TP 14713E

Aircraft Deicing Research in Natural and Simulated Ice Pellet Conditions

Prepared for
Transportation Development Centre

In cooperation with

Civil Aviation
Transport Canada

And

The Federal Aviation Administration
William J. Hughes Technical Center

Prepared by

APS Aviation Inc.

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Aircraft Deicing Research in Natural and Simulated Ice Pellet Conditions

by

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APS Aviation Inc.

January 2007
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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/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 14713E, has the following objective:

- To evaluate whether holdover times should be developed for ice pellet conditions.

The research described in this report is still ongoing. The results obtained were used to substantiate the current preliminary guidance material for operations in ice pellet conditions.

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.

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

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). Nine reports (including this one) were produced as part of this winter's research program. Their subject matter is outlined in the preface. This research project has been funded by the Civil Aviation Group of Transport Canada.

16. Abstract

The objective of this study was to obtain experimental data in order to provide guidance for operations in ice pellet conditions. To satisfy this objective, research was aimed at characterizing the precipitation condition, conducting endurance time research in natural and simulated ice pellet conditions, and conducting full-scale aerodynamic testing.

Natural ice pellet research indicated that the diameter of the natural ice pellets collected generally ranged from 1 to 3 mm, and up to 5 mm during severe events. Endurance time testing conducted in natural ice pellets demonstrated that fluid failure was difficult to determine. Ice precipitation dissolving time research showed that snow requires a shorter amount of time, to fully dissolve in the deicing fluid in comparison the ice pellets. Also, simulated ice pellets were deemed a suitable and representative substitute for natural ice pellets for endurance time testing. Far vs. Near-Pilot's Perspective research showed that fluid condition was difficult to determine from far primarily due to the transparency of the ice pellets.

During the Falcon 20 full-scale research, the airflow at takeoff removed ice-pellet contaminated anti-icing fluid from the leading edge, leaving only a very thin film of fluid even at very high precipitation rates; in one extreme case, some contamination was found on the trailing edge. A preliminary test with Type I fluid showed some signs of adhesion to the wing surface; an operational deicing would generate more heat, likely generating more adhesion. Bare wing departures are not recommended as ice pellet conditions mixed with freezing rain or drizzle may be conducive to a rough adhesion of the precipitate to the surface that will likely not come off at the time of rotation.

Adherence was observed during preliminary Type II/III/IV fluid endurance time testing conducted in mixed ice pellet and freezing rain/drizzle conditions. Adherence was also observed during testing conducted with Type I heated fluid during ice pellet conditions. Testing conducted using Type II/III/IV fluids in ice pellet conditions alone did not demonstrate any signs of adherence.

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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). Neuf rapports (y compris celui-ci) ont été produits dans le cadre du programme de recherche de cet hiver. Leur objet est résumé à la préface. Le présent projet de recherche a été financé par le Groupe de l'Aviation civile de Transports Canada.

16. Résumé

La présente étude avait pour but d'acquérir des données expérimentales à utiliser comme lignes directrices pour l'exploitation dans des conditions de granules de glace. Pour satisfaire cet objectif, la recherche visait à définir la condition de précipitation, à mener des recherches sur l'endurance dans des conditions naturelles et simulées de granules de glace, ainsi qu'à mener des essais aérodynamiques complets.

La recherche sur les granules de glace naturels a démontré que le diamètre des granules de glace recueillis se situaient généralement entre 1 et 3 mm, mais jusqu'à 5 mm durant les phénomènes importants. Les essais d'endurance menés sur les granules de glace naturels ont démontré que la défaillance du liquide est difficile à établir. Les recherches sur le temps de dissolution des précipitations de glace ont démontré que la neige prend moins de temps à se dissoudre complètement dans le liquide de dégivrage, comparativement aux granules de glace. De plus, les granules de glace simulés se sont avérés un substitut acceptable et représentatif des granules de glace naturels pour les essais d'endurance. Éloigné c. Rapproché – La recherche sur le point de vue du pilote a démontré que la condition du liquide est difficile à établir à distance, surtout en raison de la transparence des granules de glace.

Au cours des recherches complètes avec le Falcon 20, l'écoulement aérodynamique au décollage a enlevé du bord d'attaque le liquide d'antigivrage contaminé de granules de glace, ne laissant qu'un mince film de liquide, même à des taux très élevés de précipitation ; dans un cas extrême, de la contamination s'est trouvée sur le bord de fuite. Un essai préliminaire avec du liquide de Type I a montré des signes d'adhérence à la surface de l'aile ; un dégivrage opérationnel créerait plus de chaleur, ce qui générerait probablement plus d'adhérence. Les départs sans antigivrage ne sont pas recommandés, car des conditions de granules de glace mêlés à de la pluie verglaçante ou de la bruine verglaçante pourrait favoriser l'adhérence grossière de la précipitation à la surface, qui ne se détacherait probablement pas à la rotation.

On a noté de l'adhérence au cours d'essais préliminaires d'endurance avec des liquides de Types II, III et IV, menés dans des conditions mixtes de granules de glace, de pluie verglaçante et de bruine verglaçante. On a également noté de l'adhérence au cours d'essais menés avec des liquides chauffés de Type I, dans des conditions de granules de glace. Les essais menés avec des liquides de Types II, III et IV dans des conditions de granules de glace seulement n'ont révélé aucun signe d'adhérence.

17. Mots clés Dégivrage, intensité des chutes de neige, durée d'efficacité, granule de glace, adhérence, précipitation mixte	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), with financial support from the Federal Aviation Administration (FAA), APS Aviation Inc. (APS) undertook a test program to investigate fluid endurance times in simulated and natural ice pellet conditions.

Aircraft deicing operations during ice pellet conditions have occurred, and although holdover times do not currently exist, aircraft have departed during ice pellet conditions following aircraft deicing using a pre-takeoff contamination check. This protocol is feasible for common air carrier aircraft, which provide access to emergency exit windows overlooking the leading edge of the aircraft wings; however, it poses a significant problem for cargo aircraft limited to the visibility from the cabin.

TDC, with the support of the FAA, began a research program in November 2005 to obtain experimental data in order to provide guidance for operating in ice pellet conditions. The joint effort would include work conducted by the Anti-Icing Materials International Laboratory (AMIL), APS, and McGill University. The research was aimed at characterizing the precipitation condition, conducting holdover time (HOT) research in natural and simulated ice pellet conditions, and conducting simulated full-scale aerodynamic testing. Testing was conducted with the aim of substantiating a 20-minute allowance suggested as a minimum time required to operate during ice pellet conditions.

As testing is still preliminary, and the protocol for determining fluid failure in ice pellet conditions has not yet been determined, the following objectives were given for the 2005-06 research conducted by APS:

1. Conduct natural ice pellet research;
   a) Collect samples of natural ice pellets to investigate rate of precipitation and size distribution; and
   b) Conduct endurance time testing in natural ice pellet conditions.
2. Determine method for producing simulated ice pellets;
3. Conduct ice pellet dissolving time research;
4. Conduct far vs. near pilot's perspective photo documentation;
5. Conduct full-scale research using Falcon 20 aircraft;
6. Investigate bare wing departures during ice pellet conditions; and
7. Investigate if endurance time testing conducted during ice pellet conditions will demonstrate signs of fluid adhesion to aluminum test surfaces by conducting preliminary testing during conditions most likely to exhibit adhesion.

Conclusions

Natural Ice Pellet Research

The diameter of the natural ice pellets collected generally ranged from 1 to 3 mm. During severe ice pellet events, the ice pellet diameters measured up to 5 mm. During endurance time testing conducted in natural ice pellet conditions, fluid failure was difficult to determine, much like in simulated ice pellet endurance time tests.

Ice Precipitation Dissolving Time Research

Results demonstrated that snow requires a shorter amount of time, (generally 3 to 4 times shorter) to fully dissolve in the deicing fluid in comparison to the ice pellets. Operationally, the fluid is more "slushy" and diluted in snow conditions than in ice pellet conditions.

The dissolving time of simulated ice pellets was comparable to that of natural ice pellets. The simulated ice pellets were deemed a suitable and representative substitute for natural ice pellets for endurance time testing.

Far vs. Near – Perspective Photo Documentation

It was observed that the fluid condition was difficult to determine from afar due to the transparency of the ice pellets. When bridging ice pellets are visible from afar, the fluid condition has already become severe.

Falcon 20 Full-Scale Research

For both ethylene glycol (EG) and propylene glycol (PG) Type IV fluids, the airflow at takeoff removed ice-pellet contaminated anti-icing fluid from the leading edge, leaving only a very thin film of fluid even at very high precipitation rates. In one case, at a very high precipitation rate (effective rate of 136 $g/dm^2/h$), the entire 24 seconds of the takeoff run were required to clear the leading edge of any precipitation. In this case, some contamination (up to 1 mm) remained on the trailing edge.

A test with Type I EG fluid showed some adhesion of ice to the wing surface following the transfer of heat from the heated fluid to the cold wing surface. The fluid application method was not representative of actual operations. A normal deicing may transfer more heat, leading to increased melting and fluid dilution that could generate more adhesion.

Bare Wing Departures during Ice Pellet Conditions

Ice pellet conditions mixed with freezing rain or drizzle may be conducive to a rough adhesion of the precipitate to the surface that will likely not come off at the time of rotation.

Adherence Testing in Simulated Ice Pellet Conditions

Adherence was observed during Type II, III and IV fluid endurance time testing conducted in mixed ice pellet and freezing rain/drizzle conditions, however, testing conducted in ice pellet conditions alone did not demonstrate any signs of adherence. Adherence was observed during testing conducted with Type I heated fluid during pure ice pellet conditions.

Operational Recommendations

The FAA issued the following operational recommendations for use with aircraft with rotation speeds in excess of 100 knots. It should be noted that Transport Canada (TC) did not issue the recommendation but remained status-quo until further research is conducted.

25-Minute Allowance Time

A 25-minute allowance should be entertained by the regulator when requested by the operator, provided:

- Type IV Neat fluid is used in the final anti-icing application;
- The intensity of the ice pellets as reported by the METAR or ATIS is not to exceed LIGHT, a liquid water equivalent intensity of 2.5 mm/h;
- There are no mixed icing conditions associated with the occurrence of ice pellets (snow, freezing drizzle, or freezing rain);
- Outside Air Temperature (OAT) must be -10ºC or above;
- Due to the difficulty of determining the fluid condition, exceeding the 25-minute allowance will necessitate re-de/anti-icing (this means a pre-takeoff contamination inspection cannot be used after the 25-minute allowance has been exceeded to determine whether it is safe to takeoff); and
- This allowance does not apply to propeller, turbo-propeller aircraft or aircraft with rotations speed less than 100 knots.

The 25-minute allowance is not considered a HOT since:

- HOT testing was not conducted due to lack of agreed-upon failure criteria and procedures; and
- No visual failure criteria have yet been identified.

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SOMMAIRE

En vertu d'un contrat avec le Centre de développement des transports (CDT) et avec le soutien financier de la Federal Aviation Administration (FAA), APS Aviation Inc. (APS) a entrepris un programme d'essais pour examiner l'endurance des liquides dans des conditions de granules de glace simulés et naturels.

Des opérations de dégivrage d'aéronefs ont été tenues dans des conditions de granules de glace et, bien que des durées d'efficacité n'existent pas à l'heure actuelle, des aéronefs ont décollé dans des conditions de granules de glace après un dégivrage à l'aide d'une procédure de vérification de contamination avant le décollage. Ce protocole est acceptable dans le cas d'aéronefs de transport courants, car ils donnent accès aux fenêtres de sorties d'urgence avec vue sur le bord d'attaque des ailes; cependant, il pose un important problème dans le cas d'aéronefs cargo, limités à la seule visibilité de la cabine.

Avec le soutien de la FAA, le CDT a entrepris en novembre 2005 un programme de recherche visant à recueillir des données expérimentales à utiliser comme lignes directrices pour les opérations dans des conditions de granules de glace. Cet effort conjoint intégrait les travaux menés par le Laboratoire international des matériaux antigivre (LIMA), par APS et par l'Université McGill. La recherche visait à définir la condition de précipitation, à effectuer la recherche sur les durées d'efficacité dans des conditions de granules de glace naturels et simulés, ainsi qu'à mener des essais aérodynamiques simulés complets. Les essais ont été menés dans le but de corroborer une marge suggérée de 20 minutes, comme période minimale requise pour les opérations dans des conditions de granules de glace.

Comme les essais sont encore préliminaires et que le protocole pour déterminer la défaillance du liquide dans des conditions de granules de glace n'a pas encore été établi, les objectifs suivants pour la recherche d'APS en 2005-06 ont été établis :

1. Mener des recherches sur les granules de glace naturels ;
   a) Recueillir des échantillons de granules de glace naturels pour étudier le taux de précipitation et la distribution granulométrique ; et
   b) Mener des essais d'endurance dans des conditions de granules de glace naturels.
2. Identifier une méthode de production de granules de glace simulés ;
3. Mener une recherche sur le temps de dissolution des granules de glace ;
4. Fournir de la documentation photographique sur la perspective éloignée c. rapprochée du pilote ;
5. Mener une recherche complète avec l'aéronef Falcon 20 ;

6. Examiner les départs sans antigivrage dans des conditions de granules de glace ; et
7. Évaluer si les essais d'endurance menés dans des conditions de granules de glace montreront des signes d'adhérence du liquide aux surfaces d'essai d'aluminium, au moyen d'essais préliminaires dans les conditions les plus susceptibles de montrer de l'adhérence.

Conclusions

Recherche sur les granules de glace naturels

En général, le diamètre des granules de glace naturels recueillis se situait entre 1 et 3 mm. Durant les périodes extrêmes de granules de glace, les diamètres des granules mesuraient jusqu'à 5 mm. Au cours des essais d'endurance menés dans des conditions de granules de glace naturels, la défaillance du liquide a été difficile à établir, tout comme avec les essais d'endurance sur les granules de glace simulés.

Recherche sur le temps de dissolution des précipitations verglaçantes

Les résultats ont démontré que la neige prend moins de temps (en général 3 à 4 fois moins) à se dissoudre entièrement dans le liquide de dégivrage, comparativement aux granules de glace. Du point de vue opérationnel, le liquide est plus « boueux » et plus dilué dans des conditions de neige que dans les granules de glace.

Le temps de dissolution des granules de glace simulés se comparait à celui des granules de glace naturels. Pour les essais d'endurance, les granules de glace simulés sont considérés un substitut approprié et représentatif des granules de glace naturels.

Éloigné c. rapproché – Documentation photographique de la perspective

On a observé que la condition du liquide est difficile à établir à distance en raison de la transparence des granules de glace. Lorsque l'accumulation de granules de glace est observée de loin, la condition du liquide est déjà grave.

Recherche complète avec le Falcon 20

Dans le cas de liquides éthylène glycol (EG) et propylène glycol (PG) de Type IV, l'écoulement d'air au décollage enlevait le liquide antigivrage contaminé de granules de glace du bord d'attaque, ne laissant qu'un très mince film de liquide, même à des taux très élevés de précipitation. À une occasion de taux de précipitation très élevé (taux effectif de 136 g/dm^2/h), toute la période de 24 secondes de la course de décollage a été nécessaire pour libérer le bord d'attaque de toute précipitation. En cette occasion, un peu de contamination (jusqu'à 1 mm) est resté sur le bord de fuite.

Un essai avec du liquide EG de Type I a indiqué un peu d'adhérence de glace sur la surface de l'aile suite au transfert de chaleur du liquide chauffé à la surface froide de l'aile. La méthode d'application du liquide n'était pas représentative d'opérations réelles. Un dégivrage normal peut transférer davantage de chaleur, créant plus de fonte et de dilution du liquide, ce qui pourrait générer davantage d'adhérence.

Départs sans antigivrage dans des conditions de granules de glace

Des conditions de granules de glace mêlés à la pluie verglaçante ou à la bruine verglaçante pourraient mener à une adhérence grossière de la précipitation à la surface, qui ne se détacherait probablement pas à la rotation.

Essais d'adhérence dans des conditions de granules de glace simulés

On a remarqué de l'adhérence durant des essais menés dans des conditions de granules de glace mêlés à de la pluie verglaçante ou de la bruine verglaçante, avec des liquides de Types II, III et IV, mais les essais menés dans des conditions de granules de glace seulement n'ont affiché aucun signe d'adhérence. On a observé de l'adhérence lors d'essais menés avec des liquides chauffés de Type I, dans des conditions de granules de glace seulement.

Recommandations opérationnelles

La FAA a émis les recommandations opérationnelles suivantes à appliquer avec les aéronefs dont la vitesse de rotation excède 100 nœuds. Il convient de noter que Transports Canada (TC) n'a pas émis cette recommandation mais maintient le statu quo en attente de nouvelles recherches.

Marge de tolérance de 25 minutes

À la demande de l'exploitant, une marge de tolérance de 25 minutes devrait être acceptée par l'organisme de réglementation, pourvu que :

- Du liquide pur de Type IV soit utilisé pour l'application finale d'antigivrage ;

- L'intensité des granules de glace, telle que rapportée par METAR ou ATIS ne dépasse pas FAIBLE, une intensité équivalente à 2.5 mm/h en eau liquide ;
- Les granules de glace ne sont pas accompagnés de conditions de givrage mixte (neige, bruine verglaçante ou pluie verglaçante) ;
- La température extérieure doit être de -10ºC ou plus ;
- En raison de la difficulté à établir la condition du liquide, le dépassement de la tolérance de 25 minutes nécessitera un nouveau dégivrage ou antigivrage (ce qui signifie qu'une inspection de contamination avant décollage ne peut être effectuée pour confirmer la sécurité du décollage, une fois excédée la tolérance de 25 minutes) ; et
- Cette tolérance ne s'applique pas aux aéronefs à hélice et à turbopropulseur, ou aux aéronefs dont la vitesse de rotation est de moins de 100 nœuds.

La tolérance de 25 minutes n'est pas considérée une durée d'efficacité, puisque :

- Des essais de durées d'efficacité n'ont pas été menés, en raison de l'absence de convention en matière de critères d'échec et de procédures ; et
- Des critères visuels de défaillance n'ont pas encore été établis.

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GLOSSARY

AMIL	Anti-Icing Materials International Laboratory
APS	APS Aviation Inc.
CEF	Climatic Engineering Facility
EG	Ethylene Glycol
FAA	Federal Aviation Administration
HOT	Holdover Time
IAR	Institute for Aerospace Research
IFALPA	International Federation of Air Line Pilots Associations
MSC	Meteorological Service of Canada
MVD	Median Volume Diameter
NCAR	National Center for Atmospheric Research
NRC	National Research Council (Canada)
OAT	Outside Air Temperature
PG	Propylene Glycol
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 times in simulated ice pellet conditions.

1.1 Background

Aircraft deicing operations during ice pellet conditions have occurred, and although holdover times do not currently exist, aircraft have departed during ice pellet conditions following aircraft deicing using a pre-takeoff contamination check. This protocol is feasible for common air carrier aircraft, which provide access to emergency exit windows overlooking the leading edge of the aircraft wings; however, it poses a significant problem for cargo aircraft with limited visibility from the cabin, as well as for high-wing aircraft.

On December 22, 2004, UPS aircraft in Louisville were grounded for several hours due to extended ice pellet conditions. Similar conditions were experienced in Toronto and Memphis in the same year. Due to cargo aircraft configuration, a pre-takeoff contamination check by the on-board crew was not possible. In Memphis, Fed-Ex put a ground crew in place to conduct pre-takeoff checks which allowed aircraft to be dispatched.

In response to industry pressure to issue guidance material for operations in ice pellet conditions, preliminary endurance time testing (by APS) and aerodynamic research (by AMIL) was conducted in simulated ice pellet conditions in 2005. APS documented the preliminary endurance time testing results in the TC report TP 14718E, *Preliminary Endurance Time Testing in Simulated Ice Pellet Conditions* (1).

In October 2005, the FAA issued a notice regarding ground operations in ice pellets and other icing conditions where holdover times (HOTs) currently do not exist. The notice referred to ice pellet conditions as a direct threat to the safety of flight due to:

- Lack of experimental data in ice pellet conditions;
- Uncertainty of the fluid characteristics following extended fluid exposure to ice pellet conditions;
- Difficulty in determining the fluid condition during a pre-takeoff check;
- The possibility of, and risks attributed to, adherence caused by ice pellet conditions; and
- No HOTs existing for ice pellet conditions.

The notice went on to mention that the pre-takeoff contamination check protocol is used in accordance with a numerical HOT, which provides a reference point with respect to the fluid condition following exposure to precipitation. Without HOTs for ice pellet conditions, a pre-takeoff contamination check would therefore be unreliable. Data presented at the November 2005 HOT Subcommittee meeting supported the decision made by the FAA to ground flights in ice pellet conditions. TC did not hold a position with respect to operation in ice pellet conditions.

In February 2006, the International Federation of Air Line Pilots Associations (IFALPA) issued a safety bulletin addressing the confusion experienced by some carriers following the FAA notice. The safety bulletin reported that carriers were interpreting the FAA recommendations as follows:

- Operations were permitted if no deicing or anti-icing fluid was applied (bare wing departures); and
- Operations were permitted if the contamination was not adhering to the critical surfaces.

The severity of a misinterpretation of the FAA recommendations could lead to serious implications resulting from the possibility of residual ice on wings, clear ice adhering to the critical surfaces, and difficulty experienced when determining fluid condition. TDC, with the support of the FAA, began a research program in November 2005 to obtain experimental data in order to provide guidance for operating in ice pellet conditions. The joint effort would include work conducted by the Anti-Icing Materials International Laboratory (AMIL), APS, and McGill University. The research was aimed at characterizing the precipitation condition, conducting HOT research in natural and simulated ice pellet conditions, and conducting simulated full-scale aerodynamic testing. Testing was conducted with the aim of substantiating a 20-minute allowance suggested as a minimum time required to operate during ice pellet conditions.

1.2 Objectives

The primary objective of this project was to determine fluid endurance times during ice pellet conditions.

As testing is still preliminary, and the protocol for determining fluid failure in ice pellet conditions has not yet been determined, the following objectives were set for the research conducted by APS:

1. Conduct natural ice pellet research;
    a) Collect samples of natural ice pellets to investigate rate of precipitation and size distribution; and
    b) Conduct endurance time testing in natural ice pellet conditions.
2. Determine method for producing simulated ice pellets;
3. Conduct ice pellet dissolving time research;
4. Conduct far versus near pilot's perspective photo documentation;
5. Conduct full-scale research using Falcon 20 aircraft;
6. Investigate bare wing departures during ice pellet conditions; and
7. Investigate if endurance time testing conducted during ice pellet conditions will demonstrate signs of fluid adhesion to aluminum test surfaces by conducting preliminary testing during conditions most likely to exhibit adhesion.

These objectives are provided in more detail in an excerpt from the TDC work statement which is provided in Appendix A.

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 data collected during natural precipitation conditions (Objective 1);

c) Section 4 presents the research conducted to investigate the different methods available for manufacturing simulated ice pellets (Objective 2);

d) Section 5 presents the data collected, through macroscopic photography, of simulated ice pellets and simulated snowflakes dissolving in de/anti-icing fluid (Objective 3);

e) Section 6 presents the "Far versus Near-Pilots Perspective" data collected during simulated ice pellet precipitation conditions on the airfoil (Objective 4);

f) Section 7 presents the recorded observations regarding bare wing departures during ice pellet conditions (Objective 6);

g) Section 8 presents the data collected during full-scale testing in simulated ice pellet conditions using the Falcon 20 aircraft (Objective 5);

h) Section 9 presents the endurance time data that were collected during simulated ice pellet precipitation conditions on a standard test plate and on a leading edge thermal equivalent box (Objective 7);

i) Section 10 presents the conclusions; and

j) Section 11 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 APS Montreal-Trudeau Airport Test Site

Outdoor testing was conducted during the winter of 2005-06 at the APS test site located at the Montreal-Trudeau Airport. Testing was conducted by APS personnel. The location of the test site is shown on the plan view of the airport shown in Figure 2.1. The APS test site is located near the MSC automated weather observation station.

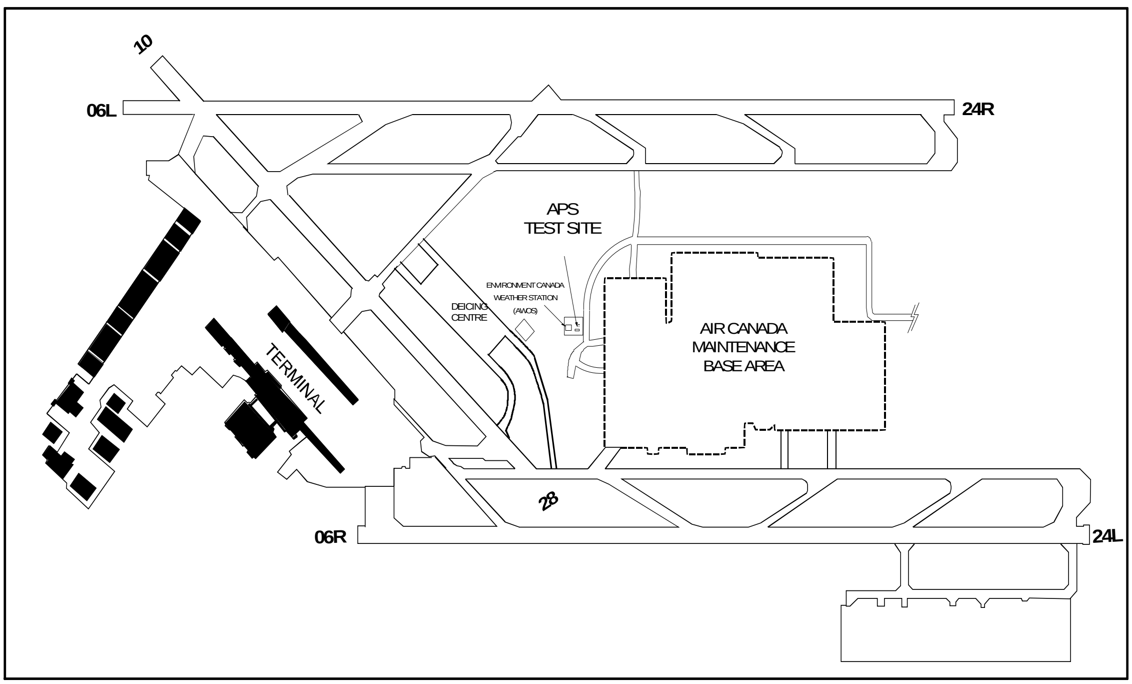

Figure 2.1: Plan View of APS Pierre Elliot Trudeau Airport Test Site

2.2 NRC Climatic Engineering Facility

To obtain the necessary climatic conditions, testing was carried out at the NRC Climatic Engineering Facility (CEF) (Photo 2.1). The CEF is equipped with a sprayer assembly (Photo 2.2) able to simulate required freezing precipitation conditions. Testing, conducted by APS personnel, was done in conjunction with other projects to minimize expenditures.

2.3 NRC Institute for Aerospace Research

Full-scale testing using the NRC Falcon 20 aircraft was carried out at the NRC Institute for Aerospace Research (IAR) (Photo 2.3). The NRC Falcon 20 research aircraft is equipped with sensors to gather data during trials. Testing was co-ordinated by APS personnel with the co-operation of NRC IAR staff members.

2.4 Description of Test Procedures

The following sections describe the procedures followed for each of the objectives given in Section 1.2.

2.4.1 Natural Ice Pellet Research

2.4.1.1 Photo Documentation of Natural Ice Pellets on Black Felt

Still photography was used to document detailed characteristics of ice pellets in a natural environment, specifically their size, diameter distribution, and appearance. Trays lined with black felt were used to collect natural ice pellet samples. When a weigh scale was available, the rate of precipitation was measured by weighing the tray prior to and after exposure. A detailed description of the test procedure can be found in Appendix B.

2.4.1.2 Endurance Time Testing in Natural Ice Pellet Conditions

Endurance time testing in natural ice pellet conditions was conducted to validate the results obtained using simulated ice pellets. Testing was conducted using the procedure entitled *Test Requirements for Natural Precipitation Flat Plate Testing*, December 23, 2004, which includes a brief summary of the test requirements and data forms needed for natural precipitation flat plate tests. In addition, still photography was used to document the fluid condition at different stages during the test. A detailed description of the test procedure can be found in Appendix C.

2.4.2 Production of Simulated Ice Pellets

Extensive work was completed exploring different methods for manufacturing simulated ice pellets. Procedural feasibility, cost, and quality of the simulated ice pellets produced were evaluated for each proposed manufacturing method. Still photography was used to document detailed characteristics of the simulated ice pellets and the manufacturing methods. A procedure was not issued for this objective.

2.4.3 Ice Pellet Dissolving Time Research

For comparison purposes, equal masses of both snow and ice pellet samples (both natural and simulated) were used to document the details of the different precipitate dissolving in various dilutions of deicing fluid. Testing was conducted at the APS test site inside a refrigerated trailer, which was maintained at a specific set temperature. The precipitate samples were dropped into 2 mm of deicing fluid cooled to the ambient temperature of the refrigerated trailer. Still photography was used to document each test and the total time required for each sample to dissolve was documented. A detailed description of the test procedure can be found in Appendix D.

2.4.4 Far vs. Near-Pilot's Perspective Photo Documentation

Still photography was used to document simultaneous perspectives representing close-in and pilot views of an airfoil subjected to ice pellet precipitation conditions and to obtain an adequate representation of the human perspective when viewing an aircraft wing. Preliminary testing was conducted at the APS Montreal-Trudeau test site. Testing in simulated ice pellet conditions was conducted at the NRC CEF as well as at the NRC IAR. A detailed description of the test procedure can be found in Appendix E.

2.4.5 Falcon 20 Full-Scale Research

Full-scale testing using the NRC Falcon 20 research aircraft was conducted to determine the amount of ice pellet contamination that will flow-off an anti-iced aircraft at takeoff. Testing was conducted at the NRC IAR. The procedure and detailed results of the full-scale research are described in TC report TP 14716E, *Falcon 20 Trials To Examine Fluid Removed From Aircraft During Takeoff With Ice Pellets* (2).

2.4.6 Adherence in Simulated Ice Pellet Conditions

Testing was conducted to determine if endurance time testing during ice pellet conditions will demonstrate signs of fluid adhesion to aluminum test surfaces. Testing was conducted following the procedure entitled *Test Requirements for Natural Precipitation Flat Plate Testing*, December 23, 2004, which includes a brief summary of the test requirements and data forms needed for natural precipitation flat plate tests. Testing was conducted in simulated precipitation using a standard aluminum test plate sitting inside a self-contained bucket that collected any fluid run off from the plate. In addition, still photography was used to document the fluid condition at different stages during the test. A detailed description of the test procedure can be found in Appendix F.

2.5 Data Forms

Data forms were provided for all objectives in the related test procedures. Sections 2.4.1 to 2.4.6 described each objective and the respective test procedure issued.

2.6 Equipment

The following section is a non-exhaustive list of equipment used for the objectives described in Section 2.4.1 to 2.4.6. For a complete list of equipment used, refer to the specific procedures issued for each objective.

2.6.1 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 2.2.

2.6.2 Standard Surfaces Leading Edge Thermal Equivalent Surfaces (Cold-Soaked Boxes)

Fluid endurance time testing was also conducted using a standard cold-soaked box. A schematic of the cold-soaked box is shown in Figure 2.3.

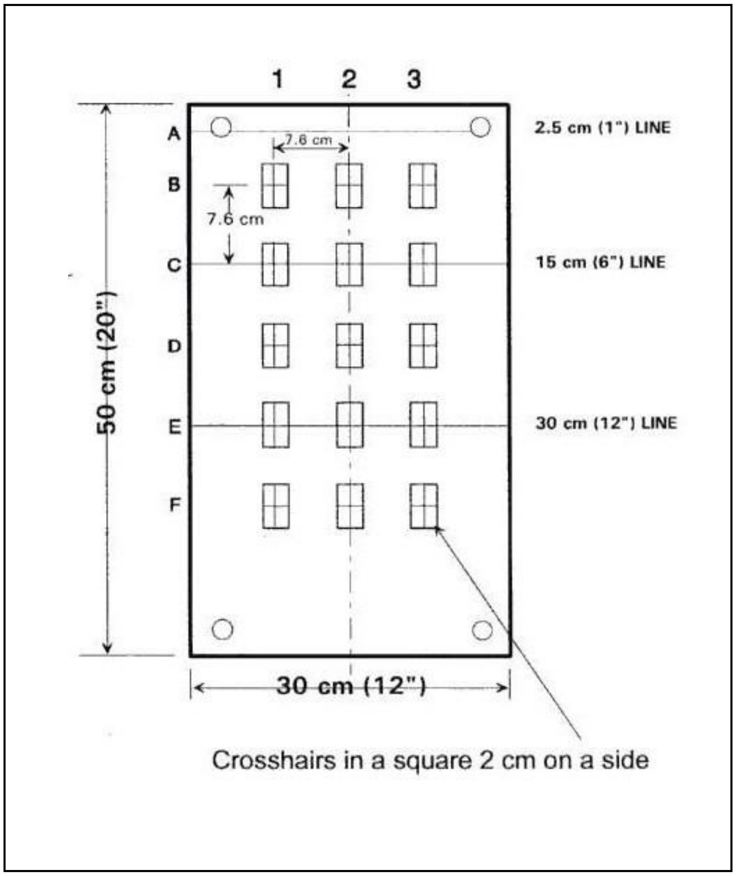

Figure 2.2: Schematic of Standard Holdover Time Test Plate

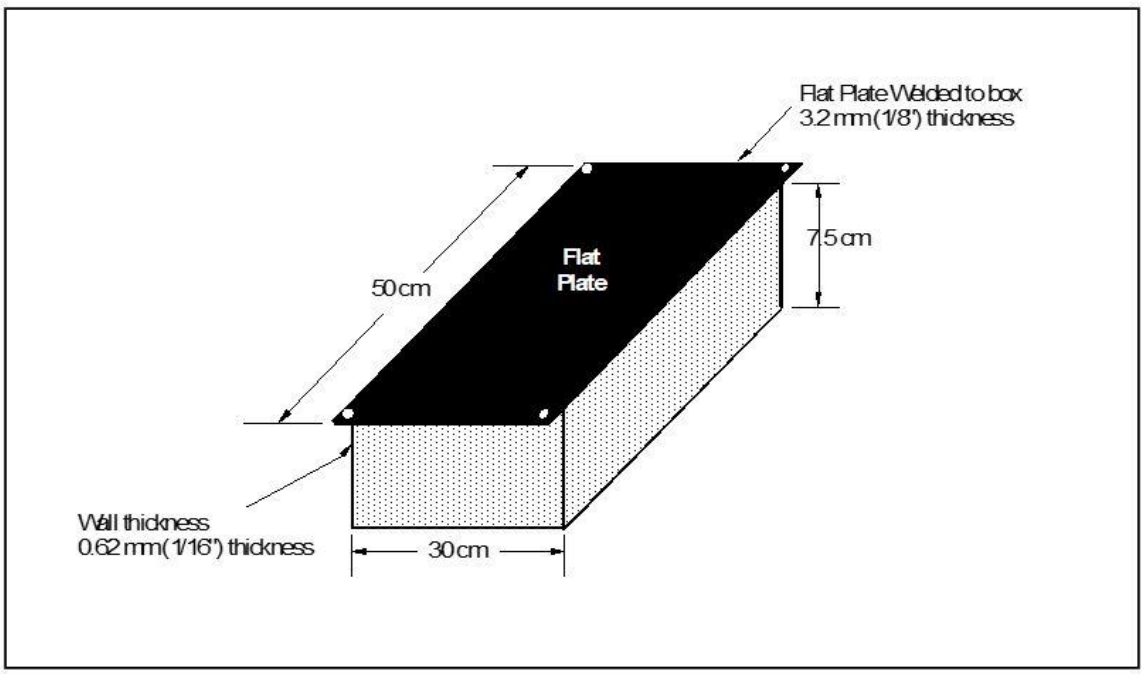

Figure 2.3: Schematic of Leading Edge Thermal Equivalent Box (Cold-Soaked Box)

2.6.3 NCAR Bucket

Fluid endurance time testing during simulated precipitation conditions was conducted using a standard aluminum test plate sitting inside a self-contained bucket (National Center for Atmospheric Research (NCAR) Bucket) that collected any fluid run off from the plate. The NCAR bucket was placed on a weigh scale to measure the rate of precipitation.

2.6.4 Weigh Scale

A weigh scale was used to measure the rate of precipitation. The scale was zeroed prior to each measurement.

2.6.5 Brixometer

Brix measurements were taken using a hand-held brixometer (Photo 2.4). Brix measurements provided data relevant to the fluid concentration; measuring Brix monitors fluid dilution.

2.6.6 Wet Film Thickness Gauge

Wet film fluid thickness measurements were recorded during endurance time tests. Figure 2.4 shows the schematic of the wet film thickness gauges.

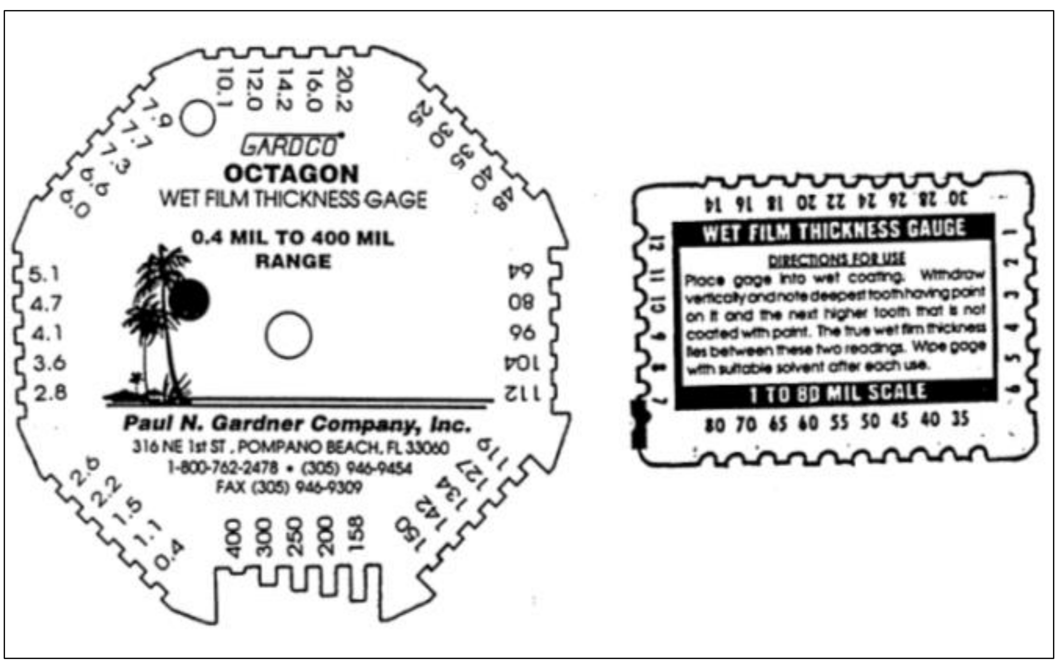

Figure 2.4: Wet Film Thickness Gauges

2.6.7 Ice Pellet Pitcher

The simulated ice pellets were distributed over the test surface using an 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.

2.7 Fluids

Table 2.1 provides information concerning the various fluids utilised for endurance time testing in simulated ice pellet conditions. Fluid viscosity was measured using the manufacturer method stated in the HOT Guidelines.

Table 2.1: List of Fluids Used for Testing

Fluid Type	Fluid Name	Viscosity Type	Viscosity (mPa.s)	Batch #
I	Battelle D3 ADF	N/A	N/A	51381
I	Type I EG	AéroMag Sample	N/A	N/A
II	Kilfrost P1792 (Batch 1)	LOWV	3,040	P1972-1
IV	Octagon MaxFlo	LOWV	8,670	041206-026
IV	Dow UCAR ADF/AAF Ultra+	AéroMag Sample	Mid-viscosity	N/A
IV	Dow UCAR Endurance EG106	LOWV	24,600	200600 147-12
IV	Kilfrost ABC-S	Degraded Sample	14,550	N/A

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Photo 2.1: Inside View of NRC Climate Engineering Facility

Photo 2.2: Sprayer Assembly Used to Produce Fine Droplets

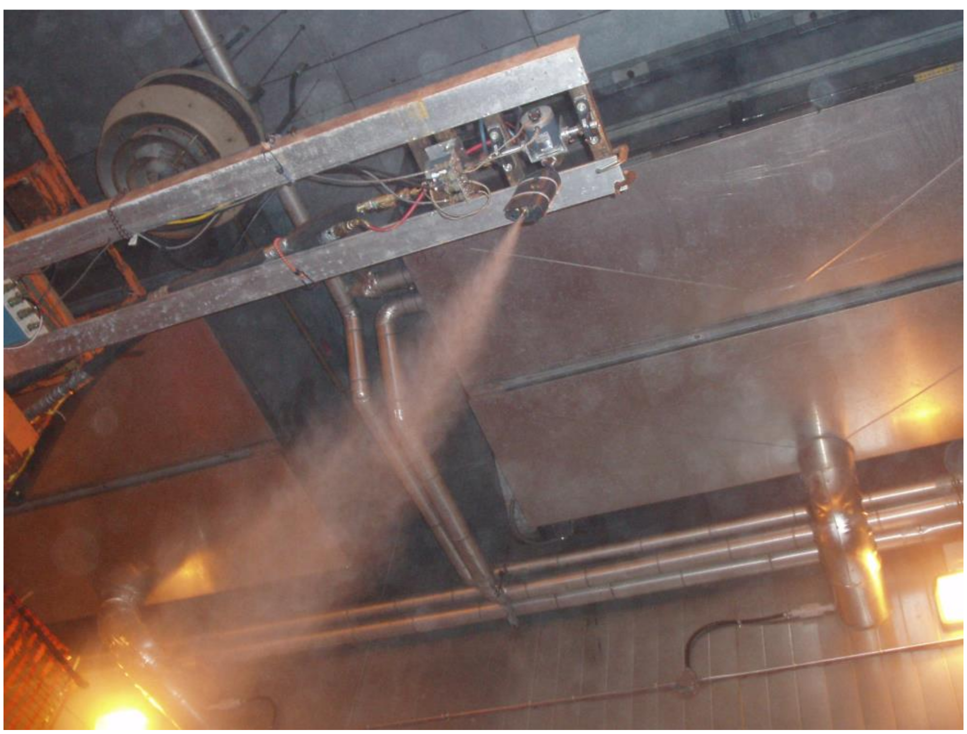


Photo 2.3: Outside View of NRC Institute for Aerospace Research and Falcon 20 Research Aircraft

Photo 2.4: Hand-Held Brixometer

3. NATURAL ICE PELLET RESEARCH

Visual fluid failure determination in ice pellet conditions was found to be a challenge. Fluid condition assessments may vary depending on the angle of incidence of the observer's line of sight to the location of the affected area. Also, while ice pellets embedded in the fluid did not adhere, it is not known whether this contamination would come off during aircraft rotation.

In an attempt to better understand these issues, a series of tests documented with photography were conducted during natural ice pellet conditions.

3.1 Photo Documentation of Natural Ice Pellets on Black Felt

Still photography was used to document detailed characteristics of ice pellets in a natural environment, specifically their size, diameter distribution, and appearance. Trays lined with black felt were used to collect natural ice pellet samples (Photo 3.1 and Photo 3.2). A sample photo from each test event is included in Appendix G. When a weigh scale was available, the rate of precipitation was measured by weighing the tray prior to and after exposure.

3.1.1 Test Log – Photo Documentation of Natural Ice Pellets on Black Felt

During the winter of 2005-06, APS personnel obtained photo documentation of natural ice pellets during eleven test events. On four of those events, multiple observers acquired photo documentation. To facilitate the understanding of the data collected, a log was created for the series of test events. The log presented in Table 3.1 provides relevant information for each test event. Each row contains data specific to one test. The following is a brief description of the column headings for the test log:

Test event:	Exclusive number identifying each test event;
Date:	Date when the test was conducted;
Start Time:	Start time for the test event recorded in local time;
End Time:	End time for the test event recorded in local time;
# Photos:	Total number of photos taken by APS observer using digital hand-held camera;
# Film Clips:	Total number of videos taken by APS observer using digital hand-held camera;

Average Rate:	Average precipitation rate, measured in g/dm²/h, for the duration of the test event;
Intermediate Rates:	Intermediate precipitation rates, measured in g/dm²/h, for set intervals during the test event;
Observed Size:	APS observer's estimated size distribution of ice pellets for the duration of the test event;
Location:	Location of the APS observer at the time of the test event;
METAR OAT:	Outside air temperature (OAT) reported by the METAR for the duration of the test event;
METAR Weather Reported:	Weather type (or transition) reported by the METAR for the duration of the test event;
MVD Sample Size:	Number of ice pellets used for calculating the mean volume diameter for the respective sample;
MVD:	Median volume diameter (MVD) for the respective sample measured in millimetres; and
Comments:	Additional pertinent information recorded by APS personnel during the test event.

3.1.2 METAR Weather Reported in Ice Pellet Conditions

APS personnel obtained samples of natural ice pellets during eleven test events. However, METAR weather reported ice pellet conditions in only six of the eleven events. Other conditions reported by METAR during the times APS obtained ice pellet samples included light freezing rain, light snow, light rain with rain, and freezing drizzle. It should be noted that the primary objective of the project was to document the occurrence of ice pellets, and that in some cases, ice pellets may not have been the dominant precipitation condition.

Figure 3.1 and Figure 3.2 demonstrate time lines for two ice pellet events which occurred on January 17, 2006 and January 21, 2006, respectively.

Table 3.1: Test Log of Natural Ice Pellet Photography on Black Felt

Test Event	Date	Start Time	End Time	Photos (#)	Film Clips (#)	Average Rate (g/dm²/h)	Intermediate Rates (g/dm²/h)	Observed Size	Location	METAR OAT (°C)	METAR Weather Reported	MVD Sample Size (# Pellets)	MVD (mm)	Comments
1	15-Nov-05	12:08:00	12:12:00	11	N/A	N/A	N/A	1-2 mm	YUL (Downtown)	0	Light Ice Pellets	75	1.73	Used navy blue tuque and ruler for photos
2	25-Dec-05	21:00:00	21:15:00	40	N/A	N/A	N/A	1-3 mm	YUL (MR Home)	0	Light Freezing Rain	60	2.37	Used black glove and ruler. Also photos on roof of silver jetta. (approx. time)
3	29-Dec-05	20:41:00	22:11:00	138	16	7	3, 2, 7, 11	1-2.5 mm	YUL (Test Site)	0	Light Ice Pellets	60	1.82	Ran ET Test at same time
	29-Dec-05	20:41:00	22:11:00	59	N/A	7	3, 2, 7, 11	1-2.5mm	YUL (Test Site)	0		N/A	N/A	Ran ET Test at same time
4	14-Jan-06	3:11:00	3:23:00	18	3	N/A	N/A	1-4 mm	YUL (MR Home)	1	Light Snow	75	2.38	Aggregates in samples
5	17-Jan-06	20:33:00	22:00:00	79	N/A	30.5	6.5, 15, 16, 23, 17, 32, 31, 30, 29, 33, 38, 58, 50	1-4 mm	YUL (Test Site)	-8	Light Ice Pellets to Light Ice Pellets w/ Rain	60	2.58	Ran ET Test - Aggregetes
	17-Jan-06	20:28:00	0:15:00	92	5	29.5	6.5, 15, 16, 23, 17, 32, 31, 30, 29, 33, 38, 58, 50	1-4 mm	YUL (Test Site)			N/A	N/A	Ran ET Test - Aggragetes - Took Photos w/ Steve Gibson
6	21-Jan-06	11:34:00	11:52:00	26	5	26.7	33, 38, 36, 21, 16, 9	1-5 mm	YUL (Test Site)	0	Light Rain with Rain to Light Rain w/ Rain and Snow to Light Snow with Snow	60	3.45	Ran ET Test - Large Aggregates
	21-Jan-06	11:35:00	12:01:00	43	1	20.9	33, 38, 36, 21, 16, 9, 10	1-5 mm	YUL (Test Site)			N/A	N/A	Ran ET Test - Large Aggregates
7	30-Jan-06	8:00	8:15:00	22	N/A	N/A	N/A	1-3mm	YUL (JD Home)	-6	Light Ice Pellets with Rain	70	2.35	
8	30-Jan-06	13:20	13:45:00	15	N/A	N/A	N/A	1-2 mm	YUL (Test Site)	-6	Light Freezing Drizzle	60	2.38	Natural ice pellet event was short. Precipitation rate was high at first but reduced drastically once the black felt was actually put outside. (time is aproximated)
	30-Jan-06	13:12:00	13:38:00	35	N/A	N/A	N/A	1-2 mm	YUL (APS Office)	-6		70	1.73	pictures taken after the event no ruller (aprox size)
9	4-Feb-06	9:47:00	9:52:00	16	N/A	N/A	N/A	1-2 mm	YUL (MR Home)	-2	Light Rain with Rain	60	1.81	
10	16-Feb-06	21:35:00	22:45:00	101	N/A	25.6	8,21,38,52,9	1-3mm	YUL Test Site	-7	Light Ice Pellets with Snow	70	2.11	Ran ET-Test Rate using cartboard pan
11	9-Mar-06	10:20:00	10:36:00	13	N/A	N/A	N/A	2-3mm	YOW (NRC IAR)	-3	Light Ice Pellets	50	2.58	

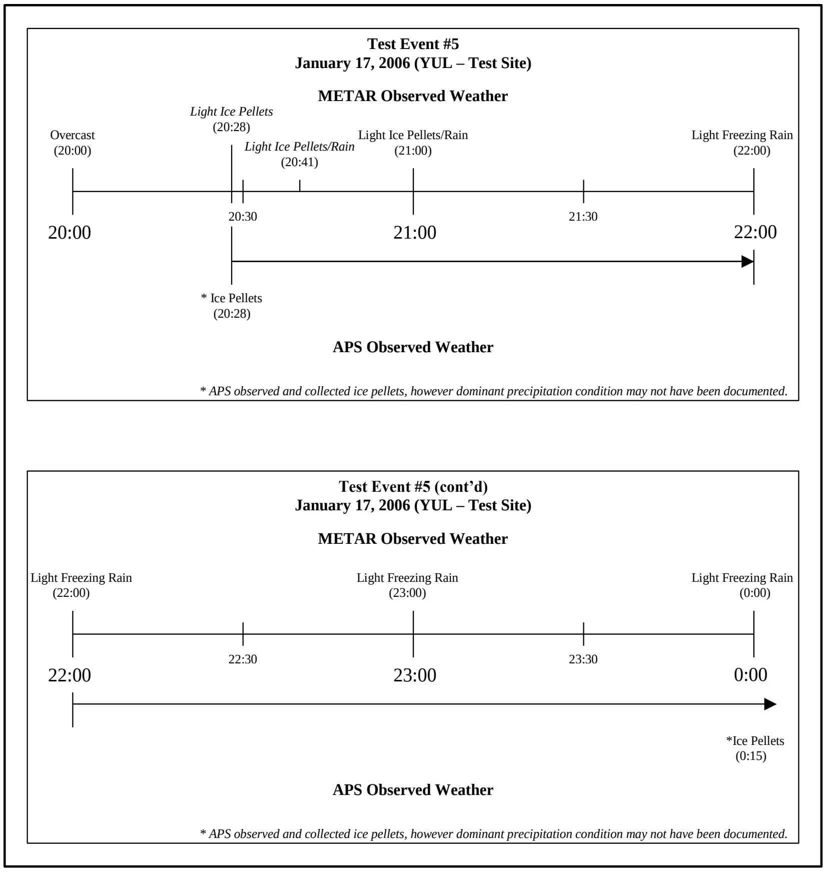


Figure 3.1: APS vs. METAR Ice Pellet Observations – Jan 17, 2006

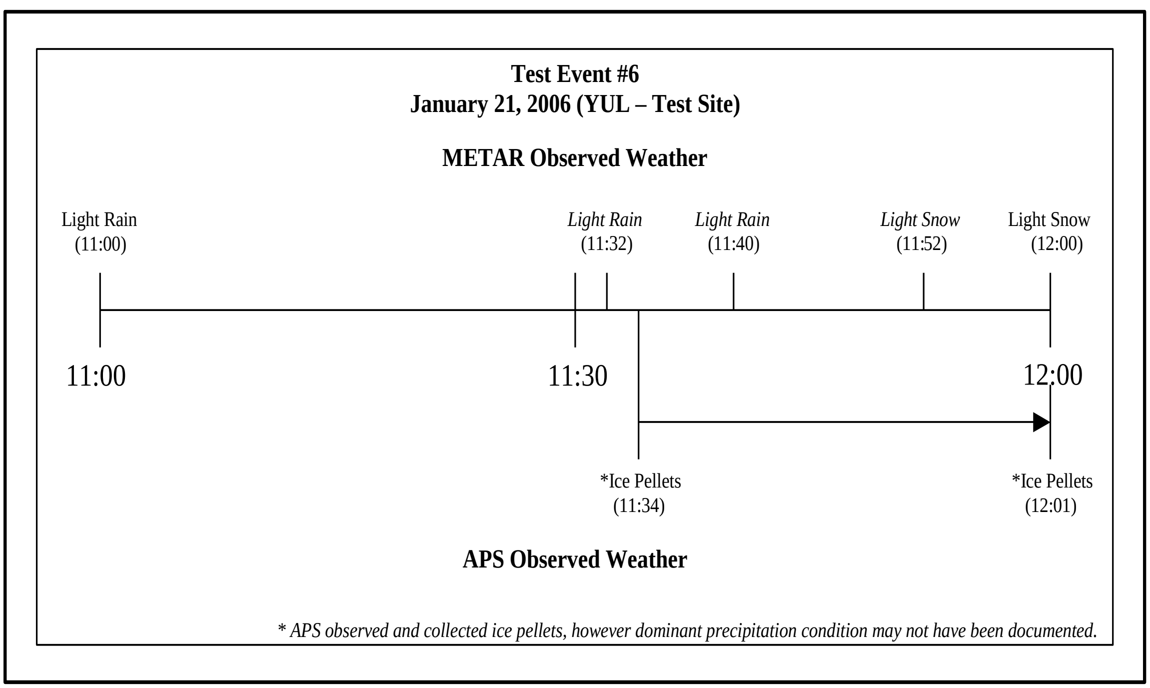


Figure 3.2: APS vs. METAR Ice Pellet Observations – Jan 21, 2006

On January 17th (Test event #5), METAR reported ice pellets from 20:28 to 22:00; however, APS observed and collected ice pellets from 20:28 until 0:15. For a period of more than two hours, APS was experiencing ice pellet precipitation that was not reported by METAR. On January 21st (Test event #6) APS observed and collected ice pellets for a period of approximately 27 minutes, however METAR did not report ice pellet conditions; special reports were issued by METAR which included only light rain and light snow.

During some events, samples were taken at different locations during short periods of time, which could be the reason METAR weather did not report ice pellet conditions. During some cases, if ice pellets were not the predominant precipitation condition, METAR may not have reported the occurrence of ice pellets.

