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Heat stress mitigation for Leopard 2C tank crew

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Defence R&D Canada
Technical Report
DRDC Toronto TR 2007-082
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Canada

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In conducting the research described in this report, the investigators adhered to the policies and procedures set out in the Tri-Council Policy Statement: Ethical conduct for research involving humans, National Council on Ethics in Human Research, Ottawa, 1998 as issued jointly by the Canadian Institutes of Health Research, the Natural Sciences and Engineering Research Council of Canada and the Social Sciences and Humanities Research Council of Canada.

Abstract

The Directorate Armament Sustainment Programme Management (DASPM) requested Defence R&D Canada (DRDC) support with the investigation and recommendation of "...technologies available to mitigate the effects of the heat stress expected for Leopard 2C crews operating in the Kandahar region of Afghanistan in summer." DRDC was asked to focus "...on technologies that are likely to be able to be delivered and installed by the beginning of June 2007."

Candidate heat stress mitigation strategies, technologies, technical reports, scientific reports, and commercial product specifications were reviewed in light of the timelines and engineering constraints. It was decided to test a vapour compression liquid circulating product as a "proof of concept" that personal micro-climate cooling would significantly mitigate the anticipated heat stress challenge in theatre. In addition, a specially designed solar heat dissipation textile was fitted to the exterior of the tank. The effects of these products were evaluated by monitoring the tank temperatures, the tank crew members' body temperatures, physiological and perceptual responses to a standardized heat stress. The heat stress involved exposure of the tank and crew members in the tank to an external air temperature of 44°C or 35°C and a simulated solar heat load of 1120 W/m^2 in accordance with NATO STANAG 2895 which provides guidance on meteorological conditions that should be used for testing of materiel in accordance with the location in the world where the equipment will be deployed.

The crew members were exposed to the heat stress on five consecutive days, either with or without the cooling or the solar shield. The cooling system consisted of a chiller unit and a worn distribution vest (liquid cooling garment or LCG) which interfaced via thick-walled supply and return lines. It was estimated that 40-164 W of cooling reached the LCG.

The results suggest that without mitigation of the heat stress, the warmest days in the Kandahar region of Afghanistan would likely render Leopard crew members as operationally impaired within 1-2 hours, and heat casualties soon thereafter. The technology review indicated that the most viable solution in the available timelines involves a powered active-cooling system capable of delivering a continuous and constant 150W of cooling to each crew member. The LCG evaluated in this trial can mitigate the heat stress to the extent that crew members would likely be able to at least double their operationally effective duration when outside temperature is as high as 44°C. In the more frequently encountered 35°C conditions, crew should be able to avoid debilitating heat strain for at least 3-5 hours.

Résumé

La Direction de l'Administration du programme de soutien de l'armement a demandé à RDDC de l'aider à enquêter et de faire des recommandations sur « …les technologies disponibles pour l'atténuation de l'impact du stress thermique anticipé sur les équipages des chars Leopard 2C en mission durant l'été dans la région de Kandahar en Afghanistan ». On a demandé à RDDC de concentrer ses efforts « …sur les technologies qui peuvent vraisemblablement être envoyées sur place et installées d'ici le début juin 2007 ».

Les stratégies, technologies, rapports techniques, rapports scientifiques et spécifications de produits commerciaux d'intérêt potentiel pour l'atténuation de l'impact du stress thermique ont été passés en revue à la lumière du délai imposé et des contraintes techniques liées à la mise en application de ces technologies. Il a été décidé de mettre à l'essai un système de circulation des liquides par compression de vapeur pour vérifier, à titre de « validation de principe », si un système personnel de refroidissement en microclimat pouvait atténuer de façon significative l'impact du stress thermique anticipé sur le théâtre des opérations. De plus, un tissu spécialement conçu pour dissiper la chaleur du soleil a été posé sur l'extérieur du char. L'impact de ces produits a été évalué en mesurant la température à divers endroits sur le char, la température interne des membres de l'équipage et leurs réactions physiologique et perceptive à des contraintes thermiques normalisées. Pour ce faire, le char et son équipage, dont chaque membre était installé à sa position assignée, ont été exposés à des températures ambiantes de 44 ^{o}C ou 35 ^{o}C et à une charge calorique simulée de 1120 W/m², conformément à la STANAG 2895 de l'OTAN qui donne des précisions sur les conditions météorologiques à utiliser pour la mise à l'épreuve du matériel en fonction de l'endroit du monde où il doit être déployé.

