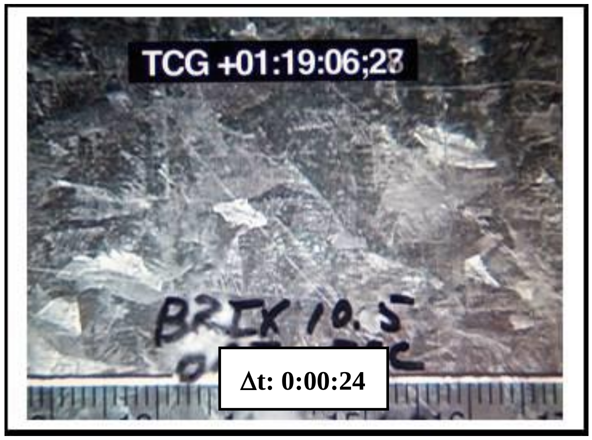
Snowflake Dissolving in Deicing Fluid

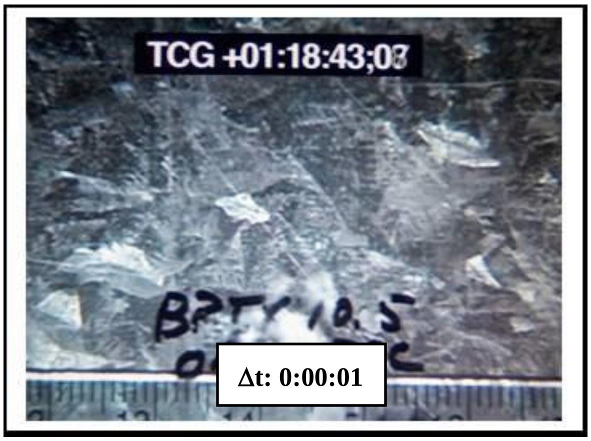
TEST # 5

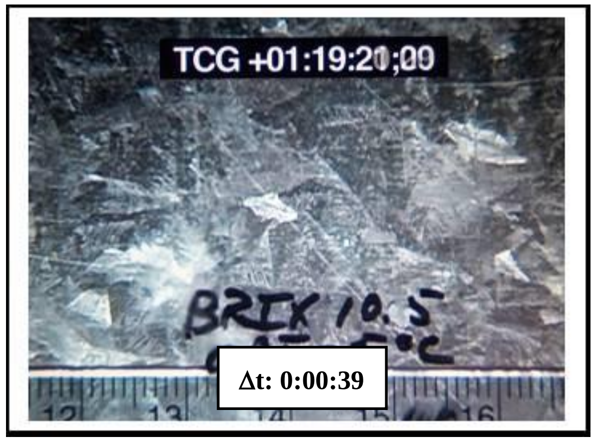
Type I EG

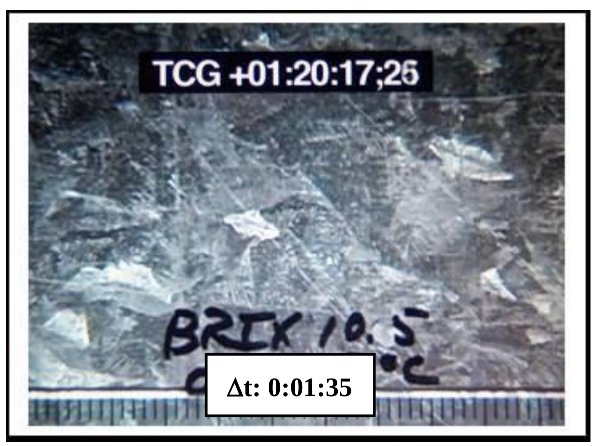
Total Time to Dissolve: 1.7 minutes

Start Time: 1:18:42
End Time: 1:20:24
Initial Brix: 10.5









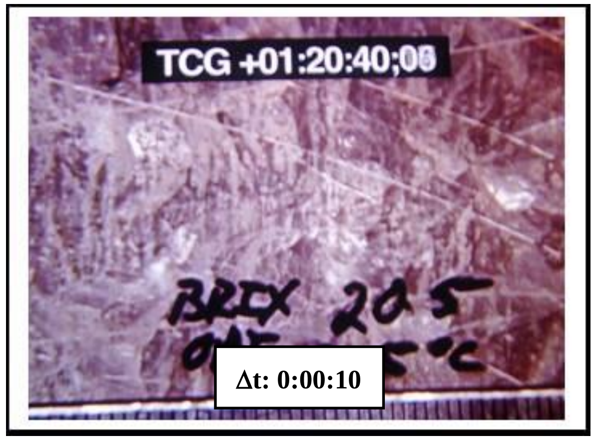
Snowflake Dissolving in Deicing Fluid

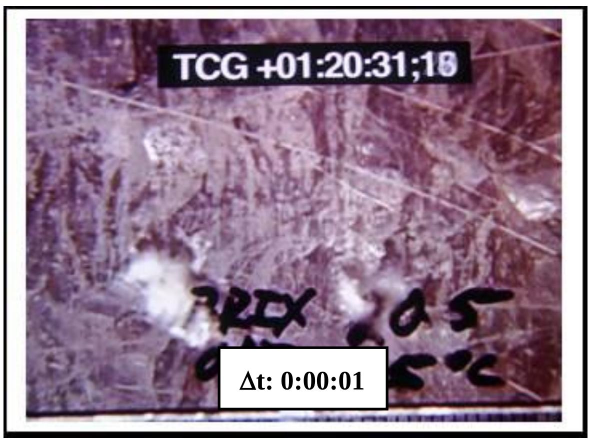
TEST # 6

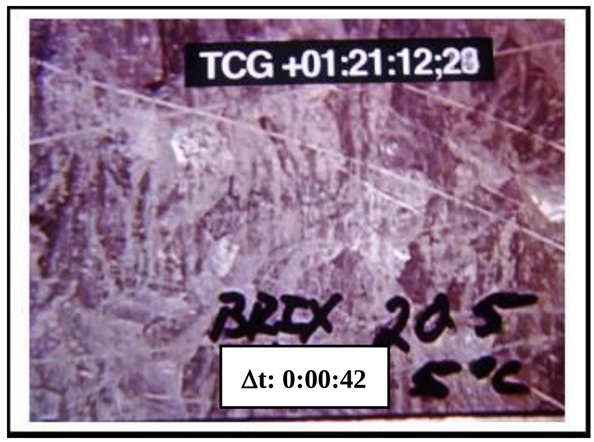
Type I EG

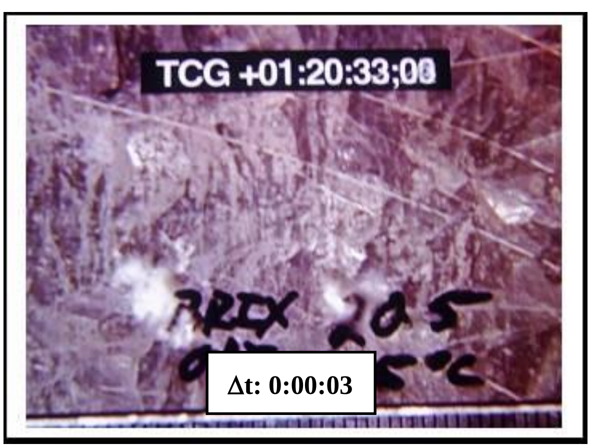
Total Time to Dissolve: 0.75 minutes

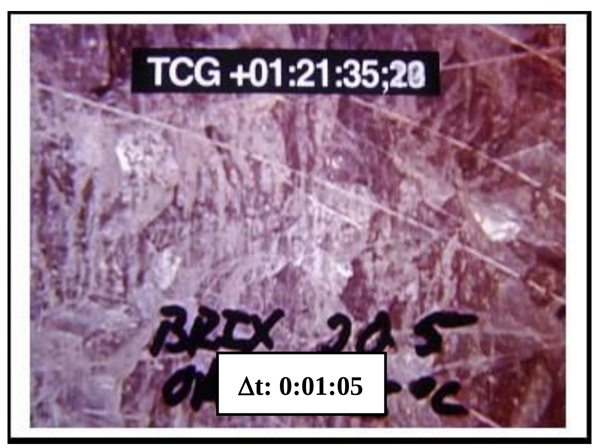
Start Time: 1:20:30
End Time: 1:21:15
Initial Brix: 20.5











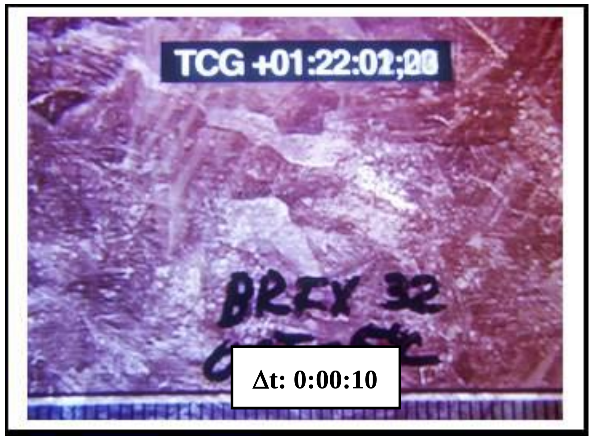
Snowflake Dissolving in Deicing Fluid

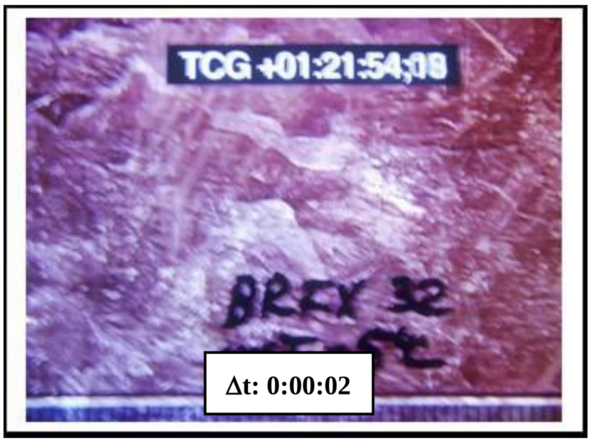
TEST # 7

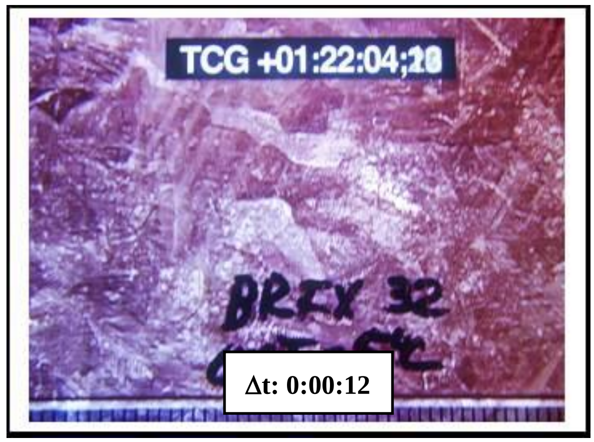
Type I EG

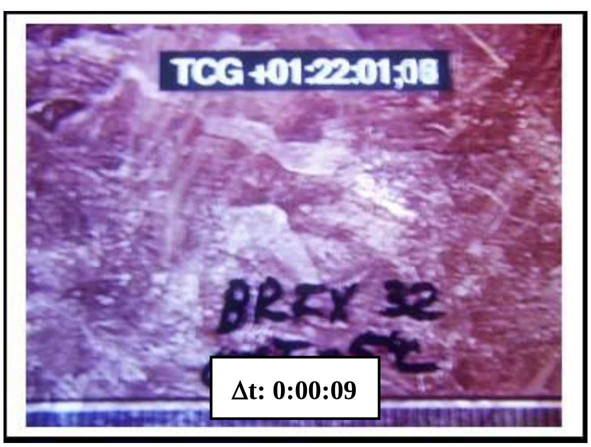
Total Time to Dissolve: 0.2 minutes

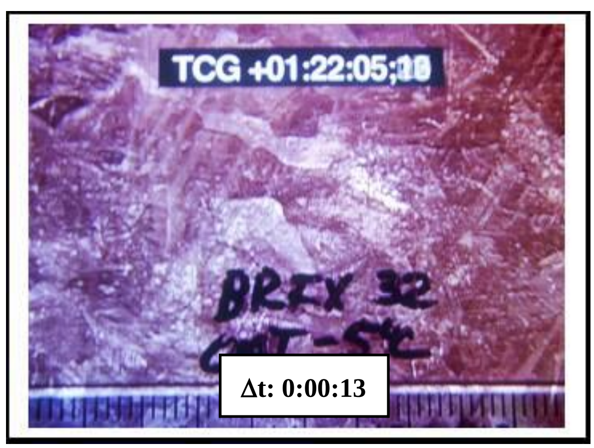
Start Time: 1:21:52
End Time: 1:22:04
Initial Brix: 32











