DOT/FAA/TC- 06/21

Federal Aviation Administration
William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

Human Visual and Tactile Ice Detection Capabilities under Aircraft Post Deicing Conditions

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February 2006

Technical Report

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U.S. Department of Transportation
Federal Aviation Administration

NOTICE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/TC-06/21		

4. Title and Subtitle Human Visual and Tactile Ice Detection Capabilities under Aircraft Post Deicing Conditions	5. Report Date February 2006
	6. Performing Organization Code ACB-330
7. Author(s) Edmundo A. Sierra, Jr., Kimberlea Bender, Isabelle Marcil, John D'Avirro, Edward Pugacz, Frank Eyre	8. Performing Organization Report No. DOT/FAA/TC-06/21
9. Performing Organization Name and Address Federal Aviation Administration William J. Hughes Technical Center Atlantic City International Airport, NJ 08405	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address FAA Office of Aviation Research, Flight Safety Branch Transport Canada, Transportation Development Centre	13. Type of Report and Period Covered Technical Note
	14. Sponsoring Agency Code

15. Supplementary Notes

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16. Abstract

Human Visual and Tactile ice detection capabilities while inspecting deiced aircraft surfaces have not been quantified. This report includes the findings of a human ice detection performance test conducted in April 2005 by the FAA Office of Aviation Research, Flight Safety Branch (William J. Hughes Technical Center) and Transport Canada, Transportation Development Centre. Six male deicers from AeroMag 2000 at Montreal Pierre Elliot Trudeau International Airport participated in the experiment. We used PMG Technology's cold chamber in Blainville, Quebec, Canada to create an environment whose temperature was -5° C with 92% humidity. Ice samples were created by APS Aviation on either white painted or unpainted aluminum panels, as either a 315 cm^2 circular patch or fully covering the panel, with thicknesses ranging from .2 mm to 1.2 mm. All of the test samples were covered with aircraft deicing fluid. We used a two-alternative forced-choice procedure in which each participant observed two panels in sequence, and then indicated on which of the two panels ice was present. The data showed that participants were 1) unable to visually detect ice less than .8 mm thick when it was in the shape of a patch and on a painted white panel; 2) unable to visually detect ice 1.2 mm thick when it covered the entire panel; and 3) participants could easily detect ice of any thickness using a tactile check.

17. Key Words	18. Distribution Statement
Deicing, ground icing, tactile inspections, visual inspections, GIDS, Ground Ice Detection Systems, human factors, engineering psychology, psychophysics, cold chamber, human capabilities, human limitations, aviation	This document is available to the public through the National Technical Information Service, Springfield, Virginia, 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	113	

Form DOT F 1700.7 (8-72) | **Reproduction of completed page authorized** | **Technical Report Documentation Page**

Acknowledgements

This report reflects the contribution of many individuals from various organizations, and the authors would like to acknowledge them and thank them for their efforts. Without them, this experiment would not have been a success.

We would like to thank Sherri Magyarits (FAA WJHTC, Simulation and Analysis Group) and Nicole S. Racine (Titan Corporation, Air Traffic Systems Division) for their assistance during the initial stages of the experiment.

Mario N. Rosa, Alex Leclair and Jean-François Morin from Aero Mag 2000 Montreal provided deicing expertise for sample creation, shakedown activities, and served as participants.

Nicoara Moc, Nicolas Blais, and Sami Chebil were responsible for creation of the ice samples and setting up the cold chamber.

We would also like to thank Christina Narlis for her dedication as a Test Administrator and for her help in reviewing and translating data collection materials.

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Executive Summary

Ice on an aircraft's wing poses a significant safety threat to flight operations. Currently, after preflight deicing operations, the presence of residual ice on an aircraft's wing is determined by a human deicer from a deicing ground crew. The presence of ice on a wing is determined visually under most circumstances. Tactile inspections may be required following deicing of certain types of "hard wing" aircraft. Tactile inspections expose extremities to cold surfaces, require close proximity to an aircraft (at times with engines on), are slow, and can be limited by the deicer's reach.

One method being proposed to eliminate post-deicing visual and tactile inspections is to use infrared camera based Ground Ice Detection Systems (GIDS). As GIDS are new technologies, many regulatory approval issues need to be addressed before these systems can be put into service. A GIDs Regulatory Approval Working Group (RAWG), under auspices of the SAE G-12 Ice Detection Sub-Committee, was formed to define the data and testing needed to provide regulatory authorities with the information they need to approve GIDS. To further this effort, Human Factor Specialists from the Federal Aviation Administration (FAA) William J. Hughes Technical Center's (WJHTC) Simulation and Analysis Group conducted an experiment on human ice detection capabilities in April 2005. These tests, sponsored by the FAA Office of Aviation Research, Flight Safety Branch (WJHTC), and Transport Canada's Transportation Development Centre, began to quantify human visual and tactile ice detection capabilities while inspecting deiced aircraft surfaces.

Six male deicers from AeroMag 2000 at Montreal Pierre Elliot Trudeau International Airport participated in the tests. The researchers used PMG Technology's cold chamber in Blainville, Quebec, Canada to create an environment whose temperature was -5° C with 92% humidity. Ice samples were created by APS Aviation on either white painted or unpainted aluminum panels, as either a 315 cm^2 circular patch or fully covering the panel, with thicknesses ranging from .2 mm to 1.2 mm. All of the test samples were covered with diluted aircraft deicing fluid. The researchers used a two-alternative forced-choice procedure in which each participant either observed or touched two panels in sequence, then indicated on which of the two panels ice was present. This process was repeated one hundred times for each ice thickness.

The data indicated that participants were unable to visually detect ice less than .8 mm thick when it was in the shape of a patch on white painted panels and unable to visually detect ice 1.2 mm thick when it covered the entire panel. Tactile ice detection was nearly without error for all thicknesses used, even with the use of gloves.

The results imply that under similar conditions in the field, visual inspections alone may be insufficient to detect residual ice.

Acronyms

2AFC	Two-Alternative Forced-Choice Procedure
FAA	Federal Aviation Administration
FOD	Foreign Object Damage
GIDS	Ground Ice Detection Systems
GOT	Grit Ordering Test
RA	Regulatory Approval
RAWG	Regulatory Approval Working Group
TA	Test Administrator
TC	Transport Canada
TLX	Task Load Index
WG	Working Group
WJHTC	William J. Hughes Technical Center

1. Introduction

Currently, after preflight deicing operations, a human deicer from a deicing ground crew determines the presence of residual ice on an aircraft's wing. The presence of ice on a wing is determined visually under most circumstances. Tactile inspections may be required following deicing of certain types of "hard wing" aircraft, or for aircraft where areas of cold soaking may be a problem. Some problems have been identified with tactile inspections. Tactile inspections expose extremities to cold surfaces, require close proximity to an aircraft (at times with engines on), are slow, and can be limited by the deicer's reach. New technologies, known as Ground Ice Detection Systems (GIDS), are proposed as alternative inspection methods for residual ice. However, the current regulations in the USA and Canada do not allow such systems to be used.

If visual and tactile inspections for the presence of ice on a wing are to be replaced with other methods, like GIDS, human visual and tactile capabilities must be determined to serve as a measure against which they can be evaluated. A detailed procedure for the determination of human capabilities must also be provided. A Ground Ice Detection System (GIDS) Regulatory Approval Working Group (RAWG), under the auspices of the SAE G-12 Ice Detection Sub-committee, was formed to find ways to meet this objective. The GIDS RAWG included representatives from the Federal Aviation Administration (FAA), Transport Canada (TC), aircraft and GIDS manufacturers, and end users. In September 2004, the GIDS RAWG met at the FAA William J. Hughes Technical Center (WJHTC) in Atlantic City, New Jersey to determine the most meaningful variables to use in the experiment whose objective was to determine human visual and tactile ice detection capabilities.

During this meeting, attendees agreed to the use of a two-alternative forced choice procedure to determine human visual and tactile ice detection capabilities. This procedure requires presenting in sequence two metal panels covered with deicing fluid to each participant and having them indicate which of the two panels had ice on it. The GIDS RAWG also discussed the independent variables to be considered in studying visual and tactile ice detection capabilities.

The members of the GIDS RAWG selected the variables from a long list that were considered important to the inspection task. After much consideration, the group determined that the color of the wing's surface and the thickness of the ice were to be studied. Color was chosen because it was frequently mentioned as one of the factors making it easy or difficult to visually detect ice on a wing. For example, it was mentioned that ice is easy to detect on unpainted aluminum surfaces, but difficult to detect on white painted surfaces. Ice thickness was also chosen for its relationship to other variables of operational significance. For example, for a given ice patch area, the curvature of the ice changes as the ice becomes thicker.

Using these variables as a starting point, we conducted preparatory tests to determine the feasibility of the procedures. Details regarding the preparatory tests are documented in Sierra, Bender, Hadley, Marcil, D'Avirro, Moc, Pugacz, and Eyre (2005); a short review of preparatory test procedures and results can be found in Appendix A. The results of the present test and those of the preparatory test are complementary and will be discussed conjointly in the discussion section.

2. Research Approach

2.1. Two-alternative Forced-choice Procedure

The primary interest in this experiment was to document visual and tactile ice detection capabilities. Because the interest in this study was with sensory capability rather than participant criterion (or bias) affecting detection, we used this forced-choice procedure (Green & Swets, 1988). Figure 1 shows a typical sequence of events within a two-alternative forced choice (2AFC) procedure. The figure shows that two observation intervals are provided. In our experiment, ice was always present in either the first or the second interval and the participant was forced to choose in which one it was present (hence, the answer interval). We had six participants. Each participant observed 100 trials during the visual part of the experiment and 100 trials during the tactile part of the experiment.

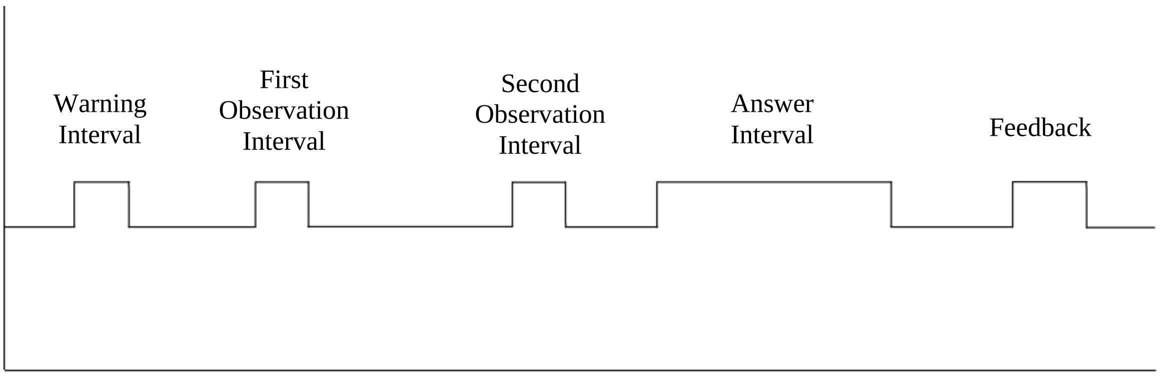

Figure 1. Events in a trial of the forced-choice procedure.

The outcome of this method was the percent of correct responses for each of the variables under study. The method we used and the resulting measures may be used to compare future ice detection devices, methods, and trainees. In Section 2.2, we will provide an overview of the theoretical concepts behind this method. We rely heavily on the information and methods presented in the book by Green and Swets (1988), who are authorities in the field, throughout this test plan (for a list of authoritative references, see Proctor & Proctor, 1997).

2.2. Statistical Decision Theory and the Psychophysical Experiment

2.2.1. The Decision

Decision theory proposes how a participant makes a response in a decision problem. A detailed explanation of the application of this theory can be found in Green and Swets (1988). We will provide an overview of the theory, which may serve to understand the rationale behind the method we used to determine the participant's ice detection capability.

As indicated in Section 2.1, the 2AFC procedure entails providing two observation intervals; also known in decision theory as sensory events (e_1 and e_2). The participant decides whether the first event is a signal (i.e.: ice in our study) and the second a non-signal, or vice-versa. One assumption of the theory is that the participant has the ability to collect information about the signal during each observation interval and determine the likelihood that ice is present based on this information. Through experience, deicers have developed the ability to assign a hypothetical value to the amount of information available in an event, in order to decide whether the evidence is sufficient to declare that ice present. This likelihood value leading to the participant's decision can be represented mathematically using the following likelihood ratio:

$$l(e_i) = \frac{f(e_i \mid s)}{f(e_i \mid n)} \quad (i = 1, 2)$$

In this equation, *l* is the likelihood ratio, *e* is the event, *s* is the signal (or presence of ice), *n* is noise alone (or no ice present), and *i* is the interval. The numerator represents the probability of a signal and the denominator represents the probability of noise.

There are two such likelihood ratios in the two-alternative forced-choice procedure, one for each interval. According to decision theory, the participant compares the likelihood ratios for each observation to decide which is the greatest. Given the certainty that ice is present on at least one panel, the participant can determine which panel has the greatest likelihood ratio, indicating the presence of the signal.

Again, there are no observable values available to the participant to determine the probabilities that ice is present or not. The participant determines the likelihood ratio from experience with the signal. The likelihood ratio is useful for understanding how the decision is made.

2.2.2. Computation of Percent of Correct Responses

In this section we discuss why the percent of correct responses is an appropriate measure of sensitivity. The concept of sensitivity, as it is used in this document, is the capacity of the participant to respond to stimulation. If the participant's response rule is to select the interval producing the larger likelihood ratio, he will be correct if the likelihood ratio associated with the signal-plus-noise distribution is greater than the likelihood ratio associated with the noise-alone distribution (an estimated value of the actual signal and the variability associated with it make up the distribution). Thus, the two intervals in a 2AFC procedure are like a sample from two statistical distributions: one a signal distribution and the other a nonsignal distribution. If the sample from the signal distribution has a higher likelihood ratio than the sample from the non-signal distribution, then the participant will be correct. We can compute the probability of making a correct response based on this fact.

The probability of a correct response can be based on the signal provided in each of the distributions. If the value of the likelihood ratio sampled from the signal distribution is *k*, then the participant will be correct if the value sampled from the nonsignal distribution is less than *k*. The sample of the likelihood ratio from the signal distribution will be called l_s and from the noise distribution will be called l_n. The participant will be correct if $l_s = k$ and $l_n < k$.

If the two samples are independent, then the probability of this joint occurrence will be the product of the two probabilities. The probability of a correct response in 2AFC task is then:

$$P_2(\mathrm{C}) = P(l_s = k) \cdot P(l_n < k)$$

The numerical value of l_s is immaterial. Therefore, the total probability of being correct is this expression summed over all possible values for *k*:

$$P_2(C) = \int_{-\infty}^{+\infty} [P(l_s = k) \cdot P(l_n < k)]\, dk$$

Hereafter, we will refer to the probability of a correct response as the percent of correct responses.

2.2.3. Use of Percent of Correct Responses

The theory described above explains what the percent of correct responses represents. In our study, we needed to set a threshold at which the rate of correct responses would reflect that the participants were able to discriminate between panels contaminated with ice and those that were clean. We used the index *d'* to set this threshold. This index is a widely used measure of sensitivity in signal detection studies and is defined as the distance between the signal and noise distribution in standard deviation units. We established our threshold at a rate of 75% of correct response. A performance rate above 75% of correct responses in a 2AFC procedure corresponds to a *d'* = 1.0 (Green & Swets, 1988). When *d'* = 1.0, the difference between the means of signal and noise distributions is one standard deviation (25%), which is enough for an observer to be able to distinguish between the ice and no ice panels.

2.3. Summary

We have provided a general overview of the method we used to collect human visual and tactile ice detection capability data and the rationale for the validity of the data. In the rest of the report, we will provide the details about the participants, the equipment, the data collection procedure, and the analysis.

3. Methodology

3.1. Participants

3.1.1. Deicers

Six deicers, ages 21 to 47, were recruited from AeroMag 2000, which operates the Central Deicing facility at Montreal Trudeau International Airport. All participants were male because that represented the majority of the deicer population in Montreal where the tests were conducted. Participants in our sample were distributed in three experience categories: Participant 1 (P1) and P3 were inexperienced (six and seven months, respectively), P2 and P4 were mid-experienced (approximately eight years on the job), and P5 and P6 were experienced (20 and 16 years, respectively). We collected participant demographic information using the questionnaire in Appendix B.

All participants received and filled out a consent form (see Appendix C). English and French versions of the forms were available to participants to ensure they had access to information in the language of their choice (the French versions of all documents are immediately followed by the English versions in the appendixes). Participant information will be kept confidential through the use of identification codes (e.g., P1, P2, P3, etc.). Consent forms required signatures, but are unmatchable with individual participants because they were collected in advance and without participant codes.

Participants were paid by their employer (AeroMag 2000) at their usual salary rate during their involvement in the experiment. It should be noted that all participants volunteered to take part in the experiment and they were informed they could withdraw at any time, without penalty or loss. All participants remained in the experiment until the end.

Participants conducted the inspections in a cold chamber that was cooled to -5° Celsius (C). Participants who were susceptible to cold related injuries and illnesses were excluded. We asked the initial pool of participants whether they had experienced any cold related illnesses or injuries and excluded them from participation on these grounds. We also asked the pool of participants to indicate whether they had any health conditions that may predispose them to cold related illnesses and excluded them from participation as well. The test administrators (TAs) collected this information using the Background Questionnaire (see Appendix B).

Far visual acuity and tactile discrimination ability were evaluated prior to beginning inspections. Far visual acuity was determined using a 20-foot Snellen Eye Chart. Participant 3 (P3) was the only Participant with worse than 20/20 vision (measured at 20/25). Tactile discrimination ability was determined with the Grit Ordering Test (GOT), which was developed specifically for this experiment. For the GOT, participants were asked to indicate the order of roughness of three sandpaper strips (400, 600, and 1500 grit), from least to most rough. The strips were 1 in x 2.5 in (see Figure 2). P2 failed the task. We did not use visual and tactile abilities to exclude deicers from participation; this information was collected to help explain outliers', if any appeared.

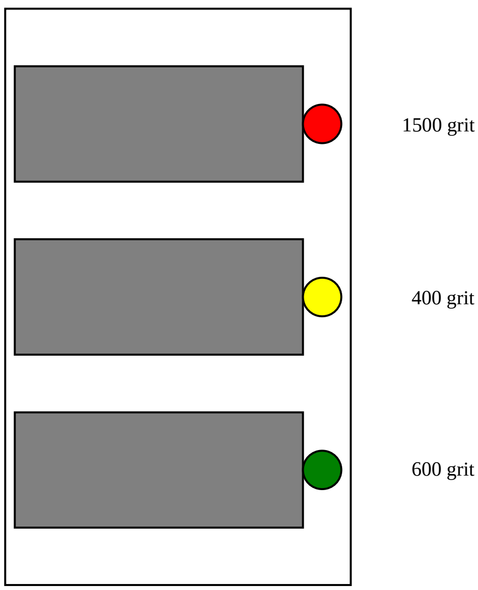

Figure 2. Grit Ordering Test on a 3 in x 5 in card showing 1 in x 2.5 in strips of different grits. The colored dots are used by the participant to identify the strip (e.g., red is first, yellow is second, etc.)