Les membres de l'équipage ont été exposés à des contraintes thermiques pendant cinq jours consécutifs, avec ou sans refroidissement ou bouclier solaire. Le système de refroidissement était constitué d'une unité de refroidissement et d'une veste de distribution (ou LCG, de l'anglais *Liquid Cooling Garment*) portée par les équipiers, reliées l'une à l'autre par des canalisations d'alimentation et de retour à paroi épaisse. On estime que la puissance de refroidissement dans les LCG était de l'ordre de 40 à 164 W.

Les résultats semblent indiquer que, sans atténuation du stress thermique, les facultés des membres d'équipage des chars Leopard seraient considérablement affaiblies sur le plan opérationnel dans l'espace d'une ou deux heures durant les journées les plus chaudes de la région de Kandahar en Afghanistan, et qu'ils seraient mis hors de combat peu après. L'étude des technologies a indiqué que la solution la plus viable, compte tenu de la limite de temps imposée, était un système de refroidissement actif mécanique capable de produire une puissance de refroidissement continue et constante de 150 W à chaque membre d'équipage. La LCG évaluée au cours des essais peut atténuer l'impact du stress thermique à tel point que les membres d'équipage pourraient vraisemblablement être en mesure de doubler leur durée effective en opération même si température extérieure atteint 44 ^{o}C. Dans les températures que l'on rencontre plus souvent, soit autour des 35 ^{o}C, les équipages devraient pouvoir éviter les effets débilitants de l'astreinte thermique pendant au moins 3 à 5 heures.

Executive summary

Heat Stress Mitigation for Leopard 2C Tank Crew

Ira Jacobs; Robert Michas; Robert Limmer; Debbie Kerrigan-Brown; Tom McLellan; Philippe Turbide; DRDC Toronto TR 2007-082; Defence R&D Canada – Toronto; May 2007.

Background: The Directorate Armament Sustainment Programme Management (DASPM) requested Defence R&D Canada (DRDC) support with the investigation and recommendation of "...technologies available to mitigate the effects of the heat stress expected for Leopard 2C crews operating in the Kandahar region of Afghanistan in summer." DRDC was asked to focus "...on technologies that are likely to be able to be delivered and installed by the beginning of June 2007." It was decided to test a vapour compression liquid circulating product as a proof of concept that a commercial off-the-shelf (COTS) personal micro-climate cooling system can significantly mitigate the heat stress challenge anticipated in theatre. In addition, a specially designed solar heat dissipation textile was fitted to the exterior of the tank. The effects of these products were evaluated by monitoring the tank temperatures, the tank crew members' body temperatures, and their physiological and perceptual responses to a standardized heat stress. The heat stress involved exposure of the tank and crew members in the tank to an external air temperature of 44°C or 35°C and a simulated solar heat load of 1120 W/m^2 in accordance with NATO STANAG 2895. The crew members were exposed to the heat stress on five consecutive days, either with or without the cooling or the solar shield. The cooling system consisted of a chiller unit and a worn distribution vest (liquid cooling garment or LCG) which interfaced via thick-walled supply and return lines.

Results: Internal tank temperatures reached 64°C in the crew commander position and around 55°C in the other crew positions. The solar shield did not significantly affect tank internal ambient temperature, probably because of air movement through the open hatches. In the absence of cooling, the high temperatures induced severe physiological and perceptual heat strain in the crew. The higher physical activity level of the "loader" exacerbated the heat strain. The open hatch above the crew commander position exacerbated the strain from the solar heat in that position. It was estimated that 40-164 W of cooling reached the LCG. Tolerance times of the crew ranged from about 1-2 hours without cooling; tolerance was approximately doubled with the LCG during the 44°C trial and extended to at least 5.5 hours during a trial at 35°C.