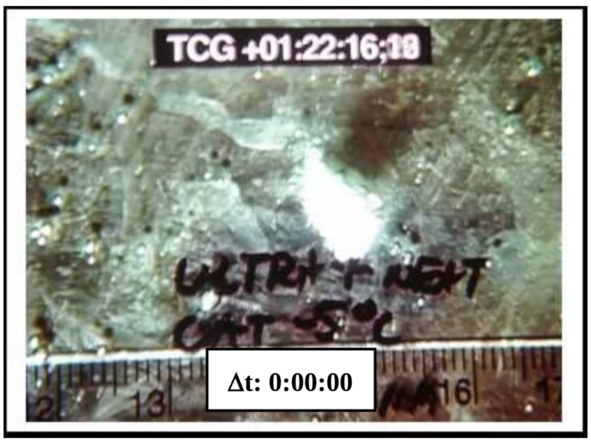
Snowflake Dissolving in Deicing Fluid

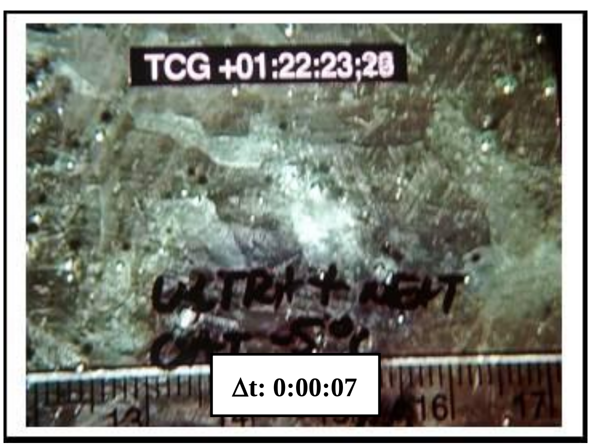
TEST # 8

Type IV EG Neat

Total Time to Dissolve: 0.18 minutes

Start Time: 1:22:16
End Time: 1:22:27
Initial Brix: 41





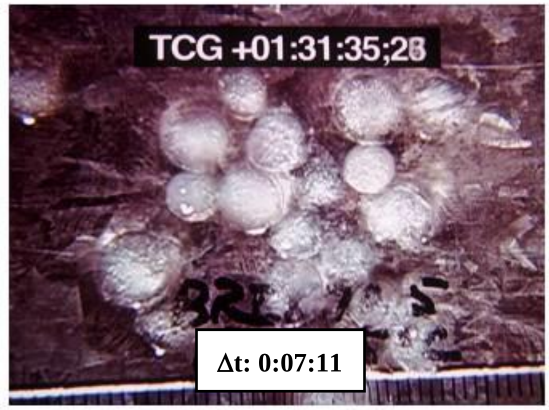
Ice Pellet Dissolving in Deicing Fluid

TEST # 9

Type I EG

Total Time to Dissolve: Did not Melt

Start Time: 1:24:24
End Time: _:__:__
Initial Brix: 10.5

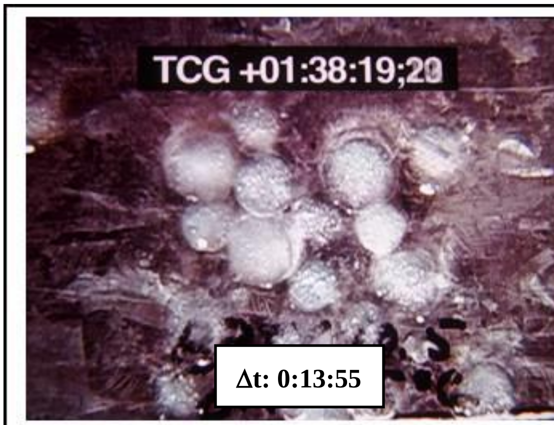


Δt: 0:07:11

Δt: 0:00:26

Δt: 0:10:44

Δt: 0:02:51



Δt: 0:13:55

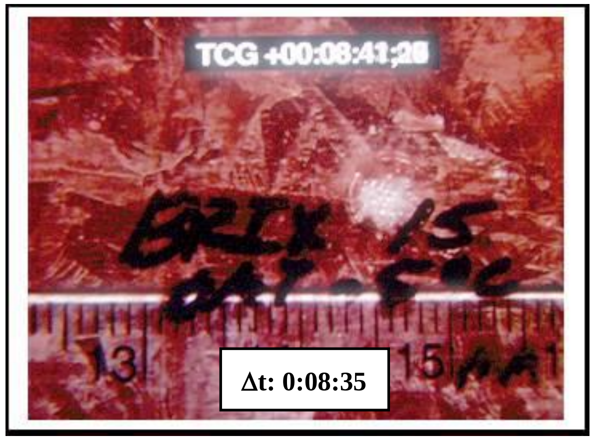
Ice Pellet Dissolving in Deicing Fluid

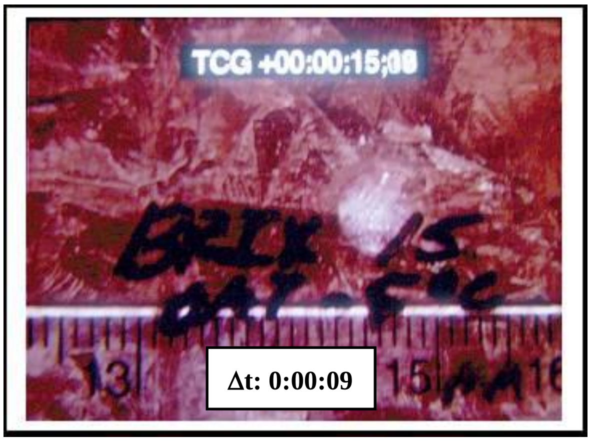
TEST # 10

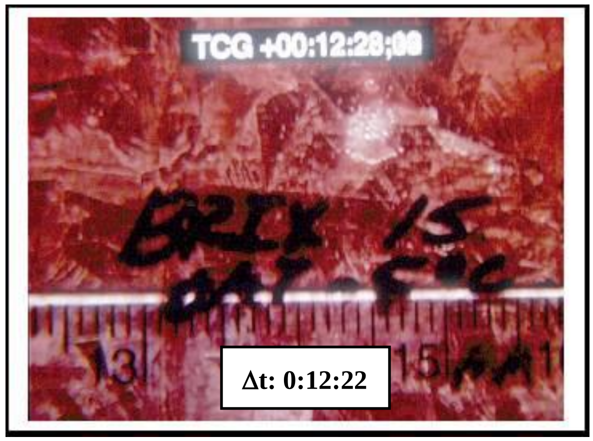
Type I EG

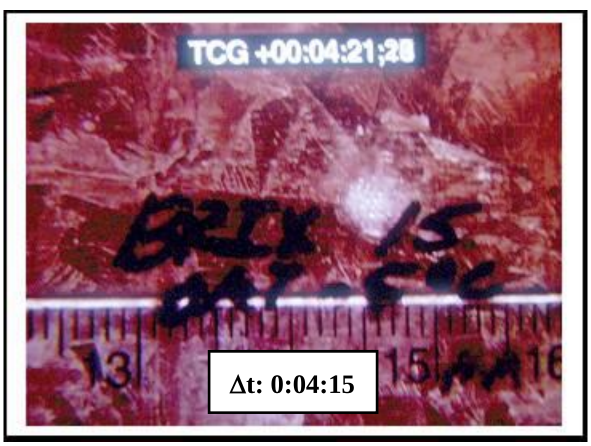
Total Time to Dissolve: 21.2 minutes

Start Time: 0:00:06
End Time: 0:21:16
Initial Brix: 15









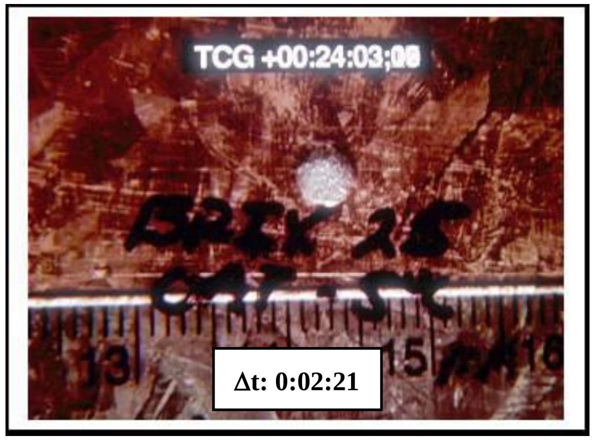
Ice Pellet Dissolving in Deicing Fluid

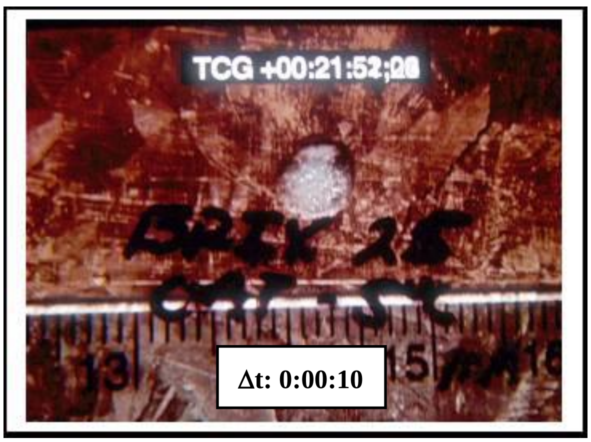
TEST # 11

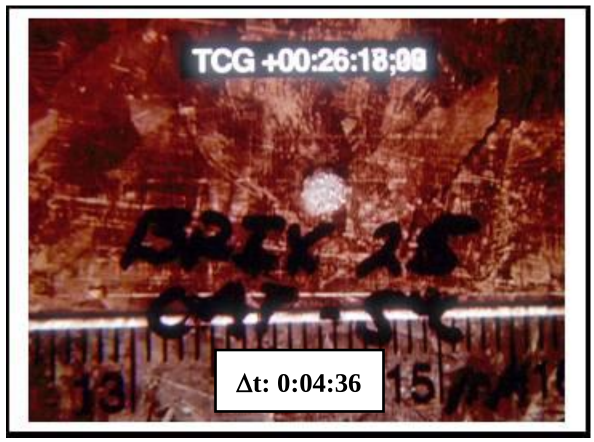
Type I EG

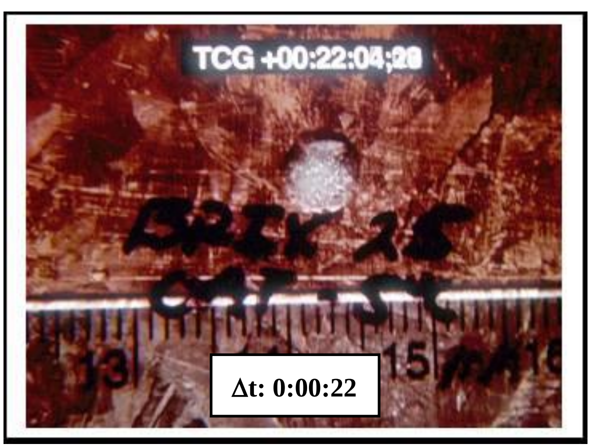
Total Time to Dissolve: 11.7 minutes

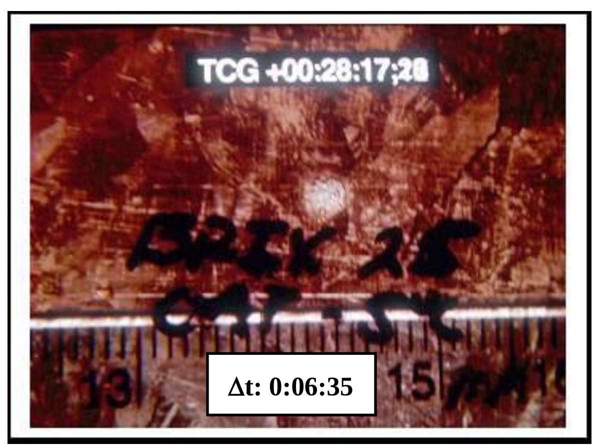
Start Time: 0:21:42
End Time: 0:33:23
Initial Brix: 25