If extensive research is being conducted to provide operators with appropriate information to operate safely during ice pellet conditions, meteorological technology will have to be developed to adequately report critical weather conditions including ice pellet conditions.

3.1.3 Median Volume Diameter (MVD) Analysis of Natural Ice Pellet Samples

For each natural ice pellet test event, one representative photo was used to conduct the MVD analysis. A sample section (generally measuring 16 cm^2) was extracted from each photo, and the diameter of each ice pellet within that section was measured and recorded.

Figure 3.3 and Figure 3.4 demonstrate the ice pellet diameter distributions for the test event of February 4, 2006. In Figure 3.3, each bar designates the frequency of occurrence of each measured pellet diameter. In Figure 3.4, the curve labelled "Number" designates the cumulative frequency of occurrence of each measured ice pellet diameter, whereas the second curve labelled "Volume" designates the cumulative volumetric frequency. Using the derived cumulative volumetric frequency curve, the MVD can be determined by calculating the diameter corresponding to fiftieth percentile of the cumulative frequency. The MVD analysis conducted for each sample photo from each respective test event is included in Appendix G.

The calculated MVD and the sample size of ice pellets for each test event is listed in the test log given in Table 3.1. The calculated MVD for the limited samples ranged from 1.7 to 3.5 mm. The MVD was greater than 2 mm for 7 of the 11 test events samples.

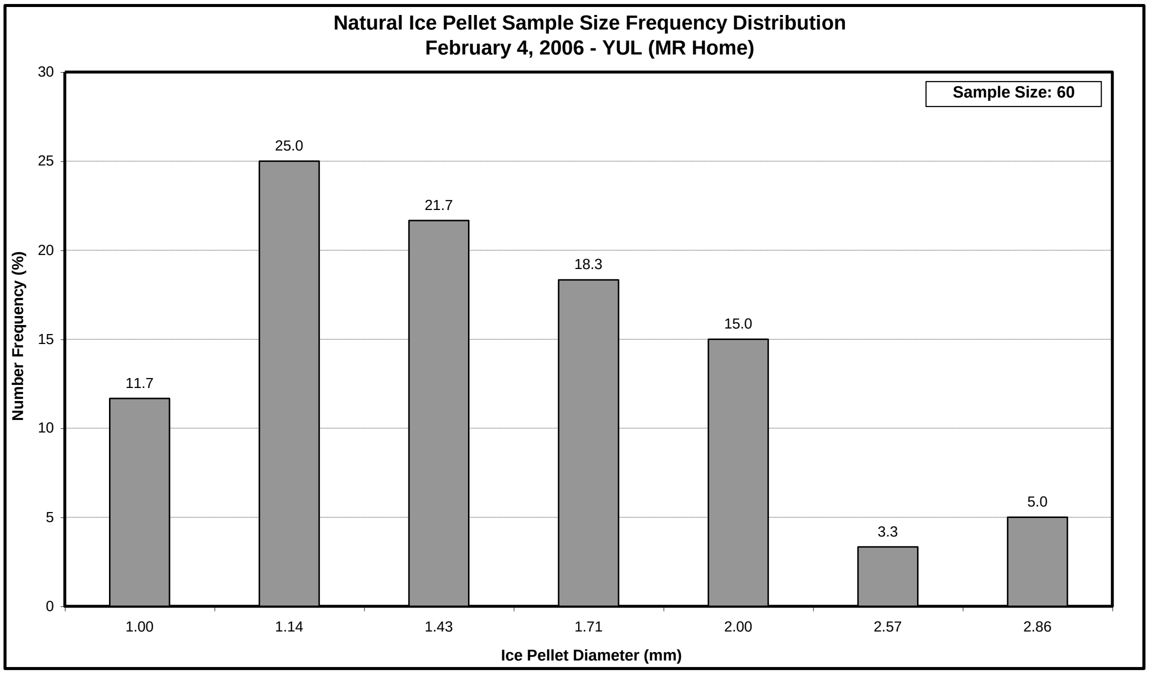


Figure 3.3: Droplet Diameter Frequency Distribution – February 4, 2006

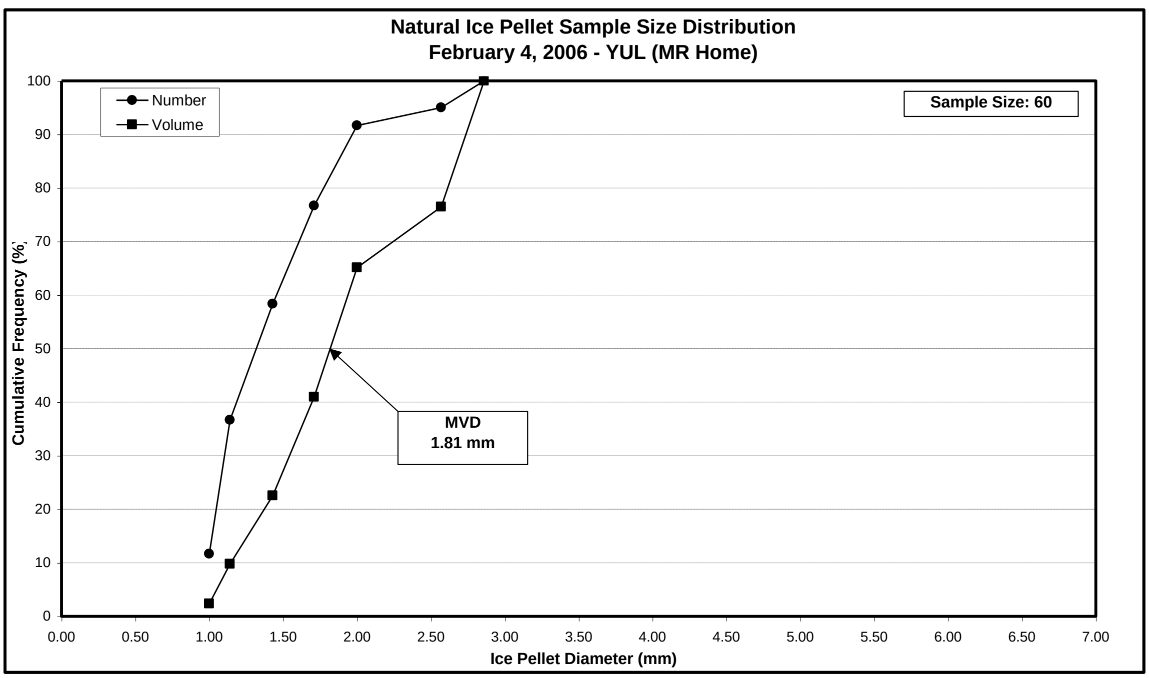


Figure 3.4: Droplet Diameter Cumulative Frequency Distribution – February 4, 2006

3.1.4 General Observations of Natural Ice Pellets

The natural ice pellets collected measured up to 5 mm in diameter. The rate of precipitation was measured during four test events. These intermediate rates of precipitation ranged from 2 to 58 g/dm²/h. It was also observed that larger ice pellets (with a greater diameter) generally occurred when the recorded rate of precipitation was the highest. Aggregates, which are adhered clusters of ice pellets, were commonly found amongst the ice pellet samples; this was especially true during warmer conditions.

Observations from the eleven natural ice pellet test events suggested that ice pellets are a transitional condition, often occurring during the transition from liquid to solid precipitation, or vice versa. As a result of this occurrence, ice pellets will often be combined with other freezing precipitate. If ice pellets are combined with freezing rain or drizzle, a risk of adhesion will arise.

Figure 3.5 and Figure 3.6 demonstrate the summary of ice pellet diameter distributions for all test events documented in the winter of 2005-06. In Figure 3.5, each bar designates the frequency of occurrence of ice pellet diameters in an assigned range. For example, 34.3 percent of ice pellet diameters were in the range of 1.51 to 2.00 mm. In Figure 3.6, the curve labelled "Number" designates the cumulative frequency of occurrence of each measured ice pellet diameter, whereas the second curve labelled "Volume" designates the cumulative volumetric frequency for all tests. The overall MVD for all the cumulative samples was calculated to be 2.69 mm.

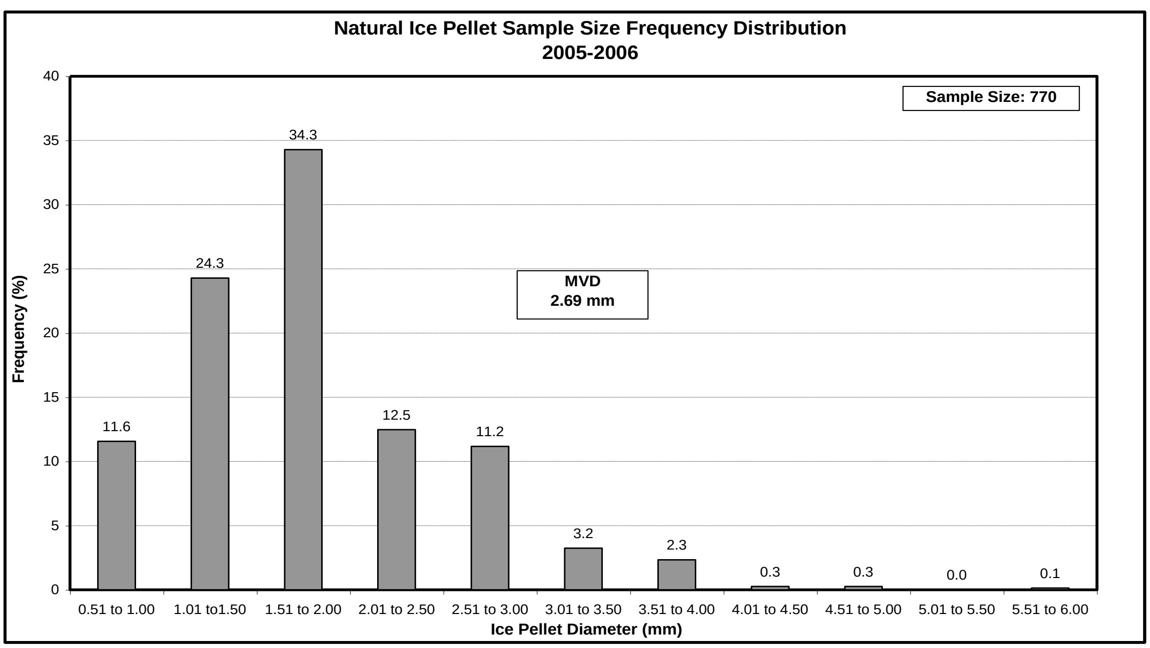


Figure 3.5: Droplet Diameter Frequency Distribution – Summary of Test Events for 2005-2006

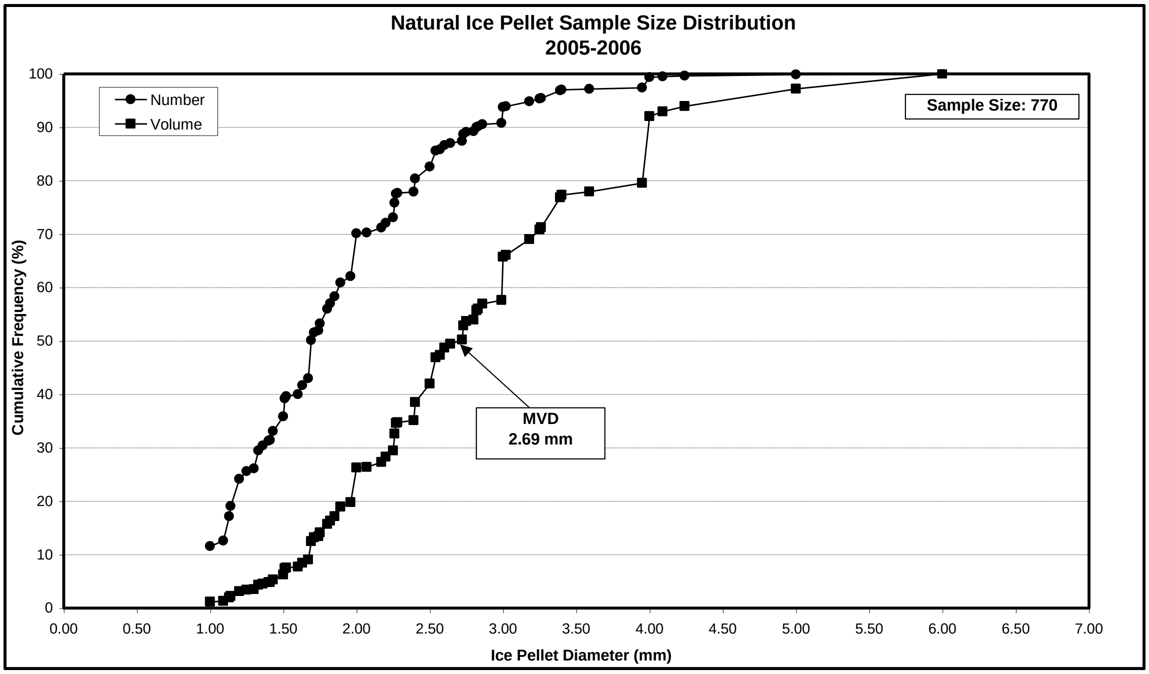


Figure 3.6: Droplet Diameter Cumulative Frequency Distribution – Summary of Test Events for 2005-2006

3.2 Endurance Time Testing in Natural Ice Pellet Conditions

Endurance time testing in natural ice pellet conditions was conducted to validate the results obtained using simulated ice pellets. In addition, still photography was used to document the fluid condition at different stages during the test.

3.2.1 Test Log - Endurance Time Testing in Natural Ice Pellet Conditions

During the winter of 2005-06, APS personnel conducted seven endurance time tests during four natural ice pellet events. In addition, photo documentation was acquired for each test conducted. It should be noted that fluid failure was difficult to determine in ice pellet conditions and therefore, each test was stopped when the fluid condition was deemed severe.

To facilitate the understanding of the data collected, a log was created for the series of tests. The log presented in Table 3.2 provides relevant information for each test event. 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;
Date:	Date when the test was conducted;
Run No.:	Run number in which the test was performed;
Start Time:	Start time for the test recorded in local time;
End Time:	End time for the test recorded in local time;
Fluid Dilution:	Aircraft deicing fluid glycol concentration;
Fluid Name:	Manufacturer brand name for each aircraft deicing fluid;
Fluid Type:	Aircraft deicing fluid type;
Fluid Temp:	Aircraft deicing fluid temperature prior to application, measured in degrees Celsius;
Total Time:	Duration of the test, measured in minutes;
Average Pan:	Average precipitation rate, measured in $g/dm^2/h$, collected by two precipitation pans at set intervals for the duration of the test run;
Average OAT:	The average of hourly outside ambient temperature readings for the duration of the test, measured in degrees Celsius, provided by MSC;
Average Wind Speed:	The average of hourly wind speed readings for the duration of the test, measured in kilometers per hour, provided by MSC; and
Average Rel. Hum.:	The average of hourly relative humidity readings for the duration of the test, measured in percentage, provided by MSC.

3.3 Photo Documentation of Endurance Time Tests in Natural Ice Pellet Conditions

Still photography was used to document each endurance time test conducted in natural ice pellet conditions. Photos were taken every 5 to 10 minutes for the duration of each test. Photo 3.3 to

Photo 3.5 demonstrate the fluid condition for Test #5 at various intervals during the test. A time stamp showing the elapsed time since the start of the test has been included in each photo.

Table 3.2: Test Log of Natural Ice Pellet Endurance Time Testing

Test No.	Date	Run No.	Start Time (Local)	End Time (Local)	Fluid Dilution	Fluid Name	Fluid Type	Fluid Temp.	Total Time [min.]	AVG PAN [g/dm²/h]	AVG OAT (°C)	AVG Wind Speed (km/h)	AVG Rel. Hum. (%)
1	Dec-29-05	1	20:13:00	20:59:00	75%	Octagon Maxflo	4	OAT	46.0	3.7	0.0	21	85
2	Jan-17-06	1	20:41:20	21:28:00	100%	UCAR Ultra +	4	OAT	46.7	24.2	-7.4	28	69
3	Jan-17-06	1	21:30:50	21:58:00	100%	UCAR Ultra +	4	OAT	27.2	46.4	-4.7	26	74
4	Jan-21-06	1	11:33:15	11:52:00	75%	Octagon Maxflo	4	OAT	18.8	26.7	0.1	31	89
5	Feb-16-06	1	21:38:00	22:07:00	75%	Octagon Maxflo	4	OAT	29.0	15.1	-7.3	23	79
6	Feb-16-06	2	22:12:13	22:58:50	100%	UCAR Ultra +	4	OAT	46.6	26.1	-7.0	26	79
7	Feb-16-06	3	22:59:35	23:15:00	75%	Octagon Maxflo	4	OAT	15.4	1.0	-6.7	30	80

Photo 3.1: Natural Ice Pellets on Black Felt – Sample 1

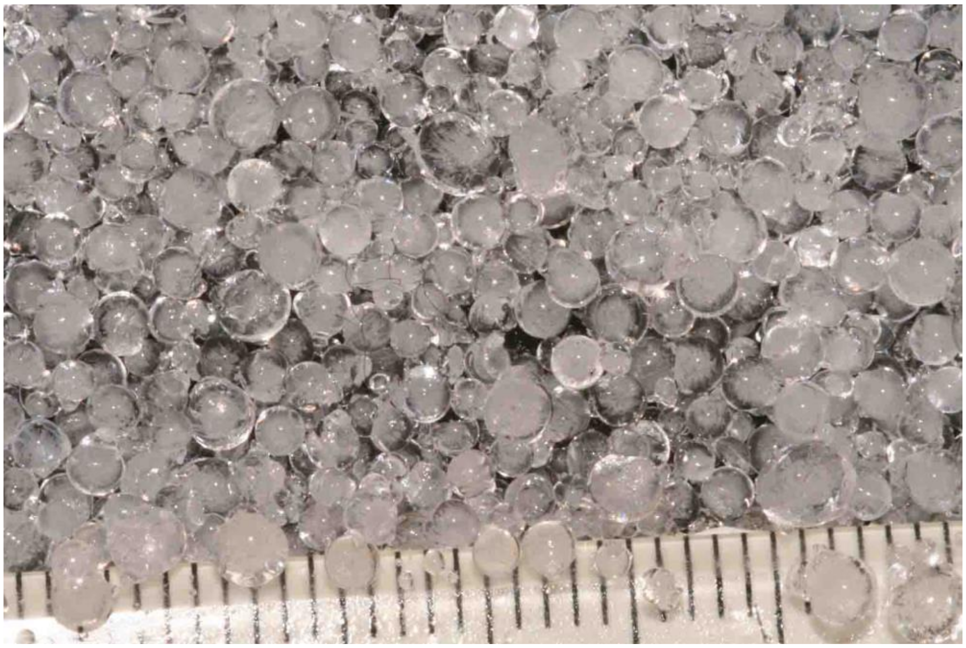


Photo 3.2: Natural Ice Pellets on Black Felt – Sample 2

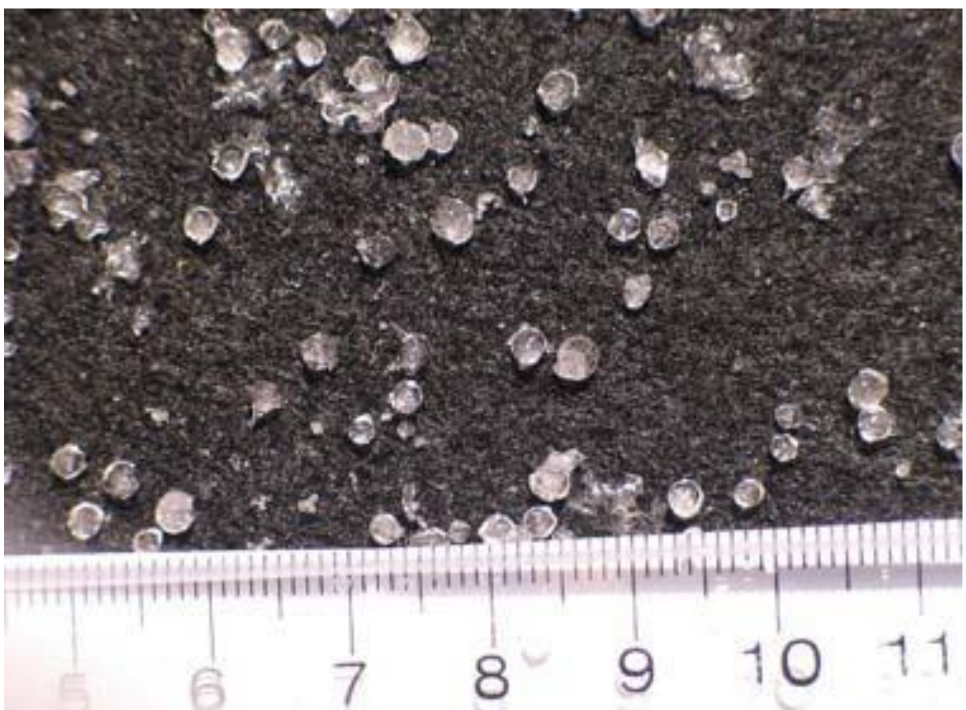


Photo 3.3: Endurance Time Test #5 – Photo 1

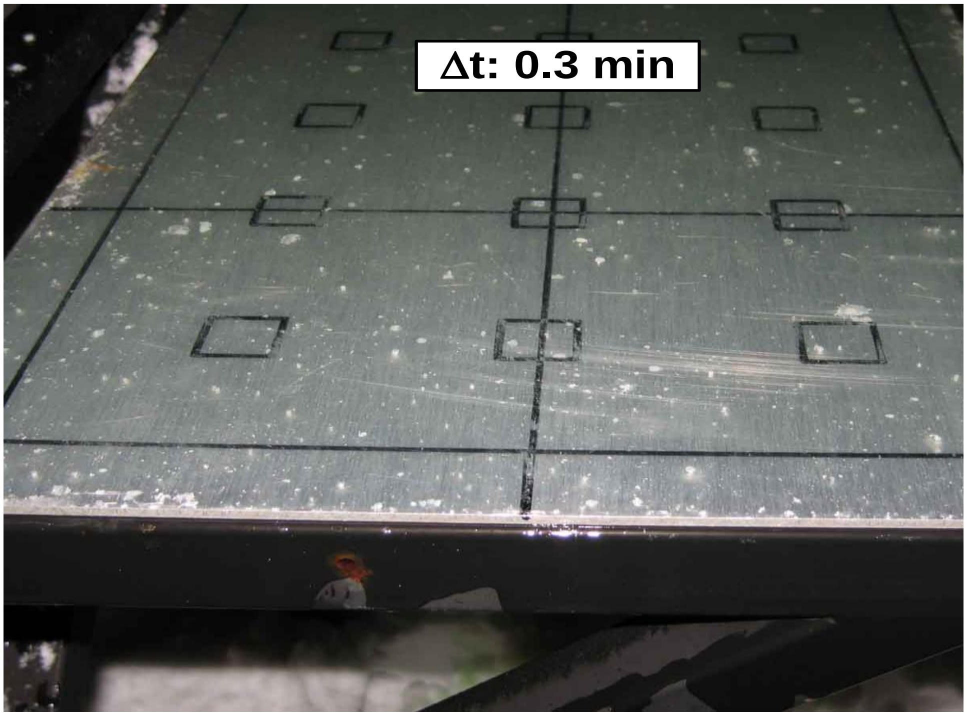


Photo 3.4: Endurance Time Test #5 – Photo 2

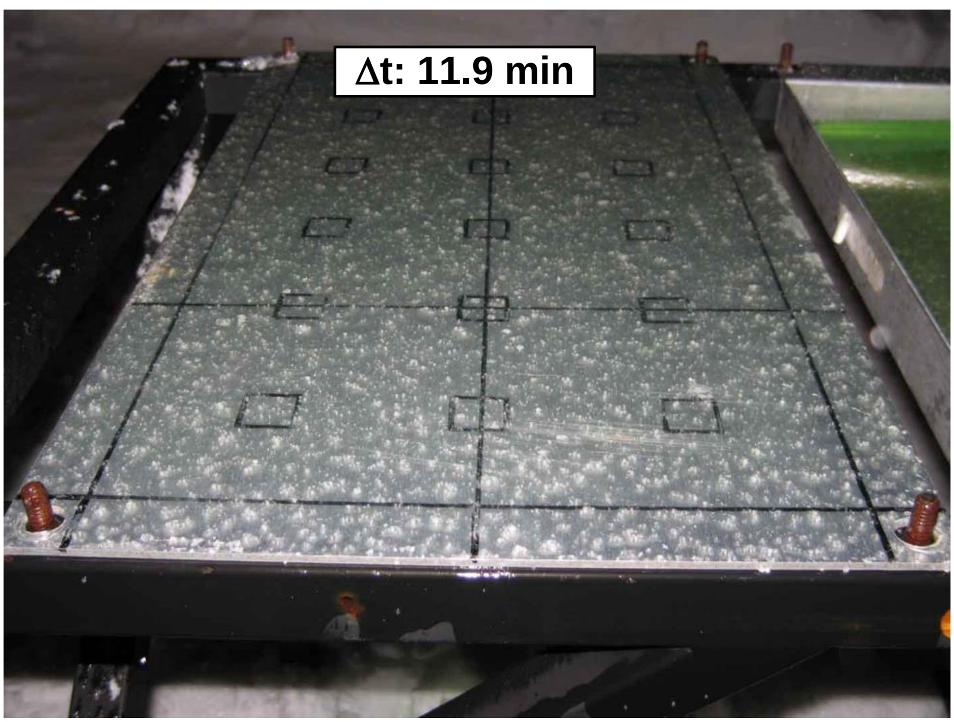
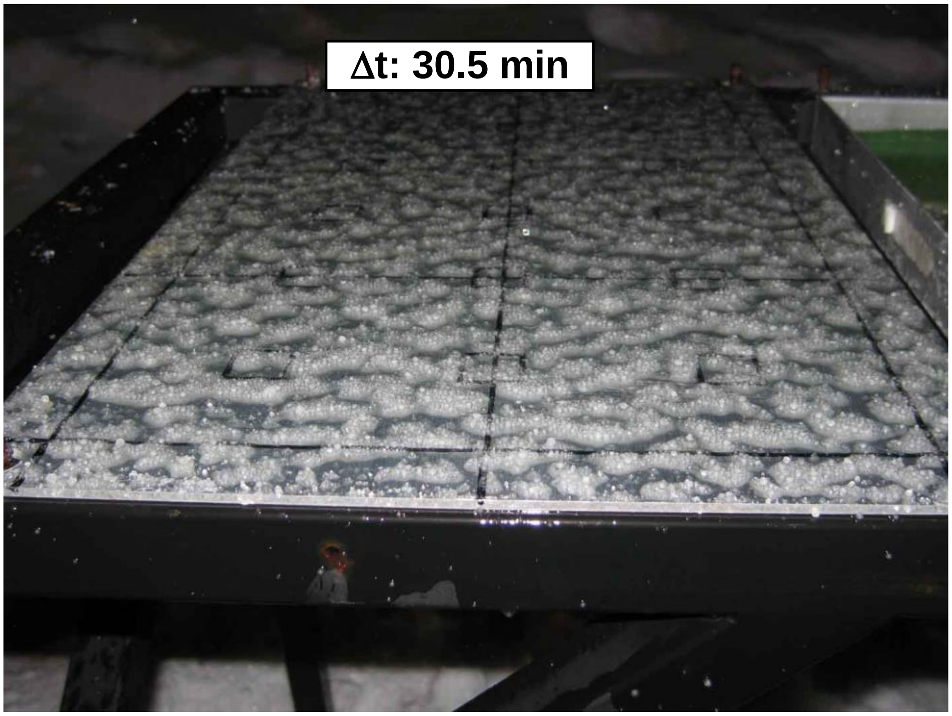


Photo 3.5: Endurance Time Test #5 – Photo 3



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4. PRODUCTION OF SIMULATED ICE PELLETS

Extensive work was done exploring different methods for manufacturing simulated ice pellets. This section will describe some of the alternatives considered and the method used for simulated ice pellet research.

4.1 Production of Simulated Ice Pellets

The following sections describe the methods for manufacturing simulated ice pellets.

4.1.1 Previous Method for Manufacturing Simulated Ice Pellets

Preliminary testing in simulated ice pellet conditions was conducted during the summer of 2005. Due to the limited number of ice pellets required, a method for creating spherical ice pellets was developed. This method consisted of spraying water on water phobic surfaces to create beads. These beads were left to freeze and were later scraped from the surface and collected. Although the size and shape of the ice pellets produced was representative of natural ice pellets, the procedure was long and tedious and was not ideal for manufacturing large quantities of ice pellets. Photo 4.1 demonstrates a sample of the "spray and scrape" ice pellets produced.

4.1.2 Current Method for Manufacturing Simulated Ice Pellets

Additional testing in simulated ice pellet conditions was planned for the winter of 2005-06. Due to the large numbers of ice pellets required, a new method for creating ice pellets was developed. This method consisted of crushing hard ice and then recuperating the desired size of pellets. In comparison to natural ice pellets, the size and shape were still representative; however, this method was less tedious and more productive. This method was used for manufacturing simulated ice pellets for the testing conducted during the winter of 2005-06. Photo 4.2 demonstrates a sample of the "crushed" ice pellets produced. A sample of natural ice pellets is shown in Photo 4.3. In addition, the very fine shavings of ice were utilised for simulated snow.

4.2 "Crushed" Ice Pellet Size and Shape Reduction

Testing was conducted to investigate the crushed-ice pellet size and shape reduction when submerged in aircraft deicing fluid. A 5 mm crushed-ice pellet was submerged in Type IV PG 75/25 fluid, and then removed from the fluid at set intervals: 8 minutes and 16 minutes. After being submerged for 8 minutes, it was observed that the edges of crushed-ice pellet began rounding off (Photo 4.4). After being submerged for 16 minutes, it was observed that the crushed-ice pellet was fairly spherical (Photo 4.5).

4.3 Full-Scale Testing Simulated Ice Pellet Quantity Requirements

Full-scale testing using the NRC Falcon 20 research aircraft was conducted in simulated ice pellet conditions. Due to the large quantity of ice pellets required, the "crushed ice" method was chosen as a suitable manufacturing method based on feasibility and quality of the pellets produced. In order for consistency in the research, fluid endurance time tests in simulated ice pellet conditions were also conducted using crushed ice rather than the spray and scrape pellets previously used.

Photo 4.1: Sample of "Spray and Scrape" Ice Pellets

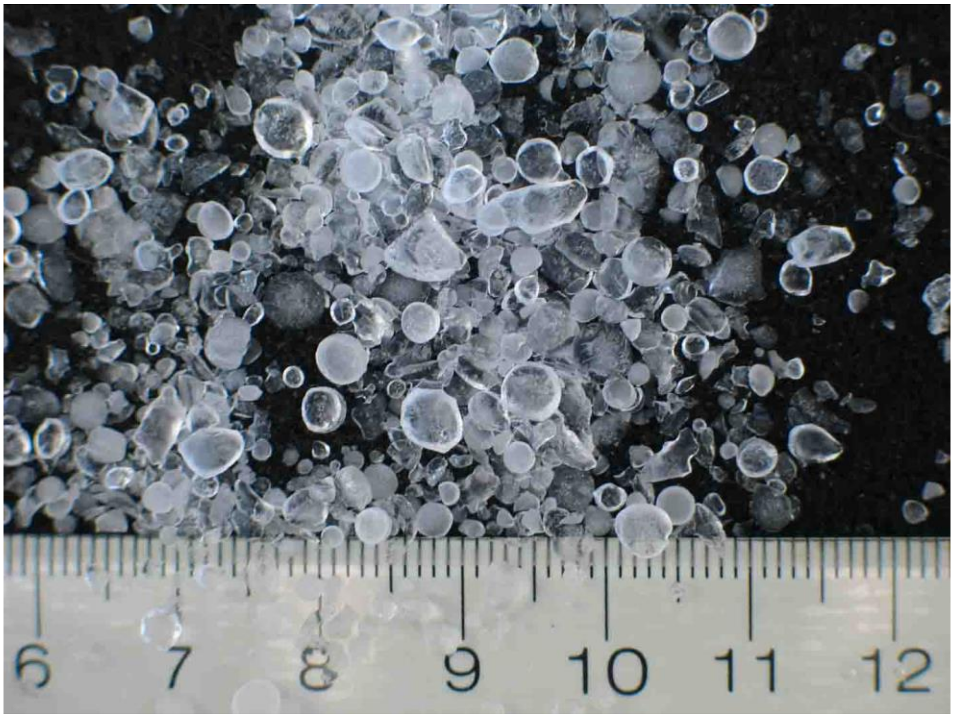

Photo 4.2: Sample of "Crushed" Ice Pellets

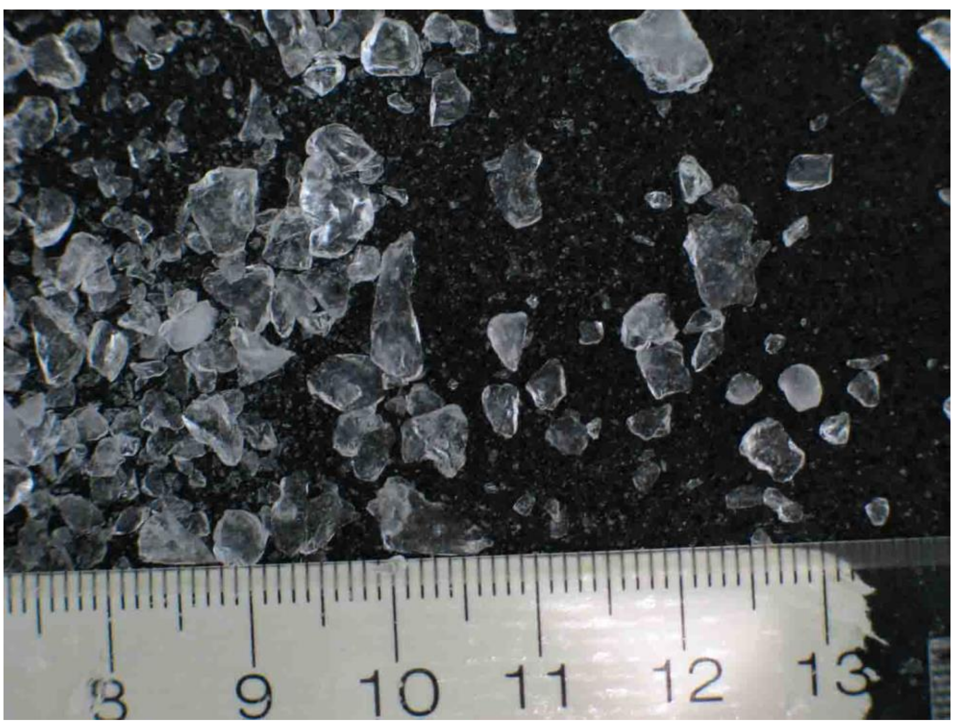

Photo 4.3: Sample of Natural Ice Pellets

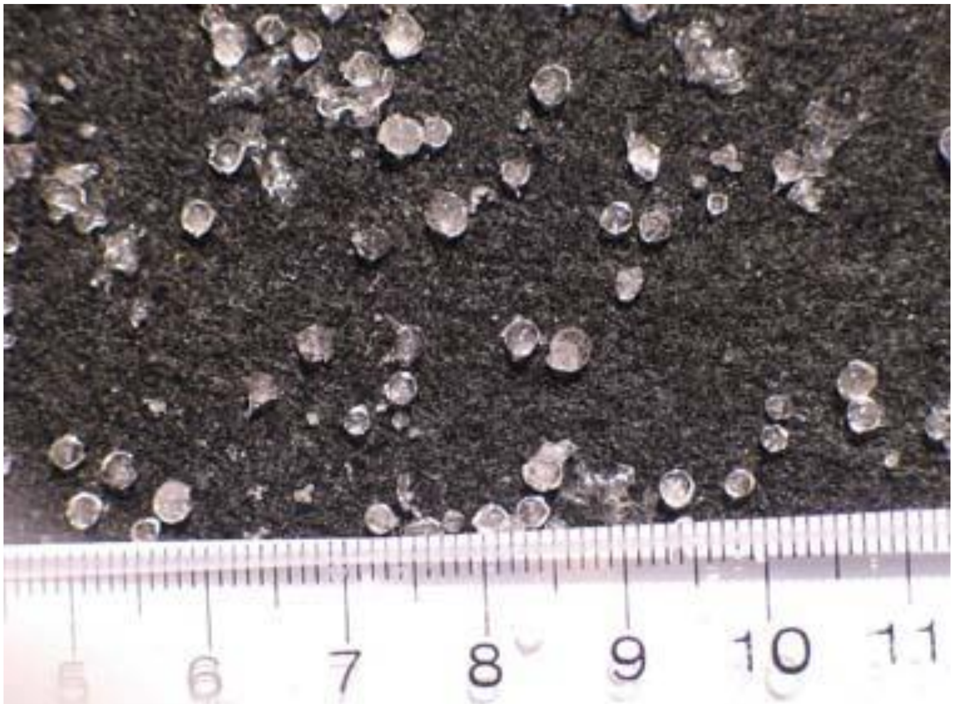

Photo 4.4: Crushed Ice Pellet After being Submerged for 8 Minutes in Aircraft Deicing Fluid

Photo 4.5: Crushed Ice Pellet after Being Submerged for 16 Minutes in Aircraft Deicing Fluid

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5. ICE PRECIPITATION DISSOLVING IN DEICING FLUID

For comparison purposes, equal masses of both snow and ice pellet samples (both natural and simulated) were used to document the details of the different precipitate dissolving in various dilutions of deicing fluid. This section describes the data collected.

5.1 Test Log – Ice Precipitation Dissolving Time Research

During the winter of 2005-06, APS personnel obtained photo documentation of natural and simulated ice precipitate dissolving in de/anti-icing fluid. To facilitate the understanding of the data collected, a log was created for the series of tests conducted. The log presented in Table 5.1 provides relevant information for each test event. Each row contains data specific to one test. The following is a brief description of the column headings for the test logs:

Test #:	Exclusive number identifying each test;
Date:	Date when the test was conducted;
Precipitation Type:	Ice precipitation placed in deicing fluid bath for respective melting time test;
Precipitation Size:	Ice precipitation mass, measured in millimetres for ice pellets and milligrams for snow;
Fluid:	Aircraft deicing fluid type;
Fluid Dilution:	Aircraft deicing fluid glycol concentration;
Initial Brix:	Aircraft deicing fluid Brix measured prior to the start of the test;
OAT:	Air temperature of the APS refrigerated research chamber, measured in degrees Celsius;
Start Time:	Start time for the test event recorded in local time;
End Time:	End time for the test event, when ice precipitation fully dissolved, recorded in local time; and
Total Time:	Total time from start to end time for the test event recorded in minutes.

Table 5.1: Log of Melting Time Tests

Test #	Date	Precipitation Type	Precipitation Size	Fluid	Fluid Dilution	Initial Brix	OAT (°C)	Start Time	End Time	Total Time (min)
1	02/13/06	IP - Crushed	5 mm	Type IV EG	100	40	-5	15:33:28	15:57:18	23.8
2	02/13/06	IP - Crushed	5 mm	Type IV EG	67/33	27.5	-5	15:33:33	15:59:42	26.1
3	02/13/06	IP - Crushed	5 mm	Type IV EG	57/43	23.5	-5	15:33:55	15:59:56	26.0
4	02/13/06	IP - Crushed	5 mm	Type IV EG	38/62	15.5	-5	15:34:10	15:53:05	18.9
5	02/13/06	IP - Crushed	5 mm	Type IV EG	21/79	8.5	-5	15:34:20	16:11:15	36.9
6	02/13/06	IP - Spray & Scrape	5 mm	Type IV EG	100	40	-5	17:12:14	17:47:57	35.7
7	02/13/06	IP - Spray & Scrape	5 mm	Type IV EG	67/33	27.5	-5	17:12:30	17:37:08	24.6
8	02/13/06	IP - Spray & Scrape	5 mm	Type IV EG	57/43	23.5	-5	17:12:40	17:48:22	35.7
9	02/13/06	IP - Spray & Scrape	5 mm	Type IV EG	38/62	15.5	-5	17:12:55	17:48:53	36.0
10	02/13/06	IP - Spray & Scrape	5 mm	Type IV EG	21/79	8.5	-5	17:13:07	17:46:13	33.1
11	02/14/06	IP - Crushed	1.5 mm	Type IV EG	100	40	-5	10:22:01	10:26:12	4.2
12	02/14/06	IP - Crushed	1.5 mm	Type IV EG	67/33	27.5	-5	10:23:09	10:26:21	3.2
13	02/14/06	IP - Crushed	1.5 mm	Type IV EG	57/43	23.5	-5	10:23:43	10:25:44	2.0
14	02/14/06	IP - Crushed	1.5 mm	Type IV EG	38/62	15.5	-5	10:32:45	10:34:45	2.0
15	02/14/06	IP - Crushed	1.5 mm	Type IV EG	21/79	8.5	-5	10:33:10	10:34:59	1.8
16	02/14/06	IP - Spray & Scrape	1.5 mm	Type IV EG	100	40	-5	11:15:42	11:19:15	3.5
17	02/14/06	IP - Spray & Scrape	1.5 mm	Type IV EG	67/33	27.5	-5	11:23:30	11:26:56	3.4
18	02/14/06	IP - Spray & Scrape	1.5 mm	Type IV EG	57/43	23.5	-5	11:30:05	11:31:34	1.5
19	02/14/06	IP - Spray & Scrape	1.5 mm	Type IV EG	38/62	15.5	-5	11:35:04	11:36:47	1.7
20	02/14/06	IP - Spray & Scrape	1.5 mm	Type IV EG	21/79	8.5	-5	11:39:55	11:42:29	2.6
21	02/14/06	IP - Natural	1.5 mm	Type IV EG	100	40	-5	13:59:00	14:02:56	3.9
22	02/14/06	IP - Natural	1.5 mm	Type IV EG	67/33	27.5	-5	14:03:42	14:07:15	3.6
23	02/14/06	IP - Natural	1.5 mm	Type IV EG	57/43	23.5	-5	14:08:12	14:11:06	2.9
24	02/14/06	IP - Natural	1.5 mm	Type IV EG	38/62	15.5	-5	14:12:18	14:15:04	2.8
25	02/14/06	IP - Natural	1.5 mm	Type IV EG	21/79	8.5	-5	14:16:56	14:25:12	8.3
26	02/14/06	IP - Natural	1.5 mm	Type I EG	57/43	34	-5	15:56:45	15:57:30	0.8
27	02/14/06	IP - Natural	1.5 mm	Type I EG	45/55	27.5	-5	15:59:17	16:00:30	1.2
28	02/14/06	IP - Natural	1.5 mm	Type I EG	37/63	23	-5	16:02:50	16:03:54	1.1
29	02/14/06	IP - Natural	1.5 mm	Type I EG	22/78	14	-5	16:23:06	16:25:23	2.3
30	02/14/06	IP - Natural	1.5 mm	Type I EG	n/a	6	-5	16:02:50	16:15:32	12.7
31	02/15/06	IP - Crushed	4 mm	Type IV EG	100	40	-5	11:27:15	11:43:13	16.0
32	02/15/06	IP - Crushed	4 mm	Type IV EG	67/33	27.5	-5	11:27:29	11:43:25	15.9
33	02/15/06	IP - Crushed	4 mm	Type IV EG	57/43	23.5	-5	11:27:41	11:37:24	9.7
34	02/15/06	IP - Crushed	4 mm	Type IV EG	38/62	15.5	-5	11:27:48	11:38:30	10.7
35	02/15/06	IP - Crushed	4 mm	Type IV EG	21/79	8.5	-5	11:27:57	11:45:54	30.0
36	02/15/06	IP - Spray & Scrape	4 mm	Type IV EG	100	40	-5	12:35:49	12:48:28	50.0
37	02/15/06	IP - Spray & Scrape	4 mm	Type IV EG	67/33	27.5	-5	12:36:08	13:08:28	32.3
38	02/15/06	IP - Spray & Scrape	4 mm	Type IV EG	57/43	23.5	-5	12:36:30	13:02:54	26.4
39	02/15/06	IP - Spray & Scrape	4 mm	Type IV EG	38/62	15.5	-5	12:36:40	13:09:10	32.5
40	02/15/06	IP - Spray & Scrape	4 mm	Type IV EG	21/79	8.5	-5	12:36:52	12:42:47	5.9
41	02/15/06	IP - Spray & Scrape	4 mm	Type I EG	57/43	34	-5	15:06:42	15:13:23	6.7
42	02/15/06	IP - Spray & Scrape	4 mm	Type I EG	45/55	27.5	-5	15:06:56	15:14:55	8.0
43	02/15/06	IP - Spray & Scrape	4 mm	Type I EG	37/63	23	-5	15:07:11	15:15:30	8.3
44	02/15/06	IP - Spray & Scrape	4 mm	Type I EG	22/78	14	-5	15:07:35	15:22:10	14.6
45	02/15/06	IP - Crushed	4 mm	Type I EG	57/43	34	-5	16:13:08	16:17:30	4.4
46	02/15/06	IP - Crushed	4 mm	Type I EG	45/55	27.5	-5	16:13:21	16:20:00	6.6
47	02/15/06	IP - Crushed	4 mm	Type I EG	37/63	23	-5	16:13:36	16:21:00	7.4
48	02/15/06	IP - Crushed	4 mm	Type I EG	22/78	14	-5	16:13:54	16:23:34	9.7
49	02/15/06	IP - Natural	4 mm	Type I EG	57/43	34	-5	18:02:14	18:07:11	4.9
50	02/15/06	IP - Natural	4 mm	Type I EG	45/55	27.5	-5	18:02:27	18:09:35	7.1
51	02/15/06	IP - Natural	4 mm	Type I EG	37/63	23	-5	18:03:37	18:12:51	9.2
52	02/15/06	IP - Natural	4 mm	Type I EG	22/78	14	-5	18:03:55	18:15:42	11.8
53	02/15/06	IP - Natural	4 mm	Type I EG	n/a	6	-5	18:04:07	18:36:56	32.8
54	02/16/06	IP - Spray & Scrape	1.5 mm	Type I EG	57/43	34	-5	7:50:17	7:52:05	1.8
55	02/16/06	IP - Spray & Scrape	1.5 mm	Type I EG	45/55	27.5	-5	7:53:51	7:56:03	2.2

Table 5.1: Log of Melting Time Tests (cont'd)

Test #	Date	Precipitation Type	Precipitation Size	Fluid	Fluid Dilution	Initial Brix	OAT (°C)	Start Time	End Time	Total Time (min)
56	02/16/06	IP - Spray & Scrape	1.5 mm	Type I EG	37/63	23	-5	7:57:23	8:00:25	3.0
57	02/16/06	IP - Spray & Scrape	1.5 mm	Type I EG	22/78	14	-5	8:01:48	8:04:49	3.0
58	02/16/06	IP - Spray & Scrape	1.5 mm	Type I EG	n/a	6	-5	20:04:28	20:20:40	16.2
59	02/16/06	IP - Crushed	1.5 mm	Type I EG	57/43	34	-5	19:00:00	19:01:40	1.7
60	02/16/06	IP - Crushed	1.5 mm	Type I EG	45/55	27.5	-5	19:02:36	19:03:35	1.0
61	02/16/06	IP - Crushed	1.5 mm	Type I EG	37/63	23	-5	19:04:16	19:05:45	1.5
62	02/16/06	IP - Crushed	1.5 mm	Type I EG	22/78	14	-5	19:09:55	19:13:30	3.6
63	02/16/06	IP - Crushed	1.5 mm	Type I EG	n/a	6	-5	19:18:45	20:25:00	66.3
64	02/20/06	IP - Natural	4 mm	Type IV PG	100	36	-5	14:32:00	15:16:59	45.0
65	02/20/06	IP - Natural	4 mm	Type IV PG	75/25	28.5	-5	14:32:55	15:20:29	47.6
66	02/20/06	IP - Natural	4 mm	Type IV PG	50/50	19	-5	14:33:18	15:31:00	57.7
67	02/20/06	IP - Natural	4 mm	Type IV PG	25/75	10	-5	13:48:30	14:46:00	57.5
68	02/20/06	IP - Spray & Scrape	4 mm	Type IV PG	100	36	-5	10:52:48	11:55:00	62.2
69	02/20/06	IP - Spray & Scrape	4 mm	Type IV PG	90/10	33	-5	10:53:17	11:44:01	50.7
70	02/20/06	IP - Spray & Scrape	4 mm	Type IV PG	75/25	28.5	-5	10:53:37	11:51:38	58.0
71	02/20/06	IP - Spray & Scrape	4 mm	Type IV PG	50/50	19	-5	10:53:55	11:44:26	50.5
72	02/20/06	IP - Crushed	1.5 mm	Type IV PG	100	36	-5	12:32:15	12:37:48	5.6
73	02/20/06	IP - Crushed	1.5 mm	Type IV PG	90/10	33	-5	12:45:10	12:48:59	3.8
74	02/20/06	IP - Crushed	1.5 mm	Type IV PG	75/25	28.5	-5	12:47:00	12:53:33	6.6
75	02/20/06	IP - Crushed	1.5 mm	Type IV PG	50/50	19	-5	12:47:30	12:55:01	7.5
76	02/20/06	IP - Crushed	1.5 mm	Type IV PG	25/75	10	-5	13:01:05	13:34:38	33.6
77	02/20/06	IP - Natural	4 mm	Type IV EG	100	40	-5	16:50:00	17:04:23	14.4
78	02/20/06	IP - Natural	4 mm	Type IV EG	67/33	27.5	-5	16:50:10	17:05:53	15.7
79	02/20/06	IP - Natural	4 mm	Type IV EG	57/43	23.5	-5	16:50:40	16:59:53	9.2
80	02/20/06	IP - Natural	4 mm	Type IV EG	38/62	15.5	-5	16:51:00	17:00:08	9.1
81	02/20/06	IP - Natural	4 mm	Type IV EG	21/79	8.5	-5	16:51:20	17:06:38	15.3
82	02/20/06	IP - Spray & Scrape	1.5 mm	Type IV PG	100	36	-5	17:43:40	17:52:09	8.5
83	02/20/06	IP - Spray & Scrape	1.5 mm	Type IV PG	90/10	33	-5	17:44:15	17:51:09	6.9
84	02/20/06	IP - Spray & Scrape	1.5 mm	Type IV PG	75/25	28.5	-5	17:44:30	17:50:08	5.6
85	02/20/06	IP - Spray & Scrape	1.5 mm	Type IV PG	50/50	19	-5	17:44:50	17:51:39	6.8
86	02/20/06	IP - Spray & Scrape	1.5 mm	Type IV PG	25/75	10	-5	17:47:10	18:02:40	15.5
87	02/21/06	Snow - Processed	30 mg	Type IV EG	100	40	-5	11:18:57	11:22:40	3.7
88	02/21/06	Snow - Processed	30 mg	Type IV EG	67/33	27.5	-5	11:24:10	11:28:20	4.2
89	02/21/06	Snow - Processed	30 mg	Type IV EG	57/43	23.5	-5	11:33:37	11:36:45	3.1
90	02/21/06	Snow - Processed	30 mg	Type IV EG	38/62	15.5	-5	11:39:55	11:44:00	4.1
91	02/21/06	Snow - Processed	30 mg	Type IV EG	21/79	8.5	-5	11:45:25	11:58:06	12.7
92	02/21/06	Snow - Processed	2 mg	Type IV EG	100	40	-5	12:11:31	12:12:22	0.8
93	02/21/06	Snow - Processed	2 mg	Type IV EG	67/33	27.5	-5	12:23:35	12:25:30	1.9
94	02/21/06	Snow - Processed	2 mg	Type IV EG	57/43	23.5	-5	12:26:12	12:27:40	1.5
95	02/21/06	Snow - Processed	2 mg	Type IV EG	38/62	15.5	-5	12:28:22	12:29:45	1.4
96	02/21/06	Snow - Processed	2 mg	Type IV EG	21/79	8.5	-5	12:30:44	12:33:30	2.8
97	02/21/06	Snow - Natural	2 mg	Type IV EG	100	40	-5	13:08:30	13:09:24	0.9
98	02/21/06	Snow - Natural	2 mg	Type IV EG	67/33	27.5	-5	13:20:02	13:21:46	1.7
99	02/21/06	Snow - Natural	2 mg	Type IV EG	57/43	23.5	-5	13:31:09	13:32:00	0.8
100	02/21/06	Snow - Natural	2 mg	Type IV EG	38/62	15.5	-5	13:35:55	13:37:17	1.4
101	02/22/06	Snow - Natural	2 mg	Type IV EG	100	40	-5	14:08:12	14:10:20	2.1
102	02/22/06	Snow - Natural	2 mg	Type IV EG	67/33	27.5	-5	14:17:21	14:19:33	2.2
103	02/22/06	Snow - Natural	2 mg	Type IV EG	57/43	23.5	-5	14:26:49	14:29:14	2.4
104	02/22/06	Snow - Natural	2 mg	Type IV EG	38/62	15.5	-5	14:32:09	14:34:21	2.2
105	02/22/06	Snow - Natural	2 mg	Type IV EG	21/79	8.5	-5	14:37:14	14:52:19	15.1
106	02/22/06	Snow - Natural	30 mg	Type IV EG	100	40	-5	15:34:38	15:37:22	2.7
107	02/22/06	Snow - Natural	30 mg	Type IV EG	67/33	27.5	-5	15:42:42	15:45:30	2.8
108	02/22/06	Snow - Natural	30 mg	Type IV EG	57/43	23.5	-5	15:50:05	15:52:58	2.9
109	02/22/06	Snow - Natural	30 mg	Type IV EG	38/62	15.5	-5	15:56:13	15:59:20	3.1
110	02/22/06	Snow - Natural	30 mg	Type IV EG	21/79	8.5	-5	16:06:22	16:20:44	14.4

Table 5.1: Log of Melting Time Tests (cont'd)

Test #	Date	Precipitation Type	Precipitation Size	Fluid	Fluid Dilution	Initial Brix	OAT (°C)	Start Time	End Time	Total Time (min)
111	02/22/06	Snow - Processed	2 mg	Type I EG	57/43	34	-5	19:01:56	19:03:26	1.5
112	02/22/06	Snow - Processed	2 mg	Type I EG	45/55	27.5	-5	19:08:29	19:09:20	0.8
113	02/22/06	Snow - Processed	2 mg	Type I EG	37/63	23	-5	19:15:28	19:16:01	0.5
114	02/22/06	Snow - Processed	2 mg	Type I EG	22/78	14	-5	19:18:54	19:21:00	2.1
115	02/23/06	Snow - Natural	2 mg	Type I EG	57/43	34	-5	12:32:26	12:32:55	0.5
116	02/23/06	Snow - Natural	2 mg	Type I EG	45/55	27.5	-5	12:35:45	12:36:38	0.9
117	02/23/06	Snow - Natural	2 mg	Type I EG	37/63	23	-5	12:38:22	12:39:41	1.3
118	02/23/06	Snow - Natural	2 mg	Type I EG	22/78	14	-5	12:45:09	12:47:54	2.7
119	02/23/06	Snow - Natural	30 mg	Type I EG	57/43	34	-5	13:38:10	13:38:55	0.7
120	02/23/06	Snow - Natural	30 mg	Type I EG	45/55	27.5	-5	13:40:28	13:41:37	1.2
121	02/23/06	Snow - Natural	30 mg	Type I EG	37/63	23	-5	13:47:37	13:51:28	3.9
122	02/23/06	Snow - Natural	30 mg	Type I EG	22/78	14	-5	13:56:00	13:58:59	3.0
123	02/23/06	Snow - Processed	30 mg	Type I EG	57/43	34	-5	15:10:45	15:12:49	2.1
124	02/23/06	Snow - Processed	30 mg	Type I EG	45/55	27.5	-5	15:14:42	15:17:02	2.3
125	02/23/06	Snow - Processed	30 mg	Type I EG	37/63	23	-5	15:19:07	15:22:49	3.7
126	02/23/06	Snow - Processed	30 mg	Type I EG	22/78	14	-5	15:23:58	15:30:13	6.3
127	02/23/06	Snow - Processed	30 mg	Type IV PG	100	36	-5	16:37:43	16:42:25	4.7
128	02/23/06	Snow - Processed	30 mg	Type IV PG	90/10	33	-5	16:46:50	16:51:27	4.6
129	02/23/06	Snow - Processed	30 mg	Type IV PG	75/25	28.5	-5	16:54:30	17:03:42	9.2
130	02/23/06	Snow - Processed	30 mg	Type IV PG	50/50	19	-5	17:16:33	17:35:36	19.0
131	02/23/06	Snow - Processed	2 mg	Type IV PG	100	36	-5	17:42:58	17:45:01	2.1
132	02/23/06	Snow - Processed	2 mg	Type IV PG	90/10	33	-5	17:49:41	17:53:08	3.5
133	02/23/06	Snow - Processed	2 mg	Type IV PG	75/25	28.5	-5	18:05:00	18:09:38	4.6
134	02/23/06	Snow - Processed	2 mg	Type IV PG	50/50	19	-5	18:13:06	18:16:49	3.7
135	02/23/06	Snow - Processed	2 mg	Type IV PG	25/75	10	-5	18:20:37	18:28:43	8.1
136	02/24/06	IP - Crushed	4 mm	Type IV PG	100	36	-5	10:47:43	11:32:15	44.5
137	02/24/06	IP - Crushed	4 mm	Type IV PG	90/10	33	-5	10:47:15	11:33:45	46.5
138	02/24/06	IP - Crushed	4 mm	Type IV PG	75/25	28.5	-5	10:48:07	11:32:45	44.6
139	02/24/06	IP - Crushed	4 mm	Type IV PG	50/50	19	-5	10:48:34	11:39:15	50.7
140	02/24/06	IP - Natural	1.5 mm	Type IV PG	100	36	-5	10:43:07	10:49:49	6.7
141	02/24/06	IP - Natural	1.5 mm	Type IV PG	90/10	33	-5	10:59:36	11:05:59	6.4
142	02/24/06	IP - Natural	1.5 mm	Type IV PG	75/25	28.5	-5	11:11:00	11:21:00	10.0
143	02/24/06	IP - Natural	1.5 mm	Type IV PG	50/50	19	-5	11:30:33	11:40:35	10.0
144	02/24/06	Snow - Natural	2mg	Type IV EG	67/33	27.5	-9	19:14:56	19:21:34	6.6
145	02/24/06	Snow - Natural	2mg	Type IV EG	57/43	23.5	-9	19:27:14	19:31:05	3.8
146	02/24/06	Snow - Natural	2mg	Type IV EG	38/62	15.5	-9	19:33:45	19:53:38	19.9
147	02/24/06	Snow - Natural	30 mg	Type IV EG	100	40	-9	18:41:19	18:50:11	8.9
148	02/24/06	Snow - Natural	30 mg	Type IV EG	67/33	27.5	-9	18:41:58	18:45:08	3.2
149	02/24/06	Snow - Natural	30 mg	Type IV EG	57/43	23.5	-9	18:42:23	18:47:29	5.1
150	02/24/06	Snow - Natural	30 mg	Type IV EG	38/62	15.5	-9	18:42:40	20:14:16	91.6
151	02/24/06	IP - Crushed	1.5 mm	Type IV EG	100	40	-9	17:30:56	17:40:20	9.4
152	02/24/06	IP - Crushed	1.5 mm	Type IV EG	67/33	27.5	-9	17:31:26	17:44:12	12.8
153	02/24/06	IP - Crushed	1.5 mm	Type IV EG	57/43	23.5	-9	17:32:00	17:44:17	12.3
154	02/24/06	IP - Crushed	1.5 mm	Type IV EG	38/62	15.5	-9	17:32:31	17:52:38	20.1
155	02/24/06	IP - Natural	1.5 mm	Type IV EG	100	40	-9	16:04:43	16:49:52	45.1
156	02/24/06	IP - Natural	1.5 mm	Type IV EG	67/33	27.5	-9	16:05:10	16:21:50	16.7
157	02/24/06	IP - Natural	1.5 mm	Type IV EG	57/43	23.5	-9	16:05:41	16:19:21	13.7
158	02/24/06	IP - Natural	1.5 mm	Type IV EG	38/62	15.5	-9	16:06:24	16:33:59	27.6
159	02/24/06	IP - Natural	4 mm	Type IV EG	100	40	-9	15:48:20	15:56:35	8.3
160	02/24/06	IP - Natural	4 mm	Type IV EG	67/33	27.5	-9	15:48:35	15:51:20	2.8
161	02/24/06	IP - Natural	4 mm	Type IV EG	57/43	23.5	-9	15:48:57	16:35:45	46.8

5.2 Photo Documentation of Ice Precipitation Dissolving Time Research

Still photography was used to document each ice precipitation dissolving time test. Photos were taken at set intervals depending on the expected duration of the test. Photo 5.1 to Photo 5.19 demonstrate the ice precipitation sample condition for Test #140, Test #66, Test #128, and Test #120 at various intervals during each test. A time stamp showing the elapsed time since the start of the test has been included in each photo, with the exception of the initial photo showing the sample prior to being immersed in the fluid. In addition, the location of the ice precipitation in the photo has been circled.

