Studies Related to Removal of Snow and Ice from Transportation Facilities

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The various research and development programs that have been conducted at the National Research Council of Canada in the general field of snow and ice removal are described briefly. The research work ranges from aircraft icing dating back to the 1940s to current research on unconventional methods of snow and ice removal by techniques such as high pressure water jets and air lubrication.

A liberal interpretation of the title of this paper has been taken partially as a result of reading the preliminary program and realizing that there would be those in attendance with rather wide interests in snow and ice. The secondary reason for the broader view was to allow for some of our own earlier work to be reported.

The Division of Mechanical Engineering of the National Research Council of Canada has been involved in one aspect of ice removal research for the past forty years. This work has been in the anti-icing and de-icing of aircraft flight and propulsion components. The physical facilities provided for research, to a large extent, have guided or limited the activities that could be pursued. Until the late 1940s laboratory facilities did not exist at NRC in which work could be conducted with ice and snow. The aircraft icing research work that was conducted prior to 1950 was carried out in flight under natural icing conditions at some personal risk to the investigators. In 1950 an icing wind tunnel capable of speeds up to 290 km/h (180 mph) was made available as one of the physical facilities of the Low Temperature Laboratory (1). This name was intended to denote that the laboratory was concerned with climatic low temperatures and as it was a section of the Mechanical Engineering Division its concern was with various engineering equipment. A number of cold chambers were included as part of the physical plant. During the first year of operation of the cold chambers requests were received for snow in off-season periods for test purposes and thus snow making has been one of the activities for the past thirty years.

Aircraft Icing Research

During the early 1950s research work was conducted in the laboratory and in flight using a North Star aircraft while investigating electro-thermal methods of de-icing flight surfaces. Previously the electro-thermal conducting rubber propeller de-icing system had been developed. This was subsequently fitted to most propeller driven transport aircraft of that era. The electro-thermal wing de-icing system was fitted to two of the first all-weather aircraft flown in North America. In addition to investigating de-icing methods considerable effort was involved in icing instrumentation development to measure in flight the conditions experienced. In the de-icing of aircraft flight and propulsion surfaces, one of the physical problems involved is that of ice adhesion. Over the past thirty years a number of facilities have been developed and used to evaluate the adhesion of ice to various surfaces. A whirling arm fixture was first developed to evaluate possible helicopter rotor blade de-icing pads. Ultimately this fixture was modified to conduct self-shedding adhesion tests of droplet formed ice (2).

In the de-icing of aircraft surfaces it is essential that an automatic control system be employed that senses the ambient icing conditions. Since 1950 work has been conducted on ice detectors for both fixed wing and rotary wing aircraft. The helicopter has posed a unique problem since it can hover at zero forward speed and yet collect ice on the rotor blades at almost the same rate as in forward flight. In the last decade considerable work has been conducted on a dynamic principle ice detector for helicopters with a high response rate that in addition to detecting ice is capable of measuring the liquid water content of the ambient clouds.

Non-Aeronautical Icing

The knowledge of cloud physics and the thermodynamics of icing that had developed during the aircraft icing research and development work eventually led into non-aeronautical icing research. One of the icing problems encountered is that of ship icing. In this case the cause of the more severe icing is not that due to either cloud icing or spindrift but is the result of high winds, high waves and heavy spray resulting from ship motion. For smaller vessels, such as fishing trawlers, the growth of superstructure ice can cause loss of stability with the subsequent capsize of the vessel. We have examined various methods of removing ice from the ship superstructure (3). For flat surfaces and cylindrical surfaces an inflatable boot, similar in principle to the early pneumatic de-icers for aircraft, is a low energy means of removing ice from surfaces. For masts, whether single or multileg design, one of the interesting means of anti-icing is by application of a two-phase thermal siphon. This converts the mast into a massive heat pipe where engine waste heat could be employed to advantage.

A novel solution to the icing problem of marine buoys was developed by personnel from the Gas Dynamics Laboratory of NRC. The problem with buoys in winter icing conditions has been loss of stability and capsize but not sinking.

By application of a thermal siphon to the buoy, the small amount of heat available in the sea water above the freezing point has been employed to anti-ice or de-ice the superstructure.

For almost a decade we have been collecting information on the icing of ships at sea off the east coast of Canada during the winter season (4). From the information gained to date we have concluded that the International Standards for the icing of ships are not sufficiently stringent for ships operating off the east coast of Canada.

The icing of various structures including electrical power transmission lines and their supporting towers, communication towers and some high rise buildings has caused millions of dollars damage. Each winter there are reports of power line failures from icing in some area and to date the main solution has been to raise the standards for new construction to allow for heavier accumulations.

