Some Experiences in Assessing Aircraft Anti-Icing Fluid Under Various Snow Conditions

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ABSTRACT

During the winter of 1991-92, assessments of the efficacy of various aircraft anti-icing fluids were carried out at the State University College at Oswego, New York. The campus is fortunately situated for the study of various types of synoptic and mesoscale precipitation, particularly in winter.

Plates simulating air foil surfaces were coated with a selection of available anti-icing fluids and were then exposed to frozen or freezing precipitation. Condition of the coated surfaces was then monitored visually and with a video cassette recorder. Concurrently observations of air temperature, plate temperature, relative humidity, wind, amount and character of precipitation were recorded at regular intervals. Failure times of the exposed fluids were carefully noted.

This paper describes the experimental setup, instrumentation, and problems encountered in the work. Tentative results indicate that the fluids last longer when precipitation rates are low and there is a slight tendency for fluids lasting longer when the wind is moderate as opposed to light.

INTRODUCTION

Aircraft icing is a consequence of supercooled liquid water depositing onto subfreezing aircraft surfaces. In the last decade, aircraft icing has become a more recognized cause of aircraft accidents by private and commercial pilots. From 1975-1988, the National Transportation Safety Board determined that icing was the cause of 803 aircraft accidents. Icing is a problem on takeoff, in flight, and on landing, with accidents occurring equally during each phase of flight (Politovich, 1991). Aircraft icing is most often found to occur in certain geographical areas, such as mountainous regions and around large bodies of water like the Great Lakes. The Great Lakes pose a serious threat because supercooled liquid water clouds are prevalent in these regions, resulting in a very large area of icing and a serious threat to aviation (Cole and Sand, 1991).

Topographic effects are also important in determining regions of icing because these regions can enhance the amount of supercooled liquid water in the area by upslope flow over the terrain. The Rocky Mountain region is of great interest because of this upslope flow and other prominent topographical features.

Studies are being conducted to learn more about aircraft icing occurrences in order to reduce the number of icing related aircraft accidents. The Federal Aviation Administration is now testing glycol-based deicing and anti-icing fluids to determine their effectiveness in winter storm conditions. Deicing fluids are designed to remove ice from aircraft while anti-icing fluids are designed to prevent buildup of ice on aircraft. Weather at Oswego offers a variety of severe winter precipitation conditions, making it a location of interest to this testing program.

At SUNY Oswego, tests of Type 2 glycol based fluid were performed. Type 2 fluid is a very thick, viscous fluid as compared to the Type 1 fluid. Type 2 fluid is often used as an anti-icing fluid because of its durability. Type 1 fluid is a common deicing agent, used mainly to remove ice on the aircraft surfaces and provides little protection against the subsequent accumulation of more ice. Viscosity and cling are important characteristics of these fluids; the former is the ability of the fluid to flow along the surface when a force (e.g. gravity) is applied, and the latter affects the affinity of the fluid molecules to the molecules of the surface. Fluids with a good cling will keep a thin layer on the surface, but a viscous fluid is desired because it maintains a thick layer of the fluid on a sloping surface allowing more ice to be melted or supercooled water to remain liquid. However, the fluid must flow well enough to slough off the plane during takeoff and take with it the accumulated ice. The work at Oswego is concerned with the efficacy of various Type 2 fluids in providing anti-icing protection.

PROJECT DESCRIPTION

The purpose of this project was to determine how long Type 2 anti-icing fluids last under various weather conditions. Previous testing had been done by manufacturers and airlines, but it was felt that analyses by independent scientists who might discern potential problems would be valuable. Some studies had been done in wind tunnels; it was felt that studies should be done in the atmosphere where conditions could not be controlled and thus unforeseen problems might arise. Professor Mike Muller of Rutgers University approached the Federal Aviation Administration about doing such a study. After gaining their interest, he approached other universities so that the inclusion of several sites might provide more adverse weather conditions as well as more data points. The sites chosen in addition to Rutgers were: SUNY Oswego, SUNY Brockport, and Central Michigan University. The work at Oswego was subsequently funded by the FAA through Rutgers University.