5.3 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:

- Type I EG – 4 mm Ice Pellets and 30 mg of Snow (Figure 5.1);
- Type IV PG – 4 mm Ice Pellets and 30 mg of Snow (Figure 5.2);
- Type IV EG – 4 mm Ice Pellets and 30 mg of Snow (Figure 5.3);
- Type I EG – 1.5 mm Ice Pellets and 2 mg of Snow (Figure 5.4);
- Type IV PG – 1.5 mm Ice Pellets and 2 mg of Snow (Figure 5.5); and
- Type IV EG – 1.5 mm Ice Pellets and 2 mg of Snow (Figure 5.6).

The data collected was plotted for each grouping. Figure 5.1 to Figure 5.6 demonstrate the fluid dilution versus the total time 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 dataset.

5.4 General Observations

The following observations were made based on the data collected.

5.4.1 Simulated Ice Pellets vs. Natural Ice Pellets

Results from the dissolving time tests demonstrated that the simulated ice pellets manufactured by APS were comparable to natural ice pellets. This result was also true for natural and simulated snow.

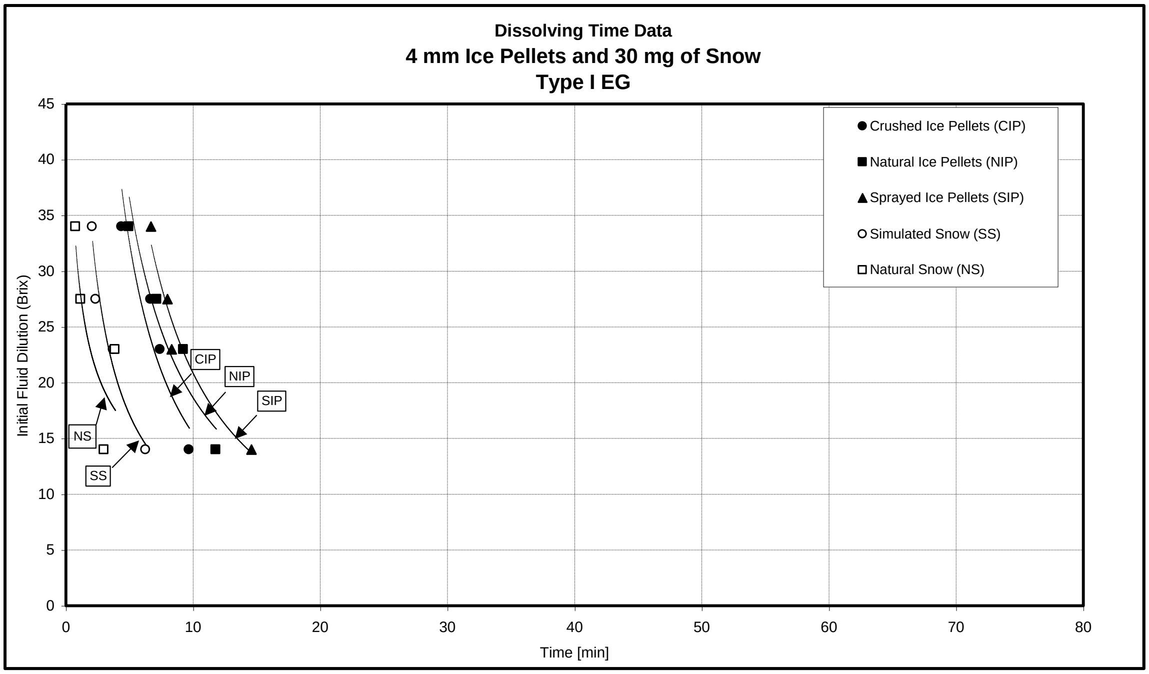

Figure 5.1: Dissolving Time Data for Type I EG – 4 mm Ice Pellets and 30 mg of Snow

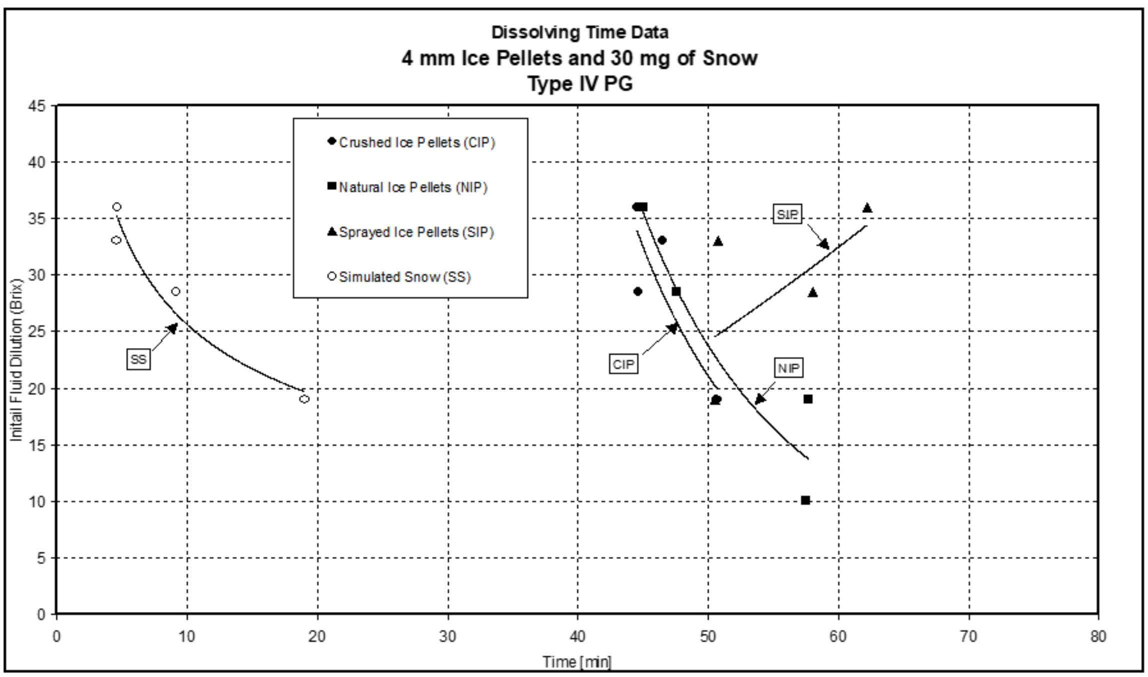

Figure 5.2: Dissolving Time Data for Type IV PG – 4 mm Ice Pellets and 30 mg of Snow

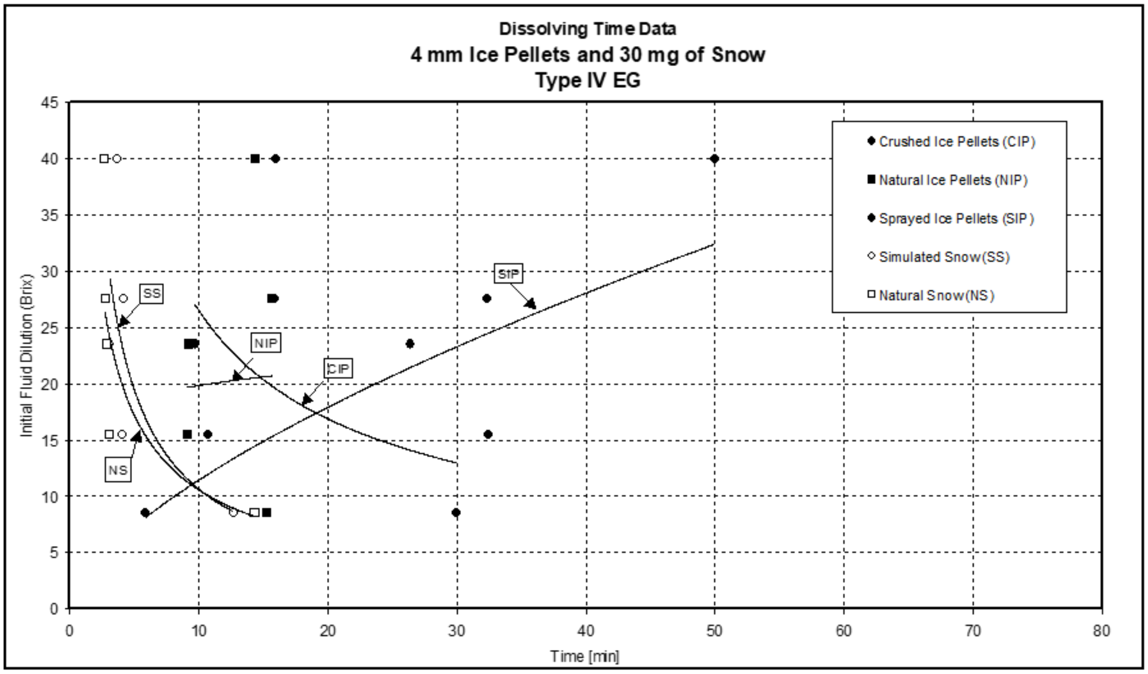

Figure 5.3: Dissolving Time Data for Type IV EG – 4 mm Ice Pellets and 30 mg of Snow

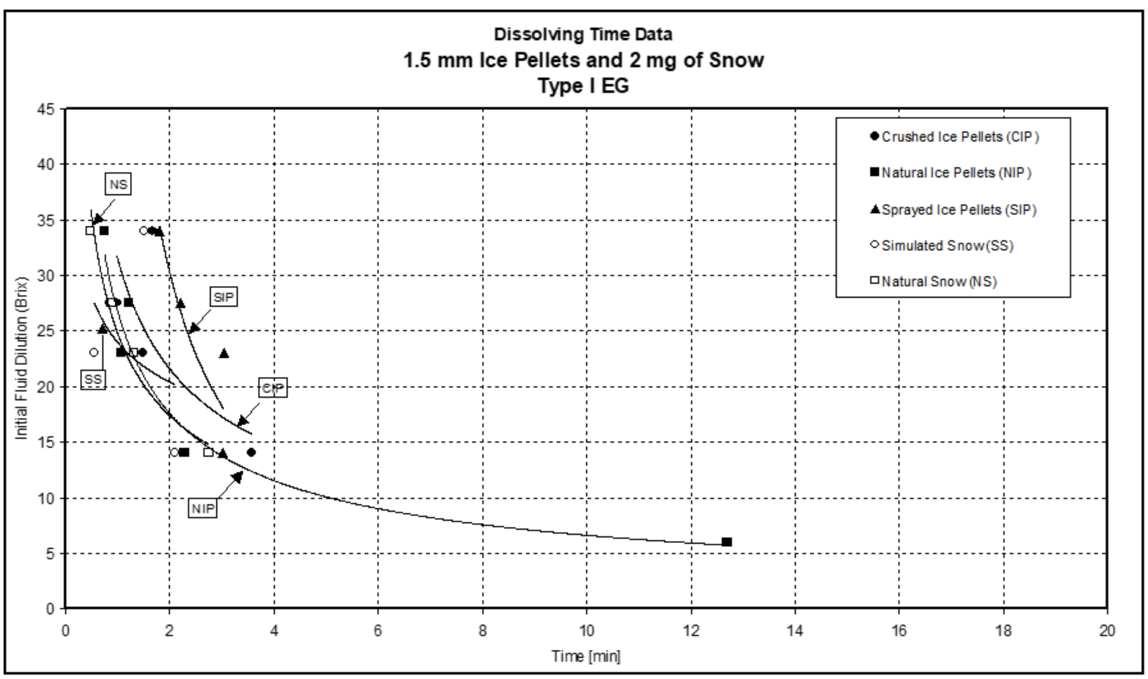

Figure 5.4: Dissolving Time Data for Type I EG – 1.5 mm Ice Pellets and 2 mg of Snow

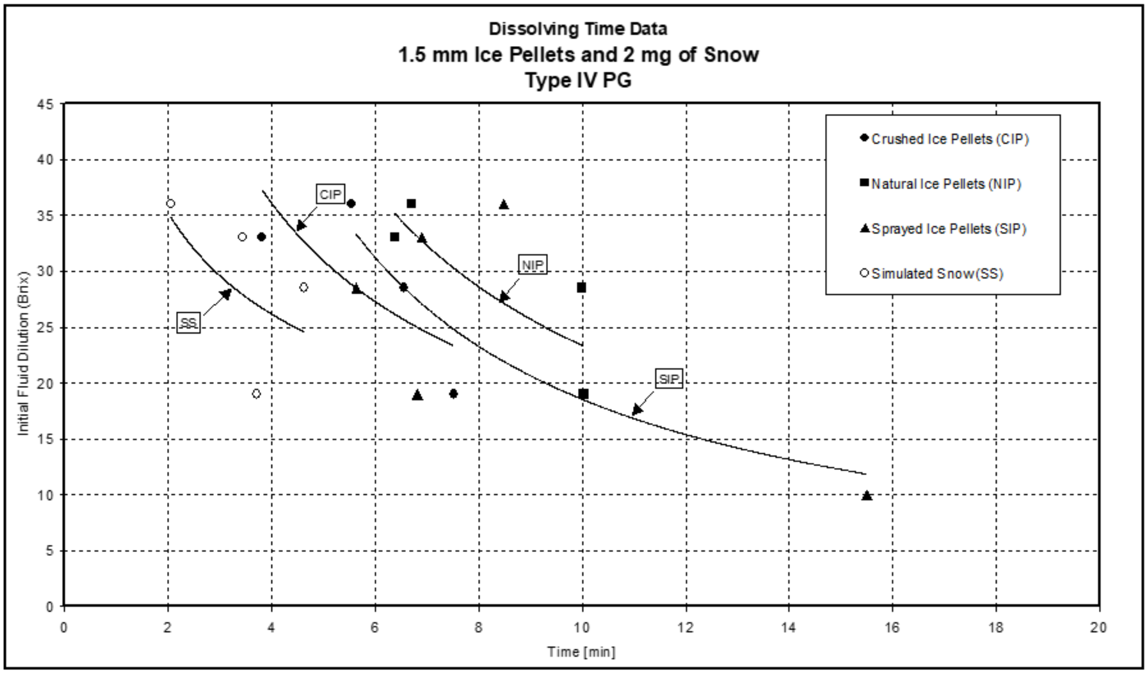

Figure 5.5: Dissolving Time Data for Type IV PG – 1.5 mm Ice Pellets and 2 mg of Snow

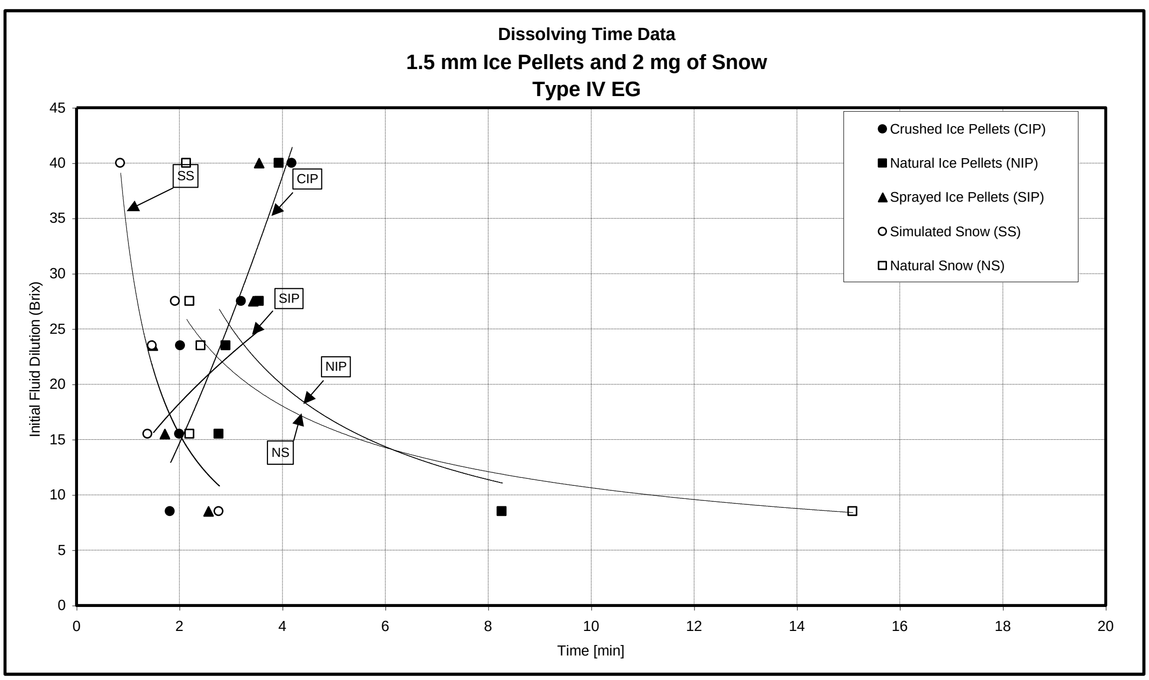

Figure 5.6: Dissolving Time Data for Type IV EG – 1.5 mm Ice Pellets and 2 mg of Snow

5.4.2 Ice Pellets vs. Snow

The data collected demonstrated that, in general, for an equal mass of ice pellet and snow, the ice pellet required a longer time to dissolve in deicing fluid. Ice pellets have less surface area in comparison to snow, which in turn requires a longer time in order to fully dissolve. For Type I fluid 57/43 mix tests with 4 mm or 30 mg precipitate samples, the ice pellet samples took on average 3.8 times longer to dissolve than the snow samples. For Type IV PG Neat fluid tests with 1.5 mm or 2 mg precipitate samples, the ice pellet samples took on average 3.3 times longer to dissolve than the snow samples. The porous properties of snow allow it to absorb the fluid, resulting in a rapid dissolving period.

5.4.3 Type I Fluid vs. Type IV Fluid

The data collected demonstrated that, in general, ice precipitation will take longer to dissolve in Type IV fluid in comparison to Type I fluid. Type I fluid is significantly less viscous than Type IV fluid, which allows for a quicker dissolving period.

5.4.4 Large Pellets vs. Small Pellets

In general, due to their smaller mass, smaller ice pellets required less time to dissolve in comparison to ice pellets with a larger mass. This was also observed for snow: larger masses of snow required more time to dissolve in comparison to smaller masses of snow.

5.4.5 High Viscosity Fluids

When conducting dissolving time tests with ice pellets in high viscosity Type IV fluids, the time required to dissolve the ice precipitate seemed to vary according to fluid viscosity, as well as fluid dilution. Results were counterintuitive in that the dissolving time required was not inversely related to the dilution. During some tests, ice pellets required a longer time to dissolve in Neat fluids in comparison to diluted fluids. It was observed that ice pellets in Neat fluid would begin to dissolve, but due to the high viscosity of the fluid, a layer of water would form and surround the ice pellet. This would delay the dissolving process and result in a longer dissolving time.

5.4.6 Dissolving Time Tests at -9°C

Some preliminary testing was conducted at -9°C. Testing was conducted using Type IV EG fluid. Due to the high viscosity of the fluid, the results demonstrated some inconsistencies (charts were not compiled for these tests), however, these tests generally demonstrated longer dissolving times in comparison to the data collected at -5°C.

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Photo 5.1: Crushed Ice Pellet Dissolving Time Test #140 – Photo 1

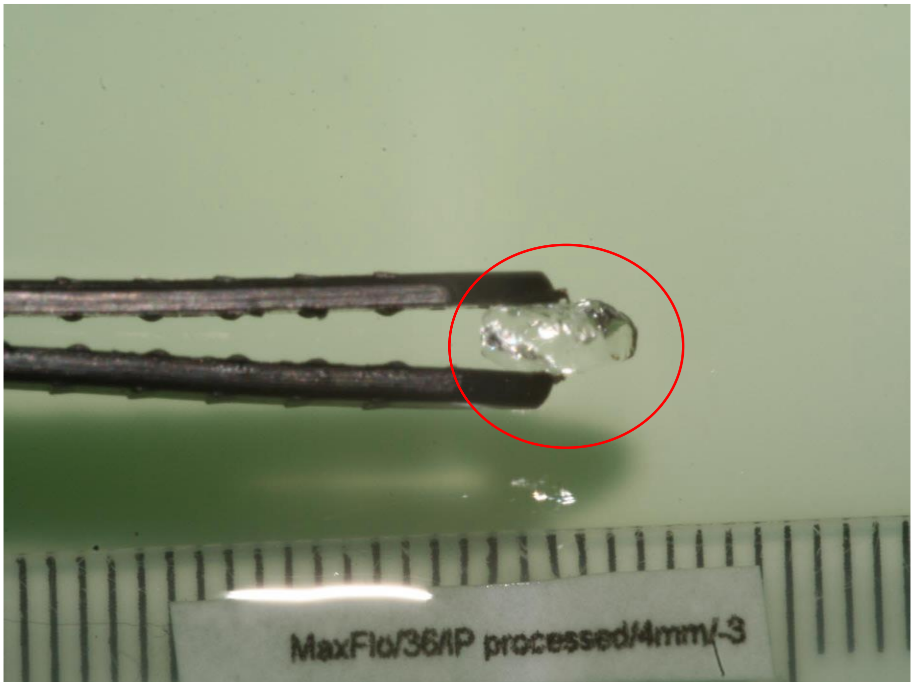


Photo 5.2: Crushed Ice Pellet Dissolving Time Test #140 – Photo 2

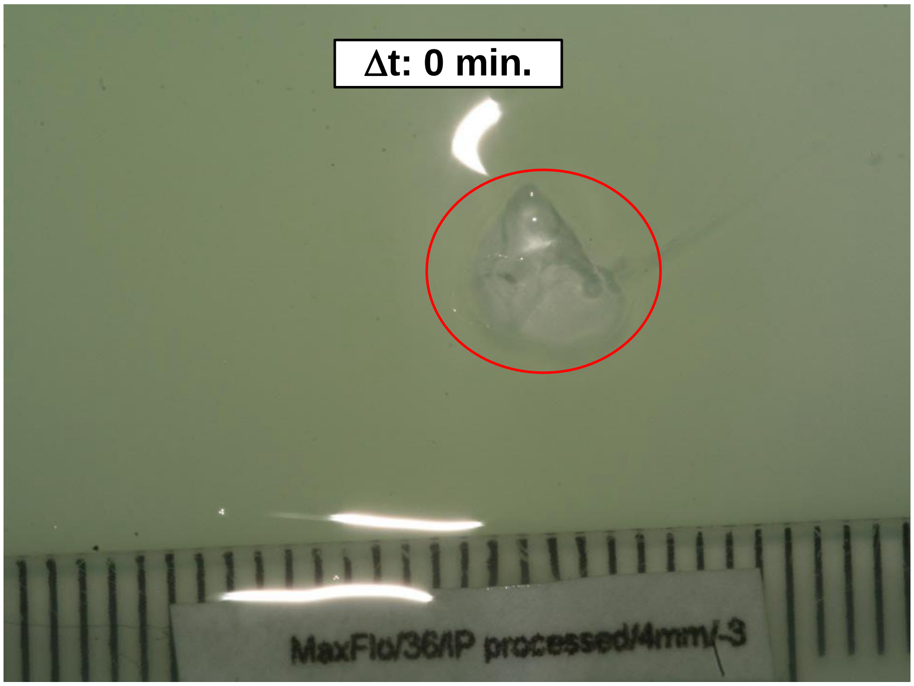


Photo 5.3: Crushed Ice Pellet Dissolving Time Test #140 – Photo 3

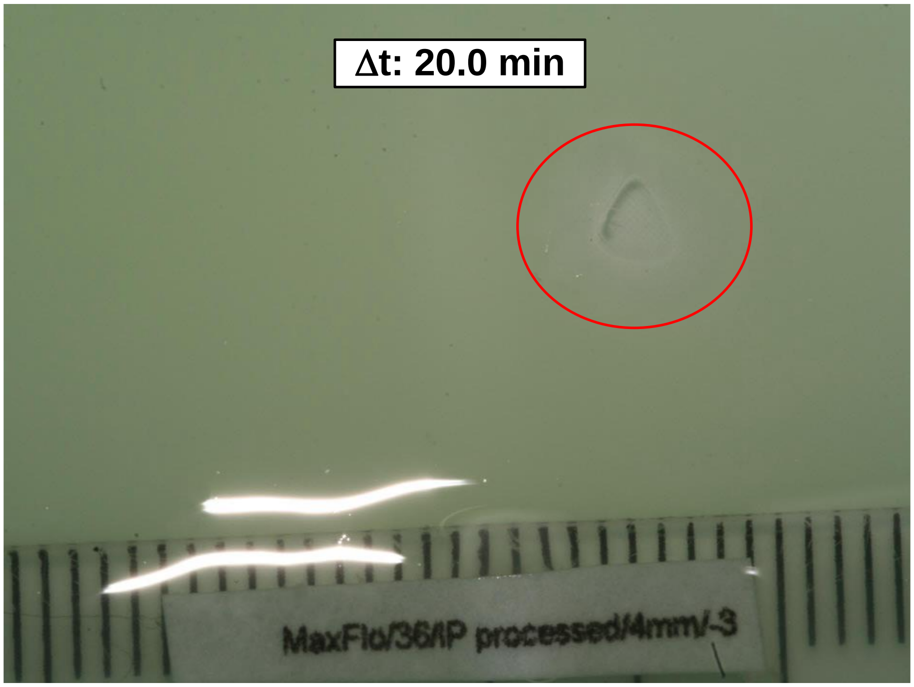


Photo 5.4: Crushed Ice Pellet Dissolving Time Test #140 – Photo 4

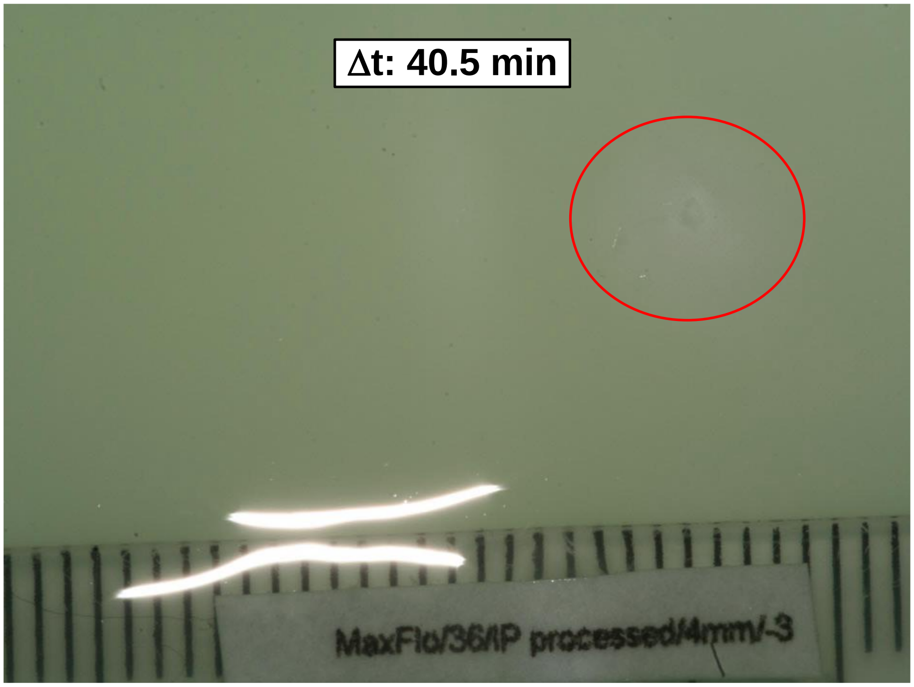


Photo 5.5: Crushed Ice Pellet Dissolving Time Test #140 – Photo 5

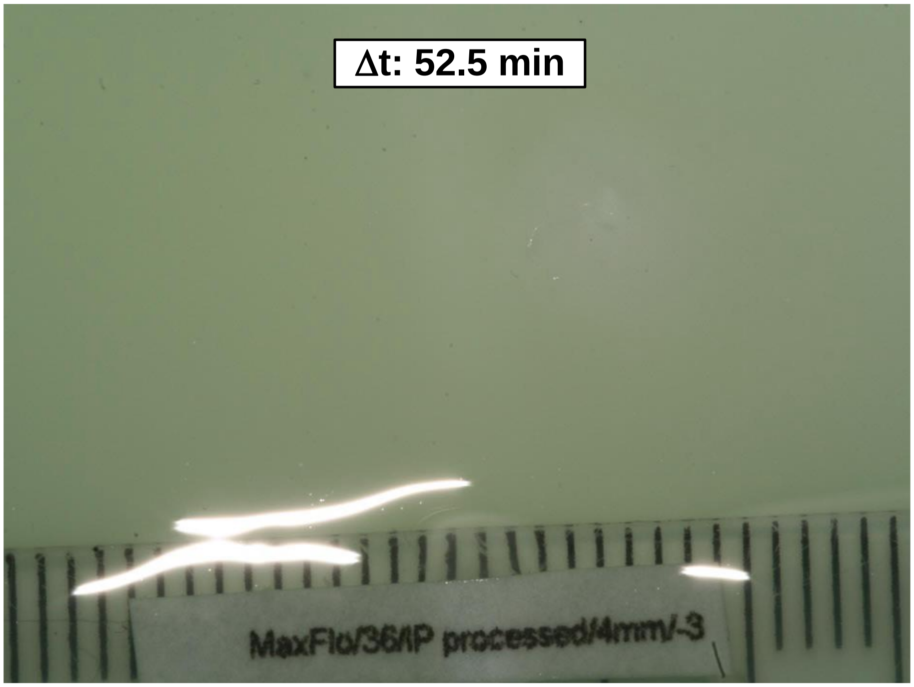


Photo 5.6: Natural Ice Pellet Dissolving Time Test #66 – Photo 1

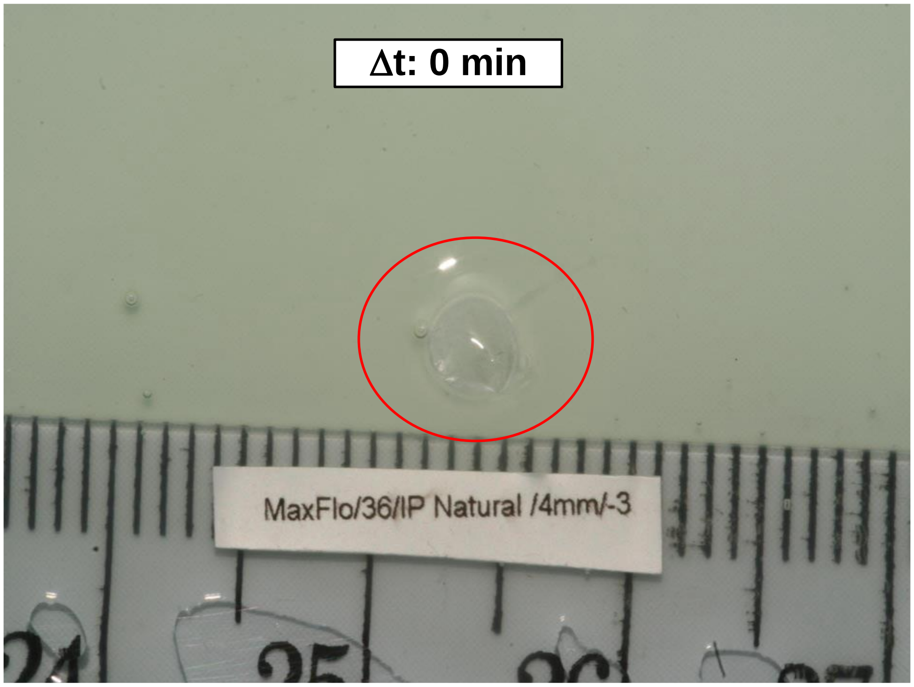


Photo 5.7: Natural Ice Pellet Dissolving Time Test #66 – Photo 2

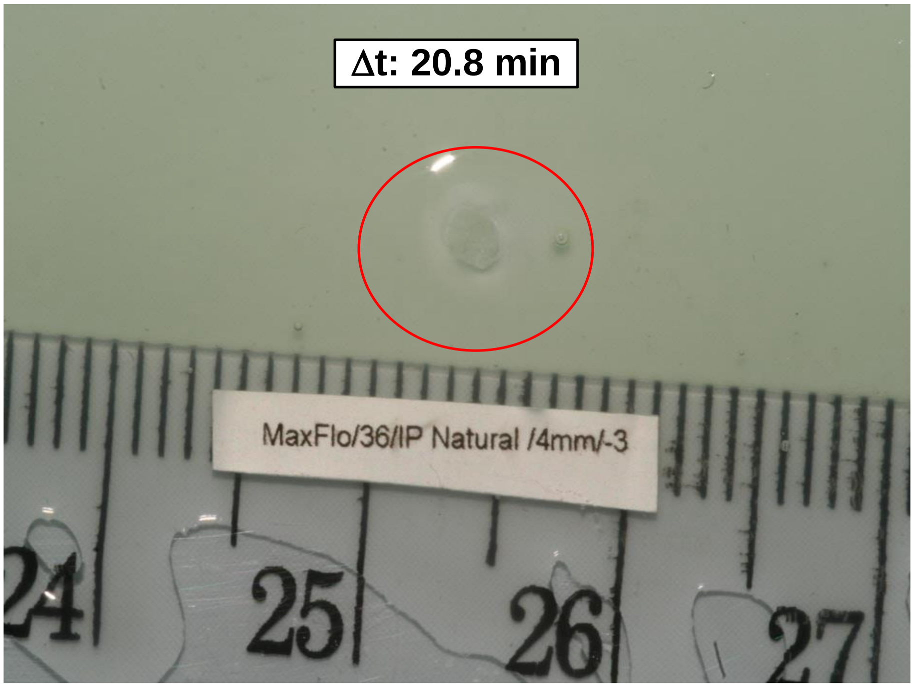


Photo 5.8: Natural Ice Pellet Dissolving Time Test #66 – Photo 3

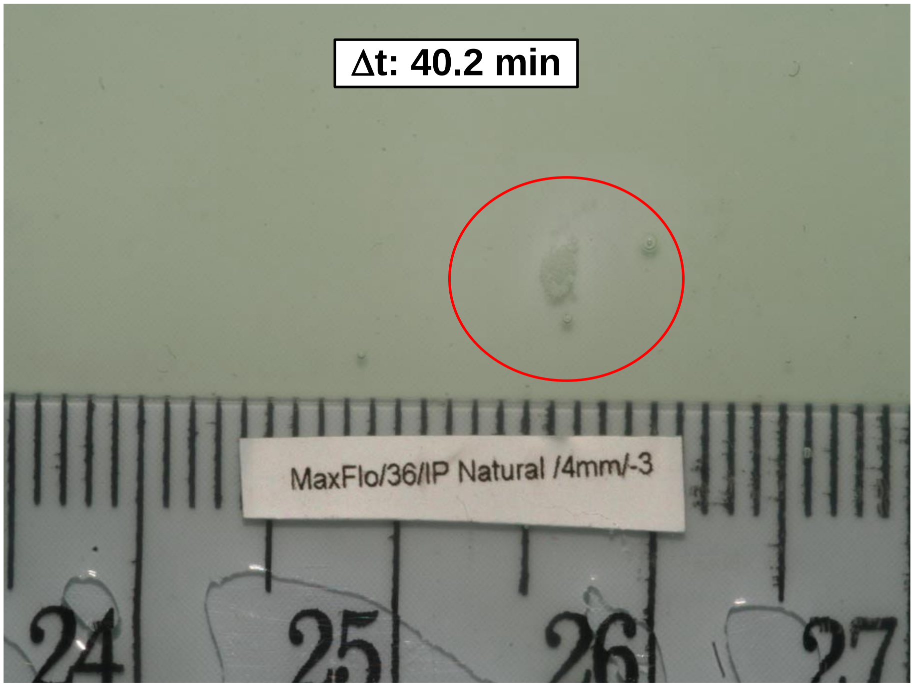


Photo 5.9: Natural Ice Pellet Dissolving Time Test #66 – Photo 4

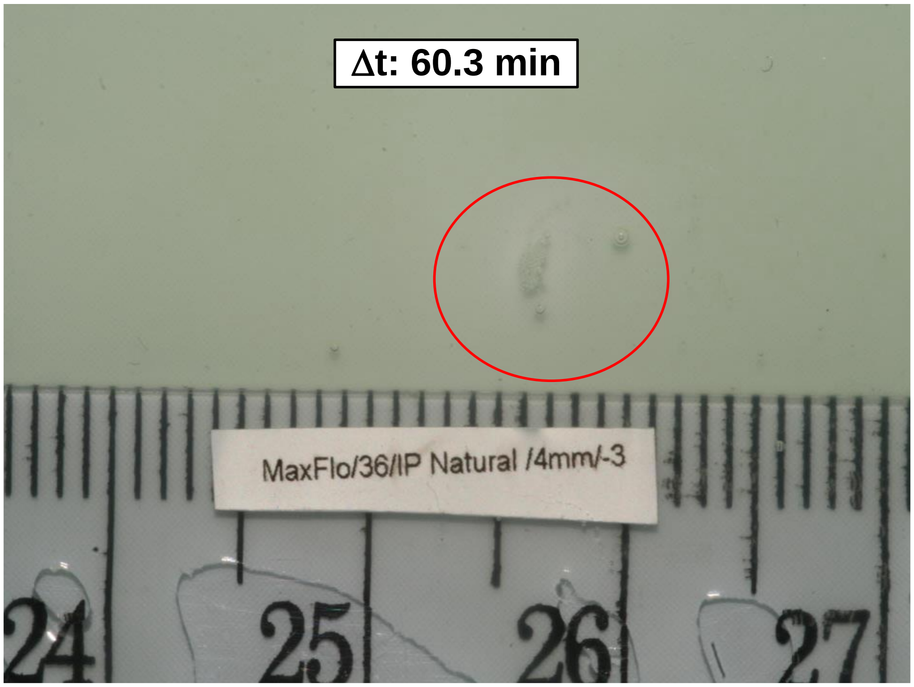


Photo 5.10: Simulated Snow Dissolving Time Test #128 – Photo 1

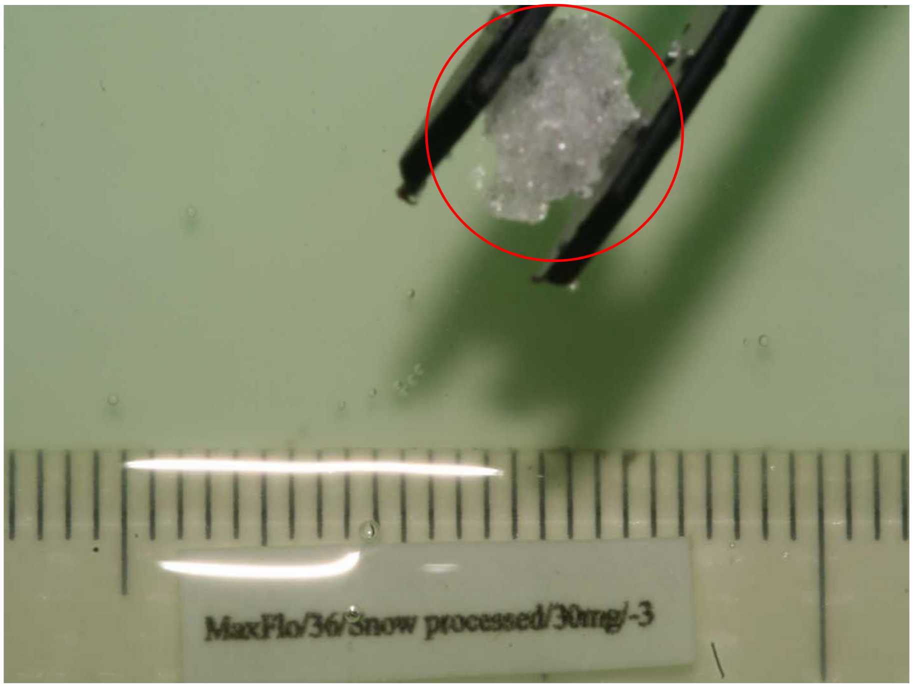


Photo 5.11: Simulated Snow Dissolving Time Test #128 – Photo 2

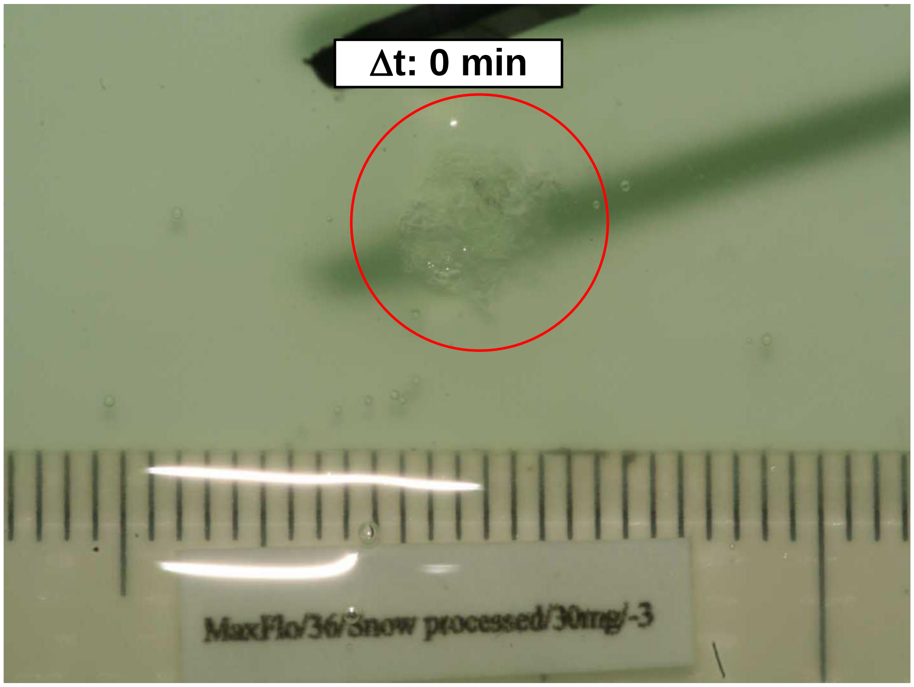


Photo 5.12: Simulated Snow Dissolving Time Test #128 – Photo 3

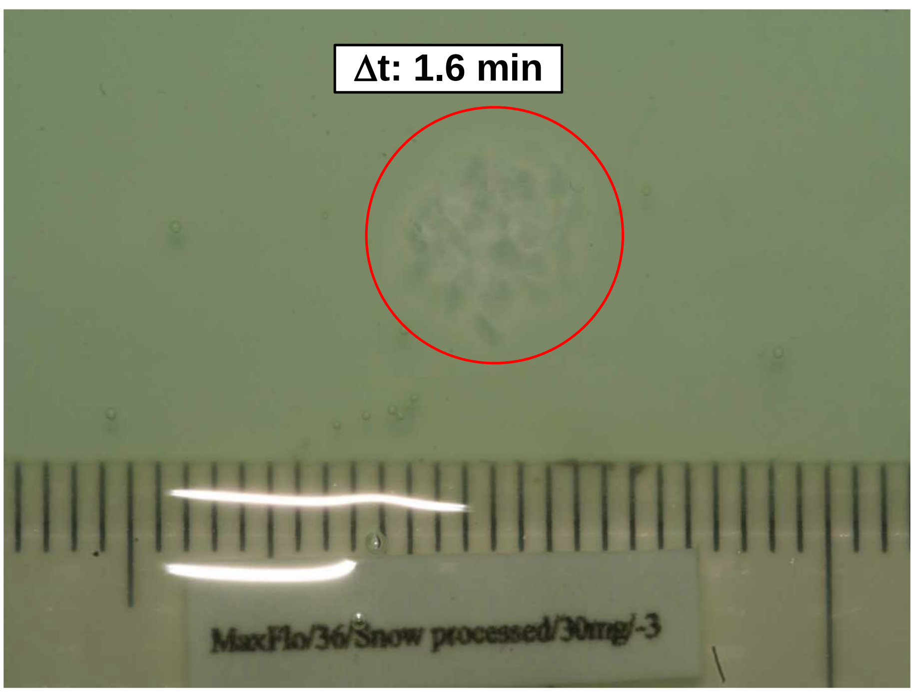


Photo 5.13: Simulated Snow Dissolving Time Test #128 – Photo 4

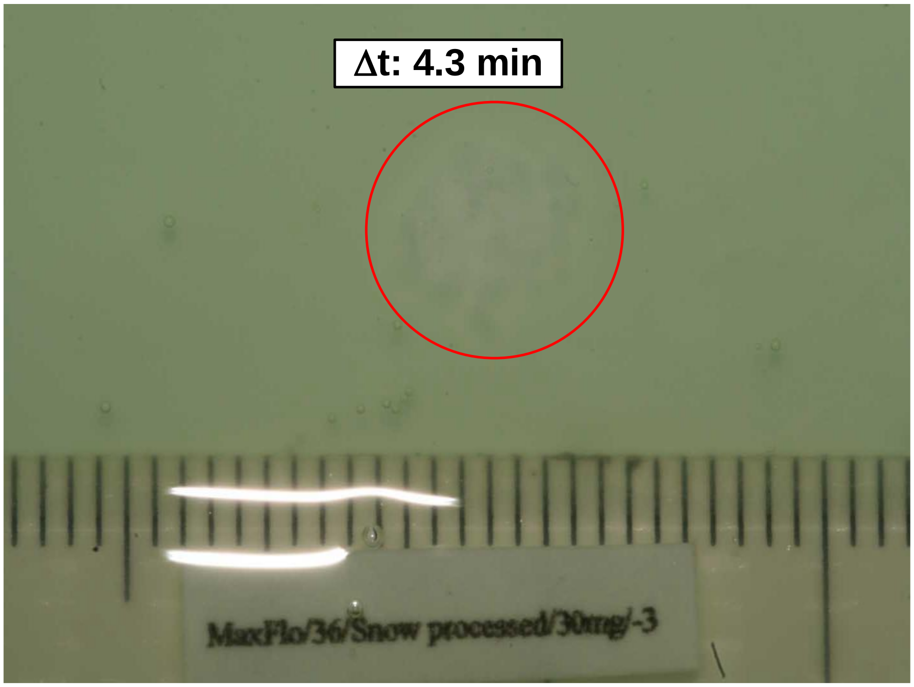


Photo 5.14: Simulated Snow Dissolving Time Test #128 – Photo 5

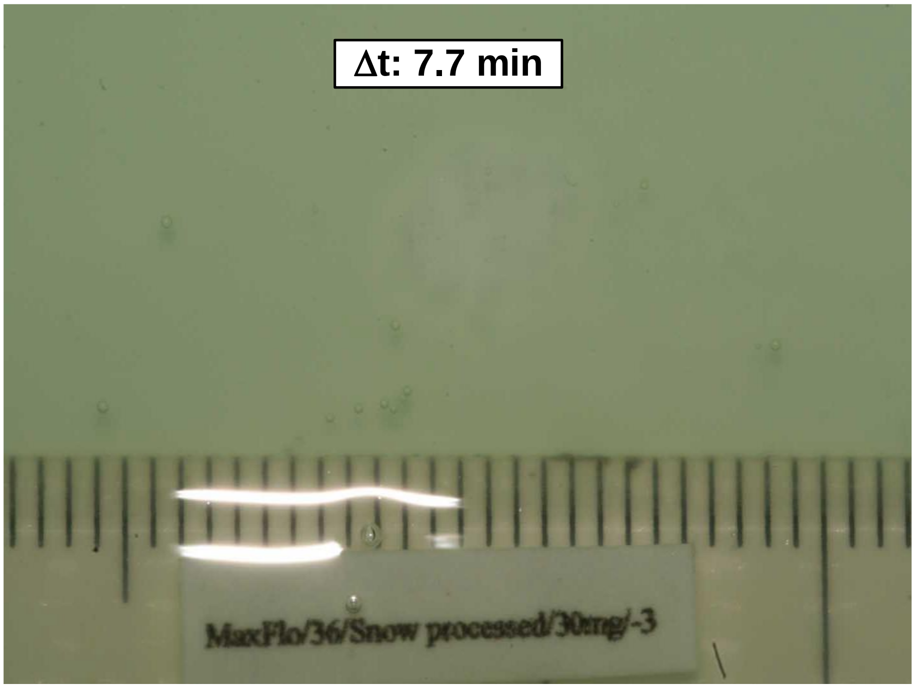


Photo 5.15: Natural Snow Dissolving Time Test #120 – Photo 1

Photo 5.16: Natural Snow Dissolving Time Test #120 – Photo 2

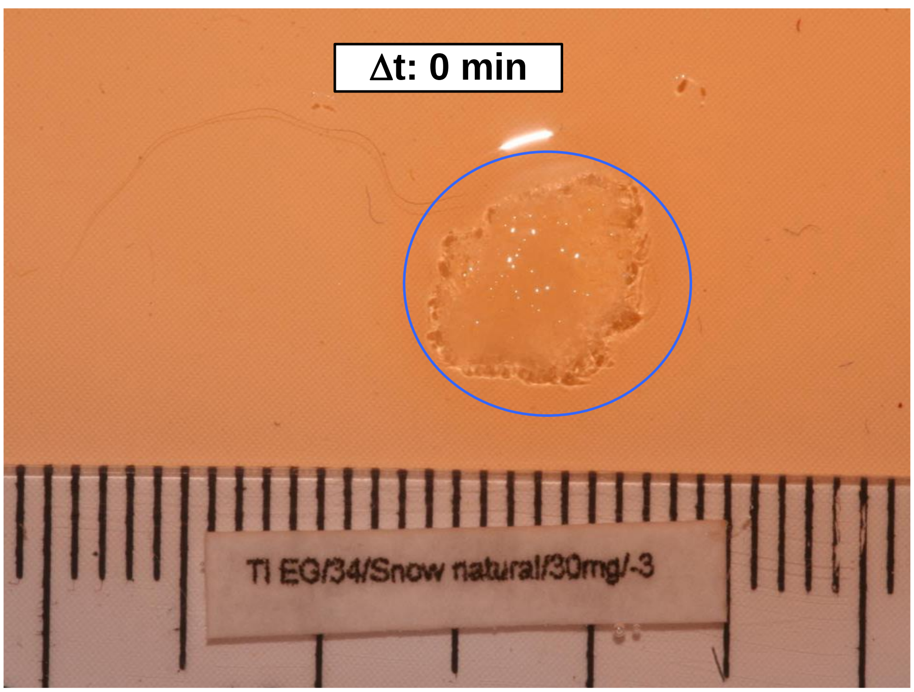


Photo 5.17: Natural Snow Dissolving Time Test #120 – Photo 3

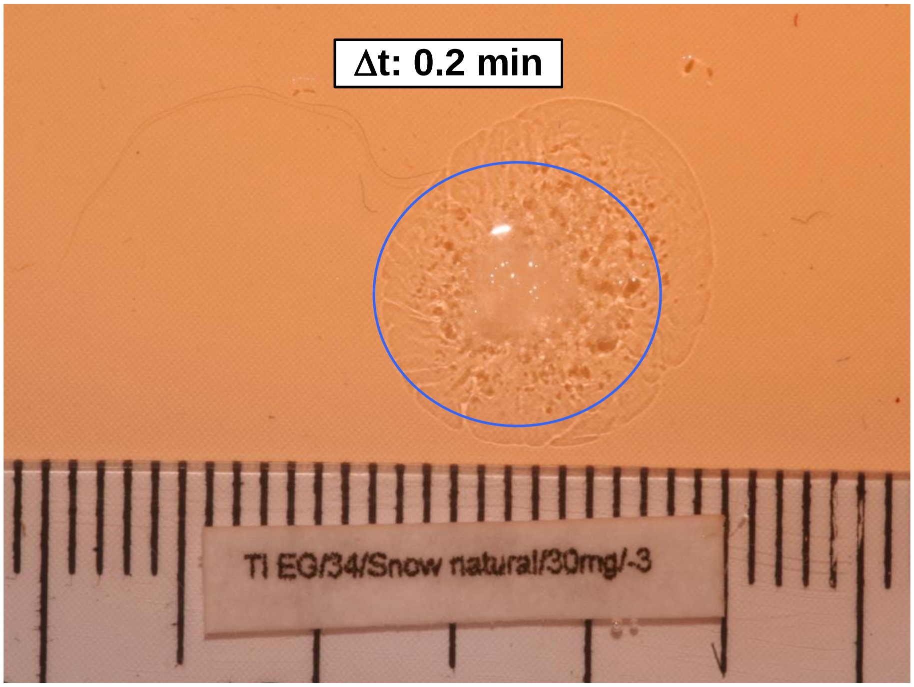


Photo 5.18: Natural Snow Dissolving Time Test #120 – Photo 4

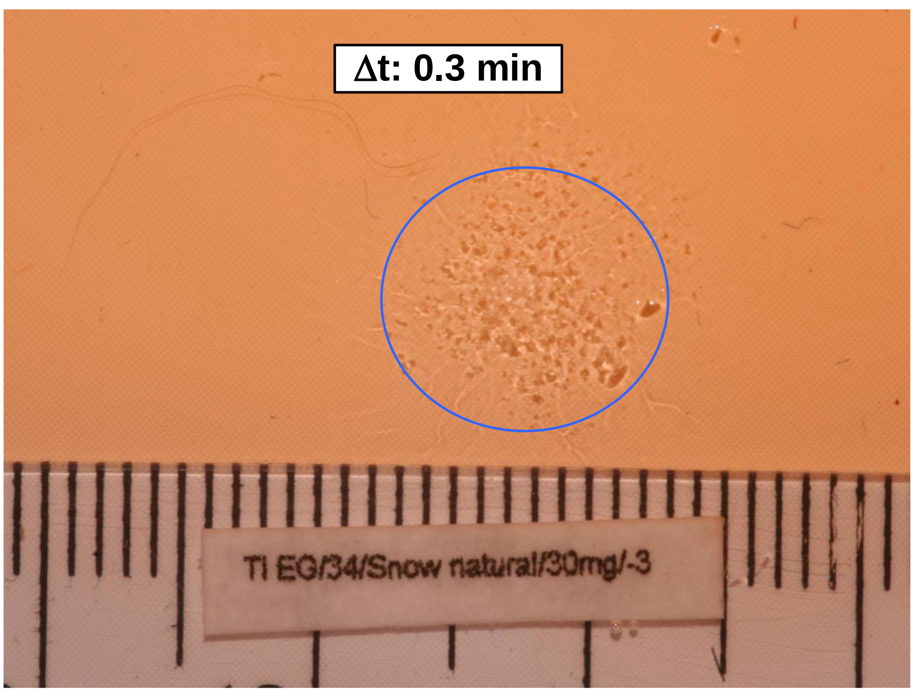
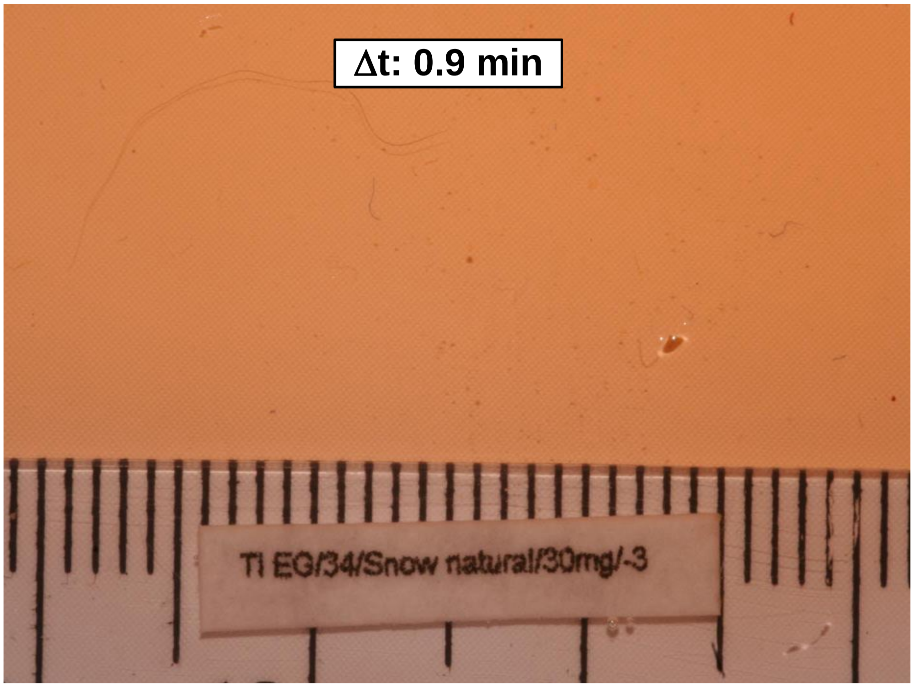


Photo 5.19: Natural Snow Dissolving Time Test #120 – Photo 5



6. FAR VS. NEAR - PERSPECTIVE PHOTO DOCUMENTATION

Still photography was used to document simultaneous perspectives representing close-in and cockpit views of an airfoil subjected to ice pellet precipitation conditions. The objective was to obtain an adequate representation of the human perspective when viewing an aircraft wing. This section describes the data collected and observations documented by the APS research team.

