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Indoor Snow Testing of Aircraft Ground Anti-Icing Fluids

April 2006

Final Report

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16. Abstract

Currently, holdover time performance for aircraft deicing and anti-icing fluids under snow conditions are determined from outdoor tests on flat plates in natural snow. The Federal Aviation Administration Airport and Aircraft Safety Research and Development Division has sponsored research to do similar tests under indoor laboratory conditions. Such indoor tests would lead to a more timely and improved assessment of a new fluid's performance without relying on outdoor snow conditions. During past investigations, when similar tests were conducted in laboratory cold rooms, the resulting holdover times were significantly different (typically shorter) from those produced outdoors in natural snow conditions. This difference was attributed to the effects of wind. Recent research at the National Center for Atmospheric Research has produced indoor procedures using temperature-controlled test plates that accounted for the effects of wind and produced holdover time results that more closely matched those obtained from outdoor snow tests.

The first objective of this current effort was to participate in round-robin tests with two other organizations, using prior outdoor results from many certified fluids for different snow intensities and temperatures. The results from this effort indicated that the data from the three test organizations/sites correlated well with results obtained from measurements in outdoor natural snow conditions. Next, the improved procedure was used to obtain holdover time performance for fluids at -25°C for snow conditions. This was performed since existing holdover time values had been based upon theoretical mathematical extrapolations, or for some new fluids. These values were assigned based upon existing worst-case values at this temperature. The results indicated that the measured laboratory values typically exhibited holdover time values shorter than those obtained from the mathematical extrapolations for a temperature range of -14° to -25°C. An additional objective of this effort was to develop and evaluate a more objective fluid failure call procedure, in lieu of the current criteria, in which fluid failure is based upon the condition when 30% of the test plate is covered with snow. Conceivably, the 30% snow coverage failure call criteria can be imprecise since it relies upon human observations. Previously, it was noted that the fluid extracts heat from the surroundings for the energy required to absorb the snow. When the snow is no longer being absorbed by the fluid, the fluid is no longer draining thermal energy, and the fluid has failed. During this investigation, the amount of heat required by the system to maintain the required plate temperature was recorded, and by observing changes in this value, it was determined that an objective fluid failure call based upon this criteria was very promising.

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LIST OF ACRONYMS

AMIL	Anti-icing Materials International Laboratory
APS	Aviation Planning Services
EG	Ethylene glycol
FAA	Federal Aviation Administration
HOT	Holdover time
NCAR	National Center for Atmospheric Research
PG	Propylene glycol

EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) Airport and Aircraft Safety Research and Development Division has been supporting research to substantiate and improve accuracy of the FAA Holdover Time (HOT) Guidelines for aircraft ground deicing and anti-icing fluids. New and improved products are constantly being introduced and each must undergo a rigorous acceptance process before they are recommended for use by the aviation community.

Currently, HOTs for aircraft deicing and anti-icing fluids under snow conditions are determined from outdoor snow tests, which are dependant on winter weather. This dependence typically limits the timely introduction of new and improved fluids. In the past, when similar tests were conducted in laboratory cold rooms, significantly shorter HOTs were observed in comparison to those obtained outdoors in a natural snow environment. Through several FAA-sponsored research efforts, these differences have been investigated and procedures were developed to reduce these HOT differences. The improved procedures used temperature-controlled test plates to produce effects similar to those produced by the wind on outdoor test plates.

Having developed the improved procedures, a series of round-robin tests were conducted with two other organizations on many certified fluids at different temperatures and snow intensities. A fixed air-to-plate temperature differential was used that had been determined experimentally in outdoor natural snow conditions and was found to be a function of snowfall rate.

Indoor laboratory snow tests were conducted on 11 certified fluids and their dilutions. The test set was selected from outdoor tests conducted during the last 5 years and covered a wide range of temperatures and snow intensities for Type II and Type IV fluids. The results showed a good correlation between the indoor and outdoor tests conducted by three separate organizations at different sites. Typically, the indoor HOT test results were slightly shorter (more conservative) than those obtained from the outdoors tests.

The second objective of this effort was to use a refined test procedure to generate, in an indoor laboratory environment, HOTs for the -14° to -25°C cell for Type II and Type IV anti-icing fluids. Since snow is typically rare at these very cold temperatures, especially at -25°C, most of the existing values had either been based on theoretical mathematical extrapolations from snow tests conducted at warmer temperatures or been assigned based upon worst-case (more conservative) prior measurements. Indoor test results from the current effort produced acceptable failure times (except for one fluid). The times were typically shorter than those produced by the theoretical mathematical extrapolation procedure.

The third objective of this effort was to investigate and develop a more objective fluid failure call methodology based upon the capacity of the fluid to absorb snow. The current defined fluid failure call criterion is based upon human observation and is deemed to be subjective. It is based upon the time it takes for snow to cover 30% of the test plate. As the fluid is absorbing snow, it extracts heat from the environment to melt the snow. This heat is extracted mainly from the test plate because it is a good thermal conductor and is in full contact with the fluid under test. For this investigation, the plate temperature was controlled at a set temperature and the energy required to maintain this temperature was recorded. During the time when the fluid is absorbing the snow and has not failed, energy is required by the test plate to maintain the set temperature.

The fluid is considered to have failed when it is no longer extracting heat from the test plate. Heat versus time plots were developed for all test events and formed the preliminary basis for establishment of a more objective fluid failure call criterion.

1. INTRODUCTION.

The Federal Aviation Administration (FAA) Airport and Aircraft Research and Development Division has been supporting research directed at substantiation and improving the utility and accuracy of the FAA Holdover Time (HOT) Guidelines for deicing and anti-icing freeze point depressant fluids that meet SAE standards. Significant improvements have been made over the past few years in deicing and anti-icing formulation, methods for acceptance testing, equipment, and procedures for the application and using these improvements to update the HOT guidelines. Deicing and anti-icing fluid technology is a dynamic science resulting in the state-of-the-art continually advancing. New or improved products are constantly being introduced and each must undergo a rigorous and time intensive acceptance process before it is recommended for use by the aviation community.

Currently, HOTs for snow are determined from outdoor testing. Data over one winter season in Montreal was gathered and compiled to fill in the snow cells of the HOT guidelines. However, there is little, if any, outdoor snow data at temperatures below -14°C. Therefore, in the past, to fill the -14° to -25°C snow cells, a mathematical extrapolation was used, employing data generated at warmer temperatures. Recently it was decided to use the lowest times of the generic HOTs, which represents the shortest times determined for any fluid. Therefore, new fluids could not be assigned longer times than existing fluids; i.e., no improvements in HOT could be achieved. At the SAE G-12 HOT meeting in Vancouver in May 2003 [1] it was recommended that tests be conducted using indoor snow machines at -25°C. At the SAE G-12 HOT meeting in Montreal in September 2003, some preliminary indoor snow data from such tests were presented, showing significantly shorter HOTs than those generated by mathematical extrapolation. This suggested that some of the values for snow in the current HOT guideline table may be too long. Therefore, it was recommended to systematically test all Type II and Type IV fluids at -25°C using both types of existing indoor snow testing machines (developed at the Anti-icing Materials International Laboratory (AMIL) and at the National Center for Atmospheric Research (NCAR)).

With support from the FAA over several years, AMIL has developed a snow machine capable of replicating outdoor snow tests inside, which takes into consideration the effect of wind on fluid temperature [2, 3, and 4]. In addition to the tests at -25°C, this report will address several other issues, including comparison of the two existing snow machines; the determination of the temperature difference between the air and the test plate; and investigation of basing a failure call on energy requirements, rather than the 30% snow coverage of the test plate as judged by an observed, which introduces an element of subjectivity into the failure call.

2. METHODOLOGY.

2.1 INDOOR SNOW TEST PROCEDURE.

Snow tests were conducted on Type IV fluids. The tests were carried out at plate temperatures between -1° and -25°C, at different snow intensities from 7.5 to 25.0 g/dm^2/h. The test plate temperature was controlled using a heating pad connected to the base of the test plate.

The test procedure consisted of pouring 1 liter of the test fluid, precooled to the test plate temperature, onto 300- by 500-mm polished aluminum plates inclined at a 10° angle. The fluid temperature was ensured by leaving the fluids in the cold room or in a controlled temperature freezer; the fluid's temperature was verified with a thermometer before the test to be within 1°C of the test temperature. Fluids were exposed to the selected snowfall intensities once the fluid adequately covered the test plate.

During the course of a test run, air and plate temperature and humidity were recorded in real time. Failure was considered when 30% of the plate was covered with white snow. After each test, the plates were cleaned with a squeegee, then ethanol. Once cleaned, the temperature of the plate was left to return to ambient, or targeted, air temperature before beginning another test. Note that temperatures in the cold room could not exceed -4°C, since at higher temperatures the snow could partially melt. Therefore, for tests above -4°C, the room temperature was set to -4°C, but the plate temperature was then controlled to obtain the targeted temperature. More details on the test procedure are presented in appendix A.

2.2 THE IMPORTANCE OF TEST PLATE TEMPERATURE.

Figure 1 presents the temperature curves for three different tests. The first test, represented by the thickest lines, was conducted outside by AMIL on the roof of one of the university buildings during the winter of 2001-2002 and was one of the first snow test sets conducted for the FAA [3]. For this test, the air temperature was around -7°C and the snow fall rate was approximately 12 g/dm^2/h. As the fluid absorbed the snow, the plate temperature descended to around -8°C, then slowly warmed up to about -7°C, and the fluid failed after about 2 hours.

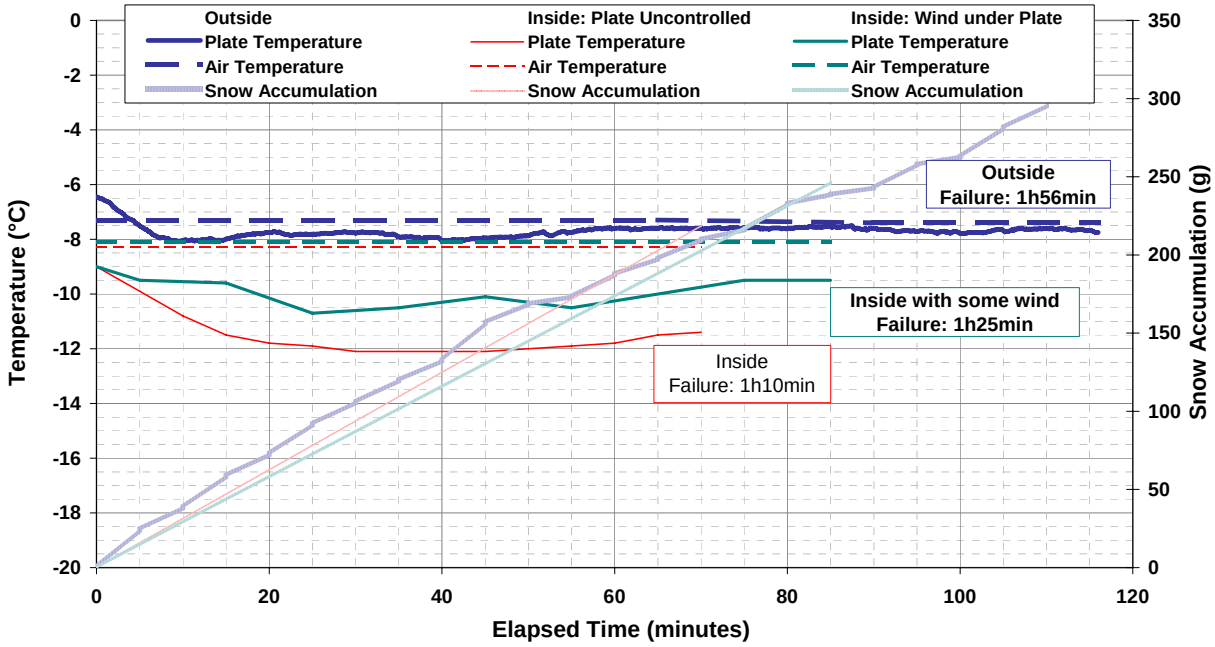

FIGURE 1. VARIATION IN PLATE TEMPERATURE DURING THREE TESTS

When the test was replicated inside, represented on the graph by the thinnest lines, the air temperature was set to around -8°C. The snow from the snow machine was started and the temperature descended to -12°C, 4°C below the air temperature, and failure occurred 1 hour and 10 minutes later. This descent in temperature was attributed to the energy required by the fluid to melt the snow, since changing the snow from its stable, solid form to liquid form requires energy. The fluid takes the energy in the form of heat from its surroundings, especially the test plate, since it is a good thermal conductor and is in full contact with the fluid. In this case, the fluid failed in about half the time as in the outdoor test and the plate temperature began to increase when the fluid failed since the fluid was no longer absorbing snow and, therefore, no longer taking energy from the plate.

For the third test, represented by the lines of medium thickness, a fan was placed under the test plate to increase air circulation, which was expected to result in a smaller decrease in the plate temperature. The plate temperature decrease was indeed less, approximately 2°C, and the fluid endurance time increased to 1 hour 25 minutes, about 75% of the outdoor endurance time. This indicated that even more energy was required to reduce the temperature difference between the air and plate. Later, tests were conducted with temperature-controlled plates, maintaining the plates at the same temperature as the air [4]. However, since the actual outdoor tests had temperature differentials, it was decided for this set of tests to use a temperature difference based on the empirically derived equation:

$$T_P = 0.509 + 0.653 I - T_A \tag{1}$$

where T_A denotes air temperature (°C), T_P denotes plate temperature (°C), and I denotes snow intensity (g/dm²/h). This equation was developed by Roy Rasmussen of NCAR and is based on outdoor measurements. For a rate of 10 g/dm²/h, the plate temperature would be around 1.1°C below the air temperature, and for a rate of 25 g/dm^2/h it would be around 2°C below air temperature.

However, by controlling the plate temperature, the information on the temperature changes is lost, i.e., how the temperature descends at the beginning of the test and then begins to increase as the fluid fails. This phenomenon was of interest in that it may provide useful information for determining fluid failure. Therefore, for this test series, the energy required to heat the plates was recorded to investigate how it behaved with respect to fluid failure and to ascertain if it might be possible to use the energy required as an indicator of fluid failure.

2.3 TEST FLUIDS.

Requests were made to all fluid manufacturers to provide fluid for the study. Ideally, all existing certified fluids would be tested. Table 1 presents a list of all the fluids received and tested.

TABLE 1. FLUID IDENTIFICATION

Company	Fluid	Type	Dilution (%)	AMIL Label	Reception Date
Clariant	Safewing MPIV Protect 2012	IV	Neat	F363	11/20/03
			75/25	F364	
			50/50	F365	
Clariant	Safewing MPII 2025 ECO	II	Neat	F442	1/06/04
			75/25	F443	
			50/50	F444	
Clariant	Safewing MPIV 2030 ECO	IV	Neat	F445	1/06/04
			75/25	F446	
			50/50	F447	
Clariant	Safewing MPIV 2001	IV	Neat	F366	11/20/03
			75/25	F367	
			50/50	F368	
Dow	Ultra+	IV	Neat	F416	12/23/03
Kilfrost	ABC-II Plus	II	Neat	F546	3/24/04
			75/25	F547	
			50/50	F548	
Kilfrost	ABC 2000	II	Neat	F549	3/24/04
			75/25	F550	
			50/50	F551	
Kilfrost	ABC-S	IV	Neat	F552	3/24/04
			75/25	F553	
			50/50	F554	
Octagon	Max Flight	IV	Neat	F455	1/21/04
			75/25	F498	
			50/50	F499	
SPCA	Ecowing 26	II	Neat	F482	2/9/04
			75/25	F500	
			50/50	F501	
SPCA	AD-480	IV	Neat	F483	2/9/04
			75/25	F502	
			50/50	F503	

The dilutions were prepared by AMIL using standard hard water as described in Aerospace Material Specification AMS 1428 [5]. In the case of Dow Chemical ULTRA+, the dilutions were not tested since they are not used.

2.4 TEST SET.

Since these tests consisted of round-robin tests with two other testing groups, an agreed upon test set needed to be selected. Aviation Planning Services (APS) was tasked to develop the test set based on outdoor data gathered in previous winters. The test set is listed in appendix B.

The tests selected were considered reliable and covered a wide range of intensities and temperatures for each fluid.

3. RESULTS.

3.1 ROUND-ROBIN TESTS.

3.1.1 Clariant Safewing MPIV Protect 2012.

Table 2 presents the endurance times for Clariant Safewing MPIV Protect 2012. It presents the times previously obtained outside and the results obtained inside, at AMIL, using the test method described in the appendix B. The results are represented graphically in figure 2, where the endurance times inside are compared to those outside with a 1:1 line drawn through the center. Ideally, all data would fall along the 1:1 line; however, outdoor tests can be highly variable because the conditions are not controlled as in the laboratory; therefore, much scatter of the outdoor test results is expected and often observed. Figure 2 shows that the indoor times are somewhat similar to but shorter than the outdoor times. Table 2 shows that the indoor times are shorter in every case, and that for five out of the six dilutions, they are less than half as long.