There were minimum clothing requirements for all participants. The clothing listed in Appendix D was designed to protect participants down to -60° C (Castellani, O'Brien, Baker-Fulko, Sawka, Young, 2001). This list of clothing (table adapted from FM 31-70) was sent to participants before the experiment. Clothing that provided similar protection was also accepted. We had extra clothing available at the test site in case participants failed to wear enough protection or would prefer more clothing to be more comfortable.

3.1.2. Research Personnel

The Test Administrators (TA) presented briefings, administered questionnaires, proctored the sessions, and conducted debriefings. The TAs were Human Factors researchers from the Simulation and Analysis Group, FAA WJHTC and a French speaking Human Factors researcher hired by the Transportation Development Centre of Transport Canada. Research personnel adhered to the same clothing requirements listed for participants.

3.2. Equipment

3.2.1. Climatic Chamber

We conducted the experiment in a climatic chamber located at the PMG Test and Research Centre, Blainville, Quebec, Canada. The temperature in the chamber was -5° C (±0.5°), humidity was 92% (± 2%), and the wind speed was about 1 meter per second. No precipitation was used.

The ambient lighting in the chamber was diffused. The source of the electric light in the chamber was a 150-watt, high-pressure sodium bulb with 14,000 mean lumens and a color temperature of 2,100 K. The light was diffused by a Halophane diffuser (Class SB1A15AHP12A). The average illumination in the chamber was 15.8 fc. This lighting is comparable to sunrise and sunset levels.

Two experimental sessions were run in parallel in one climatic chamber. The room was sectioned off so the two participants engaged in simultaneous trials could not see or communicate with each other (Figure 3).

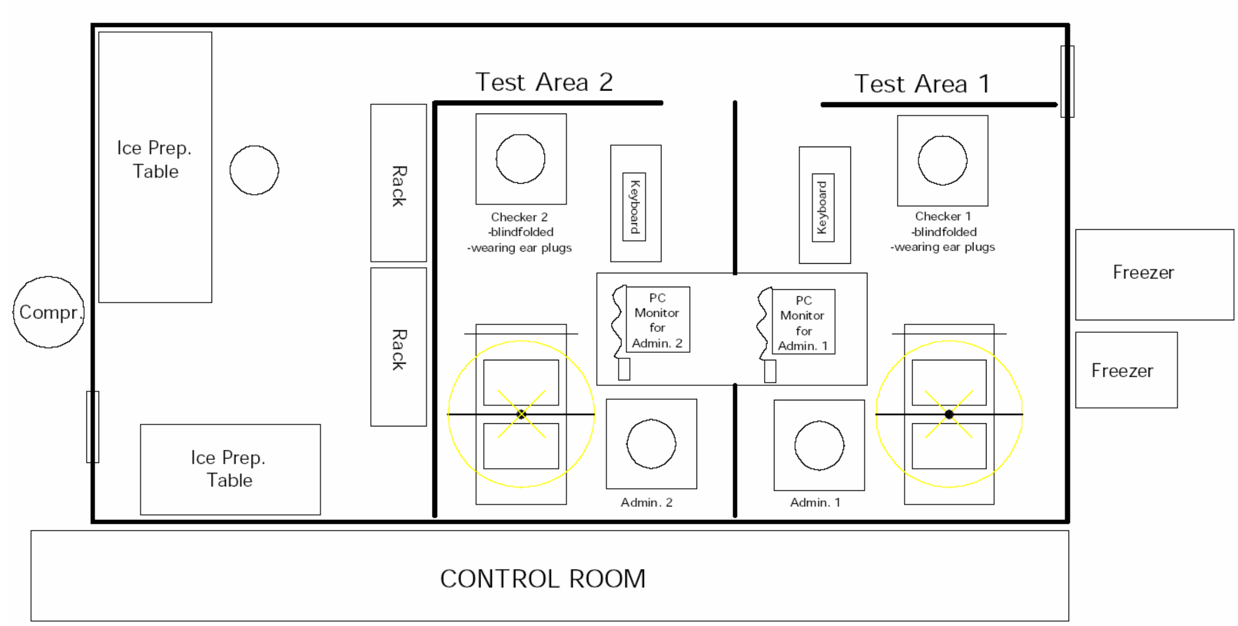

Figure 3. PMG climatic chamber, 23 x 13 ft.

For more information about the chamber, see Moc, 2005.

3.2.2. Ice Samples

The ice samples were created by APS Aviation Inc (see Moc, 2005 about the procedure developed to create the ice samples). Figure 4 shows an ice sample. The ice sample was inserted into a panel holder. The panel with the ice on it had an ice patch with a layer of Type I fluid[1] covering it. Figure 4 shows a black frame with aluminum clamps holding the fluid in place. The panel without ice only had the diluted Type I deicing fluid on it and the frame to keep it on the panel. The independent variables were ice thickness, ice shape (315 cm^2 patch or full ice cover), and panel color. Both the painted and unpainted aluminum panels were measured for roughness. The unpainted aluminum panels had a roughness of 0.53 to 0.58 microns and the white painted aluminum panels had a roughness of 0.23 to 0.31 microns. The white panels were contaminated with a 315 cm^2 patch of ice (feathered edge) that was one of five thicknesses (namely, 0.2, 0.35, 0.5, 0.65, or 0.8 mm). The unpainted aluminum panels were fully contaminated with ice of two thicknesses (namely, 0.5 and 1.0 mm). All panels, both with and without ice, were covered with diluted deicing fluid.

Figure 4. This image shows an unpainted aluminum panel with ice. Ice is formed on the panel and then covered with deicing fluid. The black frame and aluminum clamps hold the deicing fluid in place.

3.3. Data Collection

[1] Type I deicing fluid is used by the participants everyday while performing their job. A more diluted solution of water and deicing fluid than used in the field was used to prevent melting of the ice samples. See Appendix E for material safety information.

3.3.1. Session Design

3.3.1.1. Session Duration and Trial Blocks

Experimental sessions were scheduled to last no longer than eight hours per day, including a lunch break of one hour. Sessions took place in a split room (see Figure 3) and trials were managed by a data collection program developed by the Simulation and Analysis Group. The visual experiment contained 10 blocks of trials with 10 trials in a block, per participant; per combination color and thickness (see Sierra, Bender, Marcil, D'Avirro, Moc, Pugacz & Eyre, 2005 for the detailed rationale for this number of trials). The tactile experiment had two blocks of trials with 50 trials in a block, per participant, per ice thickness studied. Conditions (namely, ice thicknesses or panel color) were not randomized within blocks; participants saw the same two panels, with and without ice, trial after trial within the same block of trials. However, we did randomize conditions between blocks: participants saw one sample for one block of trials and another sample in the next block.

Participants rested in a warm room for 20 minutes following visual trials and for 60 minutes after tactile trials. Resting between blocks of trials was expected to minimize intra-session trends in the index of sensitivity. It also provided a consistent warm-up period for the participants and limited their time in the cold chamber[2]. This rest period was well within the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA; 1998) recommendations for the environmental conditions described in Section 3.2.1. With the breaks scheduled, and the temperatures to which the participants and administrators were exposed, there was little danger of cold related injuries or illnesses according to OSHA's Cold Stress Equation (Appendix F). . Furthermore, our exposure limit of 20 minutes or less was supported by guidelines from the U.S. Army Research Institute of Environmental Medicine (n.d.). They combine wind chill risk with work intensity and recommend rest periods every 15 to 20 minutes, for sedentary work, under much colder conditions (-34° C) than our participants experienced.

Hypothermia prevention measures were taken. The test administrators described the environmental conditions, potential cold-induced illnesses and injuries (e.g., frost bite and hypothermia), and emergency procedures[3] to the participants. We reviewed the signs and symptoms of cold-induced illnesses with the participants during the initial briefing and looked for symptoms throughout the sessions (see Appendix F). Safe practices, such as wearing adequate protection and rest, were enforced by all TAs.

The deicers participating showed no symptoms of frostbite, frost nip, or hypothermia during the study. They also did not report having symptoms of these cold related injuries or illnesses to the TAs or their manager, who was on-site at all times.

3.3.1.2. Number of Trials

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[2] Test Administrators relieved each other from the chamber every twenty minutes. This amount of time was within the margin for safe exposure described in this paragraph.

[3] The test administrators would have been the first to respond to medical emergencies because they were in the immediate vicinity. If an emergency arose from poisoning, frostbite, or hypothermia, first aid procedures detailed in Appendices E and F, respectively, would have been followed. These procedures were posted at a convenient place at the test site. The PMG Safety Department would be second to respond. They had available an eyewash, warm blankets, warm water, and first aid kits. Their phone number was posted at the site (see Appendix G). The emergency number in Canada was also 9-1-1.

The maximum number of trials allowable by our safety standards and budget limitations were conducted. For the visual experiment, each condition with fixed parameters (e.g., a white panel with .2 mm of ice) included 100 trials. We collected data for 100 trials per condition in the tactile experiment as well.

The a priori probability of signal occurrence (namely, ice present) was set at 0.50. That is, in this forced-choice task the signal was equally likely to occur in each interval. Because this experiment was undertaken to determine changes in the sensitivity index as a function of ice thickness, we chose five conditions (of different ice thickness) whose purpose was to elicit values of *P*(C) over a range from near chance to near 1.0.

3.3.1.3. Signal Previews

Based on pretest results (Sierra et. al., 2005), we did not allow participants to preview the sample. We realize that we risked a longer period of improvement when a new signal was introduced, and an increase in inter- and intra-participant variability. However, excluding signal previews likely yielded more valid data than including them (see Sierra et al., 2005).

3.3.2. Trial Design

3.3.2.1. Trial Events

A trial consisted of two observation intervals and a period during which the participant made his response. The response was made by pressing a button on a keyboard. Knowledge of results was not given trial by trial.

In the 2AFC, *sn* was defined as the occurrence of the signal in the first observation interval and not in the second and *ns* was defined as the occurrence of the signal in the second observation interval and not in the first. The sensory effects of stimuli in the 2AFC task thus corresponded to certain pairs of observations that occurred during the two observation intervals. The percent of correct responses was the measure of sensitivity used.

3.3.2.2. Observation Intervals

The observation intervals, which coincided with the signal's duration, were marked as accurately as possible using the computer program. The time separating the two intervals in the two-alternative forced-choice task was 7 seconds.

3.3.2.3. Trial Duration

In both the visual and tactile experiments, the entire duration for a trial was the sum of the time taken for the first observation, the time taken by the test administrator to switch to the next sample, the time taken for the last observation, and the response. Visual and tactile observation intervals (duration of the observation) were 3 seconds. Therefore, the total trial duration was 13 seconds plus the time the participant took to make a decision.

After each trial, we asked participants to rate how confident they were in the answers they provided in the chamber and measured their subjective workload levels suing the NASA Task Load Index (TLX; see Appendix H; Users Manual Vol. 1, n.d.).

3.3.3. Participants

3.3.3.1. Instructions

The participants were given general instructions when they were introduced to the experiment. The participants were asked to wait until both of the observation intervals in a trial had been presented before making a decision. We encouraged the participant to maintain, as nearly as possible, a constant "set." We asked the participants to refrain from conducting their own experiments – for example, using a different method than the one instructed to detect the ice (e.g., scratching or adding excessive pressure to the sample). We told participants that the samples would be presented randomly and advised them of the gambler's fallacy (the tendency to move money from red to black when red has come up on the last several turns of the roulette wheel). We assured the participants that we have taken every precaution necessary to prevent them from deriving any information from the sequences of presentation.

The participants were encouraged to report to the TA anything they thought relevant. We informed the participants of all significant aspects of the experiment. Finally, we made sure that the participants were given as little latitude as possible for self-instruction.

3.3.4. Practice, Motivation, and Stability

3.3.4.1. Practice

Green and Swets (1988) report that practice effects are not of large concern. Therefore, once performance stabilizes, it should be about the same regardless of the number of trials. We ran the planned number of trials regardless of when we suspected performance became stable.

3.3.4.2. Motivation

Vroom (1964) writes that motivation may be defined as intra- and inter-individual variability in behavior not due solely to individual differences in behavior or overwhelming environmental demands that coerce or force action (as cited in Kanfer 1990). There are three key components of motivational outcomes: direction, intensity, and persistence in effort (Kanfer, 1990). We kept detailed notes throughout the experiment to make certain that our results were not confounded with changes in motivation. For example, for direction we noted whether participants showed up on time, returned from breaks on time, and showed a willingness to participate. Other behaviors indicating a desire or lack of desire to participate were also noted. For intensity, we looked for subjective differences in workload using the NASA Task Load Index (TLX; see Appendix H; Users Manual Vol. 1, n.d.). For persistence of performance, we examined the percentage of correct responses for blocks of trials that used the same thickness throughout the course of the experiment. Finally, to maintain motivation, we pointed out the contaminated panel at the end of each block of trials so that participants would be able to monitor their own performance.

3.3.4.3. Stability

Informal observations by Green and Swets (1988) have indicated that the various indices of sensitivity used with detection theory remain constant over relatively long periods of time.

4. Visual and Tactile Procedure Specifics

Thus far, we have outlined our method for getting participants' ice detection ability. There are two methods with which we were concerned and we will discuss the differences in this section. To begin, Table 1 shows a list of the variables for visual and tactile detection that we considered. We will first discuss the details of the visual detection experiment and then the tactile detection experiment.

Table 1. Variables Considered for Visual and Tactile Detection

Variable	Visual	Tactile	Note
Color	unpainted aluminum, painted white	n/a	none
Thickness	.2, .35, .50., .65, .80 mm	.50 & 1.0 mm	none
Area	315 cm^2 circle full panel	full panel	none
Curvature	none	none	Flat panels used
Substrate	aluminum panels	aluminum panels	none
Location	n/a, this applies to the wing	n/a, this applies to the wing	none
Gloves	constant	constant	Thick rubber gloves with liner for tactile
Exposure	constant	constant	up to 20 minutes
Roughness	constant	constant	smooth
Edge	feathered for patch, none for full panel	full panel	none
Waviness	constant	constant	none
Bias	constant	constant	Set at 50% by 2AFC method
Ambient temperature	constant	constant	-5° C (± 0.5°)
Viewing Angle	constant	n/a	45^o
Viewing Distance	constant	n/a	2 meters
Precipitation	none	none	none
Visibility	constant	n/a	ambient climate chamber setting
Fluid	constant	constant	Type I – cold application
Lighting	constant	n/a	diffused ambient climate chamber setting
Wind	constant	constant	1 meter/second
Fatigue	subjective questionnaire	subjective questionnaire	TA assessment and monitoring of NASA TLX
Motivation	TA Notation	TA Notation	note whether participants show on time, are willing to participate, etc; NASA TLX, consistency in performance
Experience	constant	constant	three levels were represented: less than 1 year, between 2 and 8 years & more than 10 years
Gender	male	male	none

4.1. Visual Observations

4.1.1. Sample

The participant viewed a sample of ice that was 0.2, .35, 0.5, .65 or 0.8 mm thick. The patch of ice on white panels had a feathered edge, but no edge was present on the unpainted aluminum panels because it covered the entire panel. Each sample had a static layer of Type I deicing fluid on it. Finally, the roughness of the ice patch reflected the smoothness of ice that remains once deicing has been completed in actual deicing conditions. See Appendix I for the measurements of luminance of the samples.

4.1.2. Visual Checking Method

The participant viewed the panel from a distance of 2m at a 45° angle. Figure 5 shows what a visual detection session looked like. The panels were set on a rotating platform. One of the panels had ice on it and the other did not. While the participant looked away, the TA prepared the appropriate panel for the participant according to trial specifications. The TA then called out "Sample" and showed the panel to the participant for three seconds. Afterward, the TA called out, "Away" and the participant looked to a point on the wall behind him. The TA then rotated the rotating platform within seven seconds, then called out "Sample" to show the other panel to the participant for three seconds as well. Finally, the TA called out, "Decide" and the participant indicated whether the first or the second panel had ice on it by pressing a 1 or 2 on a keyboard next to him.

Figure 5. Experiment session showing a participant (right) about to view a sample that the TA (left) has set up.

The TA spun the rotating platform between trials so that the participant would not have a frame of reference from subsequent trials.

4.2. Tactile Observation

4.2.1. Sample

The participant inspected a sample of ice that was either 0.5 or 1.0 mm thick. The ice covered the entire panel. Each sample had a static layer of diluted Type I deicing fluid on it. The roughness of the ice patch reflected the smoothness of ice that remains once deicing has been completed in actual deicing conditions. The participant was unable to view the sample while doing the tactile check. Thick, insulated rubber gloves with liners (representative of gloves typically used by deicing crews) were used for the tactile checks.

4.2.2. Tactile Checking Method

The participant was asked to check the sample using a single gentle swipe with fingertips only. No scratching of the ice sample was allowed. Figure 6 shows what a tactile detection session looked like. The panels were set on a rotating platform and were not visible to the participant. One of the panels had ice on it and the other did not. The TA told the participant that the panel was ready for checking by calling out, “Sample.” The participant then checked the first panel for ice. The TA then quickly rotated the platform and allowed the participant to check for the same amount of time after calling out, “Sample.” Finally, the participant indicated whether the first or the second panel had ice on it by pressing a 1 or 2 on the keyboard when the TA called out, “Decide.” The TA repeated this procedure 50 times for each block.