Significance: The results suggest that without mitigation of the heat stress, the warmest days in the Kandahar region of Afghanistan would likely render Leopard crew members as operationally impaired within 1-2 hours, and as heat casualties soon thereafter. The technology review indicated that the most viable solution in the available timelines involves a powered active-cooling system capable of delivering a continuous and constant 150W of cooling to each crew member. The COTS LCG evaluated in this trial can mitigate the heat stress to the extent that crew members would likely be able to at least double their operationally effective duration when outside temperature is as high as 44°C. In the more frequently encountered 35°C conditions, crew should be able to avoid debilitating heat strain for at least 3-5 hours with the LCG system.

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Heat Stress Mitigation for Leopard 2C Tank Crew

Ira Jacobs; Robert Michas; Robert Limmer; Debbie Kerrigan-Brown; Tom McLellan; Philippe Turbide; DRDC Toronto TR 2007-082; R & D pour la défense Canada – Toronto; Mai 2007.

Contexte: La Direction de l'Administration du programme de soutien de l'armement a demandé à RDDC de l'aider à enquêter et de faire des recommandations sur « […] les technologies disponibles pour l'atténuation de l'impact du stress thermique anticipé sur les équipages des chars Leopard 2C en mission durant l'été dans la région de Kandahar en Afghanistan ». On a demandé à RDDC de concentrer ses efforts « …sur les technologies qui peuvent vraisemblablement être envoyées sur place et installées d'ici le début juin 2007 ». Il a été décidé de mettre à l'essai un système de circulation des liquides par compression de vapeur pour vérifier, à titre de validation de principe, si un système personnel de refroidissement en microclimat disponible dans le commerce pouvait atténuer de façon significative l'impact du stress thermique anticipé sur le théâtre des opérations. De plus, un tissu spécialement conçu pour dissiper la chaleur du soleil a été posé sur l'extérieur du char. L'impact de ces produits a été évalué en mesurant la température à divers endroits sur le char et la température interne des membres de l'équipage, et leurs réactions physiologique et perceptive à des contraintes thermiques normalisées. Le char et son équipage ont été exposés à des températures ambiantes de 44 ^{o}C ou 35 ^{o}C et à une charge calorique simulée de 1120 W/m², conformément à la STANAG 2895 de l'OTAN. Les membres de l'équipage ont été exposés à des contraintes thermiques pendant cinq jours consécutifs, avec ou sans refroidissement ou bouclier solaire. Le système de refroidissement était constitué d'une unité de refroidissement et d'une veste de distribution (ou LCG, de l'anglais *Liquid Cooling Garment*) portée par les équipiers, reliées l'une à l'autre par des canalisations d'alimentation et de retour à paroi épaisse.

Résultats: À l'intérieur du char, les températures ont atteint 64 ^{o}C à la position du chef de char et autour de 55 ^{o}C aux autres positions. Le bouclier thermique n'a pas eu d'incidence importante sur la température ambiante à l'intérieur du char, probablement en raison de la circulation de l'air par les trappes ouvertes. Sans refroidissement, les températures élevées ont provoqué des troubles physiologiques et de perception liés au stress thermique chez les membres de l'équipage. Le niveau d'activité physique plus élevé associé au poste de chargeur a exacerbé l'astreinte thermique. Le fait que la trappe soit ouverte au-dessus de la position du chef de char a exacerbé l'astreinte associée à la chaleur solaire à cette position. On estime que la puissance de refroidissement dans les LCG était de l'ordre de 40 à 164 W. Les temps de tolérance des équipages ont été d'environ une à deux heures sans refroidissement; la tolérance a approximativement doublé avec le port du LCG durant l'essai à 44 ^{o}C et a même dépassé 5,5 heures durant l'essai à 35 ^{o}C.