TABLE 2. SNOW ENDURANCE TIMES FOR CLARIANT SAFEWING MPIV PROTECT 2012

Fluid	Dilution	Outside				Inside			
		Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity ($g/dm^2/h$)	Endurance Time (min)	Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity ($g/dm^2/h$)	Endurance Time (min)
Safewing MPIV Protect 2012	Neat	-7.9	-9.0	8.1	69.0	-8.6	-8.2	8.2	51.8
		-15.8	-16.6	4.0	68.0	-16.0	-14.6	4.0	66.0
	75/25	-8.3	-9.6	12.0	39.0	-8.7	-8.6	12.3	25.0
		-8.0	-9.0	7.9	52.0	-8.5	-8.0	7.7	23.6
		-8.0	-9.0	7.9	52.0	-8.8	-9.0	7.7	22.6
	50/50	-2.4	-3.3	6.1	34.0	-4.9	-3.3	6.6	13.1
		-2.4	-3.3	6.1	34.0	-5.1	-3.6	5.9	16.5
		-2.4	-4.5	23.8	13.0	-4.9	-3.8	23.6	6.5

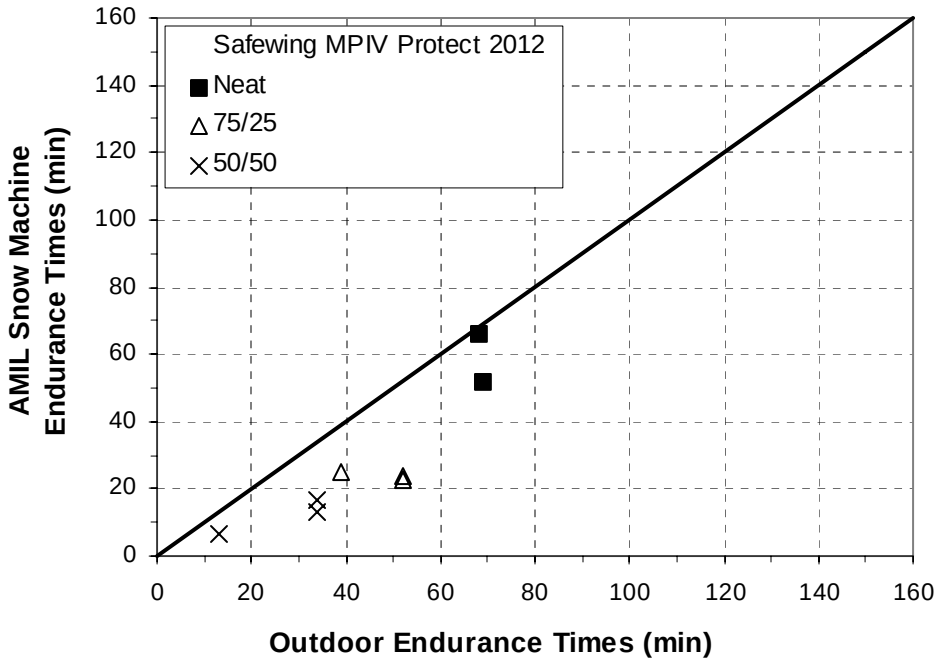

FIGURE 2. COMPARISON OF INDOOR AND OUTDOOR ENDURANCE TIMES FOR CLARIANT SAFEWING MPIV PROTECT 2012

3.1.2 Clariant Safewing MPII 2025 ECO.

Table 3 presents the endurance times obtained in the indoor tests for Clariant Safewing MPII 2025 ECO compared to those previously obtained outside.

TABLE 3. SNOW ENDURANCE TIMES FOR CLARIANT SAFEWING MPII 2025 ECO

Fluid	Dilution	Outside				Inside			
		Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity ($g/dm^2/h$)	Endurance Time (min)	Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity ($g/dm^2/h$)	Endurance Time (min)
Safewing MPII 2025 ECO	Neat	-7.8	-8.7	6.5	84.0	-8.5	-8.1	6.4	68.0
		-2.5	-4.5	23.4	41.0	-4.9	-4.4	23.7	26.8
	75/25	-2.3	-4.4	23.7	25.0	-4.9	-4.2	23.8	15.7
		-4.8	-5.9	9.3	49.0	-5.5	-5.7	9.2	32.9
	50/50	-2.4	-3.5	9.1	17.0	-5.7	-3.4	8.8	16.2
		-2.5	-4.9	29.0	9.0	-5.2	-4.9	28.9	6.7

Figure 3 shows that the indoor results correlate fairly well with the values obtained outdoors, but in every case, the indoor time is shorter than the outdoor time.

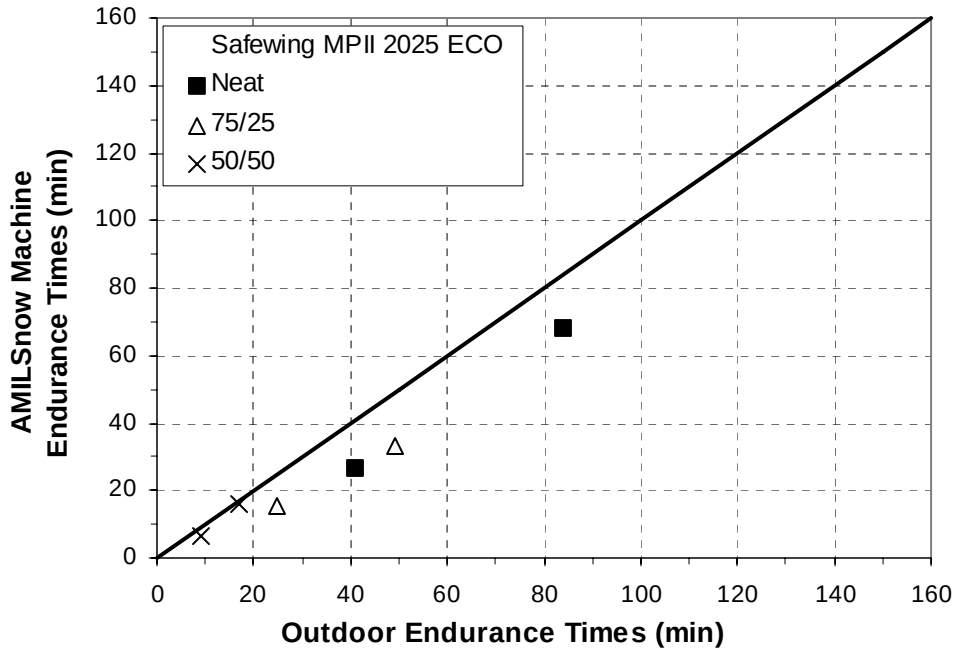

FIGURE 3. COMPARISON OF INDOOR AND OUTDOOR ENDURANCE TIMES FOR CLARIANT SAFEWING MPII 2025 ECO

3.1.3 Clariant Safewing MPIV 2030 ECO.

Table 4 presents the laboratory endurance times for Clariant Safewing MPIV 2030 ECO and its dilutions compared to the results obtained outdoors.

TABLE 4. SNOW ENDURANCE TIMES FOR CLARIANT SAFEWING MPIV 2030 ECO

Fluid	Dilution	Outside				Inside			
		Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity (g/dm^2/h)	Endurance Time (min)	Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity (g/dm^2/h)	Endurance Time (min)
Safewing MPIV 2030 ECO	Neat	-6.4	-7.8	14.2	69.0	-6.6	-7.4	14.1	50.5
		-4.7	-5.7	6.8	115.0	-5.0	-5.8	7.0	83.0
	75/25	-2.5	-4.6	25.5	37.0	-4.9	-4.5	25.1	25.6
		-6.6	-7.9	12.8	56.0	-6.7	-7.5	13.0	37.8
	50/50	-2.3	-3.3	7.7	24.0	-5.6	-3.3	7.6	22.6
		-2.5	-4.9	28.9	15.0	-5.3	-5.1	29.0	7.6

The results are graphically presented in figure 4. Again, for this fluid, the indoor results correlate fairly well with the values obtained outdoors, but the indoor time is shorter than the outdoor time in all cases, in one case, 32 minutes shorter.

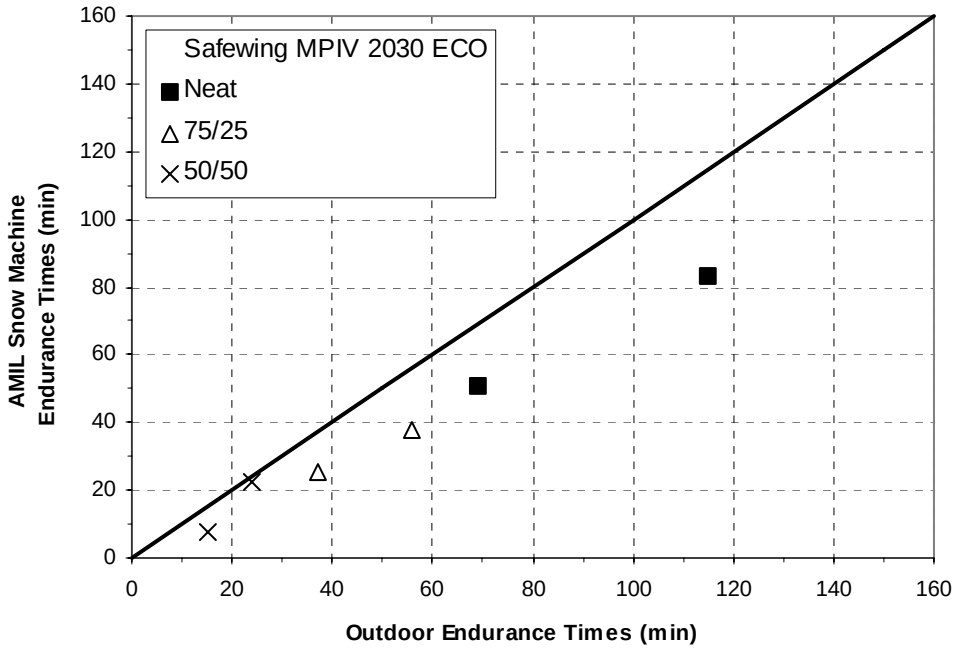

FIGURE 4. COMPARISON OF INDOOR AND OUTDOOR ENDURANCE TIMES FOR CLARIANT SAFEWING MPIV 2030 ECO

3.1.4 Clariant Safewing MPIV 2001.

Table 5 presents the indoor laboratory endurance times for the three dilutions of Clariant Safewing MPIV 2001.

TABLE 5. SNOW ENDURANCE TIMES FOR CLARIANT SAFEWING MPIV 2001

Fluid	Dilution	Outside				Inside			
		Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity ($g/dm^2/h$)	Endurance Time (min)	Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity ($g/dm^2/h$)	Endurance Time (min)
Safewing MPIV 2001	Neat	-4.9	-6.3	13.1	68.0	-5.6	-5.8	13.4	47.8
		-11.6	-14.5	37.0	30.0	-11.7	-14.1	32.1	19.0
	75/25	-3.2	-4.5	11.9	53.0	-5.5	-4.5	11.4	35.8
		-3.7	-6.0	27.8	35.0	-5.2	-5.9	27.9	18.3
		-13.0	-15.0	22.6	22.0	-13.0	-12.1	23.1	16.7
		-3.7	-6.0	27.8	35.0	-5.3	-5.9	28.4	17.5
	50/50	-2.7	-3.5	4.7	29.0	-5.0	-3.7	4.6	29.8

The results are presented graphically in figure 5. The figure shows that the indoor times correlate fairly well with those obtained outdoors, but are shorter in every case but one.

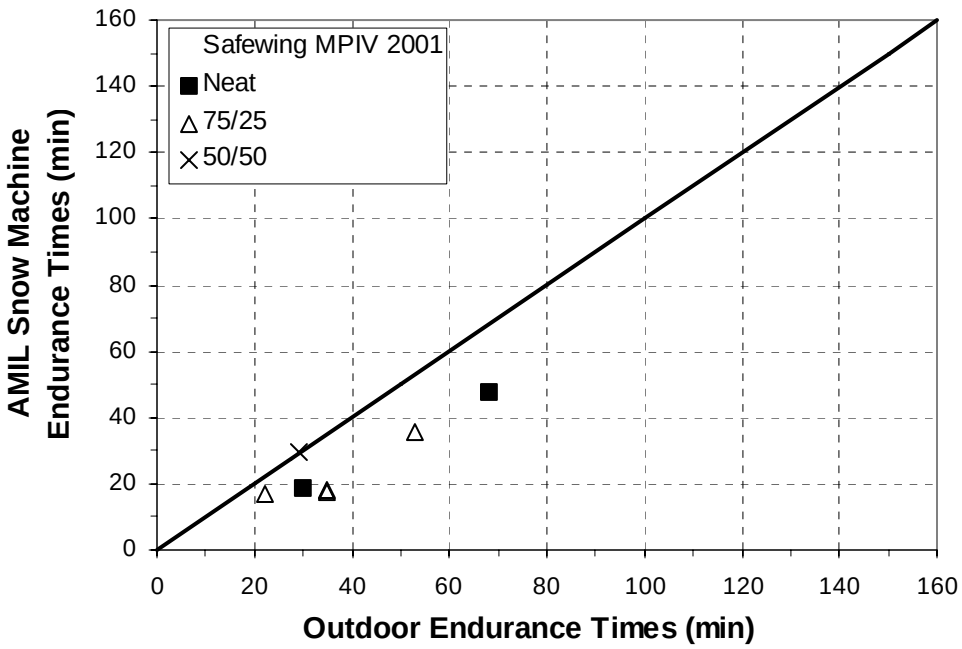

FIGURE 5. COMPARISON OF INDOOR AND OUTDOOR ENDURANCE TIMES FOR CLARIANT SAFEWING MPIV 2001

3.1.5 Dow Chemical ULTRA+.

Table 6 presents the indoor laboratory endurance times obtained for Dow Chemical ULTRA+ compared to values from outdoor tests. The dilutions of this fluid were not tested since they are not used or approved.

TABLE 6. SNOW ENDURANCE TIMES FOR DOW CHEMICAL ULTRA+

Fluid	Dilution	Outside				Inside			
		Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity ($g/dm^2/h$)	Endurance Time (min)	Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity ($g/dm^2/h$)	Endurance Time (min)
ULTRA+	Neat	-1.8	-4.0	25.6	37.0	-4.8	-3.8	25.4	54.8
		-5.4	-6.7	11.6	59.0	-5.4	-6.7	11.5	82.0
		-12.3	-13.3	8.2	79.0	-11.4	-12.7	8.2	107.0

The results are graphically presented in figure 6. The figure shows that, for this fluid, the indoor times are longer than the outdoor times, as the values are above the 1:1 line. The results are surprising, considering that, for all the other fluids, the indoor times are almost always shorter than the outdoor times. However, ULTRA+ has some properties that are significantly different from those of the other fluids. It is based on ethylene glycol (EG), whereas all the other fluids are based on propylene glycol (PG), and as a consequence, has a lower freeze point that all the others. Also, its thickener system is different from that of the other fluids, and this results in changes to other fluid properties. When water is added to this fluid, its viscosity decreases; for the other fluids, typically the viscosity increases and later decreases as water continues to be

added. It is believed that these differences contribute to differences in behavior of ULTRA+ in indoor snow tests compared to the other fluids, but this is not understood in detail.

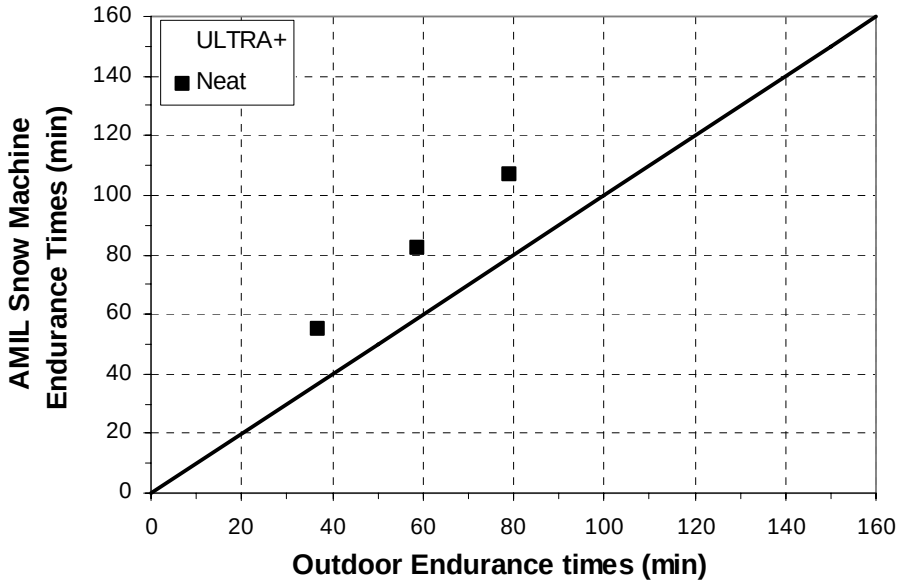

FIGURE 6. COMPARISON OF INDOOR AND OUTDOOR ENDURANCE TIMES FOR DOW CHEMICAL ULTRA+

3.1.6 Kilfrost ABC-II Plus.

Table 7 presents the indoor laboratory endurance times for Kilfrost ABC-II Plus compared to the outdoor reported results.