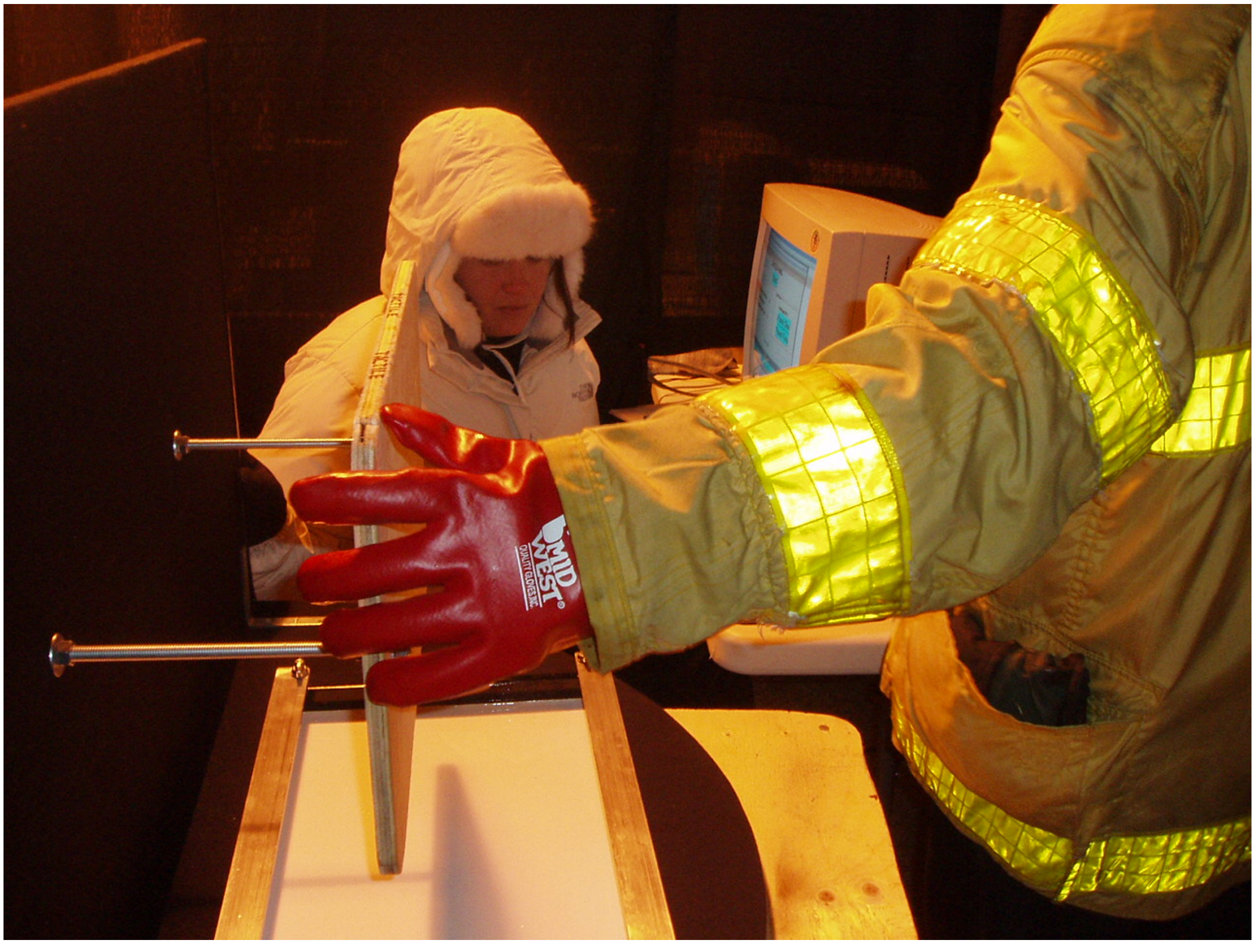

Figure 6. Tactile inspection session showing a participant finding the starting edge for the inspection using a wooden guide as the TA monitors him.

5. Constraints and Assumptions

The working group acknowledged that there could be a large number of variables that can change detection capability. However, the time constraints, budgetary constraints and the need to advance knowledge in this area required the group to limit the variables to those described here.

The group did not have available any data (e.g., eye tracker data) to indicate the amount of time that a participant should inspect an area the size of the ice panels. Therefore, we estimated the time they would be allowed to inspect the panels by determining the equality of the ratio of the amount of time scanning the area of an actual wing (Jet Star) and the ratio of the time required to scan the area of a panel.

6. Results

6.1. Visual Detection

6.1.1. Measure of Sensitivity

The percent of correct responses is the measure of sensitivity reported. Given the description of performance in Table 2 (adapted from Swets, 1996), the formula used for the percentage of correction detections will be $P(C) = 100[(a + d)/N]$.

Table 2. Formal Description of Discrimination Performance.

	Occurrence		
Choice	*A*	*B*	*Sum of row frequencies*
A	*A*	*B*	$a + b$
B	*C*	*D*	$c + d$
Sum of the column frequencies	$a + c$	$b + d$	$N = a + b + c + d$

The results for the white panels used in the visual ice detection experiment are shown in Figure 7 and Table 3. Participants were unable to visually detect 315 cm^2 ice patches that were between 0.2 mm and 0.8 mm thick when they were on a white panel.

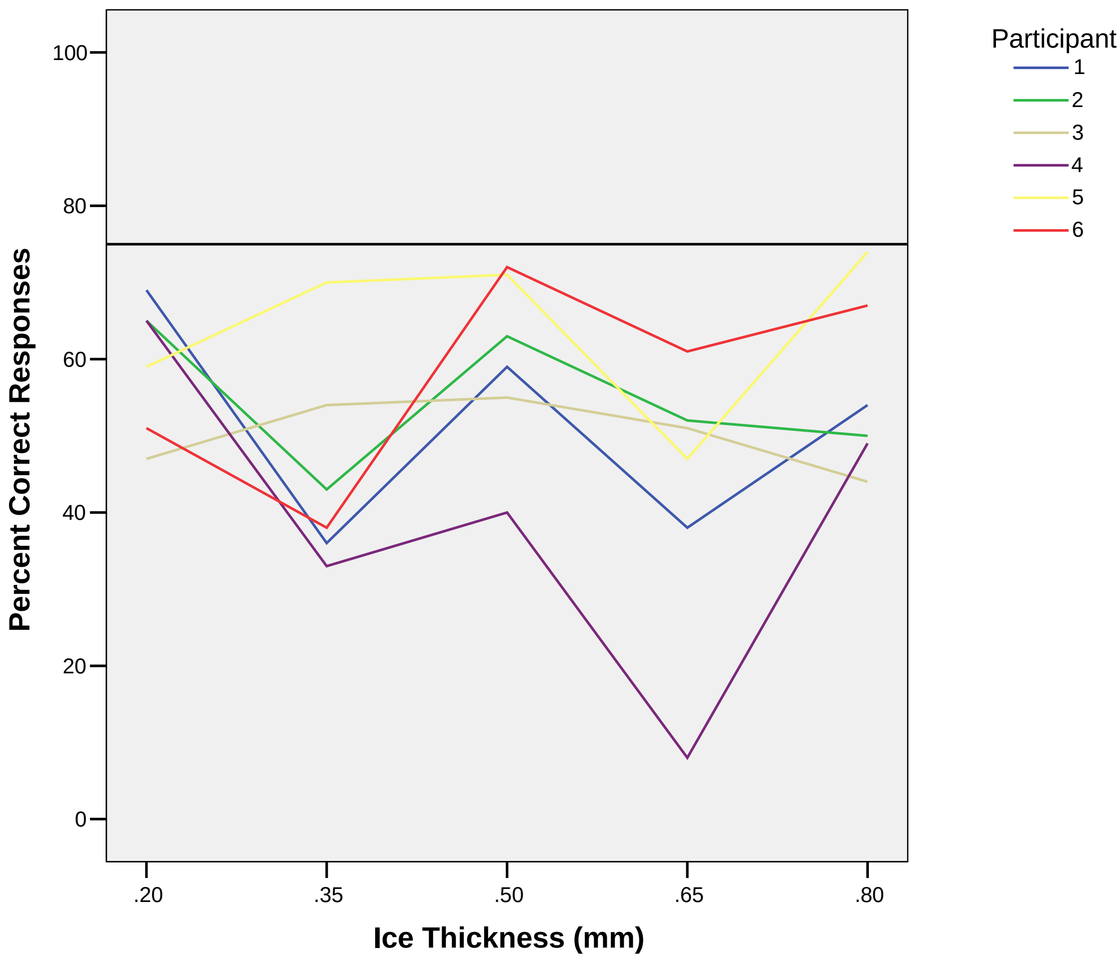

Figure 7. Participants' percent correct responses as a function of ice thickness on the white panels for visual inspections. Performance below 75% is considered to designate an inability to detect ice.

Table 3. White Panel: Percent of Correct Responses by Thickness for Visual Inspections

	Ice Thickness (mm)				
Participant	**0.20**	**0.35**	**0.50**	**0.65**	**0.80**
1	69%	36%	59%	38%	53%
2	65	43	64	52	55
3	47	54	55	51	44
4	65	33	40	08	50
5	60	70	71	47	74
6	51	38	72	61	67
Average	59	46	60	43	56

The results for the unpainted aluminum panels used in the visual ice detection experiment are shown in Table 3 and Table 4. Participants were unable to visually detect ice that was 0.5 and 1.0 mm thick that covered unpainted aluminum panels completely.

Table 4. Unpainted Aluminum Panel: Percent of Correct Responses by Thickness for Visual Inspections

	Ice Thickness (mm)	
Participant	**0.50**	**1.0**
1	12%	19%
2	39	19
3	72	36
4	25	11
5	44	50
6	47	29
Average	40	27

6.1.2. Response Bias

It was possible that a participant would develop a preference for giving a *YES* response for one of the observation intervals. If such a preference developed, $P(C)$ would be depressed. That is, the percentage of correct responses would be lower if a bias were present than if no interval bias were present. We evaluated whether a bias was present. Examination of the stimulus response matrix indicated that the data did not need to be corrected for bias.

6.1.3. Motivation

6.1.3.1. Direction

We kept detailed notes throughout the experiment to make certain that our results were not confounded with changes in motivation. For direction we noted that, with the exception of the first day, participants showed up on time. We also noted that participants returned from breaks on time, showed a willingness to participate, and ushered themselves to the testing room and interview session. Participants were also eager to give suggestions and make comments. We noted that they became frustrated because their job is to detect ice and they were unable to do so. However, with encouragement from their supervisor, they remained very professional and self-directed.

6.1.3.2. Intensity

For intensity, we looked for subjective differences in workload using the NASA TLX. Total workload was calculated using the sum of the product of each subjective rating for each dimension of workload (e.g., effort, performance, frustration, etc.) and the weights assigned to each dimension by the participant. Figure 8 shows the total workload for each participant as a function of trial and ice thickness. The figure suggests that participants felt that they expended about the same workload from the first to the last trial for each thickness.

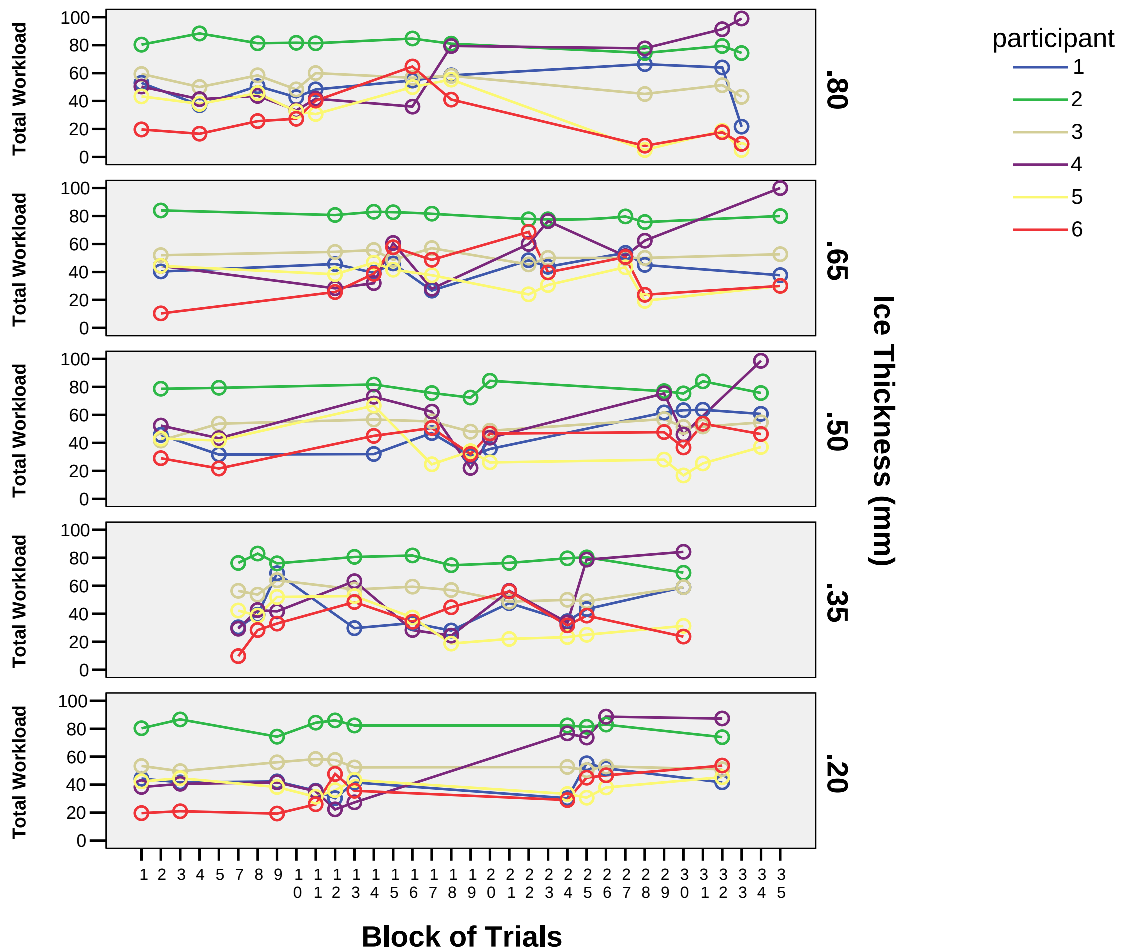

Figure 8. Total workload for visual inspections for each participant as a function of block of trials and ice thickness. The circle on the line in the figure indicates in which block of trials data for an ice thickness was collected.

6.1.3.3. Persistence

For persistence of performance, we examined the number of correct responses for blocks of trials that used the same thickness throughout the course of the experiment. Figure 9 shows each participant's total number of correct responses for each block of ten trials by ice thickness. The figure shows that responses were random throughout the trials. For this data to be interpreted as an indication of persistence, participants need to be able to detect the ice. We could then observe trends in the persistence of their detection behavior through the number of correct detections for each block of trials.

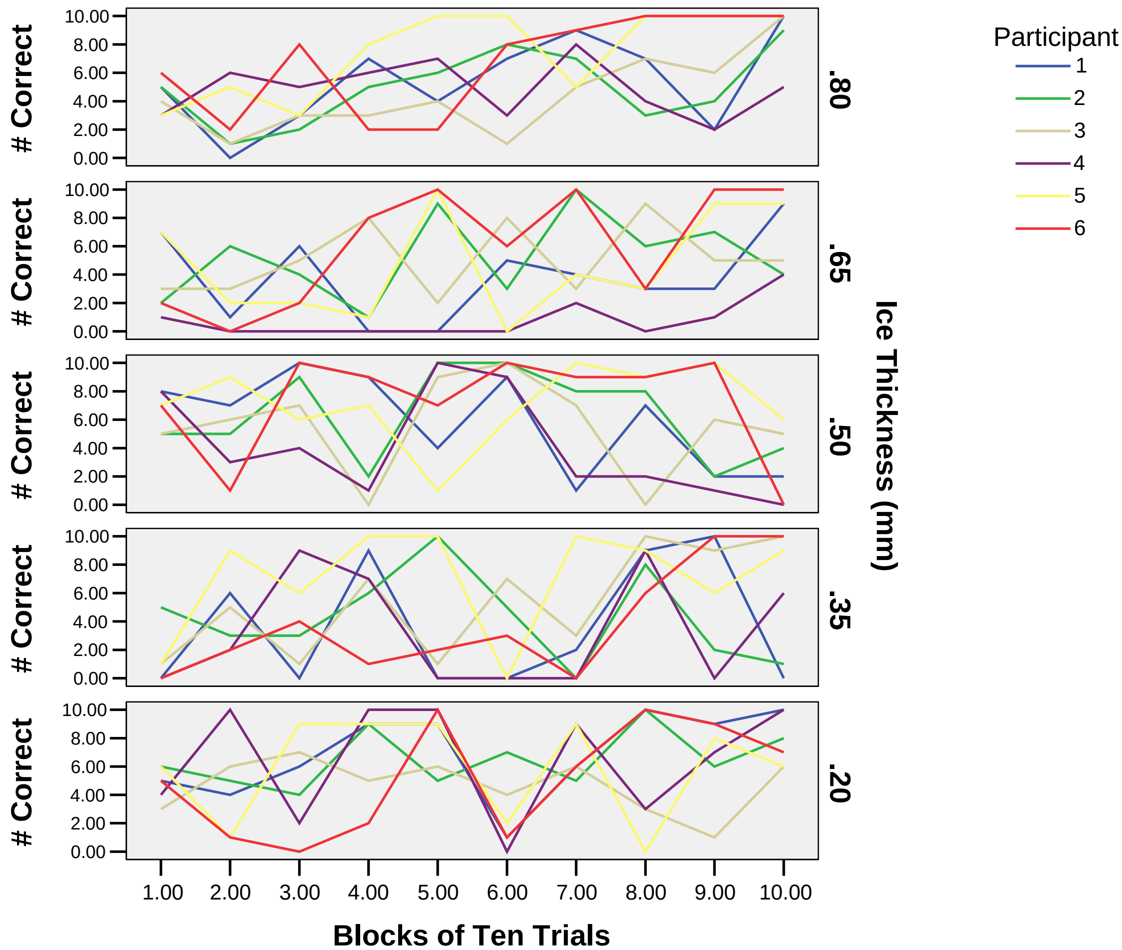

Figure 9. Participants' total number of correct responses for each block of ten trials by ice thickness for visual inspections.

6.1.4. <u>Confidence Ratings</u>

After each block of trials, we asked participants, "On a scale of 1-7 (1 = "Not Certain at All;" 7 = "Absolutely Certain;" and 4 = "Moderately Certain") how confident were you in your answers?" The median for all white panel responses, except for thickness 0.35mm, was a rating of 3. For thickness 0.35mm, the median was a rating of 4. A rating of 4 indicated that participants were moderately certain of their answers. The median for thicknesses of 0.5 and 1.0 mm on the unpainted aluminum panels were 4.5 and 5 respectively. Participants reported that they could typically see ice on the aluminum parts of the wing. This might have been the reason for the increase in confidence because there was no increase in performance to explain it.

6.1.5. <u>Participant Comments</u>

We asked the participants if they had any comments after each block of trials. Several participants reported that visual detection of ice in the real world is more difficult on white surfaces. They reported that they could usually see ice on aluminum surfaces. These assertions from the participants are consistent with the indications provided by members of the GIDS RAWG during preparatory meeting. Several participants reported that the inability to view the samples from different angles and lighting imposed by the experiment design made it more difficult to detect the ice visually.

6.2. <u>Tactile Detection</u>

6.2.1. <u>Measure of Sensitivity</u>

The percentage of correct detections was calculated using the same formula described in Section 6.1.1. The results for the unpainted aluminum panels used in the tactile ice detection experiment are shown in Figure 10 and Table 5. Participants were able to tactilely detect ice .5 and 1.0 mm thick that had no edge.

