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Environmental and Runway Surface Conditions During Friction Tests at North Bay Airport: January-February 2002

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Nirmal K. Sinha

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Environmental and Runway Surface Conditions During Friction Tests at North Bay Airport: January-February 1999

By

Nirmal K. Sinha
National Research Council Canada

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Since some of the accepted measures in the industry are imperial, metric measures are not always used in this report.

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16. Abstract

The Joint Winter Runway Friction Measurement Program (JWRFMP) was extended to include trials at North Bay Airport in Ontario, Canada, during the week of January 27 to February 8, 2002. Seven ground friction measuring devices from different countries were assembled and used at North Bay Airport. During the two weeks, one commercial passenger aircraft, a Cessna 414, also participated in the tests.

This report contains information on environmental conditions during the tests and surface contaminants collected during the tests. Due to the environmental limitations, man-made winter contaminants (in the form of ice) and natural contaminants were used for testing. Natural contaminants included freshly fallen snow and old accumulated snow significantly thicker than the allowable snow accumulation on operational runways. Consequently, some of the tests were carried out under conditions that may exceed real-life airport operational conditions.

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16. Résumé

Le Programme conjoint de recherche sur la glissance des chaussées aéronautiques l'hiver (PCRGCAH) a été prolongé de façon à inclure deux semaines d'essais réalisés à l'aéroport de North Bay, Ontario, Canada, du 27 janvier au 8 février 2002. Sept dispositifs de mesure du frottement au sol provenant de différents pays ont été réunis et mis en œuvre. Un avion commercial de passagers, soit un Cessna 414, a également pris part aux essais.

Le rapport porte sur les conditions environnementales dans lesquelles ont été menés les essais et sur les contaminants en jeu. En raison de contraintes météorologiques, il a fallu recourir à des contaminants artificiels (de la glace), en plus des contaminants naturels. Parmi les contaminants naturels figuraient de la neige fraîche et de la vieille neige accumulée qui formaient une couche beaucoup plus épaisse que ce qui est normalement admis sur des pistes aéroportuaires. Il s'ensuit que certains des essais ont été menés dans des conditions susceptibles d'exagérer les conditions réelles.

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EXECUTIVE SUMMARY

A five-year project was initiated in December 1995 to understand and to quantify the factors that influence aircraft braking friction and the contamination drag of various aircraft on winter contaminated runways, in order to estimate landing or take-off distances on wet and winter contaminated runways. A collaborative agreement was made between the National Aeronautics and Space Administration (NASA) and Transport Canada (TC) to conduct field tests using various instrumented aircraft and ground friction measuring vehicles. The U.S. Federal Aviation Administration (FAA), National Research Council Canada (NRC) and organizations from other countries (e.g., the Norwegian Civil Aviation Administration) eventually joined this program, which is now called the Joint Winter Runway Friction Measurement Program (JWRFMP).

The JWRFMP was extended to include trials at North Bay Airport in Ontario from January 27 to February 8, 2002. Seven ground friction measuring devices from different countries were assembled and used at North Bay Airport. During this period, one commercial passenger aircraft, a Cessna 414, also participated in the tests.

The primary objectives of the 2002 North Bay Airport friction tests were to:

1. Validate the International Runway Friction Index using the International Reference Vehicle (IRV)
2. Calibrate local devices a master device calibrated by the IRV
3. Conduct scarified ice tests between the IRV and the Electronic Recording Decelerometer (ERD)
4. Conduct tests with the ERD, the Surfact Friction Tester (SFT) and the IRV on operational runways
5. Compare variable slip, tires and pressure to the ERD

This report contains information on environmental conditions during the tests and surface contaminants collected during the tests. Due to the environmental limitations, man-made winter contaminants (in the form of ice) and natural contaminants were used for testing. Natural contaminants included freshly fallen snow and old accumulated snow significantly thicker than the allowable snow accumulation on operational runways. Consequently, some of the tests were carried out under conditions that may exceed real-life airport operational conditions. However, the results obtained from the ground vehicles are useful for comparative studies.

Most of the objectives were met, except for the studies on scarified ice, which experienced unavoidable limitations due to a lack of uniformly thick ice cover. An effort was made to thicken the man-made ice strip, but it was found not to be practical.

Air temperature; relative humidity; wind speed and direction; sky conditions, including cloud cover; the presence of solid or liquid particles in the air and on the pavement surface; movement-area surface texture; pavement surface temperature; the vertical and spatial temperature gradient in the pavement; and solar radiation all play important roles in determining the surface conditions of a runway. Continuity in the measurement of all these parameters should be ensured. It is also recommended that continuous measurement of solar radiation at the test site be an integral part of future measurements.

SOMMAIRE

Un programme de recherche quinquennal a été lancé en décembre 1995 dans le but d'approfondir et de quantifier les facteurs qui influent sur le coefficient de freinage et la traînée due à la contamination, lorsque divers aéronefs utilisent des pistes contaminées. Le but ultime état d'établir les distances d'atterrissage ou de décollage des aéronefs sur des pistes mouillées et des pistes chargées de contamination hivernale. Une entente de collaboration a été conclue entre la National Aeronautics and Space Administration (NASA) et Transports Canada (TC) en vue de la conduite d'essais en vraie grandeur à l'aide de divers avions instrumentés et véhicules de mesure du frottement au sol. La U.S. Federal Aviation Administration (FAA), le Conseil national de recherches du Canada (CNRC) et des organismes d'autres pays (entre autres, l'Administration de l'aviation civile de Norvège) se sont par la suite joints au programme, appelé Programme conjoint de recherche sur la glissance des chaussées aéronautiques l'hiver (PCRGCAH).

Le PCRGCAH a été prolongé de façon à inclure des essais menés à l'aéroport de North Bay, en Ontario, du 27 janvier au 8 février 2002. Ces essais mettaient en jeu sept dispositifs de mesure du frottement au sol provenant de différents pays. Un avion commercial de passagers, soit un Cessna 414, a également pris part aux essais.

Les principaux objectifs de ces essais étaient de :

1. valider l'indice international de glissance des pistes (IRFI, pour *International Runway Friction Index*) à l'aide du véhicule international de référence (IRV, pour *International Reference Vehicle*);
2. étalonner les dispositifs locaux de mesure du frottement par référence à un dispositif étalonné à l'aide de l'IRV;
3. mener des essais sur glace scarifiée à l'aide de l'IRV et du décéléromètre électronique (ERD, pour *Electronic Recording Decelerometer*);
4. mener des essais avec l'ERD, le glissancemètre (SFT, pour *Surface Friction Tester*) et l'IRV sur des pistes opérationnelles;
5. faire des comparaisons des valeurs obtenues avec l'ERD selon divers degrés de glissance, pneus et pressions.

Le rapport porte sur les conditions environnementales dans lesquelles ont été menés les essais et sur les contaminants en jeu. En raison de contraintes météorologiques, il a fallu recourir à des contaminants artificiels (de la glace), en plus des contaminants naturels. Parmi les contaminants naturels figuraient de la neige fraîche et de la vieille neige accumulée qui formaient une couche beaucoup plus épaisse que ce qui est normalement admis sur des pistes aéroportuaires. Il s'ensuit que certains des essais ont été menés dans des conditions susceptibles d'exagérer les conditions réelles. Mais les résultats obtenus à l'aide des véhicules au sol demeurent valables à des fins de comparaison.

La plupart des objectifs assignés au projet ont été atteints, sauf pour ce qui est des essais sur glace scarifiée, qui se sont heurtés à une contrainte inévitable, soit l'absence d'un couvert de glace d'épaisseur uniforme. Des tentatives ont bien été faites afin d'épaissir la bande de glace artificielle, mais sans succès.

De multiples paramètres contribuent de manière importante à déterminer l'état de surface d'une piste : température de l'air, humidité relative, vitesse et direction du vent, état du ciel, y compris le couvert nuageux, présence de particules solides ou liquides dans l'air et sur la chaussée, texture de la surface de l'aire de mouvement, température de la surface de la chaussée, gradient de température vertical et spatial dans la chaussée, rayonnement solaire. Il y a lieu d'instaurer une continuité dans la mesure de tous ces paramètres. Il est également recommandé d'intégrer aux futures campagnes de mesure la mesure en continu du rayonnement solaire au site d'essai.

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GLOSSARY OF TERMS

ASTM	American Society for Testing and Materials
BV11	Trade name for friction measuring device manufactured by Skiddometer – from FAA Technical Center, USA
CRFI	Canadian Runway Friction Index
ERD	Electronic Recording Decelerometer mounted in a Chevrolet Blazer
FAA	Federal Aviation Administration, USA
GT	GripTester-Standard
IMAG	Instrument de Mesure Automatique de la Glissance
IRFI	International Runway Friction Index
IRV	International Reference Vehicle
ITTV	Instrumented Tire Test Vehicle (NASA Langley Research Center, USA)
JWRFMP	Joint Winter Runway Friction Measurement Program
NASA	National Aeronautics and Space Administration
NRC	National Research Council Canada
PIARC	World Road Association (formerly Permanent International Association of Road Congresses)
RFT	Runway Friction Tester – from FAA Technical Center, USA
SFT	Surface Friction Tester
TC	Transport Canada
TDC	Transportation Development Centre of Transport Canada

1 INTRODUCTION

1.1 Background

In December 1995, a five-year project was initiated to understand and to quantify the factors that influence the aircraft braking friction and contamination drag of various aircraft on winter contaminated runways in order to estimate landing or take-off distances on wet and winter contaminated runways. A collaborative agreement was made between the National Aeronautics and Space Administration (NASA) and Transport Canada (TC) to conduct field tests using various instrumented aircraft and ground friction measuring vehicles. The U.S. Federal Aviation Administration (FAA) and National Research Council Canada (NRC) also joined this project as additional collaborating agencies. This was known as the NASA/FAA/TC/NRC winter runway aircraft operation and surface friction measuring program. Several organizations from other countries (e.g., the Norwegian Civil Aviation Administration) eventually joined the program, which is now called the Joint Winter Runway Friction Measurement Program (JWRFMP).

The first three years of testing were conducted at North Bay Airport in North Bay, Ontario, Canada, during the winters of 1995-1996, 1996-1997 and 1997-98. These three sets of field tests were successful in providing initial comparative data between four different types of aircraft (the NRC Falcon 20, the NASA B737, the FAA B727 and the deHavilland Dash 8) and several ground friction measuring devices. During the winter of 1997-98, ground vehicle testing was also conducted on specially made test tracks beside the main runway of the newly constructed Oslo International Airport in Norway. JWRFMP was then expanded to include K.I. Sawyer Airbase in Michigan, USA, during the winter of 1998-99, in addition to tests at North Bay Airport. NASA's newly instrumented B757 aircraft participated in this test series. North Bay was used again in January 2000 when NRC's Falcon 20 was the only aircraft deployed. As part of the 1999-00 winter tests, a series of tests was carried out at North Bay and another series involving a number of passenger aircraft was carried out at Munich Airport in Germany from February 20-27, 2000. JWRFMP was extended for a sixth season, to the winter of 2000-01, and field tests were carried out at both North Bay and Erding Airbase in Germany.

Considerable efforts have been expended over the past several years to understand the correlation between the friction factors measured by the ground friction measuring devices on runways, and the friction coefficients derived from the performance of aircraft operating on runways [1, 2]. JWRFMP has gained increasing international support and recognition, and stakeholders are working cooperatively towards an approved International Runway Friction Index (IRFI) based on the most accurate and comprehensive data possible [1].

1.2 Objectives and Scope

The test objectives for the ground friction measuring devices were primarily to assess their effectiveness in measuring friction on various winter contaminated runway surfaces, and to standardize their outputs into an (IRFI. The main objective of the Munich Airport tests in February 2000 [3] was the validation of IRFI correlation between the ground devices. Devices that participated in these tests included those that were harmonized in previous field tests in 1998 and 1999. The other objectives were to explore IRFI relative to aircraft-type braking performance, to explore the new IRFI reference device equipped with aircraft test tires, to develop operational runway measurement techniques for IRFI, and to expand the IRFI for slush conditions.

Thirteen ground friction measuring devices from different countries were assembled and used at Munich Airport during the week of February 21-27, 2000. During this period five commercial passenger aircraft also participated in the tests: one Airbus A320-DALAE from Aero Lloyd airline, one Airbus A321 from Sabena airline, one Boeing B737-300 from Deutsche British Airways, one Dornier D328-100 from Dornier aircraft manufacturer and one Airbus A319 from Swissair airline. The report [3] contains information on environmental conditions during the tests and surface contaminants collected during the Munich Airport tests.

In the winter of 2000-01 field tests were carried out at both North Bay in Canada and Munich in Germany. The German site was moved to Erding Airbase, very close to the Munich International Airport, where a Dornier D328-100 aircraft participated in the tests.

An (IRFI was developed on the basis of investigations carried out in the past six years. It is designated as American Society for Testing and Materials (ASTM) Standard E2100.

The primary objectives of the 2002 North Bay Airport friction tests were to:

1. Validate IRFI using the IRV (International Reference Vehicle)
2. Calibrate local devices to a master device calibrated by the IRV
3. Conduct scarified ice tests between the IRV and ERD (Electronic Recording Decelerometer)
4. Conduct tests with the ERD, SFT (Surface Friction Tester) and IRV on operational runways
5. Compare IRV variable slip, tires and pressure to the ERD

IRFI IRV-Master calibration

These special tests will be used to verify the E2100 method of IRFI to calibrate to a master device. They will be conducted at two sets of sites. Set A will consist of compacted snow, ice and a winter wet surface, and Set B will be the same sites on another day. Set A will be used to calibrate the IRV with a master device, and Set B will be used to correlate the master device to the local devices.