6.1 Perspective Representations

Research was conducted to simulate a pilot's perspective from the cabin window looking onto the aircraft wing. Two aircraft were chosen for this study: A320 and Falcon 20. Distances were approximate due to the limited space available in the research chamber. It should be noted that the objective was not to represent a pre-takeoff contamination check, but rather to demonstrate the difficulty in observing contamination from various relative distances. In addition, a third perspective, the walk around observer, was also documented to obtain a close-in view of the contamination of the airfoil. Figure 6.1 demonstrates the layout of the still camera's representing each perspective with respect to the airfoil.

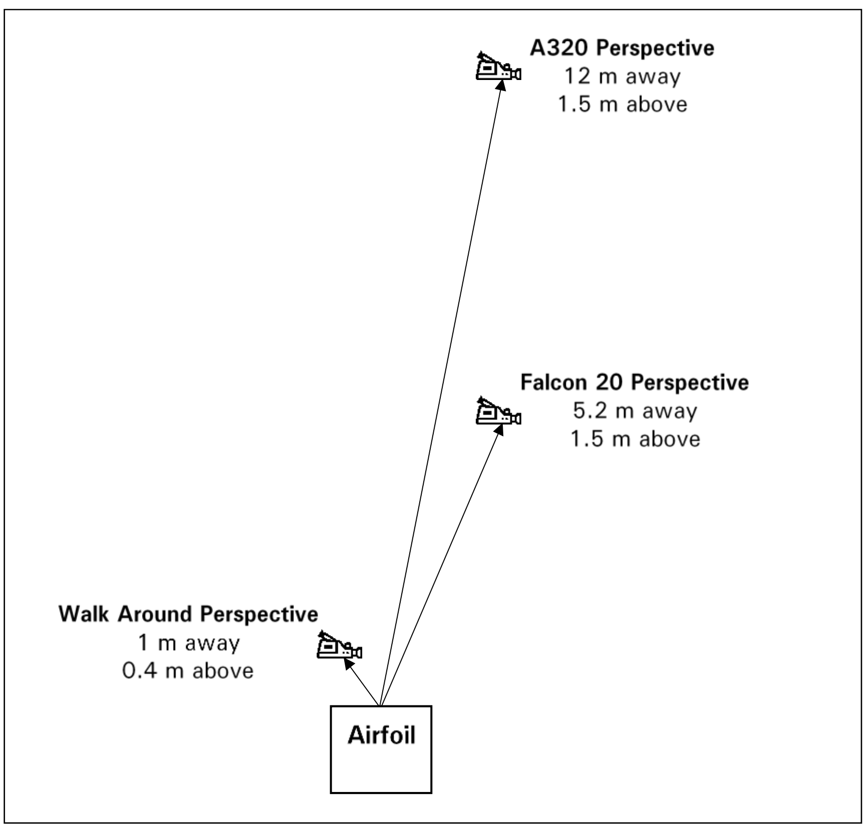


Figure 6.1: Plan View of Layout for Far vs. Near Photo Documentation

6.2 Test Log – Far vs. Near Perspective Photo Documentation

During the winter of 2005-06, APS personnel obtained photo documentation of an airfoil subjected to ice pellet contamination. To facilitate the understanding of the data collected, a log was created for the series of tests conducted. The log presented in Table 6.1 provides relevant information for each test event. Each row contains data specific to one test. The total quantity of ice pellets was applied over a short period of time, typically 30 seconds. During specific tests tracer pellets, ice pellets that were dyed blue were used to increase the visibility of the ice pellets in the fluid as clear ice pellets were very difficult to distinguish. The tracer pellets accounted for approximately 10 percent of the total quantity of ice pellets applied. The following is a brief description of the column headings for the test logs:

Test #:	Exclusive number identifying each test;
Perspective Representation:	Representation of the human perspective when viewing an aircraft wing;
Fluid:	Aircraft deicing fluid type;
Fluid Quantity:	Amount of aircraft deicing fluid applied to the airfoil, measured in litres;
Ice Pellet Size:	The range of ice pellet diameters, measured in millimetres, applied to the airfoil;
Ice Pellet Quantity:	Total quantity of ice pellets, measured in kilograms, applied to the airfoil;
Simulated 20 Minute Rate:	Quantity of ice pellets equivalent to a 20-minute exposure to a specific rate of precipitation in $g/dm^2/h$; and
Ice Pellet Condition:	Simulated ice pellet rate of precipitation.

6.3 Far vs. Near Perspective Photo Documentation

Still photography was used to document far and near perspectives of the airfoil subject to ice pellet contamination. For each test, photos were taken representing an A320 perspective, Falcon 20 perspective, and a walk around observer perspective.
Photo 6.1 to Photo 6.12 demonstrate the different perspective representations for test numbers FVN-3, FVN-6, FVN-12, and FVN-24 at various intervals during the test. Sections of the photographs were blacked out to reduce the noise effect from the background.

Table 6.1: Log Far vs. Near Tests

Test #	Perspective Representations	Fluid	Fluid Quantity (L)	Ice Pellet Size (mm)	Ice Pellet Quantity (Kg)	Simulated 20 min. Rate (g/dm²/h)	Ice Pellet Condition
FVN-1	A320/Falcon 20/ Walk Around	Type IV - PG	5	3	0.45	13	Light
FVN-2	A320/Falcon 20/ Walk Around	Type IV - PG	5	3	0.85	25	Light/Moderate
FVN-3	A320/Falcon 20/ Walk Around	Type IV - PG	5	3	2.5	75	Moderate/Heavy
FVN-4	A320/Falcon 20/ Walk Around	Type IV - PG	5	3	0.45	13	Light (w/ tracer pellets)
FVN-5	A320/Falcon 20/ Walk Around	Type IV - PG	5	3	0.85	25	Light/Moderate (w/ tracer pellets)
FVN-6	A320/Falcon 20/ Walk Around	Type IV - PG	5	3	2.5	75	Moderate/Heavy (w/ tracer pellets)
FVN-7	A320/Falcon 20/ Walk Around	Type IV - PG	5	5	0.45	13	Light
FVN-8	A320/Falcon 20/ Walk Around	Type IV - PG	5	5	0.85	25	Light/Moderate
FVN-9	A320/Falcon 20/ Walk Around	Type IV - PG	5	5	2.5	75	Moderate/Heavy
FVN-10	A320/Falcon 20/ Walk Around	Type IV - PG	5	5	0.45	13	Light (w/ tracer pellets)
FVN-11	A320/Falcon 20/ Walk Around	Type IV - PG	5	5	0.85	25	Light/Moderate (w/ tracer pellets)
FVN-12	A320/Falcon 20/ Walk Around	Type IV - PG	5	5	2.5	75	Moderate/Heavy (w/ tracer pellets)
FVN-13	A320/Falcon 20/ Walk Around	Type II - PG	5	3	0.45	13	Light
FVN-14	A320/Falcon 20/ Walk Around	Type II - PG	5	3	0.85	25	Light/Moderate
FVN-15	A320/Falcon 20/ Walk Around	Type II - PG	5	3	2.5	75	Moderate/Heavy
FVN-16	A320/Falcon 20/ Walk Around	Type II - PG	5	3	0.45	13	Light (w/ tracer pellets)
FVN-17	A320/Falcon 20/ Walk Around	Type II - PG	5	3	0.85	25	Light/Moderate (w/ tracer pellets)
FVN-18	A320/Falcon 20/ Walk Around	Type II - PG	5	3	2.5	75	Moderate/Heavy (w/ tracer pellets)
FVN-19	A320/Falcon 20/ Walk Around	Type I - EG	3	3	0.45	13	Light
FVN-20	A320/Falcon 20/ Walk Around	Type I - EG	3	3	0.85	25	Light/Moderate
FVN-21	A320/Falcon 20/ Walk Around	Type I - EG	3	3	2.5	75	Moderate/Heavy
FVN-22	A320/Falcon 20/ Walk Around	Type I - EG	3	3	0.45	13	Light (w/ tracer pellets)
FVN-23	A320/Falcon 20/ Walk Around	Type I - EG	3	3	0.85	25	Light/Moderate (w/ tracer pellets)
FVN-24	A320/Falcon 20/ Walk Around	Type I - EG	3	3	2.5	75	Moderate/Heavy (w/ tracer pellets)

6.4 Full-Scale Far vs. Near Perspective Documentation

In conjunction with the full-scale Falcon 20 testing conducted at the NRC IAR, APS obtained far vs. near pilot's perspective photo documentation using the Falcon 20 aircraft. A measured amount of simulated ice pellets was applied in a short period of time to the anti-iced portion of a Falcon 20 aircraft wing. The amount of ice pellets applied was equivalent to a 20-minute exposure to moderate/heavy ice pellet conditions. Following the application of the ice pellets, a series of photos was taken demonstrating the different perspectives. Photos were taken from just outside the cockpit window. The following three perspectives were documented:

- Falcon 20 Port Side View (Photo 6.13);
  - Zoom lens was not used.
- Falcon 20 Cockpit Perspective (Photo 6.14); and
  - Zoom lens was used to best represent human observer.
- Falcon 20 Walk Around Observer Perspective (Photo 6.15).
  - Zoom lens was used to best represent human observer.

6.5 General Observations

Ice pellets are translucent, and as a result, are difficult to see when embedded in aircraft deicing fluid. It was observed that ice pellets became increasingly difficult to see as the distance from the test surface increased. When bridging ice pellets became visible from far distances (cockpit perspective), the condition of the fluid had already become severely contaminated; operationally, the severity increases with respect to the distance from the contaminated objective.

Full-scale testing using the Falcon 20 aircraft demonstrated that the photo documentation collected using the airfoil was representative of what can be seen during actual operations.

Photo 6.1: Far vs. Near Test #FVN-3 – Photo 1

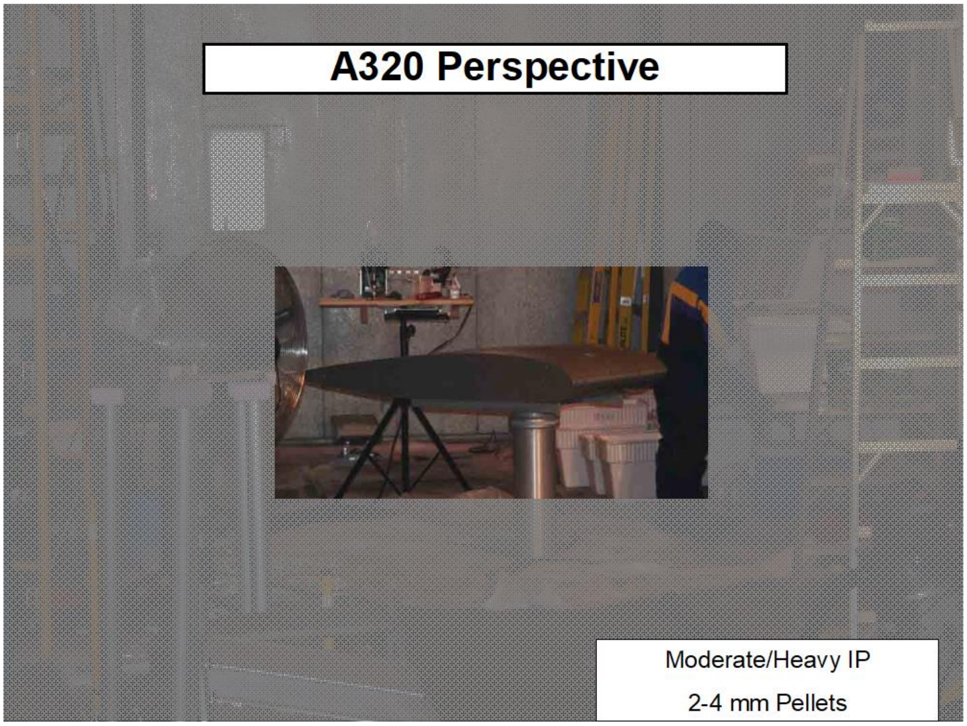


Photo 6.2: Far vs. Near Test #FVN-3 – Photo 2

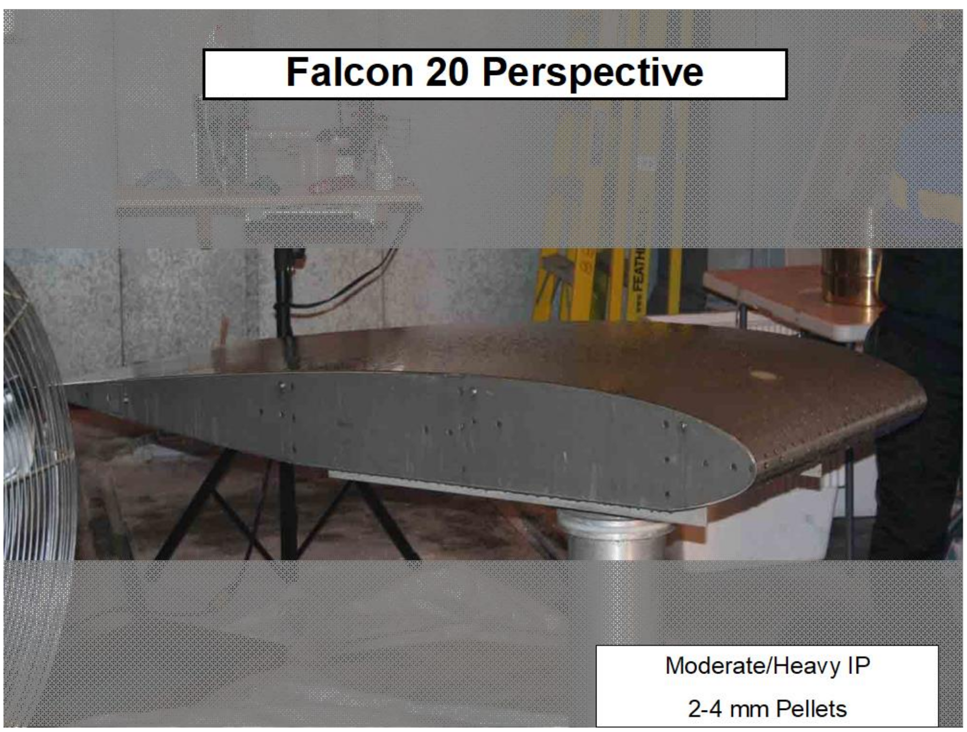


Photo 6.3: Far vs. Near Test #FVN-3 – Photo 3

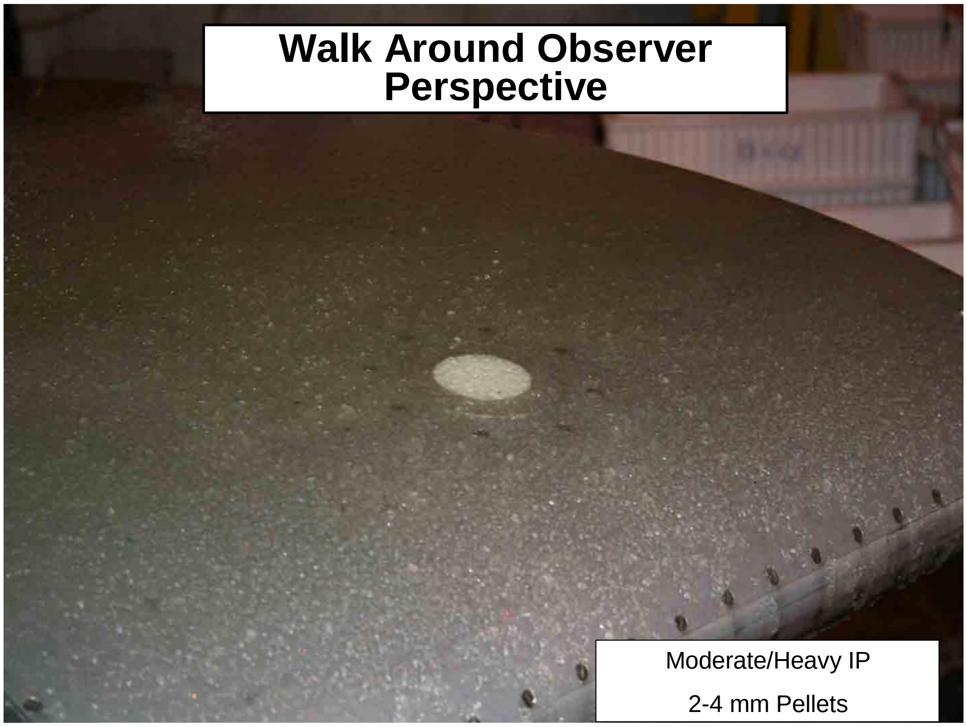


Photo 6.4: Far vs. Near Test #FVN-6 – Photo 1

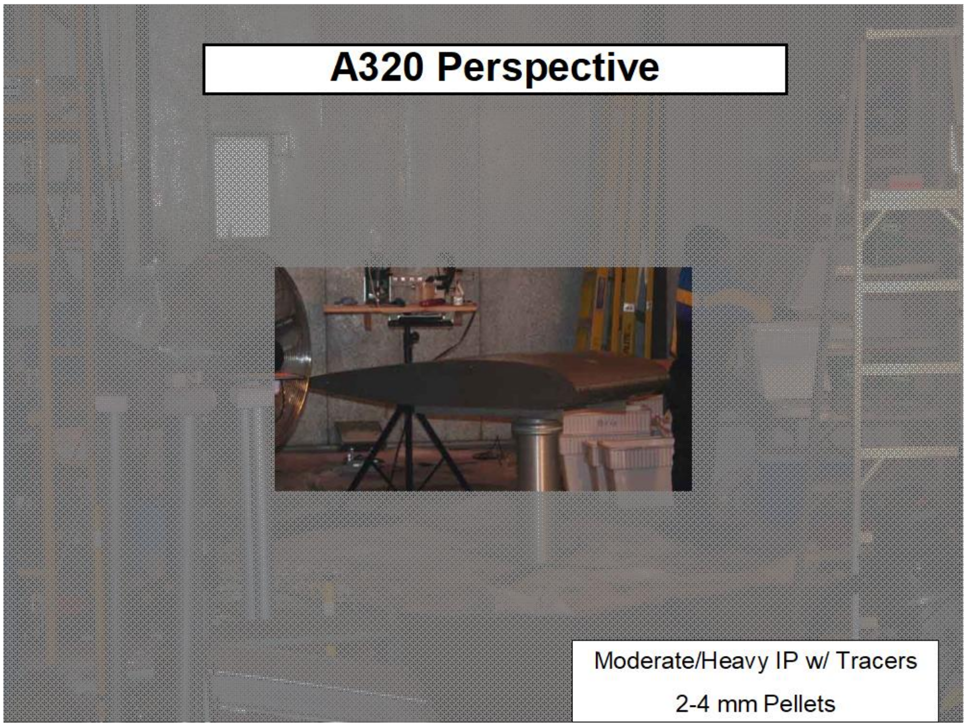


Photo 6.5: Far vs. Near Test #FVN-6 – Photo 2

Photo 6.6: Far vs. Near Test #FVN-6 – Photo 3

Photo 6.7: Far vs. Near Test #FVN-12 – Photo 1

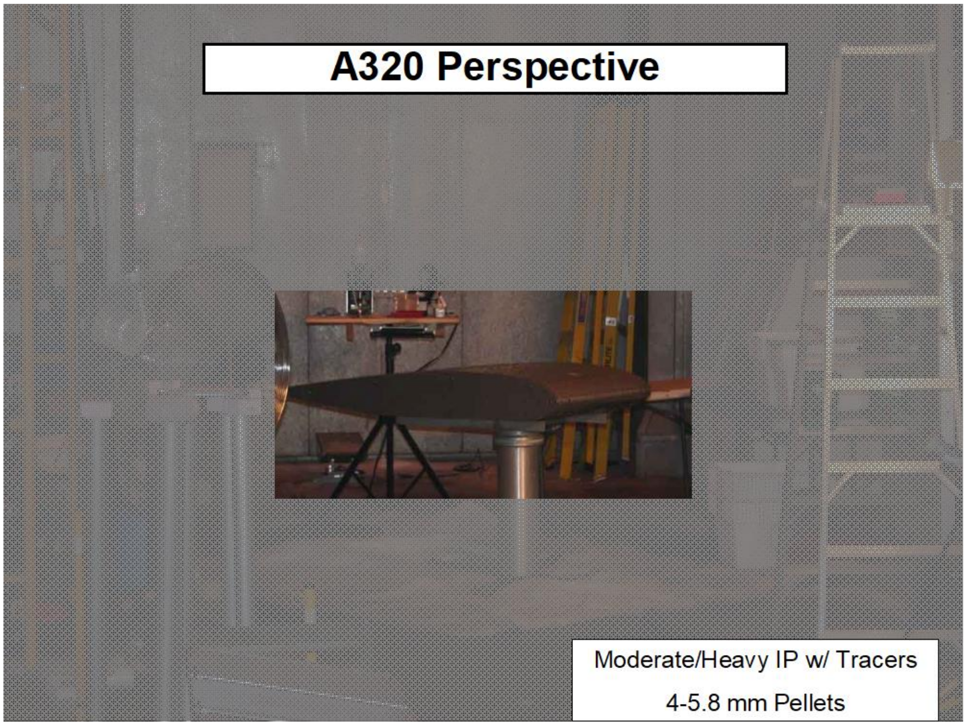


Photo 6.8: Far vs. Near Test #FVN-12 – Photo 2

Photo 6.9: Far vs. Near Test #FVN-12 – Photo 3

Photo 6.10: Far vs. Near Test #FVN-24 – Photo 1

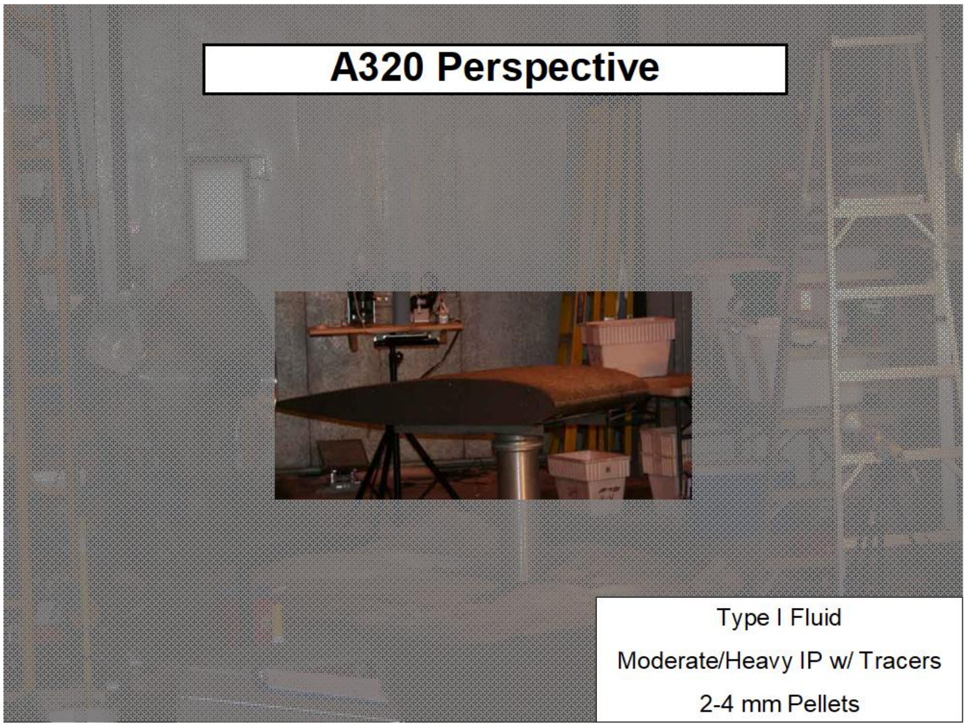


Photo 6.11: Far vs. Near Test #FVN-24 – Photo 2

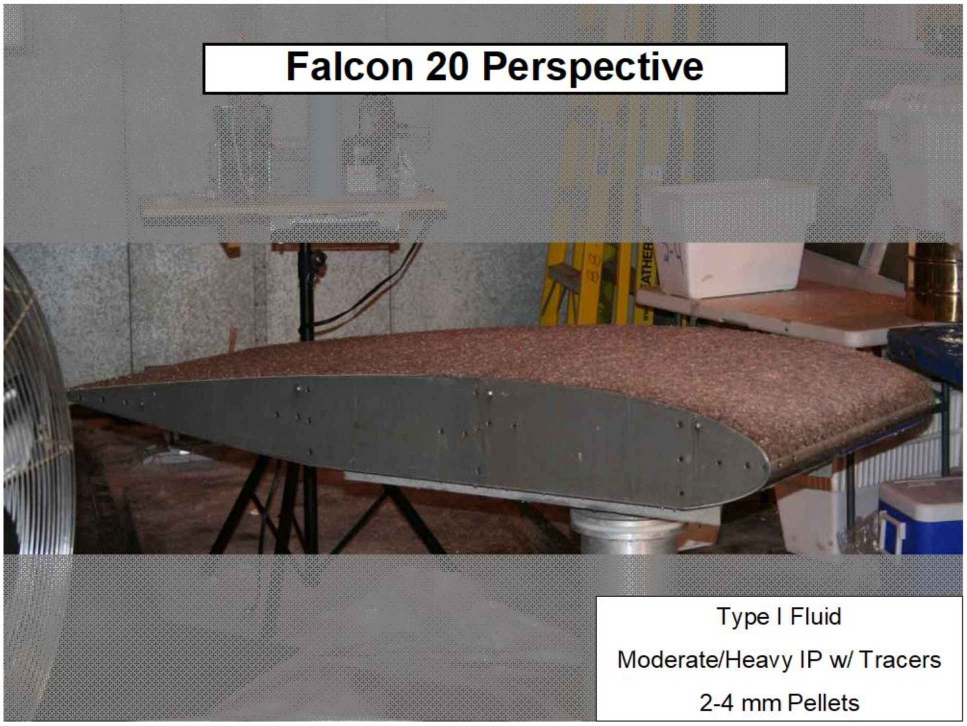


Photo 6.12: Far vs. Near Test #FVN-24 – Photo 3

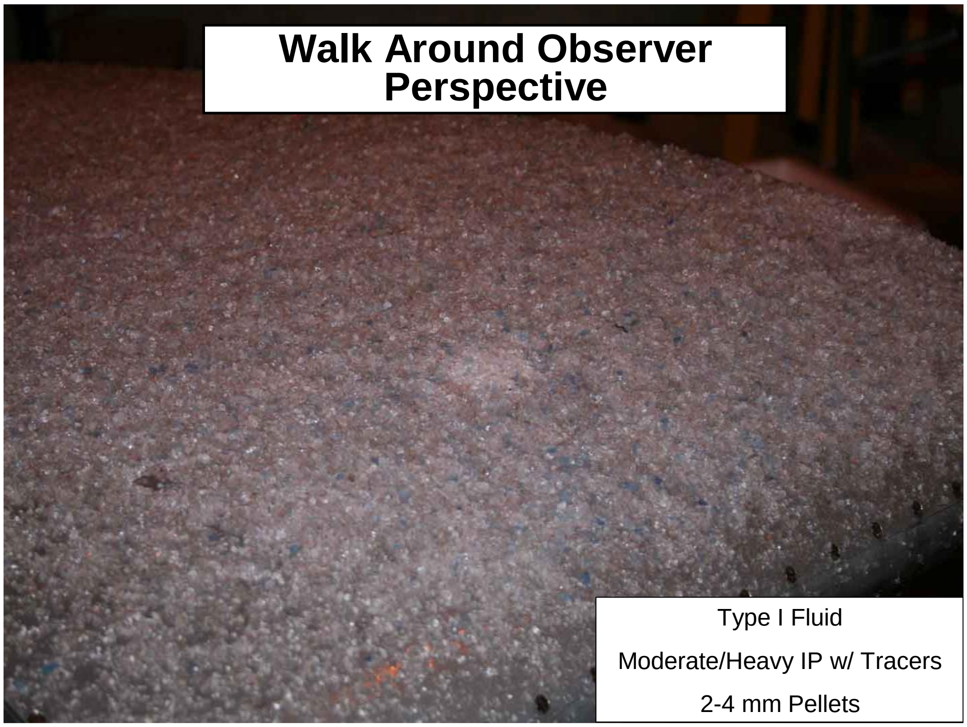


Photo 6.13: Full-Scale Far vs. Near – Falcon 20 Port Side View

Photo 6.14: Full-Scale Far vs. Near – Falcon 20 Pilot Perspective

Photo 6.15: Full-Scale Far vs. Near – Walk Around Observer Perspective

7. BARE WING DEPARTURES IN ICE PELLET CONDITIONS

The world meteorological organization describes ice pellets as "pellets of ice that usually bounce when hitting hard ground". This definition has led aircraft operators to believe that bare wing departures in ice pellet conditions are a feasible alternative to de/anti-icing. The misconception with regards to "bouncing pellets of ice" is that the contamination will not adhere and will be removed by the airflow at takeoff, therefore eliminating the requirement for de/anti-icing. The following section will describe some of the preliminary observations made with respect to bare wing aircraft departures.

7.1 Full-Scale Falcon 20 Testing – Natural Ice Pellet Event

APS conducted full-scale testing in simulated ice pellet conditions at the NRC IAR. During preparation for the second test run on March 9, 2006, testing was aborted due to mixed ice pellet and freezing rain conditions. APS personnel observed and photographed the bare wing surfaces of the Falcon 20 aircraft. Photos of the bare Falcon 20 wing during natural ice pellet conditions are given in Photo 7.1 and Photo 7.2. Photo 7.3 shows a close-up view of the rough surface caused by the adhered ice pellets and freezing rain on the bare wing surface. The contamination was adhered to the surface of the wing and it is unknown if this adhered contamination would be removed by the airflow at the time of rotation. Future work to be conducted by APS will investigate the impact of adhered precipitation on aircraft lift properties.

7.2 General Observations

Ice pellets are a transitional condition and are often followed by, or preceded by, freezing rain or drizzle. This may also result in conditions where mixed precipitation conditions occur; ice pellets and freezing rain or drizzle. Freezing rain is highly conducive to adherence to bare surfaces. When combined with ice pellets, the ice adhered to the bare surface is rough due to the pellets and is aerodynamically more harmful than ice created by freezing rain or drizzle alone. Due to the transitional nature of ice pellets and the uncertainty of whether they will be mixed with other precipitation conducive to adherence, the use of Type IV Neat anti-icing fluid is recommended during ice pellet conditions to reduce the risk of ice precipitate adhering to critical aircraft surfaces.

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Photo 7.1: View of Falcon 20 Wing Section with Adhered Ice Pellets and Freezing Rain – Photo 1

Photo 7.2: View of Falcon 20 Wing Section with Adhered Ice Pellets and Freezing Rain – Photo 2

Photo 7.3: Close-up View of Rough Surface Caused by Adhered Ice Pellets and Freezing Rain on Falcon 20 Wing Section – Photo 2

8. FULL-SCALE FALCON 20 TESTING IN SIMULATED ICE PELLET CONDITIONS

Full-scale Falcon 20 testing was conducted in simulated ice pellet conditions at the NRC IAR. TC report TP 14716E, *Falcon 20 Trials To Examine Fluid Removed From Aircraft During Takeoff With Ice Pellets* (2) includes detailed results and analysis. This section provides a brief overview of the results.

8.1 Procedure

To satisfy the program objective, simulated takeoff runs were performed with the NRC Falcon 20 research aircraft, and different parameters, including fluid thickness, wing temperature, and fluid freezing point, were recorded at designated times during the tests.

The procedure for each run was as follows:

a) A designated test area on the port wing was treated with Type IV fluid, poured in a one-step operation outside the NRC hangar. In the final run, Type I EG fluid was applied heated in a one-step operation at the runway button.

b) Manufactured ice pellets were transported in the aircraft in a temperature-controlled cooler and applied on the test area at the runway button using hand-held dispersers.

c) The aircraft was subsequently operated through a simulated takeoff run, excluding climb-out. The behaviour of the contaminated fluid during the takeoff run was recorded with digital video cameras and digital high-speed still cameras.

d) Tests with increasing ice pellet quantities and different ice pellet sizes were conducted.

8.2 Falcon 20 Design Characteristics

A three-view diagram of the Falcon 20 aircraft has been included in Figure 8.1. Some of the pertinent dimensions of the Falcon 20 are:

- Wingspan: 16.32 m (53 ft. 7 in.);
- Wing surface area (both wings): 41 m^2 (441.33 $ft.^2$); and
- Length: 17.15 m (56 ft. 3 in.).

The Falcon 20 has slotted slats outboard of the fence on each wing; the wing section inboard of the fence contains no moveable devices.

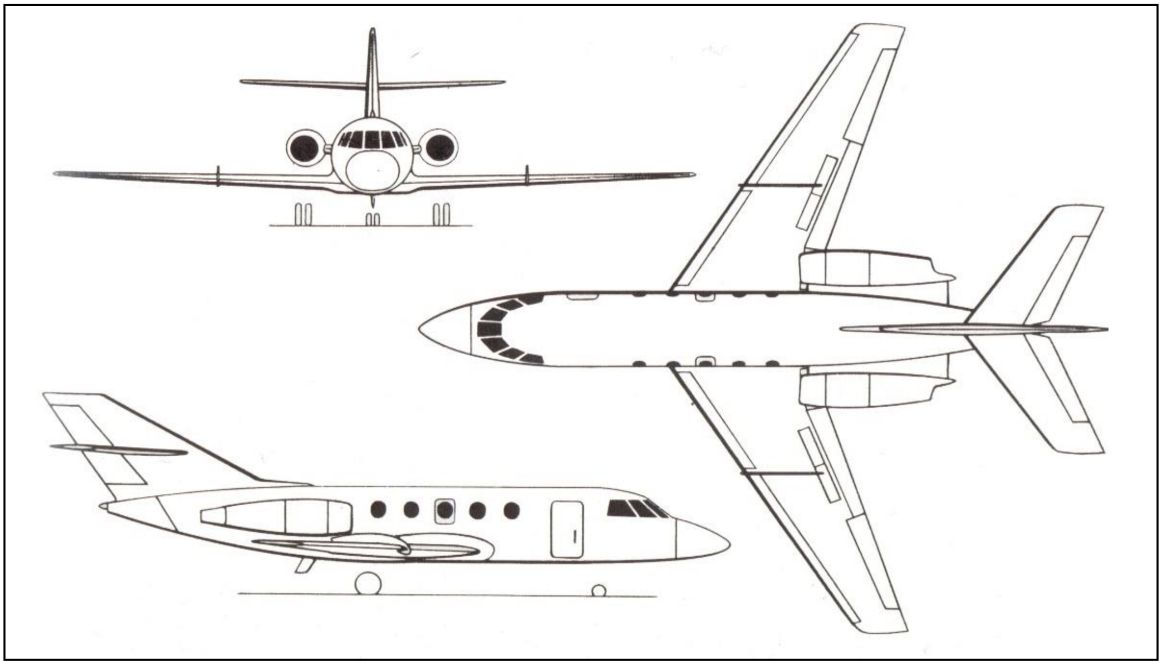

Figure 8.1: Schematic View of Dassault Falcon 20

8.3 Overview of Tests

A summary of the tests conducted is shown in Table 8.1. A more detailed summary of the pertinent parameters for each run is provided in TP 14716E, *Falcon 20 Trials To Examine Fluid Removed From Aircraft During Takeoff With Ice Pellets* (2).

Table 8.1: Summary of 2005-06 Testing with Falcon 20

RUN NUMBER	1	2	3	4	5	6	7	8	9
Date	09-Mar-06	09-Mar-06	15-Mar-06	15-Mar-06	16-Mar-06	16-Mar-06	16-Mar-06	17-Mar-06	17-Mar-06
Fluid	Ultra +	ABC-S	ABC-S	ABC-S	ABC-S	Ultra +	Ultra +	ABC-S	Type I EG
Fluid Dilution	100%	100%	100%	100%	100%	100%	100%	100%	10°C buffer
OAT [°C]	-5	-4	-6	-6	-8	-8	-7	-9	-10
Wind Direction/Speed	105/12 kt	105/10 kt	270/16 kt	300/17 kt	305/12 kt	315/18 kt	315/14 kt	335/12 kt	335/14 kt
Precipitation	Nil	-ZR	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Sky Condition	Overcast	Overcast	Overcast	Mostly overcast	Scatted clouds	Mostly sunny	Mostly sunny	Clear (sunrise)	Sunny
Pellets Size [mm]	3.35 - 4.75	3.35 - 4.75	3.35 - 4.75	1.0 - 3.35	1.0 - 3.35	1.0 - 3.35	<3.35 unprocessed	<3.35 unprocessed	1.0 - 3.35
Actual Precip. Rate for 20 min (T-IV) and 11 min (T-I) [g/dm²/h]	24.8	N/A	24.8	24.8	83.5	83.5	167.0	136.3	33.0
Approx Avg Wing Temp before Fluid Application [°C]	-2.7	-2.9	-5	-3.5	-8.2	-3.2 to -7.1	-3.7 to -5.5	-9.5	-9
Video Camera (mounted on window)	Wide / Zoom	Wide / Zoom	Zoom	Zoom	Zoom	Zoom	Zoom	Zoom	Zoom
Still Camera (mounted on window)	Nil / Nil	Nil / Nil	Zoom	Zoom	Zoom / N/A	Zoom	Zoom	Zoom	Zoom
Remarks		Test aborted due to freezing rain		Brakes seized after test	Still camera N/A		Emergency of other A/C caused delayed T/O. Precip. melted after exposure to direct sunlight	Slush remained aft of approx 20% LE	Small spots of ice adhered, fluid app method not representative of ops; more heat would have generated more adhesion

8.4 Conclusions

8.4.1 Test Coordination and Provision of Support

APS coordinated and provided support for the NRC Falcon 20 tests. The test methodologies employed for the application of ice pellets and the collection of fluid thickness, fluid viscosity, wing temperature, and fluid freezing point data were satisfactory.

8.4.2 Elimination of Contaminated Fluids

For Type IV fluid tests, a controlled quantity of ice pellets was applied at the runway button. The baseline was chosen to represent an effective precipitation rate of 25 g/dm^2/h over a period of 20 minutes. The quantity of ice pellets applied was increased for successive tests until the airflow failed to remove all the contamination.

For both EG and PG Type IV fluids, the airflow at takeoff removed ice-pellet contaminated anti-icing fluid from the leading edge, leaving only a very thin film of fluid even at very high precipitation rates. In one case, at a very high precipitation rate (effective rate of 136 g/dm^2/h), the entire 24 seconds of the takeoff run were required to clear the leading edge of any precipitation. In this case some contamination (up to 1 mm) remained on the trailing edge.

A test with Type I EG fluid showed some adhesion of ice to the wing surface following the transfer of heat from the heated fluid to the cold wing surface. The fluid application method was not representative of actual operations. A normal deicing may transfer more heat, which would likely generate more adhesion due to melting and associated fluid contamination.

8.4.3 Implication of Ice Pellet Tests on Current Holdover Times

During the winter 2002-03 and 2003-04, APS conducted a study of the adhesion of contaminated Type II/IV fluids on aluminum surfaces (see TP 14377E, *Adhesion of Aircraft Anti-Icing Fluids on Aluminum Surfaces*) (3). It was concluded that for natural snow, the adhesion failure occurs after extended periods of time. In the same report, the occurrence of adherence was observed under all other freezing precipitation conditions. Typically, adhesion was observed shortly after standard plate failure for freezing precipitation.

The 2006 Falcon 20 tests showed that ice pellets did not adhere to the wing surface. In addition, tests on flat plates with ice pellets alone also did not show signs of adhesion, similar to what was observed in the previous work in natural snow conditions. It can therefore be concluded that:

- It is possible that the current holdover times in snow are very conservative for Type II and IV fluids; and
- If adhesion is a true measure of holdover time, then endurance times in many conditions are very conservative.

9. ADHERENCE TESTING IN SIMULATED ICE PELLET CONDITIONS

Research was conducted to determine if endurance time testing during ice pellet conditions would demonstrate signs of frozen contamination adhesion to aluminum test surfaces. Testing was conducted in simulated precipitation using a standard aluminum test plate sitting inside a self-contained bucket (NCAR Bucket) that collected any fluid run off from the plate. In addition, still photography was used to document the fluid condition at different stages during the test. This section describes the data collected and observations documented by the APS research team.

9.1 Overview of Test Objectives

The following sections provide an overview of the test objectives.

9.1.1 Standard Plate Tests

The objective was to investigate if endurance time testing conducted during ice pellet conditions would demonstrate signs of adhesion to aluminum test surfaces. Testing was conducted during conditions most likely to exhibit adhesion. The following describes the tests conducted:

- Type I Heated Fluid Application Endurance Time Test;
- Type II, III and IV Fluid Application Endurance Time Test – Fluid at Room Temperature;
- Type II, III and IV Fluid Application Endurance Time Test – Fluid Heated to 60ºC;
- Type II, III and IV Fluid Application Endurance Time Test – Exceeded HOT (test continued beyond point when fluid condition was considered severe); and
- Type II, III and IV Fluid Application Endurance Time Test – Mixed Precipitation (ice pellets and freezing rain/drizzle).

9.1.2 Leading Edge Thermal Equivalent Box Tests

Additional testing was later conducted using a leading edge thermal equivalent box. The following is a description of the additional tests conducted:

- Two Step Application - Type I Heated Fluid Application Followed by Type II, III and IV Fluid Application;
- Two Litre Application of Heated Type IV fluid; and
- Two Step Application - Type I Heated Fluid Application Followed by Degraded Type II, III and IV Fluid Application.

9.2 Log of Standard Test Plate Tests

To facilitate the accessibility of the data collected, a log was created for the series of tests conducted by APS at the NRC research facility. The log presented in Table 9.1 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 log:

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;
Date:	Date when test was conducted;
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 air temperature of the NRC research facility chamber, measured in degrees Celsius;
Precip. Type:	Type of simulated precipitation, or combination of simulated freezing precipitations;
AVG. IP Precip. Rate:	Average simulated ice pellet precipitation rate, measured in $g/dm^2/h$, collected by the NCAR bucket;
AVG. ZR Precip. Rate:	Average simulated freezing rain precipitation rate, measured in $g/dm^2/h$, collected by the NCAR bucket;
Combined AVG. Precip. Rate:	Sum of the two simulated freezing precipitation rates, measured in $g/dm^2/h$, collected by the NCAR bucket;

Time of First Adhesion: Time of first documented sign of adherence recorded in minutes;

% Adhered at End of Test: % of the test plate demonstrating signs of fluid adhesion at the end of the test; and

Objective: Test objective referring to fluid application and precipitation condition.

9.3 Log of Leading Edge Thermal Equivalent Box 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 9.2 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;

Fluid Types: First step and second step aircraft deicing fluid type;

First Step Fluid Name: First step application manufacturer brand name specific for each aircraft deicing fluid;

First Step Fluid Dilution: First step application aircraft deicing fluid glycol concentration;

First Step Fluid Quantity: Quantity of aircraft deicing fluid applied during first step application, measured in litres;

First Step Fluid Temp: First step application aircraft deicing fluid temperature prior to application, measured in degrees Celsius;

Second Step Fluid Name: First step application manufacturer brand name specific for each aircraft deicing fluid;

Second Step Fluid Dilution: First step application aircraft deicing fluid glycol concentration;

Second Step Fluid Quantity: Quantity of aircraft deicing fluid applied during first step application, measured in litres;

Second Step Fluid Temp: First step application aircraft deicing fluid temperature prior to application, measured in degrees Celsius;

Precip. Type:	Type of simulated precipitation;
OAT:	Outside air temperature of the NRC research facility chamber, measured in degrees Celsius;
Time of First Step Application:	Time of first step fluid application recorded in local time;
Time of Second Step Application:	Time of second step fluid application recorded in local time;
End Time:	End time for the test recorded in local time;
Total Time:	Total time for the test, calculated from the time of the second step application to the end time of the test, recorded in minutes;
AVG. IP Precip. Rate:	Average simulated ice pellet precipitation rate, measured in g/dm²/h, collected by the NCAR bucket; and
Objective:	Test objective referring to fluid application.

Table 9.1: Data Log – Standard Plate Tests

Test #	Start Time	End Time	Total Time (min)	Fluid Name	Fluid Dilution	Fluid Type	Fluid Temp. [°C]	OAT [°C]	Precip Type	AVG. IP Precip Rate [g/dm²/h]	AVG. ZR Precip Rate [g/dm²/h]	Combined AVG. Precip Rate [g/dm²/h]	Time of First Adhesion (min)	% Adhered at End of Test	Objective
1	12:48:45	13:03:00	14.25	Battelle D3 ADF*	10° Buffer (26.75)	I	60	-3	IP	9.0	N/A	N/A	N/A	100%	Type I Heated
2	14:59:30	15:09:15	9.75	Battelle D3 ADF*	3° Buffer (14.75)	I	60	-3	IP	37.2	N/A	N/A	N/A	80%(channels)	Type I Heated
3	13:48:30	13:56:40	8.17	Battelle D3 ADF*	10° Buffer (26.75)	I	60	-3	IP	52.8	N/A	N/A	N/A	N/A	Type I Heated
4	15:12:30	15:20:00	7.50	Battelle D3 ADF*	10° Buffer (34.75)	I	60	-10	IP	49.9	N/A	N/A	N/A	100%	Type I Heated
5	17:11:15	17:31:00	19.75	Ultra + EG	75/25	IV	-10	-10	IP/ZR	22.9	24.8	47.7	12.75	100%	Type II/III/IV - Mixed Precip.
6	16:21:40	16:28:30	6.83	Battelle D3 ADF*	10° Buffer (38.50)	I	60	-14	IP	51.4	N/A	N/A	6.33	75%	Type I Heated
7	10:59:00	11:12:30	13.50	Battelle D3 ADF*	10° Buffer (46.00)	I	60	-25	IP	32.4	N/A	N/A	N/A	N/A	Type I Heated
8	18:25:50	18:41:00	15.17	Octagon Maxflo	75/25	IV	15	-14	IP	52.7	N/A	N/A	N/A	N/A	Type II/III/IV - Fluid Room Temp.
9	17:24:35	17:41:00	16.42	Kilfrost P1792 (Type II**)	75/25	II	15	-14	IP	42.8	N/A	N/A	N/A	N/A	Type II/III/IV - Fluid Room Temp.
10	15:40:10	16:13:00	32.83	Octagon Maxflo	50/50	IV	60	-3	IP	23.1	N/A	N/A	N/A	N/A	Type II/III/IV - Fluid Heated 60°C
11	9:56:00	10:19:00	23.00	Octagon Maxflo	75/25	IV	60	-14	IP	48.2	N/A	N/A	N/A	N/A	Type II/III/IV - Fluid Heated 60°C
12	11:15:45	11:36:45	21.00	Kilfrost P1792 (Type II**)	75/25	II	60	-14	IP	88.1	N/A	N/A	N/A	N/A	Type II/III/IV - Fluid Heated 60°C
13	13:41:33	13:56:00	14.45	Octagon Maxflo	Neat	IV	60	-25	IP	70.8	N/A	N/A	N/A	N/A	Type II/III/IV - Fluid Heated 60°C
14	10:28:30	10:56:00	27.50	Maxflo	50/50	IV	-3	-3	IP	116.9	N/A	N/A	N/A	N/A	Type II/III/IV - Exceeded HOT
15	12:16:00	12:37:00	21.00	Kilfrost P1792 (Type II**)	50/50	II	-3	-3	IP	166.2	N/A	N/A	N/A	N/A	Type II/III/IV - Exceeded HOT
16	9:34:25	10:11:40	37.25	Octagon Maxflo	75/25	IV	-10	-10	IP	50.1	N/A	N/A	N/A	N/A	Type II/III/IV - Exceeded HOT
17	16:31:30	16:50:00	18.50	Octagon Maxflo	50/50	IV	-3	-3	IP/ZD	66.7	10.6	77.3	N/A	N/A	Type II/III/IV - Mixed Precip.
18	17:37:00	17:55:30	18.50	Octagon Maxflo	50/50	IV	-3	-3	IP/ZD	48.4	11.9	60.3	11.00	100%	Type II/III/IV - Mixed Precip.
19	13:03:50	13:16:40	12.83	Octagon Maxflo	75/25	IV	-10	-10	IP/ZD	58.6	9.4	68.0	N/A	N/A	Type II/III/IV - Mixed Precip.
20	13:30:47	13:45:00	14.22	Octagon Maxflo	75/25	IV	-10	-10	IP/ZD	55.6	9.4	65.0	N/A	N/A	Type II/III/IV - Mixed Precip.
21	10:46:40	11:00:00	13.33	Octagon Maxflo	50/50	IV	-3	-3	IP/ZR	70.7	27	97.7	12.67	15%	Type II/III/IV - Mixed Precip.
22	20:25:40	20:57:00	31.33	DOW	75/25	IV	-10	-10	IP/ZR	22.0	16.2	38.2	21.33	100%	Type II/III/IV - Mixed Precip.
23	21:17:10	21:32:00	14.83	DOW	75/25	IV	-10	-10	IP/ZR	156.3	16.7	173.0	N/A	N/A	Type II/III/IV - Mixed Precip.