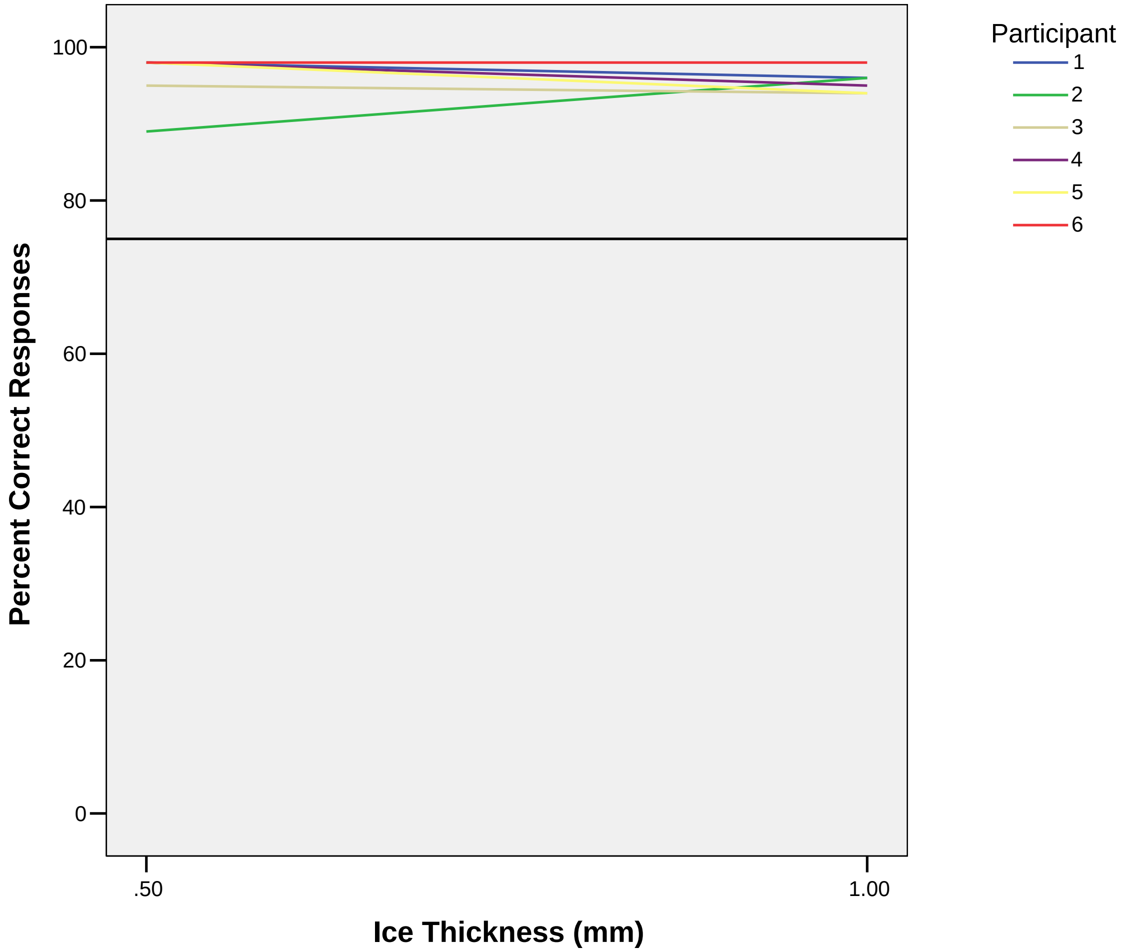

Figure 10. Participants' percent correct responses as a function of ice thickness on the unpainted aluminum panels for tactile inspections. Performance below 75% is considered to designate an inability to detect ice.

Table 5. Unpainted aluminum Panel: Percent of Correct Responses by Thickness for Tactile Inspections

	Ice Thickness (mm)	
Participant	**0.50**	**1.0**
1	100%	98%
2	100	98
3	97	96
4	100	97
5	100	96
6	100	100
Average	99	97

6.2.2. Response Bias

Examination of the stimulus response matrix indicated that the data did not need to be corrected for bias.

6.2.3. Motivation

6.2.3.1. Direction

Even though the tactile detection portion of the experiment was conducted on the fifth and last day, we noted that participants continued to return from breaks on time, continued to show a willingness to participate, and ushered themselves to the testing room and interview session.

6.2.3.2. Intensity

For intensity, we looked for subjective differences in workload using the NASA Task Load Index (TLX; see Appendix H; Users Manual Vol. 1, n.d.). Total workload was calculated using the sum of the product of each subjective rating for each dimension of workload (e.g., effort, performance, frustration, etc.) and the weights assigned to each dimension by the participant. Table 6 shows the total workload for each participant. It shows the block of trials when the data was collected for each ice thickness. The table shows that participant's subjective workload ratings were all below 50, the midpoint of the scale. A count of the direction of changes in workload ratings shows an equal number increasing and decreasing for the 0.5 mm thickness of ice. For 1.0 mm thick ice, four participants' rating increased from an average rating of 27 to an average rating of 37.

Table 6. Total Workload Reported by Participants for each Thickness For the Two Blocks Used to Collect the Data for Tactile Inspections

Participant	Thickness (mm)	Block	Total Workload
1	0.5	38	30
		40	21
	1.0	37	35
		39	24
2	0.5	37	52
		38	57
	1.0	39	45
		40	55
3	0.5	38	37
		39	35
	1.0	37	36
		40	46
4	0.5	37	13
		40	20
	1.0	38	23
		39	21
5	0.5	38	29
		39	35
	1.0	37	23
		40	39
6	0.5	38	10
		40	5
	1.0	37	5
		39	9

6.2.3.3. Persistence

For persistence of performance, we examined the number of correct responses for blocks of trials that used the same thickness throughout course of the experiment. Figure 11 shows each participant's total number of correct responses for each block of 50 trials by ice thickness. The figure shows that responses were consistently accurate throughout the trials. The only differences that show are for those participants who did not see 50 trials because of experimenter error. This can be seen in the 0.5 mm thickness graph where P2 experienced 40 trials instead of 50.

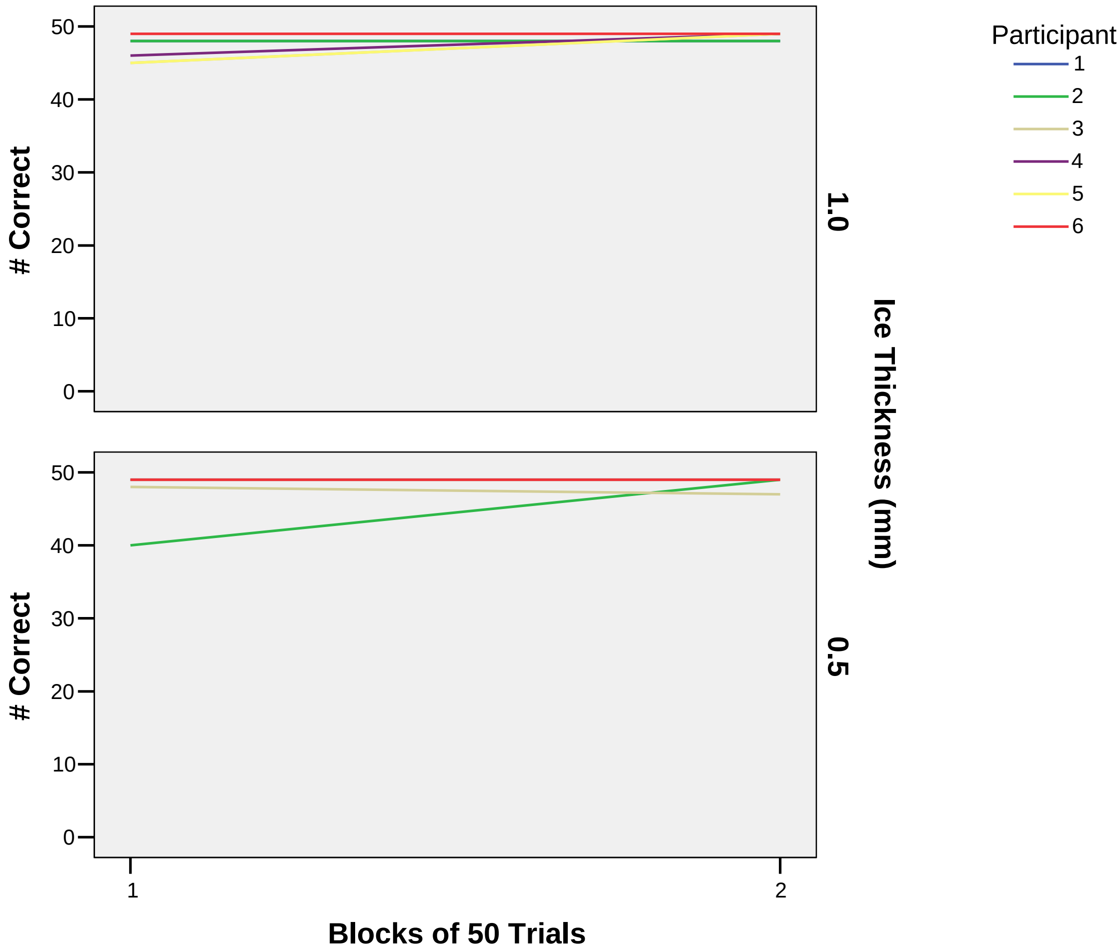

Figure 11. Participants' total number of correct responses for each block of 50 trials by ice thickness for tactile inspections.

6.2.4. Confidence Ratings

After each block of trials, we asked participants, "On a scale of 1-7 (1 = "Not Certain at All;" 7 = "Absolutely Certain;" and 4 = "Moderately Certain") how confident were you in your answers?" The median for response for both thicknesses was 6.

6.2.5. Participant Comments

We asked the participants if they had any comments after each block of trials. Participants reported that they did not necessarily employ their dominant hand during the experiment. Several participants commented that it was fairly easy to detect the ice during the tactile trials.

7. Discussion

In order to document human visual and tactile ice detection capabilities, we collected data for very thin ice patches on surfaces of reportedly varied visibility under relatively good environmental conditions in a way that we could, with practicality, generalize the results to a realistic environment.

Using these variables as a starting point, we conducted preparatory tests. We acquired a wealth of knowledge from the preparatory tests that preceded this experiment. The method and results of the present experiment were dependent on the knowledge acquired during the preparatory tests; therefore, we will discuss the findings of this experiment referencing the results of the preparatory tests. To summarize, human visual ice detection capabilities during the present experiment were inferior to the expectations we had formed based on participant performance observed during the preparatory tests. Tactile detection was nearly without error for the thicknesses we included in the experiment. We will discuss visual and tactile detection in detail below.

7.1. Visual Detection

The results suggest that poorest detection can be expected when the edge of the ice is not visible to the participant. In Study 2 of the preparatory tests, we found through objective data and comments made by participants that the presence of ice of any thickness was undetectable when it fully covered the panel. We verified this again in the experiment: participants were unable to detect ice 0.5 mm or even 1.0 mm thick when it covered the entire surface. This suggests that there is not enough evidence on the surface of the ice for the participant to differentiate it from an uncontaminated panel. This result holds for both unpainted aluminum panels and white panels.

The results also suggest that although human ice detection capability improves when an edge is present, it may be moderated by the color of the surface it is contaminating. In Study 1 of the preparatory tests, we found that ice patches on an unpainted aluminum panel could easily be visually detected, even at a thickness of 0.2 mm. However, we found that detection of ice patches on white panels was variable and that participants seemed to start to detect ice reliably at 0.8 mm. We used that information to plan the range in our experiment. From Study 1 of the preparatory tests, we expected participants to be able to detect ice patches on a white panel that were between 0.2 and 0.8 mm thick. However, the data from the experiment showed that they were unable to detect even the thickest of the ice patches.

The inability of the deicers participating in the experiment to detect even the thickest patches of ice on the white panel suggests that ice detection skill is a significant factor. The major difference between the preparatory tests and the experiment was that lead deicers participated during the preparatory tests. It is possible that the lead deicers used additional cues not used by the deicers participating in the experiment. An alternative explanation could be that, the amount of data collected and the controls in place during the experiment may have eliminated many of the chance factors that could have contributed to the lead deicers superior performance.

7.2. Tactile Detection

With regards to tactile detection, we expected to find during preparatory tests that human ice detection performance would be poor with very thin ice (less than 0.5 mm). To our surprise, participants were able to detect the thinnest ice (0.2 mm), with or without an edge, and with or without gloves. We accumulated data in this experiment to support the preparatory test findings. To summarize, human tactile ice detection capabilities were superior to the expectations we had from deicer estimates. The data showed that participants could detect ice as thin as 0.2 mm with gloves on in preparatory tests and as thin as 0.5 mm in the experiment.

8. Conclusion

The data collected during this experiment has helped to partially quantify human visual and tactile performance while attempting to detect ice in simulated post-deicing conditions. The test conditions for this experiment were purposely limited to concentrate on human detection in relative isolation. This precluded allowing the test participants from using some of the techniques they normally would during a post-deicing wing inspection.

The results of this study will be used to help establish the test parameters for a follow-on study that will compare human performance against the GIDS technologies that are currently available. The test conditions for that study will use an aircraft wing to simulate, as closely as possible in a test chamber, real post-deicing conditions.

The results of this study may also prove useful during other discussions related to deicing inspections. The results of the tactile inspection tests have proven to be especially illuminating, and will undermine some currently held assumptions about performing tactile wing-ice inspections while using gloves.

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APPENDIX A

PREPATORY TEST DOCUMENTATION

BACKGROUND

Preliminary tests were conducted in March 2005 in order to determine thickness to be used for the experiment described in this document and to gather information about our procedures. We used PMG Technology's cold chamber in Blainville, Quebec, Canada to create an environment whose temperature was -5° C with 80% humidity.

Ice samples were created by APS Aviation on either white painted or unpainted aluminum panels (30mm x 50mm), as either a 315 cm^2 circular patch or fully covering the panel, with thicknesses ranging from .2 mm to 1.2 mm. All of the test samples were covered with aircraft deicing fluid.

We used the same forced-choice procedure used for the experiment in the pretest. We presented two panels in sequence to a participant, and ask him to indicate on which of the two panels ice is present. A total of four studies were conducted. Study 1 tested visual detection of a 315 cm^2 circular patch and study 2 tested visual detection of full ice contamination. Studies 1 and 2 were both conducted with both white painted and unpainted aluminum panels. Study 3 tested the tactile detection of 315 cm^2 ice patch detection and Study 4 tested the tactile detection of full ice contamination.

STUDY 1: VISUAL DETECTION OF 315 CM^2 ICE PATCH CONTAMINATION

Participants

Two male professional deicers from AeroMag 2000 in Montreal, Quebec, Canada participated in this study. They were 27 and 31 years old and had six and nine years of deicer experience, respectively. Both had 20/20 vision or corrected to 20/20 vision and reported that they had never experienced a cold related injury (e.g., frost bite). Since these two deicers participated in all studies reported below, the Participants section will not be repeated. We conducted all studies with our participants' safety as our first priority.

Materials

Circular ice samples were created by APS Aviation on flat 30 mm x 50 mm (3.175 mm thick) white or unpainted aluminum panels. Ice thicknesses used were 0.2 mm, 0.5 mm, and 0.8 mm. The area on the panel covered by the ice patches was 315 cm^2 and the edges were feathered. Twenty-two ml of Type I deicing fluid diluted with water to a Brix 11 was added to the panels.

Procedures

The participants viewed either a white or unpainted aluminum the panel from a distance of 2 m at a 45° angle. A *Lazy Susan*, split in two with a screen, was used to show in sequence two panels to the participant, according to a randomized schedule. For each pair of observation, one of the panels had ice on it and the other did not. In each trial, the Test Administrator (TA) positioned the *Lazy Susan* and called out "Sample" while showing the first panel to the

participant. After 4 seconds, the TA called out, “Away” and the participant looked to a point on the wall in the opposite direction to the panel. During the following 8 seconds, the TA then rotated the Lazy Susan to position the second panel. When the TA called out “Sample”, the participant could inspect the second panel for 4 seconds. At the end of these observation periods, the TA called out, “Decide” and the participant indicated which panel had ice on it by pressing a 1 or 2 on a keyboard next to him.
We ran 50 trials (100 observations) for each thickness. Because of time constraints, each participant observed only one randomly assigned thickness. The dependent measure was the percent of correct detections.
After each block of trials, participants were interviewed in order to gather any relevant information on their decision-making processes and on the study procedures.

<u>Results</u>

We were able to gather valuable information about our procedures. We learned that during the first 10 to 15 visual trials, an honest effort was made by participants to determine which panel had ice on it. After the participants had made up their mind about which panel they thought had ice on it, they picked some other physical property to identify the panel (a scratch or a piece of lint on the Lazy Susan) and selected that panel throughout the rest of the block of trials. As a result, data analysis for the pretest was performed for both all 50 trial blocks and the first 10 trials for each block.

White panels. Participants detected 0.2 mm, 0.5 mm, and 0.8 mm of ice at a rate of 14%, 92%, and 100% respectively. At a level of 76%, participants are no longer considered to be guessing (Green & Swets, 1988). Figure A.1. shows a plot of the detection data. Each point represents data for one participant collected over 50 trials.

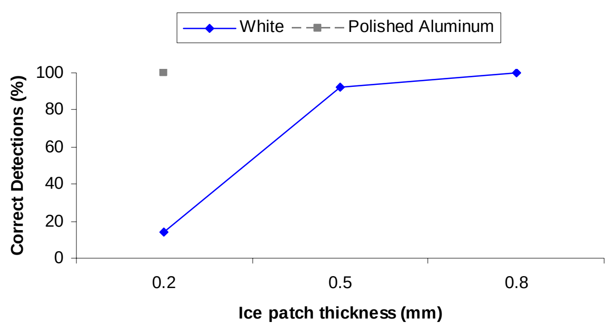


Figure A.1. Correct detection (plotted as a percent) as a function of ice thickness and panel color.

We plotted the data for the first 10 trials for Study 1. Figure A.2. shows detection at 30%, 60%, and 100% for each thickness studied.

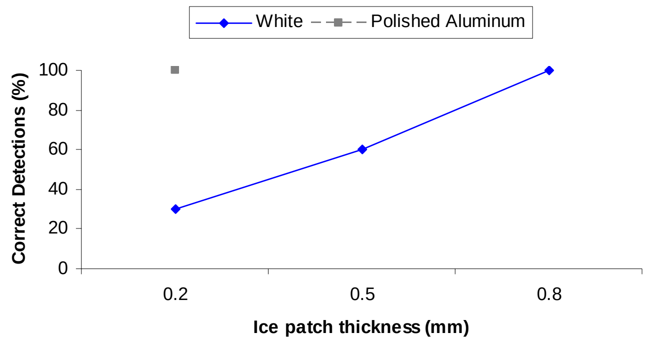


Figure A.2. Correct detection (plotted as a percent) as a function of ice thickness and panel color for the first ten trials.

Unpainted Aluminum Panels. Participants detected 0.2 mm ice patches on unpainted aluminum panels with 100% accuracy. Further tests with thicker ice would not yield additional useful data and we did not test other ice thicknesses on the aluminum panels.

<u>Implications</u>

We learned that during the first 10 to 15 visual trials, an honest effort was made by participants to determine which panel had ice on it. After the participants had made up their mind about which panel they thought had ice on it, they picked some other physical property to identify the panel (a scratch or a piece of lint on the Lazy Susan) and selected that panel throughout the rest of the block of trials. As a result, the importance of having seemingly identical panels became evident.