The icing of runways at airports where corrosive salts cannot be employed poses a special problem to the operators. While urea may be an effective, even though expensive, solution to this problem under moderate conditions, it is not satisfactory at colder temperatures or with heavy ice deposits.

Recently we have been examining the removal of ice from a concrete surface by means of high pressure water jets (5). This method has the potential advantage of using a non-mechanical contacting method, thus irregularities in the surface or the ice thickness are of minor significance. Concrete can be cut with a high pressure water jet, thus one of the initial questions in considering this method was whether the ice could be removed without damaging the concrete. Initial tests showed that concrete test slabs developed signs of surface erosion when passed under a water jet with a pressure of 35,000 KPa (5000 psi). While ice can be penetrated by a water jet of 35,000 KPa (5000 psi) tests showed that to employ a reasonable nozzle stand-off distance with small diameter orifice, higher pressures were necessary. A series of ice removal tests were conducted using ice film thicknesses of 3 mm (1/8 in.) and 6 mm (1/4 in.) at different traverse speeds, with various nozzle sizes and water pressures. Tests were also carried out with different nozzle orientations with respect to the ice surface and the direction of traverse. It was established that high pressure water jets could be employed to remove ice without damage to the concrete substrate at much higher pressures than originally considered by orienting the nozzle for a low attack angle. It was fortuitous that this orientation also proved to be the most efficient for ice removal. The high pressure water jet is employed much like a plane or wood chisel in ice removal. At a low angle pressures of over 140,000 KPa (20,000 psi) have been employed without damage to the concrete substrate. We believe this method of ice removal shows sufficient promise for runways to warrant further study and development.

Snow Making and Snow Removal

During the first twenty years of research and test work in the cold chambers of the Low Temperature Laboratory only a limited amount of the work involved snow. On occasions various programs required the production of snow in the cold chamber, for example to test small snow throwers, or to examine the performance of electrical insulators with snow covers. Snow is manufactured using raw water atomized by compressed air in an external mixing nozzle. Various arrays of nozzles have been fabricated depending on the coverage required. Two nozzle arrays are mounted on wind chill fans in order to produce snow at high velocity when necessary to simulate blizzard conditions.

In the large cold chamber, 15 x 4.5 meters (50 x 15 ft) in floor area, snow has been made at rates equivalent to a snowfall of 12.5 cm/h (5 in. per hr). More commonly, snowfall rates of 2.5 cm per hr (1 in. per hr) are simulated. While working with the railways on the problem of railway track switches failing to transfer due to the presence of snow, a standard test condition of a snowfall at 2.5 cm/h (1 in. per hr) with a 32 km/hr (20 mph) wind at an ambient temperature of -18 Celsius (zero degrees Fahrenheit) was established. A full-sized railway switch complete with ties and ballast was installed in the cold chamber and various protection systems have been tested and evaluated in the laboratory prior to field tests. The design criteria established for the test program has proven to be adequate in field applications except for a few limited areas where the ambient conditions were known to exceed the values chosen.

While snow making in the laboratory was extremely useful in evaluating and developing railway switch protection systems, for other snow related problems it is inadequate.

Some years ago when this subject of alternate high speed urban and interurban transportation systems based on air cushion technology was first considered, various schemes were proposed for use in Canada. In view of the difficulties that were experienced by existing transportation systems as a result of snow, it was considered urgent to ensure that any new system contemplated would not involve more serious problems with snow.

Various proponents of high speed transportation systems had proposed different vehicle and track designs. In discussions with the designers of the various tracks it became evident that they had not given serious consideration to the snow problem.

After considering the possibility of examining the performance of model track sections under simulated conditions in a laboratory, the decision was made to conduct field tests with full scale track sections depending on nature to supply the snow, wind and low temperature. With Ottawa as a test site there was never any doubt about the reliability of nature to provide the test conditions on a regular basis. One of the conclusions resulting from this test was rather obvious in retrospect, namely that a snow fence, or a track section similar to a fence, is a good device for accumulating snow and it matters little whether the snow fence is made of wood or concrete (6).

While waiting for snow accumulations to gather on the high speed transportation track sections, it seemed desirable to give some thought as to how snow might be removed more rapidly from these or other surfaces. It appeared that 100 km/h (60 mph) was considered high speed snow removal from either highways or airport runways. Since this speed was approximately equivalent to the legal vehicle speed on the highway it seemed doubtful that there would be any need for higher speed snow removal from highways. When compared with the proposed speeds for the new systems, however, it was evident that snow clearing at 100 km/h (60 mph) would not be compatible with high speed vehicle operation.