Table 9.2: Data Log – Leading Edge Thermal Equivalent Box Tests

Test #	Fluid Types	First Step Fluid Name	First Step Fluid Dilution	First Step Fluid Quantity	First Step Fluid Temp. [°C]	Second Step Fluid Name	Second Step Fluid Dilution	Second Step Fluid Quantity	Second Step Fluid Temp. [°C]	Precip Type	OAT [°C]	Time of First Step Application	Time of Second Step Application	End Time	Total Time (min)	AVG. IP Precip Rate [g/dm²/h]	Objective
1	I and IV	UCAR ADF EG	10° Buffer	1L	60	Maxflo	50/50	1L	60	IP	-3	10:52:40	10:53:50	11:12:30	18.7	119.8	Two Step Application, on Box
2	I and IV	UCAR ADF EG	10° Buffer	1L	60	Ultra +	50/50	1L	60	IP	-3	14:01:40	14:02:16	14:22:30	20.2	50.3	Two Step Application, on Box
3	IV	N/A	N/A	N/A	N/A	Maxflo	50/50	2L	60	IP	-3	N/A	15:31:45	15:55:00	23.3	60	2 Litres of Heated Fluid, on Box
4	I and IV	UCAR ADF EG	10° Buffer	1L	60	Ultra +	Neat	1L (degraded)	OAT	IP	-3	16:33:00	16:34:15	16:57:00	22.8	72.3	2-Step, 1L EG TIV Fluid mixed with few drops of Sodium Hydroxide, on Box
5	I and II	UCAR ADF EG	10° Buffer	1L	60	ABC-S 2000	Neat	1L (Sheared)	OAT	IP	-3	17:26:00	17:27:30	17:50:00	22.5	46.2	2-Step, 1L PG Fluid sheared to 40% of LOWV, on Box

9.4 Photo Documentation of Endurance Time Testing

Still photography was used to document each endurance time test. Photos were taken at set intervals depending on the expected duration of the test. A select series of test photos have been included at the end of this section. A time stamp showing the elapsed time since the start of the test has been included in each photo as well as pertinent information regarding fluid adhesion.

9.5 APS Observations – Endurance Time Testing on Standard Test 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. Tests were terminated when the fluid condition was deemed severe, or when significant signs of fluid adherence were apparent. The following sections describe the observations and conclusions respective to each test objective.

9.5.1 Type I Heated Fluid Endurance Time Test in Simulated Ice Pellet Conditions

When conducting endurance time tests with Type I fluid, the condition of the test surface seemed severe very shortly after the start of the test. Due to the thin fluid layer, the ice pellets were very visible on the surface of the test plate. During each test (with the exception of the Type I test conducted at an OAT of -25°C), heat transfer from the Type I fluid to the test plate caused the ice pellets to begin to melt and create channels of water which would run down the plate. These channels carried fluid as well as ice pellets down the test plate. When the plate temperature fell below freezing, the diluted fluid and transported ice pellets in the channels eventually froze and exhibited adherence.

Test # 7 in Table 9.1 was conducted at an OAT of -25°C. The heat provided by the fluid was not enough to bring the plate temperature above freezing, and the ice pellets did not melt. Adherence did not occur. During Test #3, the high rate of ice pellet precipitation quickly populated the surface of the test plate and cooled the plate temperature thereby stopping the melting of the ice pellets. The short duration when melting did occur did not produce enough melt water to raise the fluids freeze point to ambient temperature, and no freezing or adhesion resulted.

Photo 9.1 to Photo 9.6 were taken during Test #4 and demonstrate a heated Type I EG test conducted at -10°C.

9.5.2 Type II, III and IV Fluid Endurance Time Tests in Simulated Ice Pellet Conditions

It should be noted that testing was not conducted using Type III fluid; however, it is assumed that the results would be similar to those obtained with Type II and IV fluid.

9.5.2.1 Heated Type II, III and IV Fluid Tests

Testing conducted using Type II and IV heated fluids in simulated ice pellet conditions alone did not demonstrate adherence. During the heated fluid tests (fluid applied at 60ºC) and the room-temperature fluid tests (fluid applied at 15ºC), the fluid would not dilute to the freeze point before the plate temperature could fall below freezing. The high viscosity of the Type II and IV fluids was not conducive to dissolving the ice pellets even though they had penetrated into the fluid layer. In contrast, in snow conditions, the porous nature of snowflakes allows the fluid surface to absorb the precipitate and form a top layer of slush. The ice pellets would begin to dissolve, however, the thickened fluid surrounding the pellet created a "cocoon" of water which isolated the pellet and prevented further dissolving (this was also seen in the melting time tests, see Section 5).

Photo 9.7 to Photo 9.14 were taken during Test #10 and demonstrate a heated Type IV PG test conducted at -3ºC.

9.5.2.2 Type II, III and IV Fluid at OAT Tests

During the standard Type II and IV fluid tests (fluid applied at OAT), adherence did not occur due to the absence of heat and the resultant lack of ice pellet melting. Adherence of solid freezing precipitation is generally caused when heated fluid produces enough melt water to cause dilution to a level where the fluid freeze point matches the sub-zero plate temperature (approximately equal to the OAT). Adherence was not possible because the fluid freeze point temperature never reached OAT.

During the exceeded HOT tests, the test was continued beyond the point when fluid condition was considered to be severe. The likelihood of adherence in such cases was reduced due to bridging ice pellets. Due to the viscous properties of the fluid, dilution was slow and pellets remained embedded in the fluid. Once the fluid dilution reached the freeze point, the ice pellets would cease to dissolve and the ice pellets would fully populate the fluid. Once a significant amount of ice pellets was embedded in the fluid, ice pellets would begin piling up on the plate. These bridging pellets were loose and easily removed. Adherence to the test plate or amongst ice pellets was not observed.

9.5.3 Type II, III and IV Fluid Endurance Time Tests in Mixed Precipitation

It should be noted that testing was not conducted using Type II or III fluid, but it is assumed that the results would be similar to those obtained with Type IV fluid.

Testing was conducted using Type IV fluids in mixed simulated ice pellet and simulated freezing rain/drizzle conditions. During each test, the fluid was applied at ambient temperature and in diluted mixes to reduce the length of the test. Adherence was not observed during tests when the ice pellet precipitation rate was significantly higher (approximately six to one or greater) than the freezing rain/drizzle rate of precipitation. The high rates of ice pellets prevented adherence expected from the freezing rain and drizzle; bridging ice pellets prevented the freezing rain and drizzle from penetrating the fluid and adhering onto the plate surface. In some cases, bridging pellets would adhere together on the top surface and create an “ice crust”, however, a thin protective layer of fluid was still found in contact with the plate surface which prevented adherence.

It should be noted that during the tests which did not demonstrate adhesion, the generated ice pellet rates of precipitation were in excess of 50 g/dm²/h; therefore, it may be possible that at lower rates of ice pellet precipitation, minimal freezing rain may cause adherence. During three tests conducted with a smaller ratio of ice pellets to freezing rain or drizzle (approximately four to one or less) fluid adherence was observed. The ice pellets may have delayed the occurrence of adherence but it did not prevent it. The lower rate of ice pellets did not generate a sufficient level of bridging pellets and allowed the freezing rain or drizzle to penetrate the fluid and cause adherence.

Testing was conducted using diluted fluids. When using Neat fluids, the fluid protection time against adherence will likely increase.

Photo 9.5 to Photo 9.22 were taken during Test #22 and demonstrate a mixed precipitation test using a Type IV EG fluid conducted at -3ºC.

9.6 APS Observations – Endurance Time Testing on Leading Edge Thermal Equivalent Box

Additional testing was conducted using leading edge thermal equivalent boxes to investigate whether the insulating properties of the box would allow heat retention from the applied fluid long enough to cause melting of the ice pellets and subsequent adhesion.

Contaminated fluid adherence was not observed during testing in conditions of ice pellets without other precipitation types. The heat from the applied fluids was not sufficient to raise the temperature of the box long enough to allow for significant fluid dilution, and therefore adherence did not occur. This was true for the 2-step application tests (Type I followed by Type IV), excessive heated fluid quantity tests (2 litres of Type IV fluid), and degraded fluid applied at OAT tests. The results were similar to the results obtained from the standard test plate tests described in Section 9.5.

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Photo 9.1: Adherence Test #4 – Photo 1 Type I EG 10°C Buffer Applied at 60°C, IP (2-4 mm, ≈ 50 g/dm²/h), -10°C

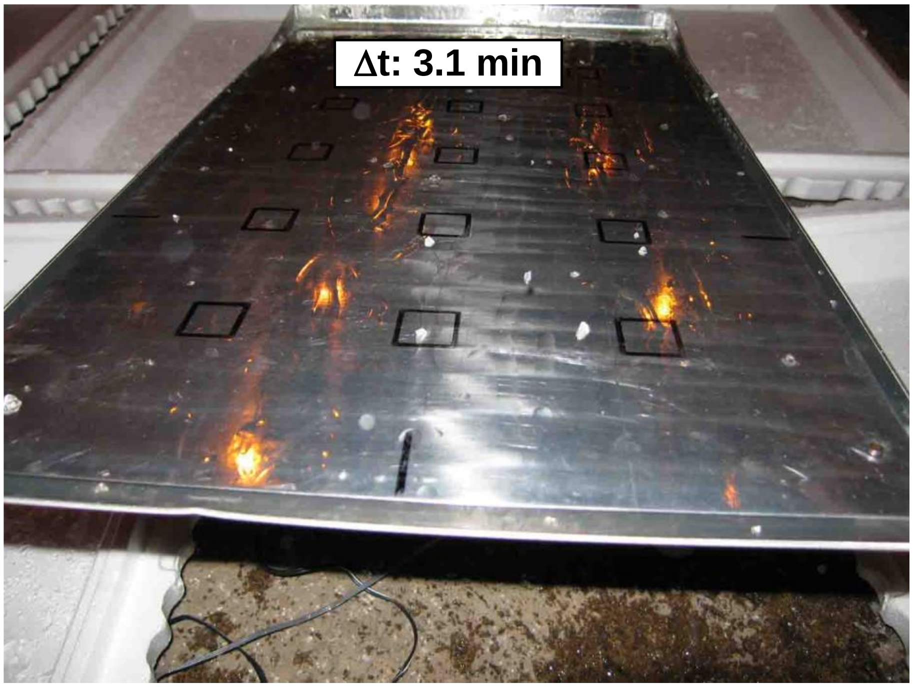


Photo 9.2: Adherence Test #4 – Photo 2 Type I EG 10°C Buffer Applied at 60°C, IP (2-4 mm, ≈ 50 g/dm²//h), -10°C

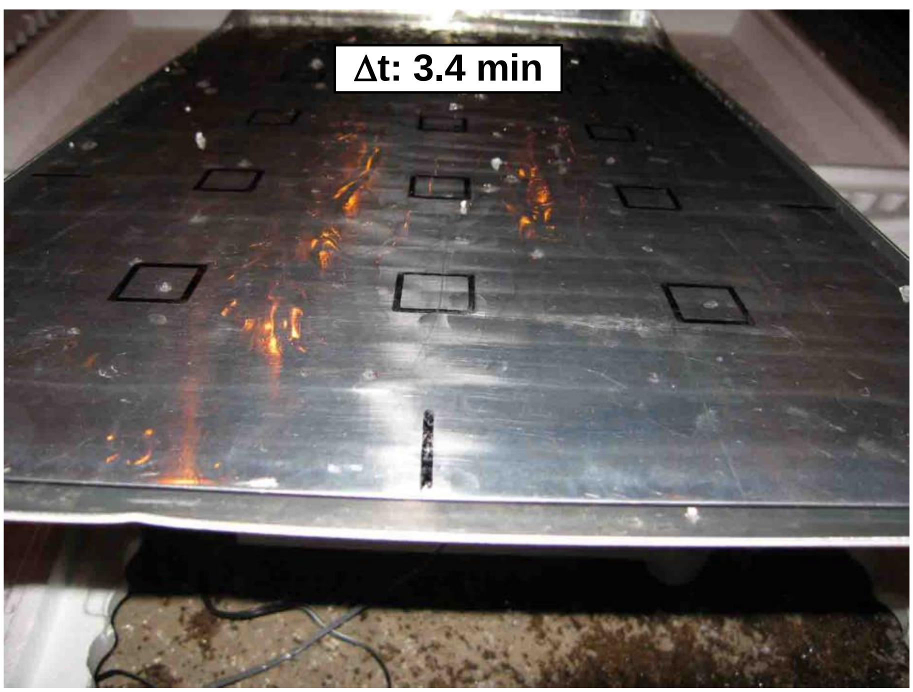


Photo 9.3: Adherence Test #4 – Photo 3 Type I EG 10°C Buffer Applied at 60°C, IP (2-4 mm, ≈ 50 g/dm^2/h), -10°C

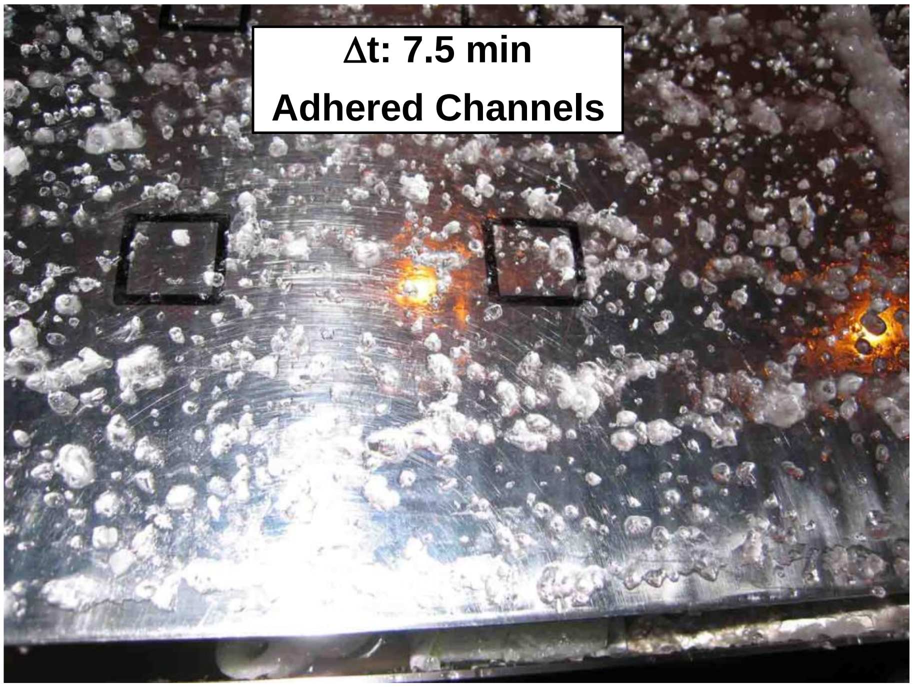


Photo 9.4: Adherence Test #4 – Photo 4 Type I EG 10°C Buffer Applied at 60°C, IP (2-4 mm, ≈ 50 g/dm^2/h), -10°C

Photo 9.5: Adherence Test #4 – Photo 5 Type I EG 10°C Buffer Applied at 60°C, IP (2-4 mm, ≈ 50 g/dm^2/h), -10°C

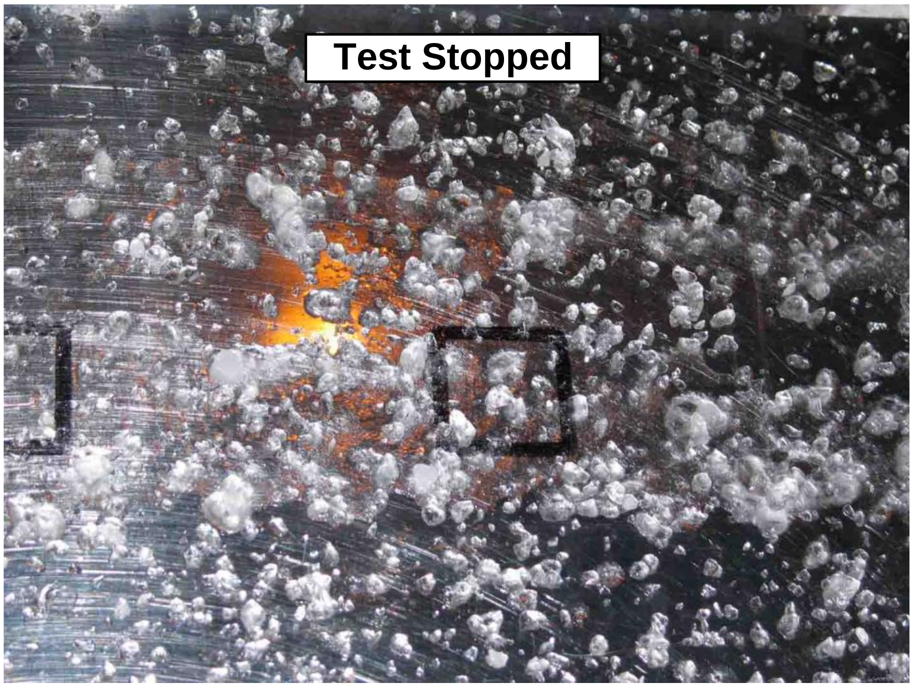


Photo 9.6: Adherence Test #4 – Photo 6 Type I EG 10°C Buffer Applied at 60°C, IP (2-4 mm, ≈ 50 g/dm^2/h), -10°C

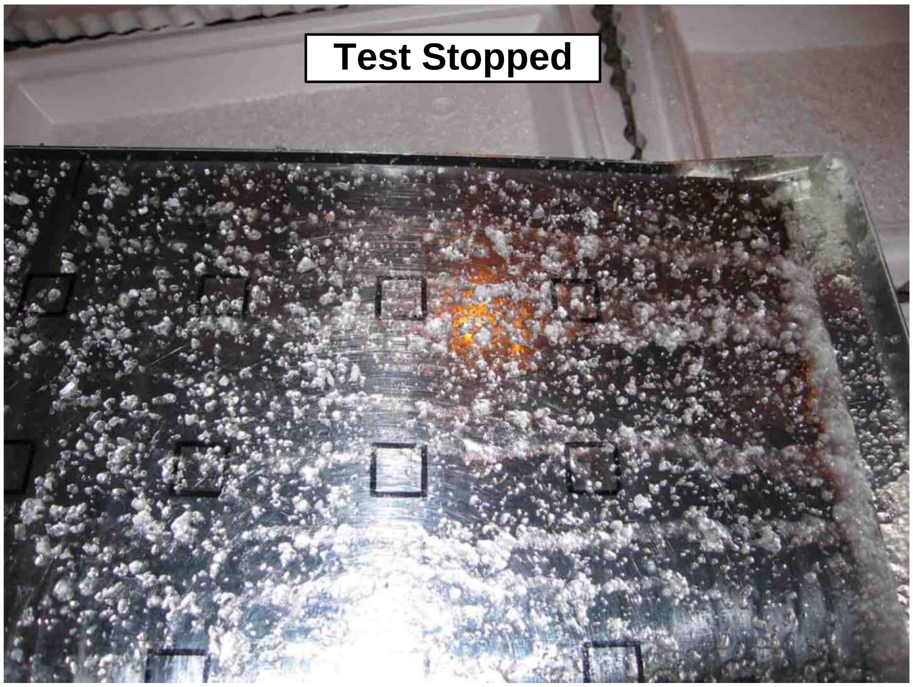


Photo 9.7: Adherence Test #10 – Photo 1 Type IV PG 50/50 Applied at 60°C, IP (4-5.8 mm, ≈ 25 g/dm^2/h), -3°C

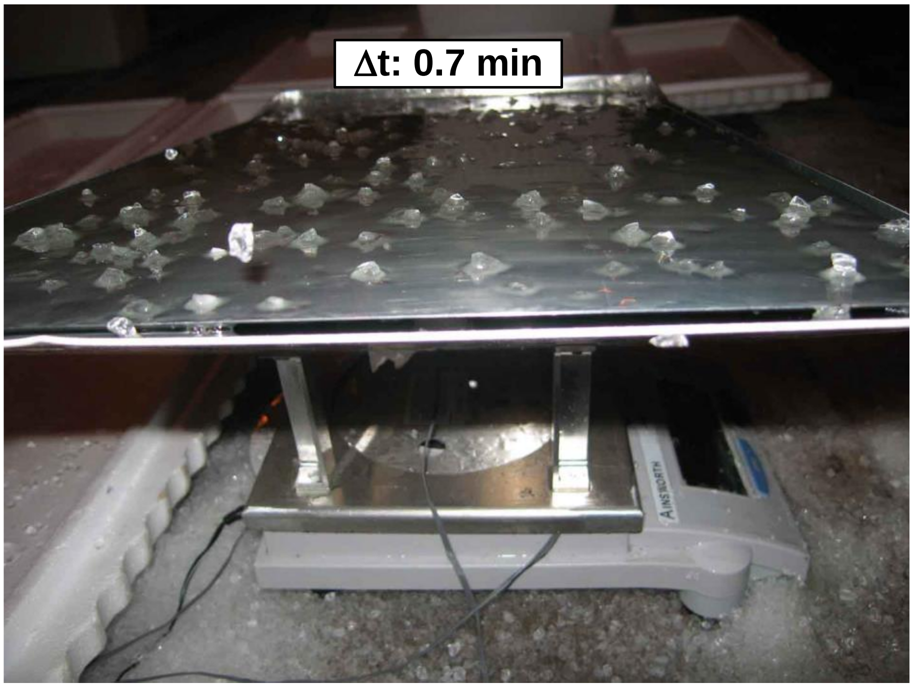


Photo 9.8: Adherence Test #10 – Photo 2 Type IV PG 50/50 Applied at 60°C, IP (4-5.8 mm, ≈ 25 g/dm^2/h), -3°C

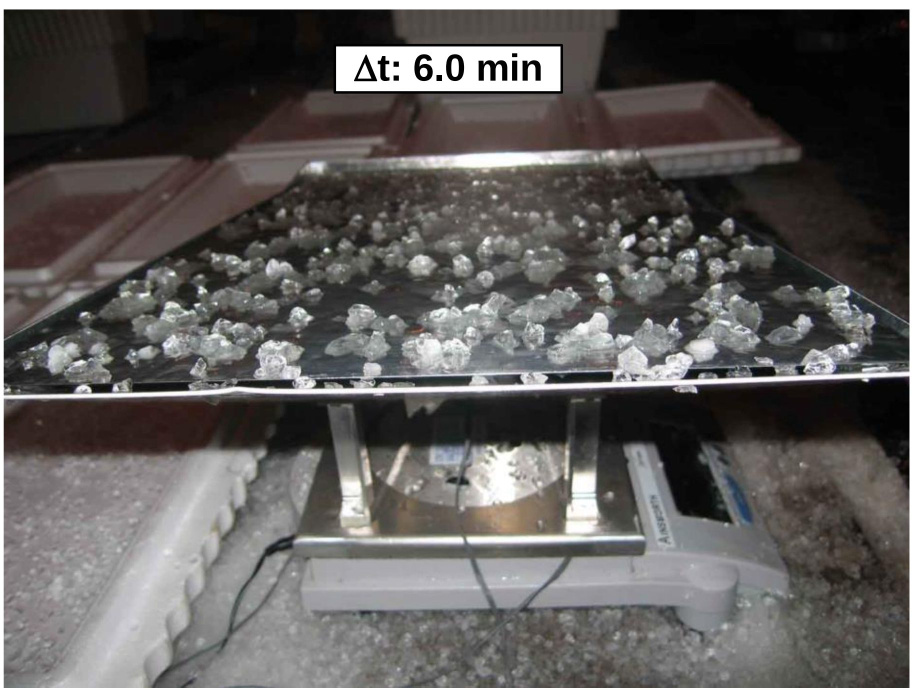


Photo 9.9: Adherence Test #10 – Photo 3 Type IV PG 50/50 Applied at 60°C, IP (4-5.8 mm, ≈ 25 g/dm²/h), -3°C

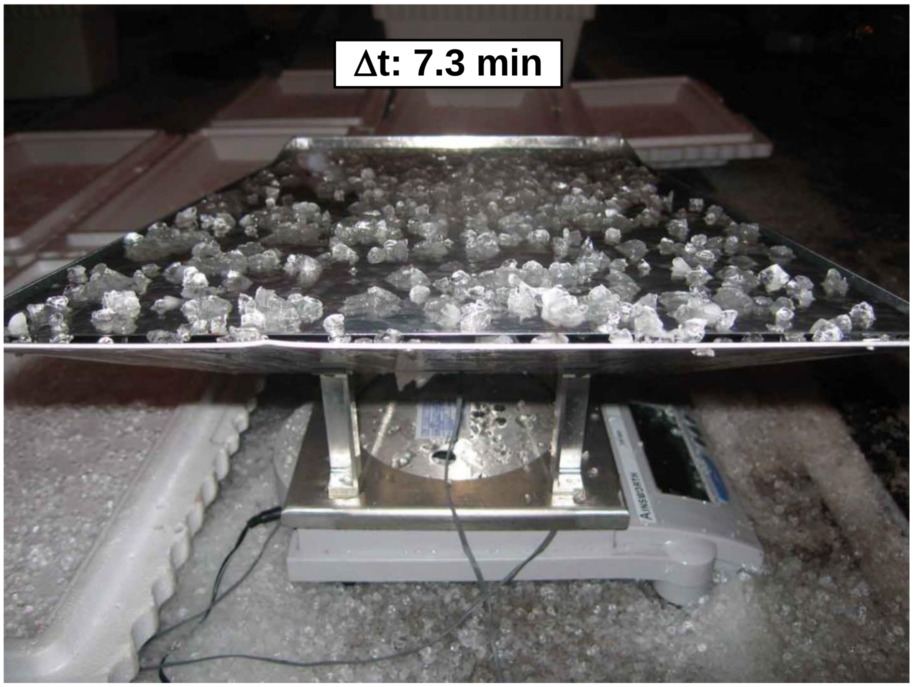


Photo 9.10: Adherence Test #10 – Photo 4 Type IV PG 50/50 Applied at 60°C, IP (4-5.8 mm, ≈ 25 g/dm²/h), -3°C

Photo 9.11: Adherence Test #10 – Photo 5 Type IV PG 50/50 Applied at 60°C, IP (4-5.8 mm, ≈ 25 g/dm^2/h), -3°C

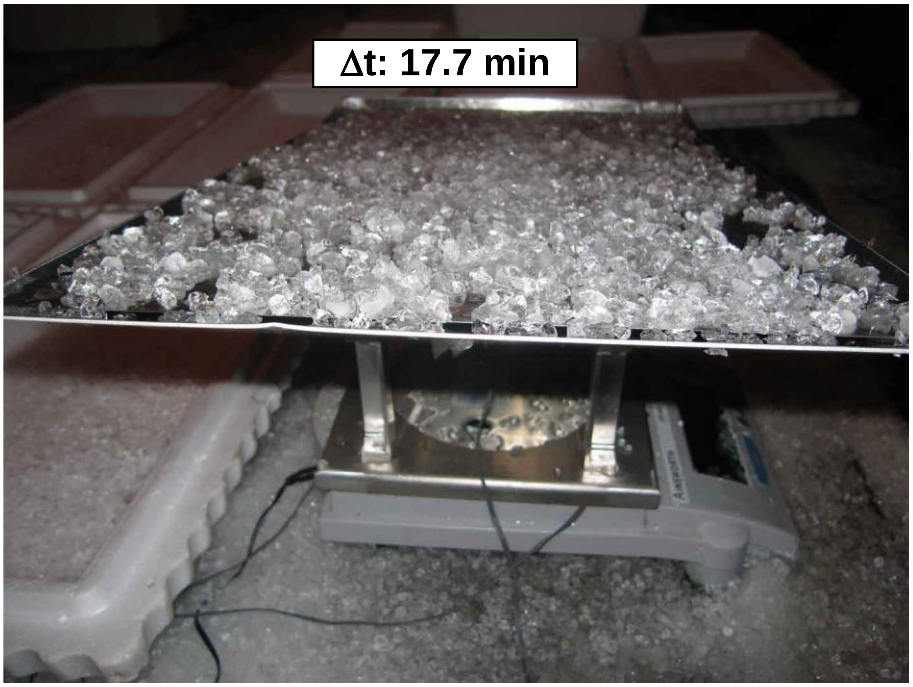


Photo 9.12: Adherence Test #10 – Photo 6 Type IV PG 50/50 Applied at 60°C, IP (4-5.8 mm, ≈ 25 g/dm^2/h), -3°C

Photo 9.13: Adherence Test #10 – Photo 7 Type IV PG 50/50 Applied at 60°C, IP (4-5.8 mm, ≈ 25 g/dm²/h), -3°C

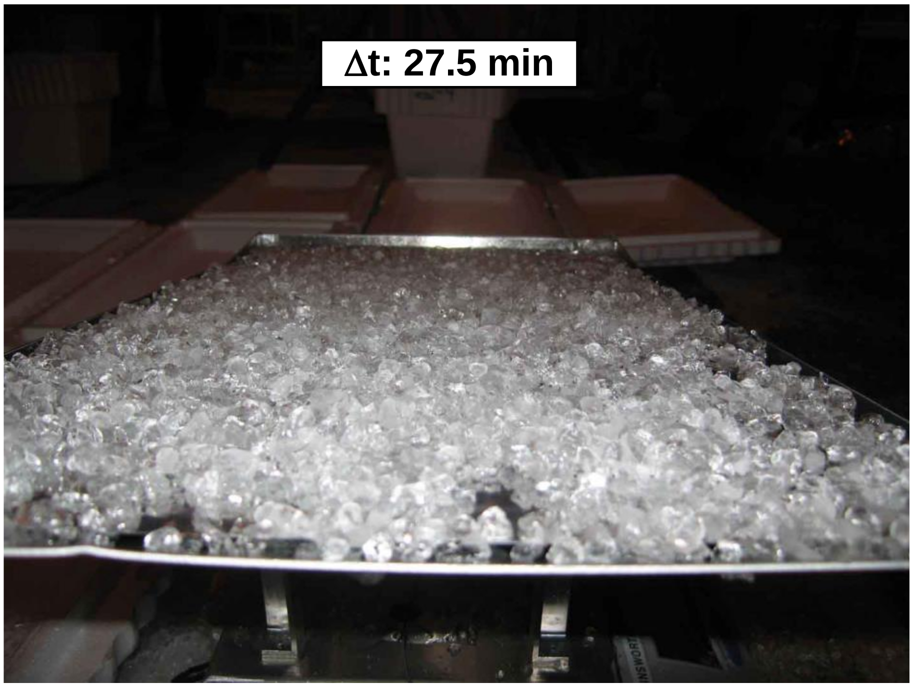


Photo 9.14: Adherence Test #10 – Photo 8 Type IV PG 50/50 Applied at 60°C, IP (4-5.8 mm, ≈ 25 g/dm²/h), -3°C

Photo 9.15: Adherence Test #22 – Photo 1 Type IV EG 75/25 Applied at OAT, ZR & IP (2-4 mm, ≈ 25 g/dm²/h), -10°C

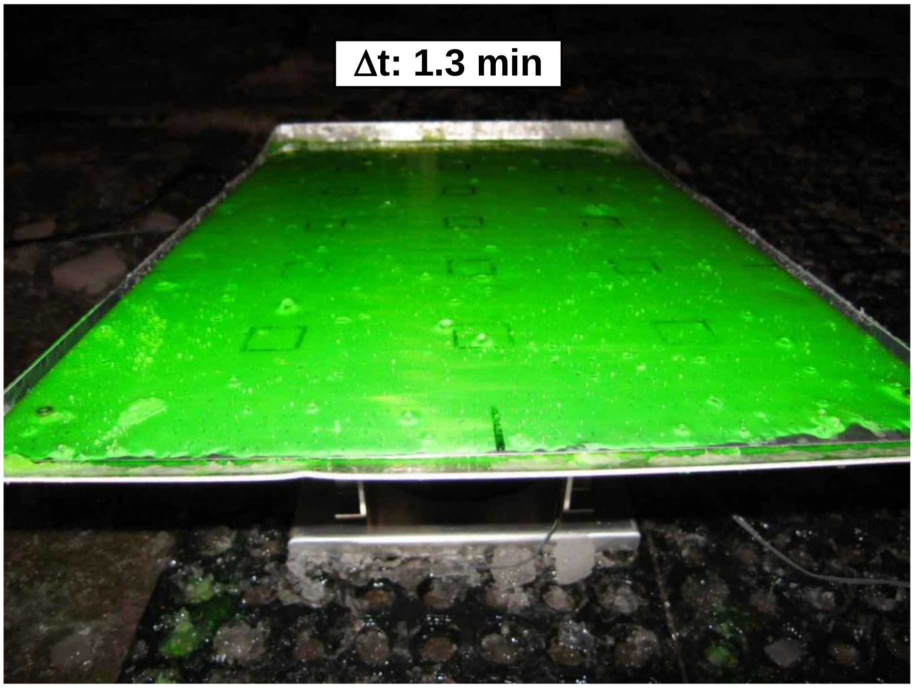


Photo 9.16: Adherence Test #22 – Photo 2 Type IV EG 75/25 Applied at OAT, ZR & IP (2-4 mm, ≈ 25 g/dm²/h), -10°C

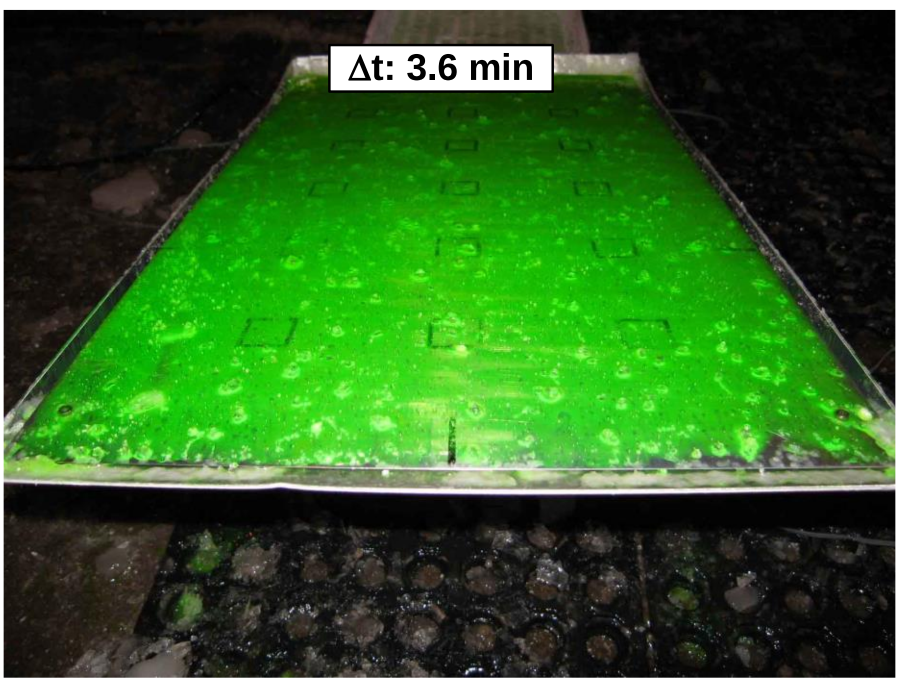


Photo 9.17: Adherence Test #22 – Photo 3 Type IV EG 75/25 Applied at OAT, ZR & IP (2-4 mm, ≈ 25 g/dm²/h), -10°C

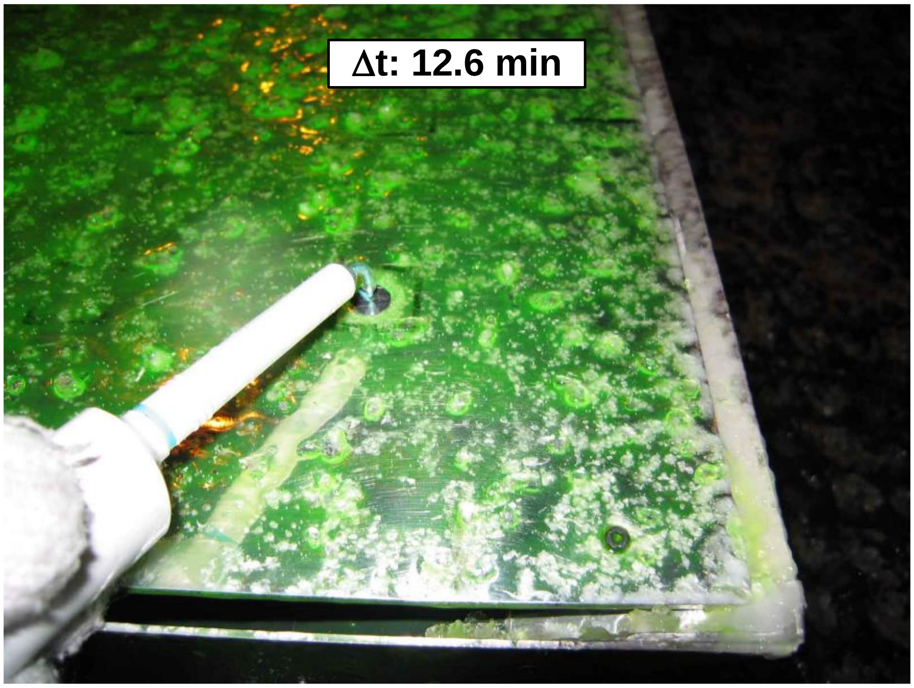


Photo 9.18: Adherence Test #22 – Photo 4 Type IV EG 75/25 Applied at OAT, ZR & IP (2-4 mm, ≈ 25 g/dm²/h), -10°C

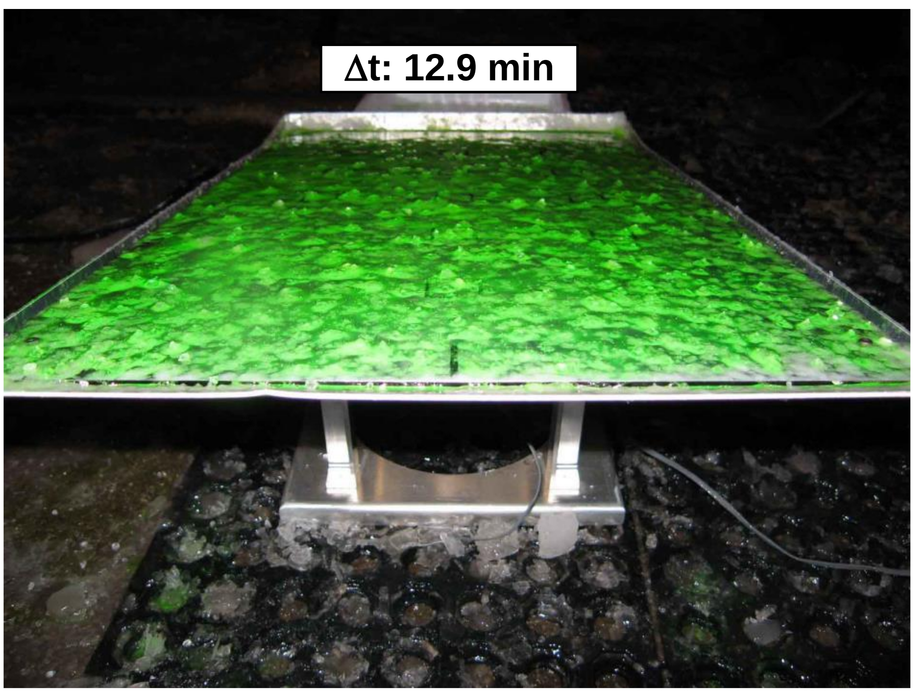


Photo 9.19: Adherence Test #22 – Photo 5 Type IV EG 75/25 Applied at OAT, ZR & IP (2-4 mm, ≈ 25 g/dm²/h), -10°C

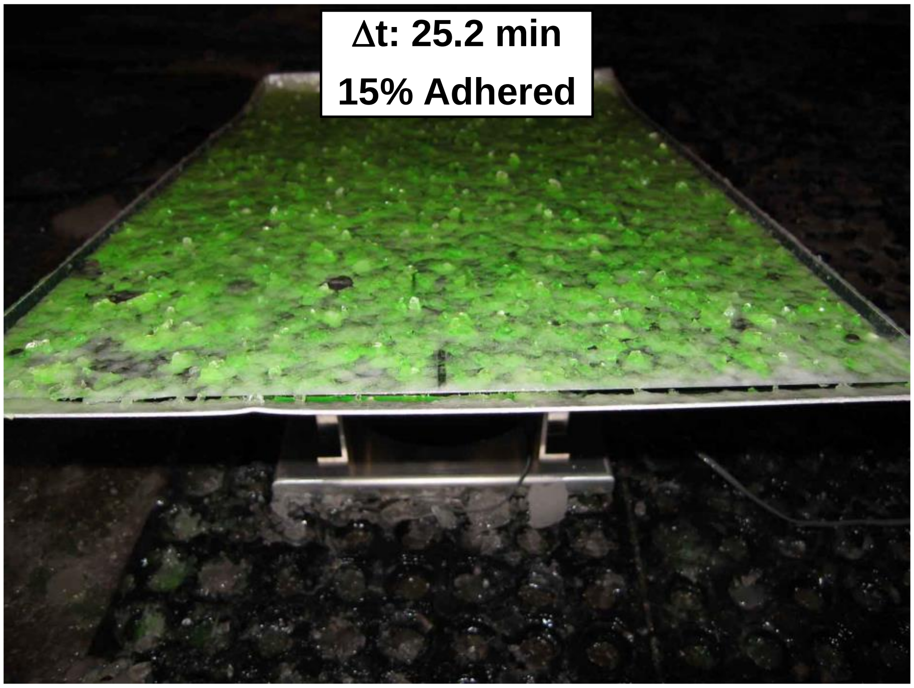


Photo 9.20: Adherence Test #22 – Photo 6 Type IV EG 75/25 Applied at OAT, ZR & IP (2-4 mm, ≈ 25 g/dm²/h), -10°C

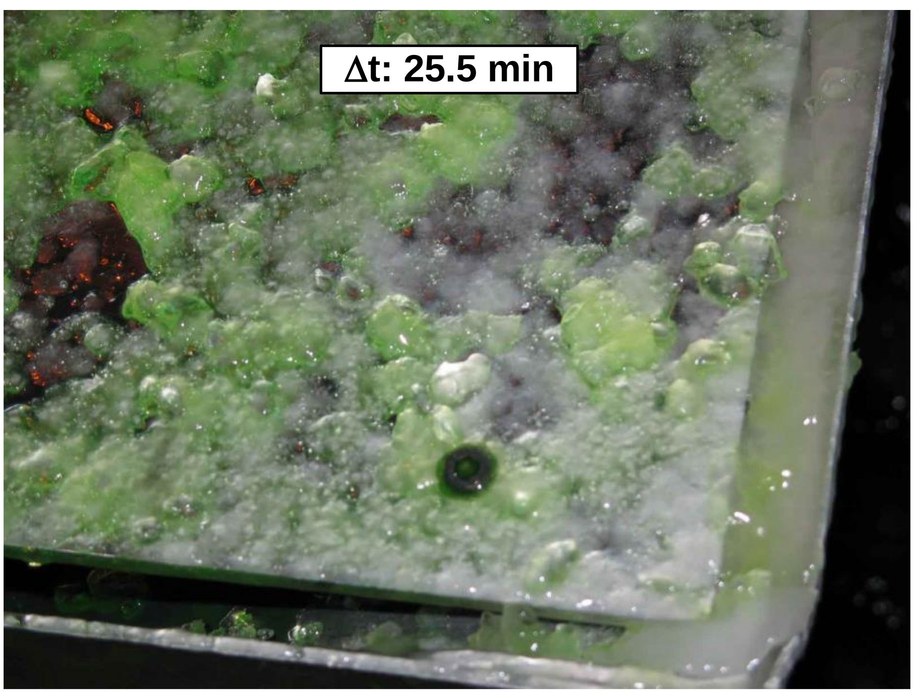


Photo 9.21: Adherence Test #22 – Photo 7 Type IV EG 75/25 Applied at OAT, ZR & IP (2-4 mm, ≈ 25 g/dm²/h), -10°C

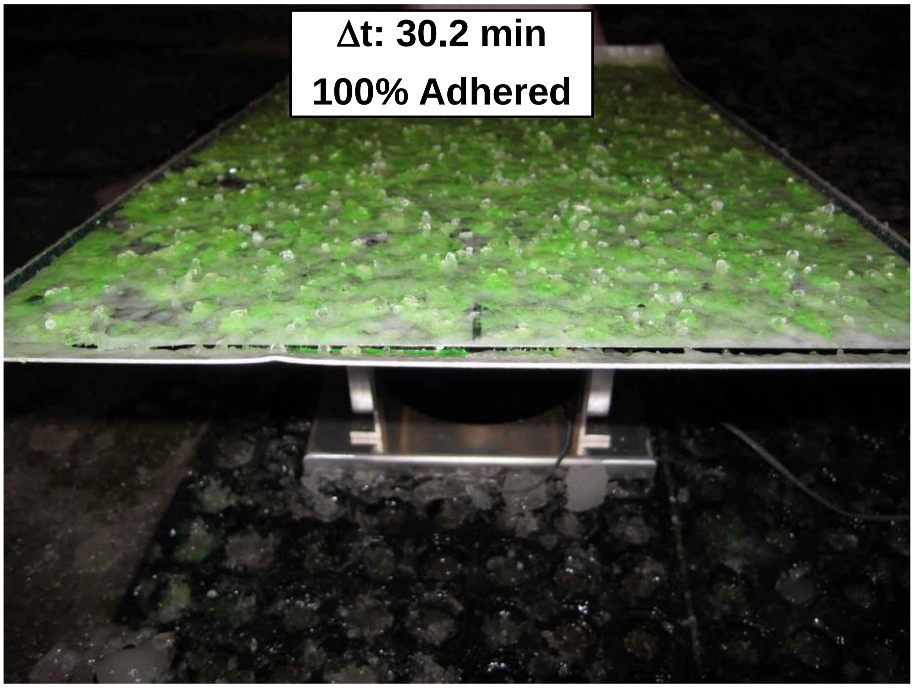
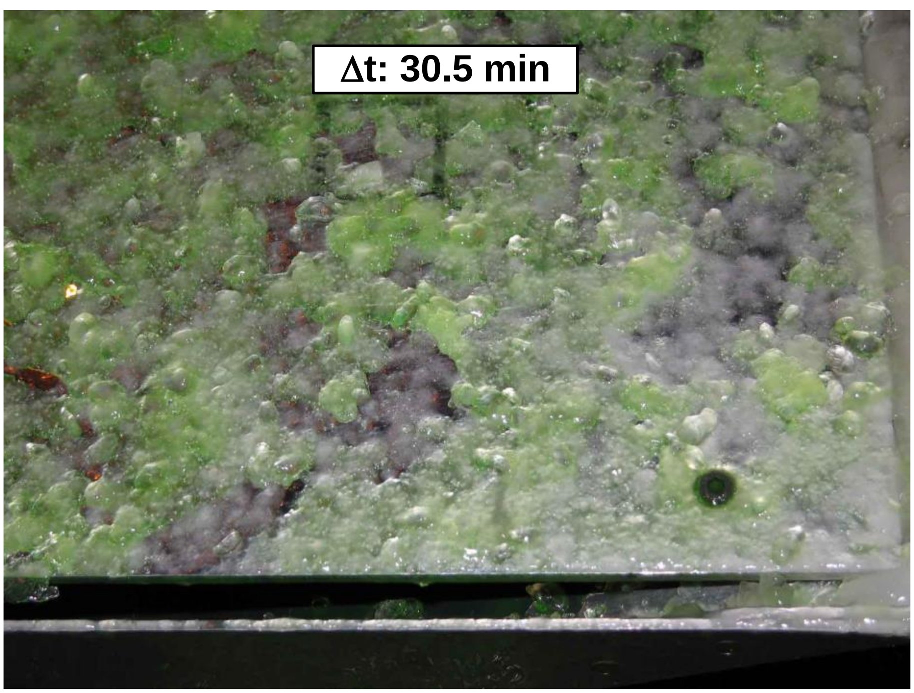


Photo 9.22: Adherence Test #22 – Photo 8 Type IV EG 75/25 Applied at OAT, ZR & IP (2-4 mm, ≈ 25 g/dm²/h), -10°C



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10. CONCLUSIONS

The conclusions drawn from the testing are described in this section.

10.1 Natural Ice Pellet Research

The diameter of the natural ice pellets collected generally ranged from 1 to 3 mm. During severe ice pellet events, the ice pellet diameters measured up to 5 mm. The overall MVD for the samples collected was calculated to be 2.7 mm. Ice pellets are a transitional condition and therefore may occur in conjunction with freezing rain or drizzle, which may be conducive to fluid adhesion. During endurance time testing conducted in natural ice pellet conditions, fluid failure was difficult to determine, much like in simulated ice pellet endurance time tests. The condition and appearance of the fluid was similar in both the natural and simulated endurance time tests.

METAR weather reports did not always indicate the presence of ice pellets during mixed precipitation conditions.

10.2 Ice Precipitation Dissolving Time Research

Results demonstrated that snow requires a shorter amount of time, (generally 3 to 4 times shorter) to fully dissolve in the deicing fluid in comparison with the ice pellets. The operational significance of this conclusion is that the condition of the fluid is more “slushy” and diluted in snow conditions versus ice pellet conditions; the porous properties of snow allow it to absorb the fluid resulting in a rapid dissolving period.

The dissolving time of simulated ice pellets was comparable to that of natural ice pellets. The simulated ice pellets were deemed a suitable and representative substitute for natural ice pellets for endurance time testing.

10.3 Far vs. Near – Perspective Photo Documentation

Ice pellets are translucent, and as a result, are difficult to see when embedded in aircraft deicing fluid. It was observed that ice pellets became increasingly difficult to see as the distance from the test surface increased. When bridging ice pellets became visible from far, the fluid condition had already become severe.

10.4 Falcon 20 Full-Scale Research

For both EG and PG Type IV fluids, the airflow at takeoff removed ice pellet contaminated anti-icing fluid from the leading edge, leaving only a very thin film of fluid even at very high precipitation rates. In one case, at a very high precipitation rate (effective rate of 136 g/dm^2/h), the entire 24 seconds of the takeoff run were required to clear the leading edge of any precipitation. In this case some contamination (up to 1 mm) remained on the trailing edge.

A test with Type I EG fluid showed some adhesion of ice to the wing surface following the transfer of heat from the heated fluid to the cold wing surface. The fluid application method was not representative of actual operations. A normal deicing may transfer more heat, which would likely increase melting of the ice pellets and lead to greater adhesion.

10.5 Bare Wing Departures during Ice Pellet Conditions

Ice pellet conditions mixed with freezing rain or drizzle may be conducive to a rough adhesion of the precipitate to the surface that will likely not come off at the time of rotation.

10.6 Adherence Testing in Simulated Ice Pellet Conditions

Adherence was observed during Type II, III and IV fluid endurance time testing conducted in mixed ice pellet and freezing rain/drizzle conditions. During these tests, the ice pellets were observed to delay the time of adherence by preventing the freezing rain/drizzle from penetrating the fluid. Adherence was also observed during testing conducted with Type I heated fluid during ice pellet conditions; however, testing conducted using Type II, III and IV fluids in ice pellet conditions alone did not demonstrate any signs of adherence.

10.7 Operational Significance of Results

The natural ice pellet research demonstrated that the diameter of ice pellets will generally vary between 1 to 3 mm, and sometimes up to 5 mm. It is not yet known which size generates a worse-case condition considering larger pellets have more momentum and are likely to penetrate the fluid, whereas smaller pellets are likely to dissolve quicker, diluting the fluid to the freeze point earlier.

Fluid adherence was not observed during testing with Type IV fluids in ice pellet conditions alone; however, the occurrence of mixed precipitation (ice pellets mixed with freezing rain or drizzle) can cause fluid adherence. The freezing rain or drizzle will penetrate the fluid and adhere to the aircraft surface once the fluid has sufficiently diluted. The presence of bridging ice pellets may delay the occurrence of adherence by preventing the freezing rain from penetrating the fluid. An unprotected aircraft surface in such conditions will be conducive to a rough adhesion of the precipitate to the surface, which is not likely to come off at rotation. It is not yet known which level of mixed precipitation contamination will cause significant lift loss.

Full-scale research was aimed at investigating the effect of ice pellet conditions (no mixed conditions) on the fluid removed at takeoff. The results showed that the contaminated fluid was completely removed during light levels of ice pellet contamination. The use of Type I fluid during one test demonstrated signs of adherence, which did not come off at the time of rotation (similar adherence results were also seen during the Type I endurance time tests).

The research indicated that ice pellet conditions alone were not a severe threat to aircraft safety; however, the occurrence of mixed precipitation could possibly create safety hazards. As a result, guidance material was provided to operators for ice pellet conditions only and was followed by a list of restrictions based on the preliminary data collected. The restrictions, based on the limited research data collected, included aircraft type, rotation speed, OAT, anti-icing fluid, and precipitation intensity, among others.

Future work was recommended to investigate the implications of mixed precipitation, specifically mixed ice pellet and freezing rain conditions. Endurance time testing as well as wind tunnel, and full-scale aircraft research are scheduled during the winter of 2006-07 with the aim of providing insight on the severity of the mixed precipitation conditions. The objective is to provide guidance material that will allow aircraft to operate efficiently in ice pellet conditions.

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11. RECOMMENDATIONS

The FAA issued the following operational recommendations for use with aircraft with rotation speeds in excess of 100 knots. Although testing was aimed at validating a 20-minute allowance time, guidance material was issued for 25 minutes; 20 minutes with an additional 5 minutes to include the pre-takeoff contamination inspection. It should be noted that TC did not issue the recommendation but remained status-quo until further research is conducted.