TABLE 7. SNOW ENDURANCE TIMES FOR KILFROST ABC-II PLUS

Fluid	Dilution	Outside				Inside			
		Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity (g/dm^2/h)	Endurance Time (min)	Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity (g/dm^2/h)	Endurance Time (min)
ABC II Plus	Neat	-5.5	-6.8	12.6	46.0	-5.6	-6.5	12.9	42.0
		-1.8	-4.0	25.2	34.0	-5.1	-4.2	25.8	29.5
		-7.2	-8.0	3.9	100.0	-7.2	-7.8	4.0	110.0
	75/25	-12.6	-13.6	7.1	29.0	-12.0	-11.3	7.0	30.6
		-13.3	-14.2	6.3	51.0	-11.3	-10.7	6.2	46.7
		-5.5	-6.5	6.9	56.0	-5.7	-6.5	7.0	54.0
		-12.6	-13.6	7.1	29.0	-12.5	-12.4	6.7	28.3
		-7.4	-8.2	4.5	71.0	-7.5	-7.9	4.4	74.0
	50/50	-1.7	-4.1	28.4	13.0	-5.2	-4.0	28.8	8.2
		-1.7	-2.7	6.6	41.0	-5.6	-2.8	6.4	30.2

The results are presented graphically in figure 7. The figure shows that the outdoor laboratory endurance times correlate very well with the indoor times, as all the points lie close to the 1:1 line. Table 7 shows, in the majority of cases, the times differ by about 10% or less.

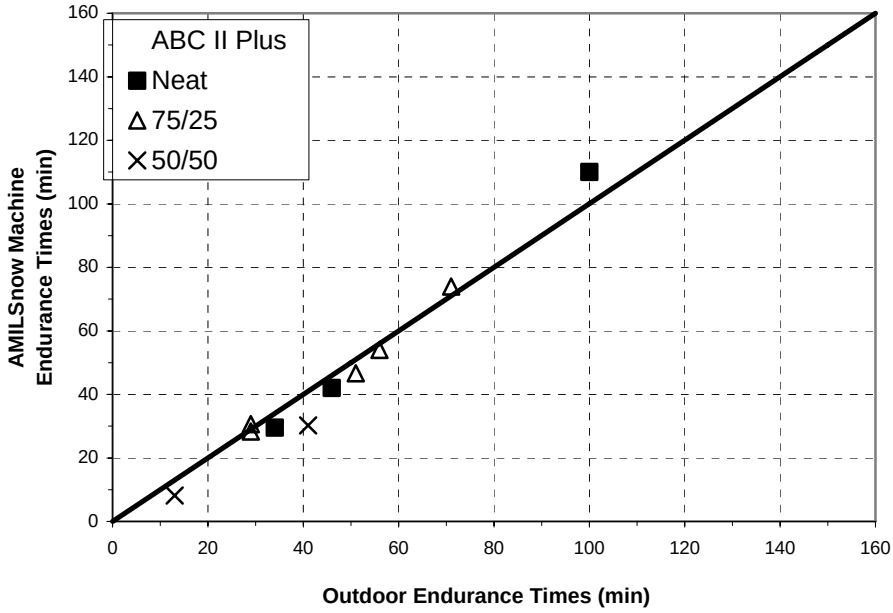

FIGURE 7. COMPARISON OF INDOOR AND OUTDOOR ENDURANCE TIMES FOR KILFROST ABC-II PLUS

3.1.7 Kilfrost ABC 2000.

Table 8 presents the laboratory endurance times obtained for Kilfrost ABC 2000 as well as the reported values from the outside under natural snow.

TABLE 8. SNOW ENDURANCE TIMES FOR KILFROST ABC 2000

Fluid	Dilution	Outside				Inside			
		Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity (g/dm^2/h)	Endurance Time (min)	Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity (g/dm^2/h)	Endurance Time (min)
ABC 2000	Neat	-9.3	-10.5	10.3	48.0	-9.5	-9.7	10.3	37.5
		-9.0	-10.1	8.5	56.0	-9.4	-10.1	8.9	42.8
		-0.9	-2.9	23.2	41.0	-5.2	-3.4	23.6	30.0
	75/25	-6.0	-7.5	15.4	47.0	-6.1	-7.2	16.0	24.1
		-0.9	-2.9	23.2	40.0	-5.6	-3.1	22.8	21.0
		-9.3	-10.5	10.6	48.0	-9.4	-10.3	10.6	27.6
		-6.0	-7.5	15.4	47.0	-6.1	-7.9	15.4	21.8
		-9.3	-10.5	10.6	48.0	-9.5	-10.3	10.0	25.5
	50/50	-2.9	-5.1	26.3	11.0	-5.2	-4.7	26.3	8.2

The results are graphically presented in figure 8. The figure shows that, for this fluid, the indoor endurance times are shorter, as all the points are below the 1:1 line. For the 75/25 dilution, the indoor times are all about one-half the outdoor times.

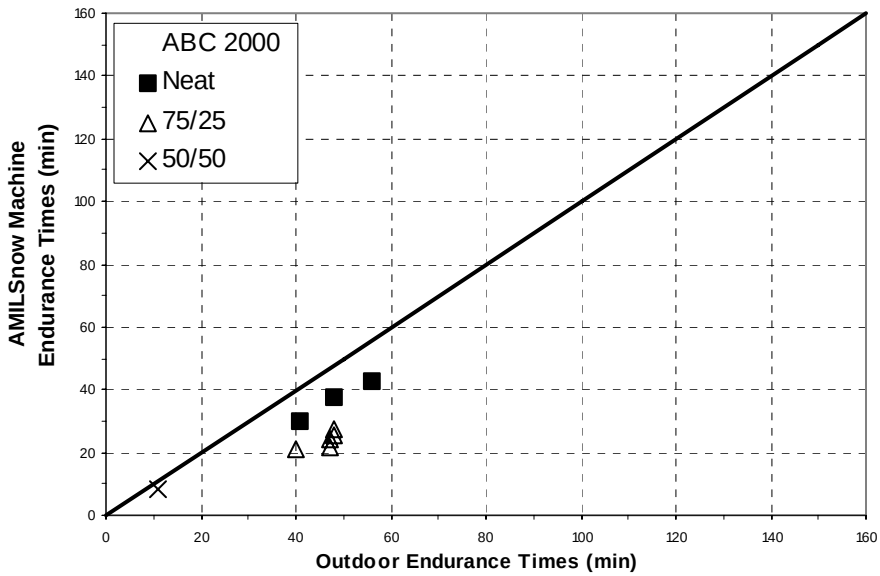

FIGURE 8. COMPARISON OF INDOOR AND OUTDOOR ENDURANCE TIMES FOR KILFROST ABC 2000

3.1.8 Kilfrost ABC-S.

Table 9 presents the laboratory indoor endurance times for Kilfrost ABC-S as well as the outdoor tests in similar conditions.

TABLE 9. SNOW ENDURANCE TIMES FOR KILFROST ABC-S

Fluid	Dilution	Outside				Inside			
		Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity ($g/dm^2/h$)	Endurance Time (min)	Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity ($g/dm^2/h$)	Endurance Time (min)
ABC-S	Neat	-1.8	-4.4	32.3	51.0	-5.4	-4.4	32.3	40.5
		-12.9	-13.7	4.8	122.0	-12.9	-12.6	5.0	87.0
		-5.4	-6.7	10.7	93.0	-5.6	-6.5	10.8	75.0
	75/25	-12.2	-13.2	7.5	71.0	-12.2	-11.3	7.5	69.0
		-5.5	-6.8	12.5	45.0	-6.3	-6.6	12.5	49.7
		-1.8	-3.8	23.1	34.0	-5.1	-4.1	23.3	33.3
		-7.6	-8.5	6.0	82.0	-7.6	-8.4	6.0	93.0
		-7.6	-8.5	5.7	88.0	-7.6	-8.4	5.9	85.0
	50/50	-1.7	-4.1	28.4	9.0	-5.2	-4.0	28.4	8.5

Figure 9 shows a graphical representation of a comparison between the two results. With the exception of the neat points, the correlation is very good.

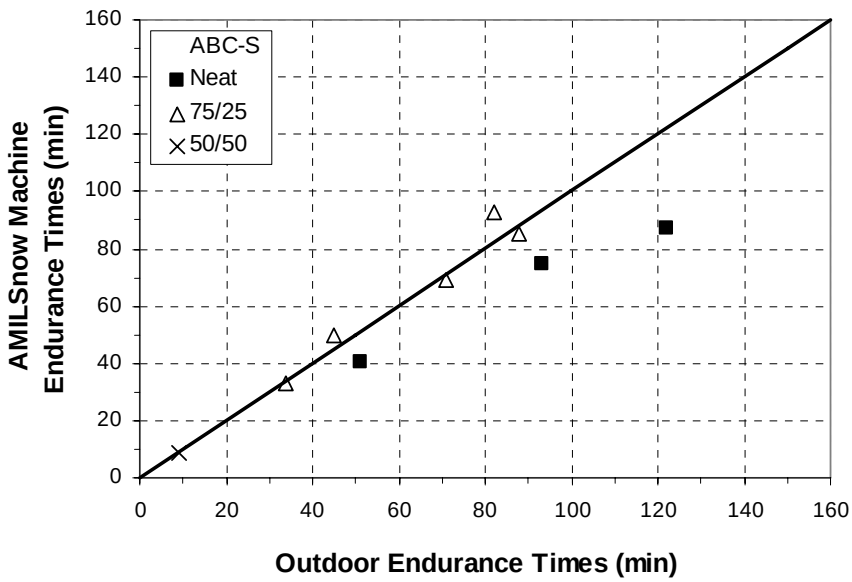

FIGURE 9. COMPARISON OF INDOOR AND OUTDOOR ENDURANCE TIMES FOR KILFROST ABC-S

3.1.9 Octagon Max Flight.

Table 10 presents the laboratory indoor endurance times obtained for Octagon Max Flight compared to those obtained outside for each dilution.

TABLE 10. SNOW ENDURANCE TIMES FOR OCTAGON MAX FLIGHT

Fluid	Dilution	Outside				Inside			
		Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity ($g/dm^2/h$)	Endurance Time (min)	Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity ($g/dm^2/h$)	Endurance Time (min)
Max Flight	Neat	-4.5	-6.2	18.8	65.0	-4.9	-6.1	18.1	71.5
		-4.7	-6.6	21.2	66.0	-5.8	-6.3	21.2	64.0
	75/25	-4.6	-6.5	20.8	58.0	-5.8	-6.4	20.8	43.7
		-8.6	-9.9	11.8	102.0	-9.1	-9.4	11.7	69.0
	50/50	-0.9	-3.0	23.7	41.0	-5.2	-3.4	23.9	10.5
		-0.9	-3.0	23.7	41.0	-4.9	-2.9	23.5	12.7

The results are presented graphically in figure 10, where the indoor laboratory results are plotted against those from the outdoors under the same conditions. The results show a good correlation for the neat fluid, but much shorter indoor times for the dilutions. Part of the difference may be the fact that the dilutions for this fluid have much longer endurance times than the other fluids outside, much longer than can be reasonably expected, given the quantities of water the fluid

must contain before freezing. For example, for a 50/50 dilution, a fluid would have about 25% glycol and a freeze point of about -10°C. Absorbing 23.7 g/dm^2/h of water for 41 minutes is the equivalent of 256 g of water, which raises the freeze point of the fluid above 0°C.

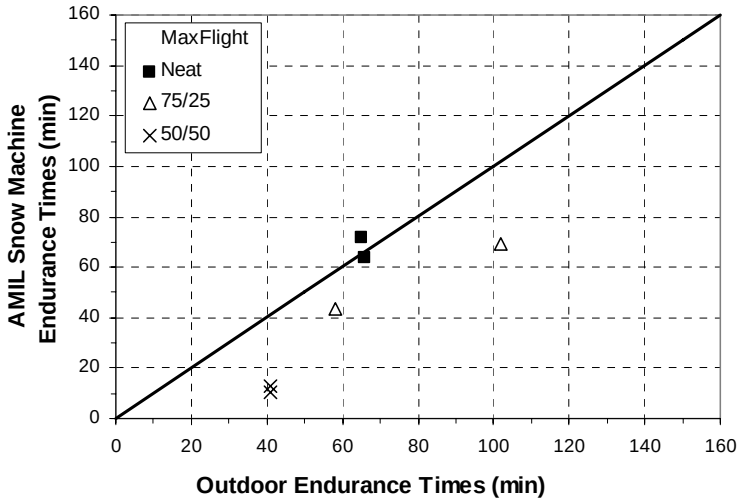

FIGURE 10. COMPARISON OF INDOOR AND OUTDOOR ENDURANCE TIMES FOR OCTAGON MAX FLIGHT

3.1.10 SPCA Ecowing 26.

Table 11 presents the laboratory indoor endurance times for SPCA Ecowing 26 as well as the equivalent outdoor tests. The results are presented graphically in figure 11. The figure shows reasonably good correlation for this fluid as all the data points are quite close to the 1:1 line. However, all the indoor times are shorter.

TABLE 11. SNOW ENDURANCE TIMES FOR SPCA ECOWING 26

Fluid	Dilution	Outside				Inside			
		Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity (g/dm^2/h)	Endurance Time (min)	Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity (g/dm^2/h)	Endurance Time (min)
Ecowing 26	Neat	-6.1	-8.2	24.0	38.0	-5.2	-7.1	23.6	23.3
		-15.7	-16.5	3.9	85.0	-16.0	-14.6	3.8	79.0
	75/25	-6.1	-8.2	23.7	24.0	-5.8	-6.8	23.3	16.5
		-2.7	-4.8	23.7	30.0	-5.3	-4.6	23.5	17.8
	50/50	-2.6	-3.9	13.3	16.0	-5.4	-3.9	13.0	12.1
		-2.6	-3.9	13.3	16.0	-5.3	-4.1	13.1	12.2
		-2.8	-5.4	32.4	8.0	-5.4	-5.2	32.6	6.9

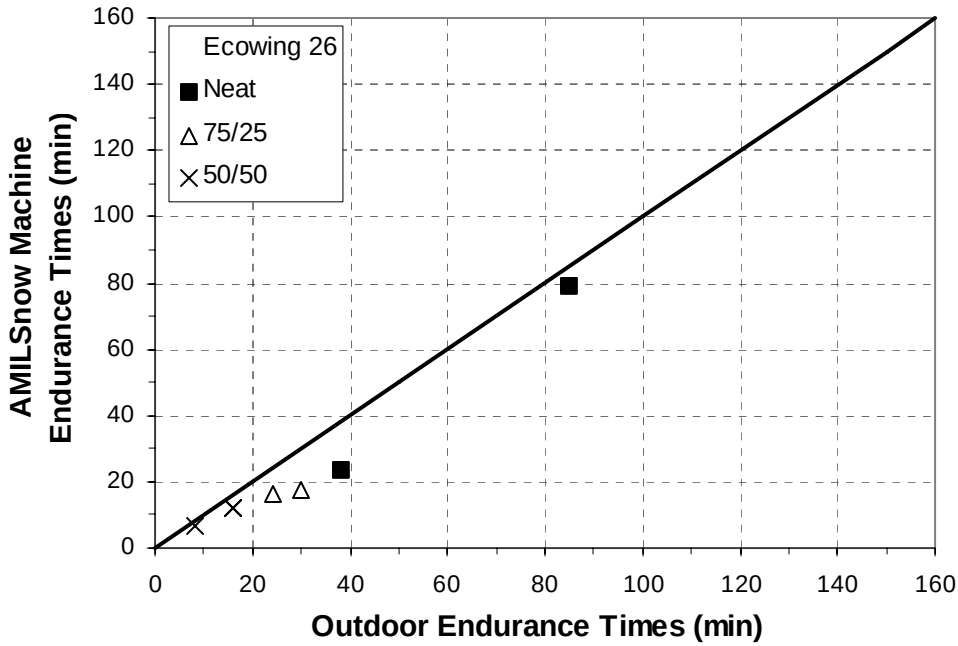

FIGURE 11. COMPARISON OF INDOOR AND OUTDOOR ENDURANCE TIMES FOR SPCA ECOWING 26

3.1.11 SPCA AD-480.

Table 12 presents the indoor laboratory endurance times obtained for SPCA AD-480 as well as the equivalent outdoor times. The results are presented graphically in figure 12. The graph shows a reasonably good correlation between the indoor and outdoor times.