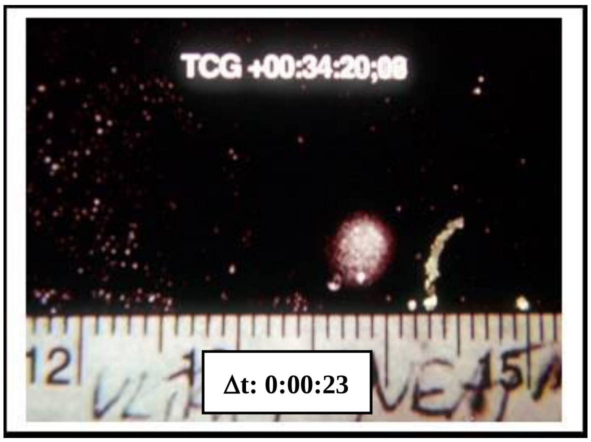
Ice Pellet Dissolving in Deicing Fluid

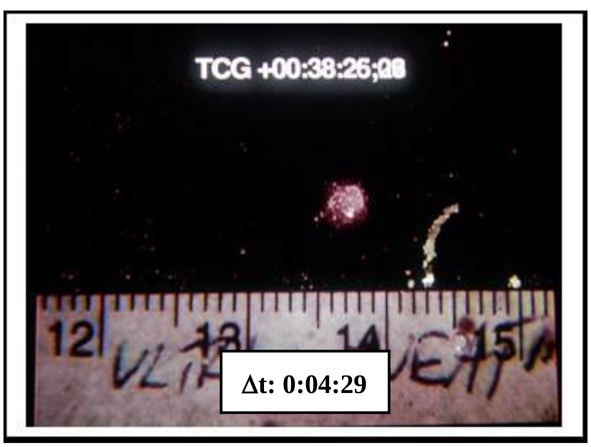
TEST # 12

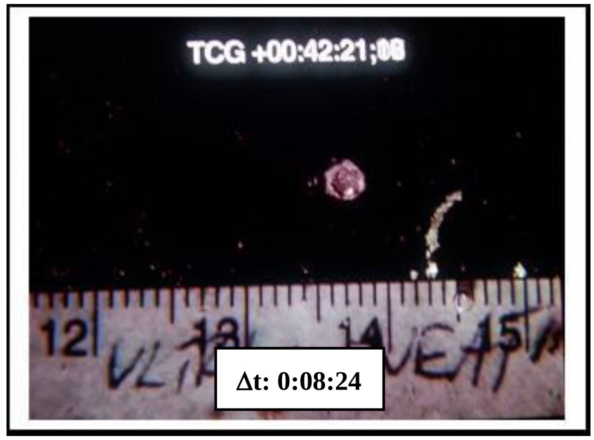
Type IV EG Neat

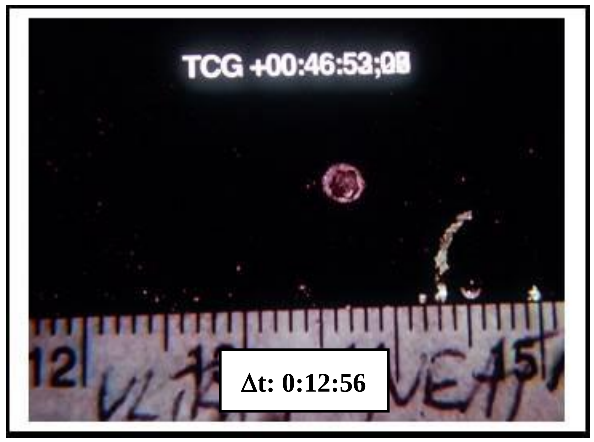
Total Time to Dissolve: 23.3 minutes

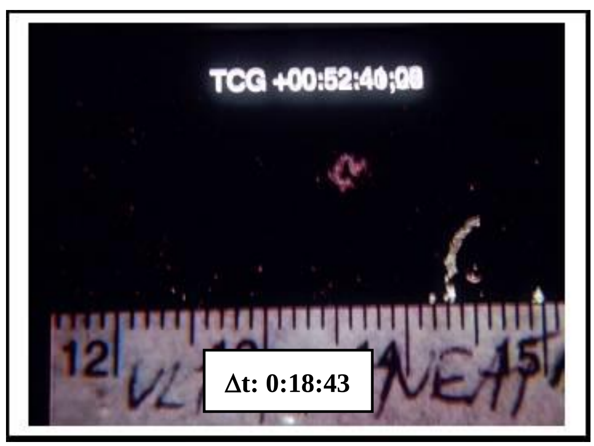
Start Time: 0:33:57
End Time: 0:57:13
Initial Brix: 41











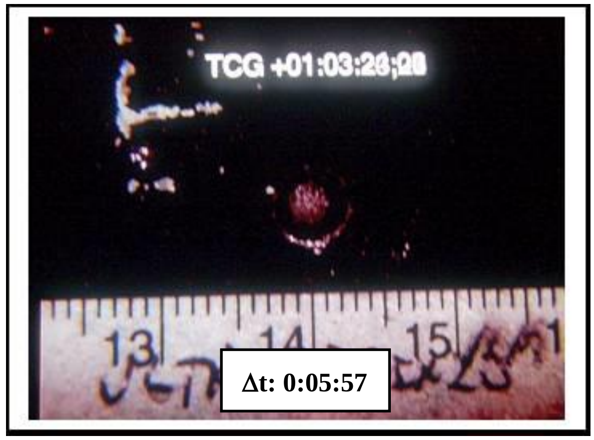
Ice Pellet Dissolving in Deicing Fluid

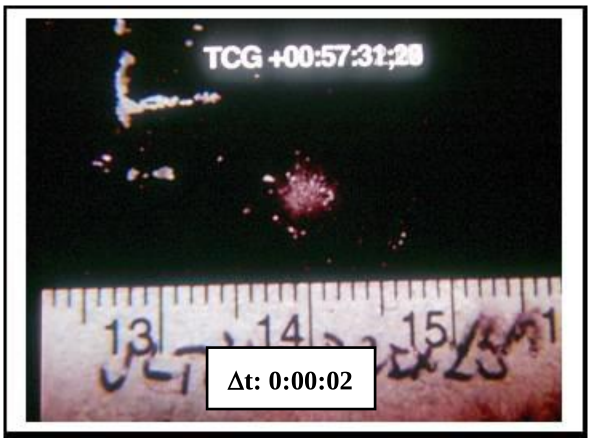
TEST # 13

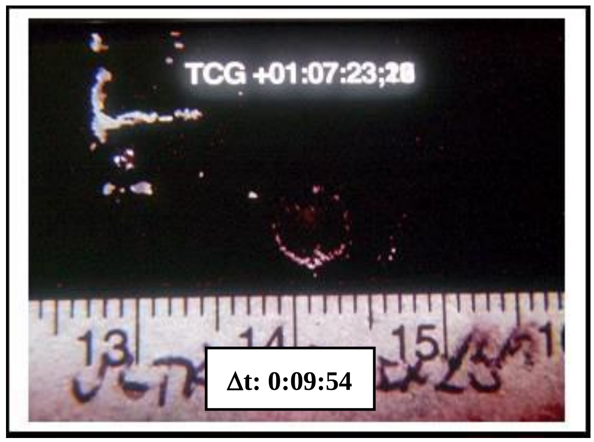
Type IV EG (50/50)

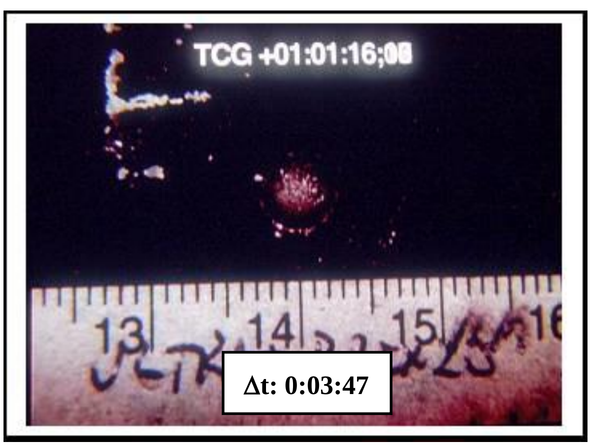
Total Time to Dissolve: 12.2 minutes

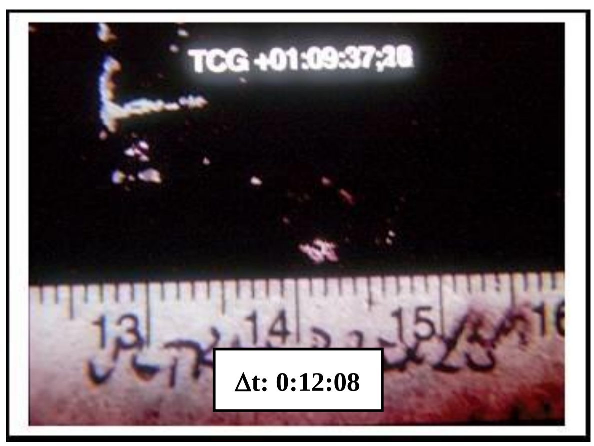
Start Time: 0:57:29
End Time: 1:09:42
Initial Brix: 25











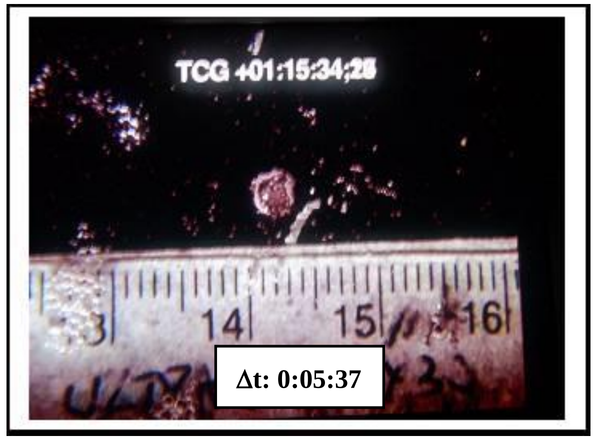
Ice Pellet Dissolving in Deicing Fluid

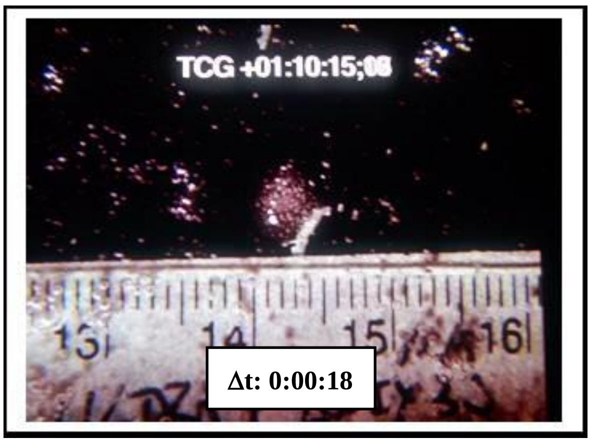
TEST # 14

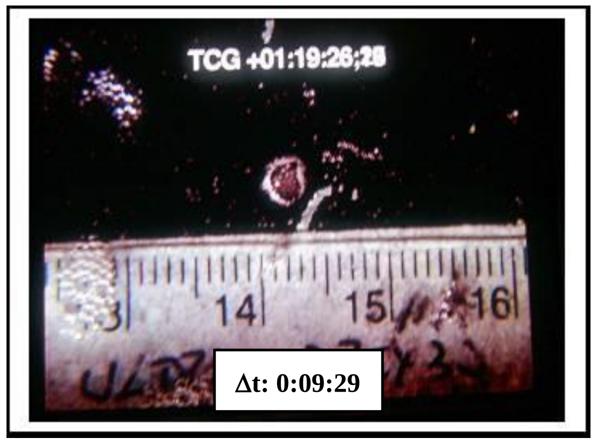
Type IV EG (75/25)

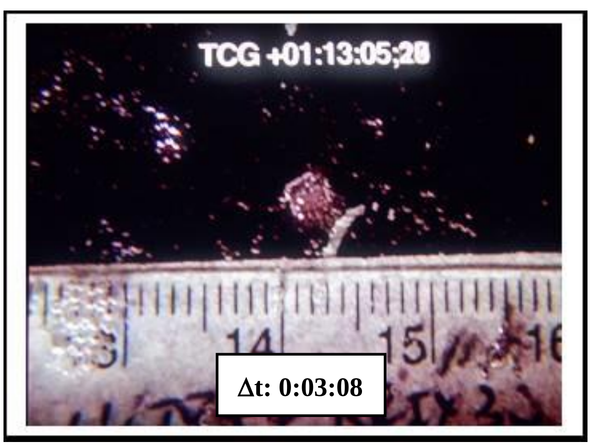
Total Time to Dissolve: 12.9 minutes

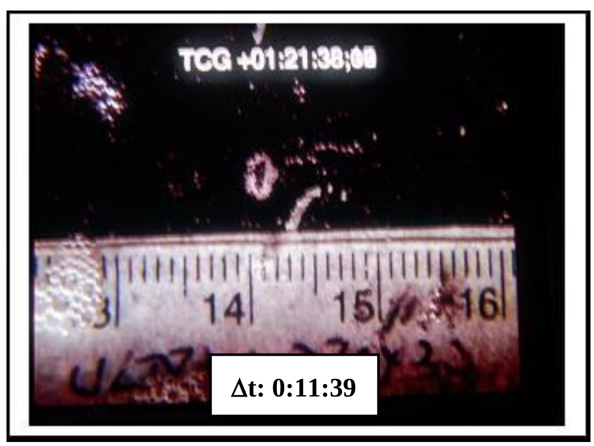
Start Time: 1:09:57
End Time: 1:22:52
Initial Brix: 32