Portée: Les résultats semblent indiquer que, sans atténuation du stress thermique, les facultés des membres d'équipage des chars Leopard seraient considérablement affaiblies sur le plan opérationnel dans l'espace d'une ou deux heures durant les journées les plus chaudes de la région de Kandahar en Afghanistan, et qu'ils seraient mis hors de combat peu après. L'étude des technologies a indiqué que la solution la plus viable, compte tenu de la limite de temps imposée,

était un système de refroidissement actif mécanique capable de produire une puissance de refroidissement continue et constante de 150 W à chaque membre d'équipage. La LCG évaluée au cours des essais peut atténuer l'impact du stress thermique à tel point que les membres d'équipage pourraient vraisemblablement être en mesure de doubler leur durée effective en opération même si température extérieure atteint 44 ^{o}C. Dans les températures que l'on rencontre plus souvent, soit autour des 35 ^{o}C, les équipages devraient pouvoir éviter les effets débilitants de l'astreinte thermique pendant au moins 3 à 5 heures.

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1 Introduction

The Directorate Armament Sustainment Programme Management (DASPM) requested Defence R&D Canada (DRDC) support with the investigation and recommendation of "...technologies available to mitigate the effects of the heat stress expected for Leopard crews operating in the Kandahar region of Afghanistan in summer." DRDC was asked to focus "...on technologies that are likely to be able to be delivered and installed by the beginning of June 2007."

The initial meeting to discuss the problem and approach was convened by DASPM-6 on 11 January 2007. The following issues were addressed at the meeting:

a. There was a requirement to rapidly clarify the "worse-case scenario" in terms of the magnitude of the expected heat stress and strain on the tank systems and crew members during the summer in the Kandahar region of Afghanistan.

b. The Climatic Facility at the National Research Council Centre for Surface Transportation Technology (CSTT) in Ottawa had been reserved for tank and crew testing during the first two weeks of February 2007.

c. DRDC Toronto could assist with assessment of the heat stress on the crew and mitigation strategies. A "proof of concept" trial would be beneficial in clarifying whether available crew cooling technologies would provide operational benefits. DASPM-6 would identify a pool of tank crew personnel from which test volunteers could be drawn.

d. Any proposed mitigation strategy should be viable in terms of being applied to all of the approximately twenty Leopard 2C vehicles that would be operational in Afghanistan, and the solution needed to be implemented for summer 2007 operations.

e. An announcement would be issued by Public Works and Government Services Canada inviting industry to provide crew cooling solutions for assessment that met the following requirements:

    i. system must be assessed during the time the CSTT chamber, tank, and crew were available for testing;

    ii. if selected, be operational in theatre for summer 2007 operations;

    iii. if electrically powered, draw no more than 45 amperes at 24 volts peak.

2 Background

2.1 Technology review

DRDC Toronto has a long history of scientific activities and human-systems integration work involving the application of personal cooling systems for heat stress mitigation, and system integration into specialized military life support and safety equipment. In fact we believe that the first military combat use of powered micro-climate cooling by any country was during the 1991 Gulf War when Canadian Forces (CF) Sea King crew successfully deployed an active liquid cooling system embedded into their underclothes while wearing TOPP High protective clothing. That system was identified, tested, and integrated with crew operations by DRDC Toronto (formerly known as Defence & Civil Institute of Environmental Medicine). For the current work the same expertise and the related defence research networks were exploited to facilitate consultations with scientists and engineers in allied defence research organizations where similar expertise is resident. The consultations resulted in a review and consideration of candidate heat stress mitigation strategies, technologies, technical reports, and scientific reports provided by these research networks, as well as a review of commercial product specifications brought to our attention in the course of our consultations. Specifically, we consulted with the following:

a. engineers and scientists at the Natick Soldier Center at the US Army Research, Development and Engineering Command, who recently conducted a comprehensive review and evaluation of COTS microclimate cooling systems (Laprise et al., 2005) and who are project managers responsible for the development and integration of personal cooling systems in several United States Army land and rotary wing platforms;

b. a defence scientist at the US Naval Health Research Center, with many years of responsibility and experience for related ship-board research and development (R&D) and personal micro-climate conditioning systems for naval personnel who experience heat stress of a similar magnitude to that anticipated inside of an armoured vehicle;

c. a defence scientist at Australia's Defence Science & Technology Organization, Human Performance & Protection Division, who conducted an evaluation of heat stress and mitigation strategies in their version of the Leopard tank;

d. a defence scientist at the Israeli Defence Forces Heller Institute of Medical Research, who was a project manager for the development and integration of the personal crew cooling system in their Merkava battle tank.