TABLE 12. SNOW ENDURANCE TIMES FOR SPCA AD-480

Fluid	Dilution	Outside				Inside			
		Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity ($g/dm^2/h$)	Endurance Time (min)	Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity ($g/dm^2/h$)	Endurance Time (min)
AD-480	Neat	-3.0	-4.2	10.1	83.0	-5.8	-4.2	10.4	79.8
		-11.0	-13.2	26.5	30.0	-11.2	-12.4	26.3	24.5
	75/25	-5.5	-8.0	29.5	26.0	-5.5	-6.2	29.5	18.1
		-2.8	-3.9	9.0	77.0	-5.8	-3.8	9.0	49.7
		-2.8	-3.9	9.0	77.0	-4.9	-4.1	8.8	65.0
		-5.5	-8.0	29.5	26.0	-5.6	-7.8	29.8	20.5
	50/50	-2.8	-3.9	9.2	25.0	-5.3	-3.7	8.8	27.8
		-3.0	-4.5	15.1	16.0	-5.6	-4.5	15.5	15.8

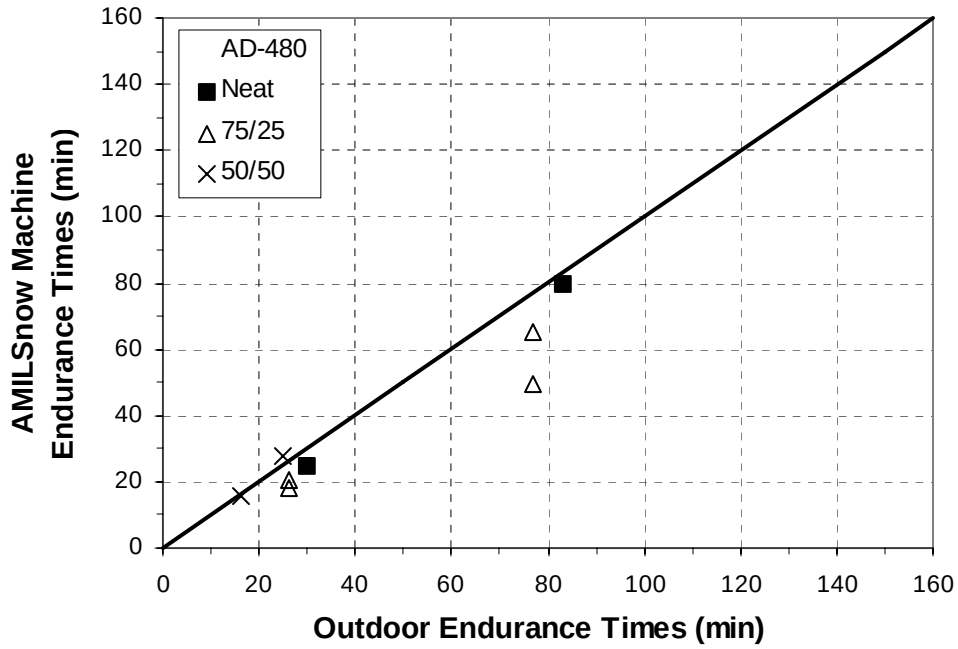

FIGURE 12. COMPARISON OF INDOOR AND OUTDOOR ENDURANCE TIMES FOR SPCA AD-480

3.1.12 Round-Robin Test Summary.

All the data points for the tests conducted at AMIL are shown in figure 13. The data shows that the indoor and outdoor times sometimes correlate fairly well, although nearly all the points for the PG fluids fall below the 1:1 line, and it is not unusual for the outdoor times to exceed the indoor times by a factor of 2. Thus, the indoor times for the PG fluids were conservative, and sometimes very conservative, compared to the outdoor times. The results were completely different for one EG fluid, ULTRA+, with the times for the indoor tests longer than those for the outdoor tests in all cases.

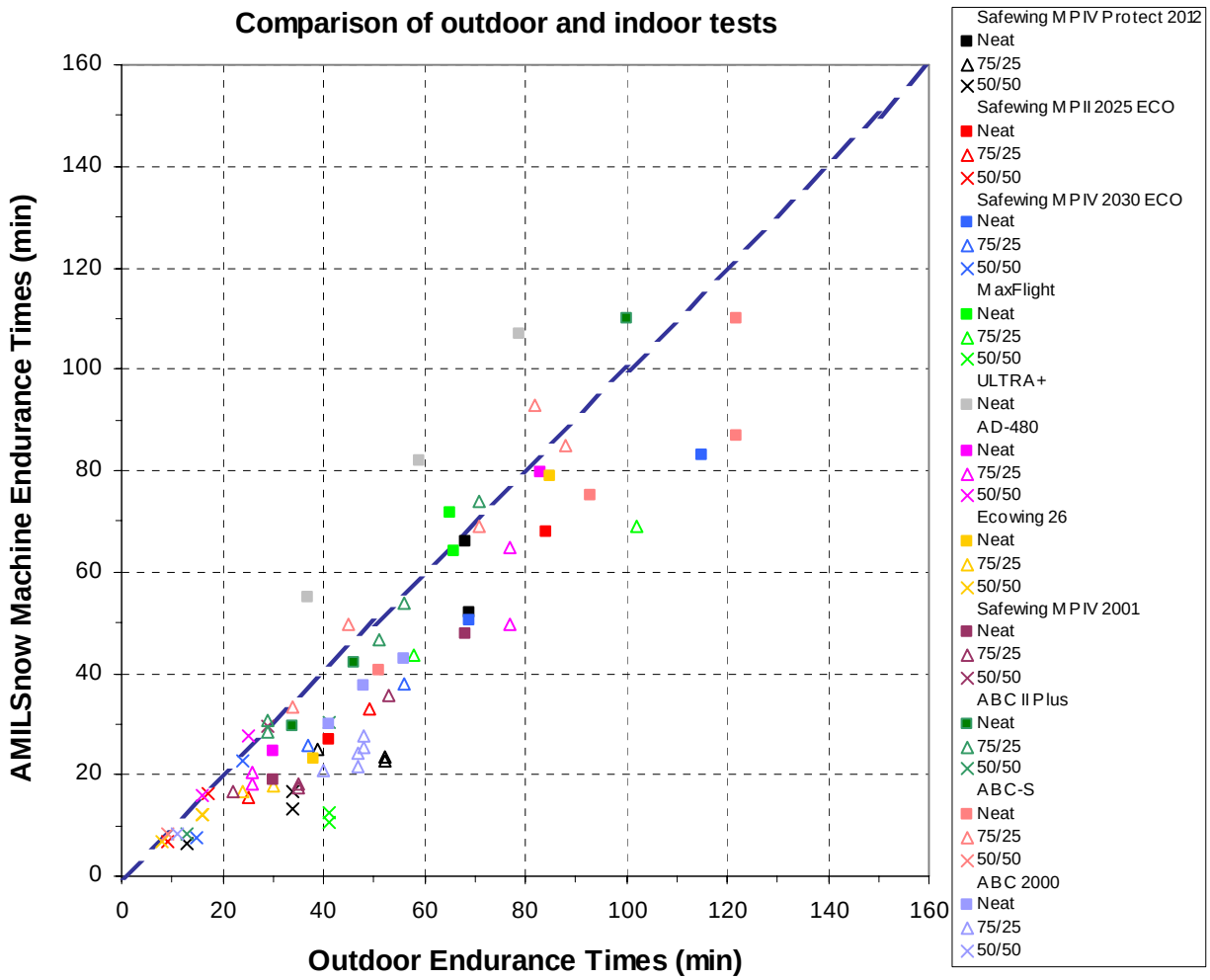

FIGURE 13. COMPARISON OF INDOOR TESTS CONDUCTED AT AMIL WITH RESPECT TO THE OUTDOOR TESTS

3.2 TESTING AT -25°C.

The second objective of this study was to test the fluids, listed in table 1, at -25°C with snow intensity rates of 10 and 25 g/dm^2/h to generate data for the HOT guideline cells of -14° to -25°C. The results are presented in table 13. The data show that, with the exception of ULTRA+, the endurance times for the fluids were mostly in the 10- to 20-minute range. The endurance time corresponds to the time it took for the snow to cover 30% of the test plate since, at these low temperatures, the fluids were barely capable of absorbing snow.

TABLE 13. SNOW EXPOSURE ENDURANCE TIMES FOR FLUIDS AT -25°C

Fluid	Dilution	Test Code	Air Temperature (°C)	Plate Temperature (°C)	Snow Intensity (g/dm²/h)	Fluid Endurance Time (min:sec)
Clariant Safewing MPIV Protect 2012	Neat	SNW182	-25.2 ±0.2	-26.2 ±0.2	9.5	19:30
Clariant Safewing MPII 2025 ECO	Neat	SNW188	-25.3 ±0.1	-26.3 ±0.2	10.6	17:30
Clariant Safewing MPIV 2030 ECO	Neat	SNW184	-25.3 ±0.04	-26.1 ±0.3	9.5	15:00
Clariant Safewing MPIV 2001	Neat	SNW181	-25.3 ±0.1	-26.1 ±0.2	10.4	18:00
Dow Chemical ULTRA+	Neat	SNW183	-25.2 ±0.2	-26.3 ±0.3	10.2	84:00
Kilfrost ABC-II Plus	Neat	SNW186	-24.7 ±0.5	-26.2 ±0.3	10.4	21:30
Kilfrost ABC 2000	Neat	SNW187	-25.2 ±0.1	-26.4 ±0.2	10.3	19:30
Kilfrost ABC-S	Neat	SNW177	-25.1 ±0.2	-25.4 ±0.5	10.5	26:10
Octagon Max Flight	Neat	SNW208	-24.9 ±0.4	-25.3 ±0.4	10.5	26:30
SPCA Ecowing 26	Neat	SNW185	-25.3 ±0.1	-26.2 ±0.3	10.8	21:40
SPCA AD-480	Neat	SNW180	-25.3 ±0.2	-26.1 ±0.1	10.7	17:50
Clariant Safewing MPIV Protect 2012	Neat	SNW207	-24.9 ±0.4	-25.6 ±0.2	24.4	10:50
Clariant Safewing MPII 2025 ECO	Neat	SNW203	-25.0 ±0.5	-25.1 ±0.1	24.6	10:50
Clariant Safewing MPIV 2030 ECO	Neat	SNW204	-24.7 ±0.04	-24.8 ±0.01	24.9	10:20
Clariant Safewing MPIV 2001	Neat	SNW199	-24.9 ±0.1	-25.3 ±0.1	24.9	10:20
Dow Chemical ULTRA+	Neat	SNW206	-25.0 ±0.4	-27.0 ±0.6	24.9	35:00
Kilfrost ABC-II Plus	Neat	SNW197	-24.9 ±0.1	-25.3 ±0.3	24.0	13:30
Kilfrost ABC 2000	Neat	SNW201	-25.0 ±0.6	-25.7 ±0.2	24.8	14:10
Kilfrost ABC-S	Neat	SNW195	-24.9 ±0.1	-25.0 ±0.3	24.7	12:45
Octagon Max Flight	Neat	SNW205	-24.9 ±0.1	-25.2 ±0.2	24.9	13:20
SPCA Ecowing 26	Neat	SNW202	-25.1 ±0.7	-25.4 ±0.1	24.7	11:30
SPCA AD-480	Neat	SNW198	-24.9 ±0.1	-25.4 ±0.2	24.4	09:50

ULTRA+ had significantly longer times than all the other fluids. At the very cold temperatures of these tests, the fluid is very thick and viscous. It is believed that the thickness on the plate led to longer endurance times since the fluid was able to continue absorbing snow for a longer period of time.

4. DISCUSSION.

4.1 IMPROVED RESULTS IN LARGER CHAMBER.

In general, the results showed shorter indoor times for most fluids, but much longer indoor times for certain fluids, such as ULTRA+, when compared with outdoor tests. In addition to wind effects (as discussed in reference 5), humidity and air mass effects for outdoor testing are different than for indoor testing. Outside, fluids may evaporate continuously with an effectively infinite air mass over the fluid. However, in a cold room, the air volume is strictly limited, and a fluid evaporating in a higher humidity environment would tend to reach saturation sooner. This saturation could occur in a small cold room. The snow tests at AMIL are normally conducted in the snow cold room, which is the same room where the snow is made, as described in appendix A. The humidity in this room can rise to levels significantly higher than outside conditions. To investigate the effect of humidity and air mass on the endurance times, additional tests were conducted in the larger freezing rain chamber at AMIL to observe possible differences. Only certain tests were repeated, in particular, those for which the correlation between indoor and outdoor times was not good.

Figure 14 shows all the data from this test set, with the repeated tests identified with circles. In addition to points that were close to the 1:1 line, the tests included points that were far from either side of the 1:1 line to see if there would be a change.

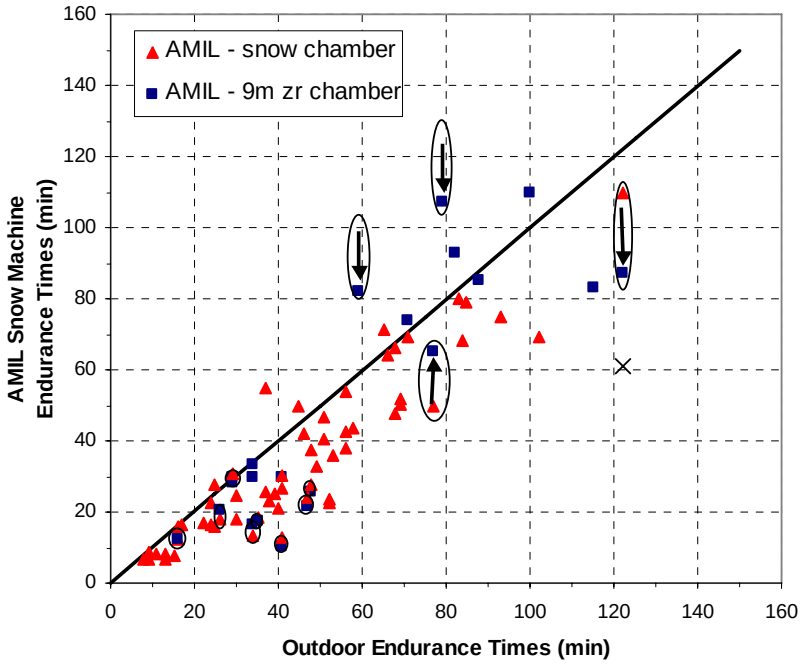

FIGURE 14. TESTS REPEATED IN THE LARGER COLD ROOM

The results were very interesting. The generally long times obtained indoors with respect to those outside, for fluids such as ULTRA+, repeated in the larger cold room, resulted in shorter times; closer to the 1:1 line, whereas little change was observed for the shorter time repeated tests. One test below the 1:1 line improved, and another gave a worse time, further from the 1:1 line. For the latter test, however, when run by the other sites involved in the round-robin tests, the time was even shorter; represented by the "x" on the graph. The reason for this behaviour is unclear.

4.2 ROUND-ROBIN TESTS AT OTHER SITES.

Figure 15 shows the data from all three test sites for all the fluids tested, compared to the 1:1 correlation line. The graph shows, in general, that the three sites obtained similar groupings of results, with most points falling at and near the 1:1 line but with more points below the line, indicative of generally conservative results from the indoor tests.

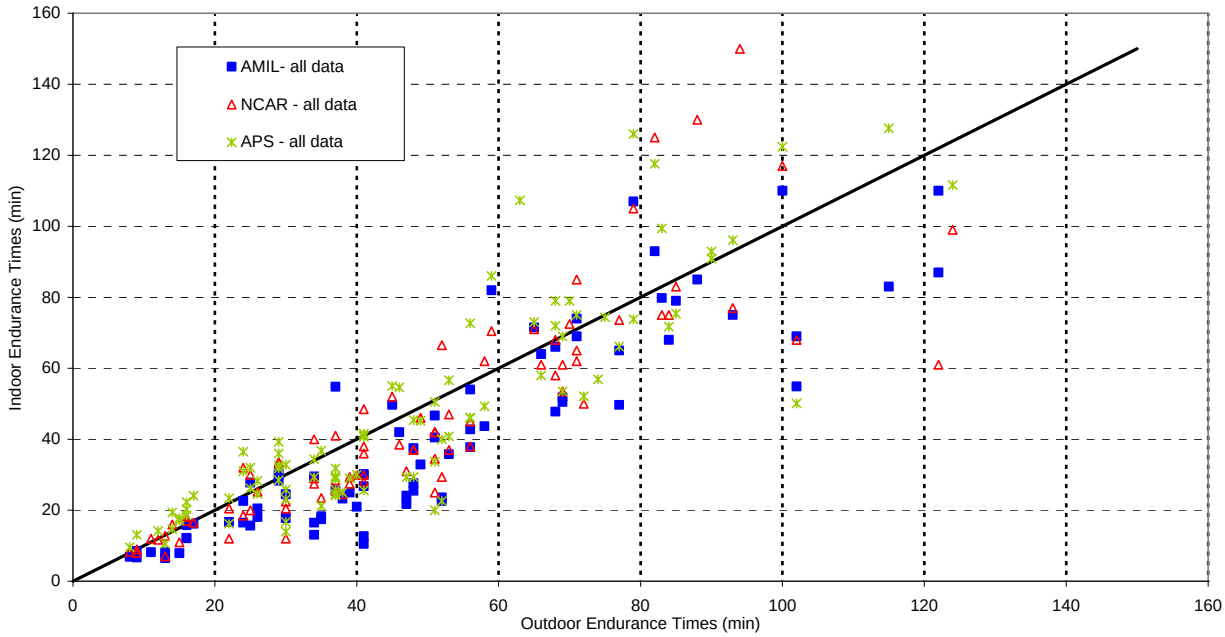

FIGURE 15. ROUND-ROBIN TEST RESULTS FROM ALL THREE TEST SITES

Figure 16 presents the same data with a 20% error envelop for the test data. These tests are dynamic with moving parts and flowing fluids, not static tests; therefore, 20% is a reasonable expected variation in fluid performance. Certain circled data points, which are further from the 1:1 line, generally exhibited similar performance in results from the other two sites as well. This variation may be attributable to irregularities in the outdoor test results to which the indoor test results are being compared.