PROCEDURE

The procedure involved exposing to the weather eight 30 X 50 cm aluminum plates mounted on a rack on the roof platform of our meteorology building. The plates were faced into the wind (tilted 10 degrees from the horizontal) in two rows (see figure 1).

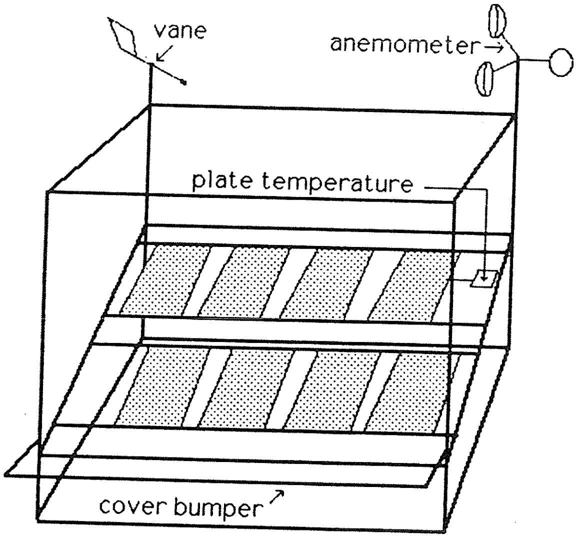

Figure 1. Test rack with plates exposed

Fluids from four manufacturers were tested so that each fluid appeared in the front and back rows with one sample of each at an outside edge and the other sample toward the center. The position of the fluid samples on the rack were changed for each test. A thermocouple was attached to one of the plates to measure its temperature. Each plate had fifteen cross hairs (2 cm square) painted on them. When five of the fifteen cross hairs became covered with snow, it was assumed that one third of the plate was covered and thus the plate had failed (see below). In addition, a line was painted 2.5 cm in from each edge; snow accumulation outside this line was ignored as edge effects were considered to be of no interest in the project. (see figure 2).

In order to expose all of the plates simultaneously,the plates were prepared under cover out of the elements. In order to facilitate handling of the cover under high winds, a roll up mechanism for the canvas cover was devised. The frame was held down with six concrete blocks; during high winds the frame was also tethered to the roof with nylon line.

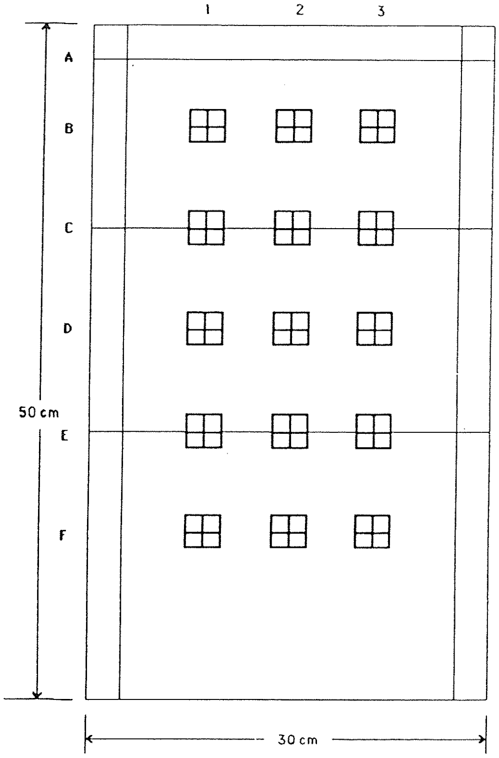

Figure 2. Experimental Plate

Under cover, the plates were prepared as follows. All liquid was removed from the plates using a window squeegee. If any ice was stuck to the plates, alcohol was used to remove it and then the alcohol was squeegeed off and the residual alcohol allowed to evaporate. The room temperature fluids were poured onto the plates from beakers until the plates were thoroughly covered. The tilt of the plates enabled excess fluid to drain onto the roof platform. (Note that the glycol based fluid is totally non-toxic.) After a short time, the thickness (depth) of the fluid was measured with a wet paint thickness gauge and was typically found to be between 24 and 30 mils.