We were able to obtain data on a useful range of ice thicknesses for inspection of white panels. With the three thicknesses we selected to study, we found a potentially undetectable thickness, 0.2 mm, and a thickness that may always be detectable, 0.8 mm.

Participants easily detected 0.2 mm ice patches on the unpainted aluminum panels. As 0.5 mm and 0.8 mm contaminations were easily detectable as well, we suspect that the edge of the patch made it easily detectable.

We tested our assumption that the edge made the ice easily detectable in Study 2 (Visual Detection). For this purpose, we asked APS to prepare panels that were fully contaminated with ice to eliminate the edge. We included both color panels in Study 2.

STUDY 2 – VISUAL DETECTION OF FULL ICE CONTAMINATION

Materials

Ice samples were created by APS Aviation. The ice samples were created on flat 30 mm x 50 mm (3.175 mm thick) white or unpainted aluminum panels. Ice thicknesses used on the white panels were 0.2 mm and 1.2 mm. Thicknesses of 0.2 mm and 0.8 mm were used on the unpainted aluminum panels. The upper limits of these thicknesses were based on the results of the first study and estimates of what the detectable thicknesses might be for each color. The panel was completely covered by the ice. Twenty-two ml of Type I deicing fluid diluted to a Brix of 11 was used to cover the panels. The fluid was held in by black barriers.

Procedures

The same procedures used in Study 1 were used to collect data for Study 2. Please refer to the procedures described in Study 1.

Results

White Panels. For the white panels, participants detected 0.2 mm and 1.2 mm of ice with 30% and 70% accuracy, respectively. Performance for the first ten trials was 70% for 0.2 mm and 60% for 1.2 mm.

Unpainted Aluminum Panels. For the unpainted aluminum panels, one participant detected 0.2 mm of ice with 90% accuracy. With regard to the 0.8 mm of ice, the other participant admitted that he could not tell which panel had ice on it. Therefore, he picked a panel by guessing and then was consistent in his choice by looking for something that was different between the two panels other than the ice (e.g., a scratch or lint on the Lazy Susan). This reaffirmed the need for identical panels. We ended the session without making all 100 observations (50 trials). The accuracy of ice detection for the first ten trials was 50% for 0.2 mm and 50% for 0.8 mm.

Implications

In Study 2, we found through objective data collection and comments made by the participants that full contamination of ice of any thickness on the test panel was undetectable. The participant who reached 90% accuracy explained that, after a few trials, he picked a panel and then chose it consistently using other physical properties than ice contamination. Accuracy for the first ten trials supports their comments.

Through Studies 1 and 2 we found some practical boundaries for the experiment. We saw that participants were able to detect ice patches on unpainted aluminum panels without fail. We also saw some variability in their detection of ice patches on white panels, where some thicknesses were detectable and others were not. Finally, we found that when an edge was absent that participants were unable to detect ice of even the upper thicknesses that we tested.

Studies 1 and 2 have provided us with some useful upper and lower limits for the Visual Detection Experiment.

STUDY 3: TACTILE DETECTION OF 315 CM^2 ICE PATCH CONTAMINATION

Materials

Ice samples were created by APS Aviation. The ice samples were created on flat 30 mm x 50 mm (3.175 mm thick) white panel. The ice thickness used on the white panel was 0.2 mm. The circular area on the panel covered by the ice patches was 315 cm^2. The edges of the patch were feathered using deicing fluid. Twenty-two ml of Type I deicing fluid diluted to a Brix of 11 was used to cover the panels. The fluid was held in by black barriers.

Procedures

Bare hand. The participants swiped the panel while standing using the fingers of a bare hand.

A *Lazy Susan,* split in two with a screen, was used to present in sequence two panels to the participant, according to a randomized schedule. For each pair of observation, one of the panels had ice on it and the other did not. The participant wore a welding mask that completely obstructed his vision. In each trial, the TA positioned the *Lazy Susan* and called out "Sample". The participant moved his hand forward until it brushed a wooden board suspended above the sample, and slid his hand down to touch the ice patch. The participant swiped the ice a single time using a light touch. At this point, the TA called out, "Away" and the participant withdrew his hand. The TA then rotated the *Lazy Susan* to expose the other sample (7 sec turn). When the TA called out "Sample" the participant inspected the second panel. The TA then called out, "Decide" and the checker indicated which panel had ice on it by showing either 1 or 2 fingers to the TA.

We ran 25 trials (50 observations) of each thickness with each participant. Because of time constraints, each participant observed only one randomly assigned thickness. Each participant performed 5 inspections at a time in order to reduce the risk of frostbite. The dependent measure was the percent of correct detections.

Gloved Hand. The procedure was the same, however, participants wore Nitrile gloves.

After each block of trials, participants were debriefed in order to gather any relevant information on their decision-making processes and on the study procedures.

Results

Participants detected the 0.2 mm ice patch with 100% accuracy with both bare hands and while wearing gloves.

Discussion

We found the ease and accuracy with which participants detected the ice with bare hands and gloves surprising. As in the visual detection study, we suspected that the presence of an edge maximized their ability to detect the ice. We examined this notion in Study 4.

STUDY 4: TACTILE DETECTION OF FULL ICE CONTAMINATION

Materials

Ice samples were created by APS Aviation on flat 30 mm x 50 mm (3.175 mm thick) white panels. The ice thicknesses used on the white panels were 0.2 mm and 1.2 mm. The entire panel was covered by the ice. Twenty-two ml of Type I deicing fluid diluted to a Brix of 11 was used to cover the panels. The fluid was held in by black barriers.

Procedure

The same procedures described in Study 3 were used. We studied the 0.2 mm ice contamination using bare hand tactile inspections and 1.2 mm using both bare hand and gloved inspections. The entire panel was covered by the ice.

Results

Participants detected the 0.2 mm of ice on the fully contaminated panel with 100% accuracy using bare hands. They also detected the 1.2 mm of ice on a fully contaminated panel with 100% accuracy with both bare hands and while wearing gloves.

Implications

We found the ease and accuracy with which participants detected the ice with bare hands and especially with gloves astonishing. The research team unsystematically checked the 0.2 mm of ice with different types of gloves (e.g., silk liners, fleece, skiing) and found that ice was easily detectable.

GENERAL DISCUSSION

We gathered data from the studies to help us narrow the types of samples for the visual and tactile ice detection experiments to be conducted in April 2005. In Study 1, we found that ice patches on an unpainted aluminum panel could easily be visually detected, even at a thickness of 0.2 mm. We also found some variability in the detection of ice patches on white panels that we could use in our experiment. In Study 2, we found through objective data and comments made by participants that the presence of ice of any thickness was undetectable when it fully covered the panel. In Studies 3 and 4, we found that participants could easily detect the presence of ice through tactile inspection

In our subsequent experiment, we investigated visual ice detection capabilities of a 315 cm^2 circular ice patch on a white panel while varying the thicknesses of the ice (namely, 0.2, 0.35, 0.5, 0.65, 0.8 mm). We also included fully contaminated unpainted aluminum panels with thicknesses .5 mm and 1.0 mm to replicate the findings of the preliminary studies that have been reported here. Finally, we replicated the tactile study findings by conducting gloved tactile inspections of panels fully contaminated with 0.5 and 1.0 mm of ice. With this experimental data, designers and regulators will have the information they need to improve ice detection systems.

We were able to gather valuable information about our procedures. We learned that during the first 10 to 15 visual trials, an honest effort was made by participants to determine which panel had ice on it. After the participants had made up their mind about which panel they thought had ice on it, they picked some other physical property to identify the panel (a scratch or a piece of lint on the Lazy Susan) and selected that panel throughout the rest of the block of trials. As a result, the need for identical panels, free of identifying cues was recognized.

APPENDIX B

DEMOGRAPHIC QUESTIONNAIRE

Expérience de détection

Données personnelles

Veuillez répondre au questionnaire et le remettre à l'administrateur de tests.

Date du jour *MM/JJ/AAAA*
Code de participant
Profession

1 Date de naissance (*MM/JJ/AAAA*) — **1** / /

2 Sexe (cochez une case) — **2** ☐ Homme ☐ Femme

3 Depuis combien de temps travaillez-vous au dégivrage des avions? — **3** ans mois

4 Avez-vous une vision normale ou corrigée de 20/20? — **4** ☐ Oui ☐ Non

5 Veuillez cocher toutes les réponses qui vous concernent. — **5**
- ☐ Lunettes
- ☐ Verres de contact
- ☐ Chirurgie correctrice

6 Veuillez indiquer si vous portez l'une ou l'autre de ces corrections. — **6**
- ☐ Lunettes
- ☐ Verres de contact

7 Avez-vous déjà été traité pour l'une ou l'autre de ces blessures/maladies? — **7**
- ☐ Gelure[4]
- ☐ Hypothermie[5]
- ☐ Autre

8 Si vous avez coché une case à la question 7, veuillez indiquer quand vous avez été traité. — **8**
- / /
- / /

---

[4] La gelure est la congélation de tissu organique (habituellement la peau) entraînant la perte de sensation et la décoloration du tissu (Brooks, 2001).

[5] L'hypothermie est une baisse générale de la température centrale du corps, qui survient lorsque la chaleur produite par la contraction des muscles, le métabolisme et le frissonnement n'arrive pas à compenser la chaleur perdue par l'organisme (Hess, 2004).

9 Le cas échéant, êtes-vous complètement guéri de toute blessure/maladie?

9 ☐ Oui ☐ Non

10 Veuillez indiquer si vous présentez l’un ou l’autre des problèmes de santé suivants, ou tout autre problème susceptible de vous prédisposer à des maladies reliées au froid.

10
☐ Diabète
☐ Hypertension
☐ Maladie cardiovasculaire
☐ Autre

Merci.
Veuillez remettre ce questionnaire à l’administrateur de tests.

Detection Experiment

Background Questionnaire

Please fill out this questionnaire and return it to the test administrator.

Today's date *MM/DD/YYYY*
Participant code
Occupation

1	Date of birth (*MM/DD/YYYY*)	**1** / /
2	Gender (check one)	**2** ☐ Male ☐ Female
3	How long have you worked deicing aircraft?	**3** years months
4	Do you have normal or corrected to normal vision (20/20)?	**4** ☐ Yes ☐ No
5	Please check all that apply to you.	**5** ☐ Eyeglasses ☐ Contact lenses ☐ Corrective surgery
6	Please indicate whether you are wearing any of the following.	**6** ☐ Eyeglasses ☐ Contact lenses
7	Have you ever received medical attention for any of the following injuries/illnesses?	**7** ☐ Frost Bite[6] ☐ Hypothermia[7] ☐ Other
8	If you checked a box in Question 7, please indicate when you received medical attention.	**8** / / / /

[6] "Frostbite refers to the freezing of body tissue (usually skin), that results in loss of feeling and color in the tissue" (Brooks, 2001).

[7] "Hypothermia is a condition of body chilling that occurs when the body looses heat faster than heat can be produced by muscle contractions, metabolism, and shivering" (Hess, 2004).

9 Did you fully recover from all of the injuries/illnesses?

9	☐ Yes ☐ No

10 Please indicate whether you have any of the following health conditions or any other health condition that may predispose you to cold related illnesses.

10	☐ Diabetes ☐ Hypertension ☐ Cardiovascular Disease ☐ Other

Thank You.
Please return this questionnaire to the Test Administrator.

APPENDIX C

CONSENT FORMS

Formule de consentement du participant

Au participant : Veuillez lire attentivement la formule de consentement du participant ci-après, ainsi que le protocole et/ou les instructions à l'intention des participants qui l'accompagnent. Il est important que vous obteniez des réponses satisfaisantes à toutes les questions que vous pourriez vous poser avant de signer la formule de consentement.

Je consens à participer à l'expérience *Détection de glace par inspection visuelle et tactile, après le dégivrage de l'avion* (ci-après appelée *Expérience de détection*). Je comprends que l'Office of Aviation Research de la Federal Aviation Administration (FAA) parraine cette expérience. La Flight Safety Branch de la FAA est le chef de projet, et le Simulation and Analysis Group de la FAA et la Direction de l'aviation civile de Transports Canada dirigent l'expérience.

Nature et but de l'expérience :
Le but de l'Expérience de détection est de déterminer la capacité humaine de détecter de la glace, visuellement et au toucher. Les vérificateurs inspecteront deux plaques d'aluminium offrant l'apparence d'une partie d'aile après le dégivrage, mais avant l'application de liquide antigivre. Il y aura de la glace sur une des plaques, et pas sur l'autre. Les deux types d'inspection (visuelle et tactile) n'auront pas lieu en même temps. Après l'inspection, le vérificateur indiquera sur quelle plaque il y a de la glace. Le but de cette expérience est de déterminer à partir de quelle épaisseur minimale il devient impossible de détecter le glace, visuellement ou au toucher.

Procédures :
Huit vérificateurs, employés d'AeroMag, participeront à l'expérience, qui se déroulera sur une période de deux semaines. Quatre des vérificateurs feront des inspections visuelles et les quatre autres, des inspections tactiles. Les vérificateurs se tiendront dans la chambre froide, en face de l'administrateur de tests. Celui-ci présentera au vérificateur une première plaque recouverte de liquide de dégivrage, puis une deuxième plaque, elle aussi recouverte de liquide de dégivrage, et il lui demandera sur laquelle des deux plaques se trouve de la glace. L'administrateur de tests notera la réponse du vérificateur.

Risques et inconforts :
L'expérience ne devrait pas engendrer de risques et d'inconforts plus grands que ceux auxquels est normalement exposé un vérificateur dans son milieu de travail. La chambre froide sera maintenue à une température d'environ -5° C, avec un vent léger. Il y a peu de risques que la peau exposée gèle et de contracter des maladies dues au froid si les précautions appropriées sont prises.

Il est de ma responsabilité d'informer l'administrateur de tests de tout problème de santé qui pourrait me prédisposer à des maladies dues au froid. Les affections prédisposantes comprennent, sans s'y limiter, les maladies cardiovasculaires, le diabète et l'hypertension. Le fait d'avoir déjà souffert de blessures ou de maladies dues au froid est aussi un facteur prédisposant et j'en informerai l'administrateur de tests si tel est mon cas.

Il est de ma responsabilité de porter une tenue appropriée, y compris un chapeau et des gants, comme l'exige mon employeur dans ces conditions. Si je ne suis pas certain des vêtements qu'il faut porter, je peux demander conseil à l'administrateur de tests.

Si je ressens quelque inconfort que ce soit ou si j'ai besoin d'une pause, j'en avertirai l'administrateur de tests. On m'accordera fréquemment, pendant l'expérience, de courtes pauses dans des locaux chauds et secs, qui me permettront de me réchauffer, mais je n'hésiterai pas à demander une pause en tout temps si j'en sens le besoin.

Avantages :
Je reconnais que l'avantage que je retirerai de l'expérience sera celui de pouvoir participer à une recherche qui porte sur la capacité de l'être humain à détecter de la glace, et ses limites.

Responsabilités du participant :
Pendant l'expérience, il sera de ma responsabilité d'inspecter les plaques pour y vérifier la présence de glace et de considérer cette inspection comme si elle était faite sur un avion réel. Je répondrai au meilleur de mes capacités à toutes les questions qui me seront posées pendant l'expérience. Je ne discuterai pas du contenu de l'expérience avec qui que ce soit jusqu'à ce qu'elle soit officiellement terminée. Je remplirai un questionnaire de données personnelles, un questionnaire post-séance à la fin de chaque séance d'inspection, et un questionnaire post-expérience à la fin de toutes les séances. Je participerai à des débreffages à la fin de chaque séance ainsi qu'à la fin de l'expérience.

Assurances données au participant :
Je comprends que ma participation à l'expérience est entièrement volontaire. L'administrateur de tests répondra à ma satisfaction à toutes les questions que je pourrai avoir sur l'expérience, sur ma participation et sur les procédures. Je comprends que tout fait nouveau susceptible d'influer sur ma décision de continuer de participer à cette recherche me sera divulgué.

En signant cette formule, je ne renonce à aucun de mes droits et ne dégage nulle personne ni institution de sa responsabilité pour négligence.

Je comprends que les renseignements recueillis au cours de cette expérience seront traités de façon strictement confidentielle, et que je ne pourrai être identifié, ni par mon nom, ni par aucune description, dans aucun des rapports ou publications sur cette expérience. Tous les enregistrements vidéo ou audio sont réservés à l'usage exclusif du FAA William J. Hughes Technical Center (WJHTC). Aucun document pouvant mener à mon identification en tant que participant ne sera utilisé à l'extérieur du WJHTC, à moins que j'y aie expressément consenti par écrit.

Je comprends que je peux en tout temps me retirer de cette expérience sans subir aucune sanction ni perdre aucun des avantages auxquels je peux avoir droit. Je comprends également que le chercheur ou le parrain de cette expérience peut mettre fin à ma participation s'il estime que cela est dans mon meilleur intérêt.

Si j'ai des questions au sujet de l'expérience ou si je dois signaler des effets indésirables du protocole de recherche, je m'adresserai à Edmundo Sierra, au (609) 485-7360.

J’ai lu cette formule de consentement du participant, j’en comprends le contenu et je consens librement à participer à cette expérience, dans les conditions décrites. J’ai reçu une copie de cette formule de consentement du participant.

Signature du participant : ______________________ Date : ___________

Directeur de la recherche : _____________________ Date : ___________

Témoin : ____________________________________ Date : ____________

Participation Consent Form

To the Research Participant: Please read this consent form and the attached protocol and/or subject instructions carefully. Make sure that any questions that you may have, have been answered to your satisfaction before signing.

I agree to participate in the experiment *Human Visual and Tactile Ice Detection Capabilities Under Aircraft Post-Deicing Conditions* (hereafter referred to as the *Detection Experiment*). I understand that the Federal Aviation Administration (FAA) Office of Aviation Research sponsors this experiment. The FAA's Flight Safety Branch and is the project manager, and that the FAA's Simulation and Analysis Group and Transport Canada Civil Aviation direct this experiment.

Nature and Purpose:
The Detection Experiment is intended to determine human visual and tactile ice detection capabilities. Deicers will inspect two aluminum panels representing what a part of a wing might look like after deicing, but before anti-icing. One of the panels will have ice on it and the other will not. The inspections will be conducted visually or tactilely, but not at the same time. After inspection, the deicer will indicate which panel has ice on it. The purpose of this experiment is to determine the thickness of ice below which it is no longer detectable visually or tactilely.

Experimental Procedures:
Eight deicers from AeroMag will participate in this experiment over a two week period. Four deicers will conduct visual inspections and the other four will conduct tactile inspections. Deicers will sit in the cold chamber facing a test administrator (TA). The TA will show the deicer one panel covered in deicing fluid, then he will show the deicer a second panel covered in deicing fluid, and finally ask the deicer which panel had ice on it. The TA will record the deicer's response.