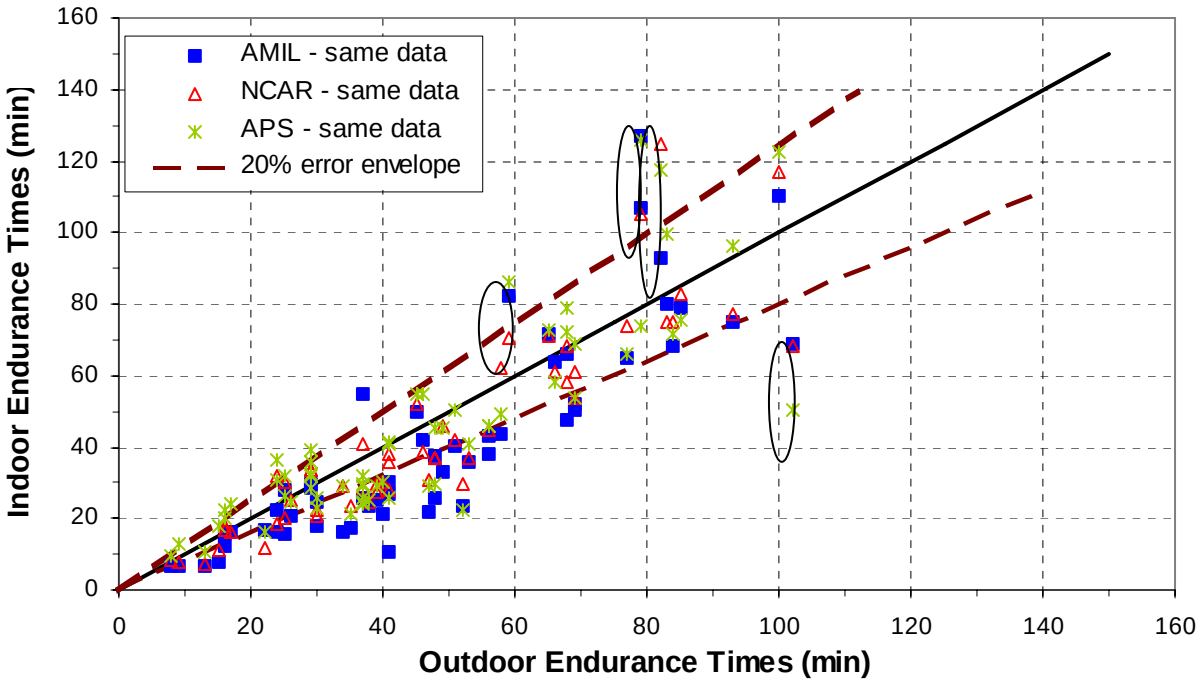

FIGURE 16. ERROR ENVELOPE TO THE ROUND-ROBIN TESTS

Figure 17 shows the results from all three test sites with best-fit lines drawn through each data set. The graph shows that all the lines are roughly parallel with each other and with the 1:1 line. Also, all three lines are very close to the 1:1 line showing good correlation for all three sites.

The list of outdoor test conditions to be replicated was lengthy (see appendix B). Each of the three sites ran only some of the conditions from the complete list. However, a substantial number of conditions were tested at all three sites. Figure 18 shows a plot of only the tests that were performed at all three sites, as well as the best-fit lines through each data set from each site. In this case, the best-fit lines are not parallel, they tend more to converge at the longer times.

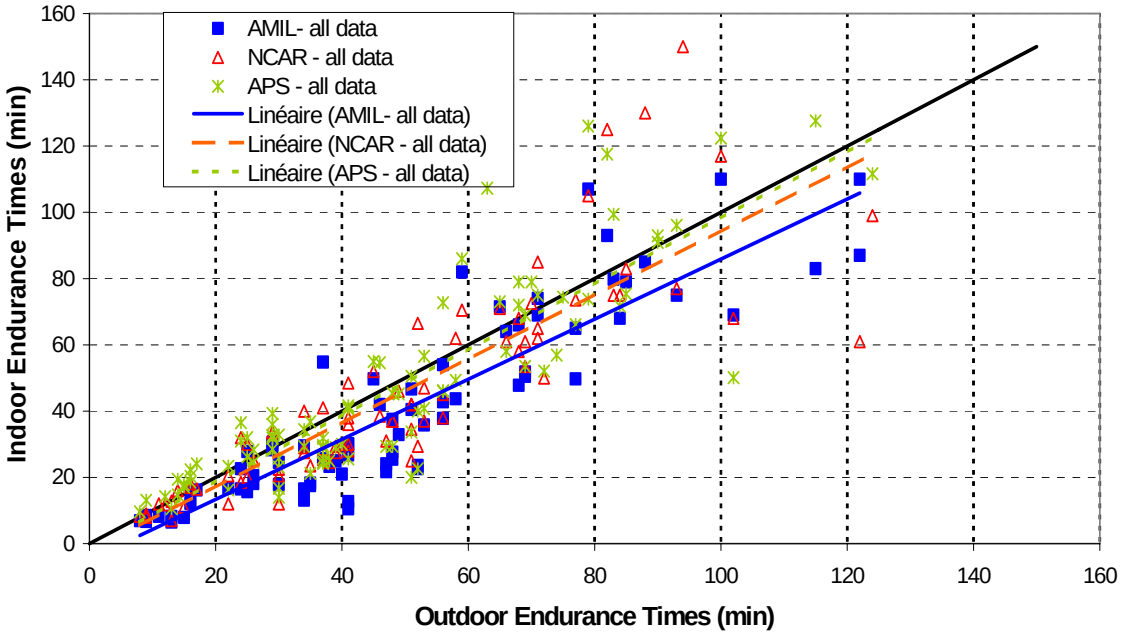

FIGURE 17. RESULTS, ALL GROUPS, ALL DATA POINTS, BEST-FIT LINES

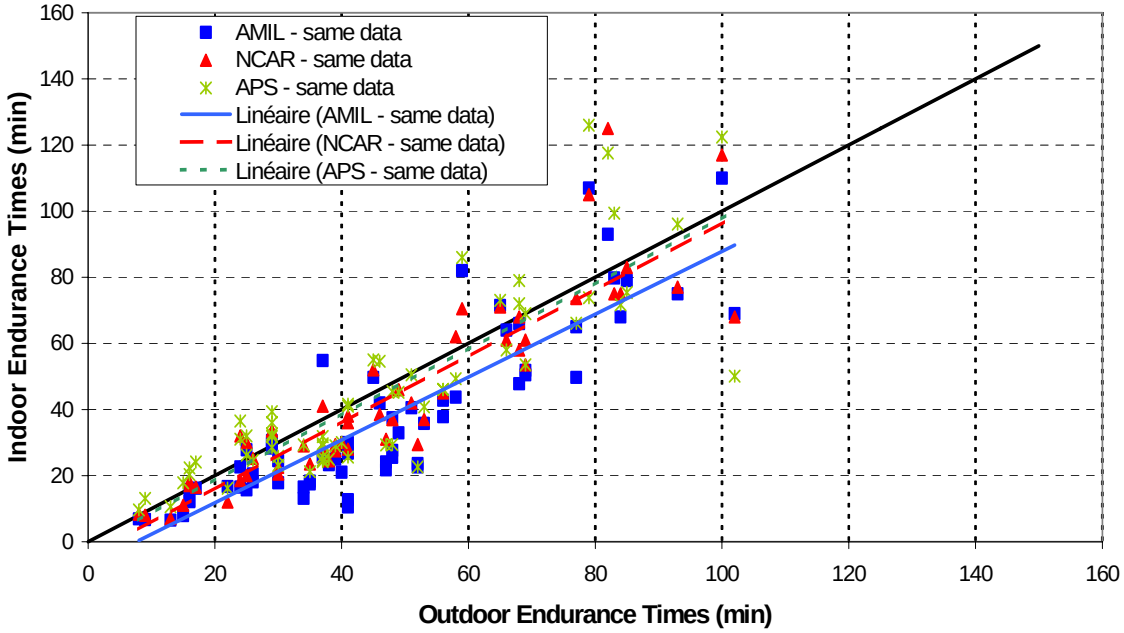

FIGURE 18. RESULTS, ALL GROUPS, SAME DATA POINTS, BEST-FIT LINES

4.3 TESTING AT -25°C AND THE EXISTING HOT CHARTS.

Since it rarely snows below -14°C (the start of the coldest temperature bracket of the HOTs), the data used to generate HOTs for anti-icing fluids is mostly mathematically extrapolated from data generated from higher-temperature results. The equations used were theoretical and often the topic of discussion during SAE meetings. Recently, fluids were assigned the shortest times for all fluids in this temperature range of -14° to -25°C, a worst-case approach. Therefore, newer fluids were automatically assigned the 15- to 30-minute time interval. Other fluids, however, kept their mathematically generated HOTs, which could be as long as 40-70 minutes. At the Vancouver SAE G-12 subcommittee meeting, in May 2003, it was resolved to generate endurance time data using the snow machines at -25°C. This was important because under the arrangements at the time, there was no incentive to develop fluids with longer HOTs in snow at -25°C, because new fluids were automatically assigned a HOT range of 15-30 minutes.

The data generated for -25°C at AMIL were presented in section 3.2. Table 14 summarizes the results obtained at AMIL, along with the current HOT charts and the data obtained by APS (one of the other sites involved in the round-robin tests). The data shows similar results between AMIL and the APS site. In general, the times were shorter than the existing HOT charts, with the exception of one fluid, ULTRA+. For this fluid, longer times were obtained in the laboratory tests than those presented in the HOT guidelines. For this fluid, the existing HOT guideline values were retained.

TABLE 14. ENDURANCE TIMES FOR FLUID TESTS AT -25°C

Fluid	Fluid Type	Current Fluid-Specific HOT Range at -25°C	APS Endurance Time Range Determined by Laboratory Testing at -25°C	AMIL Endurance Time Range Determined by Laboratory Testing at -25°C
Clariant Safewing MPIV Protect 2012	Type IV PG	15-30	11-20	11-20
Clariant Safewing MPII 2025 ECO	Type II PG	15-30	11-27	11-18
Clariant Safewing MPIV 2030 ECO	Type IV PG	15-30	12-25	10-15
Clariant Safewing MPIV 2001	Type IV PG	20-35	14-27	10-18
Dow Chemical ULTRA+	Type IV EG	20-45	32-85	35-84
Kilfrost ABC-II Plus	Type II PG	15-30	12-23	14-22
Kilfrost ABC 2000	Type II PG	15-30	17-25	14-20
Kilfrost ABC-S	Type IV PG	40-70	15-28	13-26
Octagon Process Max Flight	Type IV PG	20-40	13-30	13-27
SPCA Ecowing 26	Type II PG	30-50	12-26	12-22
SPCA AD-480	Type IV PG	25-40	12-30	10-18

4.4 FAILURE CALL AND ENERGY.

One source of error in the conduct of endurance time tests is fluid failure call, which is defined as white snow covering 30% of the test plate. However, snow does not form an even sheet of ice as with other endurance tests. When snow lands on the fluid-coated test plate, it forms slush on the fluid. However, it is quickly absorbed, at least in the beginning of the test. As the test progresses, the time to absorb the snow increases until the fluid can no longer absorb the falling snow. The snow then accumulates until the plate is covered with 30% snow, at which time the failure is called. This is how the failure typically has been called during the outdoor tests. However, fluid failure may be considered to occur when the snow adheres, since this is a criterion presented in Title 14 Code of Federal Regulations 121.629 [6] in which an aircraft is prohibited from taking off if snow is adhering to critical surfaces. Since it is difficult to determine when and to what extent the snow is adhering, the 30% failure call was developed. It was first investigated by Kuperman, et al. [7]. Flat plate results were compared to wing results in tests conducted in Denver; these tests indicated that 30% plate coverage corresponded to about 10% snow coverage on a wing.

However, since the 30% snow criterion is subjective in that it is based on a judgement by an observer, and adherence is difficult to measure, another method was proposed based on the snow absorption capacity of the fluids. Before temperature-controlled plates were used, the temperature profile was a good indicator of fluid failure (figure 1). Now, however, with the temperature-controlled plates, the indicator is not present. However, by monitoring the energy required to heat the plate, a better indicator is available. The fluid has failed when the plate no longer requires more energy to melt the snow, since it no longer has the capacity to absorb snow and, therefore, is no longer effective.

For example, figure 19 shows the heat required by the plate to maintain a constant temperature. The fine line shows the heating power, with its scale on the right side. Since the plate temperature is maintained by an on/off system, the curve is very jagged, representing more of an average of the on time. The on time is measured in volts, which gives the heating power when multiplied by the current. The higher and lower oscillation sections represent variations in air temperature control of the cold room. The jagged and oscillating nature of the curve make it hard to characterize. However, the cumulative heating power, which is the integral area below the curve, gives the energy or heat in Joules. From this curve, the variations in the heating of the test plate can be easily seen looking at the changes in the slope of the graph.

Figure 20 shows more data for the same test. The air temperature was maintained at around -5°C and the plate temperature was maintained at -7°C. Since the plates were equipped only to be heated, and not cooled, initially, the plate temperature starts out to be the same as the air temperature. As the snow falls and the fluid absorbs the snow, the plate temperature descends until it attains its set temperature; at that time, the heating begins and the required heat is recorded. For this particular test, heating begins at 10 minutes, when a sharp change in temperature is observed. The fluid failure is also plotted on this graph. Failure occurs after 75 minutes, the time which corresponds to the levelling off of the cumulative heat curve, as the plate no longer requires more energy to maintain the plate at a constant temperature (since the fluid is no longer absorbing snow and requiring heat from the test plate to do so).

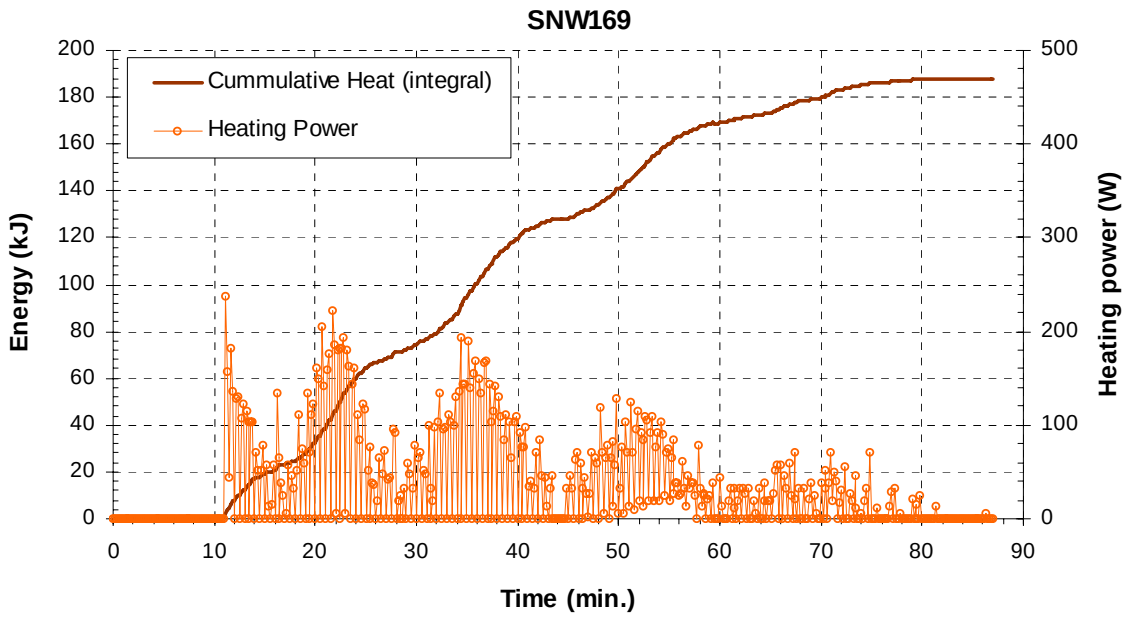

FIGURE 19. HEAT REQUIRED FOR ONE TEST

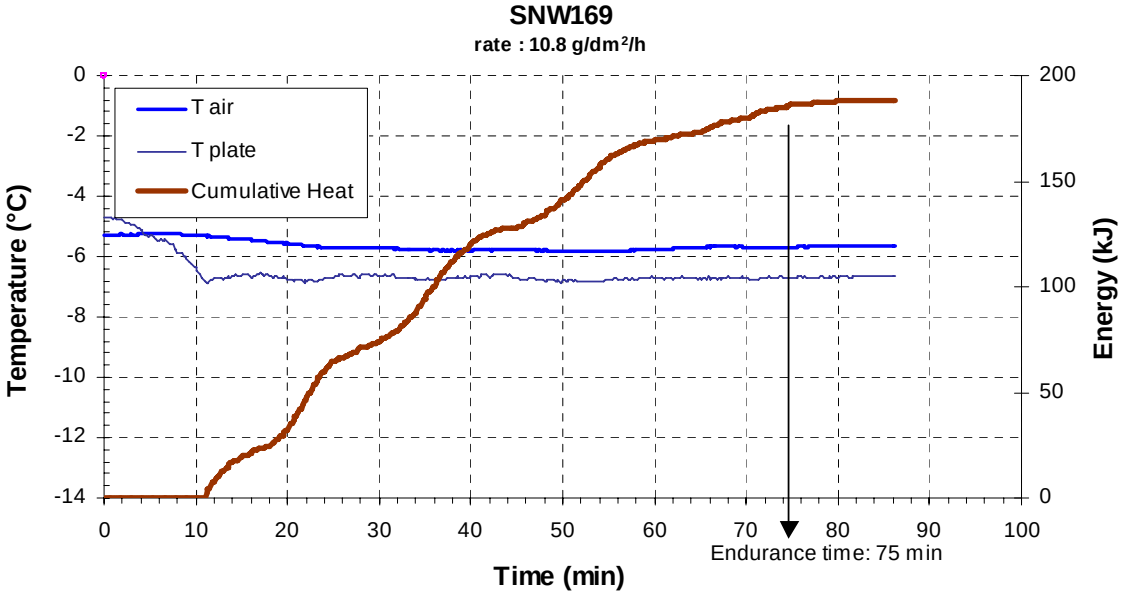

FIGURE 20. HEAT REQUIRED AND FLUID FAILURE, EXAMPLE 1

Figure 21 shows another example of the required heat recorded. As with the first example, initially, the air and fluid temperatures are about the same. The plate temperature descends until it reaches the set point (in this case, -7°C), after about 10 minutes when the heating begins. The heat is given consistently to the plate until the slope levels off, about 45 minutes, and the failure is called after 50 minutes.