Master-Local device calibration

These tests should include the IRFI-IRV, TC-SFT (SAAB 1985 or 1979), FAA-SFT, NASA-GT (GripTester), FAA-RFT (Runway Friction Tester), FAA Trailer BV-11, NASA-ITTV (Instrumented Tire Test Vehicle) and, if possible, an E274 trailer with ASTM E-524 tires at 165 kPa pressure.

Scarified ice tests between the IRV and ERD

Previous tests were attempted in 2001; however, the ice was too thin and could not be properly prepared. There is still the need to perform this test to determine why fixed-slip devices read higher on scarified ice than smooth ice, and why the ERD reads lower (about the same as smooth ice) on scarified ice.

The tests will include five sets of runs using the IRV and ERD. The IRV should change its slip ratio on each set of runs to get a 15% to 85% range. A sixth set shouldthen be run where the load is increased as much as possible on the IRV. Before each set of runs, the TC-SFT79 should be run as a control.

For these tests, a site on the edge of runway 13-31 should be prepared three to four weeks ahead and built up to at least 13 mm in thickness. A 200 m long section is suggested so that half (100 m) would be virgin and half would be scarified for the test.

Tests with the ERD, SFT and IRV on operational runways

These tests will be conducted to test the ASTM standard E2100 on combining each 100 m section into three one-third averages. They will also evaluate the effects of spot measurement versus continuous measurements. These tests should be conducted any time the North Bay ERD makes its normal runs.

IRV variable slip, tires and pressure versus ERD

These tests will compare the IRV and ERD under varying conditions of IRV to determine which conditions more nearly match the ERD. Tests will include variations in slip ratio, different tires and tire pressures, as well as different loads. At least one set of tests should be with similar contact pressure and high slip ratio. The composed snow and ice sections should be used from the calibration and scarified ice tests.

This report contains descriptions of the test conditions for the series of tests carried out at North Bay Airport from 27 January to 08 February 2002. Seven ground friction measuring devices and one small aircraft, a Cessna 414, were used in this series. A special series of tests, the IRFI IRV-Master-Local Device calibration tests, was conducted first to verify the ASTM standard E2100 method of IRFI to calibrate the IRV to a master device. A number of other tests were then performed to use the master device to calibrate the local devices. The information is presented chronologically and by test number. The results of the ground vehicle tests and aircraft tests will be published in separate TC reports, for which data collected by the author and recorded in TC field books will be used.

2 TEST PROGRAM

2.1 Aircraft and Ground Vehicles

One twin-engine aircraft, a Cessna 414, participated in the program and provided opportunities for using a regular small passenger-type aircraft without an antiskid braking system for the tests.

The following seven ground vehicles (test devices) were used to conduct contaminated surface friction measurements during the test period at North Bay Airport.

IRV	International Reference Vehicle (international runway friction standard) – from France
ERD	Electronic Recording Decelerometer mounted in a Chevrolet Blazer – from Transport Canada
TC-SFT-TURBO	Saab airport Surface Friction Tester – from Transport Canada
FAA-BV11	Friction measuring device manufactured by Skiddometer – from FAA Technical Center
FAA-RFT	Runway Friction Tester – from FAA Technical Center
NASA-GT	GripTester-Standard – from NASA Langley Research Center
NASA-ITTV	Instrumented Tire Test Vehicle – from NASA Langley Research Center

The above list included one Instrument de Mesure Automatic de la Glissance (IMAG) device from France, designated as the IRV, as one of the two standard devices. TC's ERD was used as the second standard device because of the correlation established earlier with the NRC Falcon 20 aircraft [2], leading to the development of the Canadian Runway Friction Index (CRFI).

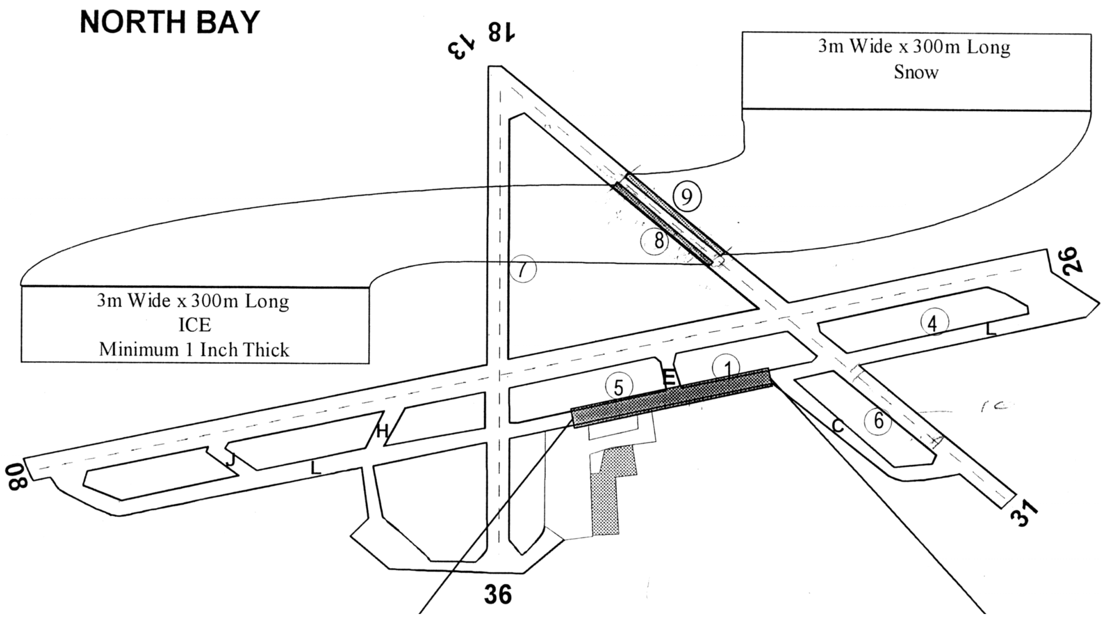


Figure 1. Sections of North Bay Airport used for Joint Winter Runway Friction Measurement Program (JWRFMP) tests in January-February 2002

2.2 Test Facility

North Bay Airport consists of one main runway (08-26), 3 048 m long and 61 m wide, and two subsidiary runways: 13-31, which is 1 829 m long and 46 m wide, and 18-36, which is 1 364 m long and 46 m wide (Figure 1). Since runway 13-31 was a decommissioned runway, it was used as the primary test area.

The daily commercial operation of the runways in North Bay imposes a limit on the use of natural snow cover accumulated on the runway. Since runways 08-26 and 18-36 are kept in operational conditions all the time by removing the natural winter contaminants as soon as possible, the use of these two runways for any testing was very restricted. Sections of runway 18-36, 08-26 and taxiway Lima were therefore used on certain occasions on a "window-of-opportunity" basis, but special permission had to be received from the airport authority for such uses. The North Bay Airport authority, however, designated the entire flight operation area of runway 13-31 for the exclusive use of the present series of tests.

There was a heavy snowfall in North Bay a few days before the start of this test series, which provided an opportunity to plan some tests on the natural, albeit not fresh, snow cover on runway 13-31. A 300 m long section of this runway, north of runway 08-26, was kept as it was after the snowfall (Figure 1). The snow cover in this section was allowed to age and compact. About a third of the width of this 15 m wide section, on the south side of the centre line, was later cleaned to make way for a 3 m wide man-made ice strip on the southern edge and a path for the return of the test vehicles (Figure 1). The rest of this runway was cleaned and an effort was made to remove all the contaminants. However, patches of previously frozen ice-covered sections remained in many areas of the runway. To avoid complications, no chemicals were used to remove these ice patches.

3. OBSERVATIONS

Conditions of the test sections were always examined immediately before the start of the tests. From time to time, the tests were stopped for short periods to allow inspections of the experimental strips and corrective actions, if necessary, before continuing the tests. The air temperature and the pavement surface temperature were measured by a hand-held calibrated digital thermometer. Snow density was evaluated by the procedure described in detail in [4].

Observations made on the environmental conditions and characteristics of the contaminants on the test strip were recorded on a daily basis in a chronological manner. An attempt was also made to link the author's observations with the test numbers, but this was not always possible for each and every test because of unavoidable technical difficulties due to logistics.

Still photographs were taken to keep records of the ever-changing characteristics of the contaminants and the interaction processes between the contaminants, the aircraft and the ground vehicle tires. The photographs were taken in an almost continuous manner during most of the tests. Those taken by the TC photographer were submitted to TC and are retained by the TC Multimedia Publishing Services Branch. The photographs taken by the NASA photographer, Margaret (Peggy) Hopkins, who worked closely with the author during most of the tests, were retained by NASA's Langley Research Center. During the field operations, Peggy Hopkins and the author edited the photographs on a daily basis and added technical information on surface characteristics and environmental conditions (e.g., see Figure 3). NASA's Langley Research Center produced a CD (see CD Attachment) that contains these annotated photographs.

3.1 Sunday 27 January 2002

The author arrived at North Bay Airport's newly opened terminal on Sunday 27 January at 17:30. He was immediately taken to the old terminal building, adjacent to the new terminal, to set up his field laboratory. This was followed by a tour of the entire facility, including an inspection of the runway conditions. It was warm and the air temperature was near the freezing point. The clear sections of the designated runway (13-31), south of main runway 08-26, and the taxiway (Lima) had wet surfaces with patches of ice. The snow cover on runway 13-31, north of runway 08-26, consisted of loose snow on top of patches of compacted snow and asphalt. It was moist and was at isothermal conditions just below the freezing point. A detailed inspection could not be made because of darkness.

A visit was made to the North Bay Airport's weather station. The records showed that most of the loose snow on runway 13-31 fell on Friday 25 January. So the deposited snow on runway 13-31 was only two days old.

3.2 Monday 28 January 2002

There was a heavy overcast with low ceiling in the morning. This condition persisted throughout the day, and it became very windy as the day progressed. The air temperature, T_{air}, was -1ºC during the morning hours, but decreased to -1.8ºC at 12:00. There were indications that a cold wave was coming and the air temperature was dropping as the day progressed.

Test No. 02-28-01, Project 500, was carried out from 14:12 to 14:27 under heavy overcast. The three test devices – IRV, TC-SFT and ERD (shown in Figure 2) – made five test runs at 65 km/h. The location was a strip on the east side of the centre line of runway 13-31, adjacent to the test strip marked as #9 in Figure 1.

The test surface consisted of a 300 m long strip of 20 mm to 25 mm thick loose snow with a 1 mm thick hard crust at the top, on an uneven surface of compacted snow with ice patches on the asphalt surface. As mentioned in section 3.1, the loose snow was about 3 days old.

At 14:05 T_{air} = -4.7ºC; T_{snow} = -1.5ºC.
At 14:35 T_{air} = -5.0ºC; T_{snow} = -1.9ºC (snow mixed with crust material).
Density, ρ, of snow and crust = 0.017 g. cm-3.
At 14:30, after the end of the series of tests, the weather station at the airport provided the following information: T_{air} = -5.5ºC, Dew Point = -9.6ºC, Wind = 18 km/h, gusting to 30 km/h.

As can be seen above, the air temperature started to drop rapidly in the afternoon.

Figure 2. Three test vehicles: IRV (top), Transport Canada's SFT-Turbo (middle) and ERD (bottom) during the tests (410/411) on the ice strip on the west side of the north end of runway 13-31 on 29 January 2002

3.3 Tuesday 29 January 2002

During the night, a cold wave came from the Arctic and the air temperature dropped drastically. At 06:00, the conditions at the airport were: T_{air} = -16ºC, Wind Chill = -25ºC, Wind = NE 17 km/h, light snow, Relative Humidity = 78%, Dew Point = -19ºC, Ceiling = 1200 ft., and Barometric Pressure =- 101.71 kPa.

Test No. 02-29-02, Project 4100, was carried out from 10:10 to 12:25. The morning was spent conducting tests on a man-made ice strip, 300 m long and about 5 m wide on the west side of runway 13-31, marked as #8 in Figure 1. This test strip consisted of clear ice on asphalt as well as patches of bubbly snow ice or granular ice (Figure 3). The surface was smooth, but had some areas of layered ice that cracked when the ERD tested the strip. Clear ice was 2 mm to 3 mm thick. Bubbly, granular ice, or snow-ice (appeared to be white), varied from 5 mm to 15 mm in thickness.

At 09:20 the air temperature, T_a, was -16.5ºC, the temperature of clear ice, T_{ci}, was -11.0ºC near the north end; T_{ci} = -11.1ºC in the middle section and T_{ci} = -11.2ºC at the south end of the test strip.

09:42 First run of first set by IRV (10% slip) and ERD on ice began. This run was preceded by a run by SFT85 (TCSFT-TURBO).

09.49 Second run by IRV (20% slip) and ERD was conducted. This was followed by two IRV tests at 40% and 80% slips, and the final SFT test.

10:10 After the first set of runs, T_a = -16.2ºC and T_{ci} = -10.1ºC near the south end. T_{si} (snow ice) = -11.4ºC in a granular ice patch near the south end. At this time, ERD-induced cracks were noticed in the sections of layered ice.

10:24 The second set of runs began and T_a had increased to -15.8ºC.

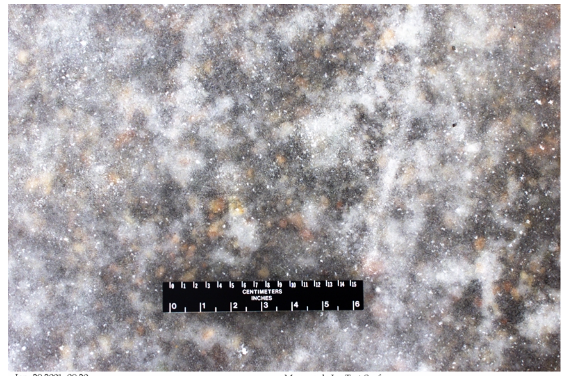
10:31 Diffused sun came out through the cloud cover, giving some solar radiation that was absorbed by the ice strip, particularly the clear and thin ice sections, and the temperature of the material increased. The bubbly or snow ice sections, however, absorbed less radiation and their temperature did not increase as much as that of the sections with clear ice.