The cover was then rolled back and the test begun. A cup anemometer and a vane were attached to the rack and the wind recorded. At the same time a snow board was swept clean and a cake pan containing a thin depth of glycol was set out to collect the snow. Two pans were used so that one could be weighed while the other was collecting the falling snow. Every five minutes the following parameters were measured: fluid thickness on each plate; snow depth; weight of the pan with the melted snow; air temperature; plate temperature; relative humidity; wind speed and direction; and weather conditions (visibility and character of precipitation). A video camera with a weather resistent cover pointed at the frame provided a visual and audio record of the experiment. Occasionally the video camera was zoomed in to view individual plates; time and date were automatically recorded. A wireless microphone was used with the video camera to record observer comments.

Plates could be considered to have failed in one of three ways. The first was when the top line(2.5 cm from the top) became obscured. The second was when five of the fifteen cross hairs became obscured. The third criterion for failure was when five of the fifteen cross hairs lost their glossy appearance indicating freezing of the fluid. The time of the loss of each cross hair mark on each plate was noted until that plate failed. The test was completed when all plates had failed. Following the completion of the test, the snow glycol mixture was squeegeed off the plates and if another test was to be run, the frame was recovered.

As was mentioned above, high winds often made implementation of these procedures difficult. In addition to stabilizing the frame with tethers and concrete blocks, the investigators were hampered by the winds during covering and uncovering the frame. An effective roll-up cover mechanism was finally designed. The high winds made use of a snow board impossible during most events. It was necessary to raise collection pans above the surface in order to minimize drift of snow into the pans.

RESULTS

Eleven tests were run on eight days, all under light snow conditions. Plate failure times ranged from 28 min to over two hours. In addition to snowfall rate, the main parameters affecting plate failure times were air temperature and wind speed. During light