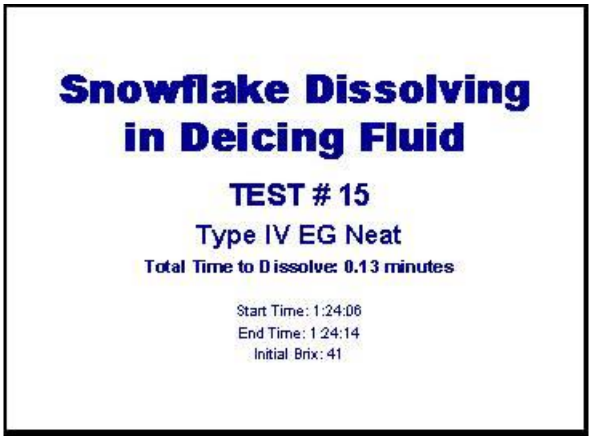


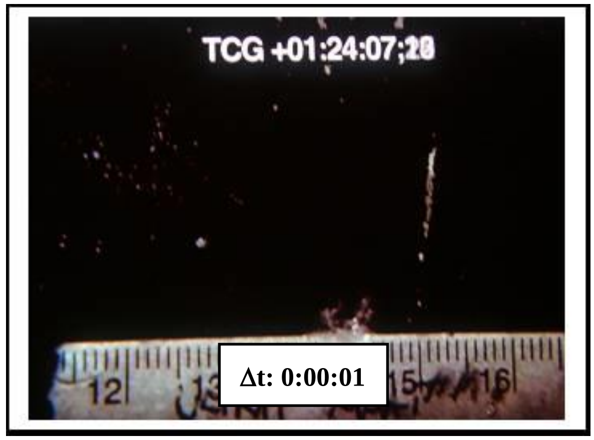




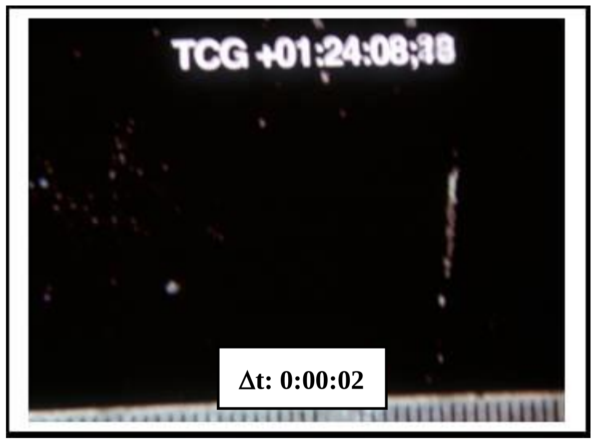


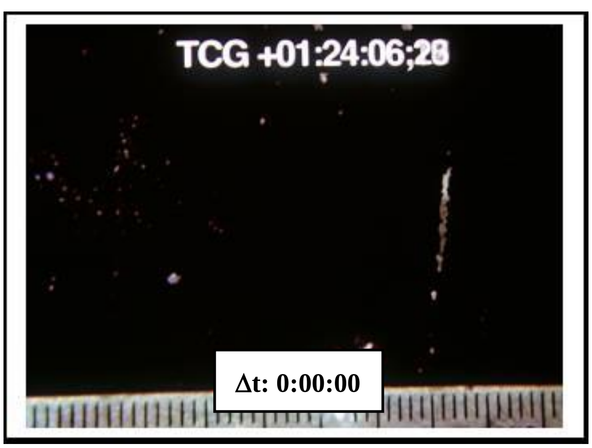


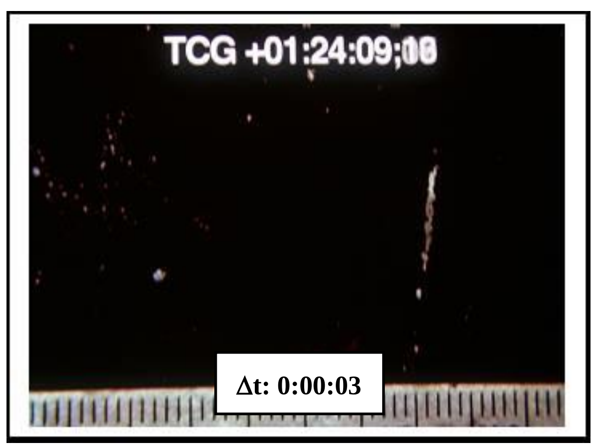

Snowflake Dissolving
in Deicing Fluid
TEST # 15
Type IV EG Neat
Total Time to Dissolve: 0.13 minutes
Start Time: 1:24:06
End Time: 1:24:14
Initial Brix: 41


TCG +01:24:07;28
Δt: 0:00:01


TCG +01:24:06;08
Δt: 0:00:00


TCG +01:24:08;18
Δt: 0:00:02


TCG +01:24:06;28
Δt: 0:00:00


TCG +01:24:09;08
Δt: 0:00:03

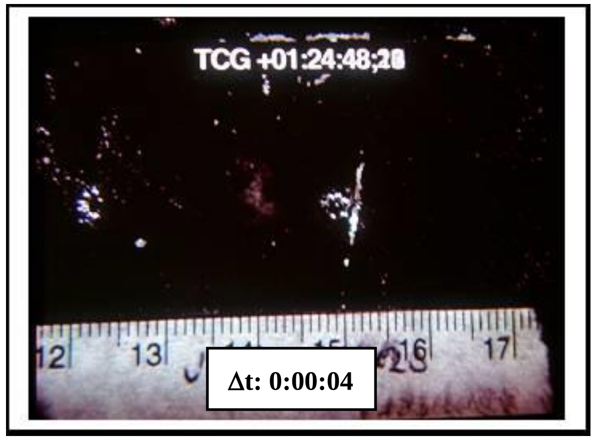
Snowflake Dissolving in Deicing Fluid

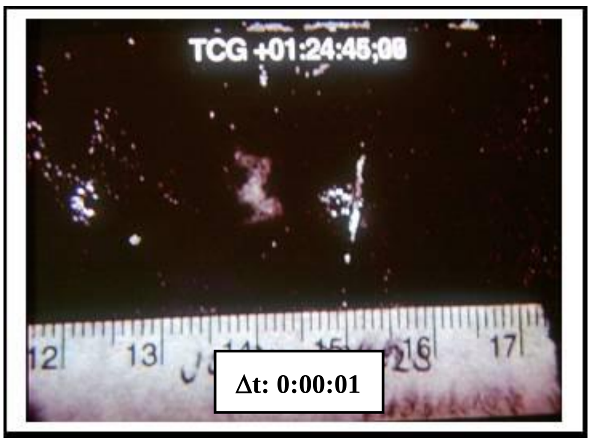
TEST # 16

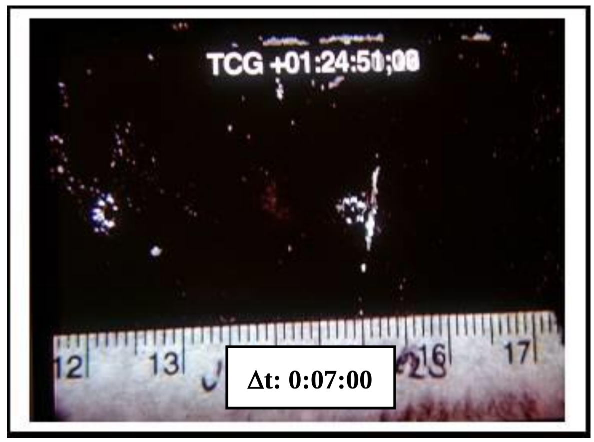
Type IV EG (50/50)

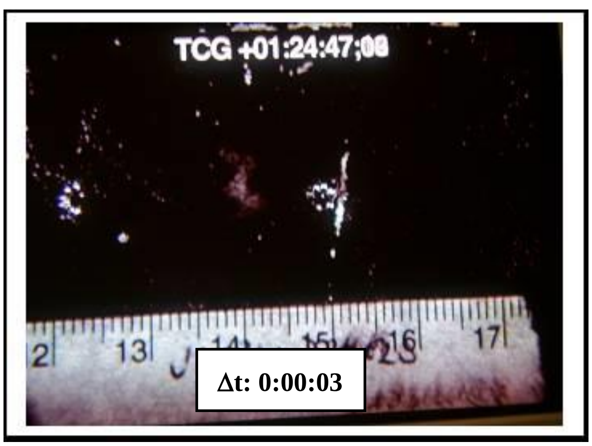
Total Time to Dissolve: 0.25 minutes

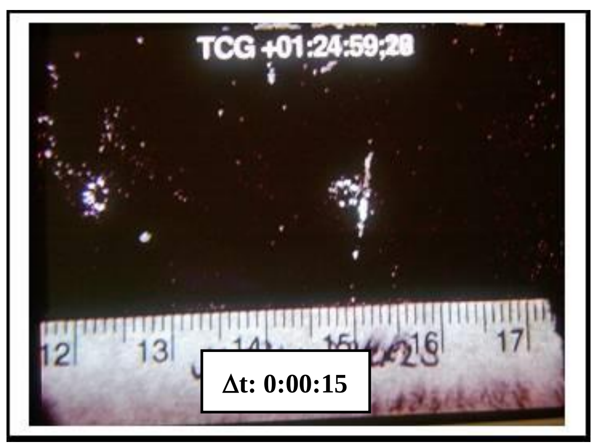
Start Time: 1:24:44
End Time: 1:24:59
Initial Brix: 25











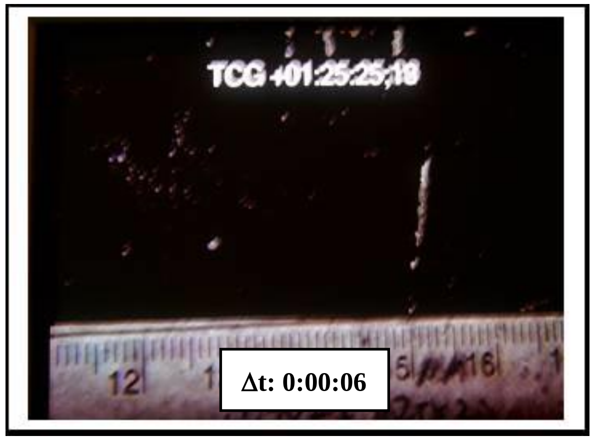
Snowflake Dissolving in Deicing Fluid

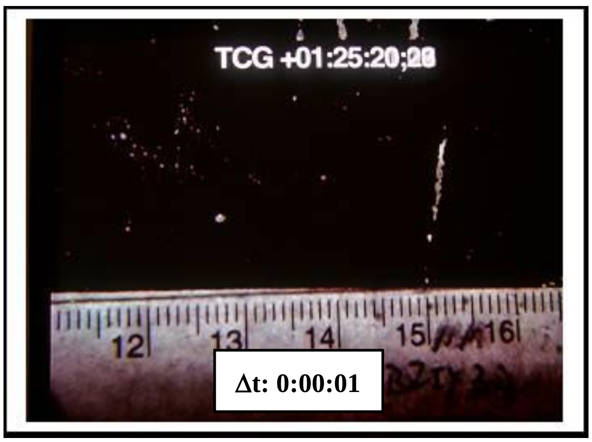
TEST # 17

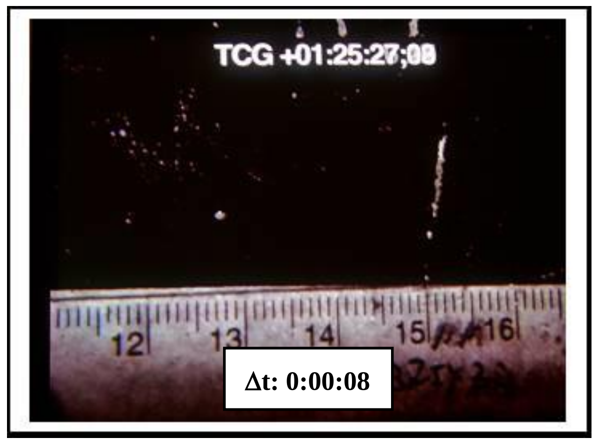
Type IV EG (75/25)

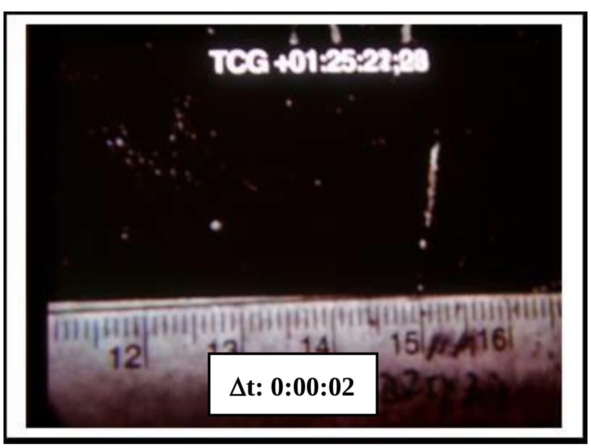
Total Time to Dissolve: 0.18 minutes

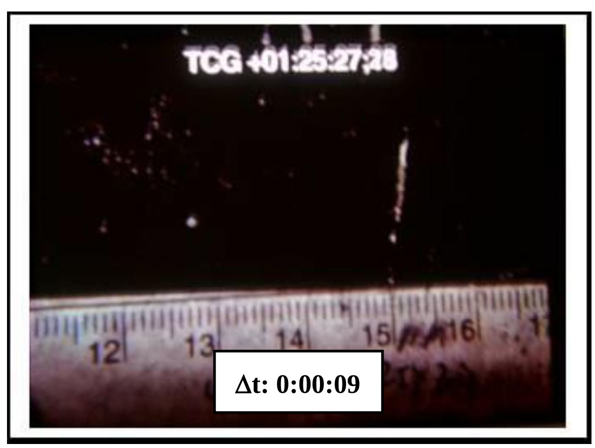
Start Time: 1:25:19
End Time: 1:25:30
Initial Brix: 32