Discomforts and Risks:
The discomforts and risks anticipated in this experiment are not greater than those ordinarily encountered by a deicer performing his or her job. The cold chamber will be at approximately -5° C with a slight wind. There is little danger of freezing to exposed flesh and cold related illnesses if appropriate precautions are exercised.

It is my responsibility to notify the TA if I have health conditions that may predispose me to cold related illnesses. Predisposing health conditions include but are not limited to cardiovascular disease, diabetes, and hypertension. Previous cold related injuries or illnesses also predispose me and I will notify the TA regarding any of these as well.

It is my responsibility to wear proper clothing including a hat and gloves, as delineated by my employer for such conditions. If I am unsure of clothing requirements for this environment, I can request specific recommendations from the TA.

I will alert the TA if I feel any discomfort or require a break. Frequent short breaks in warm dry rooms are scheduled into the experiment to allow my body to warm up, but I will not hesitate to request a break at any time.

Benefits:
I understand that the benefit to me is the opportunity to participate in research that examines human ice detection capabilities and limitations.

Participant Responsibilities:
During the experiment, it will be my responsibility to check the panels to verify whether any ice is present and to regard the inspection as if it were being performed on an actual aircraft. I will answer any questions asked during the experiment to the best of my abilities. I will not discuss the content of the experiment with anyone until after its formal completion. I will complete a background questionnaire, a post-run questionnaire at the end of each run, and a post-experiment questionnaire at the end of all the runs. I will participate in debriefs at the end of each run, and at the completion of the full experiment.

Participant's Assurances:
I understand that my participation in this experiment is completely voluntary. The TA will adequately answer any and all questions I have about this experiment, my participation, and the procedures involved. I understand that if new findings develop during the course of this research that may relate to my decision to participate, I will be informed.

I have not surrendered any of my legal rights or released any individual or institution from liability for negligence.

I understand that records of this experiment are strictly confidential, and that I will not be identifiable by name or description in any reports or publications about this experiment. Any video or audio recordings are for use within the FAA William J. Hughes Technical Center (WJHTC) only. Any of the materials that may identify me as a participant cannot be used for purposes other than internal to the WJHTC without my written permission.

I understand that I can withdraw from this experiment at any time without penalty or loss of benefits to which I may be entitled. I also understand that the researcher or sponsor of this experiment may terminate my participation if he or she feels this to be in my best interest.

If I have questions about this experiment or need to report any adverse effects from the research procedures I will contact Edmundo Sierra at (609) 485-7360.

I have read this participation form, I understand its contents, and I freely consent to participate in this experiment under the conditions described. I have received a copy of this participation form.

Signature of Research Participant: _______________Date: ____________

Research Director: ____________________________Date: ____________

Witness: ____________________________________Date: _____________

APPENDIX D

CLOTHING SUGGESTIONS

Dear Participant,

Thank you for volunteering to participate in our experiment. We would like you to be as safe and comfortable as possible during your participation. For your safety and comfort, we are providing the following information.

The cold chamber in which you will participate will be -5° C, there will be a slight wind, and no precipitation. Even though you will receive a number of breaks, you will spend a significant amount of time in this cold environment.
We suggest the clothing listed in the table below. It was adapted from U.S. Army Field Manual 31-70 and lists some basic components of cold-dry conditions clothing for these conditions. Of course, you may also refer to your employer’s guidelines and experience for adequate protection and comfort in these conditions.

Basic Components of Cold-Dry Clothing

Item	Name	Description
1	Undershirt	50 Cotton 50 Wool, Full Sleeve
2	Drawers	50 Cotton 50 Wool, Ankle Length
3	Socks	Wool Cushion Sole, Stretch Type
4	Suspenders Trousers	Scissor Back Type
5	Shirt	Wool, Nylon, Flannel
6	Trousers	Cotton Nylon, Wind Resistant Sateen
7	Liner Trousers	Nylon Quilted, 6.2 oz
8	Boot Insulated Cold Weather	Rubber w/release valve
9	Coat	Cotton and Nylon Wind Resistant Sateen, 8.5 oz
10	Liner Coat	Nylon Quilted, 6.2 oz
11	Parka	Cotton and Nylon Oxford w/o hood
12	Liner Parka Mans	Nylon Quilted 6.2 oz
13	Cap, Insulating, Helmet Liner	Cotton Nylon Oxford
14	Hood Winter	Cotton and Nylon Oxford
15	Glove Shells	Leather Black with Glove Inserts ; Wool and Nylon Knit

OPTIONAL CLOTHING in UNPAINTED ALUMINUM

If you have any questions, please contact me at the number below. We look forward to seeing you!

Edmundo Sierra
Human Factors Engineer
(609) 485-7360

Cher participant,

Merci de bien vouloir participer à notre expérience. Nous voulons que vous soyez le plus en sécurité et le plus confortable possible pendant l'expérience. Pour votre sécurité et votre confort, nous vous demandons de lire l'information qui suit.

La chambre froide dans laquelle sera menée l'expérience sera maintenue à -5° C, avec un vent léger et aucune précipitation. Même si vous aurez droit à des pauses, vous passerez beaucoup de temps dans ce milieu froid.

Nous vous suggérons de vous munir des vêtements énumérés dans le tableau ci-après. Cette liste, inspirée d'un manuel de l'armée américaine (U.S. Army Field Manual 31-70), comprend les éléments de base d'une tenue adaptée à un froid sec. Bien sûr, vous pouvez aussi vous fier aux directives de votre employeur et à votre expérience pour savoir quels vêtements porter pour être au chaud et confortable dans ces conditions.

Éléments de base d'une tenue pour froid sec

Article	Désignation	Description
1	Gilet de corps	50 % coton, 50 % laine, manches longues
2	Caleçon	50 % coton, 50 % laine, jambes longues
3	Chaussettes	En laine, à semelle matelassée, extensibles
4	Bretelles pour pantalons	Du type se croisant dans le dos
5	Chemise	Flanelle de laine et nylon
6	Pantalon	Satin de coton et nylon résistant au vent
7	Doublure de pantalon	Nylon matelassé, 6,2 oz
8	Bottes isolées pour temps froid	Caoutchouc, avec détendeur
9	Manteau	Satin de coton et nylon résistant au vent, 8,5 oz
10	Doublure de manteau	Nylon matelassé, 6,2 oz
11	Parka	Tissu Oxford coton et nylon, sans capuchon
12	Doublure de parka	Nylon matelassé, 6,2 oz
13	Bonnet sous-casque isolant	Tissu Oxford coton et nylon
14	Capuchon d'hiver	Tissu Oxford coton et nylon
15	Gants	En cuir noir avec sous-gants en tricot de laine et nylon

VÊTEMENTS FACULATIFS en GRIS

Si vous avez des questions, n'hésitez pas à me téléphoner, au numéro ci-dessous. Au plaisir de vous rencontrer!

Edmundo Sierra
Ergonome
(609) 485-7360

APPENDIX E

MATERIALS SAFETY DATA SHEET

Materials Safety Data Sheet

Dow (hereinafter, and for purposes of this MSDS only, refers to The Dow Chemical Company and to Dow Chemical Canada Inc.) encourages and expects you to read and understand the entire MSDS, as there is important information throughout the document. Dow expects you to follow the precautions identified in this document unless your use conditions would necessitate other appropriate methods or actions.

Chemical Product and Company Identification

Identification

Product Name UCAR(TM) AIRCRAFT DEICING FLUID "50/50" SAE/ISO TYPE I

Company Identification

The Dow Chemical Company
Midland, MI 48674

Emergency Telephone Number

24-HOUR EMERGENCY TELEPHONE NUMBER: (989)636-4400.
Customer Information Number: 1-800-258-2436.

Composition Information

Component	CAS #	Amount (%W/W)
Water	7732-18-5	51 %
Ethylene glycol	107-21-1	48 %
Nonhazardous processing additives	Not available	< 1%

Hazards Identification

Emergency Overview

Appearance Orange

Physical State Liquid

Odor Sweet

Hazards of product

HARMFUL OR FATAL IF SWALLOWED.
MAY CAUSE EYE IRRITATION.
MAY CAUSE RESPIRATORY TRACT IRRITATION.

ISOLATE AREA.
KEEP UPWIND OF SPILL.

Potential Health Effects

Effects of Single Acute Overexposure

Inhalation At room temperature, exposure to vapor is minimal due to low volatility. With good ventilation, single exposure is not expected to cause adverse effects. If material is heated or areas are poorly ventilated, vapor/mist may accumulate and cause respiratory irritation and symptoms such as headache and nausea.

Eye Contact May cause slight eye irritation. Corneal injury is unlikely. Vapor or mist may cause eye irritation.

Skin Contact Brief contact is essentially nonirritating to skin. Prolonged contact may cause slight skin irritation with local redness. Repeated contact may cause skin irritation with local redness.

Skin Absorption Prolonged skin contact is unlikely to result in absorption of harmful amounts. Repeated skin exposure to large quantities may result in the absorption of harmful amounts. Massive contact with damaged skin or of material sufficiently hot to burn skin may result in absorption of potentially lethal amounts.

Swallowing Oral toxicity is expected to be moderate in humans due to ethylene glycol even though tests with animals show a lower degree of toxicity. Excessive exposure may cause central nervous system effects, cardiopulmonary effects (metabolic acidosis), and kidney failure. Swallowing may result in severe effects, even death. The lethal dose in adult humans for ethylene glycol is approximately 3 ounces (100 ml) (1/3 cup). May cause nausea or vomiting. May cause abdominal discomfort or diarrhea.

Chronic, Prolonged or Repeated Overexposure

Effects of Repeated Overexposure Repeated excessive exposure may cause irritation of the upper respiratory tract. In humans, effects have been reported on the following organs: Central nervous system. Observations in humans include: Nystagmus (involuntary eye movement). In animals, effects have been reported on the following organs: Kidney, liver. Based on animal studies, ingestion of very large amounts of ethylene glycol appears to be the major and possibly only route of exposure to produce birth defects. Exposures by inhalation or skin contact, the primary routes of occupational exposure, had minimal effect on the fetus, in animal studies. Ingestion of large amounts of ethylene glycol has been shown to interfere with reproduction in animals.

Other Effects of Overexposure No information available.

See Section 11 for toxicological information and additional information about potential health effects.

Potential Environmental Effects

See Section 12 for Ecological Information.

First Aid Procedures

Inhalation

Move person to fresh air; if effects occur, consult a physician.

Eye Contact

Flush eyes thoroughly with water for several minutes. Remove contact lenses after the initial 1-2 minutes and continue flushing for several additional minutes. If effects occur, consult a physician, preferably an ophthalmologist.

Skin Contact

Immediately flush skin with water while removing contaminated clothing and shoes. Get medical attention if symptoms occur. Wash clothing before reuse. Destroy contaminated leather items such as shoes, belts, and watchbands.

Swallowing

Do not induce vomiting. Seek medical attention immediately. If person is fully conscious give 1 cup or 8 ounces (240 ml) of water. If medical advice is delayed and if an adult has swallowed several ounces of chemical, then give 3-4 ounces (1/3-1/2 cup) (90-120 ml) of hard liquor such as 80 proof whiskey. For children, give proportionally less liquor at a dose of 0.3 ounce (1 1/2 tsp.) (8 ml) liquor for each 10 pounds of body weight, or 2 ml per kg body weight [e.g., 1.2 ounce (2 1/3 tbsp.) for a 40 pound child or 36 ml for an 18 kg child].

Notes to Physician

If several ounces of EG have been ingested, early administration of ethanol may counter the toxic effects (metabolic acidosis, renal damage). Consider hemodialysis or peritoneal dialysis & thiamine 100 mg plus pyridoxine 50 mg IV every 6 hr.

If ethanol is used, a therapeutically effective blood concentration in the range of 100 - 150 mg/dl may be achieved by a rapid loading dose followed by a continuous intravenous infusion. Consult standard literature for details of treatment.

4-Methyl pyrazole (Antizol®) is an effective blocker of alcohol dehydrogenase and should be used in the treatment of ethylene glycol, di- or triethylene glycol, ethylene glycol butyl ether, or methanol intoxication if available.

Fomepizole protocol (Brent, J. et al., New England Journal of Medicine, Feb. 8, 2001, 344:6, p. 424-9): loading dose 15 mg/kg IV, follow by bolus dose of 10 mg/kg every 12 hours; after 48 hours, increase bolus dose to 15 mg/kg every 12 hours.

Continue fomepizole until serum methanol, EG, DEG, or TEG are undetectable. The signs and symptoms of poisoning include anion gap metabolic acidosis, CNS depression, renal tubular injury, and possible late stage cranial nerve involvement.

Respiratory symptoms, including pulmonary edema, may be delayed. Persons receiving significant exposure should be observed 24-48 hours for signs of respiratory distress.

In severe poisoning, respiratory support with mechanical ventilation and positive end expiratory pressure may be required.

If lavage is performed, suggest endotracheal and/or esophageal control. Danger from lung aspiration must be weighed against toxicity when considering emptying the stomach.

Fire Fighting Measures

Flammable Properties - Refer to Section 9, PHYSICAL AND CHEMICAL PROPERTIES

Extinguishing Media

To extinguish combustible residues of this product use water fog, carbon dioxide, dry chemical or foam.

Fire Fighting Procedures

Keep people away. Isolate fire and deny unnecessary entry. Use water spray to cool fire exposed containers and fire affected zone until fire is out and danger of reignition has passed. To extinguish combustible residues of this product use water fog, carbon dioxide, dry chemical or foam.

Special Protective Equipment for Firefighters

Wear positive-pressure self-contained breathing apparatus (SCBA) and protective fire fighting clothing (includes fire fighting helmet, coat, pants, boots, and gloves). Avoid contact with this material during fire fighting operations. If contact is likely, change to full chemical resistant fire fighting clothing with SCBA. If this is not available, wear full chemical resistant clothing with SCBA and fight fire from a remote location. For protective equipment in post-fire or non-fire clean up situations, refer to the relevant sections.

Unusual Fire and Explosion Hazards

This material will not burn until the water has evaporated. Residue can burn.

Hazardous Combustion Products

Under fire conditions some components of this product may decompose. The smoke may contain unidentified toxic and/or irritating compounds.

Accidental Release Measures

Steps to be Taken if Material is Released or Spilled:
Contain spilled material if possible. Small spills: Absorb with materials such as: Cat litter. Sand. Sawdust. Vermiculite. Zorb-all®. Hazorb®. Large spills: Dike area to contain spill. Pump into suitable and properly labeled containers. See Section 13, Disposal Considerations, for additional information.

Personal Precautions: Use appropriate safety equipment. For additional information, refer to Section 8, Exposure Controls and Personal Protection. Isolate area. Refer to Section 7, Handling for additional precautionary measures. Keep unnecessary and unprotected personnel from entering the area. Keep upwind of spill. Ventilate area of leak or spill.

Environmental Precautions: Prevent from entering into soil, ditches, sewers, waterways and/ or groundwater. See Section 12, Ecological Information.

Handling and Storage

Handling

General Handling
Do not swallow.
Avoid contact with eyes.
Avoid breathing mist.
Wash thoroughly after handling.
Keep container closed.
Use with adequate ventilation.

See Section 8, EXPOSURE CONTROLS AND PERSONAL PROTECTION.

Ventilation
Provide general and/or local exhaust ventilation to control airborne levels below the exposure guidelines.

Other Precautions
Spills of these organic materials on hot fibrous insulations may lead to lowering of the autoignition temperatures possibly resulting in spontaneous combustion.

Storage

Additional storage and handling information on this product may be obtained by calling your Dow sales or customer service contact. Ask for a product brochure.

Exposure Controls and Personal Protection

Exposure Limits

Component	Exposure Limits	Skin.	Form
Ethylene glycol	100 mg/m3 CEILING ACGIH		Aerosol, vapor, and mist

In the Exposure Limits Chart above, if there is no specific qualifier (i.e., Aerosol) listed in the Form Column for a particular limit, the listed limit includes all airborne forms of the substance that can be inhaled.

A "Yes" in the Skin Column indicates a potential significant contribution to overall exposure by the cutaneous (skin) route, including mucous membranes and the eyes, either by contact with vapors or by direct skin contact with the substance. A "Blank" in the Skin Column indicates that exposure by the cutaneous (skin) route is not a potential significant contributor to overall exposure.

Personal Protection

Respiratory Protection: Atmospheric levels should be maintained below the exposure guideline.
When airborne exposure guidelines and/or comfort levels may be exceeded, use an approved air-purifying respirator.

Ventilation: Provide general and/or local exhaust ventilation to control airborne levels below the exposure guidelines.

Eye Protection: Use safety glasses.
If exposure causes eye discomfort, use a full-face respirator.

Other Protective Equipment: When prolonged or frequently repeated contact could occur, use chemically protective clothing resistant to this material. Selection of specific items such as faceshield, gloves, boots, apron, or full-body suit will depend on operation.
If hands are cut or scratched, use gloves chemically resistant to this material even for brief exposures.
When handling hot material, protect skin from thermal burns as well as from skin absorption.

II

Physical and Chemical Properties

Physical State: Liquid

Appearance: Orange

Odor: Sweet

Flash Point - Closed Cup: *Pensky-Martens Closed Cup ASTM D 93* None.

Flammable Limits In Air:

Lower	*Not Determined, Aqueous System*
Upper	*Not Determined, Aqueous System*

Autoignition Temperature: *Not applicable.*

Vapor Pressure: **13 mmHg** *20 °C*

Boiling Point (760 mmHg): **107 °C 225 °F**

Vapor Density (air = 1): **1.0**

Specific Gravity (H2O = 1): **1.1** *20 °C / 20 °C*

Freezing Point: **-34 °C -30 °F**

Melting Point: *No test data available.*

Solubility in Water (by weight): **100 %** *20 °C*

pH: 7.6 - 8.6

Octanol/Water Partition Coefficient - Measured: -1.36

Evaporation Rate (Butyl Acetate = 1): **0.7**

Percent Volatiles: **100 Wt%**

Stability and Reactivity

Stability/Instability *THERMALLY STABLE AT RECOMMENDED TEMPERATURES AND PRESSURES.*

Conditions to Avoid: Some components of this product can decompose at elevated temperatures. Generation of gas during decomposition can cause pressure in closed systems.

Incompatible Materials: Avoid contact with: Strong acids. Strong bases. Strong oxidizers.

Thermal Decomposition: Decomposition products depend upon temperature, air supply and the presence of other materials.

Hazardous Polymerization *WILL NOT OCCUR.*

Toxicological Information

ACUTE TOXICITY

Peroral

Based on information for a similar material:, Rat; LD50 = 8200 mg/kg

Peroral

Human; Lethal Dose; approximately 3 ounces (100 ml) (1/3 cup); (for ethylene glycol).

Percutaneous

Based on information for a similar material:, Rabbit; LD50 = > 2000 mg/kg

DEVELOPMENTAL TOXICITY

Based on animal studies, ingestion of very large amounts of ethylene glycol appears to be the major and possibly only route of exposure to produce birth defects., Exposures by inhalation or skin contact, the primary routes of occupational exposure, had minimal effect on the fetus, in animal studies.