10:42 After the second set of runs, T_a = -15.3ºC, T_{ci} = -8.4ºC and T_{si} = -9.7ºC near the south end of the strip.

11:15 After the third set of runs, T_a = -14.4ºC, T_{ci} = -6.8ºC and T_{si} = -8.9ºC near the south end of the test strip.

11:45 After the fourth set of runs, T_a= -14.8ºC. At this time the sun was behind a cloud cover, again affecting the temperatures of the ice strip: T_{ci} = -6.4ºC and T_{si} = -8.1ºC.

(a)



(b)

(c)

Figure 3. Man-made clear ice strip on the west side of runway 13-31, north of runway 08-26 on the morning of 29 January 2002. Note the white patches of bubbly ice (a) and the details of bubbly ice (b) and clear ice (c)

12:25   After the fifth set of runs, T_a= -14.7ºC, T_{ci} = -7.1ºC and T_{si} = -7.5ºC

Note: At 11:55 North Bay Airport's weather station reported that the air temperature was -16.2ºC. This was 1.5ºC colder than T_a= -14.7ºC measured at a height of 1 m above the ice strip.

Test No. 02-29-02, Project 4101, was carried out from 09:20 to 12:25. This series consisted of five repeats at 65 km/h and involved the SFT, IRV and ERD.

The tests were carried out on a 300 m long strip (marked as #9 in Figure 1) of compacted snow with ruts, grooves and loose dry snow, as can be seen in Figure 4. It should be mentioned here that there was an effort made during the previous evening to compact the test bed mechanically by driving a truck back and forth on it. The southern half of the strip compacted reasonably well to a semi-compacted snow, but the northern half was well compacted, especially at the central zone where the IRV tests were to be conducted and the SFT could run. However, even this central compacted strip was rough and had bumps. Both sides of this central line, about a 2 m wide zone, were covered with loose snow and ruts. This could generate some problems for the interoperation of the ERD results.

The following temperature data were collected during the tests:

T_a = -15.3ºC, T_{ci} = -8.4ºC and T_{si} = -9.7ºC

09:20   Conditions before tests: although T_a was -16.5ºC, the snow was significantly warmer. The snow temperature, $T_{s,}$ was -11.7ºC at the south end (the entrance point for the test vehicles) of the strip and -12.6ºC at the north (exit) end.

10:10   After the first set of tests, T_a = -16.2ºC and T_s = -12.4ºC at the middle of the strip.

10:42   After the second set of tests, T_a = -15.3ºC, T_s = -10.8ºC at the south end and T_s = -11.6ºC at the north end. The snow strip appeared to be damaged on the sides and developed ruts and uneven loose snow. At about 10:31, a thin cloud cover came and diffused sun appeared.

11:15   After the third set of tests, T_a = -14.4ºC and T_s = -11.6ºC to -11.1ºC in the middle section. Soon after these tests, the sun went behind a thick cloud cover and the air temperature started to drop.

11:45   After the fourth set of tests, T_a = -14.8ºC and T_s = -10.6ºC to -11.1ºC in the middle.

12:25   After the fifth set of tests, T_a = -14.7ºC and T_s = -11.2ºC to -11.5ºC in the middle.

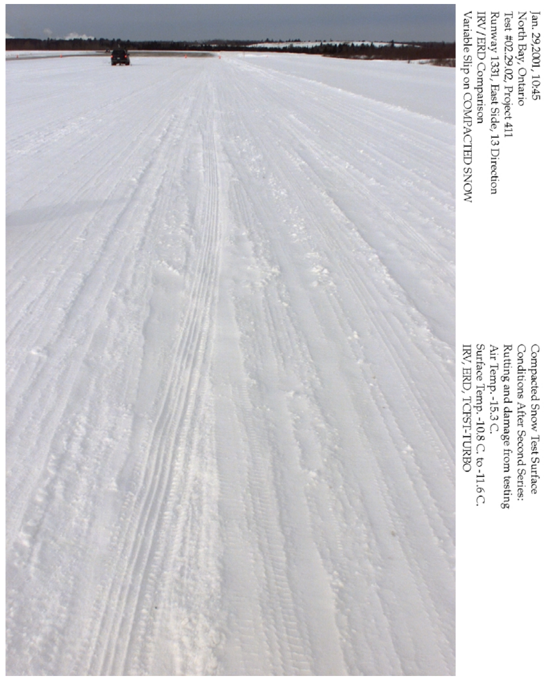


Figure 4. Compacted snow on rRunway 13-31, north side of runway 08-26, during the morning tests on Tuesday 29 January 2002

It should be noted that the snow temperature remained essentially constant during the tests, although the air temperature fluctuated measurably. At the end of this test series, the central part of the strip looked better because of additional compaction produced by the test vehicles, particularly the IRV and SFT, and because of the blowing away of loose snow by these vehicles. However, both sides of the central line developed more ruts and loose snow, and this is where the ERD operated. Thus, ERD results should be examined in the light of these conditions.

Test No. 02-29-03, Project 4110, was carried out on the man-made ice strip (#8 in Figure 1) from about 15:00 to 16:55. This series consisted of five repeats at 65 km/h and variable slip of 8%, 10%, 15%, 20%, 40% and 80% for the IRV. The ERD was used after each of the IRV tests, and the SFT was used after the second repeat and at the end.

14:35 There was a dark cloud cover at this time. The airport weather station reported a dew point of -21.3ºC and an air temperature of -16.0ºC, which was colder than T_a = -14.2ºC above the ice strip. The temperature of the ice, however, was significantly warmer than the air temperature. This was caused by the diffused solar radiation observed during the morning tests. The clear ice temperature of -6.6ºC was measurably warmer than the sections of snow ice at -7.4ºC. There was a significant variation in the temperature of the snow ice, depending on its thickness and colour. This was primarily because of the fact that the clear ice absorbed more radiation than the gray snow ice with higher albedo. And because of this, the clear ice temperature decreased during the tests.

15:28 After the second set of tests, T_a = -15.0ºC, T_i = -8.4ºC and T_{si} = -8.6ºC.

16:55 After the fifth set of tests, T_a = -15.5ºC, T_i = -8.9ºC and T_{si} = -10.1ºC.

Test No. 02-29-04, Project 4111, was carried out on the compacted snow strip (#9 in Figure 1) from about 14:35 to 16:55. Similar to Project 4110, this series consisted of five repeats at 65 km/h and variable slip of 8%, 10%, 15%, 20%, 40% and 80% for the IRV. The ERD was used after each of the IRV tests, and the SFT was used after the second repeat and at the end.

For the descriptions of the compacted snow strip #9, please see Test No. 02-29-02; Project 4101.

14:35 Conditions before tests: T_a = -14.2ºC and T_s = -11.3ºC to -11.8ºC along the length of the stip.

15:28 After the second set of tests: T_a = -15.0ºC and T_s = -11.2ºC to -11.5ºC.

16:55 After the fifth set of tests: T_a = -15.5ºC and T_s = -11.8ºC to -12.6ºC.

3.4 Wednesday 30 January 2002

During the night, the colder wave from the Arctic continued and the air temperature dropped further, but the wind speed dropped significantly from that of the previous morning. At 06:00 the conditions at the airport were: T_{air} = -18ºC, Wind Chill = -27ºC, Wind = NE 6 km/h, overcast, Relative Humidity = 59%, Dew Point = -24ºC, Ceiling = 2500 ft., Barometric Pressure = 102.8 kPa, and Visibility = 24 km.

Test No. 02-30-01, Project 414, was carried out on the man-made ice strip (# 8in Figure 1) from about 09:20 to 11:45. This series consisted of five repeats at 65 km/h and variable slip of 8%, 10%, 15%, 20%, 40% and 80% for the IRV. The ERD was used after each of the IRV tests, and the SFT was used after the second repeat and at the end.

The man-made ice strip, used in the previous day's tests, was further thickened during the night by flooding more water on it. The strip was thicker this morning than that used the previous day and the thickness varied from 5 mm to 20 mm. The surface was wavy at both the north and the south ends. Most of the ice strip had a texture with small bumps.

09:20 Conditions before tests: T_a = -17.4ºC and T_i = -12.4ºC to T_{si} = -12.3ºC.

09:36 First test began; the sun broke through the clouds. The North Bay weather station reported T_a = -18.0ºC, Dew Point = -24ºC and Wind Speed = 7 km/h at 360º.

10:25 After second set of tests, T_a = -15.5ºC, T_{ci} = -9.2ºC and T_{si} = -10.5ºC.

The cloud cover thinned and the diffused sun started to shine brighter. This affected both the air temperature and the ice temperature.

11:45 After the fifth set of tests, T_a = -12.4ºº, T_{ci} = -6.9ºC and T_{si} = -7.8ºC.

Test No. 02-30-02, Project 415, was carried out on the compacted snow strip (#9 in Figure 1) from about 09:20 to 11:45. Similar to Project 4110, this series consisted of five repeats at 65 km/h and variable slip of 8%, 10%, 15%, 20%, 40% and 80% for the IRV. The ERD was used after each of the IRV tests, and the SFT was used after the second repeat and at the end.

The strip was 300 m long, about 3 m wide, and parallel but slightly shifted to the west of the strip used the previous day.

09:20 Conditions before tests: T_a = -17.4ºC and T_s = -14.1ºC near the south end and -13.7ºC at the north end. There was 10 mm of loose, aged snow on the compacted snow. The total thickness was 50 mm at the south end and 30 mm at the north end.

09:36 First test started when the sun broke through the clouds.

10:25 After the second set of tests, T_a = -15.5ºC and T_s = -11.4ºC to -11.8ºC.

11:45 After the fifth set of tests, T_a = -12.4ºC and T_s = -11.3ºC.

Test No. 02-30-03, Project 416, was carried out on the man-made ice strip (#8 in Figure 1) from about 14:35 to 16:55. This series consisted of five repeats at 65 km/h at variable slips of 8%, 10%, 15%, 20%, 40% and 80% for the IRV. The ERD was used after each of the IRV tests, and the SFT was used after the second repeat and at the end.

14:17 The sky was clear, the sun was bright and the wind was low. Although the air temperature was low, the bright sun increased the ice temperature in a significant manner. Conditions before the start of the test series: T_a = -11.0ºC, T_{ci} = -0.3ºC and T_{si} = -4.2ºC for thick snow ice. The test series started at 14:35.

15: 25 After the second set of tests, T_a = -9.8ºC, T_{ci} = -3.3ºC and T_{si} = -4.2ºC for a thick bubbly ice section. At this time, the sun was still shining brightly, but at an angle of about 30º from the horizontal plane. The low solar angle made the ice strip colder than what it was in the beginning of the tests. The ice strip developed cracks at several locations. The cracks ran both parallel and perpendicular to the length of the strip.

16:55 After the fifth set of tests, T_a = -12.7ºC, T_{ci} = -7.4ºC for thin, clear ice and T_{si} = -8.4ºC for thick bubbly ice. The sun was setting at this time and the low angle of the sunlight was used to photograph the texture of the ice surface (Figure 5a).

Note: It was decided to flood the ice strip at night to seal the cracks, remove the bumpy texture and increase the thickness.

Test No. 02-30-04, Project 417, was carried out on the compacted snow strip (#9 in Figure 1) from 14:35 to 16:55. This series consisted of five repeats at 65 km/h with variable slips of 8%, 10%, 15%, 20%, 40% and 80% for the IRV. The ERD was used after each of the IRV tests, and the SFT was used after the second repeat and at the end. Tests started at 14:35.

15:25 After the second set of tests, the surface conditions were T_a = -9.8ºC, T_s = -9.9ºC at the south end and T_s = -10.6ºC in the middle section of the strip.

16:55 After the fifth set of tests, T_a = -12.7ºC and T_s = -12.6ºC in the middle section.

At this stage, the test strip was in a greatly altered (highly damaged) condition, as seen in Figure 5b. It was suggested that the location for next day's tests should be moved a few metres west of this strip.

Figure 5a. A general view of the surface texture of the man-made ice strip after all the afternoon ground vehicle tests of 30 January 2002

Figure 5b. A general view of the altered conditions of the compacted snow strip on the east side of runway 13-31 after all the ground vehicle tests of 30 January 2002

3.5 Thursday 31 January 2002

It was a cold, wintry morning after a clear night with strong winds. At 06:00 the conditions at the airport were: T_{air} = -17ºC, Wind Chill = -26ºC, Wind = NE 19 km/h, overcast, Relative Humidity = 50%, Dew Point = -25ºC, Ceiling = 10 000 ft., Barometric Pressure = 102.6 kPa, and Visibility = 24 km.

Test No. 02-31-01, Project 420, was carried out on the man-made ice strip (#8 in Figure 1) from about 08:55 to 10:40. This series consisted of five repeats at 65 km/h at variable slips of 8%, 10%, 15%, 20%, 40% and 80% for the IRV. The ERD was used after each of the IRV tests, and the SFT was used after the second repeat and at the end.

The ice strip was flooded during the night as per instructions given earlier. This made the ice thicker and reduced the differences in the variation of thickness between that of thin clear ice section and thick bubbly ice sections. The ice appeared to be less bumpy than that noticed during the previous day. However, the clear ice areas became partially bubbly.

08:35 Conditions before tests: T_a = -15.8ºC, T_{ci} = -12.7ºC for partially clear ice and T_{si} = -13.0ºC for thick bubbly ice.

