Thermal requirements for surviving a mass rescue incident in the Arctic: project update

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International Conference and Exhibition on Performance of Ships and Structures in Ice 2010 (ICETECH 2010), pp. 446-450, 2010-09-20

ICETECH 10-154 R2 — Thermal requirements for surviving a mass rescue incident in the Arctic: project update

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ABSTRACT

Passengers on cruise ships and aircraft traveling through the Arctic could expect to wait days for rescue, depending on weather and availability of large rescue craft. However, current standards do not specify thermal insulation for the equipment such as SOLAS[*] immersion suits or a Canadian Forces air-droppable survival kit that may be available to survivors. "MASSERT" is conducting a 3-year Transport Canada/SAR NIF-funded study to refine and validate long-term survival models and to recommend suitable thermal protection systems based on human experiments conducted in simulated arctic conditions in a lifeboat or air-droppable tent.

KEY WORDS

Arctic survival; thermal protection; long-term heat loss; thermal models; thermal manikins

INTRODUCTION

Recent increases in vessel and aircraft traffic through the Arctic, including new cruise ship routes (Arctic, 2009) and trans-polar flight routes (Boeing, 2003), are increasing the likelihood for a remote accident in extreme conditions. The search and rescue community estimates that passengers on cruise ships and aircraft in the arctic could expect to wait days for rescue, depending on weather and availability of large rescue craft. Temperatures in the arctic during the May to October cruise season can reach -20°C at night according to Environment Canada data, while survivors of an aircraft crash could experience ambient temperatures down to -40°C. In spite of these extremes, present standards including SOLAS (IMO, 2003) do not differentiate emergency equipment for arctic and warmer, less-remote regions on cruise ship itineraries. Likewise, aircraft on new trans-polar routes are not required to carry thermal protection for passengers.

Typically a large group of survivors may only have the contents of SOLAS lifeboats and immersion suits or the Canadian Forces air-droppable survival kits (allowing a day or two for delivery) to supplement their personal clothing to protect themselves from arctic conditions until rescue equipment with sufficient capacity arrives.

Considering scenarios such as a mass rescue incident in the Arctic is the focus of the **Maritime and Arctic Survival Scientific and Engineering Research Team (MASSERT)**. MASSERT includes representatives from industry, government and academia working together to recommend equipment and changes in standards that will enhance the health and safety, performance and survival of people working and traveling in the Arctic. The organizations affiliated with this team are listed in Table 1.

MASSERT is conducting a 3-year study funded through Transport Canada and the Search and Rescue Secretariat New Initiatives Fund (SAR NIF) and in-kind contributions from team members. The goals of the project are to investigate whether the current thermal protective

[*] International Convention for the Safety Of Life At Sea (SOLAS, 1974)

equipment and preparedness available to passengers traveling in the Canadian Arctic are adequate for surviving a major air or marine disaster and to identify the minimum thermal protection criteria for survival while awaiting rescue.

Table 1. MASSERT affiliates

Government partners:	
Canadian Coast Guard	Defence Research and Development Canada (DRDC)
International Maritime Organization (IMO)	National Research Council Canada Institute for Ocean Technology
Rescue Coordination Centre of New Zealand	
Academic partners:	
Brock University	Marine Institute Offshore Safety and Survival Centre
Memorial University Newfoundland (MUN) SafetyNet	MUN School of Human Kinetics
University of Texas	
Industry partners:	
The CORD Group	Helly Hansen Canada
Mustang Survival	

Terms. In this context, a "**major disaster**" involves more than 24 passengers (as defined by the Canadian Forces based on the limit of rescue helicopters currently available for the Arctic). The Canadian Forces uses the terms Major Air Disaster (MAJAID) and Major Marine Disaster (MAJMAR) for incidents involving the recovery, treatment and transport of crew and passengers from an advanced forward rescue base, or disaster scene, which exceeds the normal carrying load of one Cormorant SAR helicopter (24 persons). In the context of this project, MAJAID and MAJMAR will require a mass, multi-agency rescue operation designed to extract multiple passengers, victim of a major air or marine incident, from the harsh Arctic environment.

"**Current thermal protective equipment**" includes all equipment designed for the thermal protection of passengers and available or could be made available during a rescue operation. "**Preparedness**" refers to briefings to passengers and crew training on rescue and survival equipment, strategies and procedures that are relevant to survival in the Arctic. "**Passengers**" include all passengers and crew traveling for personal or professional reasons across the Canadian Arctic on board cruise ships, commercial vessels and aircraft during the normal traveling season for each mode.