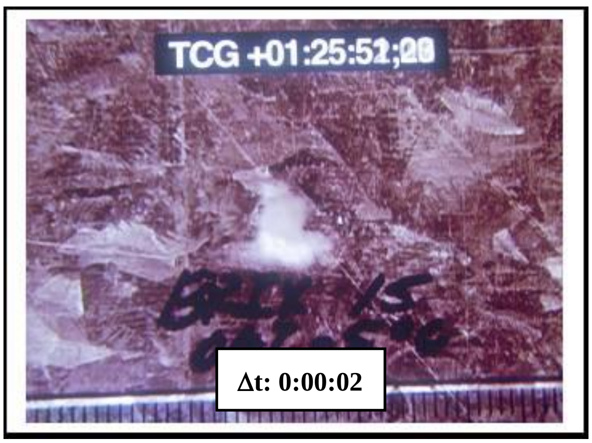
Snowflake Dissolving in Deicing Fluid

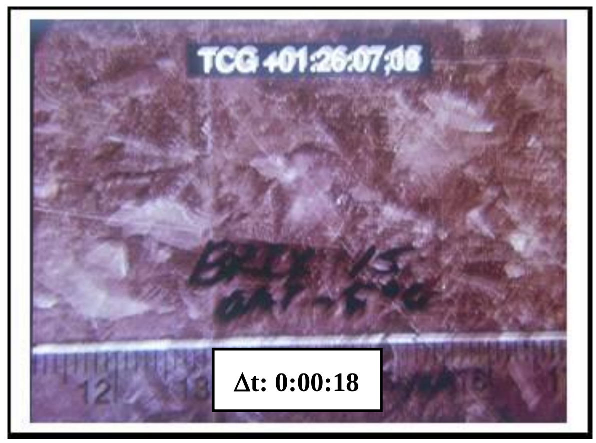
TEST # 18

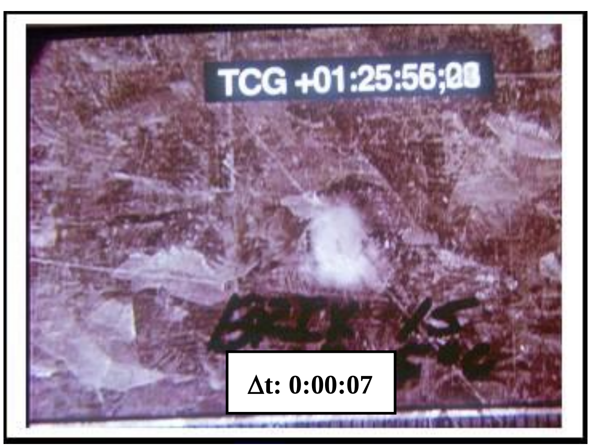
Type I EG

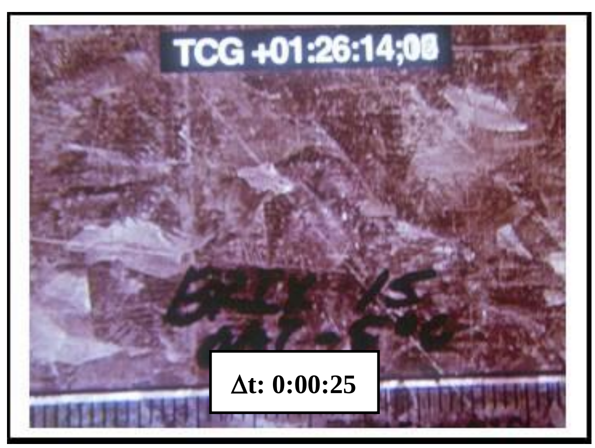
Total Time to Dissolve: 0.68 minutes

Start Time: 1:25:49
End Time: 1:26:30
Initial Brix: 15









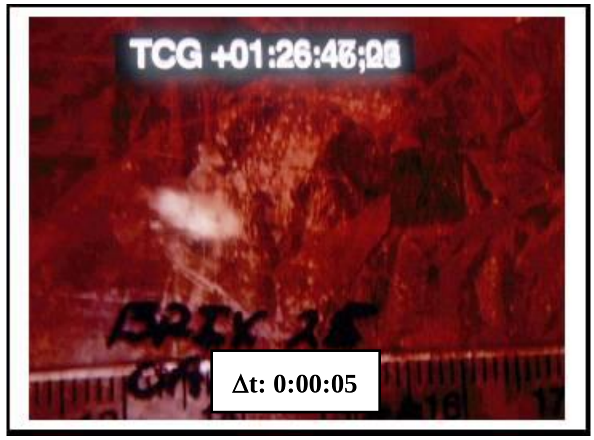
Snowflake Dissolving in Deicing Fluid

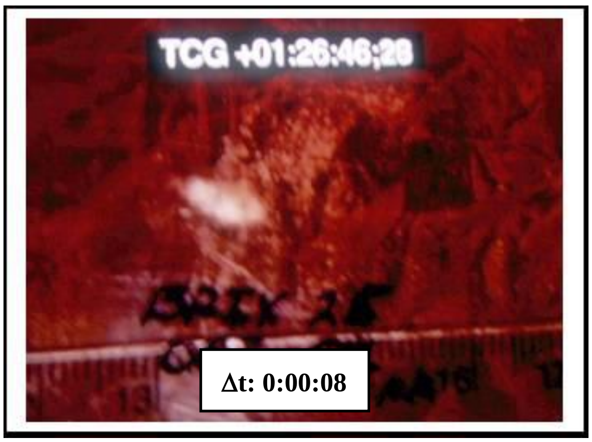
TEST # 19

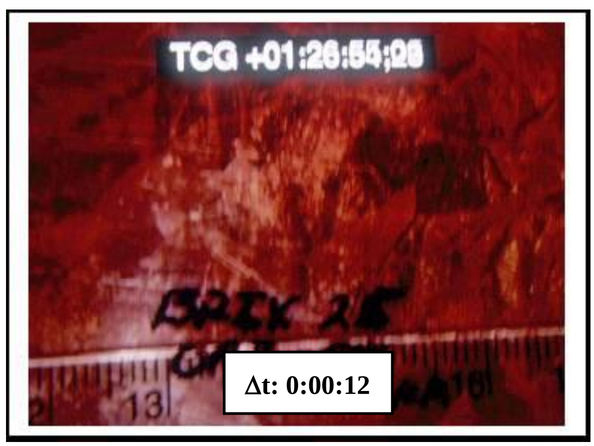
Type I EG

Total Time to Dissolve: 0.25 minutes

Start Time: 1:26:43
End Time: 1:26:58
Initial Brix: 25







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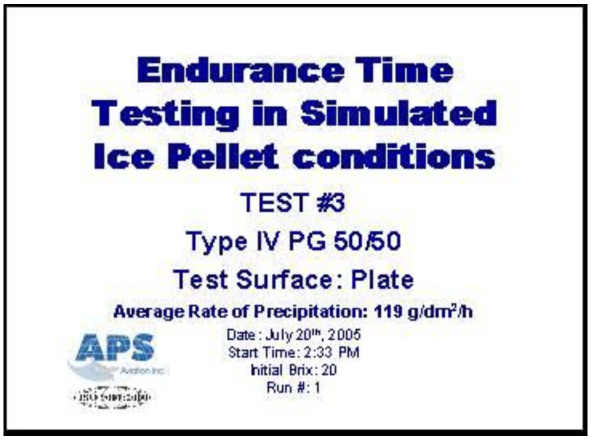
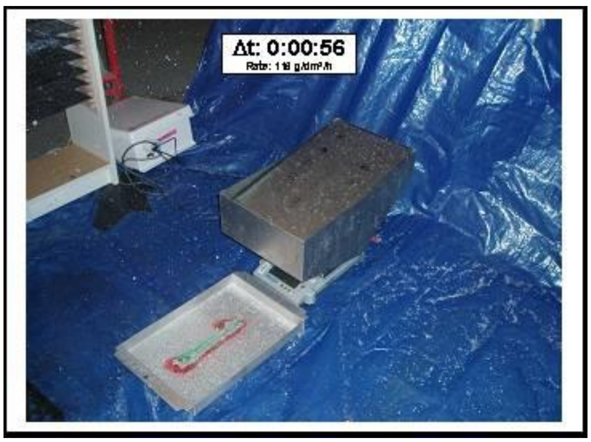
APPENDIX C

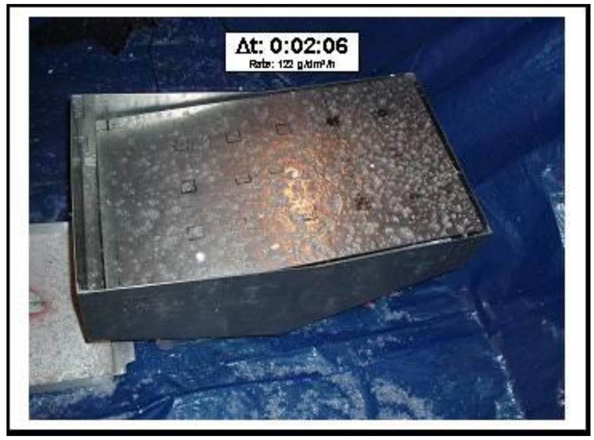
ENDURANCE TIME TESTING IN SIMULATED ICE PELLET CONDITIONS

TEST SURFACE: PLATE

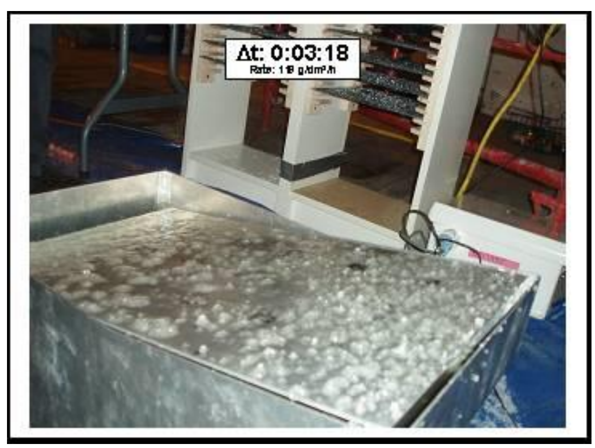

Endurance Time
Testing in Simulated
Ice Pellet conditions
TEST #3
Type IV PG 50/50
Test Surface: Plate
Average Rate of Precipitation: 119 g/dm²/h
Date: July 20th, 2005
Start Time: 2:33 PM
Initial Brix: 20
Run #: 1
APS

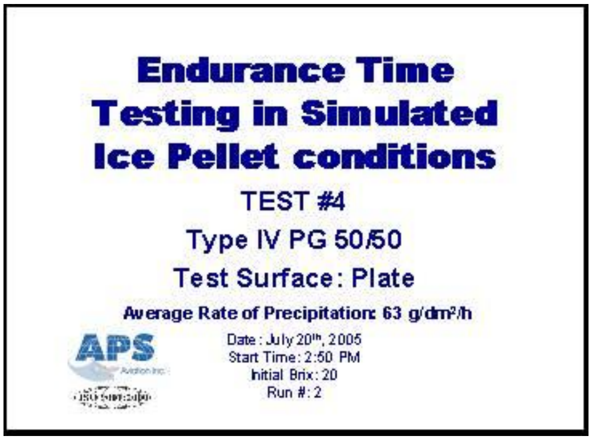

Δt: 0:00:56


Δt: 0:01:26

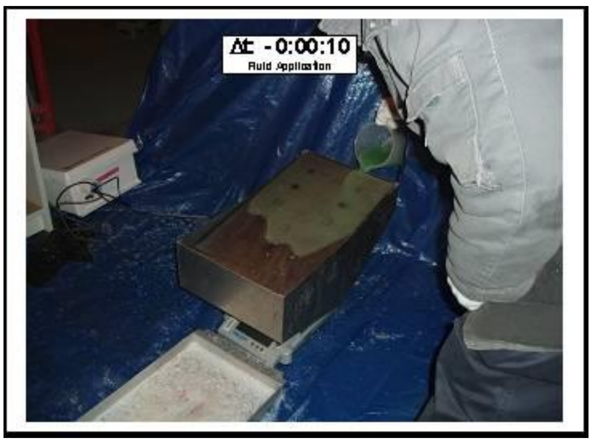

Δt: 0:02:06


Δt: 0:03:00


Δt: 0:03:18


Endurance Time
Testing in Simulated
Ice Pellet conditions
TEST #4
Type IV PG 50/50
Test Surface: Plate
Average Rate of Precipitation: 63 g/dm²/h
APS
Date: July 20th, 2005
Start Time: 2:50 PM
Initial Brix: 20
Run #: 2