08:55 Test series started.

09:32 After the second set of tests, T_a = -14.6ºC, T_{ci} = -12.1ºC and T_{si} = -12.4ºC.

10:40 After the fifth set of tests, T_a = -12.8ºC, T_{ci} = -10.7ºC and T_{si} = -10.9ºC.

The persistent wind and overcast conditions did not change the conditions of the ice surface in any noticeable manner.

Test No. 02-31-02, Project 421, was carried out on the compacted snow strip, about 2 m west of the strip used the previous day (#9 in Figure 1). The tests were carried out from 08:55 to 10:40. This series consisted of five repeats at 65 km/h with variable slips of 8%, 10%, 15%, 20%, 40% and 80% for the IRV. The ERD was used after each of the IRV tests, and the SFT was used after the second repeat and at the end.

08:35 Conditions before tests: T_a = -15.8ºC, T_s = -13.1ºC at the south end, T_s = -13.0ºC in the middle section and T_s = -13.2ºC at the north end.

08:55 Test series started.

09:32 After the second set of tests, T_a = -14.6ºC and T_s = -12.8ºC in the middle section.

10:40 After the fifth set of tests, T_a = -12.8ºC, T_s = -10.7ºC at the south end, T_s = -11.8ºC in the middle and T_s = -11.6ºC at the north end.

The central section of the snow strip, particularly in the northern half of the strip, had ice patches, and this was noticeable because of the removal of the loose snow in those areas. However, the western side (left side for the running direction of the devices) was very rough, rutted and full of loose, aged, dry snow.

Test No. 02-31-03, Project 422, was carried out on the man-made ice strip (#8 in Figure 1) from about 13:10 to about 14:40. This was essentially a continuation of Test No. 02-31-01, Project 420.

It was very windy during the afternoon.

13:00 Conditions before tests: T_a = -10.8ºC, T_{ci} = -7.3ºC and T_{si} = -8.2ºC for thicker bubbly ice.

13:10 Tests started.

14:10 After the third set of tests, T_a = -10.4ºC, T_{ci} = -7.3ºC and T_{si} = -7.8ºC.

The ice surface was in excellent condition. The entire surface was smooth and appeared to have gone through a polishing phase due to the movement of all the test vehicles. However, there was some dusting of loose snow on the ice surface. The big truck towing the IRV was in fact stirring the snow beside the ice strip and the strong wind from the southeast direction was blowing the snow particles onto the ice surface. Because the ice was cold and the surface was polished, the dusting of snow could act as surface lubrication and this could lower the frictional properties of the ice.

Test No. 02-31-04, Project 423, was carried out on the compacted snow strip, about 2 m west of the strip used the previous day (#9 in Figure 1). The tests were carried out from 13:10 to about 14:30 and were a continuation of Test No. 02-31-02, Project 421.

The test strip was in a highly damaged state, with rough, rutted, loose, aged snow. The snow depth varied significantly and there were areas where the snow was as deep as 50 mm.

13:00 Conditions before tests: T_a = -10:8ºC and T_s = -10.1ºC in the middle section.

13:10 Tests started.

14:10 After the third set of tests, T_a = -10.4ºC and T_s = -9.5ºC in the middle section.

Test No. 02-31-07, Project 426, was carried out on the man-made ice strip (#8 in Figure 1) from about 15:24 to 16:15. This was a continuation of Test No. 02-31-03, Project 422; the number of repeats, however, was decreased to three.

The southeast wind picked up strongly and it started to snow lightly with large flakes of diameters up to 5 mm.

15:10 Conditions before tests: T_a = -10.4ºC, T_{ci} = -8.0ºC and T_{si} = -8.4ºC.

15:24 Tests started.

16:15 Due to the blowing and drifting snow on the ice strip, the test series was terminated in the middle of the third set of tests. At this time, the surface conditions were T_a = -11.0ºC, T_{ci} = -9.4ºC and T_{si} = -9.5ºC.

Test No. 02-31-08, Project 427, was carried out on the compacted snow strip, about 2 m west of the strip used the previous day (#9 in Figure 1). The tests were carried out from 15:24 to 16:15 and were a continuation of Test No. 02-31-04, Project 423.

As mentioned for the previous series, this compacted snow strip was in a damaged state. Moreover, the strong wind and the blowing snow were changing the surface conditions in a continuous manner during the test series.

15:10 Conditions before the tests: T_a = -10.4ºC and T_s = -9.3ºC in the middle section.

15:24 Tests started.

16:15 Due to the blowing and drifting snow on this strip, the test series was terminated in the middle of the third set of tests. At this time, the surface conditions were T_a = -11.0ºC and T_s = -10.6ºC in the middle section.

3.6 Friday 01 February 2002

A heavy snowfall warning was in effect for the day for the entire North Bay-Nipissing and Sudbury-Nickel Belt area. The forecast described the precipitation as snow mixed with ice pellets and freezing rain over the southern sections in the morning. Total snow accumulation was predicted to be between 150 mm and 250 mm. The wind was northeast at 30 km/h with occasional gusts to 50 km/h.

At 06:00 the conditions at the airport were: T_{air} = -12ºC, Wind Chill = -21ºC, Wind = E 22 km/h gusting to 31 km/h, light snow, Relative Humidity = 72%, Dew Point = -16ºC, Ceiling = 1 000 ft., Barometric Pressure = 101.0 kPa, and Visibility = 3.2 km.

The weather conditions deteriorated as the morning progressed, and total snow accumulations of 122 mm took place by the evening. The storm was over by late evening and the sky became clear.

3.7 Saturday 02 February 2002

At 06:00 the conditions at the airport were: T_{air} = -20ºC, very calm and clear, Wind Chill = -20ºC, Relative Humidity = 70%, Dew Point = -24ºC, unlimited ceiling, Barometric Pressure = 102.68 kPa, and Visibility = 24 km.

Test No. 02-33-01, Project 428, was carried out on the man-made ice strip (#8 in Figure 1) from about 10:30 to 12:20. This was a continuation of variable slip Test No. 02-31-07, Project 426; the number of repeats, however, was increased to five.

The man-made ice strip on the west side and the entire runway 13-31 was covered with drifted snow, varying in thickness from zero to 250 mm, due to the storm during the previous day. This snow cover was removed completely from the entire runway using conventional equipment. The surface of the ice strip was then cleaned further using a high-power blower.

09:10 Conditions before tests: T_a = -17.1ºC, T_{ci} = -11.9ºC for clear ice and T_{si} = -13.3ºC for thicker bubbly ice near the south (entrance point) end. At the north (exit point) end both thin ice and thick bubbly ice had the same temperature of -12.8ºC. The difference in the air temperature and the temperature of the ice strip was primarily because of the insulating effect of the snow cover that had accumulated during the previous day's storm. Although the ice surface was bare after cleaning, the surface exhibited a texture leading to a mat finish due to the mechanical bonding of snow particles of the drifted snow cover that stayed there overnight.

The sky was absolutely clear and the sun was shining brightly. This affected the temperature of the air and the ice. Since it was calm, the solar radiation was changing the ice temperature with increased rapidity, as can be seen in the following measurements.

10:47 After the secondset of tests, T_a = -13.8ºC, T_{ci} = -7.1ºC and T_{si} = -9.6ºC for thicker bubbly ice in the middle section of the strip. By this time, the mat finish of the surface was gone and the surface appeared to be polished.

12:20 Conditions after tests: T_a = -14.0ºC, T_{ci} = -3.6ºC and T_{si} = -6.2ºC for thicker bubbly ice.

Test No. 02-33-02, Project 429, was carried out on a 300 m long compacted snow strip, in the area between the strips #8 and #9 in Figure 1, slightly west of the centre line of runway 13-31. The tests were carried out from about 10:30 to 12:20 and were of variable slip, similar to Test No. 02-31-08, Project 427.

This test area of well-travelled, compacted snow was covered with drifted snow in the morning. As mentioned in the previous test series, the loose drifted snow from the previous day's storm was removed completely before this series of tests was carried out. A 300 m long, 10 m wide section on the east side of the man-made ice strip and west of the runway's centre line was used. This section was highly compacted due to the test traffic from the previous week. The surface was, however, highly textured and Figure 7 shows photographs and an impression of the surface conditions taken by covering the surface with spray paint and using a plane paper to record the relief of the surface. It may be seen that only about 30% of the compacted snow surface, exhibiting an icy crust, was available for tire/surface interaction processes.

09:10 Conditions before tests: T_a = -17.1ºC, T_s = -14.0ºC near the south end and T_s = -15.4ºC near the north end.

10:47 After the second set of tests, T_a = -13.8ºC and T_s = -12.2ºC in the middle section.

12:20 Conditions after tests: T_a = -14.0ºC and T_s = -10.7ºC for the bulk of compacted snow in the middle section, but T_s = -11.2ºC for the icy crust that developed on the compacted snow.

Test No. 02-31-05, Project 424, originally scheduled for 31 January 2002, was carried out on the man-made ice strip (#8 in Figure 1) from 11:12 to 12:14. This was a variable slip test similar to Test No. 02-33-01, Project 428, but with the IRV equipped with PIARC ribbed tires at high load and normal pressure; the number of repeats, however, was decreased to three.

10: 47 Conditions before tests: T_a = -13.8ºC, T_{ci} = -7.1ºC and T_{si} = -9.6ºC for thicker bubbly ice in the middle section of the strip.

12:20 Conditions after tests: T_a = -14.0ºC, T_{ci} = -3.6ºC and T_{si} = -6.2ºC for thicker bubbly ice in the middle section of the strip.

Test No. 02-31-06, Project 425, originally scheduled for 31 January 2002, was carried out on the compacted snow strip (#9 in Figure 1) from 11:14 to 12:17. This was a variable slip test similar to Test No. 02-33-02, Project 429, but with the IRV equipped with PIARC ribbed tires at high Load and normal pressure; the number of repeats, however, was decreased to three.

10:47 Conditions before tests: T_a = -13.8ºC and T_s = -12.2ºC.

12:20 Conditions after tests: T_a = -14.0ºC and T_s = -10.7ºC for the bulk of compacted snow in the middle section, but T_s = -11.2ºC for the icy crust that developed on the compacted snow.

February 2, 2002 14:35
North Bay, Ontario
Test Number 02.33.05, Project 436
Runway 1331, West of Center Line
IRV/ERD Comparison, Variable Slip on ICE
IRV-A/C Tire, High Load, High Pressure

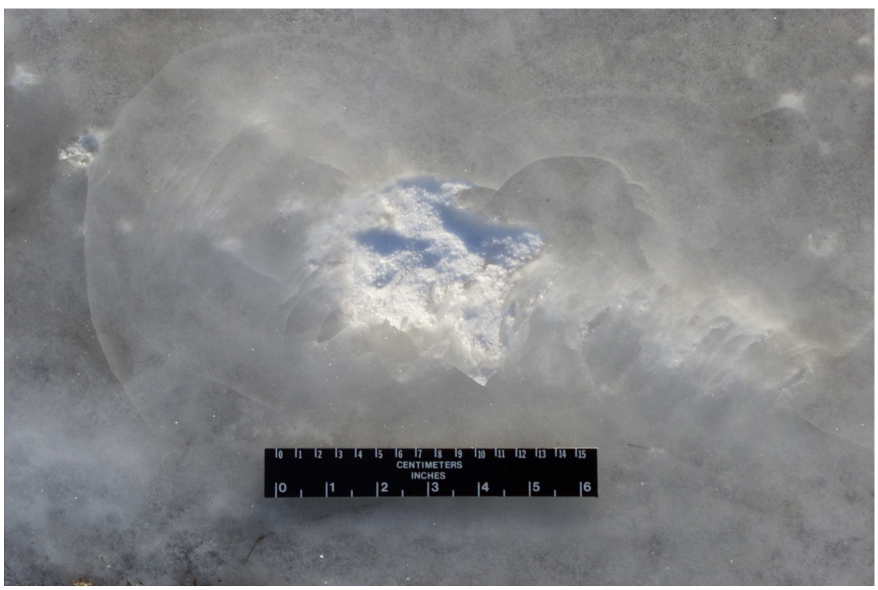
Pre Test Conditions, Air Temp. -12.2 C.
Surface Temp. -0.8 C. (Clear Ice) to -4.1 C. (Thicker, Bubbly Ice)
Ice test strip thickness varied from 5mm. to 15mm. The ice was polished by test runs earlier in the day, and the strong sun had raised the temperature of the ice almost to the melting point in some areas.

(a)

February 2, 2002 14:35, North Bay, Ontario
Test Number 02.33.05, Project 436
Runway 131, West of Center Line
IRV/ERD Comparison, Variable Slip on ICE
IRV-A/C Tire, High Load, High Pressure
Variable Slip on ICE

Conditions After 3 Sets of Tests: Air Temp. -12.2 C
Surface Temp. -1.1 C. (Clear Ice) to -3.8 C. (Thicker, Bubbly Ice)
The ice test strip was now exhibiting severe cracking in some areas, and long strips of herring bone cracking were visible (shown). There were some areas in which the ice was crushed and water was visible.

(b)



February 2, 2002 16:15
North Bay, Ontario
Test Number 02.33.05, Project 436
Runway 1331, West of Center Line
IRV/ERD Comparison, Variable Slip on ICE
IRV-A/C Tire, High Load, High Pressure

Conditions After All Tests: Air Temp. -11.6 C.
Surface Temp. -4.1 C. (Clear Ice) to -5.9 C. (Thicker, Bubbly Ice)
The ice test strip was now exhibiting severe cracking in some areas, and long strips of herring bone cracking were visible.
NOTE: These conditions serve as the pre-test conditions for the next series of tests, which began immediately: Test number 02.33.09, Project 432.