11.1 25 Minute Allowance Time

The following 25-minute allowance time recommendation was issued by the FAA and documented in the *FAA-Approved Deicing Program Updates, Winter 2006-2007*:

"Tests have shown that ice pellets generally remain in the frozen state imbedded in Type IV anti-icing fluid, and are not absorbed by the fluid in the same manner as other forms of precipitation. Using current guidelines for determining anti-icing fluid failure, the presence of a contaminant not absorbed by the fluid (remaining imbedded) would be an indication that the fluid has failed. These imbedded ice pellets are generally not detectable by the human eye during pre-takeoff contamination check procedures. Therefore, a pre-takeoff contamination check in light ice pellet conditions would not be of value and is not required.

These tests have also shown that after proper deicing and anti-icing, the accumulation of light ice pellets in Type IV fluid will still shear from the aerodynamic surfaces during takeoff. This sheering occurs with rotation speeds consistent with Type IV recommended applications for up to 25 minutes from the start of the Type IV anti-icing fluid application.

Operators with a deicing program approved in accordance with Title 14 of the Code of Federal Regulations (14 CFR) part 121, section 121.629, will be allowed, in light ice pellet conditions with no other form of precipitation present, up to 25 minutes after the start of the anti-icing fluid application to commence the takeoff with the following restrictions:

- *The aircraft critical surfaces must be free of contaminants, or the aircraft be properly deiced prior to the application of the anti-icing fluid.*
- *This allowance time, of up to 25 minutes, is valid only if the aircraft is anti-iced with undiluted Type IV fluid.*
- *Due to the shear qualities of Type IV fluids with imbedded ice pellets, this allowance is limited to aircraft with a rotation speed of 100 knots or greater.*

- *If the takeoff is not accomplished within the 25 minutes allowed, the aircraft must be completely deiced, and if precipitation is still present, anti-iced again prior to a subsequent takeoff.*
- *A pre-takeoff contamination check is not required. The allowance time of up to 25 minutes cannot be extended by an internal or external check of the aircraft critical surfaces.*
- *If ice pellet precipitation becomes heavier than light or is mixed with any other form of precipitation, the 25-minute allowance time cannot be used."*

11.2 Future Work

Further research and testing will be required to provide more detailed guidance material for ice pellet conditions. The following research will be conducted during the winter of 2006-07:

- Endurance time testing in mixed ice pellet/freezing rain conditions;
- Endurance time testing in mixed ice pellet/snow conditions;
- Endurance time testing using small and large diameter ice pellets;
- Wind tunnel tests to examine fluid removed from aircraft during takeoff with mixed ice pellet precipitation; and
- Full-Scale Falcon 20 tests to examine fluid removed from aircraft during takeoff with mixed ice pellet precipitation.

REFERENCES

1. Ruggi, M., *Preliminary Endurance Time Testing in Simulated Ice Pellet Conditions,* APS Aviation Inc., Transportation Development Centre, Montreal, February 2006, TP 14718E, XX (to be published).

2. Balaban, G., *Falcon 20 Trials To Examine Fluid Removed From Aircraft During Takeoff With Ice Pellets,* APS Aviation Inc., Transportation Development Centre, Montreal, December 2006, TP 14716E, XX (to be published).

3. Moc, N., *Adhesion of Aircraft Anti-Icing Fluids on Aluminum Surfaces,* APS Aviation Inc., Transportation Development Centre, Montreal, December 2004, TP 14377E, XX (to be published).

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APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE WORK STATEMENT EXCERPT – AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2005-06

TRANSPORTATION DEVELOPMENT CENTRE WORK STATEMENT EXCERPT – AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2005-06

5.2 FLUID PERFORMANCE RESEARCH

5.2.1 Inclusion of Ice Pellets in Holdover Time Guidelines

a) Characterization of Ice Pellets vs. Snow: Review preliminary research and compare the results with the historical HOT data collected by APS to attempt to characterize fluid failure during ice pellet conditions. Conduct additional comparative testing of dissolving time of ice pellets and snow at a cold chamber during simulated snow and simulated ice pellet conditions;

b) Natural Ice Pellet Tests: Conduct natural ice pellet holdover time tests to validate the data collected during simulated ice pellet conditions, and to measure the endurance times of selected deicing fluids;

c) Video and Photographic Documentation: Video and photograph natural ice pellet events to document size, shape, and rate of precipitation of natural ice pellets. Capture simultaneous videos, from different perspectives, of an airfoil subject to ice pellets (either natural or simulated); videos should be taken with a high definition video camera;

d) Adhesion of ice pellets: Investigate if endurance time testing during ice pellet conditions will demonstrate signs of fluid adhesion to aluminum test surfaces. Measure adhesion subject to simulated ice pellet testing; and

e) Analyse data and prepare report.

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APPENDIX B

PROCEDURE:
PHOTOGRAPHY OF ICE PELLETS ON BLACK FELT

CM (TC-Deicing 05-06)

PROCEDURE
PHOTOGRAPHY OF ICE PELLETS ON BLACK FELT

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: David Youssef

Reviewed by: John D'Avirro

December 22, 2005
Version 3.0

PHOTOGRAPHY OF ICE PELLETS ON BLACK FELT

1. BACKGROUND

Visual fluid failure determination in ice pellet conditions was found to be a challenge, as it can vary based on location from the affected area and the observers angle of incidence. Also, while ice pellets embedded in the fluid were not adhering, it is not known whether this contamination in the fluid would come off during aircraft rotation.

Among other tasks, it was recommended that fluid failure during ice pellet conditions be characterized. The characterization should be done similarly to that of failure of fluid in snow conditions. This would enable comparison of the end condition in ice pellets to the long used end condition in snow.

In an attempt to better understand the issues described above, a series of five procedures using both photography and videography will be developed for testing in ice pellet conditions.

1. Video Documentation of Pilot's Perspective in Ice Pellets;

2. Melting Time Indoors: Video Documentation of Simulated Snow and Ice Pellets Dissolving in Fluid;

3. Melting Time Outdoors: Video Documentation of Ice Pellets and Snow Dissolving in Fluid;

4. Photography of Ice Pellets on Black Felt;

5. Endurance Time Testing in Natural Ice Pellets.

In addition to the above five procedures, other procedures may be developed for the ongoing study of ice pellets.

This procedure, *Photography of Ice Pellets on Black Felt,* is described in this document; the other procedures are described in separate documents.

2. OBJECTIVES

Using still photography, document detailed characteristics of ice pellets in a natural environment; specifically their size, diameter distribution, and appearance.

Testing will be conducted primarily at the APS test site, located at Pierre Elliot Trudeau Airport during natural ice pellet conditions. APS personnel regardless of location may collect additional data.

3. SETUP

The setup will require a black felt surface measuring approximately 30 cm x 30 cm. To properly collect the ice pellets and to prevent pellets from bouncing out, a 10 cm edge will be included (see Figure 3.1). In the centre will be an affixed 15 cm ruler, used to measure the size of the natural ice pellets accumulating on the felt surface. An APS employee will use a hand-held digital camera to capture the ice pellet precipitation on the felt surface. The professional photographer will capture high-resolution images. A sample size will consist of 40 to 50 ice pellets. Once images are downloaded to a computer, APS staff will be able to properly zoom in to capture the data as needed.

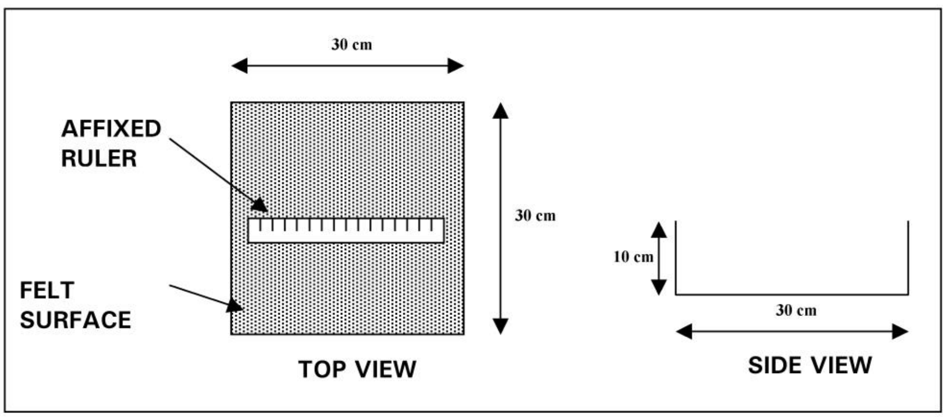

Figure 3.1: Setup Diagram for Photography

4. LIGHTING CONDITIONS

Lighting conditions that enable the best possible detail to be drawn out of the images should be created. A flash photography camera may be used.

5. PROCEDURE

1. Synchronize the date and time on the camera to local time;
2. Affix ruler to felt surface;
3. Measure intensity of precipitation (see Section 6) and other environmental conditions.
4. Expose felt surface to natural ice pellet conditions;
5. Capture images of felt surface with 40-50 ice pellet samples and download to PC for analysis; and
6. Complete data form and submit with pictures for analysis.

6. INTENSITY OF PRECIPITATION

The intensity shall be measured using the following methods:

Method 1: The time that the black felt is exposed to the precipitation shall be measured in hr:min:sec. The intensity will be estimated based on the view of the photograph and sizes of the ice pellets. Ensure start and end time of exposure of felt is entered in Attachment I.

Method 2: The standard measurement method used for endurance time testing shall be used if a weigh scale is available. Use the data form in Attachment II to measure the intensity. Expose the standard plate pans (numbers 1 and 2) just prior to exposing the black felt, and then bring in Pan 1 within a minute or two after the felt has been exposed. Bring in Pan 2 about 5 minutes after the felt was exposed. Pan 2 is used to supplement the measurement from Pan 1.

Method 3 Using the test surface itself, measure its weight “dry” before exposure to ice pellets, and then again after to calculate rate of precipitation.

7. PERSONNEL

The services of a professional photographer will be retained, as well as an APS employee for events in which the photographer could not be available.

8. EQUIPMENT

Three equipment sets will be made up and distributed to the:

- Program Manager;
- Designated APS Employee; and
- Professional Photographer.

Two equipment sets will be made up and kept ready at the:

- APS Downtown Office; and
- APS Test Site.

Equipments Sets will be made up of the following:

- Test Surface with Black Felt;
- Affixed Ruler;
- Weigh Scale if available;
- Digital Camera; and
- Data Forms.

9. DATA FORMS

The Photography of Ice Pellets On Black Felt data form and the Meteo/Precipitation Rate data form will be included in every equipment set (see Attachments I and II). These will be used to log relevant information to the ice pellet event.

ATTACHMENT I
Photography of Ice Pellets on Black Felt Data Sheet (for each sample)

Name of Photographer	
Date	
Location	
Approx. OAT	
Start Time of Precipitation	
End Time of Precipitation	

Photograph Number	Time	Observations

Note: After completion, please submit this form to office, including documented photos.

M:\Groups\CM (TC-Deicing 05-06)\Procedures\Data Forms\Photography of IP on Felt

Comments

Name

Signature

ATTACHMENT II: Meteorological and Precipitation Rate Data Form

REMEMBER TO SYNCHRONIZE TIME WITH MSC - USE LOCAL TIME

LOCATION: DATE: RUN # : STAND # :

HAND HELD VIDEO CASSETTE #:

PLATE PAN WEIGHT MEASUREMENTS *

PAN #	t TIME BEFORE (h:min:s)	BUFFER TIME (s)	t TIME AFTER (h:min:s)	BUFFER TIME (s)	w WEIGHT BEFORE (g)	w WEIGHT AFTER (g)	COMPUTE RATE ($\Delta w*4.3/\Delta t$) ($g/dm^2/h$)	WIND SPEED** (km/h)	WIND DIR*** (°)

* Measurements every 10 min. and at failure time of each test panel.
** Wind speed measurements required every time the precipitation rate is measured and only if data not available from MSC
*** Wind direction shall be recorded at least every 15 minutes.

METEO OBSERVATIONS ****

TIME (h:min)	TYPE (Table 1) ZR, ZL, S, SG, IP, IC, RAIN	CLASSIF. (See snow classification diagram.)	If SNOW, WET or DRY

**** Observations at beginning, end, and every 10 min. intervals. Additional observations when there are significant changes.

AIR TEMPERATURE AT START OF TEST ________ °C

WIND DIRECTION AT START OF TEST ________ °

TEST STAND ORIENTATION
(measured along long axes of the test panels) ________

COMMENTS : ________

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

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APPENDIX C

PROCEDURE:
ENDURANCE TIME TESTING IN NATURAL ICE PELLETS

CM (TC-Deicing 05-06)

PROCEDURE
ENDURANCE TIME TESTING IN NATURAL ICE PELLETS

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: David Youssef

Reviewed by: John D'Avirro

December 19, 2005
Version 1.0

ENDURANCE TIME TESTING IN NATURAL ICE PELLETS

1. BACKGROUND

Visual fluid failure determination in ice pellet conditions was found to be a challenge, as it can vary based on location from the affected area and the observers angle of incidence. Also, while ice pellets embedded in the fluid were not adhering, it is not known whether this contamination in the fluid would come off during aircraft rotation. As a result, the FAA have issued a notice that prevents operations from departing in ice pellet conditions.

In an attempt to better understand the issues described above, a series of procedures using both photography and videography will be developed for testing in ice pellet conditions. During the course of the winter season, more procedures may be developed based upon results from initial testing and discussions with the industry.

1. Video Documentation of Pilot's Perspective in Ice Pellets;
2. Dissolving Time Indoors: Video Documentation of Simulated Snow and Ice Pellets Dissolving in Fluid;
3. Dissolving Time Outdoors: Video Documentation of Ice Pellets and Snow Dissolving in Fluid;
4. Photography of Ice Pellets on Black Felt; and
5. Endurance Time Testing in Natural Ice Pellets.

In addition to the above five procedures, other procedures may be developed for the ongoing study of ice pellets.

This procedure, *Endurance Time Testing in Natural Ice Pellets,* is described in this document; the other procedures are described in separate documents.

2. OBJECTIVES

It was recommended that natural ice pellet endurance time data be collected to validate the results obtained using simulated ice pellets.

Tests will be conducted at the APS test site adjacent to Meteorological Services of Canada at Trudeau Airport.

3. TEST REQUIREMENTS

The test plan, shown in Table 3.1 provides the temperature and requirements for fluid type testing.

Table 3.1: Ice Pellet Precipitation Test Plan

Temperature Range	Type II/IV Neat	Type II/IV 75/25	Type II/IV 50/50	Type III
Above -3°C	Yes	Yes	Yes	Yes
-3 to -14°C	Yes	Yes	No	Yes
-14 to -25°C	Yes	No	No	Yes
Below -25°C	Yes	No	No	Yes

4. SETUP AND PROCEDURES

The procedure, *Test Requirements for Natural Precipitation Flat Plate Testing*, December 23, 2004, provides a brief summary of the test requirements and data forms needed for natural precipitation flat plate tests in the 2004-05 winter season. The procedure containing a detailed description of the test parameters, snow measurement methods, testing procedure and test equipment for conducting endurance time tests for SAE Type II, III and IV de/anti-icing fluids is stored on APS's local network and can be found at the following location: M:\Groups\CM1892 (TC-Deicing 03-04)\Procedures\AS5485\.

This document is based on the aforementioned procedure. It was developed for documentation purposes, to be inserted in the final report after the completion of endurance time testing, and to provide the latest data forms.

5. PROCEDURAL DIFFERENCES FROM NATURAL SNOW

5.1 Photography

- Photograph entire test from beginning of application to end of test every one or two minutes (for long tests, greater than one hour, every five minutes);

- Three photos should be taken, one from the back of the plate at approximately 20° to horizontal, one from the front of the plate at approximately 20° to horizontal, and one perpendicular; and
- Attempt to position camera in the same positions for all tests.

5.2 Surface Temperature

Test surface temperature logging is to be implemented using one thermistor probe mounted at the 15 cm (6") line. The connection will be designed to last for the entire test season and to not impede the fluid flow. A SmartReader Eight-Channel temperature logger will be used to measure and record temperature. This temperature logger will run continuously and is independent of any external power supply or computer; the logger constantly measures and records readings from any enabled channels. The sampling rate (i.e. how often the logger takes readings) will be set to eight seconds, the smallest possible increment.

5.3 Fluid Dilution

Fluid dilution will be measured at the 15 cm (6") line, using a Misco 10431VP brixometer. These measurements determine the concentration of the fluid on the test surface before and after fluid failure. The initial Brix value will be measured in the container before pouring. The second measurement will be taken right after pouring on the test surface, and typically a few more times until the fluid fails. After significant fluid contamination the dilution measurements will be conducted every 10 minutes. Brix values and corresponding sample times should be recorded on the Brix/Thickness Data Form (Attachment I).

5.4 Fluid Thickness

Fluid thickness measurements should be taken at the start of the test (right after pouring) and every five minutes thereafter. Thickness measurements and times should be noted on the Brix/Thickness data form (Attachment 1). Fluid thickness will be measured with wet film thickness gauges at the 15 cm (6") line.

6. FLUIDS

Since early work was done with Dow UCAR Ultra + and Octagon MaxFlo, the same fluids will be used. Some tests with Diluted (75/25 and 50/50) MaxFlo will also be attempted.

7. TEST PLAN

The following tests will be conducted simultaneously (Figure 7.1).

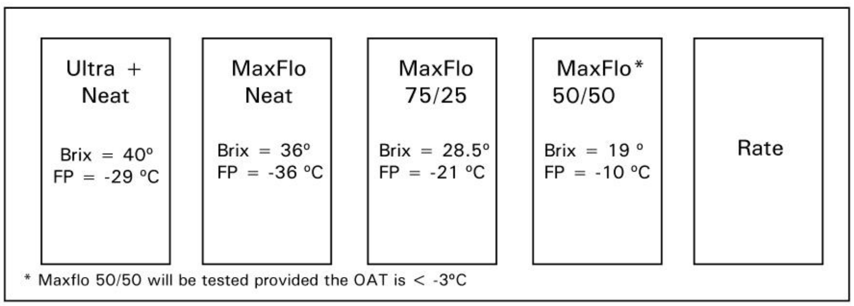

Figure 7.1: Fluids To Be Tested

8. DATA FORMS

The data forms are included in Attachments to III. Attachment I shows the data form developed for the end-condition tester. Attachment II shows the data form for the meteo/video tester. Attachment III shows the fluid Brix and thickness data form.

Attachment I: End Condition Data Form for Natural Snow

LOCATION: DATE: RUN NUMBER: STAND #:

TIME TO FAILURE FOR INDIVIDUAL CROSSHAIRS (real time)

Time of Fluid Application:

Initial Plate Temperature (°C)

Initial Fluid Temperature (°C)

	Plate 1	Plate 2	Plate 3	Plate 4	Plate 5	Plate 6
FLUID NAME/DILUTION						
B1 B2 B3						
C1 C2 C3						
D1 D2 D3						
E1 E2 E3						
F1 F2 F3						
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA						

Time of Fluid Application:

Initial Plate Temperature (°C)

Initial Fluid Temperature (°C)

	Plate 7	Plate 8	Plate 9	Plate 10	Plate 11	Plate 12
FLUID NAME/DILUTION						
B1 B2 B3						
C1 C2 C3						
D1 D2 D3						
E1 E2 E3						
F1 F2 F3						
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA						

AMBIENT TEMPERATURE: _______ °C

NOTE: PLEASE ENSURE CORRECT FUNCTIONING OF PLATE TEMPERATURE LOGGING SYSTEM AT START OF TEST. AT THE END OF TEST SESSION, SAVE THE ELECTRONIC LOGGER FILE ON A FLOPPY DISK AND ALSO E-MAIL IT TO THE OFFICE. LABEL THE DISKETTE AND PLACE IT WITHIN THE DATA FORM ENVELOPE.

COMMENTS:

FAILURES CALLED BY:

LEADER / MANAGER:

Attachment II: Meteorological and Precipitation Rate Data Form

LOCATION: DATE: RUN #: STAND #:

HAND HELD VIDEO CASSETTE #:

PLATE PAN WEIGHT MEASUREMENTS *

PAN #	TIME BEFORE (h:min:s)	BUFFER TIME (s)	TIME AFTER (h:min:s)	BUFFER TIME (s)	WEIGHT BEFORE (g)	WEIGHT AFTER (g)	COMPUTE RATE (g/dm²/h)	WIND SPEED** (km/h)	WIND DIR** (°)

METEO OBSERVATIONS ***

TIME (h:min)	TYPE	CLASSIF.	If SNOW, WET or DRY

AIR TEMPERATURE AT START OF TEST _______ °C

WIND DIRECTION AT START OF TEST _______ °

TEST STAND ORIENTATION (measured along long axis of the test panels)

COMMENTS:

WRITTEN & PERFORMED BY:

VIDEO BY:

TEST SITE LEADER:

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ATTACHMENT III
FLUID BRIX/THICKNESS DATA FORM

DATE: ______________ PERFORMED BY: ______________

RUN #: ______________ WRITTEN BY: ______________

STAND: ______________ LOCATION: ______________

Plate / BOX: Fluid:			Plate / BOX: Fluid:			Plate / BOX: Fluid:			Plate / BOX: Fluid:		
TIME	Brix at 15 cm Line	Thick. at 15 cm Line	TIME	Brix at 15 cm Line	Thick. at 15 cm Line	TIME	Brix at 15 cm Line	Thick. at 15 cm Line	TIME	Brix at 15 cm Line	Thick. at 15 cm Line

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APPENDIX D

PROCEDURE:
DISSOLVING TIME INDOORS: VIDEO DOCUMENTATION OF SIMULATED SNOW AND ICE PELLETS DISSOLVING IN FLUID

CM (TC-Deicing 05-06)

PROCEDURE
DISSOLVING TIME INDOORS: VIDEO DOCUMENTATION OF SIMULATED SNOW AND ICE PELLETS DISSOLVING IN FLUID

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: David Youssef

Reviewed by: John D'Avirro

December 12, 2005
Version 1.0

DISSOLVING TIME INDOORS: VIDEO DOCUMENTATION OF SIMULATED SNOW AND ICE PELLETS DISSOLVING IN FLUID

1. BACKGROUND

Visual fluid failure determination in ice pellet conditions was found to be a challenge, as it can vary based on location from the affected area and the observers angle of incidence. Also, while ice pellets embedded in the fluid were not adhering, it is not known whether this contamination in the fluid would come off during aircraft rotation. As a result, the FAA have issued a notice that prevents operations from departing in ice pellet conditions.

In an attempt to better understand the issues described above, a series of procedures using both photography and videography will be developed for testing in ice pellet conditions. During the course of the winter season, more procedures may be developed based upon results from initial testing and discussions with the industry.

1. Video Documentation of Pilot's Perspective in Ice Pellets;
2. Dissolving Time Indoors: Video Documentation of Simulated Snow and Ice Pellets Dissolving in Fluid;
3. Dissolving Time Outdoors: Video Documentation of Ice Pellets and Snow Dissolving in Fluid;
4. Photography of Ice Pellets on Black Felt;
5. Endurance Time Testing in Natural Ice Pellets.

In addition to the above five procedures, other procedures may be developed for the ongoing study of ice pellets.

This procedure, *Dissolving Time Indoors: Video Documentation of Simulated Snow and Ice Pellets Dissolving in Fluid*, is described in this document; the other procedures are described in separate documents.

In 2004-05, APS conducted tests to demonstrate a single snowflake and a single ice pellet dissolving in deicing fluid. Based on those 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 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 and continue this research.

2. OBJECTIVES

For comparison purposes, equal masses of both snow and ice pellet samples will be used to:

- Document the details of snow dissolving in different dilutions of deicing fluid; and
- Document the details of an ice pellet dissolving in different dilutions of deicing fluid.

Testing will be conducted in a cold chamber.

3. SETUP

The setup requires a micro lens camera to document the dissolving of snowflakes and an ice pellet in a deicing fluid bath. The camera will be required to video a 3 cm^2 area. The time stamped videos will later be edited to provide still shots at predetermined times during each test. Figure 3.1 demonstrates the side view setup required.

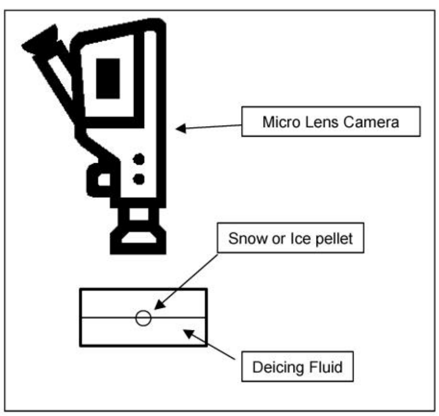

Figure 3.1: Side View of Micro Lens Setup

4. PROCEDURE

An appropriate weigh scale will be used to measure out equal masses of both snow and ice pellet samples. The samples will be dropped into 2 mm of deicing fluid at the chamber ambient temperature. Additional lighting should be used if lighting provided in the test chamber is insufficient.

As part of this procedure, time will be spent determining the best way to manipulate snow shavings to match closely the weight of ice pellets without drastically affecting the density. The first day of the test period will be spent investigating the following three options:

1. Snow shavings spread evenly across a surface and scraped into the fluid;
2. Snow shavings piled into one small area on a surface and dropped into the fluid; or
3. A small hollow tube filled with snow shavings, and dropped into the fluid.

The services of a professional videographer will be retained to collect video footage. Testing will be conducted in a cold chamber at an OAT of -3°C, and -9°C.

Two sizes of ice pellets will be examined:

- Small: 1 mm diameter (0.5 mg)
- Large: 5 mm diameter (65 mg)

The following procedure will be followed for both of the sizes when collecting footage:

1. Synchronize the date and time on the camera to local time;
2. Set up the camera according to Figure 1;
3. Weigh out appropriate sample of masses of snow and ice pellets; and
4. Video the following tests for both snow and ice pellets until all precipitation has dissolved. They will be prioritized as follows:

   Priority 1. Ultra+, Type I EG, five Dilutions (Neat to FFP @ -3°C)

   Priority 2. Type IV PG, five Dilutions (Neat to FFP @ -3°C)

   Priority 3. Ultra+, Type I, and Type IV PG, four Dilutions (Neat to FFP @ -9°C)

Time for each test will vary. Tests will be run back to back until all are completed. It is expected that snow tests will on average last between 10 and 20 minutes. Ice pellet tests can take up to one hour.

5. TIMING AND TEST PLAN

It is estimated that completion of the 108 tests outlined in Attachment I will take approximately 10 days (including setup). This is based on the maximum failure times of 20 and 60 minutes for snow and ice pellets, respectively.

Time may be shortened as not all tests will be run at a chamber temperature of -9°C; this will depend on the results of the -3°C tests.

It is anticipated that tests will be conducted in January 2006.

6. FLUIDS AND DILUTIONS

The fluids and dilutions listed in Attachment II will be used for the testing. The initial dilutions for each fluid were selected based upon the Neat formulations. Further dilutions will be tested for the freezing points of -29°C, -21°C, -10°C, and -4°C. The last dilution will not be tested at the chamber temperature of -9°C.

7. PERSONNEL

A minimum of two individuals will be required to obtain the video footage: a professional videographer and an individual to coordinate the video shots.

8. DATA FORMS

A Snow and Ice Pellet Dissolving Time Data Sheet will be used to document results pertaining to each fluid used. Refer to Attachment III.

DISSOLVING TIME INDOORS: VIDEO DOCUMENTATION OF SIMULATED SNOW & ICE PELLETS DISSOLVING IN FLUID

Table 1: Test Plan

Test Number	Chamber Temperature °C	Precip. Type	Fluid Name	Dilution	Maximum Expected Time to Dissolve (minutes)	Brix °	FFP °C
1	-3	IP (1mm)	Ultra+ (Type IV)	100/0	60	40	<-59
2	-3	IP (1mm)	Ultra+ (Type IV)	n/a	60	27.5	-29
3	-3	IP (1mm)	Ultra+ (Type IV)	n/a	60	23.5	-21
4	-3	IP (1mm)	Ultra+ (Type IV)	n/a	60	15.5	-10
5	-3	IP (1mm)	Ultra+ (Type IV)	n/a	60	8.5	-4
6	-3	IP (1mm)	MaxFlo (Type IV)	100/0	60	36	**-36**
7	-3	IP (1mm)	MaxFlo (Type IV)	90/10	60	**33**	**-29**
8	-3	IP (1mm)	MaxFlo (Type IV)	75/25	60	28.5	**-21**
9	-3	IP (1mm)	MaxFlo (Type IV)	50/50	60	19	**-10**
10	-3	IP (1mm)	MaxFlo (Type IV)	25/75	60	**10**	**-4**
11	-3	IP (1mm)	UCAR ADF (Type I)	57/43	60	34	<-40
12	-3	IP (1mm)	UCAR ADF (Type I)	45/55	60	27.5	-29
13	-3	IP (1mm)	UCAR ADF (Type I)	37/63	60	23	-21
14	-3	IP (1mm)	UCAR ADF (Type I)	22/78	60	14	-10
15	-3	IP (1mm)	UCAR ADF (Type I)	n/a	60	**6**	-4
16	-3	IP (5mm)	Ultra+ (Type IV)	100/0	60	40	<-59
17	-3	IP (5mm)	Ultra+ (Type IV)	n/a	60	27.5	-29
18	-3	IP (5mm)	Ultra+ (Type IV)	n/a	60	23.5	-21
19	-3	IP (5mm)	Ultra+ (Type IV)	n/a	60	15.5	-10
20	-3	IP (5mm)	Ultra+ (Type IV)	n/a	60	8.5	-4
21	-3	IP (5mm)	MaxFlo (Type IV)	100/0	60	36	**-36**
22	-3	IP (5mm)	MaxFlo (Type IV)	90/10	60	**33**	**-29**
23	-3	IP (5mm)	MaxFlo (Type IV)	75/25	60	28.5	**-21**
24	-3	IP (5mm)	MaxFlo (Type IV)	50/50	60	19	**-10**
25	-3	IP (5mm)	MaxFlo (Type IV)	25/75	60	**10**	**-4**
26	-3	IP (5mm)	UCAR ADF (Type I)	57/43	60	34	<-40

DISSOLVING TIME INDOORS: VIDEO DOCUMENTATION OF SIMULATED SNOW & ICE PELLETS DISSOLVING IN FLUID

Table 1: Test Plan (cont.)

Test Number	Chamber Temperature °C	Precip. Type	Fluid Name	Dilution	Maximum Expected Time to Dissolve (minutes)	Brix °	FFP °C
36	-3	Snow (0.5 mg)	MaxFlo (Type IV)	100/0	20	36	**-36**
37	-3	Snow (0.5 mg)	MaxFlo (Type IV)	90/10	20	**33**	**-29**
38	-3	Snow (0.5 mg)	MaxFlo (Type IV)	75/25	20	28.5	**-21**
39	-3	Snow (0.5 mg)	MaxFlo (Type IV)	50/50	20	19	**-10**
40	-3	Snow (0.5 mg)	MaxFlo (Type IV)	25/75	20	**10**	**-4**
41	-3	Snow (0.5 mg)	UCAR ADF (Type I)	57/43	20	34	<-40
42	-3	Snow (0.5 mg)	UCAR ADF (Type I)	45/55	20	27.5	-29
43	-3	Snow (0.5 mg)	UCAR ADF (Type I)	37/63	20	23	-21
44	-3	Snow (0.5 mg)	UCAR ADF (Type I)	22/78	20	14	-10
45	-3	Snow (0.5 mg)	UCAR ADF (Type I)	n/a	20	**6**	-4
46	-3	Snow (65 mg)	Ultra+ (Type IV)	100/0	20	40	<-59
47	-3	Snow (65 mg)	Ultra+ (Type IV)	n/a	20	27.5	-29
48	-3	Snow (65 mg)	Ultra+ (Type IV)	n/a	20	23.5	-21
49	-3	Snow (65 mg)	Ultra+ (Type IV)	n/a	20	15.5	-10
50	-3	Snow (65 mg)	Ultra+ (Type IV)	n/a	20	8.5	-4
51	-3	Snow (65 mg)	MaxFlo (Type IV)	100/0	20	36	**-36**
52	-3	Snow (65 mg)	MaxFlo (Type IV)	90/10	20	**33**	**-29**
53	-3	Snow (65 mg)	MaxFlo (Type IV)	75/25	20	28.5	**-21**
54	-3	Snow (65 mg)	MaxFlo (Type IV)	50/50	20	19	**-10**
55	-3	Snow (65 mg)	MaxFlo (Type IV)	25/75	20	**10**	**-4**
56	-3	Snow (65 mg)	UCAR ADF (Type I)	57/43	20	34	<-40
57	-3	Snow (65 mg)	UCAR ADF (Type I)	45/55	20	27.5	-29
58	-3	Snow (65 mg)	UCAR ADF (Type I)	37/63	20	23	-21
59	-3	Snow (65 mg)	UCAR ADF (Type I)	22/78	20	14	-10
60	-3	Snow (65 mg)	UCAR ADF (Type I)	n/a	20	**6**	-4
61	-9	IP (1mm)	Ultra+ (Type IV)	100/0	60	40	<-59
62	-9	IP (1mm)	Ultra+ (Type IV)	n/a	60	27.5	-29
63	-9	IP (1mm)	Ultra+ (Type IV)	n/a	60	23.5	-21

DISSOLVING TIME INDOORS: VIDEO DOCUMENTATION OF SIMULATED SNOW & ICE PELLETS DISSOLVING IN FLUID

Table 1: Test Plan (cont.)

Test Number	Chamber Temperature °C	Precip. Type	Fluid Name	Dilution	Maximum Expected Time to Dissolve (minutes)	Brix °	FFP °C
68	-9	IP (1mm)	MaxFlo (Type IV)	50/50	60	19	**-10**
69	-9	IP (1mm)	UCAR ADF (Type I)	57/43	60	34	<-40
70	-9	IP (1mm)	UCAR ADF (Type I)	45/55	60	27.5	-29
71	-9	IP (1mm)	UCAR ADF (Type I)	37/63	60	23	-21
72	-9	IP (1mm)	UCAR ADF (Type I)	22/78	60	14	-10
73	-9	IP (5mm)	Ultra+ (Type IV)	100/0	60	40	<-59
74	-9	IP (5mm)	Ultra+ (Type IV)	n/a	60	27.5	-29
75	-9	IP (5mm)	Ultra+ (Type IV)	n/a	60	23.5	-21
76	-9	IP (5mm)	Ultra+ (Type IV)	n/a	60	15.5	-10
77	-9	IP (5mm)	MaxFlo (Type IV)	100/0	60	36	**-36**
78	-9	IP (5mm)	MaxFlo (Type IV)	90/10	60	**33**	**-29**
79	-9	IP (5mm)	MaxFlo (Type IV)	75/25	60	28.5	**-21**
80	-9	IP (5mm)	MaxFlo (Type IV)	50/50	60	19	**-10**
81	-9	IP (5mm)	UCAR ADF (Type I)	57/43	60	34	<-40
82	-9	IP (5mm)	UCAR ADF (Type I)	45/55	60	27.5	-29
83	-9	IP (5mm)	UCAR ADF (Type I)	37/63	60	23	-21
84	-9	IP (5mm)	UCAR ADF (Type I)	22/78	60	14	-10
85	-9	Snow (0.5 mg)	Ultra+ (Type IV)	100/0	20	40	<-59
86	-9	Snow (0.5 mg)	Ultra+ (Type IV)	n/a	20	27.5	-29
87	-9	Snow (0.5 mg)	Ultra+ (Type IV)	n/a	20	23.5	-21
88	-9	Snow (0.5 mg)	Ultra+ (Type IV)	n/a	20	15.5	-10
89	-9	Snow (0.5 mg)	MaxFlo (Type IV)	100/0	20	36	**-36**
90	-9	Snow (0.5 mg)	MaxFlo (Type IV)	90/10	20	**33**	**-29**
91	-9	Snow (0.5 mg)	MaxFlo (Type IV)	75/25	20	28.5	**-21**
92	-9	Snow (0.5 mg)	MaxFlo (Type IV)	50/50	20	19	**-10**
93	-9	Snow (0.5 mg)	UCAR ADF (Type I)	57/43	20	34	<-40
94	-9	Snow (0.5 mg)	UCAR ADF (Type I)	45/55	20	27.5	-29
95	-9	Snow (0.5 mg)	UCAR ADF (Type I)	37/63	20	23	-21

Table 1: Test Plan (cont.)

Test Number	Chamber Temperature °C	Precip. Type	Fluid Name	Dilution	Maximum Expected Time to Dissolve (minutes)	Brix °	FFP °C
96	-9	Snow (0.5 mg)	UCAR ADF (Type I)	22/78	20	14	-10
97	-9	Snow (65 mg)	Ultra+ (Type IV)	100/0	20	40	<-59
98	-9	Snow (65 mg)	Ultra+ (Type IV)	n/a	20	27.5	-29
99	-9	Snow (65 mg)	Ultra+ (Type IV)	n/a	20	23.5	-21
100	-9	Snow (65 mg)	Ultra+ (Type IV)	n/a	20	15.5	-10
101	-9	Snow (65 mg)	MaxFlo (Type IV)	100/0	20	36	**-36**
102	-9	Snow (65 mg)	MaxFlo (Type IV)	90/10	20	**33**	**-29**
103	-9	Snow (65 mg)	MaxFlo (Type IV)	75/25	20	28.5	**-21**
104	-9	Snow (65 mg)	MaxFlo (Type IV)	50/50	20	19	**-10**
105	-9	Snow (65 mg)	UCAR ADF (Type I)	57/43	20	34	<-40
106	-9	Snow (65 mg)	UCAR ADF (Type I)	45/55	20	27.5	-29
107	-9	Snow (65 mg)	UCAR ADF (Type I)	37/63	20	23	-21
108	-9	Snow (65 mg)	UCAR ADF (Type I)	22/78	20	14	-10

Note: Figures in Bold are estimates
Not all tests will be run at -9°C, it will depend on the results of the -3°C tests.

ATTACHMENT II
Fluid Mixtures for Testing

<u>UCAR ADF Concentrate (Type I)</u>

1.	STD Mix (57% Glycol)	Brix = 34°	FP = <-40°C
2.	45/55	Brix = 27.5°	FP = -29°C
3.	37/63	Brix = 23°	FP = -21°C
4.	22/78	Brix = 14°	FP = -10°C
5.	N/A	Brix = **6°**	FP = -4°C

<u>DOW Ultra+ (Type IV)</u>

1.	100/0	Brix = 40°	FP = <-59°C
2.	N/A	Brix = 27.5°	FP = -29°C
3.	N/A	Brix = 23.5°	FP = -21°C
4.	N/A	Brix = 15.5°	FP = -10°C
5.	N/A	Brix = 8.5°	FP = -4°C

<u>MaxFlo (Type IV)</u>

1.	100/0	Brix = 36°	FP = **-36°C**
2.	90/10	Brix = **33°**	FP = **-29°C**
3.	75/25	Brix = 28.5°	FP = **-21°C**
4.	50/50	Brix = 19.0°	FP = **-10°C**
5.	25/75	Brix = **10°**	FP = **-4°C**

Note: Figures in bold are estimates.

ATTACHMENT III
SNOW AND ICE PELLET DISSOLVING DATA SHEET

DATE: ______________________________ **OAT:** ________________________

LOCATION: __________________________

Test #	Start Time	End Time	Total Time (minutes)	Precipitation Type (Snow or Ice Pellet)	Snow Weight (mg)	Fluid Name	Fluid Dilution	Fluid Type	Brix

M:\Groups\CM (TC-Deicing 05-06)\Procedures\Data Forms\IP & SF Dissolving Fluid Data Sheet

Name: ______________________________ **Signature:** ______________________________

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APPENDIX E

PROCEDURE:
VIDEO DOCUMENTATION OF PILOT'S PERSPECTIVE IN ICE PELLETS

CM (TC-Deicing 05-06)

VIDEO DOCUMENTATION OF PILOT'S PERSPECTIVE IN ICE PELLETS

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: David Youssef

Reviewed by: John D'Avirro

December 12, 2005
Version 1.0

VIDEO DOCUMENTATION OF PILOT'S PERSPECTIVE IN ICE PELLETS

1. BACKGROUND

Visual fluid failure determination in ice pellet conditions was found to be a challenge, as it can vary based on location from the affected area and the observers angle of incidence. Also, while ice pellets embedded in the fluid were not adhering, it is not known whether this contamination in the fluid would come off during aircraft rotation. As a result, the FAA have issued a notice that prevents operations from departing in ice pellet conditions.

In an attempt to better understand the issues described above, a series of procedures using both photography and videography will be developed for testing in ice pellet conditions. During the course of the winter season, more procedures may be developed based upon results from initial testing and discussions with the industry.

1. Video Documentation of Pilot's Perspective in Ice Pellets;
2. Dissolving Time Indoors: Video Documentation of Simulated Snow and Ice Pellets Dissolving in Fluid;
3. Dissolving Time Outdoors: Video Documentation of Ice Pellets and Snow Dissolving in Fluid;
4. Photography of Ice Pellets on Black Felt;
5. Endurance Time Testing in Natural Ice Pellets.

In addition to the above five procedures, other procedures may be developed for the ongoing study of ice pellets.

This procedure, *Video Documentation of Pilot's Perspective in Ice Pellets,* is described in this document; the other procedures are described in separate documents.

In the past, APS discovered that the video camera resolution played an important role into the effectiveness of capturing the human perspective. It was found that the camera's span of vision does not give an accurate representation of the human perspective (i.e. a camera will see "in focus" the entire objective). The human eye however, will only be able to focus in on approximately 15 degrees of clear vision, as shown in Figure 1.1. With this in mind, perspective of the footage was not representative of what the pilot would see. This is due to the camera's ability to represent far more detail in focus, in comparison to the human eye.

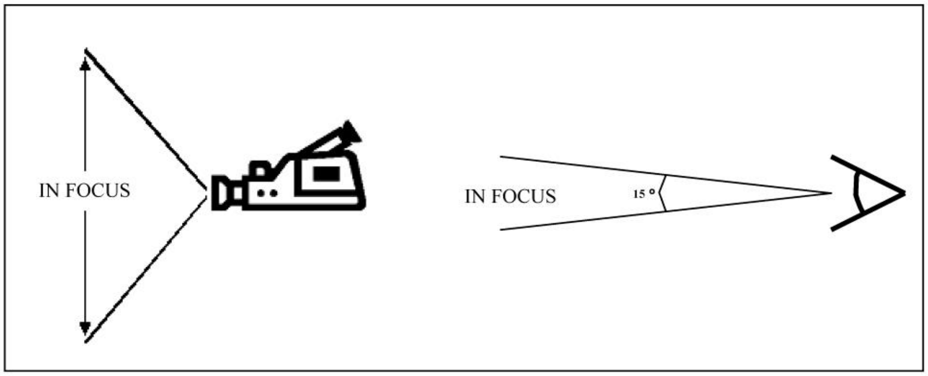


Figure 1.1: Plan View of Camera and Human Perspective

2. OBJECTIVES

This project addresses the following objectives:

- To document simultaneous perspectives representing close in and pilot views of an airfoil subjected to snow and ice pellet precipitation conditions; and
- To obtain an adequate representation of the human perspective when viewing an aircraft wing.

Testing will be conducted in a natural setting at the Trudeau test site for snow. Testing for ice pellets will be conducted "best case scenario" at Trudeau test site, or at NRC, depending on outdoor weather conditions.

3. METHODOLOGY

In order to best represent the human perspective when viewing a wing, at least three potential setups will be investigated with the guidance of a professional videographer. For each of the three setups, the goal will be for the two cameras to provide what a human observer would see at a distance of 0.94 metres (close in perspective) and 5 metres (pilot's perspective).

Setup 1 Setting the cameras closer to the airfoil than the location of human perspective. Camera 1 would be positioned less than 5 m away for a person standing at this distance. A similar setup would be used for camera 2.

Setup 2 Setting the cameras further from the airfoil than the location of the human perspective, while simultaneously zooming in close. Camera 1 would be positioned further than 5 m for a person standing at this distance. A similar setup would be used for camera 2.

Setup 3 Setting the cameras at the same distance from the airfoil as the human perspective. Through screen editing and special effects the video would be altered to show exactly what the human would see.

4. SETUP FOR SIMULTANEOUS FILMING

In preparation for an ice pellet event, a "dry run" of the setup will be performed in order to properly mark out the location for the airfoil and locations for the two cameras. This will be done in advance to ensure efficient use of time during an ice pellet event.

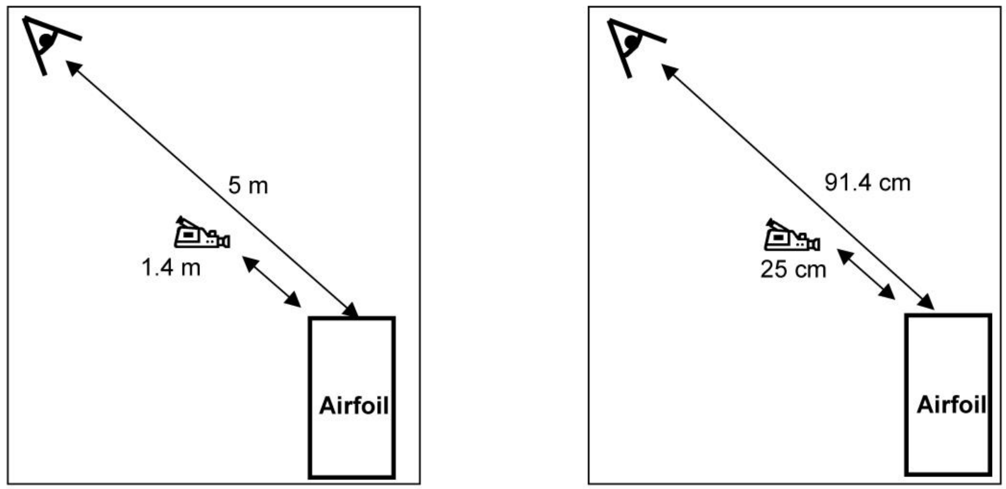
Example using Setup 1:

- The first camera will be set up at a distance of 1.4 m away to demonstrate what a person would see at 5 m away, or roughly a 15 to 20 ft. perspective.
- At the same time, a second camera will be set up at a distance of 25 cm away, to demonstrate what a person would see at 91 cm or roughly a 3 ft perspective.

Figure 4.1 represents an example of the plan view of the setup required using Setup 1.

The setup will require two high-resolution video cameras to document simultaneous perspectives representing an observer's view. The time stamped videos will later be edited to provide still shots of predetermined times during each test.

Figure 4.1: Example Using Setup 1 – View of Setup Required



PERSON AT A DISTANCE OF 5 M (15 TO 20 FT.)

PERSON AT A DISTANCE OF 0.91 M (3 FT.)

5. LIGHTING CONDITIONS FOR SIMULTANEOUS FILMING

The objective is to document a human perspective of an airfoil subject to precipitation conditions; therefore, zoom lenses, lighting, and film exposure should be modified to best represent what the human eye observes. Little or no additional lighting should be used to document the simultaneous video of the airfoil subjected to snow and ice pellet precipitation conditions.

6. PROCEDURE

The services of a professional videographer will be retained to collect video footage. Testing will be conducted either outdoors at OAT or in the NRC cold chamber (OAT of -3°C). The following procedure will be followed when collecting footage:

In Preparation for Ice Pellet Event (with Videographer)

1. Place airfoil in desired location;
2. Through trial and error, decide on location for two cameras in accordance with methodology;
3. Affix wooden pegs, marked with orange paint into the ground to mark locations of cameras in relation to airfoil; and
4. Capture footage for analysis.

During Ice Pellet Event

1. Synchronize the date and time on the two cameras to local time;
2. Set up the cameras. The position of the airfoil should be oriented with the leading edge into the wind and the cameras should be positioned in the same orientation facing the leading edge to avoid camera lens contamination with ice pellets;
3. Video the following tests:
    - Airfoil anti-iced with Maxflo 50/50 fluid; and
    - Airfoil anti-iced with Ultra+ Neat fluid (If time permits).
4. Place a collection pan underneath the airfoil to collect any excess fluid;
5. Measure rate of precipitation using standard plate pans that are used for endurance time testing, using the standard protocol for measurement; and

6. During each observation after application of the fluid at least three photographs should be taken; one photograph from a top view, second photograph facing the leading edge of the airfoil at a shallow angle such as 20°, and a third photograph from the trailing edge at a shallow angle of 20°.

7. PERSONNEL

A minimum of two individuals will be required to obtain the video footage: a professional videographer and an individual to coordinate the video shots.

8. DATA FORMS

Dry Run: During the dry run several camera positioning alternatives will be examined. For each alternative a data form will be filled in (see Attachment I). Comments related to each of the setups will be noted on the data form and photographs taken.

Actual Test: An airfoil failure observation data form will be used to document any important observations during testing. Refer to Attachment I.

Attachment II shows the data form for the meteorological and precipitation rate for the meteo/video tester.

ATTACHMENT I
Video Documentation Of Pilots Perspective In Ice Pellets

Date:

Test Observed by:

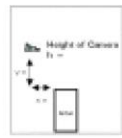
Fluid Name:

Fluid Type: **Dilution:**

Time of Start:

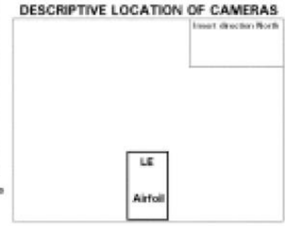
Time of Finish:

Example:



Instructions:
1. Mark the x and y coordinates for camera 1.
2. Mark the x2 and y2 coordinates for camera 2.
3. Include the height of each camera to the ground.
4. Include Northern direction.

DESCRIPTIVE LOCATION OF CAMERAS



Wind Speed ________

Height of Camera h = ________

Height of Camera h_2 = ________

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.

Comments

Name: ____________________ Signature: ____________________

M:\Groups\CM (TC-Deicing 05-06)\Procedures\Data Forms\Airfoil Observation Data Form

ATTACHMENT II
Meteorological and Precipitation Rate Data Form

REMEMBER TO SYNCHRONIZE TIME WITH MSC - USE LOCAL TIME

LOCATION: **DATE:** **RUN # :** **STAND # :**

HAND HELD VIDEO CASSETTE #:

PLATE PAN WEIGHT MEASUREMENTS *

PAN #	t TIME BEFORE (h:min:s)	BUFFER TIME (s)	t TIME AFTER (h:min:s)	BUFFER TIME (s)	w WEIGHT BEFORE (g)	w WEIGHT AFTER (g)	COMPUTE RATE (Δ w*4.7/ Δt) (g/dm²/h)	WIND SPEED** (km/h)	WIND DIR*** (°)

* Measurements every 10 min. and at failure time of each test panel

** Wind speed measurements required every time the precipitation rate is measured and only if data not available from MSC

*** Wind direction shall be recorded at least every 15 minutes

METEO OBSERVATIONS ****

TIME (h:min)	TYPE (Table 1) ZR, ZL, S, SG [illegible]	CLASSIF. (See snow classification diagram.)	If SNOW, WET or DRY

**** Observations at beginning, end, and every 10 min. intervals. Additional observations when there are significant changes.

AIR TEMPERATURE AT START OF TEST ________ °C

WIND DIRECTION AT START OF TEST ________ °

TEST STAND ORIENTATION
(measured along long axes of the test panels) ________

COMMENTS : ________________

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

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APPENDIX F

PROCEDURE:
ADHESION OF AIRCRAFT DE/ANTI-ICING FLUIDS ON ALUMINUM SURFACES DURING SIMULATED ICE PELLET CONDITIONS

CM2020.002 (05-06)

EXPERIMENTAL PROGRAM
ADHESION OF AIRCRAFT DE/ANTI-ICING FLUIDS ON ALUMINUM SURFACES DURING SIMULATED ICE PELLET CONDITIONS

Winter 2005-06

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Marco Ruggi

Reviewed by: John D'Avirro

APS Aviation Inc

January 23, 2006
Version 1.1

EXPERIMENTAL PROGRAM
ADHESION OF AIRCRAFT DE/ANTI-ICING FLUIDS ON ALUMINUM SURFACES DURING SIMULATED ICE PELLET CONDITIONS

Winter 2005-06

1. BACKGROUND

Preliminary endurance time testing during simulated ice pellet conditions was conducted by APS at the PMG research facility. Endurance time testing was conducted using Type I and Type IV fluid applications. Fluid adherence was only observed during the heated Type I fluid application endurance time test conducted on the airfoil during simulated ice pellet conditions. This has generated a need to investigate if aircraft surfaces are prone to fluid adherence during ice pellet conditions.

Previous endurance time testing was conducted by APS during snow and freezing precipitation conditions. A full account of these tests can be found in TP 14377E, *Adhesion of Aircraft Anti-Icing Fluids on Aluminum Surfaces (2003-04)*, December 2004.

During conduct of adhesion tests using Type I, II and IV fluids, it was observed that:

- Typically, the Type I adhesion tests conducted under moderate or heavy snow precipitation conditions exhibit adherence regardless of ambient temperature and test surface type;

- Under light and very light snow conditions Type I,II, and IV fluids do not usually dilute to a level that would stimulate bonding to the test surface, irrespective of the surface type and initial fluid temperature;

- Higher glycol concentrations (at colder temperatures) applied heated on empty aluminum box surfaces generate longer endurance times and extended safety buffers for Type I, II, and IV fluids;

- Type II/IV fluids were not observed to adhere to the underlying surface under snow conditions, irrespective to the precipitation rate and outside temperature. However, if the fluid is exposed to precipitation far beyond complete plate failure, the failed fluid might eventually adhere to the surface providing its freeze point reached 0°C;

- If the Type II/IV fluid is heated, melting of snowflakes is facilitated, generating fairly large quantities of water for fluid dilution. This can lead to early dilution of the fluid and, subsequently, to fluid adhesion; and

- Contrary to snow conditions, adhesion was detected under freezing precipitation conditions for both Type I and Type II/IV fluids. Independent of the fluid type, precipitation rate and the ambient temperature, fluid adhesion was observed under freezing drizzle, light freezing rain and rain on cold-soaked wing conditions. However, Type IV testing conducted during the 1998-99 winter season showed that only Type IV ethylene glycol-based fluids demonstrated failure adhesion under freezing precipitation conditions.

Based on the conclusions from previous testing conducted in snow and freezing precipitation conditions, preliminary testing will be conducted in simulated ice pellet conditions using the current fluid application methods most likely to exhibit adhesion.

2. OBJECTIVES

The objective of this project is to investigate if endurance time testing conducted during ice pellet conditions will demonstrate signs of fluid adhesion to aluminum test surfaces. Preliminary testing will be conducted during conditions most likely to exhibit adhesion.

3. TEST PLAN

A table of the tentative tests to be conducted is shown in Table 3.1. The failure times on test surfaces will be recorded using the standard ET data form (Attachment I). Measurements will be continued after the fluid fails in an attempt to properly document the fluid adherence. Fluid type, fluid appearance, OAT, rate of precipitation and other factors will determine the duration of the test. After the fluid fails, the test surface will be examined to determine whether or not adherence is likely to occur within a reasonable time. Progressive measurements will be conducted to help in reaching a decision. During tests where adhesion seems plausible, testing should continue and the adhesion should be documented for at least one hour after fluid failure. The methodology for measuring failure adhesion is described in Section 4.10.