REPRODUCTIVE TOXICITY

Ingestion of large amounts of ethylene glycol has been shown to interfere with reproduction in animals.

CHRONIC TOXICITY AND CARCINOGENICITY

Ethylene glycol did not cause cancer in long-term animal studies.

GENETIC TOXICOLOGY

In Vitro

For the major component:, In vitro genetic toxicity studies were negative.

In Vivo

For the major component:, Animal genetic toxicity studies were negative.

SIGNIFICANT DATA WITH POSSIBLE RELEVANCE TO HUMANS
Repeated excessive exposure may cause irritation of the upper respiratory tract.
In humans, effects have been reported on the following organs:
Central nervous system.
Observations in humans include:
Nystagmus (involuntary eye movement).
In animals, effects have been reported on the following organs:
Kidney, liver.

Ecological Information

Environmental Fate

Based largely or completely on information for: Ethylene glycol. Material is readily biodegradable. Passes OECD test(s) for ready biodegradability.

BOD (% Oxygen consumption)
Based largely or completely on information for the concentrate for this product:

	Day 5	Day 10	Day 15	Day 20	Day 28/30
	69 %	85 %		96 %	

Ecotoxicity

Based on extrapolation of data on the concentrate for this product:, Material is practically non-toxic to aquatic organisms on an acute basis (LC50/EC50 >100 mg/L in the most sensitive species tested).

Toxicity to Micro-organisms
Based largely or completely on data for major component(s):
bacteria; 16 h; Growth inhibition; EC50
Result value: > 10000 mg/L

Toxicity to Aquatic Invertebrates
Based on extrapolation of data on the concentrate for this product:
water flea Daphnia magna; Acute immobilization EC50
Result value: 81560 mg/L

Toxicity to Fish

Based on extrapolation of data on the concentrate for this product:
rainbow trout (Oncorhynchus mykiss); Acute LC50
Result value: 22050 mg/L

Toxicity to Fish
Based on extrapolation of data on the concentrate for this product:
fathead minnow (Pimephales promelas); Acute LC50
Result value: 34980 mg/L

Further Information

Based largely or completely on information for: Ethylene glycol. Bioconcentration potential is low (BCF < 100 or Log Pow < 3). Potential for mobility in soil is very high (Koc between 0 and 50). Soil organic carbon/water partition coefficient (Koc) is estimated to be: 1.
Theoretical Oxygen Demand (THOD) - calculated:: 1.30 mg/mg

Octanol/Water Partition Coefficient - Measured: -1.36

Disposal Considerations

Disposal

All disposal practices must be in compliance with all Federal, State/Provincial and local laws and regulations. Regulations may vary in different locations. Waste characterizations and compliance with applicable laws are the responsibility solely of the waste generator. DOW HAS NO CONTROL OVER THE MANAGEMENT PRACTICES OR MANUFACTURING PROCESSES OF PARTIES HANDLING OR USING THIS MATERIAL. THE INFORMATION PRESENTED HERE PERTAINS ONLY TO THE PRODUCT AS SHIPPED IN ITS INTENDED CONDITION AS DESCRIBED IN MSDS SECTION 2 (Composition/ Information on Ingredients). FOR UNUSED & UNCONTAMINATED PRODUCT, the preferred options include sending to a licensed, permitted: Reclaimer. Recycler. Incinerator or other thermal destruction device. Waste water treatment system. As a service to its customers, Dow can provide names of information resources to help identify waste management companies and other facilities which recycle, reprocess or manage chemicals or plastics, and that manage used drums. Telephone Dow's Customer Information Group at 1-800-258-2436 or 1-989-832-1556 (U.S.), or 1-800-331-6451 (Canada) for further details .

Transport Information

U.S. D.O.T.

NON-BULK
Proper Shipping Name : NOT REGULATED

BULK
Proper Shipping Name : OTHER REGULATED SUBSTANCES, LIQUID, NOS
Technical Name : CONTAINS ETHYLENE GLYCOL
Hazard Class : 9
ID Number : NA3082
Packing Group : PG III

Reportable Quantity : 10,352 LB

This information is not intended to convey all specific regulatory or operational requirements/information relating to this product. Additional transportation system information can be obtained through an authorized sales or customer service representative. It is the responsibility of the transporting organization to follow all applicable laws, regulations and rules relating to the transportation of the material.

Regulatory Information

Federal/National

OSHA HAZARD COMMUNICATION STANDARD

This product is a "Hazardous Chemical" as defined by the OSHA Hazard Communication Standard, 29 CFR 1910.1200.

SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT OF 1986 TITLE III (EMERGENCY PLANNING AND COMMUNITY RIGHT-TO-KNOW ACT OF 1986) SECTION 313

This product contains the following substances which are subject to the reporting requirements of Section 313 of Title III of the Superfund Amendments and Reauthorization Act 1986 and which are listed in 40 CFR Part 372.

Component	CAS #	Amount
Ethylene glycol	107-21-1	<= 48.0000%

COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT OF 1980 (CERCLA) SECTION 103

This product contains the following substances which are subject to CERCLA Section 103 reporting requirements and which are listed in 40 CFR 302.4.

Component	CAS #	Amount
Ethylene glycol	107-21-1	<= 48.0000%

SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT OF 1986 TITLE III (EMERGENCY PLANNING AND COMMUNITY RIGHT-TO-KNOW ACT OF 1986) SECTION 302

To the best of our knowledge this product does not contain chemicals at levels which require reporting under this statute.

SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT OF 1986 TITLE III (EMERGENCY PLANNING AND COMMUNITY RIGHT-TO-KNOW ACT OF 1986) SECTIONS 311 AND 312

Delayed (Chronic) Health Hazard : Yes
Fire Hazard : No
Immediate (Acute) Health Hazard : Yes
Reactive Hazard : No
Sudden Release of Pressure Hazard : No

TOXIC SUBSTANCES CONTROL ACT (TSCA)

All components of this product are on the TSCA Inventory or are exempt from TSCA Inventory requirements under 40 CFR 720.30.

EUROPEAN INVENTORY OF EXISTING COMMERCIAL CHEMICAL SUBSTANCES (EINECS)

The components of this product are on the EINECS inventory or are exempt from EINECS inventory requirements.

CEPA - DOMESTIC SUBSTANCES LIST (DSL)

This product contains one or more substances which are not listed on the Canadian Domestic Substances List (DSL). Contact your Dow representative for more information.

State/Local

PENNSYLVANIA (WORKER AND COMMUNITY RIGHT-TO-KNOW ACT): PENNSYLVANIA HAZARDOUS SUBSTANCES LIST AND/OR PENNSYLVANIA ENVIRONMENTAL HAZARDOUS SUBSTANCE LIST:

The following product components are cited in the Pennsylvania Hazardous Substance List and/or the Pennsylvania Environmental Substance List, and are present at levels which require reporting.

Component	CAS #	Amount
Ethylene glycol	107-21-1	<= 48.0000%

CALIFORNIA PROPOSITION 65 (SAFE DRINKING WATER AND TOXIC ENFORCEMENT ACT OF 1986)

WARNING: This product contains a chemical(s) known to the State of California to cause cancer.

Component	CAS #	Amount
1,4-Dioxane	123-91-1	<= 0.2470PPM

CALIFORNIA SCAQMD RULE 443.1 (SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT RULE 443.1, LABELING OF MATERIALS CONTAINING ORGANIC SOLVENTS)

VOC: Vapor pressure 13 mmHg @ 20 °C
515 g/l
1138 g/l less water and less exempted solvents

This section provides selected regulatory information on this product including its components. This is not intended to include all regulations. It is the responsibility of the user to know and comply with all applicable rules, regulations and laws relating to the product being used.

Other Information

Additional Information

Additional information on this and other Dow products may be obtained by visiting our web page at www.dow.com.
Additional information on this product may be obtained by calling Dow's Customer Information Group at 1-800-258-2436 (U.S.) or 1-800-331-6451 (Canada). Ask for a product brochure.

Hazard Rating System

NFPA ratings for this product are: H - 2 **F -** 1 **R -** 0

These ratings are part of a specific hazard communication program and should be disregarded where individuals are not trained in the use of this hazard rating system. You should be familiar with the hazard communication programs applicable to your workplace.

Recommended Uses and Restrictions

For industrial use.

Dow recommends that you use this product in a manner consistent with the listed use. If your intended use is not consistent with Dow's stated use, please contact Dow's Customer Information Group at 1-800-258-2436 (U.S.) or 1-800-331-6451 (Canada) for more information.

Revision

Version: 7.
Revision: 02/17/2004
Most recent revision(s) are noted by the bold, double bars in left-hand margin throughout this document.

Legend

Bacterial/NA	Non Acclimated Bacteria
F	Fire

H	Health
IHG	Industrial Hygiene Guideline
N/A	Not available
NFPA	National Fire Protection Association
O	Oxidizer
R	Reactivity
TS	Trade secret
VOL/VOL	Volume/Volume
W	Water Reactive
W/W	Weight/Weight

NOTICE: Dow urges each customer or recipient of this MSDS to study it carefully and consult appropriate expertise, as necessary or appropriate, to become aware of and understand the data contained in this MSDS and any hazards associated with the product. The information herein is provided in good faith and believed to be accurate as of the effective date shown above. However, no warranty, express or implied, is given., Regulatory requirements are subject to change and may differ between various locations. It is the buyer's/user's responsibility to ensure that its activities comply with all federal, state, provincial or local laws. The information presented here pertains only to the product as shipped. Since conditions for use of the product are not under the control of Dow, it is the buyer's/user's duty to determine the conditions necessary for the safe use of this product., Due to the proliferation of sources for information such as manufacturer-specific MSDSs, Dow is not and cannot be responsible for MSDSs obtained from any source other than Dow. If you have obtained a Dow MSDS from a non-Dow source or if you are not sure that a Dow MSDS is current, please contact Dow for the most current version.

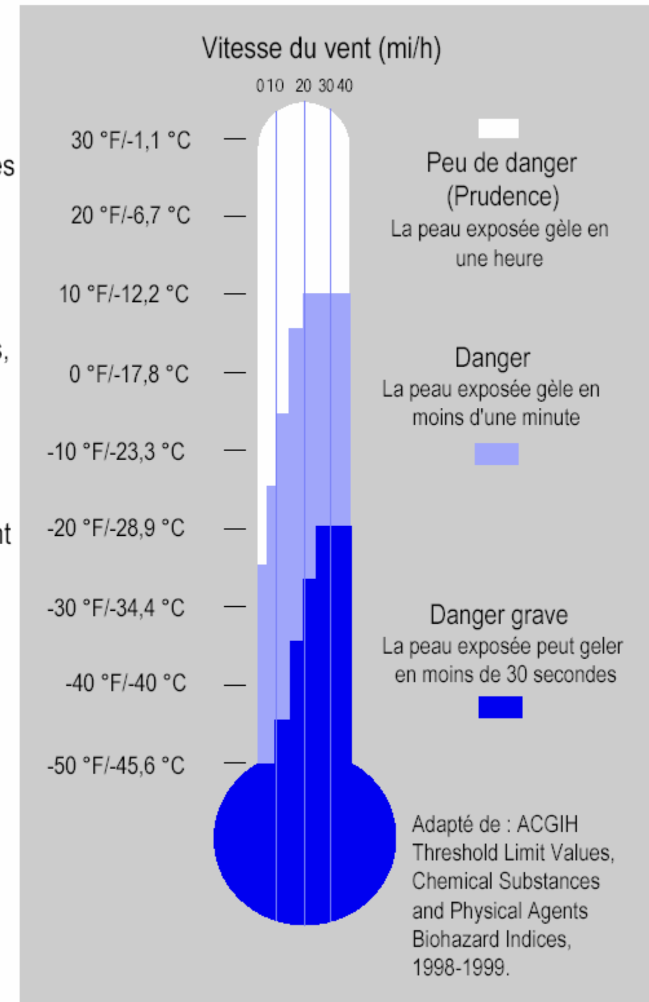
APPENDIX F

OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION COLD STRESS

ÉQUATION DU STRESS DÛ AU FROID

BASSE TEMPÉRATURE + VITESSE DU VENT + HUMIDITÉ = BLESSURES ET MALADIES

Lorsque l'organisme ne réussit pas à se réchauffer lui-même, des blessures et maladies graves reliées au froid peuvent survenir, lesquelles peuvent entraîner des dommages permanents aux tissus, voire la mort. L'**hypothermie** peut survenir quand la *température de l'air* est **au-dessus** du point de congélation ou quand la *température de l'eau* est inférieure à 98,6 °F/37 °C. Les maladies dues au froid peuvent finir par avoir raison d'une personne exposée à des basses températures, à des vents intenses ou à l'humidité de vêtements mouillés.



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GELURE

Ce qui arrive à l'organisme :

CONGÉLATION DES COUCHES PROFONDES DE LA PEAU ET DES TISSUS; PEAU BLANCHE ET D'APPARENCE CIREUSE; LA PEAU DEVIENT DURE AU TOUCHER et ENGOURDIE; AFFECTE HABITUELLEMENT LES DOIGTS, LES MAINS, LES ORTEILS, LES PIEDS, LES OREILLES et LE NEZ

Ce qu'il faut faire : (basse température de l'air)

- Évacuer la personne vers un local chaud et sec. Ne pas laisser la personne seule.
- Retirer les vêtements mouillés et tout vêtement serré qui pourrait gêner la circulation du sang dans la zone touchée.
- **NE PAS** frictionner la zone touchée, car cela pourrait causer des dommages à la peau et aux tissus.
- Placer **doucement** la zone touchée dans un bain d'eau chaude (105 °F/40,5 °C) et contrôler la température de l'eau, afin de réchauffer **lentement** les tissus. Ne pas verser d'eau chaude directement sur la zone touchée, car cela pourrait endommager les tissus en les réchauffant trop rapidement. Le réchauffement doit prendre environ 25 à 40 minutes.
- Une fois la zone touchée réchauffée, il est possible qu'une enflure et des cloques apparaissent et qu'une sensation de brûlure ou un engourdissement se manifestent. Lorsque les sensations, les mouvements et la couleur de la peau reviennent à la normale, sécher la zone touchée et la couvrir pour la garder au chaud. **NOTA** : Si la zone touchée doit de nouveau être exposée au froid, ne pas réchauffer la peau. Si la peau est réchauffée et qu'elle refroidit de nouveau, les tissus risquent d'être lourdement endommagés.
- Obtenir des soins médicaux sans tarder.

HYPORTHERMIE - (Urgence médicale)

Ce qui arrive à l'organisme :

LA TEMPÉRATURE NORMALE DU CORPS (98,6 °F/37 °C) DESCEND À 95 °C (35 °C) OU PLU BAS; FATIGUE OU SOMNOLENCE; FRISSONNEMENTS INCONTRÔLÉS; PEAU FROIDE ET BLEUÂTRE; ÉLOCUTION DIFFICILE; MOUVEMENTS MALADROITS; COMPORTEMENT IRRIT IRRATIONNEL OU CONFUS.

Ce qu'il faut faire : (baisse température de l'air)

- Appeler les secours (ambulanciers ou 911).
- Évacuer la personne vers un local chaud et sec. Ne pas laisser la personne seule. Retirer les vêteme mouillés et les remplacer par des vêtements chauds et secs ou emmitoufler la personne dans des cou
- Donner à la personne des boissons tièdes et sucrées (eau sucrée ou boissons énergétiques), si elle est bien éveillée. **Évitez les boissons contenant de la caféine** (café, thé, chocolat chaud) ou de l'
- Demander à la personne de bouger les bras et les jambes (la contraction des muscles produit de la Si elle est incapable de bouger, lui placer des bouillottes ou des compresses chaudes sous les aisse à l'aine, dans le cou et sur la tête. **NE PAS** la frictionner ni la bouger dans un bain chaud. Cela pourr causer un arrêt cardiaque.

Ce qu'il faut faire : (basse température de l'eau)

- Appeler les secours (ambulanciers ou 911). La température corporelle s'abaisse 25 fois plus vite da l'eau que sur terre.
- **NE** retirer **AUCUN** vêtement. Attacher les boutons et les agrafes, et fermer les fermetures à glissière en serrant bien les cols, poignets, souliers et capuchons, car la couche d'eau emprisonnée près du corps joue le rôle d'un isolant et ralentit la perte de chaleur. Garder la tête hors de l'eau, couverte d'un chapeau ou d'un capuchon.
- Sortir de l'eau au plus vite ou se hisser sur un objet flottant. **NE PAS** essayer de nager à moins que ce soit pour atteindre un objet flottant ou pour rejoindre quelqu'un d'autre, car le fait de nager ou une autre activité physique dissipe la chaleur corporelle et réduit le temps de survie d'environ 50 p. 100.
- Si vous ne pouvez pas sortir de l'eau, attendez calmement et ménagez votre chaleur corporelle en p la position suivante : bras repliés sur la poitrine, cuisses serrées, genoux pliés et chevilles croisées. a quelqu'un d'autre à l'eau, blottissez-vous l'un contre l'autre, poitrine contre poitrine.

Comment protéger les travailleurs

- Prendre conscience des conditions ambiantes et des conditions du milieu de travail pouvant mener à des blessures ou des maladies dues au froid.
- Apprendre les signes et les symptômes des maladies/blessures dues au froid et savoir ce qu'il faut faire pour venir en aide au travailleur touché.
- Donner de la formation aux travailleurs sur les maladies et les blessures dues au froid.
- Choisir des vêtements appropriés pour l'exposition au froid, à l'humidité et au vent. Porter plusieurs couches de vêtements afin de pouvoir mieux s'adapter aux changements de température ambiante. Porter un chapeau et des gants, ainsi que des sous-vêtements (en polypropylène) qui empêchent l'humidité d'entrer en contact avec la peau.
- Prendre fréquemment de courtes pauses dans des abris chauds et secs, pour permettre au corps de se réchauffer.
- Éxécuter les travaux pendant la période la plus chaude de la journée.
- Éviter de s'épuiser ou de se fatiguer, car il faut de l'énergie pour garder les muscles au chaud.
- Utiliser un système de jumelage (travailler deux par deux).
- Boire des boissons chaudes et sucrées (eau chaude, boissons énergétiques). Éviter les boissons contenant de la caféine (café, thé ou chocolat chaud) ou de l'alcool.
- Manger des aliments chauds contenant beaucoup de calories, comme des plats chauds de pâtes.