"**Rescue**" occurs when the passengers are evacuated from the incident site. Based on the current SAR capacity in the Canadian Arctic region, passengers involved in a major incident should be able to survive for a period of 5 days before being rescued. Five days is the proposed retrieval time from IMO COMSAR considering the remoteness of areas such as Arctic and the lack of SAR resources (IMO, 2006)

It is assumed that the passengers survived the initial event and that hydration, injuries and health are not limiting factors for the targeted population. There is evidence from the literature of significant risk of dying from spontaneous ventricular fibrillation when core temperature drops below 28°C. "**Adequate for survival**" implies being able to maintain core temperature above 28°C for at least 5 days. Thus, for the purpose of this project, death by hypothermia is the outcome of interest.

This paper describes the methodology that will be used to achieve these goals and the potential import of the results.

METHOD

The project includes 3 phases. Phase 1 assesses the thermal protection offered by clothing ensembles currently available in a mass rescue scenario. Phase 2 investigates human shivering endurance to validate survival models. Phase 3 compares existing ensembles to a system based on recommendations from the earlier phases.

Phase 1 Methods

In Phase 1, completed in winter 2009/2010, the thermal protection offered by clothing ensembles typically available to cruise ship and airline passengers in an emergency were tested using two thermal manikins in simulated arctic conditions. This would include the clothing available to passengers, liferaft, lifeboat, and equipment in an air droppable survival kit such as the MAJAID or MAJMAR kits. It also refers to the equipment typically available onboard cruise ships and commercial vessels and aircrafts currently traveling in the Canadian Arctic with more than 24 passengers.

To represent the current thermal protective equipment, the thermal resistance for a range of clothing recommended for survival kits such as SOLAS liferaft gear and the air-droppable MAJAID kit were measured.

The test plan included wet and dry ensembles in windy and calm conditions at near-zero and sub-zero temperatures.

Facilities & Equipment. The tests were conducted in the CORD Group Wind Tunnel and the Composites Atlantic Environmental Simulation Lab using the IOT and CORD Group thermal manikins: respectively, NEMO (Measurement Technology NW) and the TIM™ Thermal Instrumented Manikin (The CORD Group), shown in Figure 1. The Wind Tunnel is equipped with an array of four large (42-inch diameter, 3 horsepower) fans and can maintain temperatures to ±0.5°C; the Environmental Simulation Lab can maintain temperatures to ±0.1°C.

Figure 1. Thermal manikins NEMO and TIM™ testing immersion suits

Instrumentation. Each manikin measures power by segment (22 for NEMO, 13 for TIM) and calculates the thermal resistance of its clothing. Wind speed is measured with a propeller-style digital anemometer (±0.1 m/s).

Test procedures. Arctic conditions were simulated in the CORD Group Wind Tunnel using ambient outside air to maintain a 7°C ±0.5°C environment with and without wind and in the thermally-controlled Composites Atlantic Environmental Simulation Lab at -15°C ±0.1°C.

The clothing ensembles (listed in Table 2) included cabin wear, layered thermal clothing, SOLAS-approved immersion suits and parkas that are supplied with the MAJAID kit.

Table 2. Phase 1 clothing ensembles

1	Cabin wear (aircraft/boat) – socks, briefs, jeans, long sleeve shirt, shoes
2	Deck wear – cabin wear plus long underwear, fleece, WVP† shell and head wear and hand wear (rationale: would likely protect head and hands when donning 4 layers of clothing)
3	Expedition wear #1 – deck wear but wool socks, boots.
4	Expedition wear #2 – Expedition wear #1 minus WVP plus "wet suit" style buoyant coat or jacket or suit
5	Abandonment wear #1a – Deck wear (gloves replace mitts because TPA‡ has gloves) + TPA + SOLAS life preserver
6	Abandonment wear #1b – Deck wear (gloves replace mitts because suit has gloves) + Once-only ship abandonment suit (bag with a draw string) + SOLAS life preserver
7	Abandonment wear #2 – Deck wear (gloves replace mitts because suit has gloves) but wool socks minus footwear + SOLAS immersion suit (rationale: footwear too cumbersome)
8	MAJAID #1 – Cabin wear minus shoes, parka, pants, head/hand/footwear (rationale: likely survivors when MAJAID delivered would have dry clothing)
9	MAJAID #2 - MAJAID #1 worn inside casualty bag

Each ensemble was tested dry on both manikins at 5°C in calm and in wind (~8 m/s) and at -15°C in calm. Selected ensembles were also tested wet. The test plan is listed in Table 3

Table 3. Phase 1 test plan

Ensembles	Ensemble condition	Temperature	Wind
all	Dry	+7ºC	0 m/s
1, 3, 8	Wet	+7°C	0 m/s
all	Dry	+7ºC	8 m/s
1, 3, 8	Wet	+7°C	8 m/s
1, 3, 8	Wet	-15°C	0 m/s
1, 3, 8	Wet	-15°C	8 m/s

Expected outcome. The results of Phase 1 were analyzed and input to the Cold Water Survival Model (Wissler, 1985) to predict conditions suitable for Phase 2.