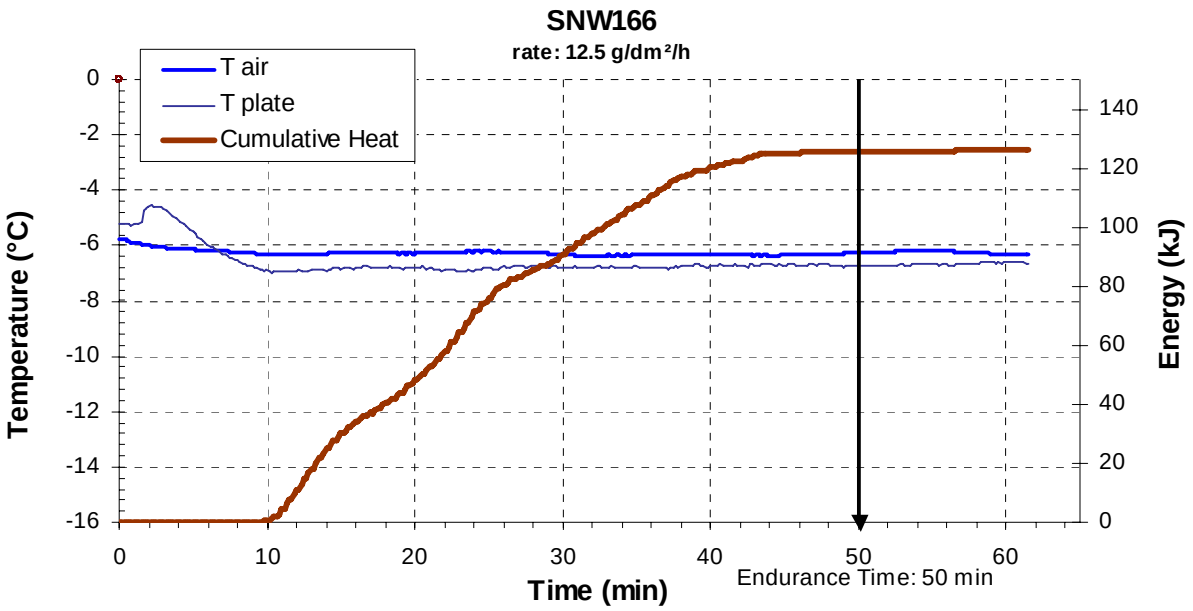

FIGURE 21. HEAT REQUIRED AND FLUID FAILURE, EXAMPLE 2

Figure 22 presents a typical heating curve for a snow at these cold temperatures (see section 4.3). For this test, the air temperature was set to -25°C and the plate to -26°C. The figure shows that there was no change in the temperatures and the failure was never called. This is further proof that the fluid was never really absorbing snow, since it was not taking heat from its surroundings (section 3.2).

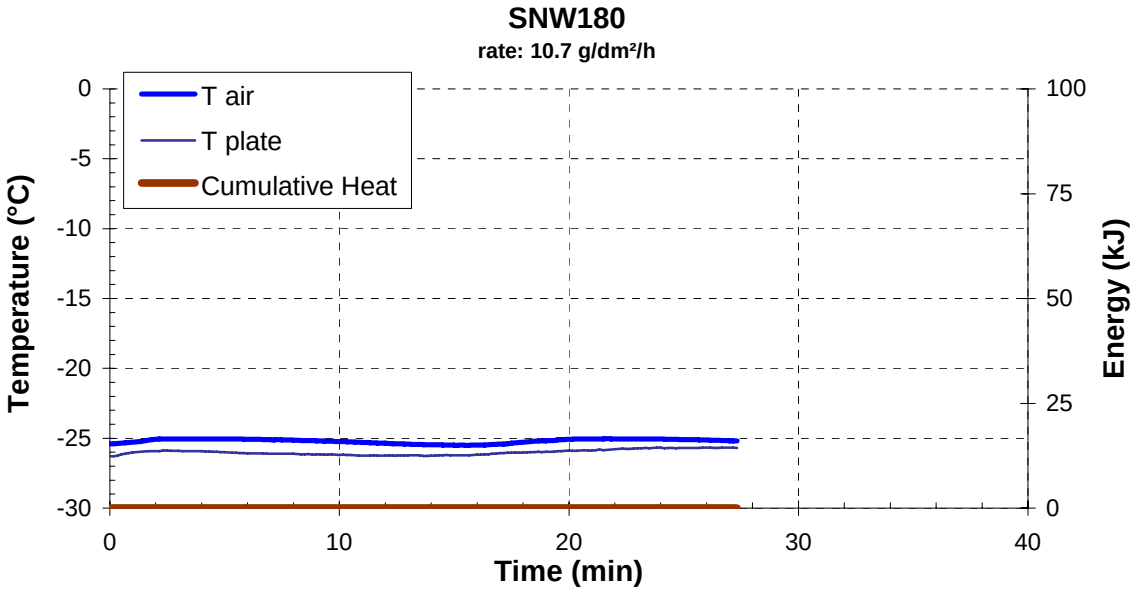

FIGURE 22. ENERGY BALANCE FOR A TEST AT -25°C

A preliminary attempt at an energy balance was made on one test to determine the absolute values for the heat or energy required by the fluid to melt the snow. This could lead to being able to model fluid behavior and predict fluid failure. Figure 23 shows the test studied. The x axis represents time and starts, in the negative, since all systems are started before pouring the fluid on the test plate and the start of precipitation. The first zone comprises the area from -4 to 0 minutes when there is no precipitation. The fluid is applied at zero minutes where there is an input of energy shown by the increase in plate temperature, the amount depends on the temperature differential and the fluid's specific heat. The zone from zero to about 2 minutes covers the time where the fluid has an excess of heat that is slowly used up to melt the snow. The zone from 2 to 6 minutes consists of the time where the fluid is taking heat from the surroundings and completely melting the snow. Then, there is a zone from 6 to about 8 minutes where the snow is only partially melted and the snow begins to accumulate. The fluid fails at 8 minutes when the plate is covered with 30% snow. Note that the outside time obtained for this fluid test was at 13 minutes, which does not seem possible given the heat balance; therefore, there must have been different characteristics to the outdoor tests.

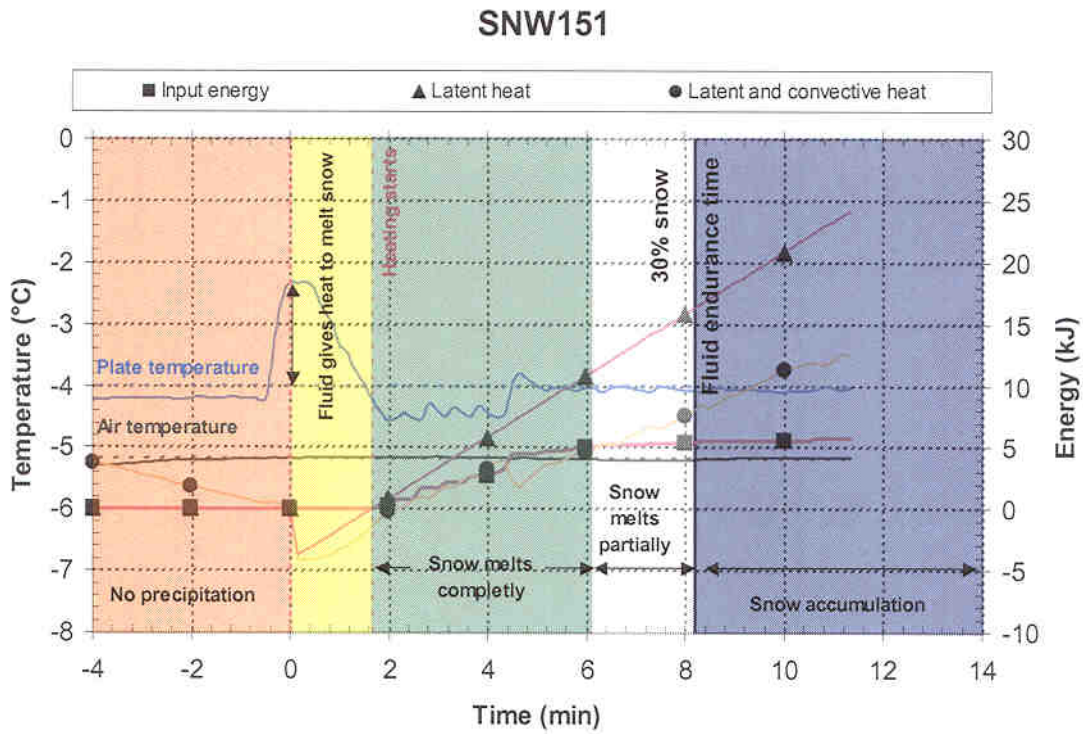

FIGURE 23. ENERGY BALANCE FOR A TYPICAL FLUID TEST

For the test of figure 23, the cumulative latent heat required to melt the snow can be calculated according to the equation:

$$Q_1 = \int_0^t L_f \cdot \dot{m}_s dt \tag{2}$$

where

Q_1 = Cumulative latent heat of melting (J)
$\dot{m}_s$ = Mass rate of collected snowflakes (kg/s)
L_f = Latent heat of melting (J/kg)

Given the rate of snow, precipitation was known to be 28.5 g/dm²/h. Q_1 can be calculated and is represented by the pink line in figure 23. Since it does not correspond exactly to the measured energy provided to the test plate, other terms must be considered.

The cumulative convective heat is given by the equation

$$Q_c = \int_0^t hA_P (T_A - T_P) dt \tag{3}$$

where

Q_c = Cumulative convective heat (J)
h = Convective heat transfer coefficient (W/m·°C)
A_P = Area of the test plate (m^2)
T_A = Air temperature (°C)
T_P = Plate temperature (°C)

The line with the circle symbols in figure 23 represents the latent and convective heat terms. Those two terms alone were adequate to follow the curve of the heat input to the test plate. Therefore, this curve could entirely be predicted by thermodynamics. However, other examples studied, not shown, show that other heat terms may also be involved, further study is needed.

However, by calculating the latent heat (input energy and other heat terms involved in the process), the curves can be modeled, and a prediction can be made for the fluid failure based on the thermodynamics and the capacity of the fluid to absorb snow.

5. SUMMARY.

Indoor anti-icing fluid endurance time tests in simulated snow conditions using temperature-controlled plates were conducted in a cold room at AMIL during the winter of 2004. Results were compared to earlier data obtained from outdoor tests. It was found that the indoor times correlated reasonably well with the outdoor times, although the indoor times were usually shorter. The exception was Dow Chemical ULTRA+, for which the indoor times were consistently longer, and sometimes much longer, than the outdoor times. ULTRA+ is the only one of the fluids tested that is EG-based. The results indicate a need for further investigation, and possibly the introduction of an indoor test temperature offset criterion for EG-based fluids.

For most fluids, the indoor snow tests at AMIL resulted in shorter times at -25°C than the currently published holdover times, which are largely based on a mathematical extrapolation; again, Ultra+ was the exception.

Indoor tests were conducted by two other organizations using the snow generation systems at their sites for a subset of the conditions conducted at AMIL. Comparison with times from the other sites indicated that they correlated reasonably well with the times measured at AMIL.

A limited investigation was conducted at AMIL to determine if testing in a larger cold room with a larger air mass produced better correlation with results from outdoor tests. Promising, but not conclusive, results were obtained.

A limited investigation was also conducted at AMIL concerning definition of fluid failure based on the energy profile of heat required by the fluid to melt the incoming snow. Promising results were obtained, which may justify further investigation and refinement of this approach with the goal of establishing an objective fluid failure call criterion.

6. REFERENCES.

1. Society of Automotive Engineers G-12 minutes from the Vancouver Fluids Subcommittee meeting, May 2003.

2. Bernardin, S., Dubuisson, C., and Laforte, J.L. (AMIL), "Development of Laboratory Test Procedures to Replace Field Anti-Icing Fluid Tests (Snow Equivalence Tests)," prepared for Transportation Development Centre, Transport Canada, TP 13141E, November 1997.

3. Beisswenger, A., Bouchard, K., and Laforte, J.L. (AMIL), "Development of a Procedure for Indoor Testing of Type IV Fluids to Replicate Natural Snow," FAA report, DOT/FAA/AR-02/82, August 2002.

4. Beisswenger, A., Gagné, N., Laforte, J.-L., and Perron, J., "Effect of Wind on Indoor Snow Testing of Type IV Aircraft Ground Anti-icing Fluids," prepared for the Federal Aviation Administration, 2003.

5. Aerospace Material Specifications Deicing and Anti-Icing Fluid Aircraft, AMS 1428D Non-Newtonian Pseudo-Plastic SAE Type II, Type III, and Type IV, February 2002.

6. Federal Aviation Administration, 14 CFR 121.269.

7. Kuperman, M.H. and Moore, R.K., "Deicing/Anti-Icing Fluid HOT Measurements Aircraft and Frosticator Panel Correlation - Snow Conditions," United Airlines internal report, June 1993.

APPENDIX A—ARTIFICIAL SNOW FABRICATION AND TEST METHODS

A.1 ARTIFICIAL SNOW.

Natural snow crystals occur with a wide variety of sizes, shapes, and water content due to variations in temperature and super saturation environments that snow crystals grow in. The process of snow generation, therefore, is difficult to reproduce in a cold room. To simulate the effect of natural snow on an aircraft deicing and anti-icing fluid, a snow simulation system was developed at the Anti-icing Materials International Laboratory (AMIL). This consisted of forming ice particles similar to frost in a cold room, which are then distributed over a fluid-coated test plate by means of the snow distribution machine. The system was developed in 1998 and continuously improved and refined through several contracts with the Federal Aviation Administration (FAA). Initially, it was constructed to simulate snow pellets, believed to be the type of snow that with the shortest holdover times based on the available data [A-1]. However, since then, the objectives of the SAE committee have shifted to desire simply replicating the average snow endurance times obtained outdoors. The two-step system was developed to be able to achieve a very even and controlled distribution, which can be carried out in any cold room. The snow can be made in a cold room from a fine water spray under the conditions detailed in section A.1.1 or collected outside. Then, by any means, even manual distribution, the snow can be distributed over fluid-coated plates. This procedure has resulted in endurance times similar to those obtained outside. However, for repeatable results, more control is deemed necessary, and is described in the following sections.

New aspects to the snow distribution test system, recently added and improved, include improved computer control, temperature-controlled plates, improved air circulation, as well as snow rate control using the computer.

A.1.1 SNOW MAKING.

The artificial snow was made in a cold room by means of two pneumatic water spray nozzles supplied with water and compressed air (see figure A-1). The nozzles produce a spray of very fine water droplets, which become supercooled in cold air and freeze to form solid ice crystals on contact with a collection plate on the chamber floor.

Water flow and air pressure were adjusted to obtain a snow density of about 0.1 g/cm^3. Typical parameters included:

- Air temperature: -20°C ±5
- Water droplet size: 22µm MVD ±3
- Water flow rate to nozzle: 70 ml/min
- Air pressure to nozzle: 260 kPa

FIGURE A-1. ARTIFICIALLY MADE SNOW ON COLD ROOM FLOOR

A.1.2 SNOW STORAGE.

The laboratory-made snow was then placed in an insulated container, which was stored in a freezer and kept at a temperature below -10°C. The snow quality was verified prior to each test by means of a density measurement. Furthermore, if the artificial snow showed any evidence of sintering, agglomeration, or crystallization, it was not used.

A.1.3 SNOW DISTRIBUTION SYSTEM.

For the indoor snow tests, the artificially made snow was distributed in the form of clusters in the range of the targeted intensities. The snow distribution system was designed so that the mass of each cluster is 0.10 g or less. The snow was placed in a U-shaped aluminum box, 320 mm long, 253 mm high, and 132 mm wide at the top, with a 65-mm-high drawer at the top and a sliding base, to add snow in between and during tests (figure A-2.). The box was suspended from a track approximately 760 mm above the center of the test plate. The track was attached to a motor that provided the lateral movement of the snow box. The lateral displacement speed depended on the desired snow intensity. The snow was continually stirred inside the box by a rotating system consisting of three blades disposed at 120° angles from each other (figure A-3). Each blade measured 50 by 300 mm and consisted of a frame housing and a wire mesh. The continued rotation of the blades prevented clumping of the snow prior to dispensing.