At least one of the vehicle developers considered the problem of snow removal as insignificant. They believed air cushion vehicles would maintain a track clear of snow if operated at sufficiently frequent intervals. While this supposition is probably true for some types of snow and some snowstorms, there are other snow conditions that seemed to be less amenable to this solution.

In order to evaluate some unconventional methods of removing snow, including the air cushion, a short test track was constructed on a test site in Ottawa adjacent to the site with the high speed track sections. This test track was a concrete slab 36 meters (120 ft) long between steel rails on standard gage. The dual steel track is 90 meters (300 ft) long to allow for accelerating a vehicle prior to the test section and braking afterwards. This test track was intended only for the initial, low speed tests of unconventional snow removal. The test section is elevated approximately 1.3 meters (4 ft) above the surrounding terrain to allow for some accumulated snowfall without interference. A propulsion vehicle and a test vehicle for mounting experimental equipment have been provided. Both of these are modified railway maintenance equipment vehicles.

One of the first methods examined was a system based on the claim of the air cushion vehicle developer. An engine driven fan capable of developing pressures to 45 cm (18 in.) water column or flows to 324 cu. meters/h. (12,000 cfm) was installed on the experimental vehicle. The fan outlet was connected to a full track wide plenum with a lower adjustable outlet. This outlet simulated the gap between the air cushion vehicle skirt and the normal substrate. At low speed and with dry non-adherent snow the snow removal was excellent. With a wet adherent snow the plenum acted as a mechanical snow plow and some snow cover remained. With a wet snow that had been allowed to sinter and freeze to the substrate the removal was completely inadequate.

Various nozzle systems were evaluated with this fan system and on another vehicle at higher speeds and with higher nozzle pressures. All of these nozzles showed similar results, i.e., with dry, non-adherent snow the removal is excellent; with wet adhesive snow, removal is adequate at higher nozzle pressures, while with snow compacted onto the substrate or frozen to the substrate, removal is unsatisfactory.

While conducting the test work with nozzles on unconventional snow removal simulating an air cushion vehicle the discussion of the low friction characteristic of this vehicle led to the consideration of the inversion concept. If a vehicle supported on an air cushion passes over snow with low friction, then might not snow pass over a vehicle surface, a snow plow blade for example, with low friction if supported on a film of air? This technique might allow for higher speed snow removal. Work on this concept has been progressing and is discussed in another paper (7).

Snow has been a somewhat unexpected source of trouble with another transportation system, in this case a helicopter. Flight of one type of helicopter in snow had resulted in engine flame-out. Since this was a single engine helicopter, this type of failure was not only undesirable, it was disconcerting to the pilots. It was shown that the cause of the difficulty was accumulation of snow in the engine inlet plenum which on entering the engine in an accumulation caused the engine to flame out. As a follow-on to this investigation work has been carried out on the measurement of airborne snow and the correlation of these measurements with visibility (8). This work is being reported in another paper.

Some of the work conducted in the Low Temperature Laboratory that falls in the classification of snow and ice removal has been described. In other papers that are due to be presented at this Symposium the work is described in greater detail.

References

1. J. L. Orr and D. G. Henshaw. A New Canadian Laboratory for Arctic Testing. Refrigerating Engineering, Sept. 1949.
2. J. R. Stallabrass and R. D. Price. On the Adhesion of Ice to Various Materials. NRC Aeronautical Report LR-350, July 1962. Canadian Aeronautics & Space Journal, Vol. 9, No. 7, Sept. 1963, pp. 199-204.
3. J. R. Stallabrass and P. F. Hearty. Methods for the Alleviation of Ship Icing. NRC Mechanical Engineering Report MD-51, August 1970.
4. J. R. Stallabrass. Trawler Icing off Eastern Canada. NRC Mechanical Engineering Report LTR-LT-50, Dec. 1973.
5. H. J. Kimberley and W. H. Brierley. Ice Removal from Concrete by High Pressure Water Jets. NRC Mechanical Engineering Report LTR-LT-74, April 1977.
6. T. R. Ringer and R. D. Price. Snow Accumulations on Air Cushion Vehicle Track Sections. NRC Mechanical Engineering Report MD-52, Oct. 1972.
7. T. R. Ringer and T. M. Mazur. Research on an Air Lubricated Snow Plow. Presented at the Second International Symposium on Snow Removal and Ice Control Research, Hanover, New Hampshire, May 15-19, 1978.
8. J. R. Stallabrass. Airborne Snow Concentration and Visibility. Presented at the Second International Symposium on Snow Removal and Ice Control Research, Hanover, New Hampshire, May 15-19, 1978.