Phase 2 Methods

Phase 2 testing, to be completed by September 2010, investigates human shivering endurance. Shivering is a natural physiological response to maintain heat balance in a cold environment by generating heat through large muscle activity. Shivering has been studied with subjects exposed to cold for up to 6 hours. However, for long-term exposure (on the order of days), an identified gap in the literature is whether low-intensity shivering could be sustained given fuel (ingested calories) to maintain the required metabolic rate (Tikuisis, Eyolfson, & Giesbrecht, 2002). This knowledge is required for the development of the survival model that will be used in the recommendations for suitable thermal protection systems

In this phase, subjects are exposed to a fixed cool temperature in a thermally-controlled chamber for up to 24 hours to determine whether low-intensity shivering is a sustainable activity given periodic energy in the form of survival rations or whether muscle exhaustion occurs.

In addition to finding a limit for shivering endurance, this phase will investigate the following questions:

1. Will cognitive performance be significantly affected by long-term exposure to cold conditions?
2. Will individuals be able to perform the basic survival skills necessary to signal for help after 24 hours of cold exposure?
3. How long will individuals be able to maintain heat balance in cold conditions?
4. What are the effects of prolonged mild cold exposure on major physiological systems?
5. How might these effects impact overall survival: cardiovascular response, neuromuscular function, metabolism, and blood flow distribution

Facilities & Equipment. The human subject testing will be conducted in the environmental chamber at the Brock University Environmental Ergonomics Laboratory.

Instrumentation & Tests. For each subject, heart rate, blood pressure, skin temperature, heat flow, core temperature and muscular activity and shivering intensity (via electromyography) will be continuously measured and monitored. Periodically, expired gases will be collected using a Moxus metabolic cart, from which metabolic rates will be calculated. The instruments are listed in Table 4. Pre- and post-experiment and every 6 hours during the experiment, subject cardiac response to an orthostatic challenge and muscle function will be tested. Urine and blood samples will also be taken periodically (every 6 hours) to measure hydration and metabolic by-products including lactate, glucose, non-esterified fatty acids, insulin, and cortisol.

† water vapour permeable
‡ thermal protective aid (SOLAS, 1974)

Table 4. Phase 2 instrumentation

Criteria	Instrument
% body fat	skinfold thickness measurement
heart rate and heart rate variability	Polar RS800 telemetric heart rate monitor
skin temperature, heat flow	heat flow sensors (13)
core temperature	Ingestible telemetric pill (CorTemp™, HQInc)
cardiovascular function (blood pressure, baroreflex function, cardiac output)	NexFin cardiovascular monitor
muscle activity (shivering intensity) over 8 muscle sites	Electromyography (Muscle Tester ME3000)
Muscle function and dexterity	Variety of manual function tests (e.g. grip strength, Purdue Pegboard assembly task), maximal voluntary contractions and force production tasks
Responses of fingers to cold exposure	Skin blood flow (Perimed 5000 laser-Doppler monitor), skin temperature (Mallinkrodt skin temperature sensors)
expired gases (oxygen consumption, metabolic heat production)	AEI Technologies Moxus Modular VO2 System

Test procedures. The Research Ethics Boards of Brock University and NRC approved human subject testing as described in part here following a full review. Sixteen healthy male and female participants, 18-55 years of age with no major illnesses or injuries, will be recruited for the proposed research. The participants will be recruited from a specialized population that has experienced long-term cold exposure situations.

Participants will be randomly assigned to one of two conditions (cold exposure or control, i.e., no cold exposure). Those individuals selected to complete the cold exposure testing will complete both physiological and cognitive assessments before, during, and following a 24-hour cold exposure while those who are assigned to the control group will complete the assessments during a familiarization session and after a 24 hour delay.

During the familiarization test, predicted Maximal Oxygen Consumption (VO_{2peak}) will be determined on a treadmill capable of regulating and recording speed (up to 5 mph for females, 6 mph for males) and incline (up to 12%). This maximal test will be used to determine a pace that is equivalent to 50% of their VO_{2peak} for a distance of 5 km during the pre/post-exposure testing. Additionally, body fat percentage, lean body mass, and resting metabolic rate will be collected.