Δt: 0:01:16


Δt: -0:00:10
Fluid Application

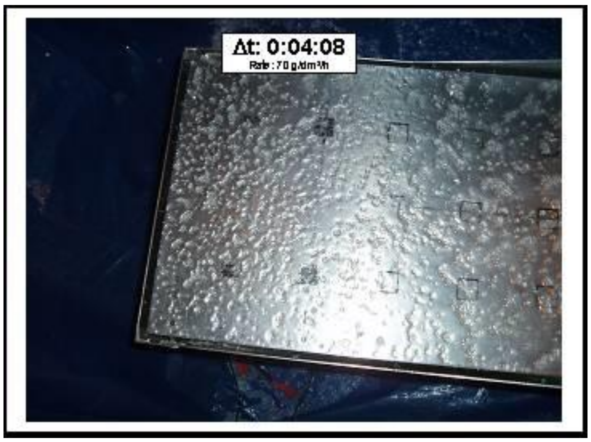

Δt: 0:01:32


Δt: 0:00:26
Rate : 62 g/dm²/h


Δt: 0:02:08

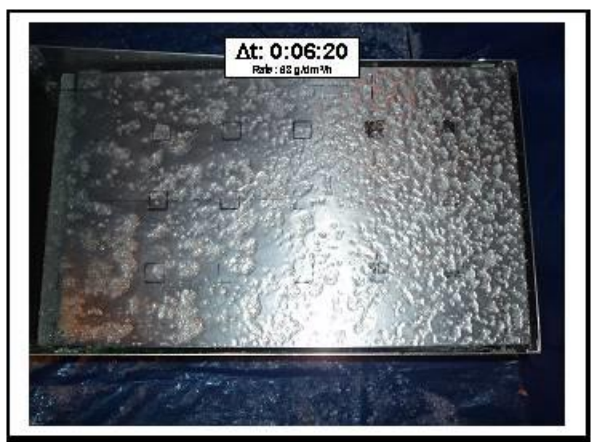

Δt: 0:03:14


Δt: 0:06:06


Δt: 0:04:08


Δt: 0:06:12


Δt: 0:05:24


Δt: 0:06:20

Endurance Time Testing in Simulated Ice Pellet conditions

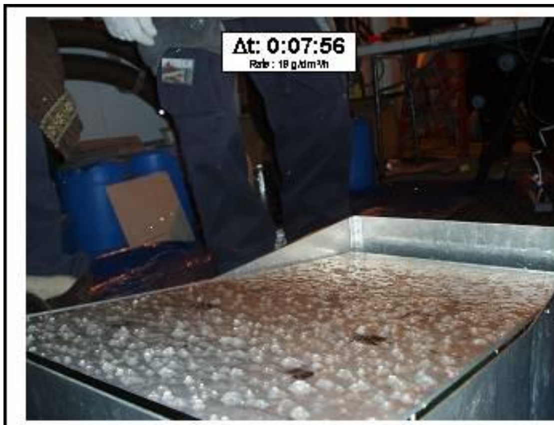
TEST #5

Type IV PG 50/50

Test Surface: Plate

Average Rate of Precipitation: 13.4 g/dm²/h

Date: July 20th, 2005
Start Time: 4:04 PM
Initial Brix: 20
Run #: 3




Δt: 0:13:02
Rate : 16 g/dm²/h

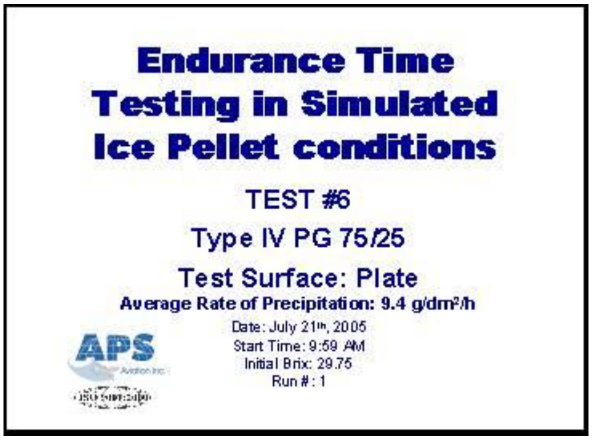

Δt: 0:20:08
Rate : 11 g/dm²/h


Δt: 0:15:38
Rate : 13 g/dm²/h


Δt: 0:26:24
Rate : 10 g/dm²/h

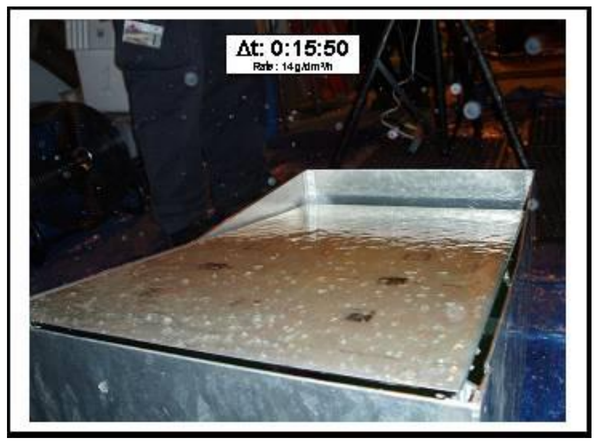

Δt: 0:16:24
Rate : 13 g/dm²/h

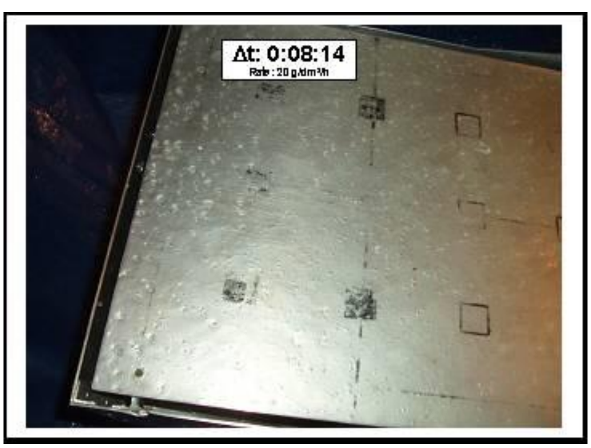

Δt: 0:31:06
Rate : 8 g/dm²/h


Endurance Time
Testing in Simulated
Ice Pellet conditions
TEST #6
Type IV PG 75/25
Test Surface: Plate
Average Rate of Precipitation: 9.4 g/dm²/h
Date: July 21th, 2005
Start Time: 9:59 AM
Initial Brix: 29.75
Run # : 1
APS


Δt: 0:12:32
Rate : 17 g/dm²/h


Δt: 0:02:18
Rate : 24 g/dm²/h


Δt: 0:15:50
Rate : 14 g/dm²/h


Δt: 0:08:14
Rate : 20 g/dm²/h

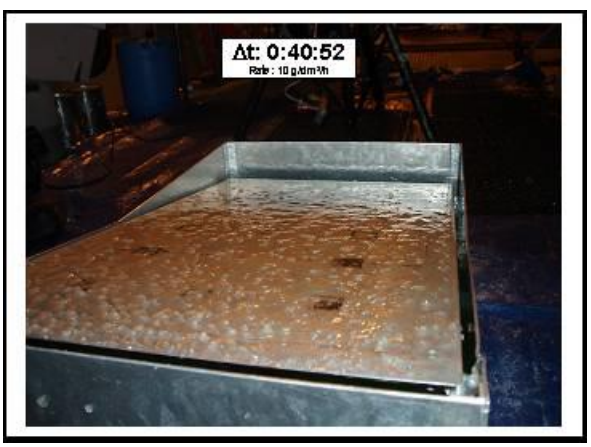

Δt: 0:21:48
Rate : 13 g/dm²/h

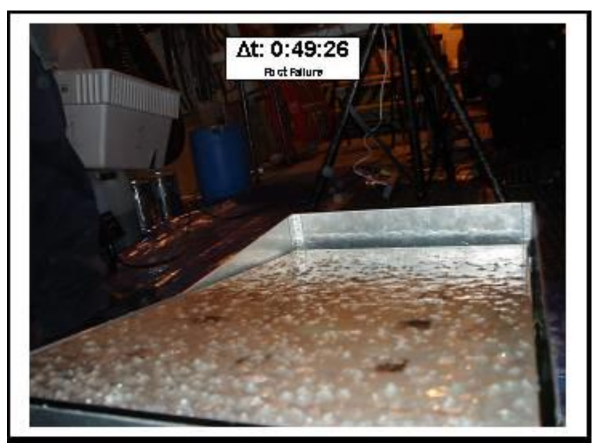

Δt: 0:24:30
Rate : 13 g/dm²/h

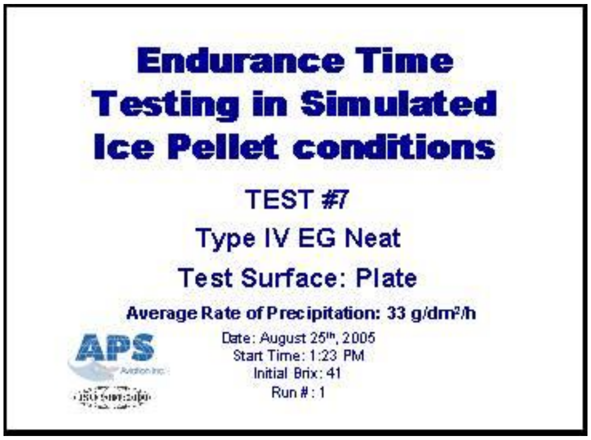

Δt: 0:48:26
Rate : 8 g/dm²/h


Δt: 0:33:18
Rate : 10 g/dm²/h

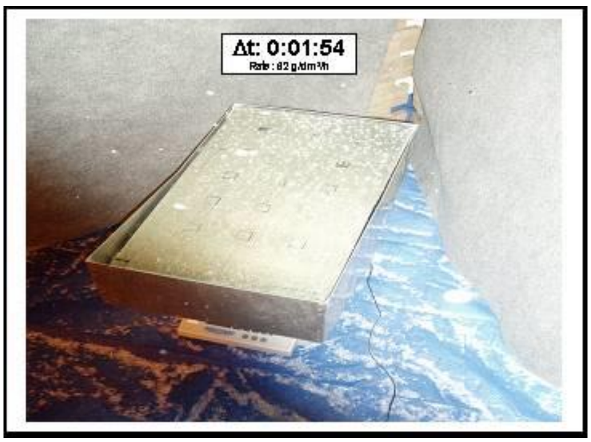

Δt: 0:49:16
Rate : 8 g/dm²/h

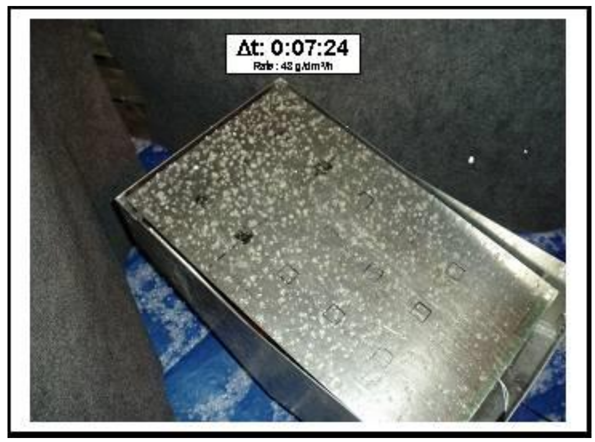

Δt: 0:40:52
Rate : 10 g/dm²/h

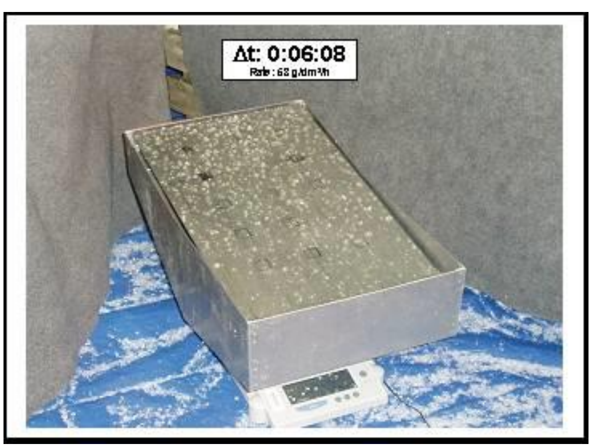

Δt: 0:49:26
Plate Failure


Endurance Time
Testing in Simulated
Ice Pellet conditions
TEST #7
Type IV EG Neat
Test Surface: Plate
Average Rate of Precipitation: 33 g/dm²/h
Date: August 25th, 2005
Start Time: 1:23 PM
Initial Brix: 41
Run #: 1


Δt: 0:06:24


Δt: 0:01:54


Δt: 0:07:24

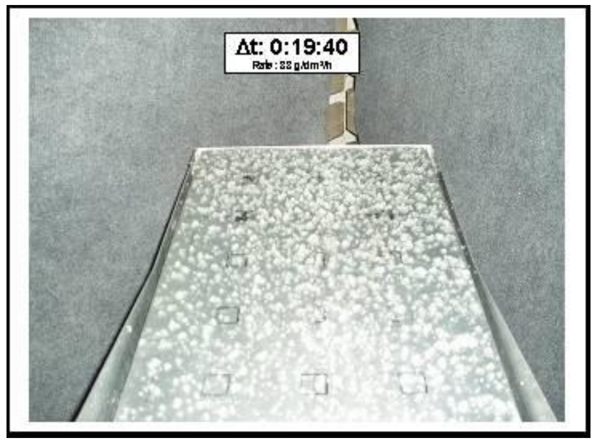

Δt: 0:06:08


Δt: 0:07:58

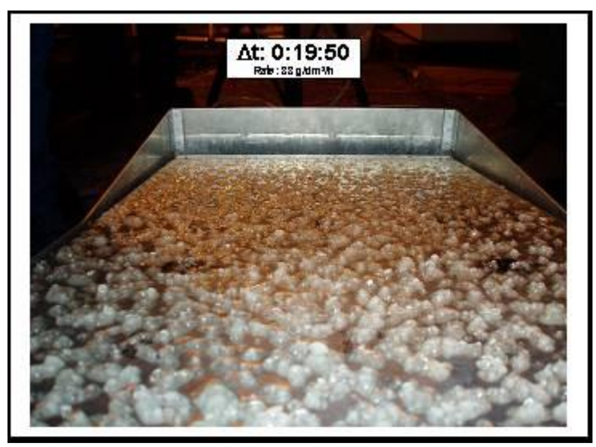

Δt: 0:08:08
Rate : 46 g/dm²/h

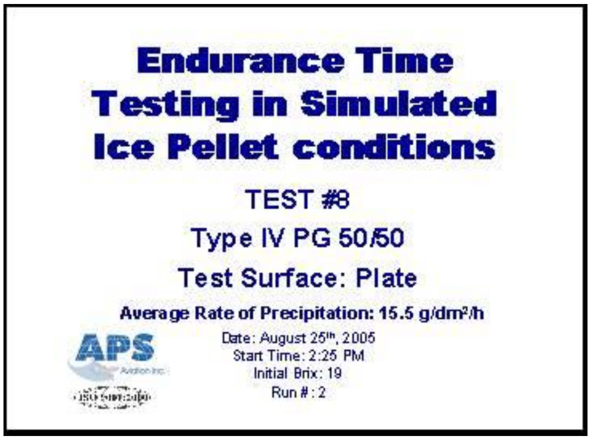

Δt: 0:16:38


Δt: 0:08:20
Rate : 44 g/dm²/h


Δt: 0:19:40

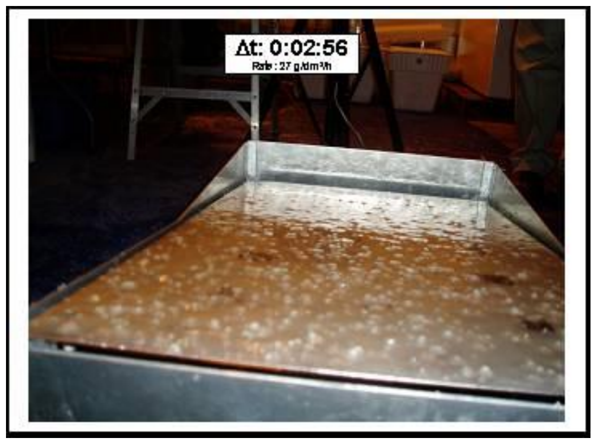

Δt: 0:13:52

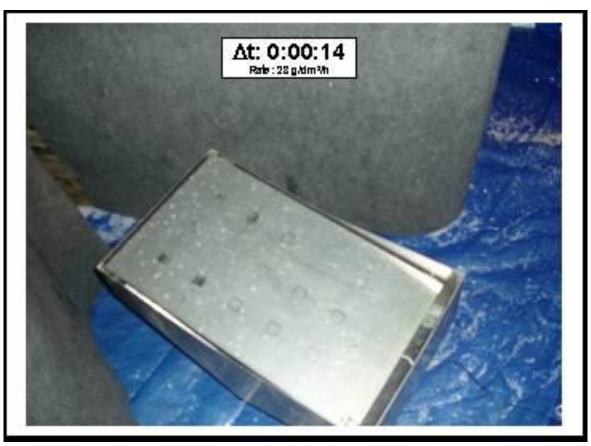

Δt: 0:19:50


Endurance Time Testing in Simulated Ice Pellet conditions
TEST #8
Type IV PG 50/50
Test Surface: Plate
Average Rate of Precipitation: 15.5 g/dm²/h
APS
Date: August 25th, 2005
Start Time: 2:25 PM
Initial Brix: 19
Run #: 2