(c)

Figure 6. The man-made ice strip at 14:35 before the afternoon tests of 02 February 2002 (a) and exhibiting herringbone cracks (b) and crushed ice (c) after the tests at 16:15

Test No. 02-33-05, Project 436, was carried out on the man-made ice strip (#8 in Figure 1) from about 14:40 to 16.15. This was a continuation of the variable slip on ice tests for the IRV equipped with aircraft tires at high load and high pressure.

14:35 At this time, the surface of the man-made ice strip was shining like a mirror (Figure 6). The ice had been polished by the operation of the test vehicles during the morning Test No. 02-33-02; Project 428. However, due to the bright sunshine, the ice absorbed solar energy and the temperature rose almost to the melting point in some areas, depending on the clarity of the ice and its thickness.

Conditions before tests: T_a = -12.2ºC, T_{ci} = -0.8ºC and T_{si} = -4.1ºC for thicker bubbly ice in the middle section. Since the ice thickness varied from 5 mm to 15 mm, the temperature varied greatly.

15:15 After the third set of tests, T_a = -11.3ºC, T_{ci} = -1.1ºC and T_{si} = -3.8ºC for thicker bubbly ice in the middle section. Several areas of the ice were highly cracked and long strips of herringbone-type cracked ice were visible (Figure 6b). There were some areas where the ice was crushed completely and free water was noticeable (Figure 6c). There was practically no wind and the sun was shining brightly, but at a lower angle. Thus, the highest ice-temperature ambient conditions had passed and the ice temperature was expected to decrease with time from now on.

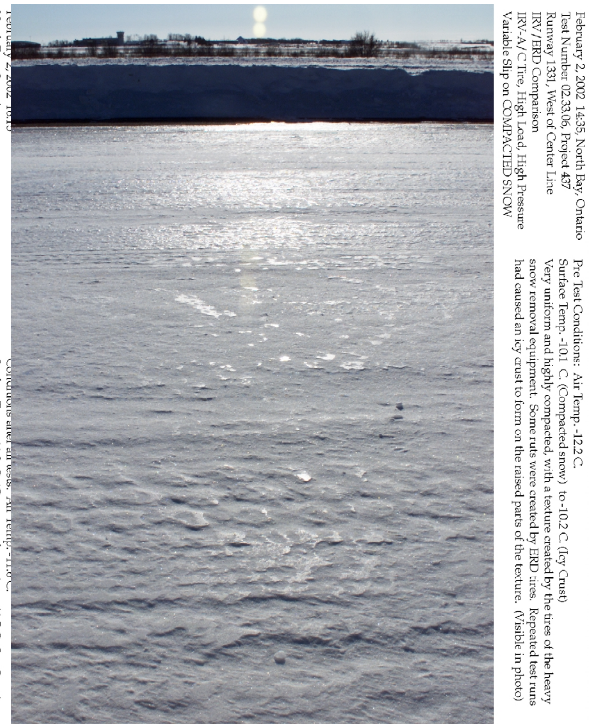
16:15 Conditions after tests: T_a = -11.6ºC, T_{ci} = -4.1ºC and T_{si} = -5.9ºC for thicker bubbly ice in the middle section.

Test No. 02-33-06, Project 437, was carried out on a 300 m long compacted snow strip in the area between the strips #8 and #9 in Figure 1, west of the centre line of runway 13-31 and east of the ice strip. The tests were carried out from about 14:40 to 15:15 and were of variable slip similar to Test No. 02-33-02, Project 429.

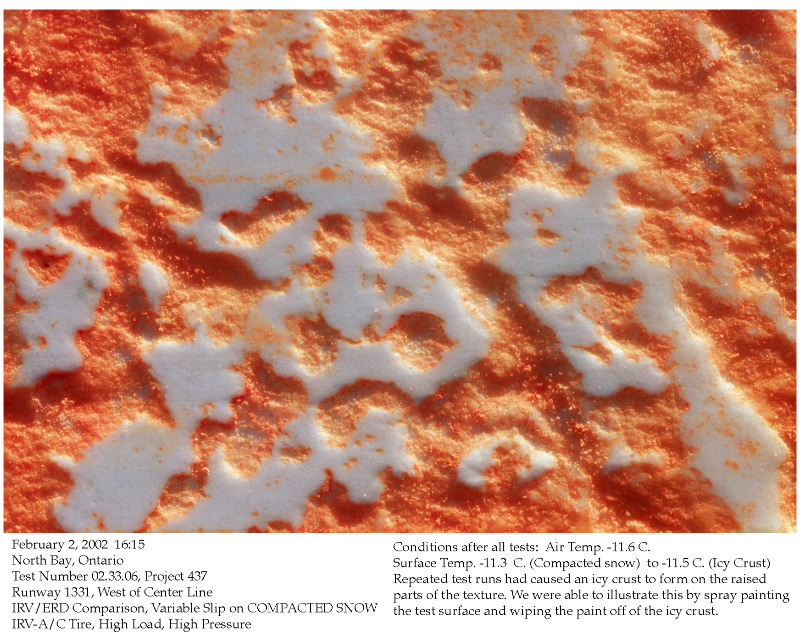
14:35 At this time, there was practically no wind and the sun was bright. The surface of the compacted snow strip was shining and revealed the texture well (Figure 7 a,b). For a general description of the compacted snow, see the test report for Test No. 02-33-02, Project 429. Although the strip was flat and free from any loose snow, except for the ruts created by the ERD tests in the morning, the entire strip had a texture that varied significantly along the width and length of the strip. As may be seen in Figures 7b and 7c, the surface texture could be related to the footprints of tires of heavy snow removal equipment used in the area.

Conditions before tests: T_a = -12.2ºC and T_s = -10.2ºC for icy crust at the surface and -10.1ºC for the compacted snow below the crust in the middle section.

(a)



(b)



(c)

Figure 7. Pre-test conditions of compacted snow strip at 14:35 on 02 February 2002 (a) and the details of its surface texture in the reflected sunlight (b). Post-test details of the surface texture, using spray paint, are shown in (c)

Since the ice crust texture covered about 30% of the total surface area and since the less compacted snow had been eroded from the spaces between the crusts, the test tires were expected to "see" only the icy sections. Consequently, the friction values were expected to be low. Since the texture varied significantly from one location to the other, the test results were expected to vary significantly along the width of the path and length of the strip, particularly for the IRV and SFT. Lower temperatures than that of the ice strip in the adjacent lane will, of course, result in relatively higher friction values than for the pure ice strip.

15:15 After the third set of tests, T_a = -11.3ºC, T_s = -9.7ºC for crust and T_s = -10.1ºC for compacted snow below the surface in the middle section.

16:15 Conditions after tests: T_a = -11.6ºC, T_s = -11.5ºC for crust and T_s = -11.3ºC for compacted snow below the surface in the middle section. The surface temperatures dropped because of the sunset.

Note: An effort was made to develop methods for recording the texture of the surface by (1) spray painting and replicating the surface on a paper as described in Test No. 02-33-02, Project 429 and (2) spray painting the surface, removing the paint from the icy crust with tissue papers and photographing the surface. The latter technique worked well and the hard crust appeared white against the coloured background, as can be seen in Figure 6c.

Test No. 02-33-07, Project 434, was carried out on the man-made ice strip (#8 in Figure 1) from about 15:25 to 15:54. This was a continuation of the variable slip on ice Test No. 02-33-05, Project 436, for the IRV equipped with aircraft tires at high load and normal pressure.

15:15 Conditions before tests for the middle section: T_a = -11.3ºC, T_{ci} = -1.1ºC and T_{si} = -3.8ºC for thicker bubbly ice.

16:1 Conditions after tests for the middle section: T_a = -11.6ºC, T_{ci} = -4.1ºC and T_{si} = -5.9ºC for thicker bubbly ice.

Please see general observations made for Test No. 02-33-05; Project 436.

Test No. 02-33-08, Project 435, was carried out on the compacted snow strip with icy crust on the east side of runway 13-31 (#9 in Figure 1) from about 15:27 to 15:56. This was a continuation of the variable slip on ice Test No. 02-33-07, Project 434, for the IRV equipped with AC tires at high load and normal pressure.

15:15 Conditions before tests for the middle section: T_a = -11.3ºC, T_s = -9.7ºC for ice crust and T_s = -10.1ºC for snow below the crust.

16:15 Conditions after tests for the middle section: T_a = -11.6ºC, T_s = -11.5ºC for ice crust and T_s = -11.3ºC for snow below the crust.

Please see general observations made for Test No. 02-33-05; Project 436.

Test No. 02-33-09, Project 432, was carried out on the man-made ice strip (#8 in Figure 1) from about 16:30 to 17:00. This was a continuation of the IRV/ERD comparative study on ice for variable slip for the IRV equipped with AC tires at normal load and high pressure. For a description of the ice strip, see the observations made for Test No. 02-33-05; Project 436.

16:15 Conditions before tests for the middle section: T_a = -11.6ºC, T_{ci} = - 4.1ºC and T_{si} = -5.9ºC for thicker bubbly ice.

17:00 Conditions after tests for the middle section: T_a = -13.0ºC, T_{ci} = - 5.6ºC and T_{si} = -7.4ºC for thicker bubbly ice.

At this time, the sun was near the horizon and there was a slight breeze in comparison to the perfectly calm conditions experienced earlier. A thin cloud cover was also moving into the area. Note the decrease in temperature of the air and the ice.

Test No. 02-33-10, Project 433, was carried out on a 300 m long compacted snow strip, in the area between ice strip #8 and compacted snow strip #9 in Figure 1, west of the central line of runway 13-31, but east of the ice strip. The tests were conducted from about 16:15 to 17:00 and were of variable slip similar to Test No. 02-33-06; Project 437 for the IRV equipped with AC tires at normal load and high pressure.

16:15 Conditions before tests for the middle section: T_a = -11.6ºC, T_s = -11.5ºC for icy crust and T_s = -11.3ºC for compacted snow below the surface.

17:00 Conditions after tests for the middle section: T_a = -13.0ºC, T_s = -12.1ºC for crust and T_s = -11.7ºC for compacted snow below the surface. As noted for the previous test series, the sun was setting and the air temperature was dropping. Solar radiation was disappearing at this time and a thin cloud cover was moving into the area.

Test No. 02-33-11, Project 430, was carried out on the man-made ice strip (#8 in Figure 1) from about 17:00 to 17:40. This was a continuation of the IRV/ERD comparative study on ice for variable slip for the IRV equipped with AC tires at normal load and normal pressure. For a general description of the ice strip, see the observations made for Test No. 02-33-05; Project 436.

17:00 Conditions before tests for the middle section: T_a = -13.0ºC, T_{ci} = - 5.6ºC for thin (about 5 mm), clear ice and T_{si} = -7.4ºC for thicker bubbly ice.

17:40 Conditions after tests for the middle section: T_a = -16.1ºC, T_{ci} = - 9.1ºC for thin, clear ice and T_{si} = -10.1ºC for thicker bubbly ice.

Note the decrease in the air temperature during this test series, as well as the larger changes in ice temperature, particularly for thin, clear ice. Because the sunset was at about 17:10, it was already rather dark at the end of the tests. The high emmisivity and higher thermal conductivity of clear ice allowed the ice cover to cool rapidly.

Test No. 02-33-12, Project 431, was carried out on the compacted snow strip with icy crust on the east side of runway 13-31 (#9 in Figure 1) from about 17:00 to 17:40. This was a continuation of Test No. 02-33-1, Project 430.

17:00 Conditions before tests for the middle section: T_a = -13.0ºC, T_s = -12.1ºC for ice crust and T_s = -11.7ºC for compacted snow under the crust.

17:40 Conditions after tests for the middle section: T_a = -16.1ºC, T_s = -12.4ºC for ice crust and T_s = -12.9ºC for compacted snow under the crust.

Note that the snow temperature did not change much even though the air temperature dropped significantly during the testing time. This is because of the lower (in comparison to ice) emmisivity and lower thermal conductivity of snow ice.

The wind was picking up and a thick cloud cover was moving in for the expected snowfall during the coming night and next day. The air temperature reached a minimum of -15.8ºC in the early hours of the morning.

3.8 Sunday 03 February 2002

A snowstorm and high wind speed, up to 35 km/h, stopped all the activities during the day. The air temperature, however, rose dramatically to a maximum of -2.3ºC in the afternoon. A total of 86 mm of snow fell during the day.

The snowstorm stopped in the evening and the sky cleared partially. The air temperature started to drop rapidly during the night, reaching a minimum of –20ºC, but a cloud cover moved in during the early morning hours and snow flurry activities started.

3.9 Monday 04 February 2002

At 06:00 the conditions at the airport were: T_{air} = -20ºC, light snow, Wind = N 20 km/h, Wind Chill = -31ºC, Relative Humidity = 70%, Dew Point = -24ºC, unlimited ceiling, Barometric Pressure = 101.52 kPa, and Visibility = 19 km.

The entire runway 13-31 and the associated test areas were all covered with a layer of fresh snow that had precipitated during the previous day and in the early morning hours. The first part of the morning was used in removing the loose snow in the test areas of runway 13-31. The light precipitation stopped during this period and the sun started to shine brightly.

Test No. 02-35-01, Project 101, was carried out on the man-made ice strip (#8 in Figure 1) from about 10:50 to 11:35. This was a six-vehicle test involving the NASA-GT, FAA-RFT, IRV, TC-SFT-TURBO, FAA-BV11 and ERD. Figure 8 shows these test vehicles assembled on compacted snow on the runway. A total of five runs were made at 65 km/h.