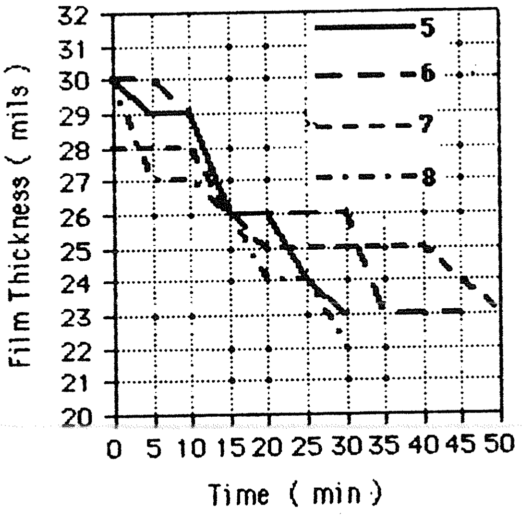

Figure 3. Film thickness for plates 5-8
Test 10 - March 22, 1992

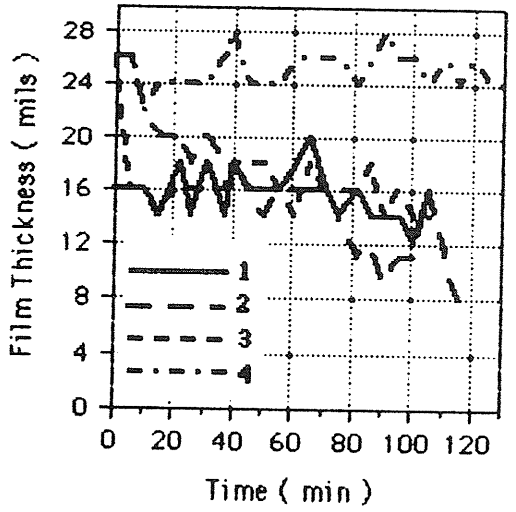

Figure 4. Film thickness for plates 1-4
Test 7 - March 11, 1992

wind conditions, gravity caused the fluids to slowly drain down the plates (see figure 3 where the wind averaged 3.4 m/s). Fluid thicknesses were measured between the second and third row of cross hairs. Fluid thicknesses measured above this line were less and below this line greater. When the wind was stronger, the fluids maintained their thickness since the wind pushed the fluids back up the plates (see figure 4 where the wind averaged 6.7 m/s). In one case the wind was strong enough (averaging 13.2 m/s) to cause the fluids to ripple, making depth measurements impossible. Most of the plates collected snow where the fluid was thick and the snow blew clear of where it was thin so that the plates failed in a ripple pattern. However, on one plate the ripples moved up and down the plate recoating areas that started to fail and after two hours only one mark had been covered while all but four of the 105 marks on all of the other plates had been covered, including all marks on the other plate of the same fluid.

The other effect of the wind was to increase the cooling rates of the plates due to convection. Since the fluids were applied at room temperature, the plates started out warmer than the air. If the wind was strong, the plate temperature dropped quickly. In one case when the air temperature was about -1°C, the plates remained above +1°C for 40 min while the wind averaged 2 m/s. At 40 min the wind increased to 5 m/s and the plates dropped below freezing 8 min later (48th minute). The first mark failed at 54 min, the first plate at 56 min and the last plate at 66 min. The snow had been accumulating and melting all along on the plates, and when they suddenly dropped below freezing, they quickly failed. When the air temperature was well below freezing, the cooling by the wind effect was not important since the plates quickly dropped below freezing even though they may have remained warmer than the air for some time.

Bearing in mind that we only have a total of eighty eight failure points as our data set, it would be premature to offer any strong conclusions. In addition, since our data are a fraction of the total data acquired by the overall project, we will not identify the fluids by manufacturers name or product. We will refer to the fluids as fluids A, B, C, or D.

Predictably all fluids showed a tendency for shorter failure time as average precipitation rate increased (see figure 5). Because the character of the snow varied considerably from event to event and within events, this correlation still appears rather weak. Much more data of all snow characterizations is necessary. It might be interesting to include untreated, dry plates for comparison of ice formation to the treated plates in subsequent experiments.

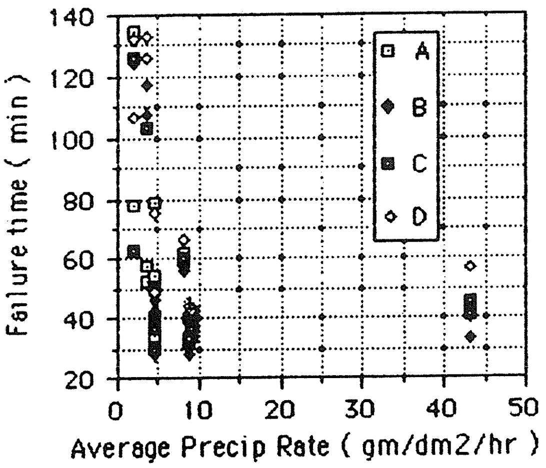

Figure 5. Failure time vs. average precipitation rate for fluids A-D (all events)

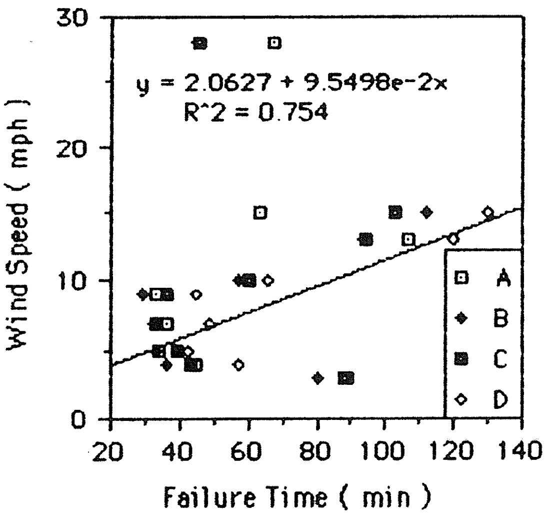

Figure 6. Effect of wind speed on failure time (all events, all fluids)