During cold exposure, subjects will be in the thermal climate chamber at a constant cool (5°C) temperature to elicit the shivering response for a period up to 24 hours. Subjects will be clad in light clothing (t-shirt, briefs) and socks and gloves to prevent non-freezing cold injuries. Metabolic rate will be measured over a 24-hour exposure as subjects perform intermittent cognitive tests. Subjects will be fed SOLAS life rations on a fixed schedule to provide energy. Participants will be free to move about the chamber to sleep, eat, and relax.

Cognitive testing will be performed at each stage. The proposed tests are listed in Table 5.

Table 5. Phase 2 cognitive tests

Criteria	Test
mindfulness	cognitive failures questionnaire (CFQ)
advanced observation and clear thinking	Raven's Advanced Progressive Matrices (RAPM)
attention and spatial awareness	attention network test (ANT) Groton maze learning test Hebb-Williams maze Vandenberg Mental Rotation Test (VMRT) Guilford-Zimmerman Spatial Orientation Test (GZSOT)

Expected outcome. This analysis is expected to be complete in fall 2010 to improve existing survival models including Cold Water Survival Model provided by Eugene Wissler (Wissler 1985) and CESM used by DRDC to predict survival time. Based on the outcome from Phase 2, a thermal protection system will be recommended for use in a five-day survival scenario.

Phase 3 Methods

In Phase 3, human subjects clad in clothing required by current regulations for use in survival kits will be tested against the recommendations of this study in simulated arctic conditions.

Facilities & Equipment. The tests will be conducted in the IOT Ice Tank in St. John's. An enclosure (either a SOLAS liferaft or MAJAID tent) will be installed on a sheet of ice designed to support humans working on it. The Ice Tank controls the air and water temperatures; fans will be used to generate wind. The IOT thermal manikin may be used during an extreme cold scenario.

Instrumentation & Tests. Subjects will be instrumented for skin temperature, heat flow and core temperature. Periodically, expired gases will be collected as for Phase 2. Similarly, cognitive testing will also be performed. The proposed instruments are listed in Table 6.

Table 6. Phase 3 instrumentation

Criteria	Instrument
skin temperature, heat flow	heat flow sensors (13)
core temperature	rectal probe
expired gases	AEI Technologies Moxus Modular VO2 System

Test procedures. The Ice Tank air temperature will be controlled at -15°C; some tests will include wind. Subjects will be instrumented and clad in one of the two clothing ensembles and seated in the enclosure. The test will continue for up to 8 hours. Subjects will return after a wash-out period (2 days) to test the alternate clothing ensemble. Cognitive testing will be conducted as for Phase 2.

Expected outcome. This experiment is scheduled for February to March 2011. The results may confirm the need for a higher level of thermal protection than the equipment currently required.

EXPECTED OUTCOME

The findings from this research will help provide a better understanding of the likelihood of survival with current equipment available to accident victims in the Arctic. The knowledge gained can be used to improve survival prediction tools.

The project results will help Transport Canada address shortcomings in current international guidelines (IMO, 2002) by recommending improved clothing and equipment to enhance survival and improved regulations.

While the Arctic has attracted a lot of interest in escape, evacuation and rescue (EER) from the offshore oil and gas industry, it has not drawn nearly the same attention from the cruise industry. Yet, Arctic cruise tourism is increasing, with over 1.5 million people visiting Alaska, Norway, Iceland, Canada, Greenland and Russia each year. The untrained, unprotected and generally much older passengers, many with mobility problems and other health factors, are at far greater risk than the workers in the well-regulated offshore oil industry.

This research will identify and quantify risk factors and recommend steps to reduce the risks inherent in the burgeoning Arctic.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the other members of the Maritime and Arctic Survival Scientific & Engineering Research Team for their expert advice on the conception and execution of this project, including:

Fabien Basset, Memorial University of Newfoundland School of Human Kinetics

Rob Brown and James Boone (dec.), Marine Institute Offshore Safety and Survival Centre

Brian Farnworth and Ross Johnston, Helly Hansen Canada

Heike Hoppe, International Maritime Organization

Ron Kroeker, National Search and Rescue Secretariat

Andrew Kuczora, NRC Institute for Ocean Technology

David Lever, Canadian Coast Guard

Scott MacKinnon, Memorial University of Newfoundland SafetyNet

Paul Potter and Dana Sweeney, The CORD Group

David Wilson, Rescue Coordination Centre of New Zealand

Wendell Uglene, Mustang Survival

E.H. Wissler, University of Texas

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