The parameters to be measured during testing are the following: test surface temperature, fluid dilution (Brix), precipitation rate, and fluid adhesion. All of these parameters are to be measured as the test progresses to gain a better understanding of the phenomena that take place as the fluid becomes diluted.

Table 3.1: Test Plan

Test #	Fluid Type	Fluid Brand	Dilution	Fluid Temp. [°C]	Precip Type	Test Temp. [°C]	Precip Rate [g/dm²/h]	Objective
1	I	Any	10° Buffer	60	IP	Any	>25	Type I Heated
2	II/III/IV	Any	Neat	15	IP	-3	75	Type II/III/IV - Fluid Room Temp.
3	II/III/IV	Any	Neat	60	IP	-3	>25	Type II/III/IV - Fluid Heated 60°C
4	II/III/IV	Any	Neat	-10	IP	-10	75	Type II/III/IV - Exceeded HOT
5	II/III/IV	Any	Neat	-10	IP/ZD	-10	>25	Type II/III/IV - Mixed Precip.

4. PROCEDURE

Endurance time testing will be conducted in a cold room using a standard test plate sitting in the "NCAR Bucket". The bucket will be placed on a weigh scale and the weight will be manually recorded to monitor the rate of precipitation. The "Ice Pellet Dispenser" will be positioned approximately 1.2 m (4 ft.) away from, and 1.2 m above the test plate. Fluid Brix will be measured at set intervals during each test.

4.1 Type I Heated Fluid Application Endurance Time Test

0.5 L of Type I fluid heated to 60 °C should be poured onto the test plate with a warm 12-hole spreader. The target rate of precipitation should be in the magnitude of 25 g/dm²/h or greater. Rate measurements should be taken every 2-4 minutes depending on the intensity of precipitation. Brix measurements should be taken every 2 minutes.

4.2 Type II/III/IV Fluid Application Endurance Time Test – Fluid at Room Temperature

1L of fluid at approximately 15°C should be poured onto the test plate. The fluid should be hand poured from a 1L container. The target rate of precipitation should be in the magnitude of 75 g/dm²/h. Rate measurements should be taken every 2 minutes throughout the test.

4.3 Type II/III/IV Fluid Application Endurance Time Test – Fluid Heated to 60°C

0.5L of fluid heated to approximately 60°C should be poured onto the test plate with a warm 12-hole spreader (if fluid is too viscous, then hand pour). The target rate of precipitation should be in the magnitude of 25 g/dm²/h or greater. Rate measurements should be taken every 2-4 minutes depending on the intensity of precipitation. Brix measurements should be taken every 2 minutes.

4.4 Type II/III/IV Fluid Application Endurance Time Test – Exceeded HOT

1L of fluid at ambient temperature should be poured onto the test plate. The fluid should be hand poured from a 1L container. The target rate of precipitation should be in the magnitude of 75 g/dm²/h. Rate measurements should be taken every 2 minutes throughout the test. The test plate should be subjected to precipitation far beyond the point of fluid failure. Brix measurements should be taken every 2 minutes, and every 4 minutes once fluid failure has been called.

4.5 Type II/III/IV Fluid Application Endurance Time Test – Mixed Precipitation

In conjunction with holdover time testing conducted at NRC, a setup will be required to expose the test plate to simulated freezing rain or drizzle, and simulated ice pellets simultaneously.1L of fluid at ambient temperature should be poured onto the test plate. The fluid should be hand poured from a 1L container. The target rate of precipitation should be in the magnitude of 25 g/dm²/h or greater. Rate measurements should be taken every 2 to 4 minutes throughout the test.

4.6 Surface Temperature

Test surface temperature logging is to be implemented using one thermistor probe mounted at the 15 cm (6") line. The connection will be designed to last for the entire test season and to not impede the fluid flow. A SmartReader Eight–Channel temperature logger will be used to measure and record temperature. This temperature logger will run continuously and is independent of any external power supply or computer; the logger constantly measures and records readings from any enabled channels. The sampling rate (how often the logger takes readings) will be set to eight seconds, the smallest possible increment.

4.7 Fluid Dilution

Fluid dilution will be measured at the 15 cm (6") line, using a Misco 10431VP brixometer. These measurements determine the concentration of the fluid on the test surface before and after fluid failure. The Brix value will originally be measured in the container before pouring. The second measurement will be taken right after pouring on the test surface, and at set intervals until fluid failure. After fluid failure the dilution measurements will be conducted every 10 minutes. Brix values and corresponding sample times should be recorded on the Brix/Thickness data form (Attachment II).

4.8 Precipitation Rate

Precipitation rates will be measured throughout the adherence test. Precipitation rates will be monitored by measuring the increase in weight of the self-contained NCAR bucket supporting the test plate.

4.9 Fluid Failure

Previous endurance time testing in simulated ice pellet conditions demonstrated that visual fluid failure was difficult to determine. Fluid failure determination is not critical to this project. APS members should use their best judgment in approximating the fluid time of failure.

4.10 Fluid Adherence

The first occurrence of fluid adhesion at any location on the surface of the plate should be recorded. Fluid adherence should be determined at the 5th crosshair immediately following failure at this location and at location B2 (see Attachment III). When the entire plate (15 crosshairs) has failed, again verify the fluid adherence at the 15 cm (6") line, and at all crosshairs B2, C2, D2, E2 and F2. Adherence should be noted by the plate observer on the Adherence of Fluid Failure data form (Attachment III). In addition to measuring adherence at the time of plate failure and complete plate failure, adherence should be measured progressively following fluid failure to determine the onset of adherence. A narrative description of the appearance of the fluid as it progresses toward failure could also be recorded.

In the absence of a recognized standard method or apparatus for measuring failure adhesion, the degree of bonding will be determined using an electrically driven dental flossing device. During operation, the device spins a thread of floss. The floss segment extends about 3 to 4 mm from the tip of the unit, and upon spinning could carve out a circle (or not, depending upon whether adhesion had occurred) 3 to 4mm in radius on a failed surface element. In a layer of non–adhered fluid failure, the force of the spinning floss is sufficient to expose the surface of the test plate. As the rotation speed of the unit is fixed, the applied force will be constant for all tests, providing a basis of comparison among various test conditions, and between different stages of contamination for individual tests. This device proved to be the most satisfactory of the various approaches to establish whether an area had undergone surface bonding to the substrate and to give a measure of the strength of the bond formed.

An analysis of the shearing force exerted by this instrument (presented as Appendix C of the Transport Canada report, TP 14377E, *Adhesion of Aircraft Anti-Icing Fluids on Aluminum Surfaces (2003-04)*, December 2004) determined it to be in the range of 1.3 $\times 10^{-4}$ to 2.0 $\times 10^{-4}$ MPa.

4.11 Test Sequence

The steps to be followed are specific to each precipitation type.

1) Synchronize computer and test clocks to the atomic clock;
2) Prepare NCAR bucket and test plate;
3) Initiate temperature logging;
4) Monitor precipitation rates;
5) Prepare fluids for testing. The fluid types, fluid amounts and application temperatures are specific to each test;
6) Just before pouring, the test surface should be cleaned of all contamination with a scraper and a squeegee;
7) Apply the fluid to the test surfaces according to specific test procedure;
8) Determine failure times on test surfaces, and record using standard ET data forms (Attachment I);
9) Measure Brix of the fluid and record on Brix/Thickness data form (Attachment II);
10) Determine fluid adherence and record on Adherence of Fluid Failure data form (Attachment III); and
11) At the end of the testing session save the temperature data on a memory stick or floppy disk and also e-mail it to the office. Label the diskette and place in the same envelope with the data forms.

5. EQUIPMENT AND FLUIDS

5.1 Equipment

The equipment to be used is, in general, the same as for the fluid holdover time tests. A comprehensive description of the equipment can be found in Transport Canada Report *Aircraft Ground De/Anti–Icing Fluid Holdover Time Development Program for the 2002-03 Winter*, TP 14144E, December 2004.

- NCAR bucket and test plate;
- Fluid spreader device, with 12 holes, will be used for applying Type I fluids under natural frost conditions;
- SmartReader Eight–Channel temperature logger and thermistor probes will be used for logging test surface temperatures;
- Misco 10431VP brixometer will be utilized for fluid dilution rate measurements; and

5.2 Fluids

Tests shall be conducted using Type I and Type II/III/IV fluids as presented in Table 1.

Type I fluids are to be mixed to a freeze point 10°C below OAT. Any SAE Type I fluid, EG or PG–based, can be used.

Type II/III/IV fluids will be tested as ready. Octagon Maxflo can be used for testing, however if a new HOT fluid becomes available, it can also be used.

6. PERSONNEL

Three technicians are needed to conduct the tests:

- Technician one calls failures, and documents adherence; and
- Technician two prepares fluids, measures precipitation rates and measures Brix and thickness; and
- Technician three will be in charge of running the ice pellet dispenser system.

7. DATA FORMS

The same data forms from the procedure, *Adhesion Of Aircraft De/Anti-Icing Fluids On Aluminum Surfaces* (see Version 1.0 from November 13, 2003, located in Appendix B of TP14144E) will be used for this project. Some fields of the data forms will not need to be filled out as they are not relevant to this project (refer to Section 3 for pertinent data). The following data forms are included in this procedure:

- End Condition data form (Attachment I);
- Fluid Brix/Thickness data form (Attachment II);
- Adherence of Fluid Failure data form (Attachment III); and
- Meteo/Plate Pan data form (Attachment IV).

ADHESION OF AIRCRAFT DE/ANTI-ICING FLUIDS ON ALUMINUM SURFACES DURING SIMULATED IP CONDITIONS

ATTACHMENT I
END CONDITION DATA FORM

REMEMBER TO SYNCHRONIZE TIME WITH ATOMIC CLOCK - USE REAL TIME

VERSION 1.0 Winter 2003/2004

LOCATION: DORVAL TEST SITE	DATE:	RUN #:	STAND # :

***TIME (After Fluid Application) TO FAILURE FOR INDIVIDUAL CROSSHAIRS (hr:min)**

Time of Fluid Application: _______ hr:min:ss _______ hr:min:ss _______ hr:min:ss

	BOX / PLATE ____			BOX / PLATE ____			BOX / PLATE ____		
FLUID NAME									
B1 B2 B3									
C1 C2 C3									
D1 D2 D3									
E1 E2 E3									
F1 F2 F3									
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA									
CALCULATED FAILURE TIME (MINUTES)									
BRIX / FLUID TEMPERATURE AT START	/			/			/		

Time of Fluid Application: _______ hr:min:ss _______ hr:min:ss _______ hr:min:ss

	BOX / PLATE ____			BOX / PLATE ____			BOX / PLATE ____		
FLUID NAME									
B1 B2 B3									
C1 C2 C3									
D1 D2 D3									
E1 E2 E3									
F1 F2 F3									
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA									
CALCULATED FAILURE TIME (MINUTES)									
BRIX / FLUID TEMPERATURE AT START	/			/			/		

OTHER COMMENTS (Fluid Batch, etc):

____

____

____

____

____

____

____

PRINT SIGN

FAILURES CALLED BY : ____________ ____________

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M:\Groups\PM2020 (TC-Deicing 05-06)\Procedures\Adhesion Ice Pellets\Version 1.1.doc
Version 1.1, January 06

10 of 13

ADHESION OF AIRCRAFT DE/ANTI-ICING FLUIDS ON ALUMINUM SURFACES DURING SIMULATED IP CONDITIONS

ATTACHMENT II

FLUID BRIX/THICKNESS DATA FORM

DATE: ____________ PERFORMED BY: ____________

RUN #: ____________ WRITTEN BY: ____________

STAND: ____________ LOCATION: ____________

Plate / BOX: Fluid:			Plate / BOX: Fluid:			Plate / BOX: Fluid:			Plate / BOX: Fluid:		
TIME	Brix at 15 cm Line	Thick. at 15 cm Line	TIME	Brix at 15 cm Line	Thick. at 15 cm Line	TIME	Brix at 15 cm Line	Thick. at 15 cm Line	TIME	Brix at 15 cm Line	Thick. at 15 cm Line

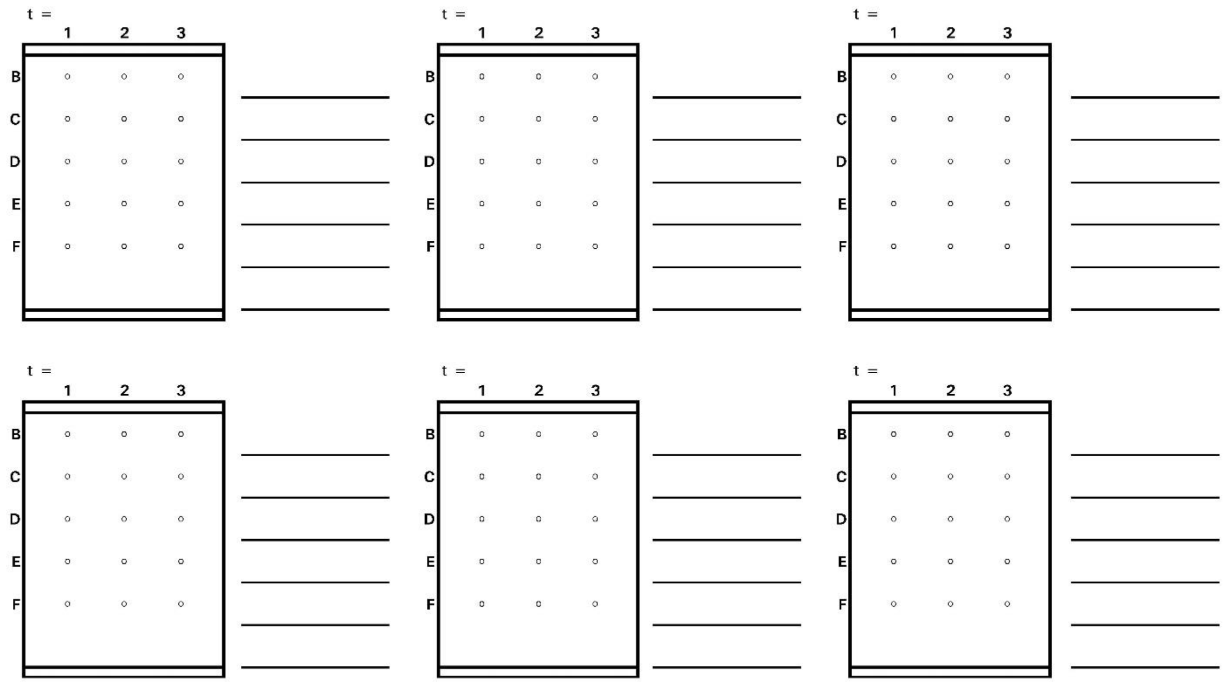
M:\Groups\CM (TC-Deicing 05-06)\Procedures\Data Forms\Fluid Brix Thickness Data Form

ATTACHMENT III

ADHERENCE OF FLUID FAILURE

Date: ____________ Time: ______________ Plate Location: _________

Run #: ____________ Fluid Name: ______________ Fluid Dilution: _________



M:\Groups\CM (TC-Deicing 05-06)\Procedures\Data Forms\Adherence of Fluid Failure

ADHESION OF AIRCRAFT DE/ANTI-ICING FLUIDS ON ALUMINUM SURFACES DURING SIMULATED IP CONDITIONS

ATTACHMENT IV
METEO/PLATE PAN DATA FORM

REMEMBER TO SYNCHRONIZE TIME WITH ATOMIC CLOCK - USE REAL TIME

VERSION 1.0 Winter 2003/2004

LOCATION: DORVAL TEST SITE **DATE:** **RUN # :** **STAND # :**

PLATE PAN WEIGHT MEASUREMENTS

PAN #	t TIME BEFORE (hh:mm:ss)	BUFFER TIME (Seconds)	t TIME AFTER (hh:mm:ss)	BUFFER TIME (Seconds)	w WEIGHT BEFORE (grams)	w WEIGHT AFTER (grams)	COMPUTE RATE (△w*4.7/ △t) ($g/dm^2/h$)

Precipitation rate will be measured every 10 minutes.

METEO OBSERVATIONS *

TIME (hr:min)	TYPE ZR, ZL,S, SG IP, IC, BS, SP	SNOW CLASSIF. (See Fig. 3)

*observations at beginning, end, and every 10 min. intervals. Additional observations when there are significant changes.

COMMENTS :

PRINT SIGN

WRITTEN & PERFORMED BY :

M:\Groups\CM (TC-Deicing 05-06)\Procedures\Data Forms\Forms 10 & 11

M:\Groups\PM2020 (TC-Deicing 05-06)\Procedures\Adhesion Ice Pellets\Version 1.1.doc
Version 1.1, January 06

13 of 13

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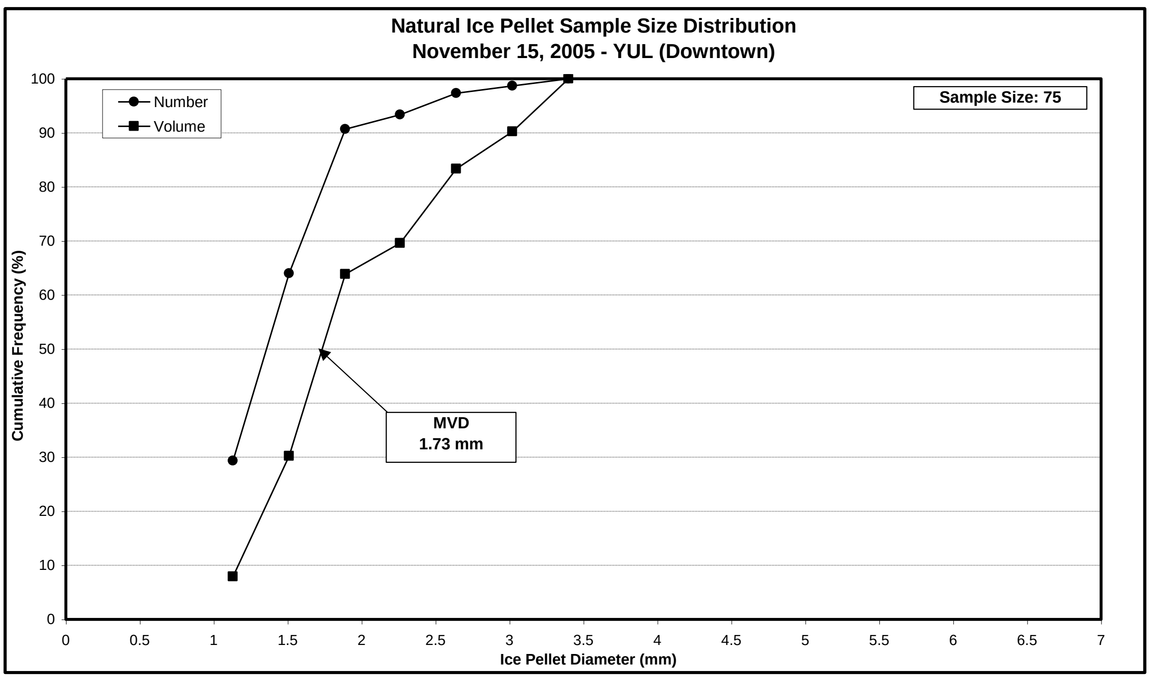
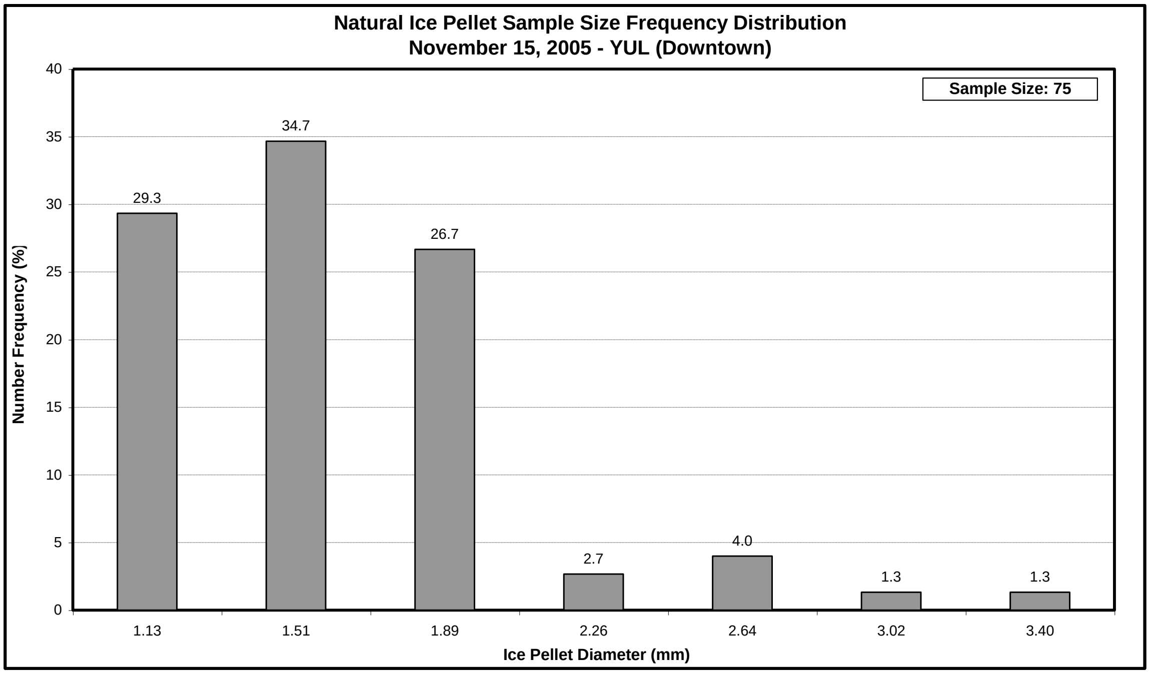
APPENDIX G

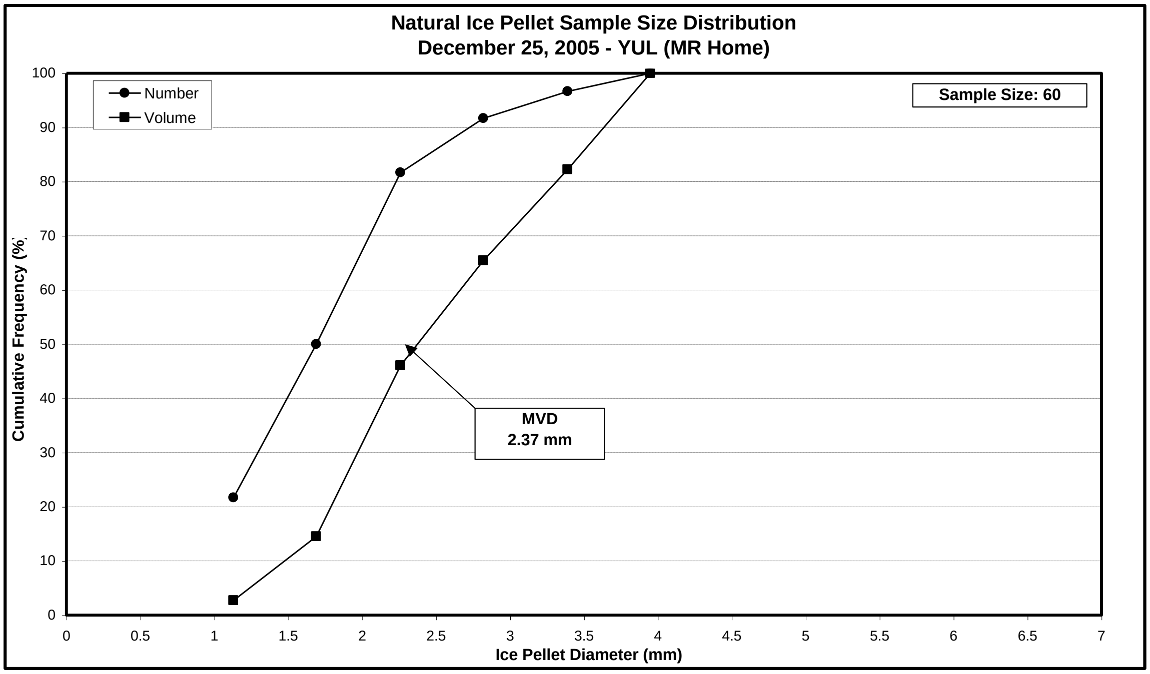
NATURAL ICE PELLET SAMPLE SIZE DISTRIBUTION CHARTS

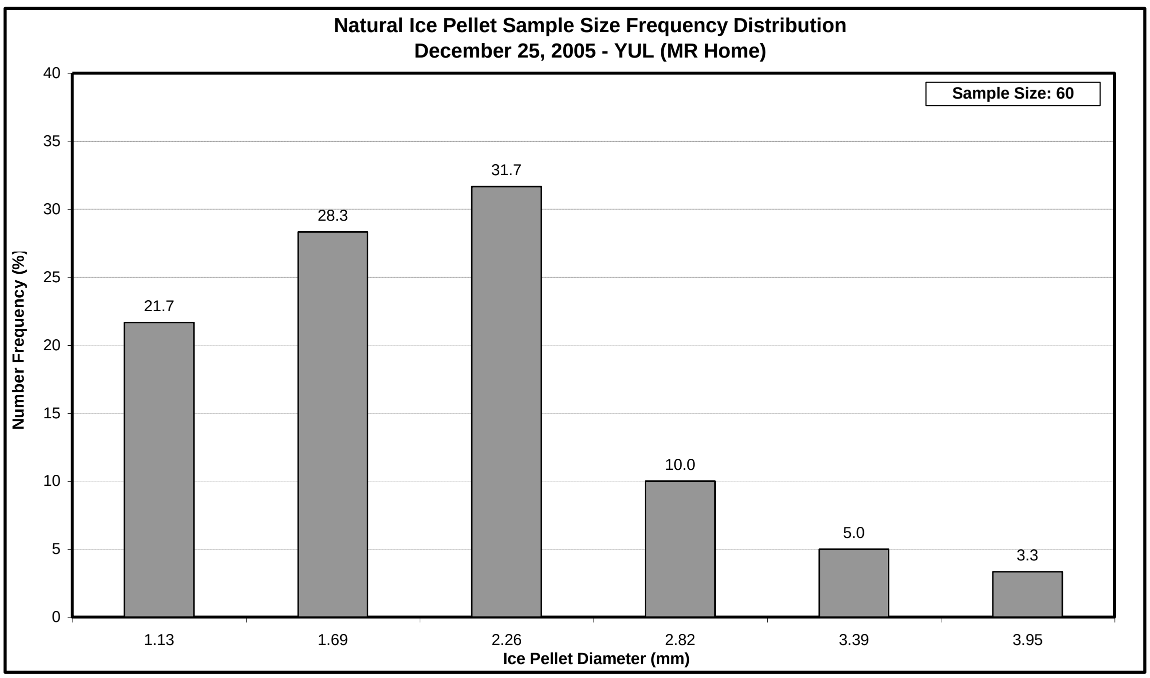

November 15, 2005 YUL

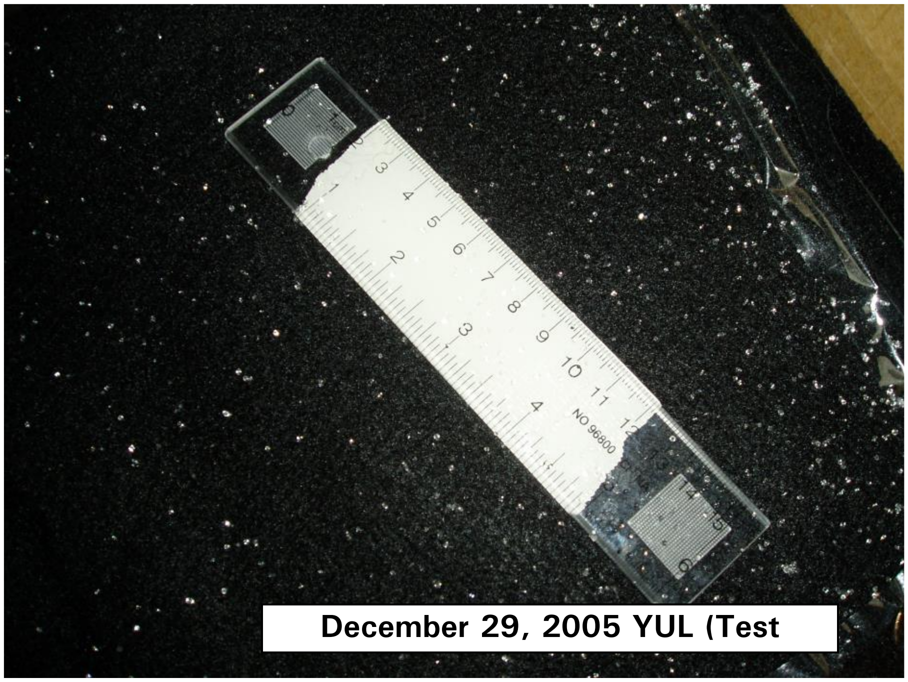

Natural Ice Pellet Sample Size Distribution
November 15, 2005 - YUL (Downtown)
Number
Volume
Sample Size: 75
MVD
1.73 mm
Cumulative Frequency (%)
Ice Pellet Diameter (mm)
0
10
20
30
40
50
60
70
80
90
100
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7

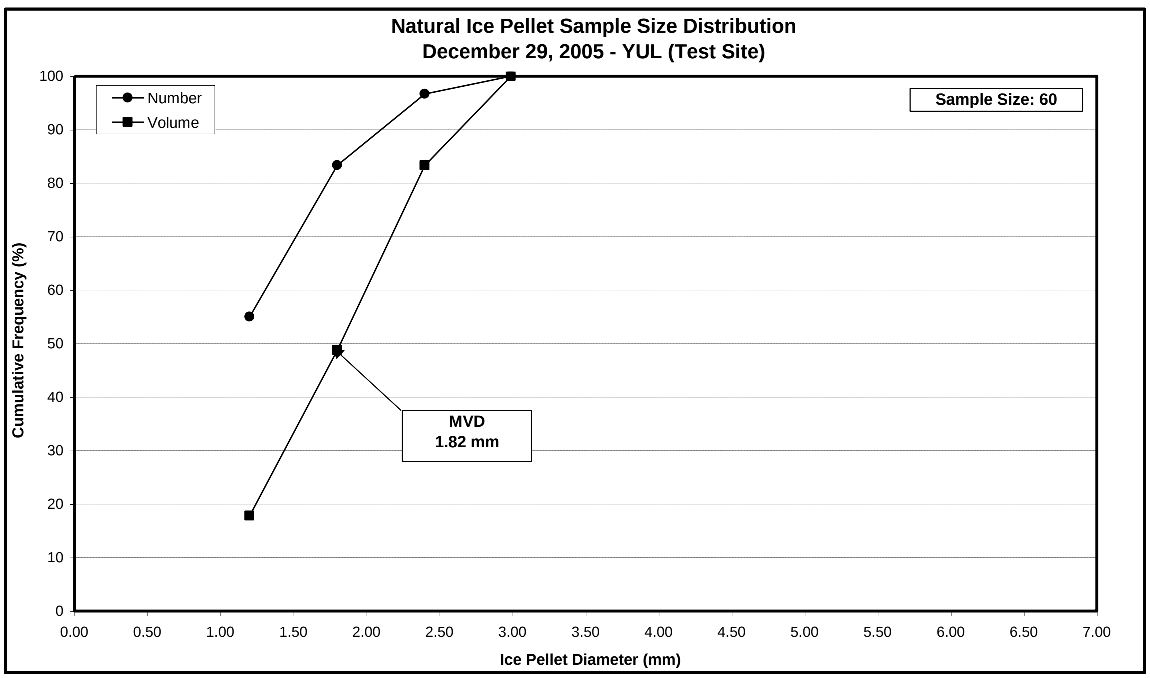

Natural Ice Pellet Sample Size Frequency Distribution
November 15, 2005 - YUL (Downtown)
Sample Size: 75
Number Frequency (%)
Ice Pellet Diameter (mm)
40
35
30
25
20
15
10
5
0
29.3
34.7
26.7
2.7
4.0
1.3
1.3
1.13
1.51
1.89
2.26
2.64
3.02
3.40

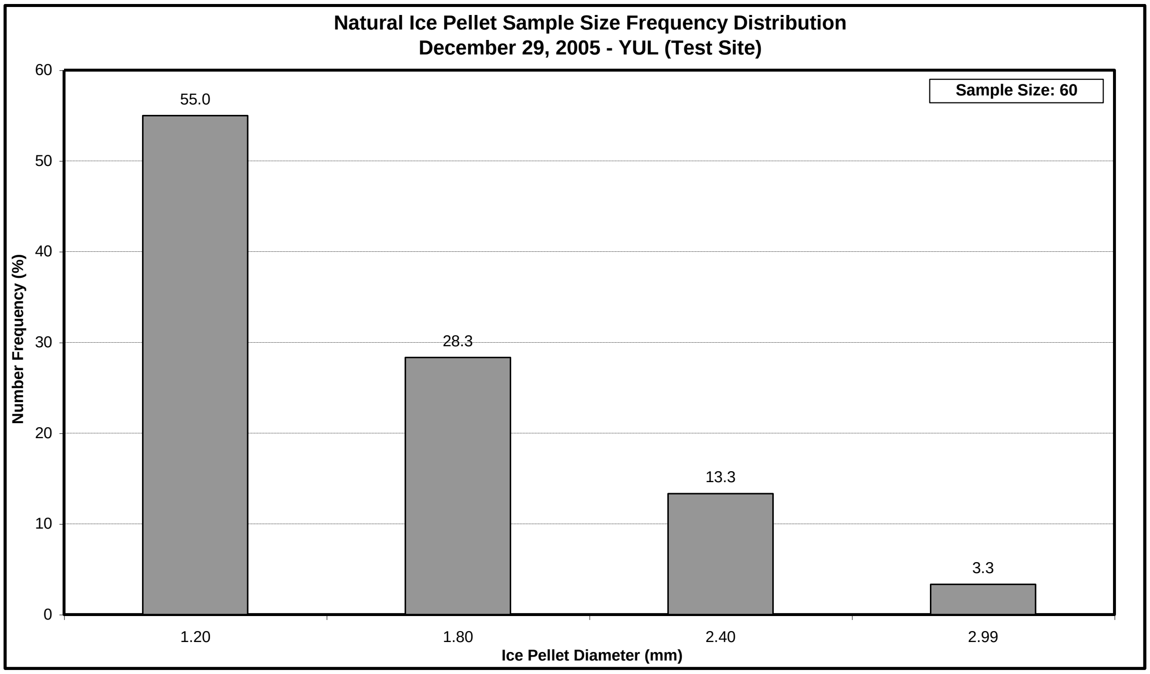

December 25, 2005 YUL (MR

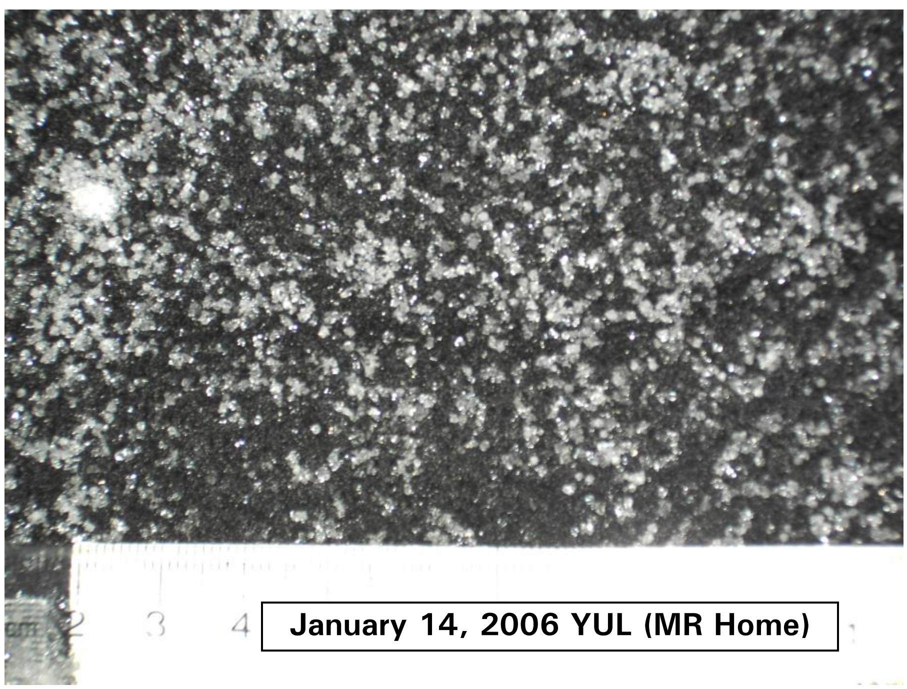

Natural Ice Pellet Sample Size Distribution
December 25, 2005 - YUL (MR Home)
Number
Volume
Sample Size: 60
MVD
2.37 mm
Cumulative Frequency (%)
Ice Pellet Diameter (mm)
0
10
20
30
40
50
60
70
80
90
100
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7

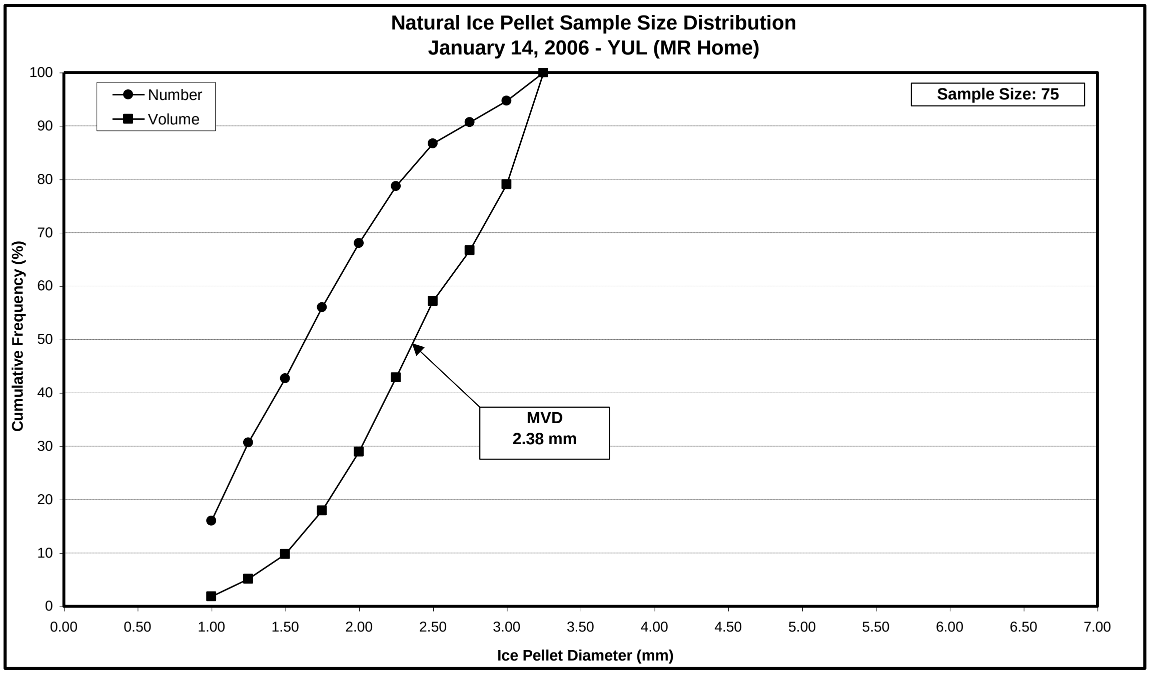

Natural Ice Pellet Sample Size Frequency Distribution
December 25, 2005 - YUL (MR Home)
Sample Size: 60
Number Frequency (%)
Ice Pellet Diameter (mm)
0
5
10
15
20
25
30
35
40
21.7
28.3
31.7
10.0
5.0
3.3
1.13
1.69
2.26
2.82
3.39
3.95

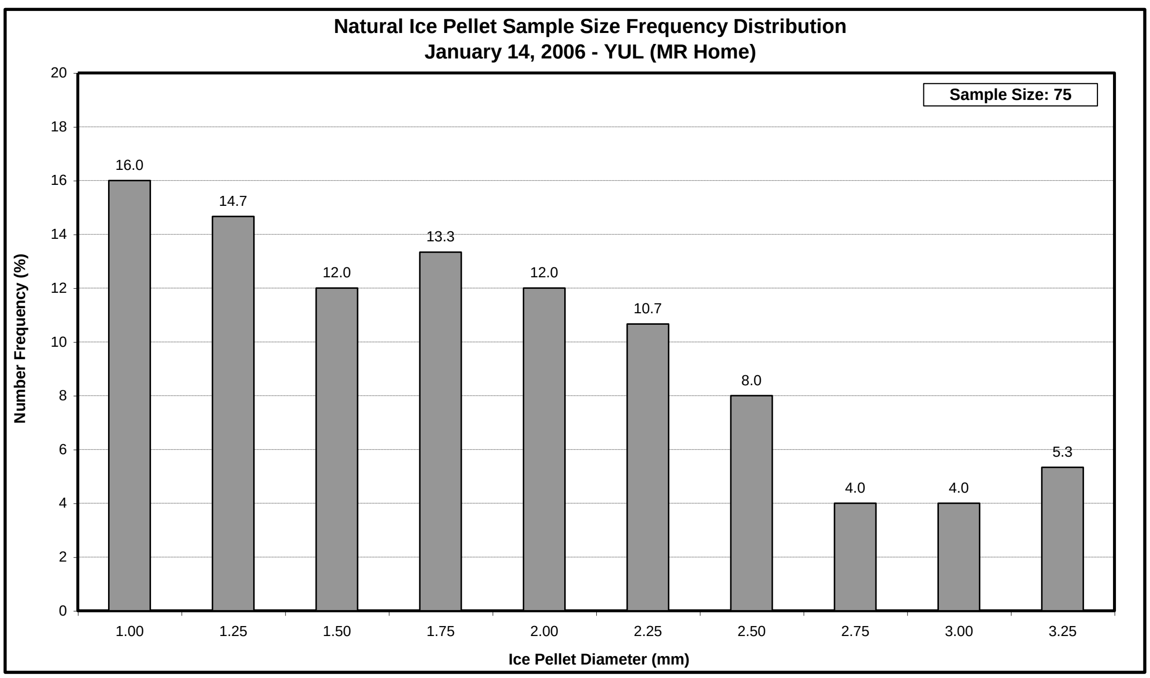

December 29, 2005 YUL (Test


Natural Ice Pellet Sample Size Distribution
December 29, 2005 - YUL (Test Site)
Number
Volume
Sample Size: 60
MVD
1.82 mm
Cumulative Frequency (%)
Ice Pellet Diameter (mm)
0
10
20
30
40
50
60
70
80
90
100
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
6.50
7.00

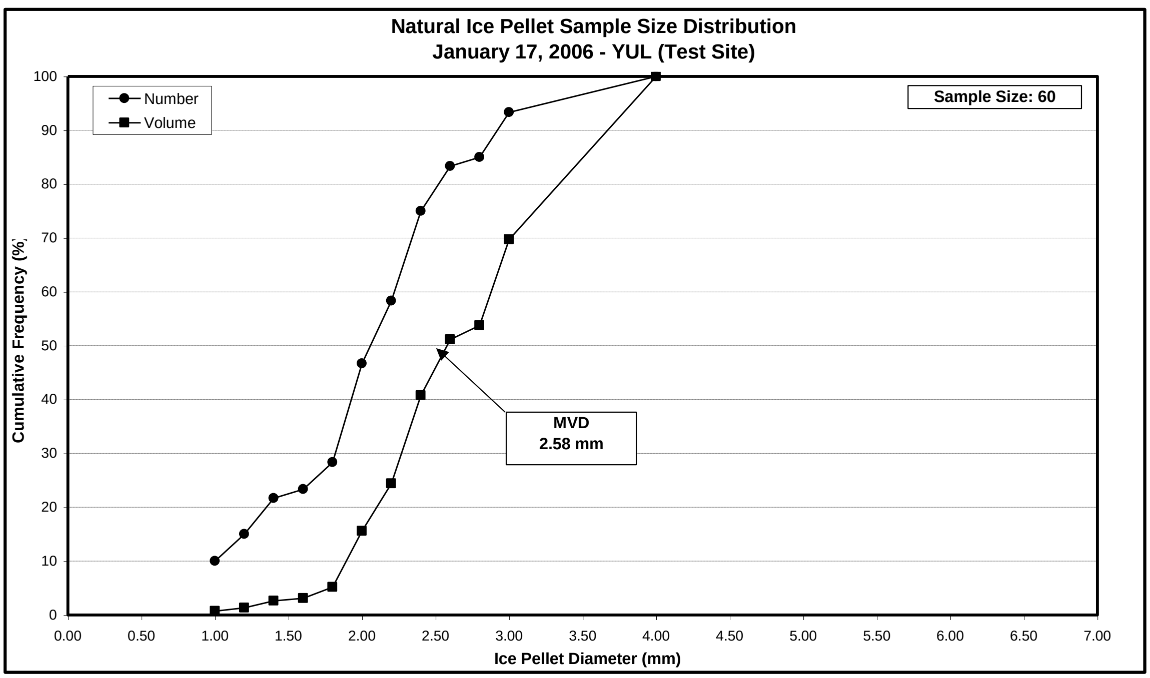

Natural Ice Pellet Sample Size Frequency Distribution
December 29, 2005 - YUL (Test Site)
Sample Size: 60
Number Frequency (%)
0
10
20
30
40
50
60
55.0
28.3
13.3
3.3
1.20
1.80
2.40
2.99
Ice Pellet Diameter (mm)

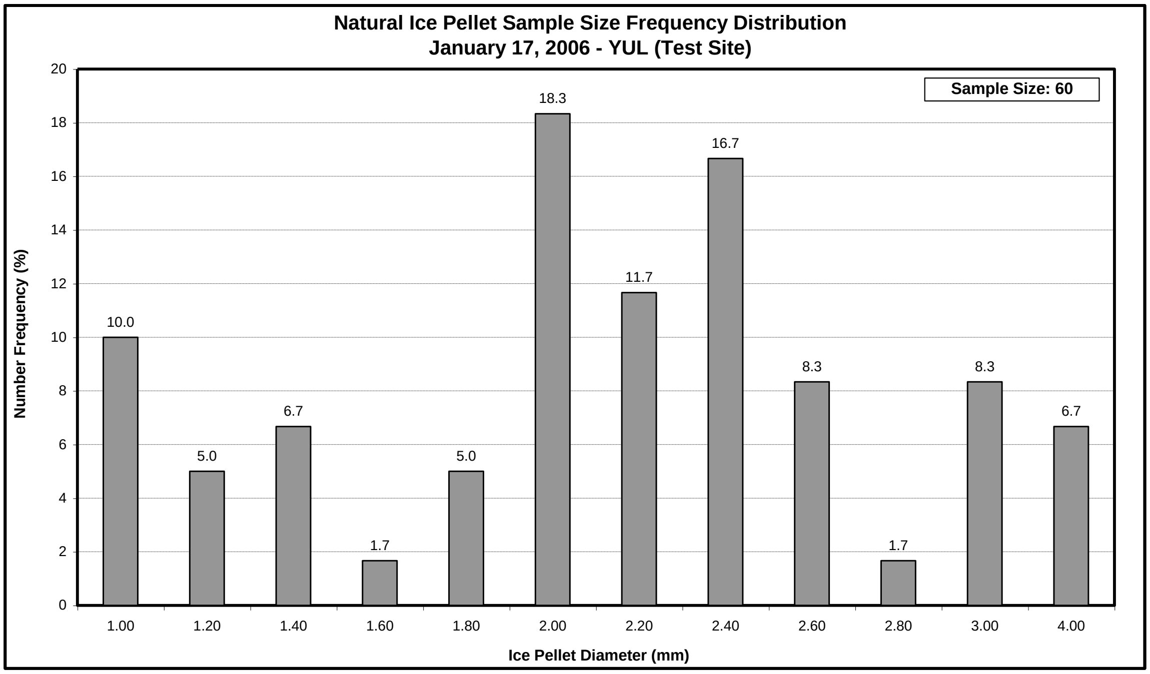

January 14, 2006 YUL (MR Home)

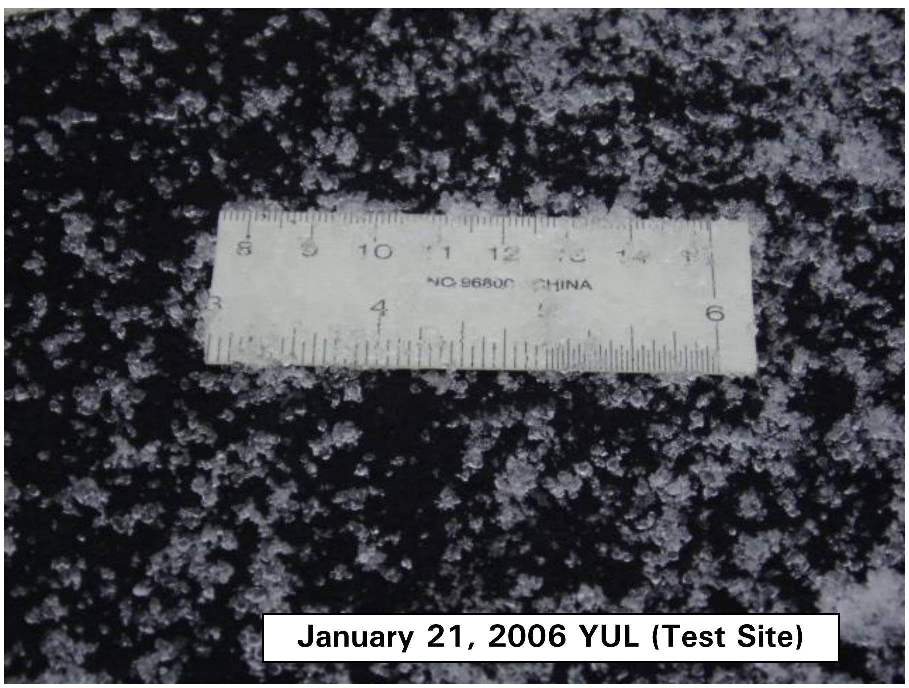

Natural Ice Pellet Sample Size Distribution
January 14, 2006 - YUL (MR Home)
Number
Volume
Sample Size: 75
MVD
2.38 mm
Cumulative Frequency (%)
Ice Pellet Diameter (mm)
0
10
20
30
40
50
60
70
80
90
100
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
6.50
7.00

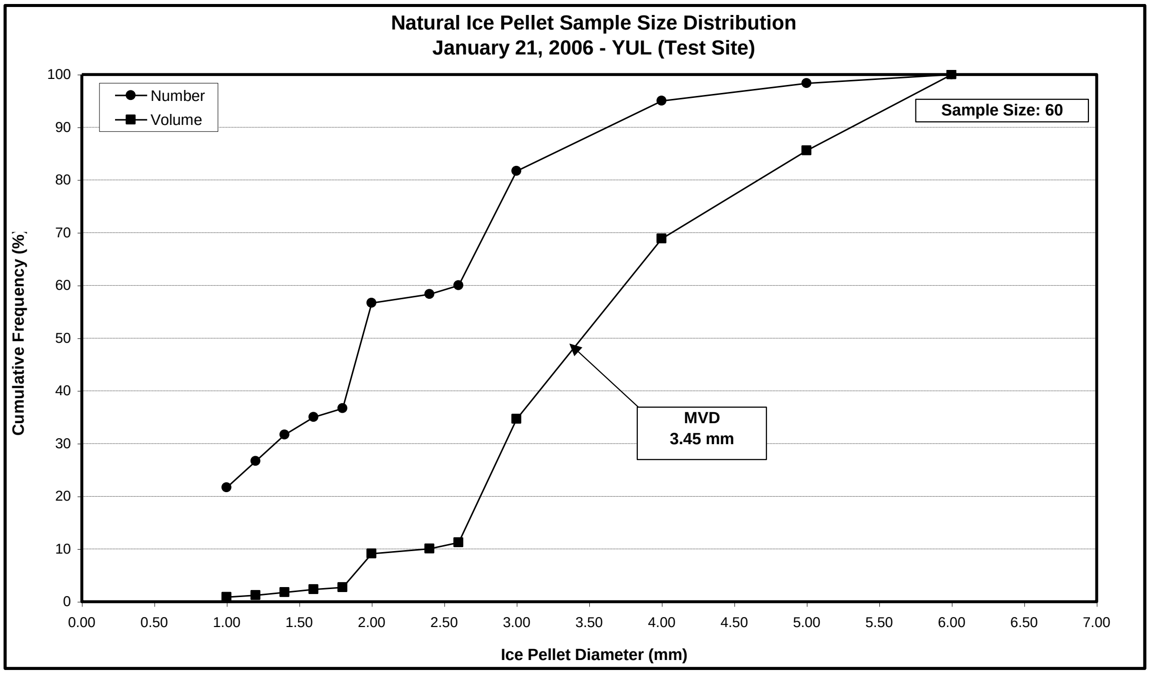

Natural Ice Pellet Sample Size Frequency Distribution
January 14, 2006 - YUL (MR Home)
Sample Size: 75
Number Frequency (%)
Ice Pellet Diameter (mm)
16.0
14.7
12.0
13.3
12.0
10.7
8.0
4.0
4.0
5.3
1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00
3.25
0
2
4
6
8
10
12
14
16
18
20

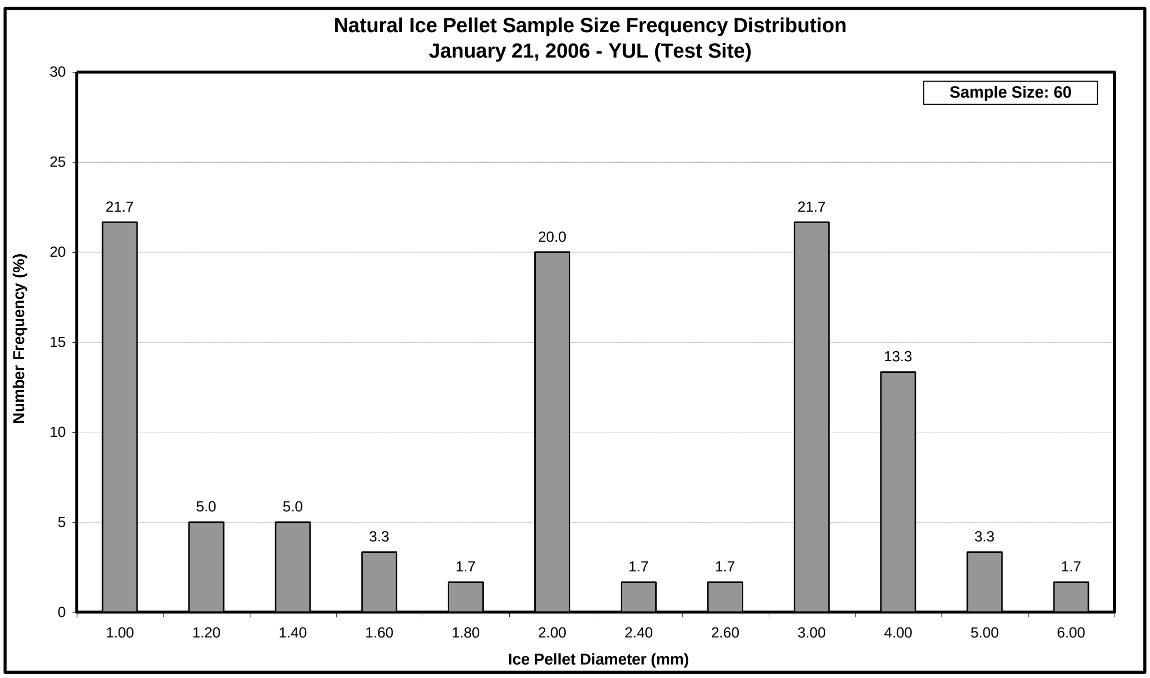

5
6
January 17, 2006 YUL (Test Site)