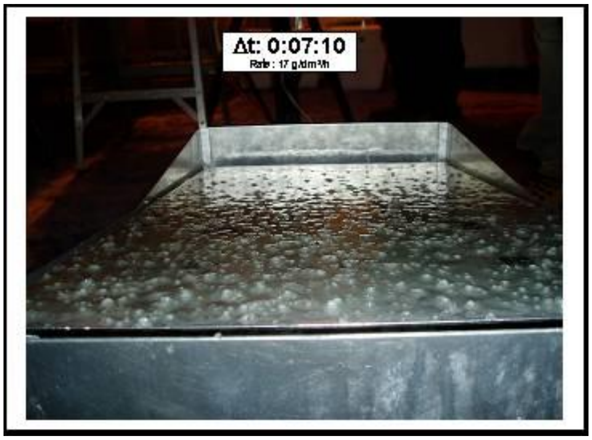

Δt: 0:02:48
Rate : 27 g/dm²/h


Δt: -0:01:14
Fluid Application


Δt: 0:02:56
Rate : 27 g/dm²/h


Δt: 0:00:14
Rate : 28 g/dm²/h


Δt: 0:07:04
Rate : 17 g/dm²/h


Δt: 0:07:10


Δt: 0:14:34


Δt: 0:10:02


Δt: 0:14:40


Δt: 0:10:08


Δt: 0:14:46

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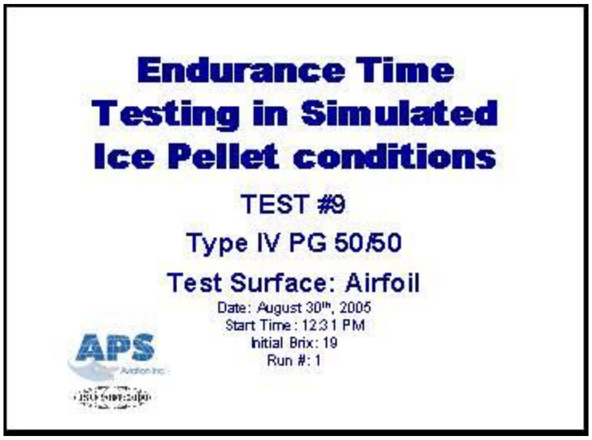
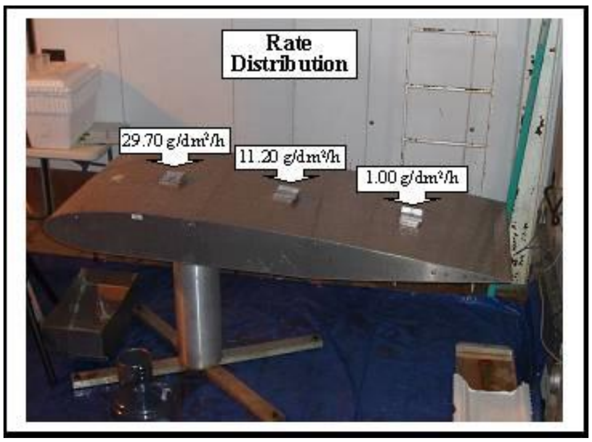
APPENDIX D

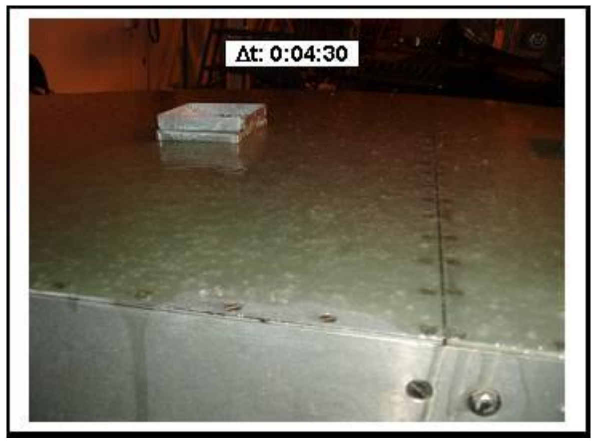
ENDURANCE TIME TESTING IN SIMULATED ICE PELLET CONDITIONS

TEST SURFACE: AIRFOIL


Endurance Time
Testing in Simulated
Ice Pellet conditions
TEST #9
Type IV PG 50/50
Test Surface: Airfoil
Date: August 30th, 2005
Start Time: 12:31 PM
Initial Brix: 19
Run #: 1
APS

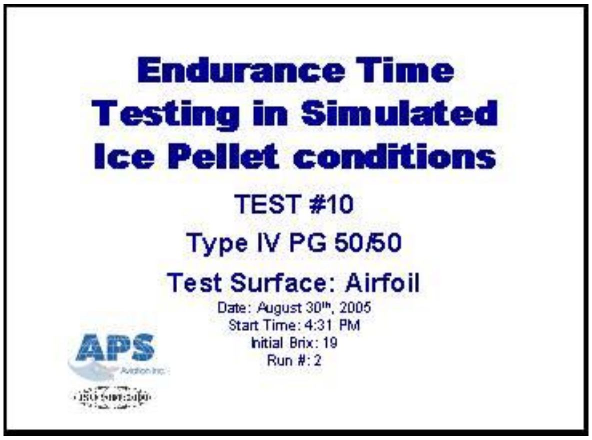

Δt: 0:02:28


Rate
Distribution
29.70 g/dm²/h
11.20 g/dm²/h
1.00 g/dm²/h

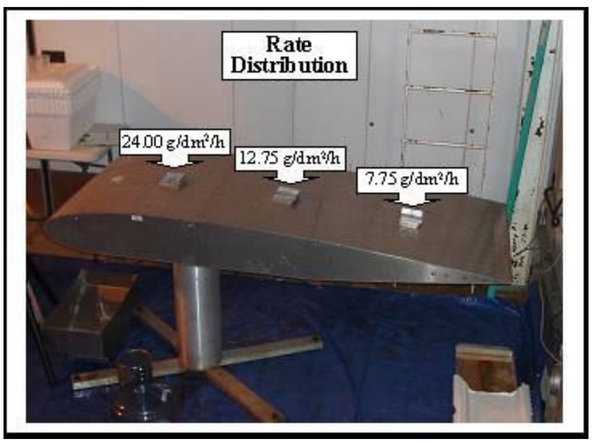

Δt: 0:04:30

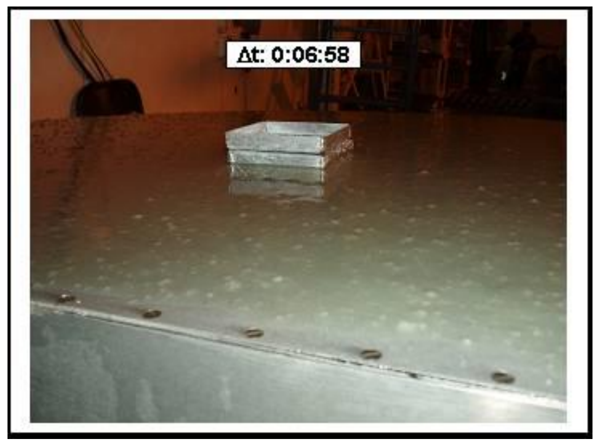

Δt: 0:00:00


Δt: 0:07:54


Endurance Time
Testing in Simulated
Ice Pellet conditions
TEST #10
Type IV PG 50/50
Test Surface: Airfoil
Date: August 30th, 2005
Start Time: 4:31 PM
Initial Brix: 19
Run #: 2
APS


Δt: 0:01:34


Rate Distribution
24.00 g/dm²/h
12.75 g/dm²/h
7.75 g/dm²/h


Δt: 0:06:58


Δt: 0:00:00


Δt: 0:07:04


Δt: 0:11:18

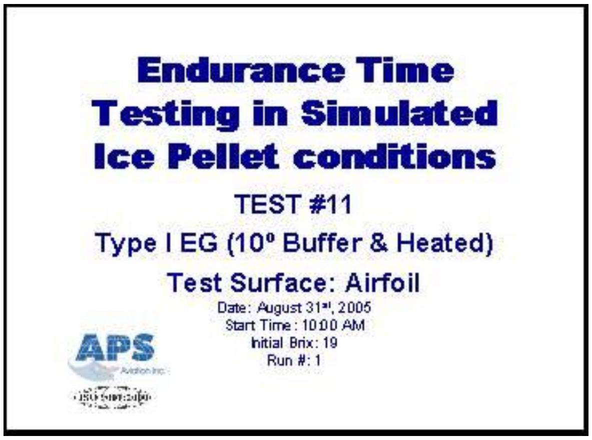

Δt: 0:15:24


Δt: 0:19:16

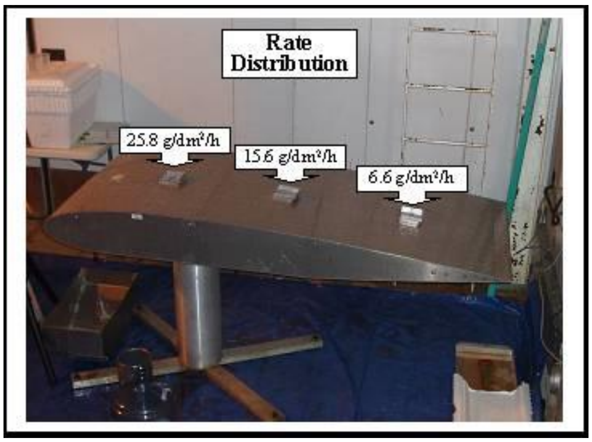

Δt: 0:24:34


Δt: 0:31:12


Δt: 0:32:30

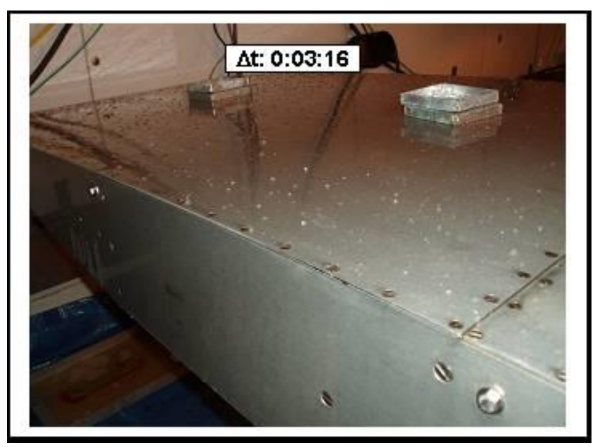

Endurance Time
Testing in Simulated
Ice Pellet conditions
TEST #11
Type I EG (10° Buffer & Heated)
Test Surface: Airfoil
Date: August 31st, 2005
Start Time: 10:00 AM
Initial Brix: 19
Run #: 1
APS


Δt: 0:00:40

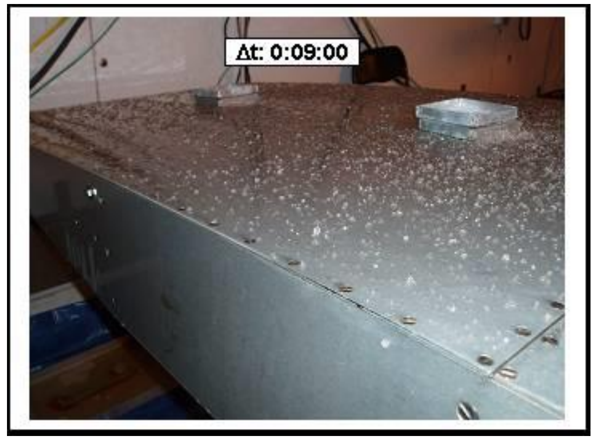

Rate
Distribution
25.8 g/dm²/h
15.6 g/dm²/h
6.6 g/dm²/h


Δt: 0:01:42


Δt: 0:00:00
Starting Time


Δt: 0:03:16


Δt: 0:04:00


Δt: 0:09:00


Δt: 0:05:40


Δt: 0:10:10


Δt: 0:08:06


Δt: 0:10:36

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APPENDIX E

NEAR VERSUS FAR-PILOTS PERSPECTIVE

Near-Pilots Perspective

(Approx. Distance: 0.9 m away)