10:00 Preliminary observations after snow removal activities: T_a = -20.6ºC, T_{ci} = -13.3ºC and T_{si} = -13.3ºC for thicker bubbly snow ice. The quick snow removal process exposed the ice suddenly to low ambient air temperature and the ice sheet developed thermal cracks, as can be seen in Figure 9. These cracks were visible everywhere from one end of the test strip to the other.

10:45 Conditions before tests: T_a = -20.0ºC, T_{ci} = -10.5ºC for thin, clear ice and T_{si} = -12.7ºC for thicker bubbly snow ice. Note the difference in temperature of the clear ice and the bubbly ice. This was caused by the differences in the absorption characteristics of solar radiation for the two types of ice.

11:35 Conditions after tests: T_a = -19.5ºC, T_{ci} = -9.0ºC for thin, clear ice and T_{si} = -10.5ºC for thicker bubbly snow ice.

Test No. 02-35-02, Project 102, was carried out on the compacted snow strip with icy crust on the east side of runway 13-31 (#9 in Figure 1) 10:50 to 11:35. This was a six-vehicle test series involving the NASA-GT, FAA-RFT, IRV, TC-SFT-TURBO, FAA-BV11 and ERD. The six vehicles in this test series are shown in Figure 8 parked on compacted snow. A total of five runs at 65 km/h were made with each vehicle.

10:00 Preliminary observations after snow removal activities: T_a = -20.6ºC and T_s = -15.0ºC. The test strip was fairly uniform, with no loose snow or ruts, and consisted of highly compacted snow, as shown in Figure 10a. The strip had, however, developed a surface texture, which can be associated with the tires of snow removal equipment and other test vehicles that had used the track in the past few days (Figure 10b).

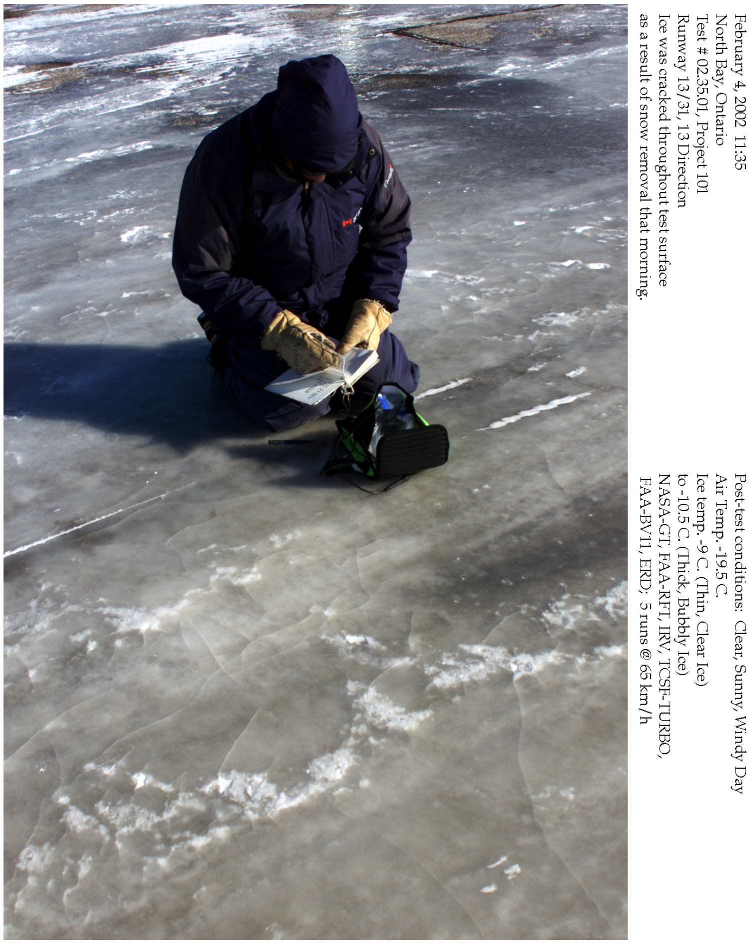
10:45 Conditions before tests: T_a = -20.0ºC and T_s = -15.0ºC for both the ice crust at the top and the compacted snow below the crust.

11:35 Conditions after tests: T_a = -19.5ºC and T_s = -15.0ºC for both the ice crust at the top and the compacted snow below the crust.

Note that the temperature of the compacted snow did not change during the test period in spite of the bright solar radiation. This was because of high albedo (reflectivity) of compacted snow.

February 4, 2002 11:35
North Bay, Ontario
Test # 02.35.02/01, Project 102/101
Runway 13/31
NASA-GT, FAA-RFT, IRV,
TCSF-TURBO, FAA-BV11, ERD

Figure 8. Six test vehicles (ERD, IRV, FAA-BV11, FAA-RFT, NASA-GT and TC-SFT-TURBO) on the compacted snow on runway 13-31 on 04 February 2002 at 11:35



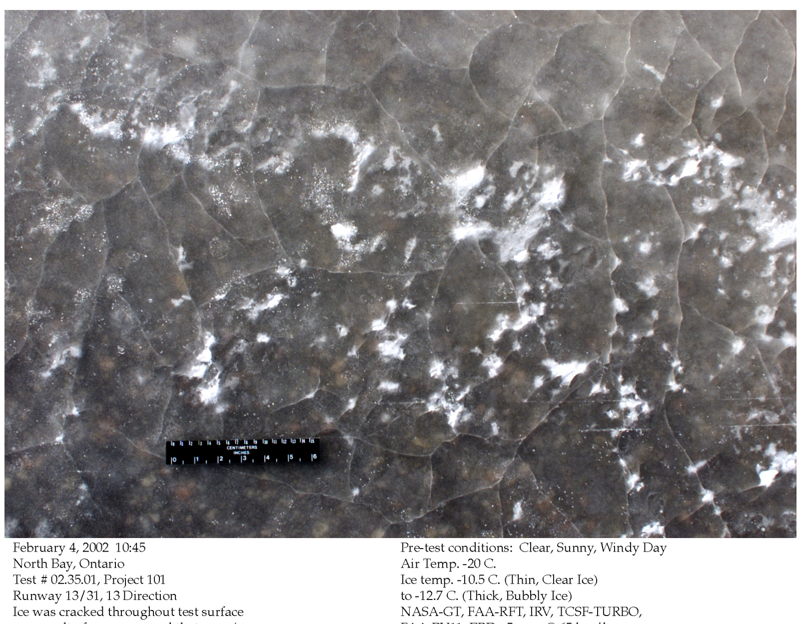
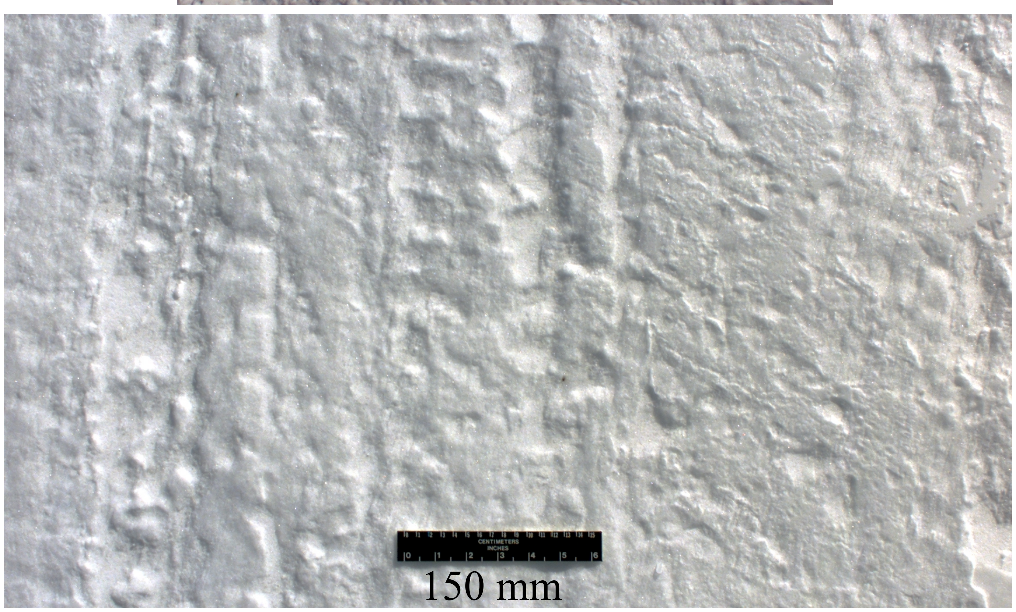


Figure 9. Thermal cracks induced in the ice strip during the morning of 04 February 2002 due to the quick removal of snow cover from it when the ambient temperature was -21 C: general view (top) and a close up (bottom)

(a)



(b)

Figure 10. A general view of the compacted snow on the east side of runway 13-31 during the morning tests of 04 February 2002 (a) and a close up of the surface texture (b)

Test No. 02-35-03, Project 103, was carried out on the man-made ice strip (#8 in Figure 1) from about 14:12 to 14:35. This was a six-vehicle test involving the NASA-GT, FAA-RFT, IRV, TC-SFT-TURBO, FAA-BV11 and ERD. A total of seven runs were made at 65 km/h.

Please note the descriptions of the ice strip given for Test No. 02-35-01, Project 101, of this morning. As mentioned, the ice was full of thermally induced cracks.

13:50 Conditions before tests: T_a = -15:5ºC, T_{ci} = -5.6ºC for thin, clear ice and T_{si} = -7.2ºC for thicker bubbly snow ice.

14:12 Tests started.

14:35 Conditions after tests: T_a = -15.6ºC, T_{ci} = -6.2ºC for thin, clear ice and T_{si} = -8.1ºC for thicker bubbly snow ice.

Test No. 02-35-04, Project 104, was carried out on the compacted snow strip with icy crust on the east side of runway 13-31 (#9 in Figure 1) from 14:12 to 14:35. This was a six-vehicle test series involving the NASA-GT, FAA-RFT, IRV, TC-SFT-TURBO, FAA-BV11 and ERD. A total of seven runs were made at 65 km/h with each vehicle.

13:50 Conditions before tests: T_a = -15.5ºC, T_s = -12.2ºC for ice crust and T_s = -13.2ºC for compacted snow below the crust.

The increasing angle of solar radiation during the morning and the continued exposure to this radiation for more than six hours produced a temperature gradient in the compacted snow in spite of its high albedo. Note the difference in the temperatures of the crust and the bulk of the snow, about 2 mm below the crust.

14:12 Tests started.

14:35 Conditions after tests: T_a = -15.6ºC, T_s = -12.7ºC for ice crust and T_s = -13.2ºC for compacted snow below the crust.

At this time, the temperature of the crust was found to be about 0.5ºC colder than it was at the beginning of the tests. This was caused by the gradual decrease in the angle of solar radiation during the test period.

Test No. 02-35-03, Project 103, was carried out on the man-made ice strip (#8 in Figure 1) from about 14:37 to 15:00. This was a continuation of the six-vehicle Test No. 02-35-03, Project 103. Again, seven runs at 65 km/h were made.

14:35 Conditions before tests: T_a = -15:6ºC, T_{ci} = -6.2ºC for thin, clear ice and T_{si} = -8.1ºC for thicker bubbly snow ice.

14:37 Test started. At this time, a fine dusting of snow started to precipitate. This powder snow could act as a lubrication on the surface and affect the tire/ice surface interaction processes.

15:00 Conditions after tests: T_a = -15:5ºC, T_{ci} = -6.1ºC for thin, clear ice and T_{si} = -7.4ºC for thicker bubbly snow ice.

Test No. 02-35-06, Project 106, was a continuation of the six-vehicle Test No. 02-35-04, Project 104, but was carried out on the compacted snow strip, about 3 m west of the strip on the east side of runway 13-31 (#9 in Figure 1). However, this new section was partly damaged and had ruts. The series was carried out from 14:37 to 15:00. Again, seven runs at 65 km/h were made with each vehicle.

14:35 Conditions before tests: T_a = -15.6ºC, T_s = -12.7ºC for ice crust and T_s = -13.2ºC for compacted snow below the crust.

14:37 Tests started.

15:00 Conditions after tests: T_a = -15.5ºC, T_s = -12.2ºC for ice crust and T_s = -12.6ºC for compacted snow below the crust.

3.10 Tuesday 05 February 2002

A storm system moved into the area late during the previous evening and it started to snow, heavily at times. A total accumulation of about 55 mm of snow fell during the night. At 06:00 the conditions at the airport were: T_{air} = -13ºC, overcast, Wind = S 6 km/h, Wind Chill = -18ºC, Relative Humidity = 72%, Dew Point = -17ºC, Ceiling = 8 000 ft., Barometric Pressure = 101.81 kPa, and Visibility = 24 km.

Test No. 02-36-01, Project 301, involving six vehicles – the NASA-GT, FAA-RFT, IRV, TC-SFT-TURBO, FAA-BV11 and ERD – was carried out on runway 18-36, which was covered with freshly fallen snow (Figure 11). The snow was dry and the average depth was 55 mm. One set of runs was made at 65 km/h, on an opportunity basis, on the length of runway from 08-26 to the button of 18. There was a breeze of about 5 km/h from the south, almost parallel to the runway.

09:20 Test direction was 18 to 36 (against the wind).

Test conditions: T_a = -10.4ºC and T_s = -10.2ºC, with an average snow depth of 55 mm of density 34 $kg.m^{-3}$.