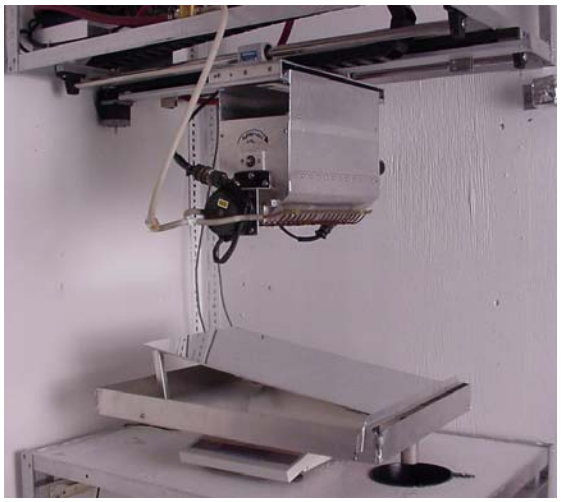

FIGURE A-2. SNOW BOX SUSPENDED OVER TEST PLATE

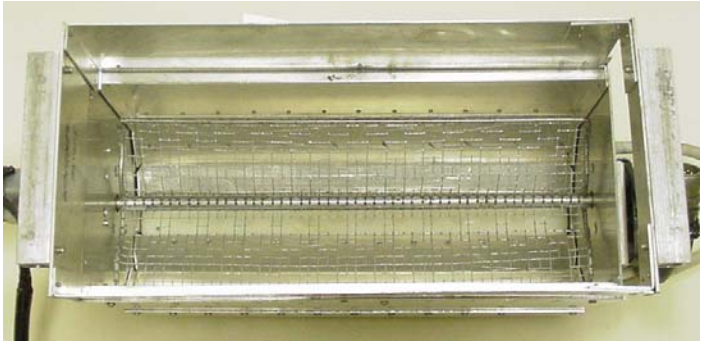

FIGURE A-3. WIRE MESH IN SNOW DISPENSING BOX TO STIR SNOW

The snow dispensing box contains an opening at the base, 10 mm wide along the length of the box. This opening houses a 32-mm Acetal cylinder (figures A-4 and A-5). A diagram of the snow distribution system is given in figure A-6 and a cross-section of the snow dispensing box is depicted in figure A-7. The Acetal cylinder in the snow distribution box contains 144 cavities arranged in 6 rows of 24 cavities each at 60° spacing (figure A-8) that transfers snow from the box to the test plate. The cavities on each row are spaced at 12.5-mm intervals, which are out of phase with each other row. Each cavity has a diameter of 7.9 mm and is drilled in a U-shape. The cylinder turns after a given time interval, thus dispensing snow clusters onto the test plate. The rotation speed of the cylinder is controlled to obtain the desired intensity.

FIGURE A-4. ACETAL CYLINDER

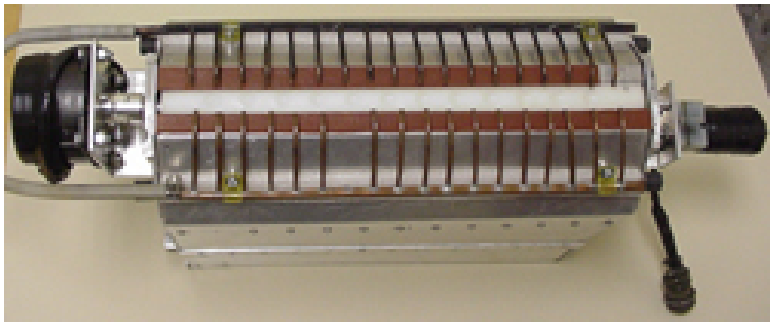

FIGURE A-5. ACETAL CYLINDER IN SNOW DISTRIBUTION BOX

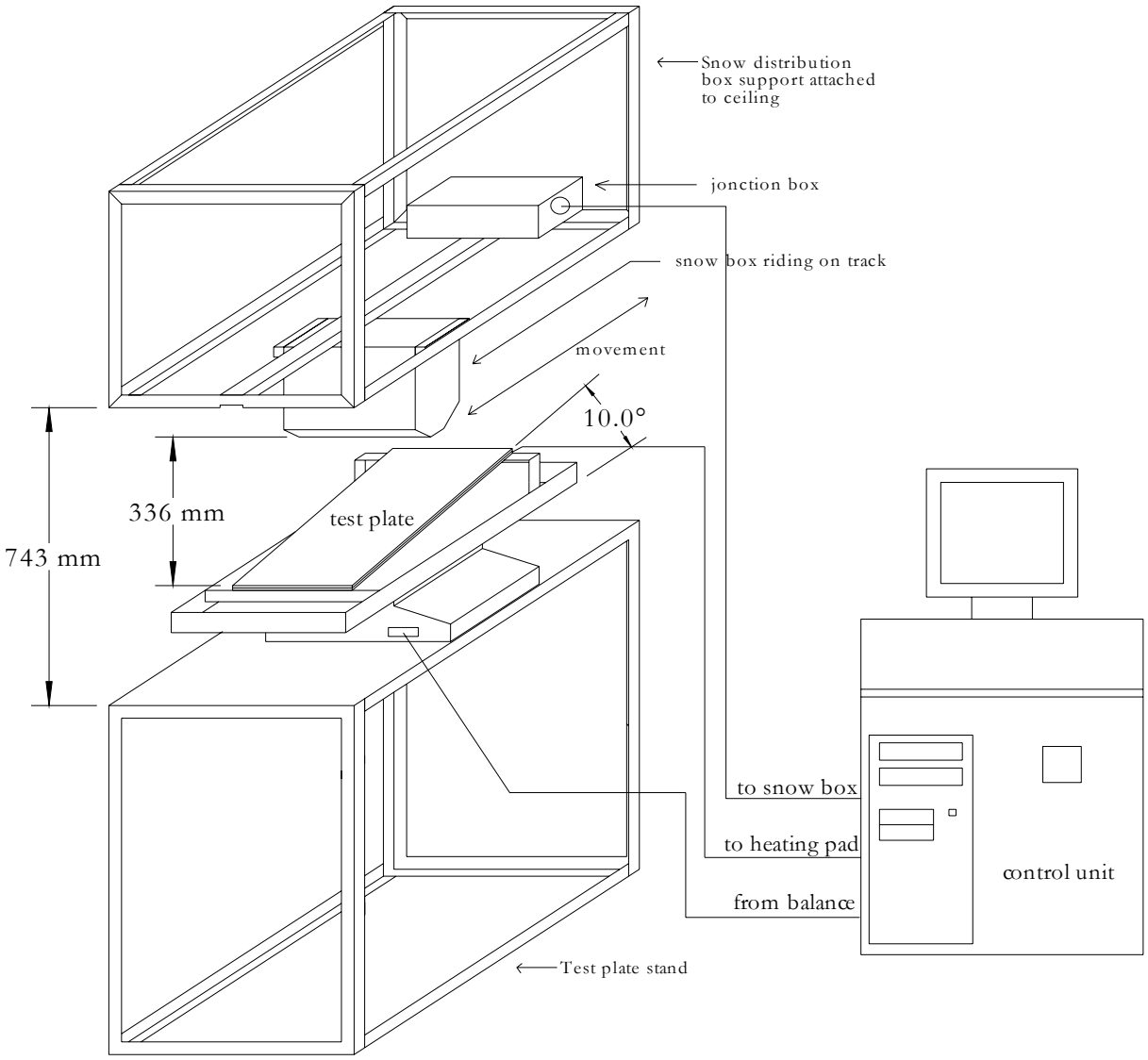

FIGURE A-6. SNOW DISTRIBUTION SYSTEM

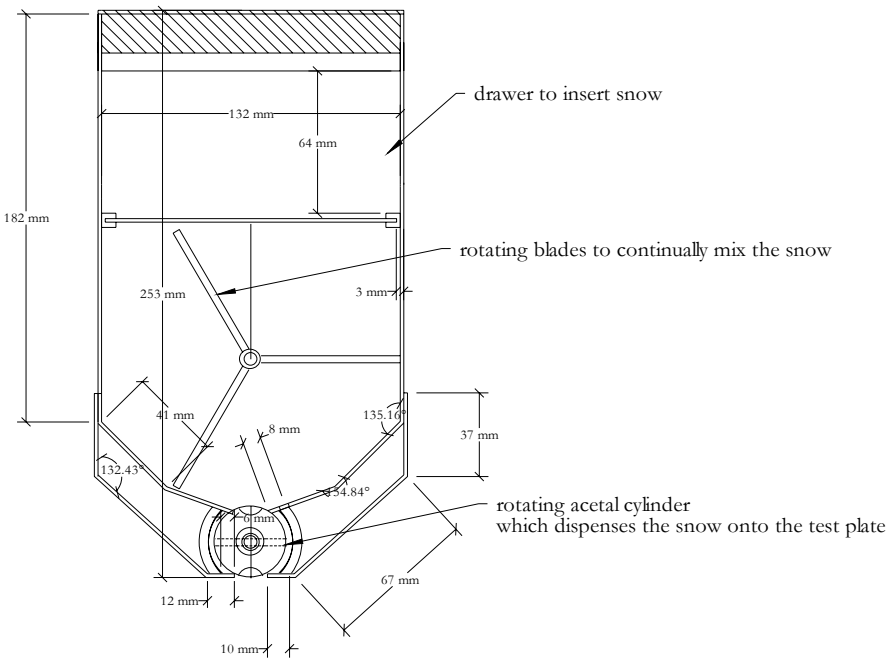

FIGURE A-7. CROSS-SECTION OF SNOW DISPENSING BOX

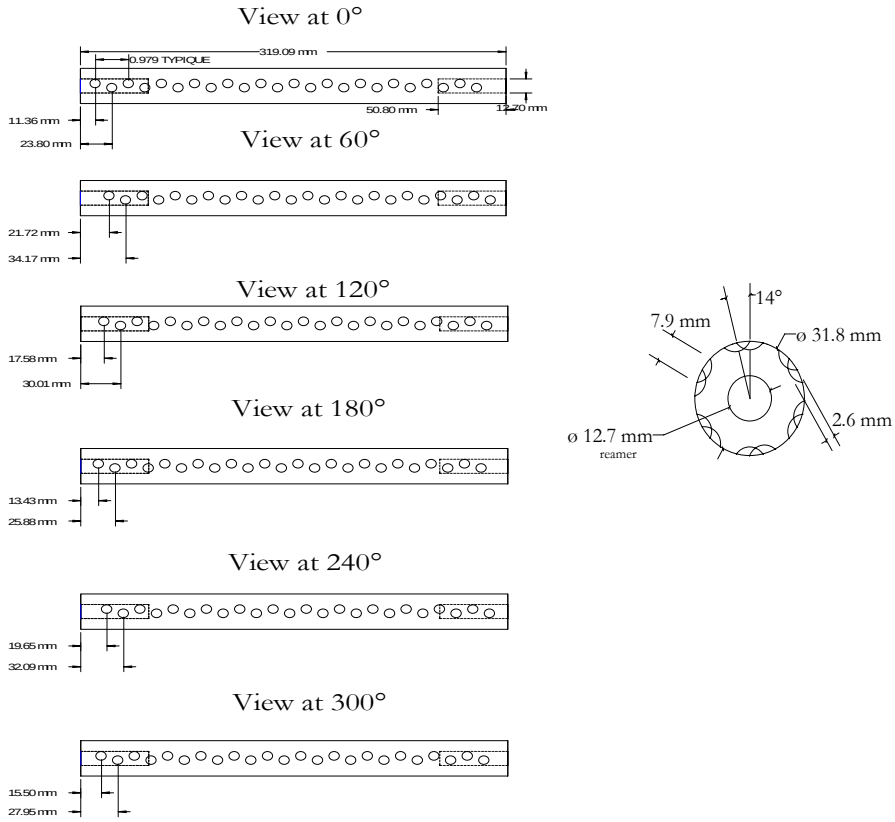

FIGURE A-8. SIDE VIEWS AND CROSS SECTION OF ACETAL CYLINDER

A.1.4 TEST PLATE AND RATE CONTROL.

The test plate consists of a 30- by 50-cm aluminum panel with a heating pad adhered to the bottom of the test plate to control the plate temperature during the test. Underneath, there is a pan that catches fluid and snow flowing off the test plate (figure A-6) with a digital balance underneath it. It is set to zero once the fluid is applied and records the weight of snow falling. This balance is connected to the computer control system (figure A-9), which adjusts the snow dispensing rate to obtain the desired intensity.

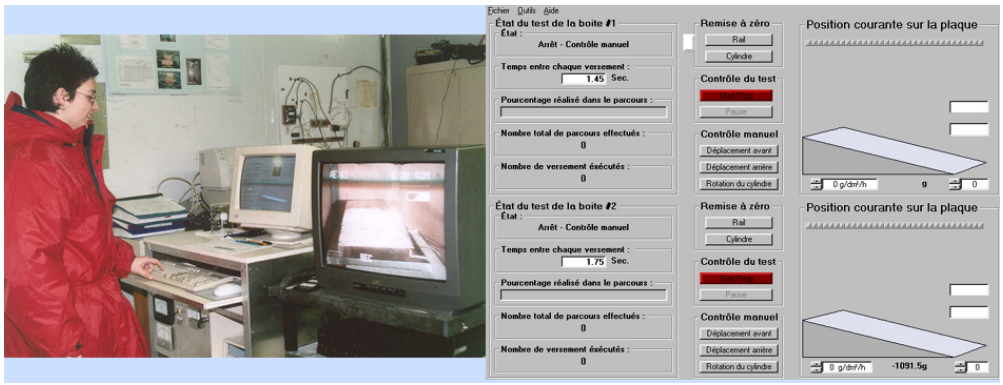

FIGURE A-9. SNOW MACHINE COMPUTER CONTROL SYSTEM

A.1.5 CALIBRATION.

The validity of the tests depended essentially on the three following environmental parameters: icing intensity, air, and plate temperatures. Recordings of the air and plate temperatures ensured that they were maintained throughout the test at target values within a prescribed allowable variation. Air temperature and humidity sensors were located within 1.5 m of the test plates. The plate temperature sensors consisted of thermocouples, or platinum resistance temperature devices (RTD), fixed to the underside of the test plate at 150 mm from the top and the side edges. All sensors were linked to a data acquisition system computer, which recorded and logged test data and controlled the speed to reach the desired intensity in real time throughout the course of a test run at the sampling rate of two datum per second. Calibration tests were conducted to establish even and reproducible snow falls occurred over the surface of the test plates, i.e., that the snow intensity over the surface of the panels exhibited an even distribution. Calibration tests consisted of measuring the snow intensity by means of ten small 100- by 150-mm snow catch pans with a 15-mm edge placed on the test panels. The snow catch pans are weighed prior to, and on completion, of each test. For a calibration test to be considered valid, the distribution had to be within ±1 g/dm^2/h, if not, adjustments were made and the calibration was repeated.

A.2 REFERENCE.

A-1. Society of Automotive Engineers G-12 Fluids Committee meeting, “Workgroup on Laboratory Methods to Derive HOT Guidelines,” Montreal, November 1997.