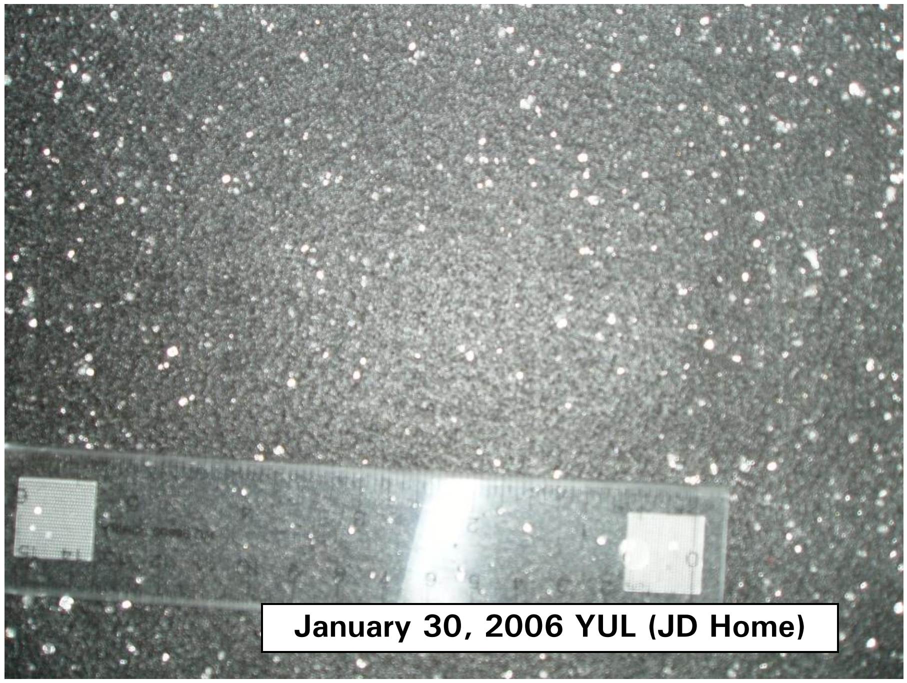

Natural Ice Pellet Sample Size Distribution
January 17, 2006 - YUL (Test Site)
Number
Volume
Sample Size: 60
MVD
2.58 mm
Cumulative Frequency (%)
Ice Pellet Diameter (mm)
0
10
20
30
40
50
60
70
80
90
100
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
6.50
7.00

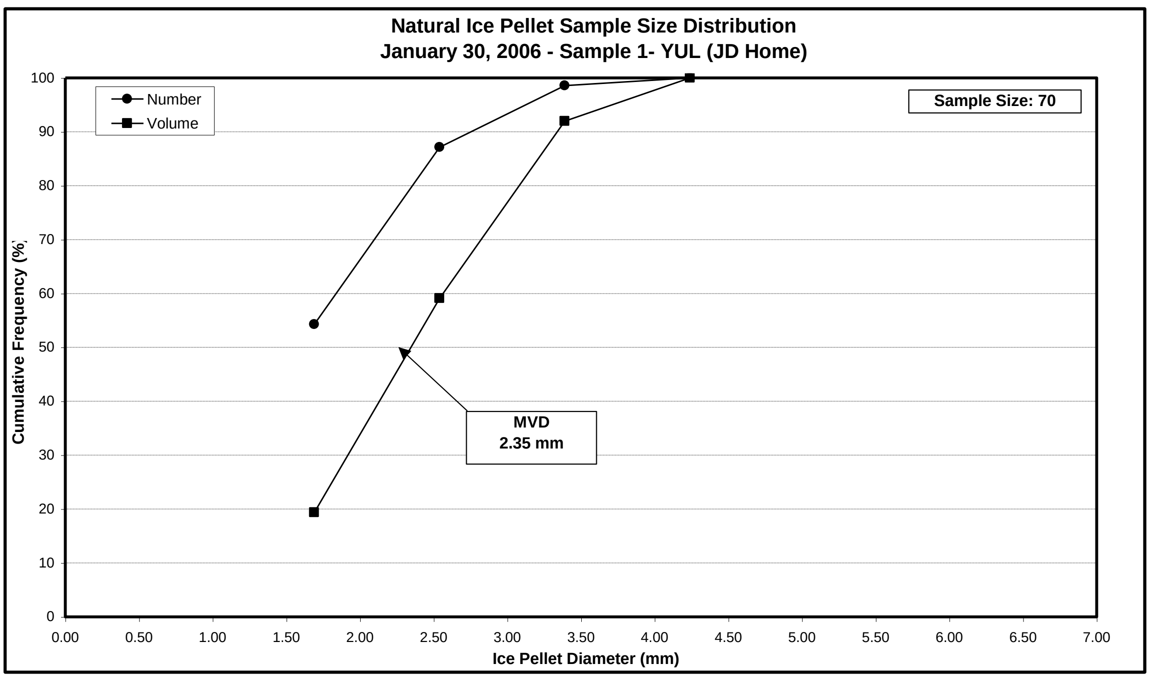

Natural Ice Pellet Sample Size Frequency Distribution
January 17, 2006 - YUL (Test Site)
Sample Size: 60
Number Frequency (%)
Ice Pellet Diameter (mm)
0
2
4
6
8
10
12
14
16
18
20
1.00
1.20
1.40
1.60
1.80
2.00
2.20
2.40
2.60
2.80
3.00
4.00
10.0
5.0
6.7
1.7
5.0
18.3
11.7
16.7
8.3
1.7
8.3
6.7

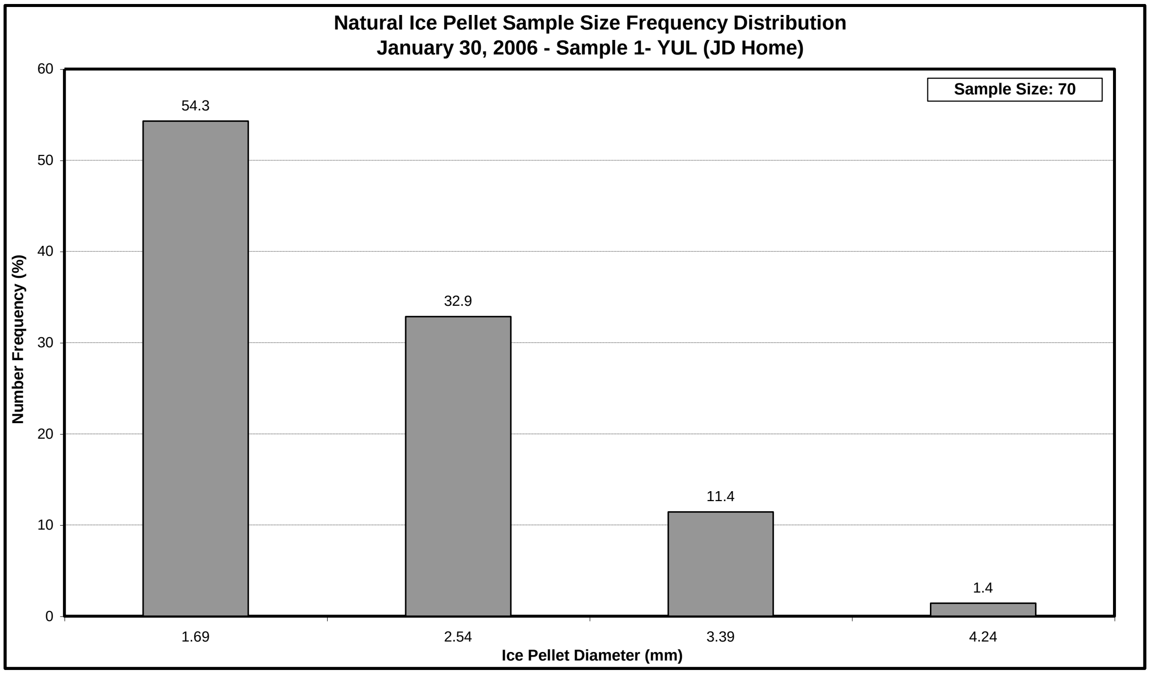

January 21, 2006 YUL (Test Site)

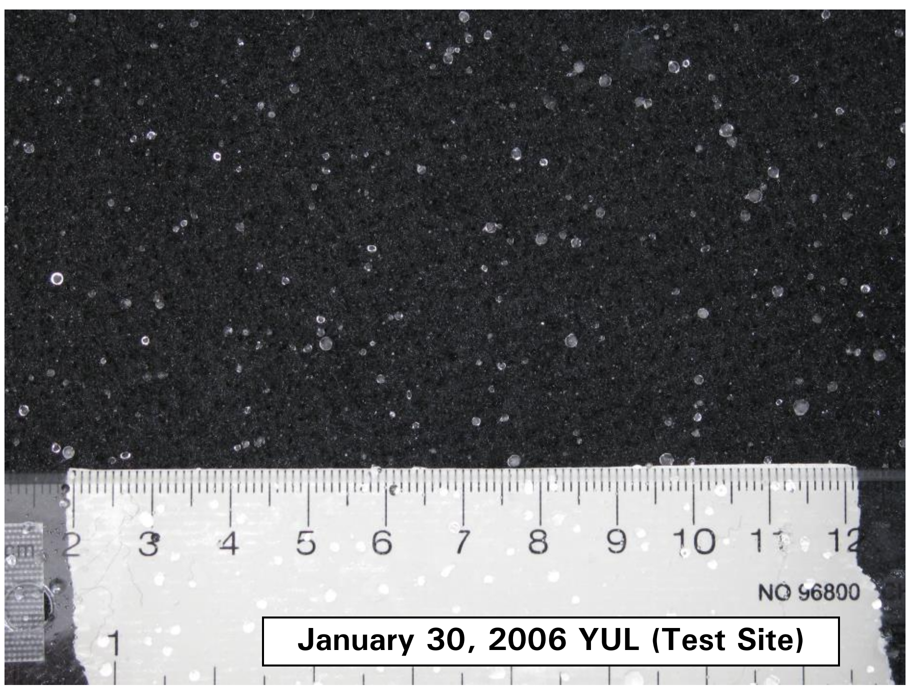

Natural Ice Pellet Sample Size Distribution
January 21, 2006 - YUL (Test Site)
Number
Volume
Sample Size: 60
MVD
3.45 mm
Cumulative Frequency (%)
Ice Pellet Diameter (mm)
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
6.50
7.00
0
10
20
30
40
50
60
70
80
90
100

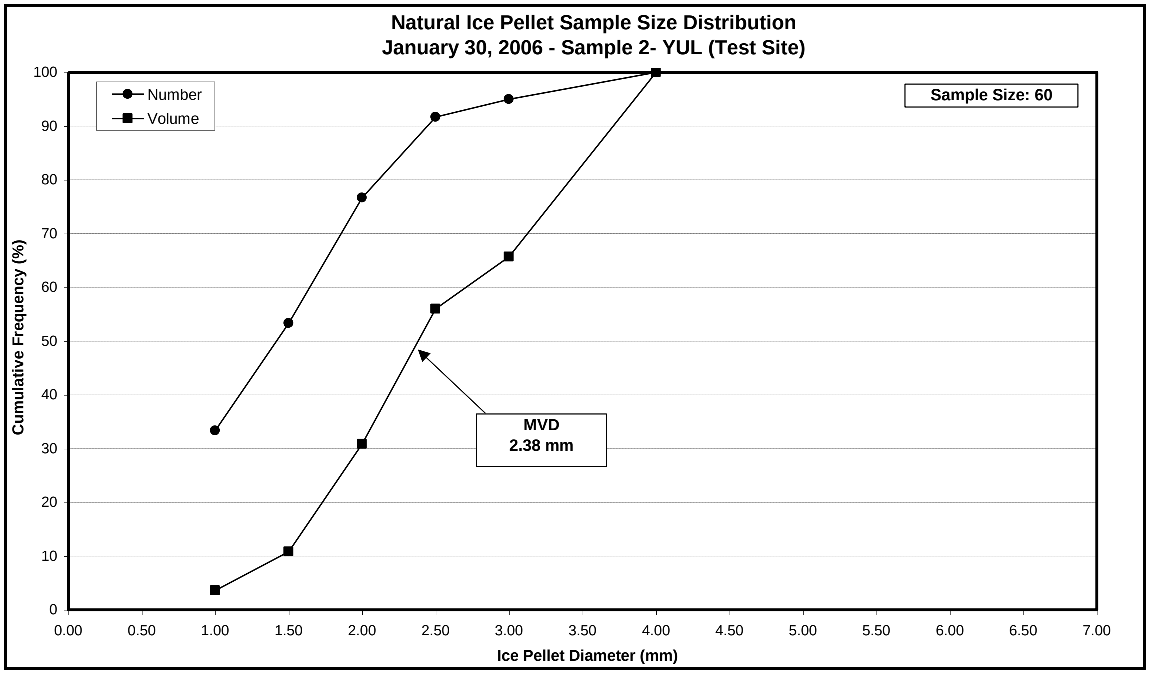

Natural Ice Pellet Sample Size Frequency Distribution
January 21, 2006 - YUL (Test Site)
Sample Size: 60
Number Frequency (%)
Ice Pellet Diameter (mm)
21.7
5.0
5.0
3.3
1.7
20.0
1.7
1.7
21.7
13.3
3.3
1.7
1.00
1.20
1.40
1.60
1.80
2.00
2.40
2.60
3.00
4.00
5.00
6.00
0
5
10
15
20
25
30


January 30, 2006 YUL (JD Home)

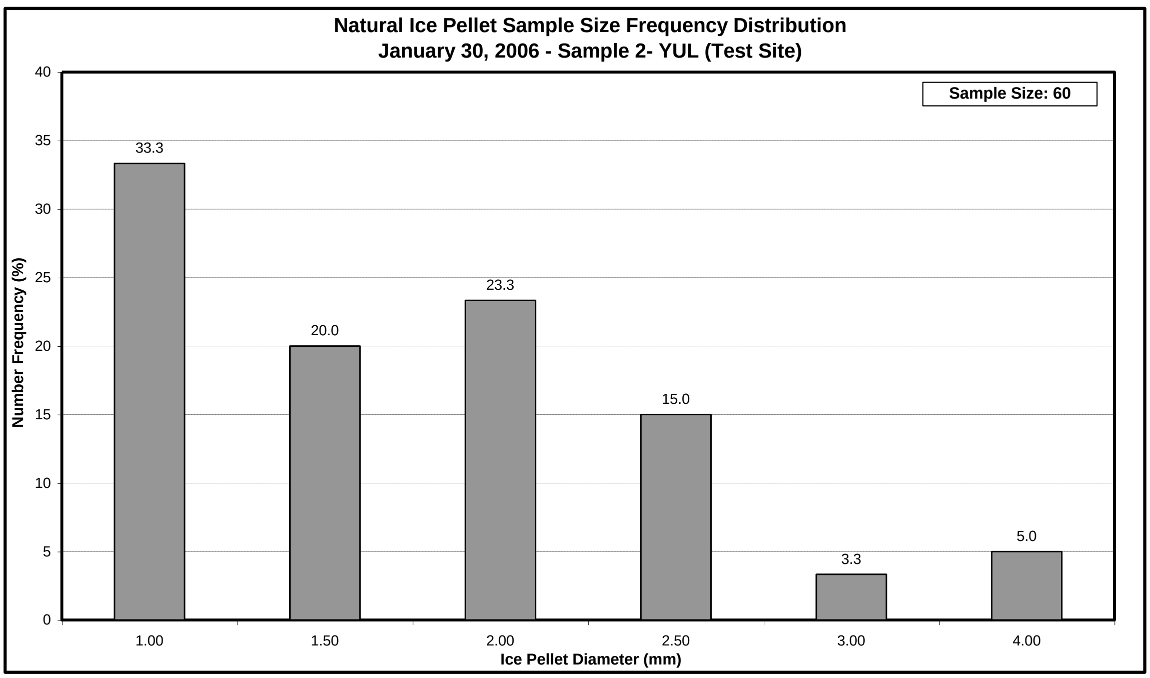

Natural Ice Pellet Sample Size Distribution
January 30, 2006 - Sample 1- YUL (JD Home)
Number
Volume
Sample Size: 70
MVD
2.35 mm
Cumulative Frequency (%)
Ice Pellet Diameter (mm)
0
10
20
30
40
50
60
70
80
90
100
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
6.50
7.00


Natural Ice Pellet Sample Size Frequency Distribution
January 30, 2006 - Sample 1- YUL (JD Home)
Sample Size: 70
Number Frequency (%)
Ice Pellet Diameter (mm)
0
10
20
30
40
50
60
54.3
32.9
11.4
1.4
1.69
2.54
3.39
4.24

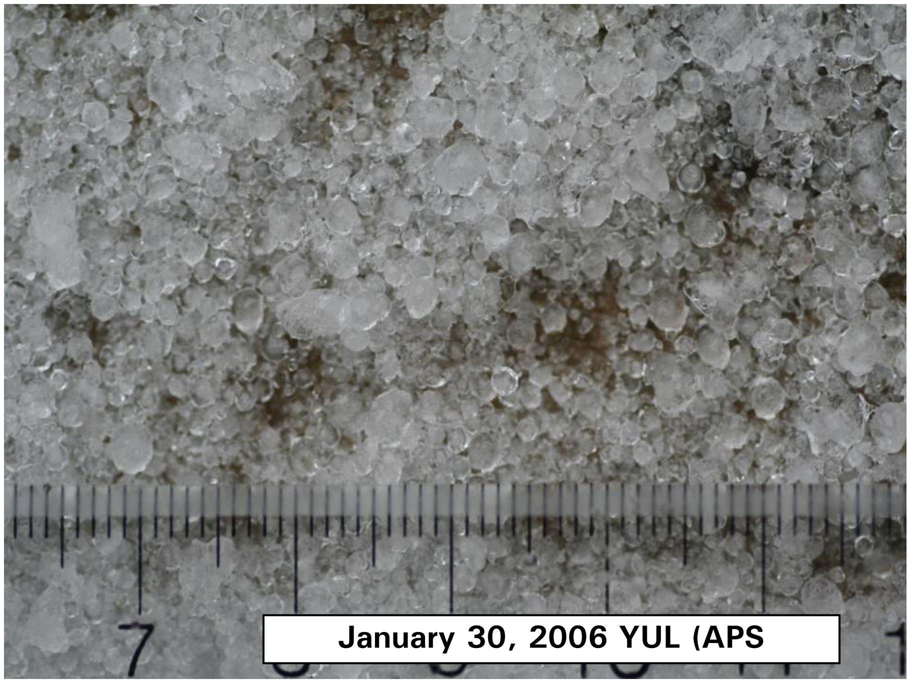

NO 96800
January 30, 2006 YUL (Test Site)

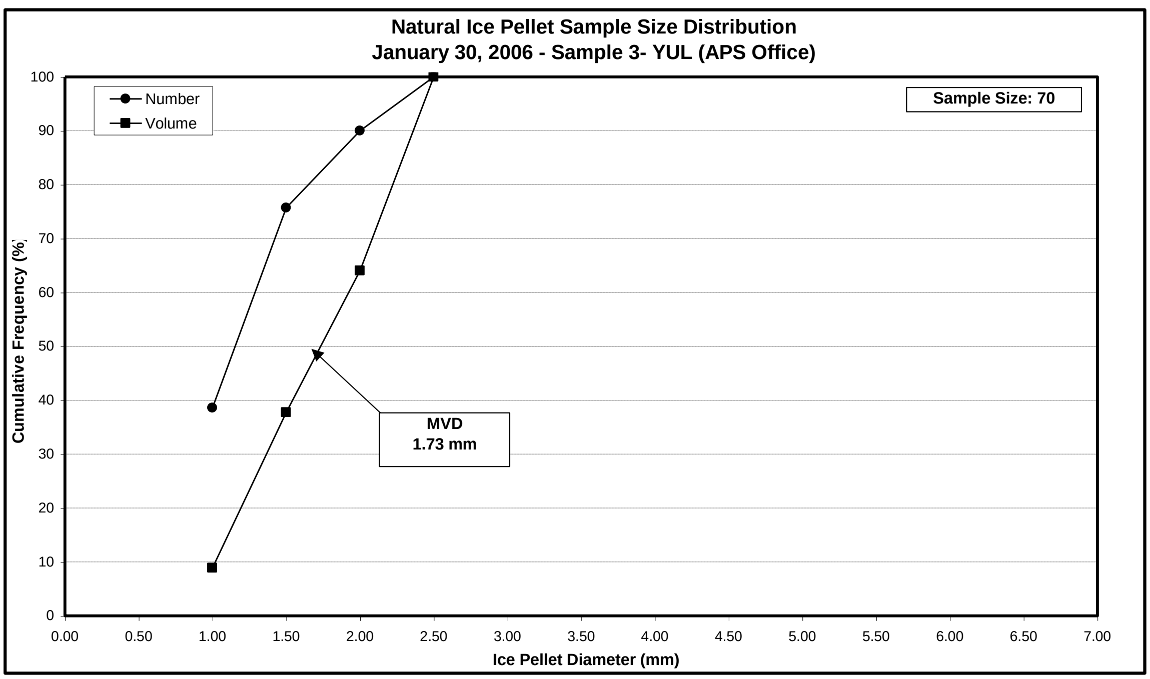


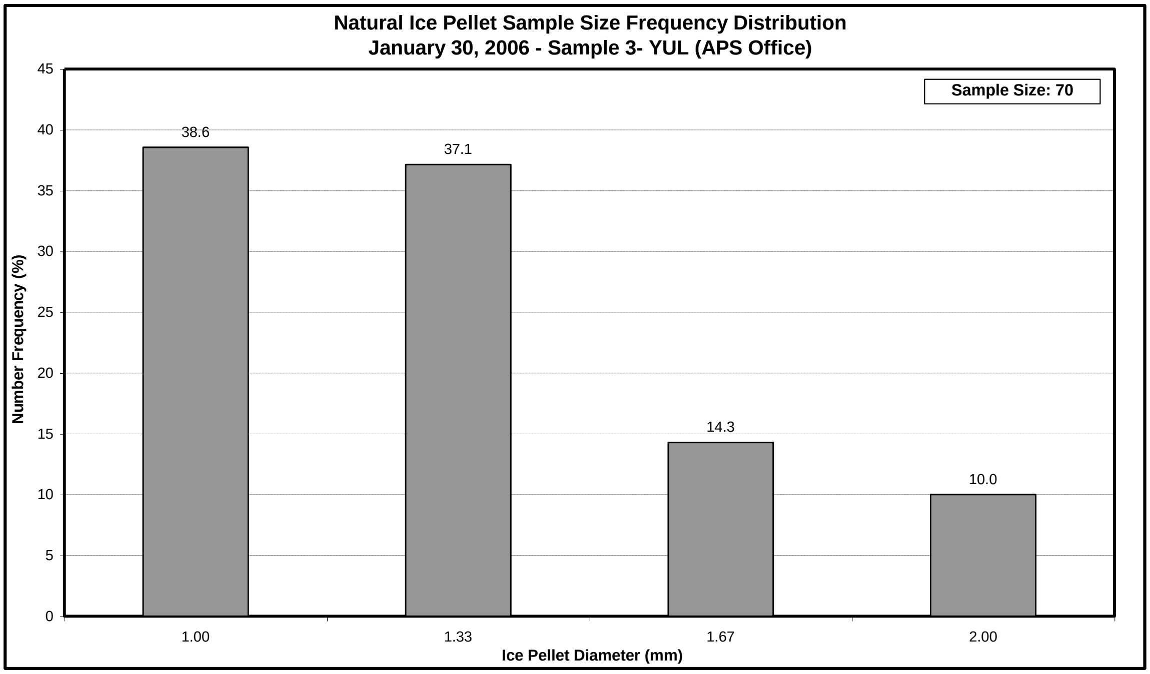
Natural Ice Pellet Sample Size Distribution
January 30, 2006 - Sample 2- YUL (Test Site)
Number
Volume
Sample Size: 60
MVD
2.38 mm
Cumulative Frequency (%)
Ice Pellet Diameter (mm)
0
10
20
30
40
50
60
70
80
90
100
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
6.50
7.00

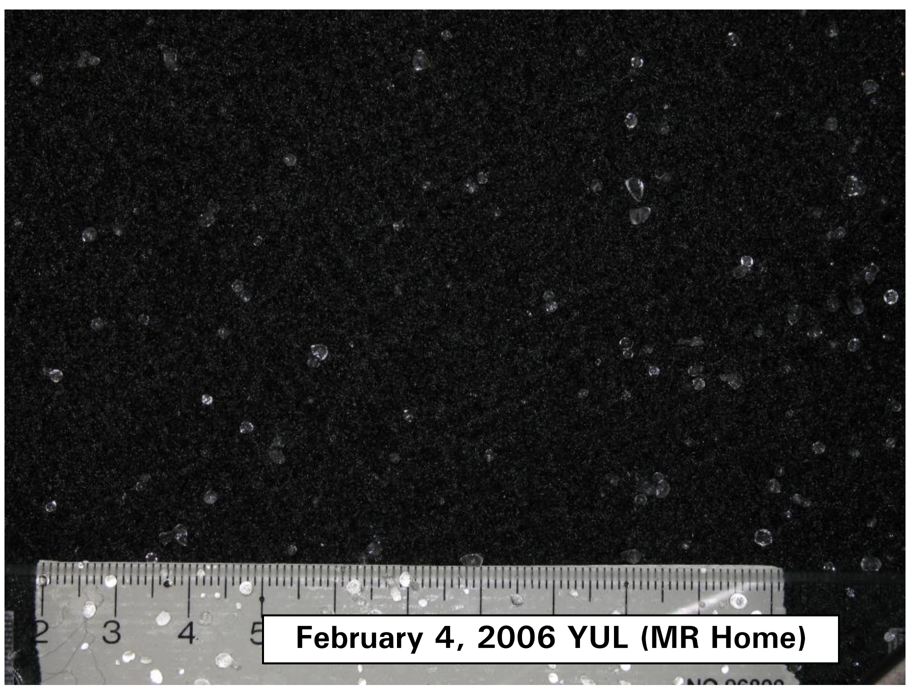


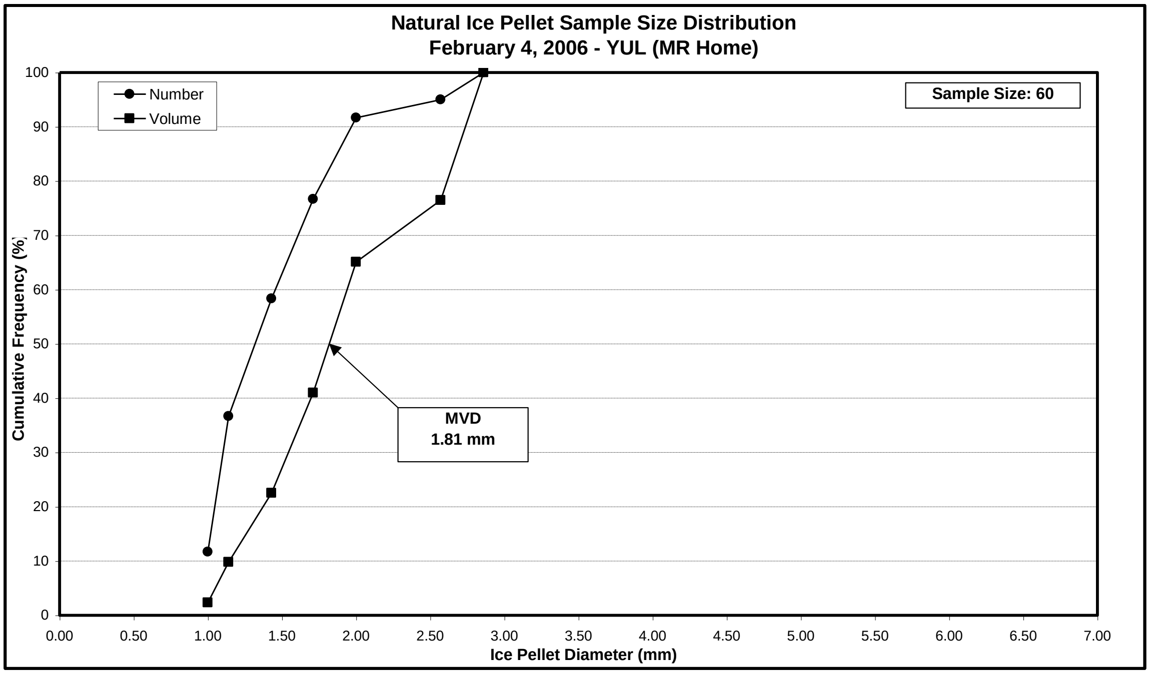
Natural Ice Pellet Sample Size Frequency Distribution
January 30, 2006 - Sample 2- YUL (Test Site)
Sample Size: 60
Number Frequency (%)
Ice Pellet Diameter (mm)
0
5
10
15
20
25
30
35
40
33.3
20.0
23.3
15.0
3.3
5.0
1.00
1.50
2.00
2.50
3.00
4.00


January 30, 2006 YUL (APS

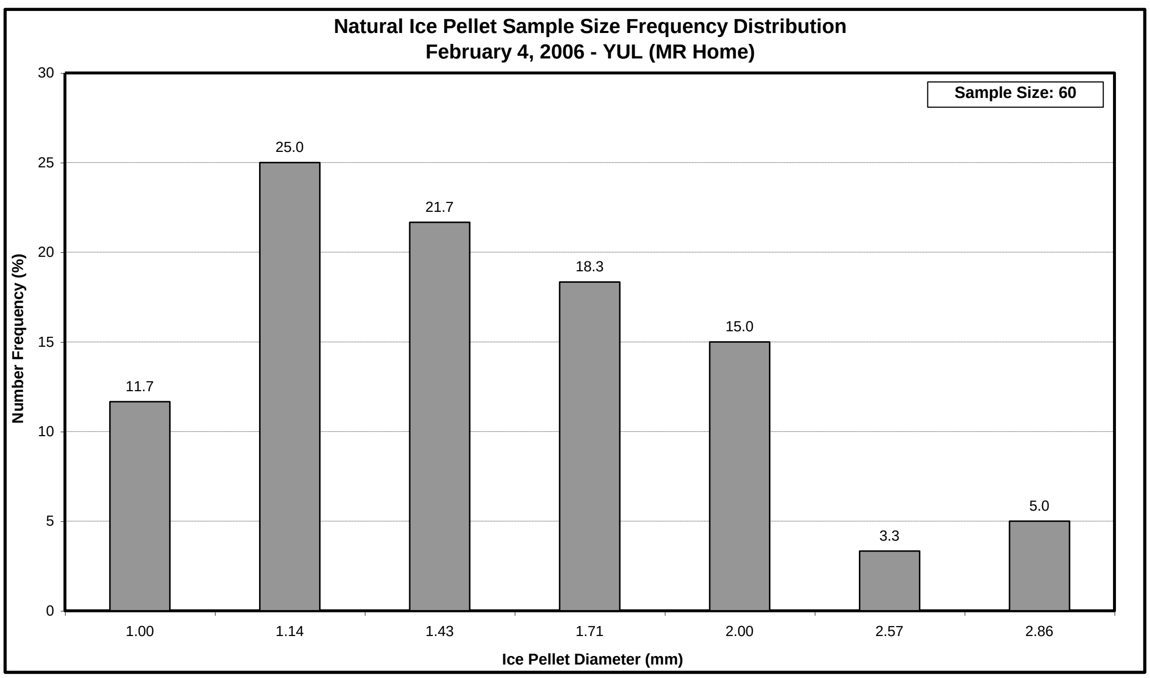

Natural Ice Pellet Sample Size Distribution
January 30, 2006 - Sample 3- YUL (APS Office)
Number
Volume
Sample Size: 70
MVD
1.73 mm
Cumulative Frequency (%)
Ice Pellet Diameter (mm)
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
6.50
7.00
0
10
20
30
40
50
60
70
80
90
100


Natural Ice Pellet Sample Size Frequency Distribution
January 30, 2006 - Sample 3- YUL (APS Office)
Sample Size: 70
Number Frequency (%)
Ice Pellet Diameter (mm)
1.00
1.33
1.67
2.00
38.6
37.1
14.3
10.0
0
5
10
15
20
25
30
35
40
45

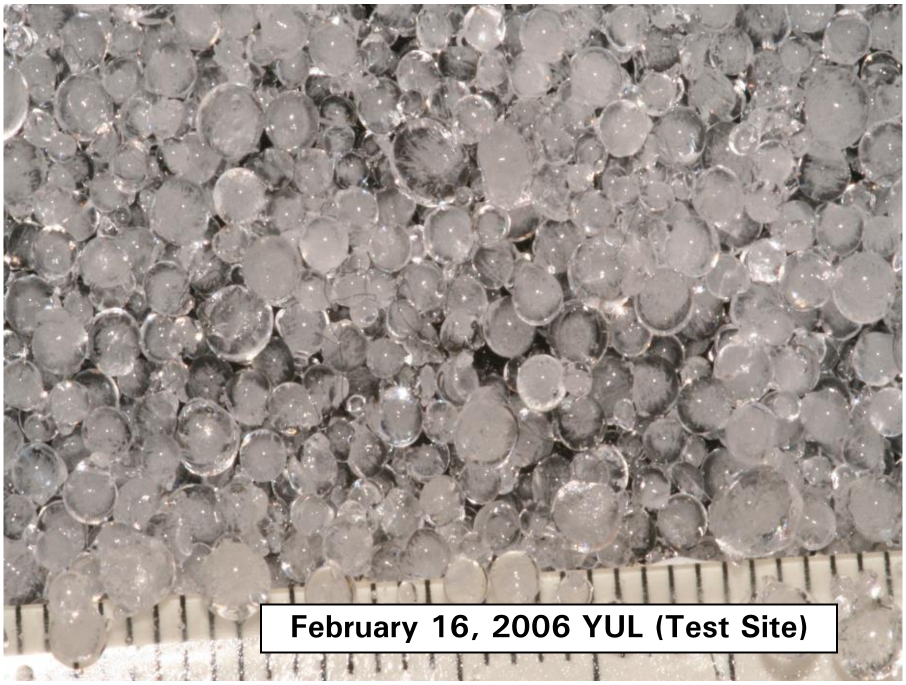

February 4, 2006 YUL (MR Home)

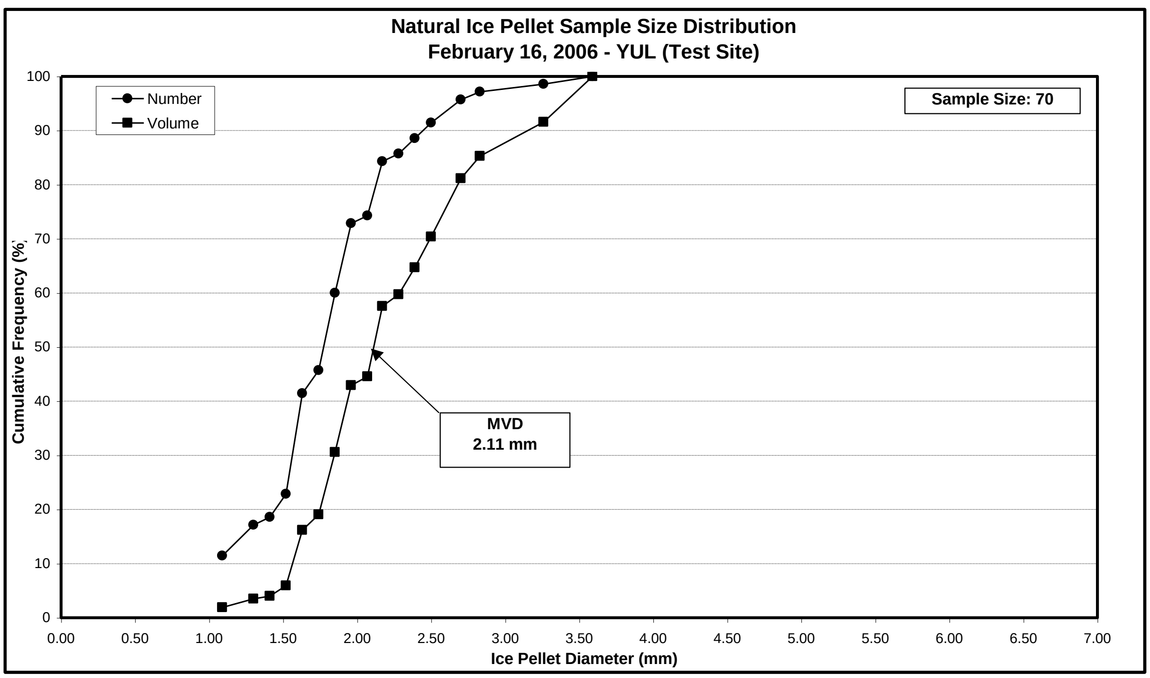


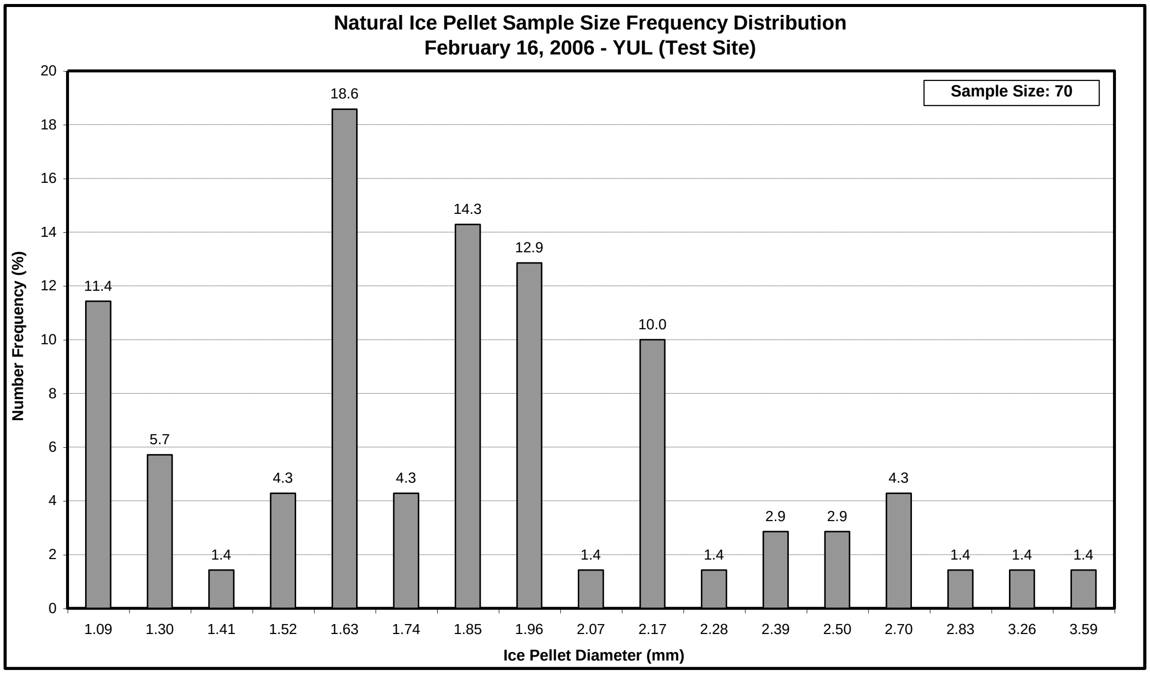
Natural Ice Pellet Sample Size Distribution
February 4, 2006 - YUL (MR Home)
Number
Volume
Sample Size: 60
MVD
1.81 mm
Cumulative Frequency (%)
Ice Pellet Diameter (mm)



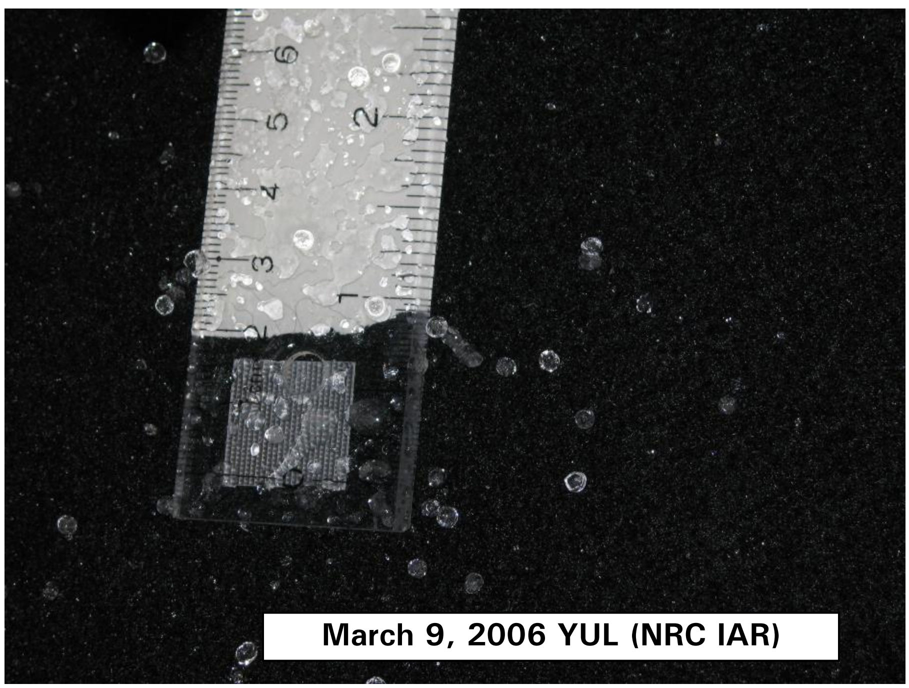
Natural Ice Pellet Sample Size Frequency Distribution
February 4, 2006 - YUL (MR Home)
Sample Size: 60
11.7
25.0
21.7
18.3
15.0
3.3
5.0
1.00
1.14
1.43
1.71
2.00
2.57
2.86
Number Frequency (%)
Ice Pellet Diameter (mm)

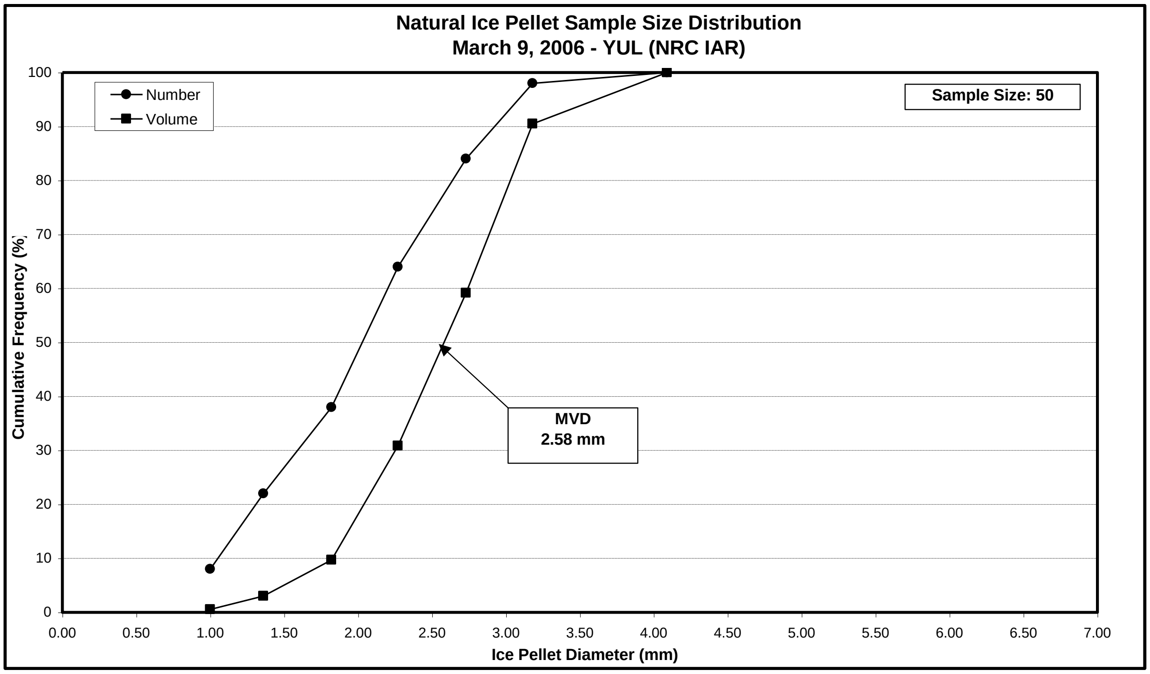

February 16, 2006 YUL (Test Site)

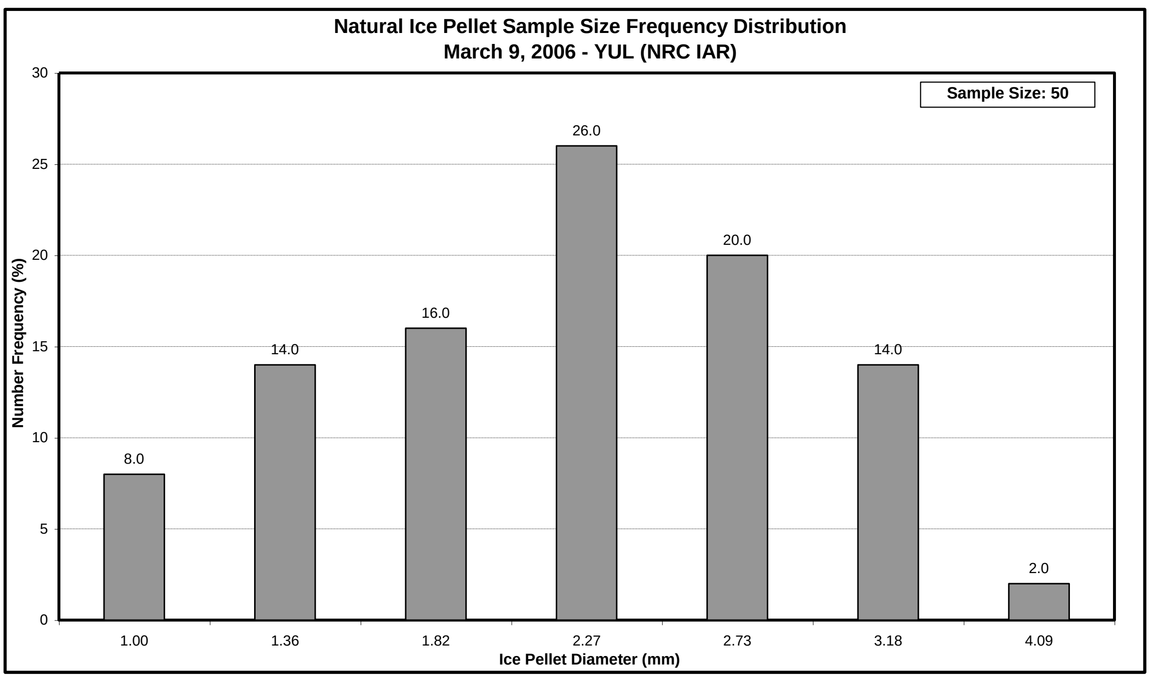

Natural Ice Pellet Sample Size Distribution
February 16, 2006 - YUL (Test Site)
Number
Volume
Sample Size: 70
Cumulative Frequency (%)
MVD
2.11 mm
Ice Pellet Diameter (mm)
0
10
20
30
40
50
60
70
80
90
100
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
6.50
7.00

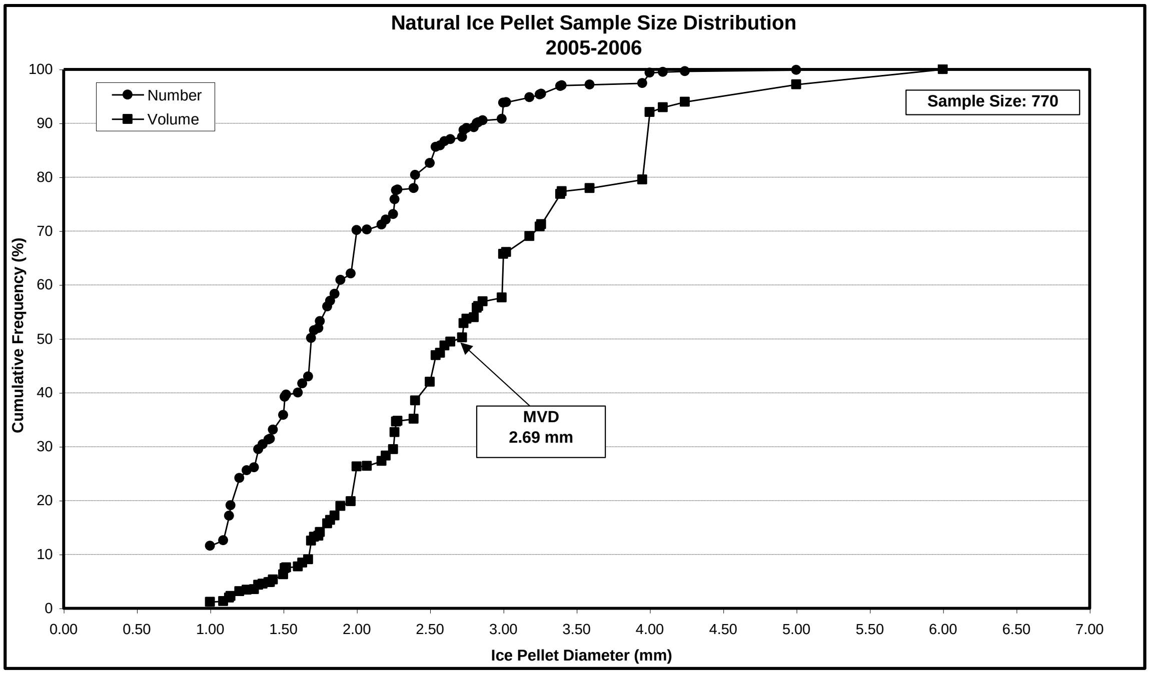


Natural Ice Pellet Sample Size Frequency Distribution
February 16, 2006 - YUL (Test Site)
Sample Size: 70
Number Frequency (%)
Ice Pellet Diameter (mm)
0
2
4
6
8
10
12
14
16
18
20
11.4
5.7
1.4
4.3
18.6
4.3
14.3
12.9
1.4
10.0
1.4
2.9
2.9
4.3
1.4
1.4
1.4
1.09
1.30
1.41
1.52
1.63
1.74
1.85
1.96
2.07
2.17
2.28
2.39
2.50
2.70
2.83
3.26
3.59

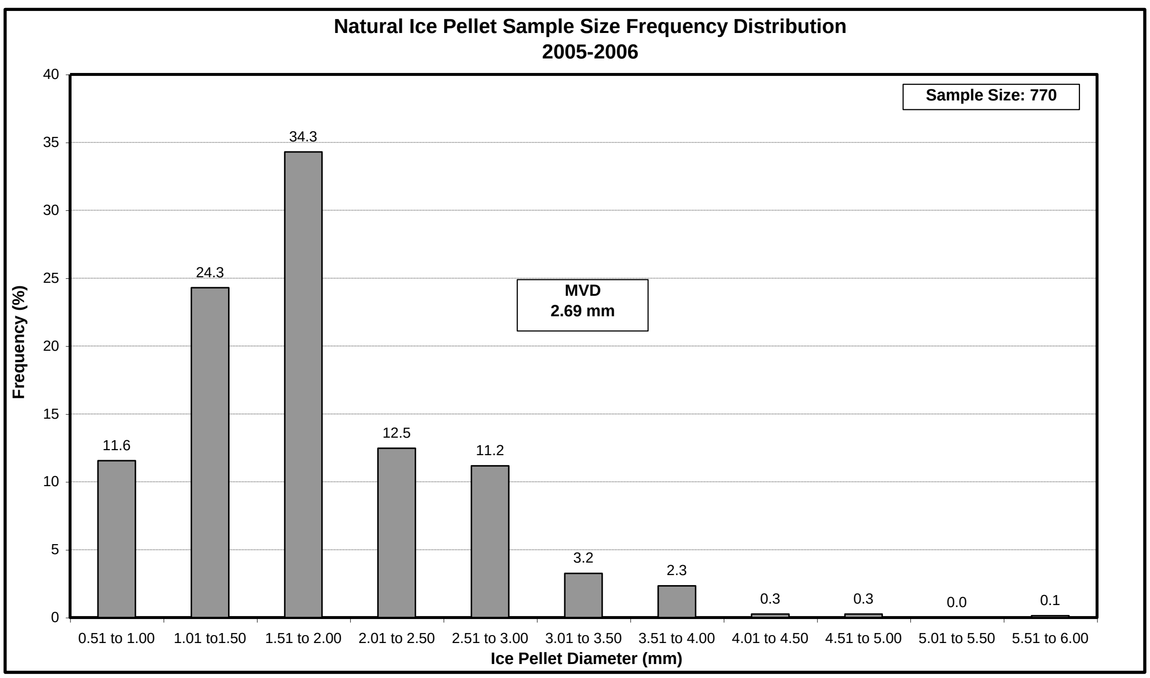

March 9, 2006 YUL (NRC IAR)


Natural Ice Pellet Sample Size Distribution
March 9, 2006 - YUL (NRC IAR)
Number
Volume
Sample Size: 50
MVD
2.58 mm
Cumulative Frequency (%)
Ice Pellet Diameter (mm)
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
6.50
7.00
0
10
20
30
40
50
60
70
80
90
100


Natural Ice Pellet Sample Size Frequency Distribution
March 9, 2006 - YUL (NRC IAR)
Sample Size: 50
Number Frequency (%)
Ice Pellet Diameter (mm)
8.0
14.0
16.0
26.0
20.0
14.0
2.0
1.00
1.36
1.82
2.27
2.73
3.18
4.09
0
5
10
15
20
25
30



Natural Ice Pellet Sample Size Distribution
2005-2006
Number
Volume
Sample Size: 770
MVD
2.69 mm
Cumulative Frequency (%)
Ice Pellet Diameter (mm)
0
10
20
30
40
50
60
70
80
90
100
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
6.50
7.00



Natural Ice Pellet Sample Size Frequency Distribution
2005-2006
Sample Size: 770
MVD
2.69 mm
Frequency (%)
Ice Pellet Diameter (mm)
11.6
24.3
34.3
12.5
11.2
3.2
2.3
0.3
0.3
0.0
0.1
0.51 to 1.00
1.01 to1.50
1.51 to 2.00
2.01 to 2.50
2.51 to 3.00
3.01 to 3.50
3.51 to 4.00
4.01 to 4.50
4.51 to 5.00
5.01 to 5.50
5.51 to 6.00

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