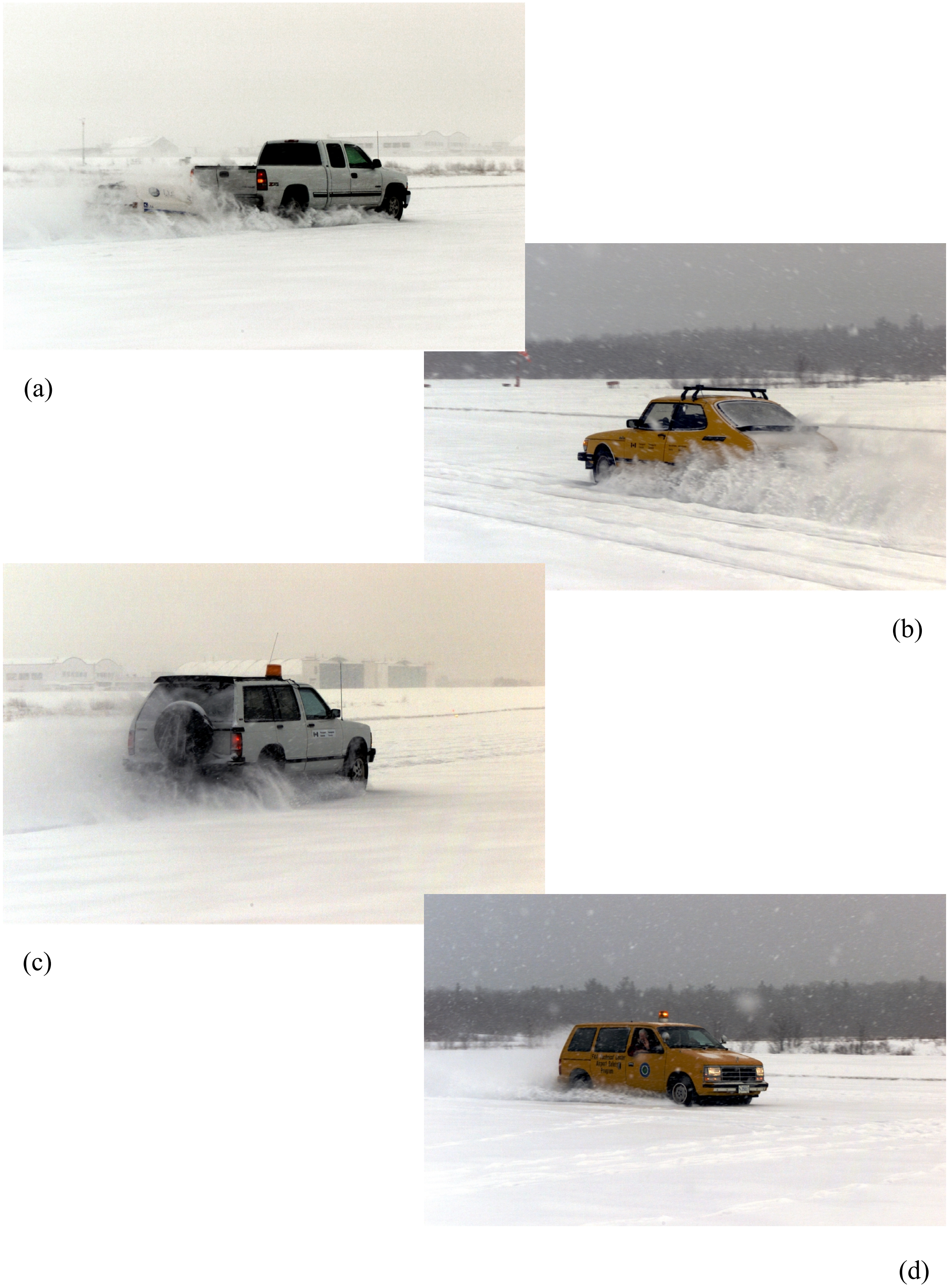


Figure 11. 05 February 2002 tests on runway 18-36 covered with 55 mm of fresh snow of density of 34 kg.m^{-3}, showing IRV (a), TC-SFT-TURBO (b), ERD (c) and FAA-RFT (d)

Test No. 02-36-02, Project 302, performed at 09:18, was the same as Test No. 02-36-01, Project 301, except for the fact that the test direction was 36 to 18 (with the wind).

Test No. 02-36-05, Project 305, involving six vehicles – the NASA-GT, FAA-RFT, IRV, TC-SFT-TURBO, FAA-BV11 and ERD – was carried out on runway 18-36 after all the deposited snow was removed. Although the runway surface was cleaned, there were stripes of snow 2 mm to 3 mm thick and 100 mm to 150 mm wide along the length of the runway, produced by the tires of the snow-removal equipment. The sky was partly cloudy and the sunshine was diffused. It was very windy, with gusts up to about 30 km/h. One set of runs at 65 km/h from button 36 to button 18 was carried out.

14:40 Test conditions: T_a = -6.2ºC and T_p = -4.5ºC for the surface of the bare asphalt pavement.

Test No. 02-36-01, Project 107, was carried out on the man-made ice strip (#8 in Figure 1) from 15:05 to 15:50. This was a six-vehicle test series involving the NASA-GT, FAA-RFT, IRV, TC-SFT-TURBO, FAA-BV11 and ERD. A total of seven runs were made at 65 km/h by each vehicle.

The ice strip was very non-uniform. There were no areas of clear ice anymore. There were many areas where the ice sheet was cracked and layers of low-density (frozen slush) ice flaked off the base ice. The original ice strip had been destroyed during the previous evening, when an effort was made to thickenit by flooding when it was very windy and blowing snow conditions persisted. Moreover, the snow removal process, using a broom, made the ice surface very rough as a result of the scarification process (see Figure 12).

14:55 Conditions before tests: T_a = -6.3ºC and T_i = -6.1ºC.

15:05 Tests started.

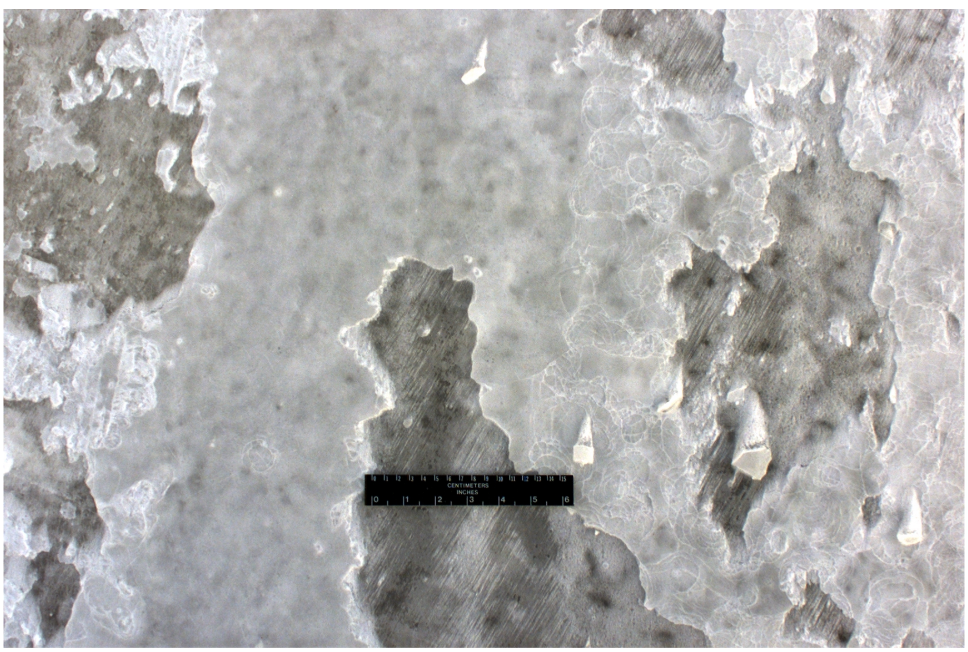
15:50 Conditions after tests: T_a = -6.4ºC and T_i = -6.0ºC.

Test No. 02-36-02, Project 108, was carried out on the compacted snow strip on the east side of runway 13-31 (#9 in Figure 1) from 15:05 to 15:50. All the snow that had been deposited on this test strip was removed during the noon hour (Figures 13 and 14). The snow cover kept the test bed cold, even though there was diffused sun and the air temperature increased during the later part of the day. This series was a six-vehicle test involving the NASA-GT, FAA-RFT, IRV, TC-SFT-TURBO, FAA-BV11 and ERD. A total of seven runs were made at 65 km/h by each vehicle.

14:55 Conditions before tests: T_a = -6.3ºC and T_s = -8.6ºC.

15:05 Tests started.

15:50 Conditions after tests: T_a = -6.4ºC and T_s = -8.6ºC.



February 5, 2002 14:55 , North Bay, Ontario
Test # 02.36.01, Project # 107
Runway 13/31, Direciton 13, 7 Runs at 65 km/h
Pre-Test Conditions:
Air Temp. -6.3 C., Ice Temp. -6.1 C.
NASA-GT, FAA-RFT, IRV, TCSF-TURBO, FAA-BV11, ERD

Ice test section was reflooded the previous night; wind and blowing snow had caused the surface to become very non-uniform and crusty (shown). Snow removal equipment left the surface rough, appearing partially scarified.
There were many areas of cracking and areas of frozen slush that had flaked off of the base ice.

Figure 12. Scarified man-made ice strip during the afternoon of 05 February 2002 showing a general view (top) and details of flaked ice (bottom)

February 5, 2002 14:55
North Bay, Ontario
Test # 02.36.02
Project # 108
NASA-GT, FAA-RFT, IRV, TCSF-TURBO, FAA-BV11, ERD
7 Runs at 65 km/h

Figure 13. NASA-GT (top), FAA-RFT (middle) and FAA-BV11 (bottom) on compacted snow during the afternoon tests of 05 February 2002

Figure 14. Compacted snow strip on the centre-line of runway 13-31 (a) and the NASA-ITTV on the compacted snow (b) during the afternoon of 05 February 2002

Test No. 02-36-08, Project 109, was carried out on the compacted snow strip on the centre line of runway 13-31 (between #8 and #9 in Figure 1) from 16:40 to 17:05, when it was rather dark and the air temperature was decreasing with time. All the snow that had been deposited on this test strip was removed during the noon hour. The test strip was bare but rough. This series was a six-vehicle test involving the NASA-GT, FAA-RFT, IRV, TCSF-TURBO, FAA-BV11 and ERD. A total of seven runs were made at 65 km/h with each vehicle. The IRV was equipped with ribbed tires at high pressure.

16:40 Conditions before tests: T_a = -7.4ºC and T_s = -9.7ºC.

16:47 Tests started.

16:05 Conditions after tests: T_a = -8.5ºC and T_s = -9.5ºC.

Test No. 02-36-09, Project 110, was a repeat of the previous test series (Test No. 02-36-08, Project 109), except for the fact that the IRV had ribbed tires with low pressure.

17:05 Conditions before tests: T_a = -8.5ºC and T_s = -9.5ºC.

17:10 Tests started.

17:30 Conditions after tests: T_a = -9.0ºC and T_s = -9.4ºC.

3.11 Wednesday 06 February 2002

At 06:00 the conditions at the airport were: T_{air} = -19ºC, overcast, Wind = S 13 km/h, Wind Chill = -27ºC, Relative Humidity = 64%, Dew Point = -24ºC, Ceiling = 2 000 ft., Barometric Pressure = 102.05 kPa, and Visibility = 24 km.

Test No. 02-37-01, Project 800, involving the aircraft Cessna 414, was carried out on the section of runway 13-31 south of the main runway 08-26. This test section was essentially a bare and dry asphalt pavement. There were some scattered patches of thin ice (1 mm to 2 mm in thickness) on the pavement (Figure 15). These patches were 1 m to 2 m in length and 0.5 m to 1 m in width. About 5% of the total pavement surface area was covered with ice.

Two ground vehicles, the IRV and ERD, were involved in this test series. One friction measuring run was carried out before the aircraft tests. Another run was performed after the end of the aircraft tests. The morning was cloudy, but diffused sun came out around 09:00 and the air temperature started to increase continuously during the morning hours.

08:30 Conditions before tests: T_a = -8.8ºC, T_p = -8.5ºC for the pavement surface and T_i = -8.5ºC for the ice patches.

(a)

(b)

(c)

February 6, 2002 08:36
North Bay, Ontario
Test Number 02.37.01
Project 800
Runway 1331 South, 31 Direction
A/C Runs- Cessna 414

Pre Test Conditions:
Surface was bare and dry with 5% ice patches
Air Temp. -8.8 C.
Surface Temp. -8.5 C. (Pavement) to -8.5 C. (Ice Patches)

Figure 15. Runway 13-31 conditions during the morning aircraft tests on 06 February 2002: general view looking towards south (a), snow/ice patches (b) and Cessna 414 during a test (c)

11:30 Conditions after tests: T_a = -2.0ºC and T_p = T_i = -0ºC to -0.2ºC. The ice patches were still intact, but showed signs of melting.

Test No. 02-37-02, Project 111, was carried out on the compacted snow strip on the centre line of runway 13-31 (between #8 and #9 in Figure 1) from 13:50 to 14:35. During the test period, the strip consisted of warm compacted snow with thickness up to about 30 mm. The surface was bare but rough, with ruts and ice strips. Due to the continued diffused solar radiation and high ambient air temperature, the temperature of the snow was high. The test series involved all seven vehicles: the NASA-GT, FAA-RFT, IRV, TC-SFT-TURBO, FAA-BV11, ERD and NASA-ITTV. The IRV was equipped with PIARC smooth tires at normal pressure and normal load. Five runs were made at 65 km/h by each vehicle.

13:50 Conditions before tests: T_a = -0.3ºC and T_s = -2.0ºC.

14:35 Conditions after tests: T_a = -0.3ºC and T_s = -2.5ºC. Towards the end of the test series, the sun went behind the cloud, causing the snow surface temperature to decrease slightly.