APPENDIX B—LIST OF OUTDOOR SNOW TESTS FOR ROUND-ROBIN TESTS

TABLE B-1. OUTDOOR TEST SET

Unique Test No.	Original Test No.	Date	Fluid Dilution	Fluid Name *	Fluid Type	Outdoor Endurance Time (min)	Outdoor/Set Icing Intensity ±0.1 (g/dm²/h)	Outdoor MSC Data		Fluid Set Temp ±1.0 (°C)	Room Set Temp ±0.5 (°C)	Plate Set Temp ±0.1 (°C)
								Temp (°C)	Wind Speed (km/h)			
RR 82	202	Mar-09-03	75%	C 2025 ECO	2b	25	23.7	-2.3	18.3	-4.0	-4.0	-4.4
RR 83	246	Apr-05-03	75%	C 2025 ECO	2b	56	6.7	-4.0		-4.0	-4.0	-4.9
RR 84	65	Feb-23-03	75%	C 2025 ECO	2b	49	9.3	-4.8	19.0	-4.8	-4.8	-5.9
RR 81	23	Feb-04-03	50%	C 2025 ECO	2a	17	9.1	-2.4	23	-4.0	-4.0	-3.5
RR 79	206	Mar-09-03	50%	C 2025 ECO	2a	12	21.8	-2.4	18.9	-4.0	-4.0	-4.3
RR 80	213	Mar-09-03	50%	C 2025 ECO	2a	9	29.0	-2.5	18.3	-4.0	-4.0	-4.9
RR 85	209	Mar-09-03	Neat	C 2025 ECO	2	41	23.4	-2.5	19.2	-4.0	-4.0	-4.5
RR 86	245	Apr-05-03	Neat	C 2025 ECO	2	90	6.2	-4.4		-4.4	-4.4	-5.3
RR 88	167	Mar-05-03	Neat	C 2025 ECO	2	84	6.5	-7.8	13.8	-7.8	-7.8	-8.7
RR 87	148	Mar-05-03	Neat	C 2025 ECO	2	90	5.9	-7.9	13.4	-7.9	-7.9	-8.8
25C 41	-	-	**Neat**	**C 2025 ECO**	**2**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 43	-	-	**Neat**	**C 2025 ECO**	**2**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
25C 42	-	-	**Neat**	**C 2025 ECO**	**2**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 44	-	-	**Neat**	**C 2025 ECO**	**2**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
RR 92	215	Mar-09-03	75%	C 2030 ECO	4b	37	25.5	-2.5	19.3	-4.0	-4.0	-4.6
RR 93	46	Feb-22-03	75%	C 2030 ECO	4b	56	12.8	-6.6	49.0	-6.6	-6.6	-7.9
RR 94	160	Mar-05-03	75%	C 2030 ECO	4b	75	7.0	-7.8	15.0	-7.8	-7.8	-8.8
RR 91	218	Mar-09-03	50%	C 2030 ECO	4a	24	7.7	-2.3	13.7	-4.0	-4.0	-3.3
RR 90	208	Mar-09-03	50%	C 2030 ECO	4a	16	21.9	-2.4	19.3	-4.0	-4.0	-4.3
RR 89	214	Mar-09-03	50%	C 2030 ECO	4a	15	28.9	-2.5	18.5	-4.0	-4.0	-4.9
RR 97	251	Apr-05-03	Neat	C 2030 ECO	4	115	6.8	-4.7		-4.7	-4.7	-5.7
RR 98	33	Feb-22-03	Neat	C 2030 ECO	4	74	14.1	-5.5	43	-5.5	-5.5	-6.9
RR 96	39	Feb-22-03	Neat	C 2030 ECO	4	69	14.2	-6.4	46.0	-6.4	-6.4	-7.8
RR 95	151	Mar-05-03	Neat	C 2030 ECO	4	107	7.0	-8.0	16.0	-8.0	-8.0	-9.0
25C 45	-	-	**Neat**	**C 2030 ECO**	**4**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 47	-	-	**Neat**	**C 2030 ECO**	**4**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
25C 46	-	-	**Neat**	**C 2030 ECO**	**4**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 48	-	-	**Neat**	**C 2030 ECO**	**4**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
RR 33	305	Mar-22-98	75%	CLARIANT 2001	4b	53	11.9	-3.2	35	-4.0	-4.0	-4.5
RR 34	324	Mar-22-98	75%	CLARIANT 2001	4b	35	27.8	-3.7	34	-4.0	-4.0	-6.0
RR 35	64	Jan-23-98	75%	CLARIANT 2001	4b	22	22.6	-13.0	22	-13.0	-13.0	-15.0
RR 32	394	Mar-19-98	50%	CLARIANT 2001	4a	29	4.7	-2.7	28	-4.0	-4.0	-3.5
RR 31	416	Mar-19-98	50%	CLARIANT 2001	4a	34	3.9	-2.8	29	-4.0	-4.0	-3.6
RR 37	147	Jan-23-98	Neat	CLARIANT 2001	4	68	13.1	-4.9	15	-4.9	-4.9	-6.3
RR 36	136	Jan-23-98	Neat	CLARIANT 2001	4	51	22.3	-6.4	18	-6.4	-6.4	-8.4
RR 38	71	Jan-23-98	Neat	CLARIANT 2001	4	30	37.0	-11.6	21	-11.6	-11.6	-14.5
RR 39	52	Jan-23-98	Neat	CLARIANT 2001	4	41	13.1	-14.6	23	-14.6	-14.6	-15.9
25C 17	-	-	**Neat**	**CLARIANT 2001**	**4**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 19	-	-	**Neat**	**CLARIANT 2001**	**4**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
25C 18	-	-	**Neat**	**CLARIANT 2001**	**4**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 20	-	-	**Neat**	**CLARIANT 2001**	**4**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
RR 51	104	Feb-05-01	75%	Clariant Safewing Protect 2012	4b	52	7.9	-8.0	17	-8.0	-8.0	-9.0
RR 52	83	Jan-31-01	75%	Clariant Safewing Protect 2012	4b	39	12.0	-8.3	26	-8.3	-8.3	-9.6
RR 49	158	Feb-19-01	50%	Clariant Safewing Protect 2012	4a	13	23.8	-2.4	24.2	-4.0	-4.0	-4.5
RR 50	97	Feb-02-01	50%	Clariant Safewing Protect 2012	4a	34	6.1	-2.4	14	-4.0	-4.0	-3.3
RR 54	101	Feb-05-01	Neat	Clariant Safewing Protect 2012	4	69	8.1	-7.9	16	-7.9	-7.9	-9.0
RR 53	55	Jan-15-01	Neat	Clariant Safewing Protect 2012	4	124	4.9	-8.0	21	-8.0	-8.0	-8.8
RR 55	193	Feb-22-01	Neat	Clariant Safewing Protect 2012	4	68	4.0	-15.8		-15.8	-15.8	-16.6
25C 25	-	-	**Neat**	**Clariant Safewing Protect 2012**	**4**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 27	-	-	**Neat**	**Clariant Safewing Protect 2012**	**4**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
25C 26	-	-	**Neat**	**Clariant Safewing Protect 2012**	**4**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 28	-	-	**Neat**	**Clariant Safewing Protect 2012**	**4**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
RR 75	498	March-18-02	75%	Kilfrost ABC 2000	2b	40	23.2	-0.9		-4.0	-4.0	-2.9
RR 74	170	Feb-26-02	75%	Kilfrost ABC 2000	2b	47	15.4	-6.0		-6.0	-6.0	-7.5
RR 73	247	March-2-02	75%	Kilfrost ABC 2000	2b	48	10.6	-9.3		-9.3	-9.3	-10.5
RR 72	710	Mar-26-02	50%	Kilfrost ABC 2000	2a	11	26.3	-2.9	28	-4.0	-4.0	-5.1
RR 78	497	March-18-02	Neat	Kilfrost ABC 2000	2	41	23.2	-0.9		-4.0	-4.0	-2.9
RR 76	265	March-2-02	Neat	Kilfrost ABC 2000	2	56	8.5	-9.0		-9.0	-9.0	-10.1
RR 77	249	March-2-02	Neat	Kilfrost ABC 2000	2	48	10.3	-9.3		-9.3	-9.3	-10.5
25C 37	-	-	**Neat**	**Kilfrost ABC 2000**	**2**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 39	-	-	**Neat**	**Kilfrost ABC 2000**	**2**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
25C 38	-	-	**Neat**	**Kilfrost ABC 2000**	**2**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 40	-	-	**Neat**	**Kilfrost ABC 2000**	**2**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
RR 42	386	Mar-11-99	75%	KILFROST ABC-II PLUS	2b	56	6.9	-5.5	20	-5.5	-5.5	-6.5
RR 45	123	Feb-06-99	75%	KILFROST ABC-II PLUS	2b	71	4.5	-7.4	12	-7.4	-7.4	-8.2
RR 43	337	Mar-06-99	75%	KILFROST ABC-II PLUS	2b	29	7.1	-12.6	24	-12.6	-12.6	-13.6
RR 44	322	Mar-06-99	75%	KILFROST ABC-II PLUS	2b	51	6.3	-13.3	28	-13.3	-13.3	-14.2
RR 41	286	Mar-04-99	50%	KILFROST ABC-II PLUS	2a	41	6.6	-1.7	31	-4.0	-4.0	-2.7
RR 40	236	Mar-03-99	50%	KILFROST ABC-II PLUS	2a	13	28.4	-1.7	17	-4.0	-4.0	-4.1
RR 47	230	Mar-03-99	Neat	KILFROST ABC-II PLUS	2	34	25.2	-1.8	17	-4.0	-4.0	-4.0
RR 46	399	Mar-11-99	Neat	KILFROST ABC-II PLUS	2	46	12.6	-5.5	18	-5.5	-5.5	-6.8
RR 48	125	Feb-06-99	Neat	KILFROST ABC-II PLUS	2	100	3.9	-7.2	11	-7.2	-7.2	-8.0
25C 21	-	-	**Neat**	**KILFROST ABC-II PLUS**	**2**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 23	-	-	**Neat**	**KILFROST ABC-II PLUS**	**2**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
25C 22	-	-	**Neat**	**KILFROST ABC-II PLUS**	**2**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 24	-	-	**Neat**	**KILFROST ABC-II PLUS**	**2**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**

TABLE B-2. OUTDOOR TEST SET (Continued)

Unique Test No.	Original Test No.	Date	Fluid Dilution	Fluid Name *	Fluid Type	Outdoor Endurance Time (min)	Outdoor/Set Icing Intensity ±0.1 (g/dm²/h)	Outdoor MSC Data		Fluid Set Temp ±1.0 (°C)	Room Set Temp ±0.5 (°C)	Plate Set Temp ±0.1 (°C)
								Temp (°C)	Wind Speed (km/h)			
RR 6	243	Mar-03-99	75%	KILFROST ABC-S	4b	34	23.1	-1.8	16	-4.0	-4.0	-3.8
RR 2	397	Mar-11-99	75%	KILFROST ABC-S	4b	45	12.5	-5.5	18	-5.5	-5.5	-6.8
RR 4	450	Mar-12-99	75%	KILFROST ABC-S	4b	82	6.0	-7.6	16	-7.6	-7.6	-8.5
RR 3	449	Mar-12-99	75%	KILFROST ABC-S	4b	88	5.7	-7.6	15	-7.6	-7.6	-8.5
RR 5	372	Mar-06-99	75%	KILFROST ABC-S	4b	71	7.5	-12.2	32	-12.2	-12.2	-13.2
RR 1	237	Mar-03-99	50%	KILFROST ABC-S	4a	9	28.4	-1.7	17	-4.0	-4.0	-4.1
RR 9	233	Mar-03-99	Neat	KILFROST ABC-S	4	51	32.3	-1.8	17	-4.0	-4.0	-4.4
RR 7	404	Mar-11-99	Neat	KILFROST ABC-S	4	93	10.7	-5.4	18	-5.4	-5.4	-6.7
RR 8	326	Mar-06-99	Neat	KILFROST ABC-S	4	122	4.8	-12.9	26	-12.9	-12.9	-13.7
25C 1	-	-	**Neat**	**KILFROST ABC-S**	**4**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 3	-	-	**Neat**	**KILFROST ABC-S**	**4**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
25C 2	-	-	**Neat**	**KILFROST ABC-S**	**4**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 4	-	-	**Neat**	**KILFROST ABC-S**	**4**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
RR 66	670	Mar-26-02	75%	Octagon E Max II	2b	31	20.3	-4.3	22	-4.3	-4.3	-6.1
RR 68	259	March-2-02	75%	Octagon E Max II	2b	55	9.9	-9.0		-9.0	-9.0	-10.2
RR 67	250	March-2-02	75%	Octagon E Max II	2b	50	10.5	-9.3		-9.3	-9.3	-10.5
RR 65	407	Mar-18-02	50%	Octagon E Max II	2a	12	18.6	-0.6	26.0	-4.0	-4.0	-2.3
RR 71	520	Mar-18-02	Neat	Octagon E Max II	2	44	27.1	-1.0	33	-4.0	-4.0	-3.3
RR 70	276	March-2-02	Neat	Octagon E Max II	2	87	7.0	-9.0		-9.0	-9.0	-10.0
RR 69	238	March-2-02	Neat	Octagon E Max II	2	71	10.4	-9.3		-9.3	-9.3	-10.5
25C 33	-	-	**Neat**	**Octagon E Max II**	**2**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 35	-	-	**Neat**	**Octagon E Max II**	**2**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
25C 34	-	-	**Neat**	**Octagon E Max II**	**2**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 36	-	-	**Neat**	**Octagon E Max II**	**2**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
RR 16	49	Dec-30-00	75%	OCTAGON MAXFLIGHT	4b	58	20.8	-4.6	43	-4.6	-4.6	-6.5
RR 17	126	Feb-14-01	75%	OCTAGON MAXFLIGHT	4b	72	16.5	-6.0	4.8	-6.0	-6.0	-7.6
RR 18	220	Feb-25-01	75%	OCTAGON MAXFLIGHT	4b	102	11.8	-8.6	21	-8.6	-8.6	-9.9
RR 15	405	Mar-13-01	50%	OCTAGON MAXFLIGHT	4a	41	23.7	-0.9	10	-4.0	-4.0	-3.0
RR 19	173	Feb-19-01	Neat	OCTAGON MAXFLIGHT	4	71	24.1	-2.4	27.2	-4.0	-4.0	-4.4
RR 21	48	Dec-30-00	Neat	OCTAGON MAXFLIGHT	4	65	18.8	-4.5	44	-4.5	-4.5	-6.2
RR 20	50	Dec-30-00	Neat	OCTAGON MAXFLIGHT	4	66	21.2	-4.7	42	-4.7	-4.7	-6.6
25C 9	-	-	**Neat**	**OCTAGON MAXFLIGHT**	**4**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 11	-	-	**Neat**	**OCTAGON MAXFLIGHT**	**4**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
25C 10	-	-	**Neat**	**OCTAGON MAXFLIGHT**	**4**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 12	-	-	**Neat**	**OCTAGON MAXFLIGHT**	**4**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
RR 24	440	Feb-16-00	75%	SPCA AD-480	4b	77	9.0	-2.8	20	-4.0	-4.0	-3.9
RR 25	511	Mar-11-00	75%	SPCA AD-480	4b	53	13.8	-3.2	21	-4.0	-4.0	-4.6
RR 26	391	Feb-14-00	75%	SPCA AD-480	4b	26	29.5	-5.5	44	-5.5	-5.5	-8.0
RR 27	260	Feb-11-00	75%	SPCA AD-480	4b	22	23.6	-11.0	31	-11.0	-11.0	-13.1
RR 22	449	Feb-16-00	50%	SPCA AD-480	4a	25	9.2	-2.8	20	-4.0	-4.0	-3.9
RR 23	433	Feb-16-00	50%	SPCA AD-480	4a	16	15.1	-3.0	26	-4.0	-4.0	-4.5
RR 28	497	Mar-11-00	Neat	SPCA AD-480	4	83	10.1	-3.0	21	-4.0	-4.0	-4.2
RR 29	671	Mar-14-00	Neat	SPCA AD-480	4	70	12.7	-5.4	14	-5.4	-5.4	-6.8
RR 30	261	Feb-11-00	Neat	SPCA AD-480	4	30	26.5	-11.0	32	-11.0	-11.0	-13.2
25C 13	-	-	**Neat**	**SPCA AD-480**	**4**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 15	-	-	**Neat**	**SPCA AD-480**	**4**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
25C 14	-	-	**Neat**	**SPCA AD-480**	**4**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 16	-	-	**Neat**	**SPCA AD-480**	**4**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
RR 59	175	Feb-19-01	75%	SPCA Ecowing 26	2b	30	23.7	-2.7	30.2	-4.0	-4.0	-4.8
RR 60	379	Mar-13-01	75%	SPCA Ecowing 26	2b	24	23.7	-6.1	25.3	-6.1	-6.1	-8.2
RR 57	355	Mar-11-01	50%	SPCA Ecowing 26	2a	14	16.1	-1.5	15.2	-4.0	-4.0	-3.1
RR 56	150	Feb-19-01	50%	SPCA Ecowing 26	2a	16	13.3	-2.6	22.1	-4.0	-4.0	-3.9
RR 58	176	Feb-19-01	50%	SPCA Ecowing 26	2a	8	32.4	-2.8	31.3	-4.0	-4.0	-5.4
RR 62	406	Mar-13-01	Neat	SPCA Ecowing 26	2	37	24.1	-0.9	10.0	-4.0	-4.0	-3.0
RR 61	438	Mar-13-01	Neat	SPCA Ecowing 26	2	51	16.1	-1.6	5.0	-4.0	-4.0	-3.2
RR 64	386	Mar-13-01	Neat	SPCA Ecowing 26	2	38	24.0	-6.1	26.9	-6.1	-6.1	-8.2
RR 63	195	Feb-22-01	Neat	SPCA Ecowing 26	2	85	3.9	-15.7		-15.7	-15.7	-16.5
25C 29	-	-	**Neat**	**SPCA Ecowing 26**	**2**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 31	-	-	**Neat**	**SPCA Ecowing 26**	**2**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
25C 30	-	-	**Neat**	**SPCA Ecowing 26**	**2**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 32	-	-	**Neat**	**SPCA Ecowing 26**	**2**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
RR 10	277	Mar-03-99	Neat	UCAR ULTRA +	4	52	14.9	-0.9	17	-4.0	-4.0	-2.4
RR 13	231	Mar-03-99	Neat	UCAR ULTRA +	4	37	25.6	-1.8	17	-4.0	-4.0	-4.0
RR 14	402	Mar-11-99	Neat	UCAR ULTRA +	4	59	11.6	-5.4	18	-5.4	-5.4	-6.7
RR 11	367	Mar-06-99	Neat	UCAR ULTRA +	4	79	8.2	-12.3	32	-12.3	-12.3	-13.3
RR 12	362	Mar-06-99	Neat	UCAR ULTRA +	4	94	5.4	-12.4	30	-12.4	-12.4	-13.3
25C 5	-	-	**Neat**	**UCAR ULTRA +**	**4**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 7	-	-	**Neat**	**UCAR ULTRA +**	**4**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**
25C 6	-	-	**Neat**	**UCAR ULTRA +**	**4**	**30**	**10.0**	**-25.0**	-	**-25.0**	**-25.0**	**-26.2**
25C 8	-	-	**Neat**	**UCAR ULTRA +**	**4**	**15**	**25.0**	**-25.0**	-	**-25.0**	**-25.0**	**-27.1**

Increasing Precip.

M:\Groups\CM1832 (TC-Dicing 03-04)\Procedures\MCAR\working documents\log of possible tests-procedure

*** Tests may also be conducted with new fluids depending on their availibility and on the scheduling of these tests; the matrix of tests could be developed at a later date.**