Near-Pilots Perspective

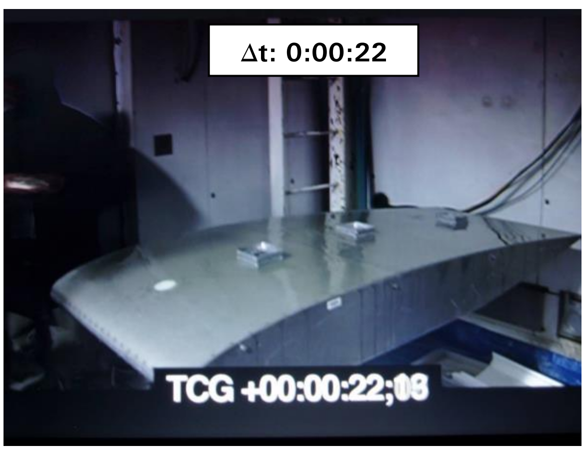
TEST #9

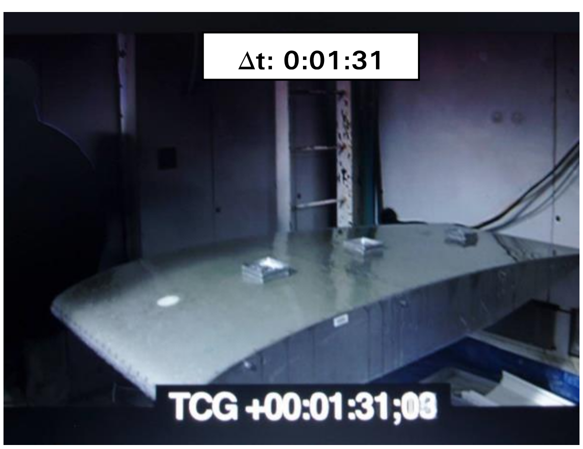
Type IV PG 50/50

Test Surface: Airfoil

Approx. Distance: 3 ft away

Start Time: 12:31:00
End Time: 12:38:30





Far-Pilots Perspective

(Approx. Distance: 4.6 m away)

Far-Pilots Perspective

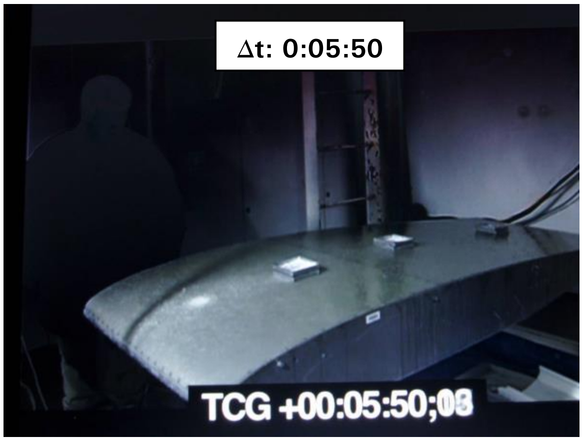
TEST #9

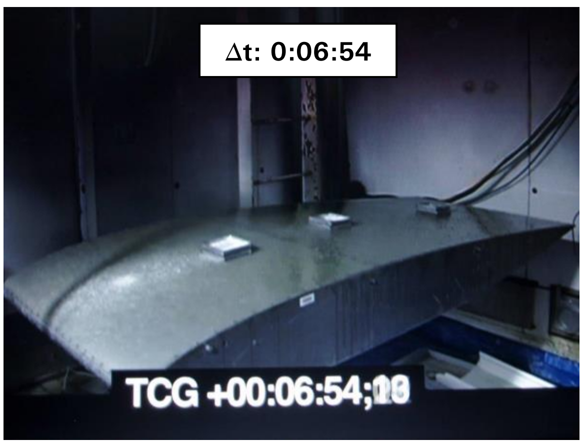
Type IV PG 50/50

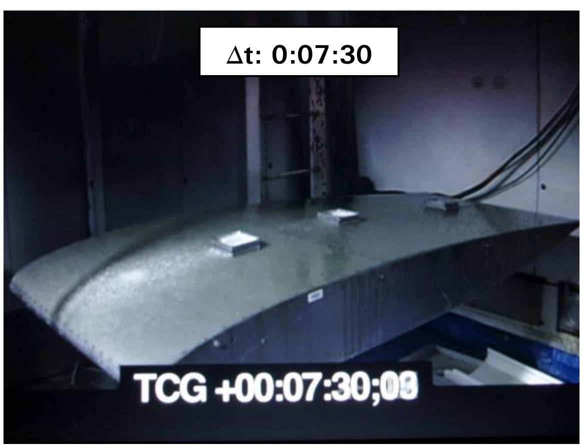
Test Surface: Airfoil

Approx. Distance: 15 ft away

Start Time: 12:31:00
End Time: 12:38:30

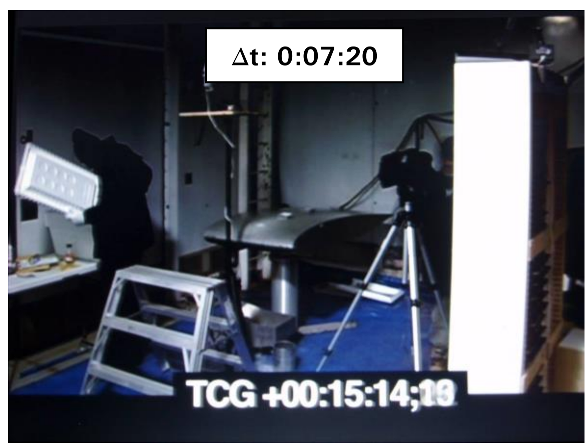

Δt: 0:05:50
TCG +00:05:50;08


Δt: 0:06:54
TCG +00:06:54

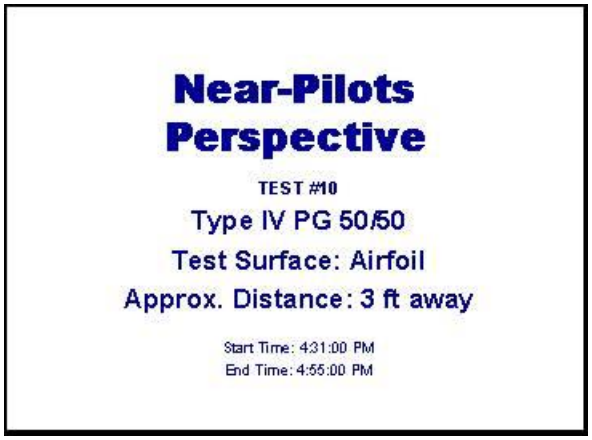

Δt: 0:07:30
TCG +00:07:30

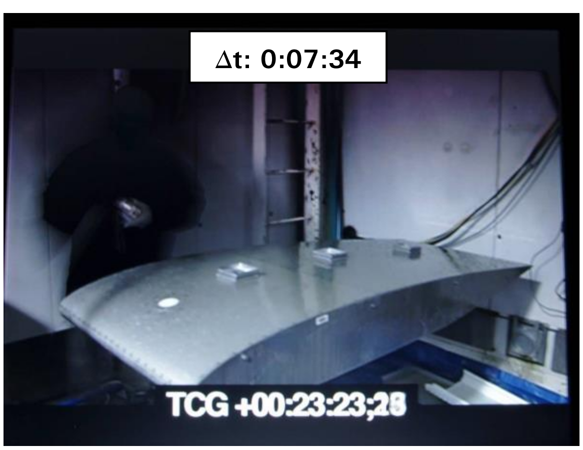

Δt: 0:02:46
TCG +00:10:40;28


Δt: 0:05:50
TCG +00:13:44;08

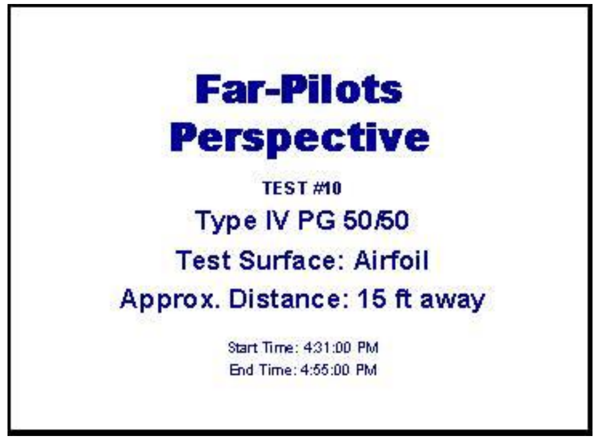

Δt: 0:07:20
TCG +00:15:14

Near-Pilots Perspective
(Approx. Distance: 0.9 m away)

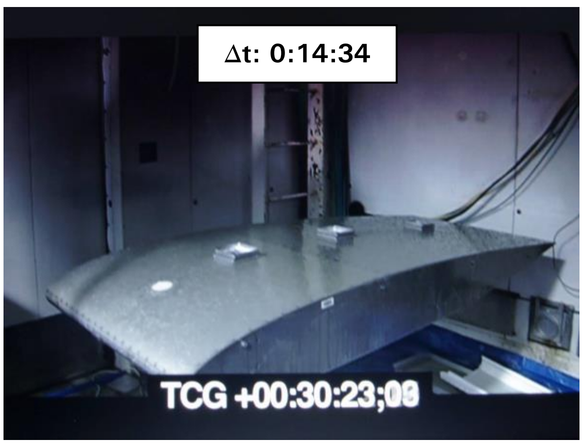


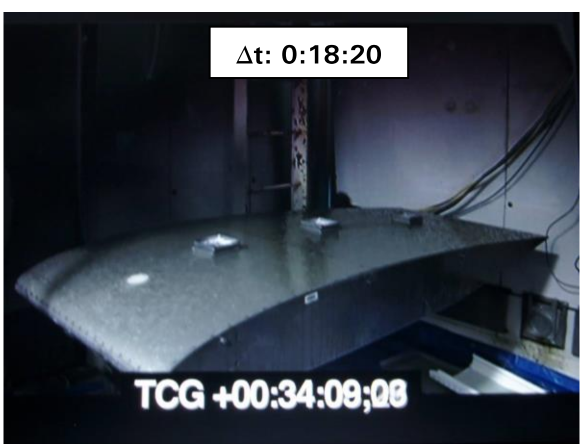


Far-Pilots Perspective
(Approx. Distance: 4.6 m away)




Δt: 0:12:52
TCG +00:28:41;08


Δt: 0:14:34
TCG +00:30:23;08

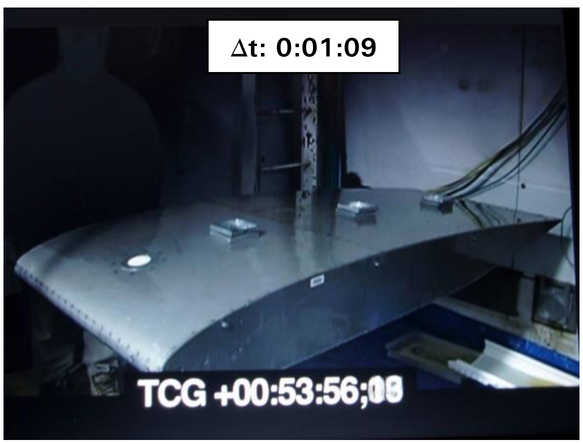

Δt: 0:18:20
TCG +00:34:09;08

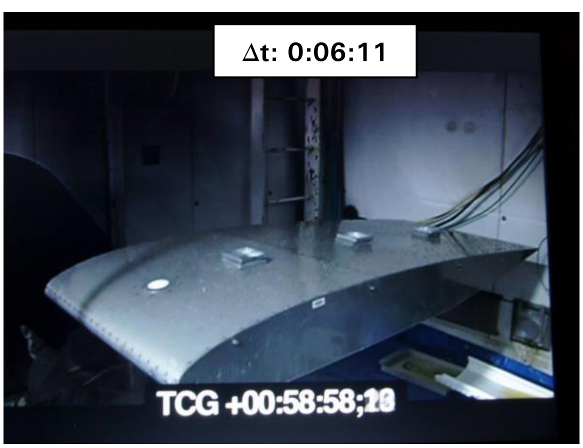

Δt: 0:12:01
TCG +00:46:12;28


Δt: 0:15:08
TCG +00:49:20;08


Δt: 0:17:05
TCG +00:51:17;28

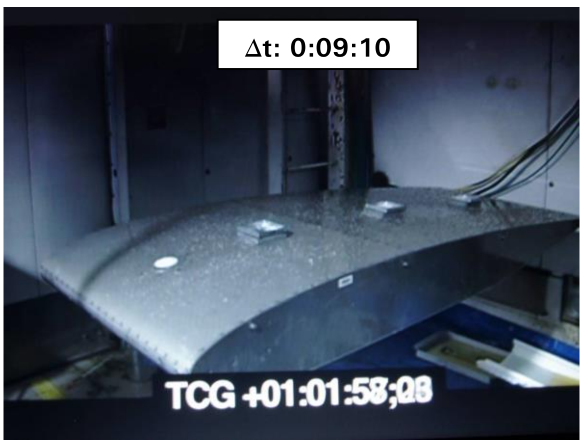
Near-Pilots Perspective
(Approx. Distance: 0.9 m away)

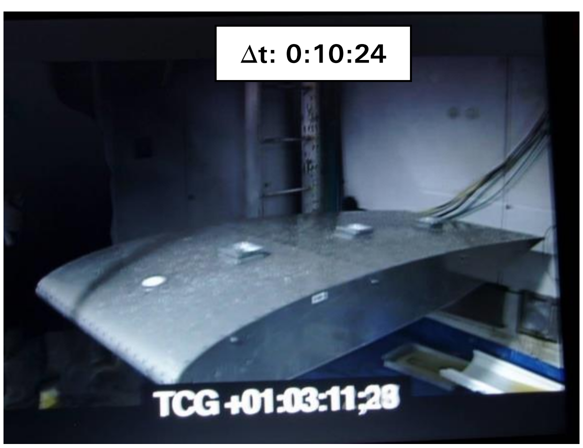




Far-Pilots Perspective
(Approx. Distance: 4.6 m away)


Δt: 0:07:44
TCG +01:00:31;28


Δt: 0:09:10
TCG +01:01:58;28


Δt: 0:10:24
TCG +01:03:11;28


Δt: 0:06:58
TCG +01:13:13;08


Δt: 0:09:28
TCG +01:15:43;28


Δt: 0:13:01
TCG +01:19:16;28