Test No. 02-37-03, Project 112, was similar to the previous series, Test No. 02-37-02, Project 111, involving all seven test vehicles, except for the fact that it was carried out on the compacted snow strip on the east side of runway 13-31 (#9 in Figure 1). Similar to the strip at the centre line, this test strip also consisted of warm compacted snow, but it was slightly colder (one degree) during the beginning of the tests because of thicker snow, up to about 40 mm.

13:50 Conditions before tests: T_a = -0.3ºC and T_s = -3.1ºC.

14:35 Conditions after tests: T_a = -0.3ºC and T_s = -2.5ºC.

3.12 Thursday 07 February 2002

At 06:00 the conditions at the airport were: T_{air} = -2ºC, overcast, Wind = S 24 km/h, Wind Chill = -8ºC, Relative Humidity = 80%, Dew Point = -5ºC, Ceiling = 900 ft., Barometric Pressure = 100.48 kPa, and Visibility = 13 km.

Test No. 02-38-01, Project 113, was similar to Test No. 02-37-02, Project 111, involving all seven test vehicles. This series was carried out on the compacted snow strip on the centre line of runway 13-31 (between #8 and #9 in Figure 1). The strip consisted of warm compacted snow with ruts and ice patches.

08:35 Conditions before tests: T_a = -1.3ºC and T_s = -2.2ºC.

09:20 Conditions after tests: T_a = -1.8ºC and T_s = -2.2ºC.

Test No. 02-38-02, Project 114, was a continuation of Test No. 02-38-01, Project 113, but was carried out on the compacted snow strip on the east side of runway 13-31 (#9 in Figure 1) from 08:58 to 09:20.

08:35 Conditions before tests: T_a = -1.3ºC and T_s = -2.6ºC.

09:20 Conditions after tests: T_a = -1.8ºC and T_s = -2.6ºC.

Test No. 02-38-04, Project 201, involving all seven test vehicles – the NASA-GT, FAA-RFT, IRV, TC-SFT-TURBO, FAA-BV11, ERD and NASA-ITTV – was carried out from 14:00 to 14:35 on the scarified surface of the compacted snow strip on the east side of runway 13-31 (#9 in Figure 1). The scarification was made after completing the morning tests. The usual airport equipment was used for this purpose. However, the snow strip was heavily scarified, which resulted in bare patches near the north end. Although most of the loose snow was removed after scarification and pushed to both sides of the strip, the test surface was littered with a layer of scattered pieces of compacted snow. Moreover, some snow flurry activities took place during the tests. Five runs at 65 km/h were carried out with each vehicle.

13:55 Conditions before tests: T_a = +2.6ºC and T_s = -0.4ºC.

14:00 Tests started.

14:35 Conditions after tests: T_a = +2.6ºC and T_s = -0.3ºC.

The surface characteristics changed significantly as the test series progressed. During the tests, the loose pieces of moist compacted snow on the surface were crushed by the passage of the test vehicles, which created a layer of loose moist snow on the scarified compacted snow.

Test No. 02-38-03, Project 202, involving all seven test vehicles, was a continuation of Test No. 02-38-04, Project 201. These tests were carried out on the lightly scarified surface of the ice strip on the west side of runway 13-31 (#8 in Figure 1). The scarification was made after completing the morning tests. Since the strip was lightly scarified, the surface was very uneven. There were areas where the ice was debonded either from the internal ice layers or from the asphalt below the ice cover. No water could be seen at sections where the ice was thick, but some water was noticed between the ice and the asphalt pavement surface at sections where the ice was thin. Snow flurry activities added complications to the test conditions. Five runs at 65 km/h were carried out with each vehicle.

13:55 Conditions before tests: T_a = +2.6ºC and T_i = -0.1ºC.

14:00 Tests started.

14:35 Conditions after tests: T_a = +2.6ºC and T_s = 0ºC.

Towards the end of the series, the ice sheet was essentially destroyed. Crushed ice and slush could be seen in many places on the asphalt pavement. The slush, consisting of crushed ice, actually made the test strip less slippery to walk on. Since the entire test strip was extremely non-uniform and there were large variations in the nature of the contaminants, the collected test data could be of no value for any analysis.

Test No. 02-38-05, Project 801, involved the aircraft Cessna 414 and two test vehicles, the IRV and ERD. This series was carried out on runway 13-31, south of the main runway 08-26 from 16:25 and 17:40, after a snowstorm that deposited a thin, very non-uniform layer of snow, 1 mm to 5 mm in thickness. There were also patches of wind-blown snow (Figure 16) with diameters in the range of 1 m to 2 m and depths up to 10 mm. The snow was powdery and dry, although its temperature remained high during the test series. The sky cleared and a bright sun came out after the storm. A strong wind from the northwest with a speed of 13 km/h, gusting to 20 km/h, with a direction parallel to runway 13-31, persisted during the tests. Since the test direction was 31 to 13, the wind direction was directly against the direction of the test runs (headwind). Six Cessna 414 runs were made (Figure 17). The IRV and ERD measurements were made before and after the aircraft tests.

16:25 Conditions before tests: T_a = -0.3ºC and T_s = -0.5ºC.

17:40 Conditions after tests: T_a = -1.5ºC and T_s = -2.7ºC.

During the evening hours, the air temperature started to drop rapidly, but the strong wind persisted.

3.13 Friday 08 February 2002

At 06:00 the conditions at the airport were: T_{air} = -14ºC, clear, Wind = N 13 km/h, Wind Chill = -21ºC, Relative Humidity = 72%, Dew Point = -18ºC, unlimited ceiling, Barometric Pressure = 101.49 kPa, and Visibility = 24 km.

Test No. 02-39-01, Project 115, involving five test vehicles – the FAA-RFT, IRV, TC-SFT-TURBO, FAA-BV11 and ERD – was conducted on the man-made (#8 in Figure 1) and lightly scarified ice strip on the west side of runway 13-31 from 08:54 to 09:15. The scarification had been made the previous day and the scarified ice had beens tested the previous afternoon (see the test conditions for Test No. 02-38-03, Project 202) before the snowstorm occurred. As reported, towards the end of the previous day's test, the scarified ice sheet was essentially destroyed. Crushed ice and slush could be seen in many places on the asphalt pavement. The free water and the slush mixed with the freshly fallen snow froze during the cold, clear night. The strong wind that persisted through the previous evening and night deposited a significant amount of wind-blown snow on the test strip. The excess snow on the ice strip was removed with a plough, a brush and a blower. The ice cover exhibited a mat finish due to the formation of granular or snow ice in the areas of refrozen slush.

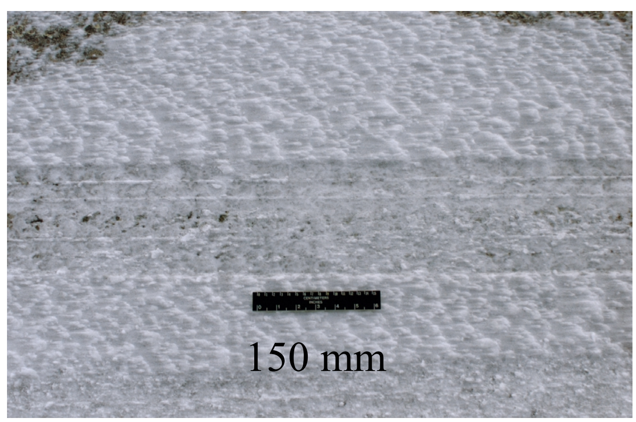
(a)

(b)

Figure 16. Conditions of runway 13-31 south at 16:25 on 07 February 2002 just prior to aircraft testing, showing (a) blowing snow, almost parallel to the length of the runway and (b) Cessna 414 preparing to test

(a)

(b)



(c)

Figure 17. Cessna 414 testing (No. 02.38.05, Project 801) on runway 13-31 south in the evening of 07 February 2002 from about 16:30 to 17:30 (a) and aircraft tire marks in a snow patch (b, c). The marker on the snow is 150 mm in length.

08:30 Conditions before tests: T_a = -13.5ºC and T_i = -10.4ºC.

The first run of test vehicles started at 08:54, when the wind started to blow snow on the test strip and the sun went behind cloud cover. The diffused sun and the increased air temperature increased the ice temperature by one degree.

09:15 Conditions after tests: T_a = -12.8ºC and T_i = -9.3ºC.

Test No. 02-39-02, Project 116, involving five test vehicles – the FAA-RFT, IRV, TC-SFT-TURBO, FAA-BV11 and ERD – was conducted on the previously scarified compacted snow on the east side of the centre line of runway 13-31 (between #8 and #9 in Figure 1). The snow that had been deposited on the runway during the previous afternoon's snowstorm was removed using a plough. Since no blower was used, a layer of loose snow remained on the top surface.

08:30 Conditions before tests: T_a = -13.5ºC and T_s = -10.8ºC.

09:15 Conditions after tests: T_a = -12.8ºC and T_s = -10.7ºC.

The movement of the test vehicles during the test runs blew away some of the loose and dry snow on top of the surface of the test strip. Unlike the ice temperature in Test No. 02-39-01, Project 115, because of its high albedo the snow temperature remained constant during the test runs in spite of the diffused sun.

Test No. 02-39-03, Project 117, involving five test vehicles – the FAA-RFT, IRV, TC-SFT-TURBO, FAA-BV11 and ERD – was conducted on the highly compacted snow strip with ice crust at about the centre line of runway 13-31 (between #8 and #9 in Figure 1). The test strip was not uniform. It had ruts in many places and some areas were covered with loose snow.

09:20 Conditions before tests: T_a = -12.8ºC and T_s = -10.8ºC.

09:37 Special note: Because the test strip was not uniform and had a texture with ice crust and ruts, it was decided to perform one set of reverse runs that consisted of a run in the direction from 31 to 13 followed by a run in the direction from 13 to 31.

09:41 Conditions after tests: T_a = -12.8ºC and T_s = -10.2ºC.

The sun was diffused at this time because of cloud cover.

Test No. 02-39-04, Project 118, involving five test vehicles – the FAA-RFT, IRV, TC-TURBO, FAA-BV11 and ERD – was conducted on the highly compacted and uniform snow strip on the east side of runway 13-31 (#9, Figure 1). This test strip was rather uniform compared to the centre-line strip used concurrently with this series.

09:20 Conditions before tests: T_a = -12.8ºC and T_s = -10.5ºC.

09:37 Special note: One set of reverse test runs was also made on this strip (see note for Test No. 02-39-03, Project 117).

09:41 Conditions after tests: T_a = -12.8ºC and T_s = -10.5ºC.

The sun was diffused at this time because of cloud cover and did not affect the temperature of the compacted snow because of its relatively high albedo.

Test No. 02-39-05, Project 307, involving five test vehicles – the FAA-RFT, IRV, TC-TURBO, FAA-BV11 and ERD – was conducted on the whole length of runway 13-31 from the north end (13) to the south end (31) on a narrow 3 m wide strip west of the runway's centre line.

This test strip was extremely non-uniform in its surface characteristics. About 70% of the runway pavement surface was covered with a dusting of snow, caught between the aggregates of the asphalt concrete, and snow drifts with accumulations up to 5 mm. This included the entire section of runway 13-31 south of the main runway 08-26 (Figure 18). There were wind-driven patterns and snow textures on the pavement surface, which consisted of elongated patches of snow 0.5 m to 1 m wide and 1 m to 3 m long, parallel to the length of the runway. This irregular drifted snow cover resulted from the persistent blowing snow conditions that prevailed during the previous day and night. Because of the wind-driven snow deposition process, the snow density varied significantly and was high, in the range of 300 $kg.m^{-3}$.

The section between #8 and #9 in Figure 1 on the north side of runway 13-31 was extremely non-uniform, as can be seen in Figure 18. There were patches of bare asphalt pavement, ice and compacted snow in addition to the wind-driven drifted snow patterns (Figure 18). The depth of the snow patches varied from 5 mm to 10 mm, depending on their overall size: the larger patches had deeper snow.

09:50 Conditions before tests: T_a = -13.3ºC and T_s = -8.8ºC (for snow patches).

(a)

(b)

Figure 18. Conditions of runway 13-31on 08 February 2002 during morning test no. 02.39.05, project 307, for the section north of runway 08-26 (a) and south of runway 08-26 (b)

4 CONCLUSIONS AND RECOMMENDATIONS

Despite the restrictions imposed by the weather conditions, the 2002 field tests at North Bay were carried out very smoothly and efficiently. The North Bay Airport authorities provided an excellent base for conducting the tests.

Due to the environmental limitations, man-made winter contaminants (in the form of ice) and natural contaminants were used for testing. Natural contaminants included freshly fallen snow and old accumulated snow significantly thickerr than the allowable snow accumulation on operational runways. Consequently, some of the tests were carried out under conditions that may exceed real-life airport operational conditions. However, the results obtained from the ground vehicles are useful for comparative studies.

Most of the objectives laid out for ground vehicle tests were met, except for the limitations on the studies on scarified ice. This, however, was unavoidable. The scarification process is normally applied to a thick ice. No freezing rain occurred either before or during the days of testing. There were no areas of uniformly thick ice covers on any part of the runways or taxiways. This situation was beyond the control of the test planners, because only natural processes can provide a uniformly thick ice cover over a vast span of space. For testing purposes requiring uniformly scarified ice surface, the thickness should be in the range of 15 mm to 20 mm. An effort was made to thicken the man-made ice strip, but it was found not to be practical.

Air temperature; relative humidity; wind speed and direction; sky conditions, including cloud cover; the presence of solid or liquid particles in the air and on the pavement surface; movement-area surface texture; pavement surface temperature; the vertical and spatial temperature gradient in the pavement; and solar radiation (during the day) all play important roles in determining the surface conditions of a runway. Continuity in the measurement of all these parameters should be ensured. It is also recommended that continuous measurement of solar radiation at the test site be an integral part of future measurements.

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