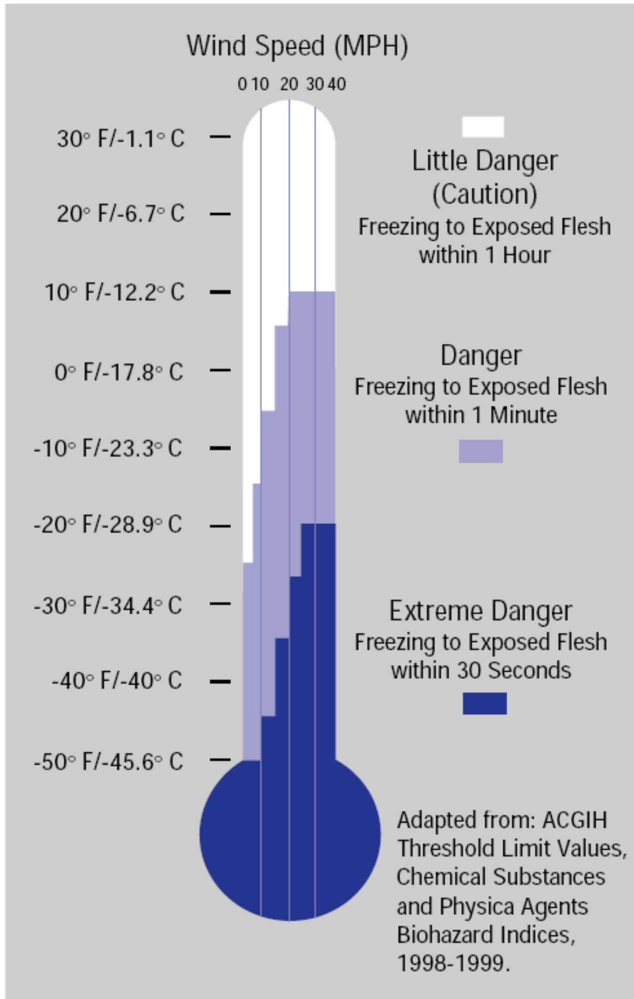
Les travailleurs sont exposés à un risque accru si...

- Ils ont un problème de santé prédisposant, comme une maladie cardiovasculaire, le diabète et l'hypertension.
- Ils prennent certains médicaments (vérifiez auprès de votre médecin, une infirmière ou votre pharmacien si les médicaments que vous prenez ont des effets particuliers lorsque vous travaillez dans des environnements froids).
- Ils sont en mauvaise condition physique, s'alimentent mal ou sont âgés.

THE COLD STRESS EQUATION

LOW TEMPERATURE + WIND SPEED + WETNESS = INJURIES & ILLNESS

When the body is unable to warm itself, serious cold-related illnesses and injuries may occur, and permanent tissue damage and death may result. **Hypothermia** can occur when *land temperatures* are **above** freezing or *water temperatures* are below 98.6°F/37°C. Cold-related illnesses can slowly overcome a person who has been chilled by low temperatures, brisk winds, or wet clothing.



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FROST BITE

What Happens to the Body:

FREEZING IN DEEP LAYERS OF SKIN AND TISSUE; PALE, WAXY-WHITE SKIN COLOR; SKIN BECOMES HARD and NUMB; USUALLY AFFECTS THE FINGERS, HANDS, TOES, FEET, EARS, and NOSE.

What Should Be Done: (land temperatures)

- Move the person to a warm dry area. Don't leave the person alone.
- Remove any wet or tight clothing that may cut off blood flow to the affected area.
- **DO NOT** rub the affected area, because rubbing causes damage to the skin and tissue.
- **Gently** place the affected area in a warm (105°F) water bath and monitor the water temperature to **slowly** warm the tissue. Don't pour warm water directly on the affected area because it will warm the tissue too fast causing tissue damage. Warming takes about 25-40 minutes.
- After the affected area has been warmed, it may become puffy and blister. The affected area may have a burning feeling or numbness. When normal feeling, movement, and skin color have returned, the affected area should be dried and wrapped to keep it warm. **NOTE:** If there is a chance the affected area may get cold again, do not warm the skin. If the skin is warmed and then becomes cold again, it will cause severe tissue damage.
- Seek medical attention as soon as possible.

HYPOTHERMIA - (Medical Emergency)

What Happens to the Body:

NORMAL BODY TEMPERATURE (98.6° F/37°C) DROPS TO OR BELOW 95°F (35° C); FATIGUE OR DROWSINESS; UNCONTROLLED SHIVERING; COOL BLUISH SKIN; SLURRED SPEECH; CLUMSY MOVEMENTS; IRRITABLE, IRRATIONAL OR CONFUSED BEHAVIOR.

What Should Be Done: (land temperatures)

- Call for emergency help (i.e., Ambulance or Call 911).
- Move the person to a warm, dry area. Don't leave the person alone. Remove any wet clothing and replace with warm, dry clothing or wrap the person in blankets.
- Have the person drink warm, sweet drinks (sugar water or sports-type drinks) if they are alert. **Avoid drinks with caffeine** (coffee, tea, or hot chocolate) or alcohol.
- Have the person move their arms and legs to create muscle heat. If they are unable to do this, place warm bottles or hot packs in the arm pits, groin, neck, and head areas. **DO NOT** rub the person's body or place them in warm water bath. This may stop their heart.

What Should Be Done: (water temperatures)

- Call for emergency help (Ambulance or Call 911). Body heat is lost up to 25 times faster in water.
- **DO NOT** remove any clothing. Button, buckle, zip, and tighten any collars, cuffs, shoes, and hoods because the layer of trapped water closest to the body provides a layer of insulation that slows the loss of heat. Keep the head out of the water and put on a hat or hood.
- Get out of the water as quickly as possible or climb on anything floating. **DO NOT** attempt to swim unless a floating object or another person can be reached because swimming or other physical activity uses the body's heat and reduces survival time by about 50 percent.
- If getting out of the water is not possible, wait quietly and conserve body heat by folding arms across the chest, keeping thighs together, bending knees, and crossing ankles. If another person is in the water, huddle together with chests held closely.

How to Protect Workers

- Recognize the environmental and workplace conditions that lead to potential cold-induced illnesses and injuries.
- Learn the signs and symptoms of cold-induced illnesses/injuries and what to do to help the worker.
- Train the workforce about cold-induced illnesses and injuries.
- Select proper clothing for cold, wet, and windy conditions. Layer clothing to adjust to changing environmental temperatures. Wear a hat and gloves, in addition to underwear that will keep water away from the skin (polypropylene).
- Take frequent short breaks in warm dry shelters to allow the body to warm up.
- Perform work during the warmest part of the day.
- Avoid exhaustion or fatigue because energy is needed to keep muscles warm.
- Use the buddy system (work in pairs).
- Drink warm, sweet beverages (sugar water, sports-type drinks). Avoid drinks with caffeine (coffee, tea, or hot chocolate) or alcohol.
- Eat warm, high-calorie foods like hot pasta dishes.

Workers Are at Increased Risk When…

- They have predisposing health conditions such as cardiovascular disease, diabetes, and hypertension.
- They take certain medication (check with your doctor, nurse, or pharmacy and ask if any medicines you are taking affect you while working in cold environments).
- They are in poor physical condition, have a poor diet, or are older.

APPENDIX G

EMERGENCY POSTER

URGENCE

1. **Alertez les responsables de l'expérience**
2. **Appelez le Service de sécurité**
   (450) 430-7981

SI PERSONNE NE RÉPOND
Appelez le 911

GELURE OU HYPOTHERMIE :

Suivez les instructions indiquées dans la chemise bleue marquée GELURE/HYPOTHERMIE, située à l'entrée de la chambre froide.

INTOXICATION PAR/CONTACT AVEC DU LIQUIDE DE DÉGIVRAGE :

Suivez les instructions indiquées dans la chemise orange marquée URGENCE – LIQUIDE DE DÉGIVRAGE située à l'entrée de la chambre froide.

EMERGENCY

1. **Alert the Test Staff**

2. **Call the Safety Department**
   (450) 430-7981

IF NO ONE IS AVAILABLE
Call 911

FOR FROST BITE OR HYPOTHERMIA
Follow procedures in the blue folder marked FROST BITE/HYPOTHERMIA hanging outside the chamber door.

FOR DEICING FLUID POISON/CONTACT
Follow procedures in orange folder marked DEICING FLUID EMERGENCY hanging outside the chamber door.

APPENDIX H

NASA TASK LOADING INDEX

INDICE DE LA CHARGE DE TRAVAIL DE LA NASA

INSTRUCTIONS

Nous sommes intéressés non seulement à évaluer votre performance, mais aussi à connaître votre expérience subjective de l'exécution des tâches qui vous ont été demandées. Voici comment nous allons nous y prendre pour obtenir cette information. En gros, nous nous pencherons sur la «charge de travail» que vous aurez ressentie. Le concept de charge de travail est difficile à définir avec précision, mais il est simple à comprendre. Divers facteurs influent sur notre expérience de la charge de travail : la tâche comme telle, nos sentiments à l'égard de notre performance, l'effort que l'on déploie, et le stress et la frustration que l'on ressent. La charge de travail associée à une tâche n'est pas toujours la même. Ainsi, elle peut s'alléger à mesure que l'on se familiarise avec la tâche, ou s'alourdir lorsqu'on passe d'une tâche à une autre, et il peut exister des versions faciles et difficiles d'une même tâche. Les composantes physiques de la charge de travail sont relativement faciles à conceptualiser et à évaluer. Mais il en va tout autrement des composantes mentales.

Comme la charge de travail est une expérience subjective, il n'existe pas de «règle» efficace pour mesurer la charge de travail associée à différentes activités. Une façon d'évaluer la charge de travail est de demander aux gens de décrire ce qu'ils ont ressenti en accomplissant une tâche. Comme la charge de travail est constituée de plusieurs facteurs, nous vous demanderons d'évaluer un par un ces facteurs, plutôt que de coter globalement la charge de travail. Les six échelles d'évaluation ont été conçues pour vous permettre d'indiquer comment vous vous êtes senti subjectivement au cours des différentes tâches. Veuillez lire attentivement la description de chacune des échelles. Si vous avez des questions sur l'une ou l'autre de ces descriptions, n'hésitez pas à me les poser. Il est extrêmement important qu'elles soient très claires pour vous. Vous pouvez garder ces descriptions avec vous pour pouvoir les consulter pendant l'expérience.

DÉFINITION DES ÉCHELLES D'ÉVALUATION		
Dimension	Cotes extrêmes	Description
EXIGENCE MENTALE	Faible/élevée	Quel niveau d'activité mentale et d'activité perceptive avez-vous dû déployer (p. ex., réfléchir, décider, calculer, se souvenir, examiner, chercher, etc.)? La tâche était-elle facile ou exigeante, simple ou complexe, astreignante ou agréable?
EXIGENCE PHYSIQUE	Faible/élevée	Quel niveau d'activité physique avez-vous dû déployer (p. ex., pousser, tirer, tourner, commander, activer, etc.)? La tâche était-elle facile ou exigeante, lente ou rapide, «mollo» ou fatigante, reposante ou pénible?
PRESSION TEMPORELLE	Faible/élevée	Dans quelle mesure vous sentiez-vous pressé par le temps, à cause de la cadence de la tâche? Ce rythme était-il lent et posé, ou rapide et frénétique?
EFFORT	Faible/élevé	Avez-vous dû travailler fort (mentalement et physiquement) pour atteindre votre niveau de performance?
PERFORMANCE	Bonne/médiocre	Dans quelle mesure pensez-vous avoir atteint les buts de la tâche, fixés par l'administrateur de tests (ou vous-même)? Dans quelle mesure êtes-vous satisfait de votre performance, par rapport à l'atteinte de ces buts?
FRUSTRATION	Faible/élevée	Dans quelle mesure vous sentiez-vous incertain, découragé, agacé, stressé et ennuyé, par opposition à sûr, heureux, content, détendu et satisfait de vous-même pendant que vous accomplissiez les tâches?

Observateur _________________ Date ____________________ Heure _____________

EXIGENCE MENTALE

Faible **Élevée**

EXIGENCE PHYSIQUE

Faible **Élevée**

PRESSION TEMPORELLE

Faible **Élevée**

EFFORT

Faible **Élevé**

PERFORMANCE

Bonne **Médiocre**

FRUSTRATION

Faible **Élevée**

IMPORTANCE DE BIEN SUIVRE LES INSTRUCTIONS

Pendant toute l'expérience, les échelles d'évaluation serviront à évaluer votre expérience subjective au cours des différentes tâches. Des échelles de ce genre sont extrêmement utiles, mais elles souffrent du fait que les gens ont tendance à les interpréter à leur manière. Par exemple, pour certaines personnes, l'exigence mentale ou la pression temporelle sont les aspects essentiels de la charge de travail, peu importe l'effort qu'ils ont déployé ou le niveau de performance qu'ils ont atteint. D'autres ont le sentiment que si leur performance est bonne, c'est que la charge de travail était forcément légère, et inversement. D'autres encore estiment que l'effort ou les sentiments de frustration sont les facteurs les plus importants de la charge de travail, et ainsi de suite. Des études antérieures ont déjà mis au jour toutes sortes de systèmes de valeurs. De plus, les facteurs qui contribuent à alourdir la charge de travail diffèrent d'une tâche à l'autre. Par exemple, la difficulté de certaines tâches peut tenir au fait qu'elles doivent être exécutées très rapidement. D'autres tâches peuvent paraître faciles ou difficiles en raison de l'intensité de l'effort mental ou physique exigé. D'autres encore semblent difficiles parce qu'il est impossible d'avoir une bonne performance, peu importe l'effort qu'on pourra déployer.

La fiche d'évaluation que l'on vous demande de remplir a été conçue par la NASA. Elle sert à évaluer l'importance relative que vous accordez à six facteurs dans la lourdeur de la charge de travail ressentie. La procédure est simple : on vous présente une série de paires de dimensions (par exemple, Effort vs Exigence mentale) et vous devez choisir quelle dimension a été plus importante que l'autre dans **votre** expérience de la charge de travail associée à la tâche (ou aux tâches) que vous venez d'exécuter. Chaque paire de dimensions apparaîtra une après l'autre sur l'écran. **Vous devez choisir chaque fois la dimension qui a le plus contribué à votre expérience subjective de la charge de travail associée à la tâche (ou aux tâches) que vous avez accomplie(s) au cours de l'expérience.**

Observateur ________________ Date ___________________ Heure ____________

À chaque rangée, choisissez la dimension qui a le plus contribué à votre expérience subjective de la charge de travail associée à la tâche que vous avez accomplie.

1	☐	**EXIGENCE MENTALE**	☐	**EXIGENCE PHYSIQUE**
2	☐	**EXIGENCE MENTALE**	☐	**PRESSION TEMPORELLE**
3	☐	**EXIGENCE MENTALE**	☐	**EFFORT**
4	☐	**EXIGENCE MENTALE**	☐	**PERFORMANCE**
5	☐	**EXIGENCE MENTALE**	☐	**FRUSTRATION**
6	☐	**EXIGENCE PHYSIQUE**	☐	**PRESSION TEMPORELLE**
7	☐	**EXIGENCE PHYSIQUE**	☐	**EFFORT**
8	☐	**EXIGENCE PHYSIQUE**	☐	**PERFORMANCE**
9	☐	**EXIGENCE PHYSIQUE**	☐	**FRUSTRATION**
10	☐	**PRESSION TEMPORELLE**	☐	**EFFORT**
11	☐	**PRESSION TEMPORELLE**	☐	**PERFORMANCE**
12	☐	**PRESSION TEMPORELLE**	☐	**FRUSTRATION**
13	☐	**EFFORT**	☐	**PERFORMANCE**
14	☐	**EFFORT**	☐	**FRUSTRATION**
15	☐	**PERFORMANCE**	☐	**FRUSTRATION**

INSTRUCTIONS

We are interested not only in assessing your performance but also the experiences you had during the different task conditions. Right now we are going to describe the technique that will be used to examine your experiences. In the most general sense we are examining the "workload" you experienced. Workload is a difficult concept to define precisely, but a simple one to understand generally. The factors that influence your experience of workload may come from the task itself, your feelings about your own performance, how much effort you put in, or the stress and frustration you felt. The workload contributed by different task elements may change as you get more familiar with a task, perform easier or harder versions of it, or move from one task to another. Physical components of workload are relatively easy to conceptualize and evaluate. However, the mental components of workload may be more difficult to measure.

Since workload is something experienced individually by each person, there are no effective "rulers" that can be used to estimate the workload of different activities. One way to find out about workload is to ask people to describe the feelings they experienced. Because workload may be caused by many different factors, we would like you to evaluate several of them individually rather than lumping them into a single global evaluation of overall workload. This set of six rating scales was developed for you to use in evaluating your experiences during different tasks. Please read the descriptions of the scales carefully. If you have a question about any of the scales in the table, please ask me about it. It is extremely important that they be clear to you. You may keep the descriptions with you for reference during the experiment.

RATING SCALE DEFINITIONS		
Title	Endpoints	Descriptions
MENTAL DEMAND	Low/High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	Low/High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
EFFORT	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
PERFORMANCE	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
FRUSTRATION LEVEL	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

MENTAL DEMAND

Low — High

PHYSICAL DEMAND

Low — High

TEMPORAL DEMAND

Low — High

EFFORT

Low — High

PERFORMANCE

Good — Poor

FRUSTRATION

Low — High

IMPORTANCE OF SCALE INSTRUCTIONS

Throughout this experiment the rating scales are used to assess your experiences in the different task conditions. Scales of this sort are extremely useful, but their utility suffers from the tendency people have to interpret them in individual ways. For example, some people feel that mental or temporal demands are the essential aspects of workload regardless of the effort they expended or the performance they achieved. Others feel that if they performed well, the workload must have been low, and vice versa. Yet others feel that effort or feelings of frustration are the most important factors in workload and so on. The results of previous studies have already found every conceivable pattern of values. In addition, the factors that create levels of workload differ depending on the task. For example, some tasks might be difficult because they must be completed very quickly. Others may seem easy or hard because of the intensity of mental or physical effort required. Yet others feel difficult because they cannot be performed well, no matter how much effort is expended.

The evaluation you are about to perform is a technique developed by NASA to assess the relative importance of six factors in determining how much workload you experienced. The procedure is simple: You will be presented with a series of pairs of rating scale titles (for example, Effort vs. Mental Demands) and asked to choose which of the items was more important to **your** experience of workload in the task(s) that you just performed. Each pair of scale titles will appear separately on the screen. **Select the Scale Title that represents the more important contributor to workload for the Specific task(s) you performed in this experiment.**

APPENDIX I

ILLUMINATION MEASUREMENTS

Illumination Measurements in the Cold Chamber
Two Thicknesses on Two Color Panels at Two Stations

Thickness	**Station**	**Panel Color**	**Ice Type**	**Illuminance foot candles**	**CCT K**	**Luminance foot-lamberts**	**Reflectance**
0.5	1	unpainted aluminum	full	16.2	1958	2.56	0.158025
0.5	1	unpainted aluminum	noise	16.2	1996	1.36	0.083951
0.5	2	unpainted aluminum	full	15.4	1966	2.76	0.179221
0.5	2	unpainted aluminum	noise	15.4	1966	1.85	0.12013
0.8	1	white	circle	16.2	1958	12.3	0.759259
0.8	1	white	noise	16.2	1996	12.2	0.753086
0.8	2	white	circle	15.4	1966	11.6	0.753247
0.8	2	white	noise	15.4	1966	12	0.779221