Surprisingly, all fluids showed a slight tendency for failure time to increase with increasing wind speed (see figure 6). This seemed especially true of fluid D which was more viscous than the otherthree (see regression line for fluid D on figure). This effect might be attributed, as mentioned above, to the wind countering gravity thus keeping the fluid present on the plate. One can speculate that this effect might lead to nonuniform failure patterns in aircraft operation since each part of an aircraft and its airfoil surfaces is positioned and oriented differently to the prevailing wind and gravity. The overall performance of the fluids can be determined in terms of average failure time (see figure 7). Fluid D showed the longest average failure time of over 70 min , while the average failure times for the other fluids ranged between 53 and 57 min. Figure 7 shows the range and average failure times for each fluid. A t-test shows that the difference between the average failure time of fluid D and the average failure time of the other three fluids is significant at the 10% level.

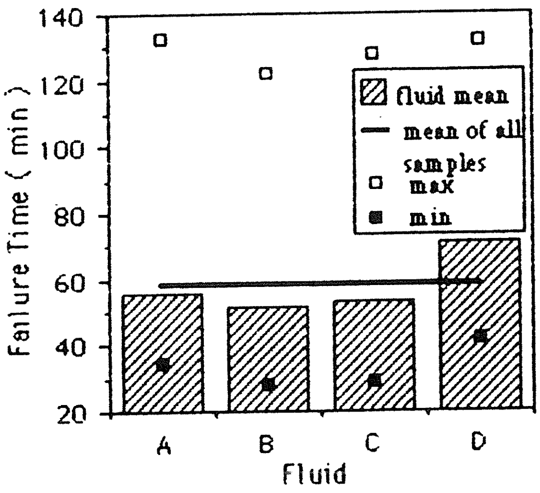

Figure 7. Average Failure Time for all fluids

CONCLUSIONS

A great deal was learned about the difficulties of performing this kind of experiment under high wind conditions. The location of the study very near Lake Ontario ensures that high winds and their accompanying gusts must be managed. The investigators feel that they now have an acceptable design for equipment and procedures in order to continue to acquire quality data.

Generally there is much spread to the data, particularly in regards to failure rate versus average precipitation rate during events. Much more data will be necessary to make sense of this dependence. It is probable that precipitation rate alone is not sufficient to explain failure but that failure is tied to character of precipitation as well. It might be well to capture samples of precipitation particles in order to assess the amount of riming or ice content of the snow. Then precipitation rates of various character can be related to failure time.

The slight tendency of failure time to increase with increasing wind speed mentioned above leads one to speculate about the effect of orientation of a plate and by extension to the orientation of airfoils and plane surfaces with respect to the wind. Future experiments should involve an array of plates at varying orientations to the mean wind. Further, it would be interesting to study the effects of wind on slightly curved plates to see if thinned regions are created by the wind thickening effect.

In connection with character of precipitation and relative humidity, it would be useful to include among the plates a pair of untreated or dry plates as well. In snows with very high ice to water ratios (a dry fluffy snow for example), we might expect little sticking and therefore little or no icing of a surface. We could speculate that a dry plate under these circumstances might do as well as a treated plate.

Finally it seems that viscosity of the icing fluid may account for some of the failure rate differences observed. Fluid D appeared to be more viscous after absorbing water than the other three and was , at the 10% significance level, more effective than the other three fluids. Since a requirement for a type 2 fluid is that it slough off the airfoil easily when the aircraft is in motion, the viscosity may have a double and perhaps contradictory significance. That is, a fluid must be viscous enough to afford anti-icing protection but not so viscous that the airfoil surfaces cannot shed it uniformly and efficiently.

References

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Politovich, M. K. , 1991: *Aircraft icing as an applied winter storms problem.* Preprints, First Int'l Winter Storms Sympos., New Orleans, 14-18 January, pp. 235-240.