2.2 Micro-climate conditioning technology choice

A recent, relevant, and useful report by the US Army Research, Development and Engineering Command provided an excellent review of "commercial, off-the-shelf" products. The report includes a technology classification categorization (Laprise et al., 2005) of micro-climate cooling systems into one or more of the following groups: evaporative products, passive phase change material products, vapour compression liquid circulating products, thermoelectric liquid circulating products, compressed air products, active phase change material products, and other products.

Our technology review resulted in a recommendation to DASPM-6 that a vapour compression liquid circulating product be tested as proof of concept that personal micro-climate cooling would offer operational benefits given the magnitude and duration of the anticipated heat stress challenge for Leopard crew members. This recommendation was based on consideration of the following factors:

a. availability of COTS products;
b. time-lines available for testing, procurement, integration with the vehicle;
c. electrical power limitations in the vehicle;
d. logistical challenges associated with replenishing systems that are not electrically powered;
e. safety concerns such as flammability;
f. cooling power and duration of effective cooling;
g. analysis of available test and evaluation reports.

2.3 Med-Eng system description

The announcement mentioned in section 1e. above resulted in the identification and delivery for assessment of one such vapour compression liquid circulating product manufactured by Med-Eng Systems, Inc. (Ottawa, Ontario, Canada) The system and its components are depicted in Figures 1-3. The two primary components are a vapour-compression chiller unit (the cooling source) and a worn distribution vest (the liquid cooling garment, or LCG). They interface via thick-walled supply and return lines. The connector at the end of the vest tether can be released manually or, for easy rapid vehicle egress, with a nominal 12-pound pull. Two different chiller units (DC250, DC500) were provided; relevant Leopard trial application and performance specifications are listed in Table 1. Line length was about 3-4.5 metres, depending on crew position. The DC500 and parts of lines exposed to radiant heat were protected with insulation.

Table 1. Characteristics of chiller units manufactured by Med-Eng Systems, Inc.

	DC250	**DC500**
Trial Application:	3 crew positions in turret (gunner, commander & loader)	1 crew position in hull (driver)
Location in Trial:	On top of turret	Inside hull, behind driver
Cooling Capacity:	600 W	500 W
Input Power:	25 A @ 28 VDC	21 A @ 28 VDC
Circulating Fluid:	50/50 mixture, propylene glycol & water	Same as DC250
Total Output Flow:	2.1 litres/min	1.7 litres/min

Figure 1. Med-Eng Systems DC250 and DC500 chiller units.

a. Opened flat

b. Closed as worn

Figure 2. Liquid cooling garment (LCG) with supply/return lines

Figure 3. Connector between vest and supply/return lines

Figure 4. Liquid cooling garment worn under uniform

2.4 Test objectives

A test protocol was designed with the following objectives:

a. determination of the magnitude of the heat stress inside of the vehicle in accordance with NATO STANAG 2895 (Extreme Climatic Conditions and Derived Conditions for Use in Defining Design/Test Criteria for NATO Forces Materiel);

b. clarification of the Leopard crew members' physiological and perceptual responses to the heat stress;

c. clarification of the crew members heat tolerance improvements, if any, as a result of using the LCG; and,

d. clarification of crew heat-stress mitigation benefits, if any, associated with a novel solar protection textile fitted to the exterior of the tank. This solar shield was developed by DRDC Valcartier.

3 Test methods

3.1 Approval of human testing protocol

Testing involved the use of human volunteers as test subjects. The test protocol was approved in accordance with those Department of National Defence Administrative Orders and Directives applicable to research with human subjects. The approving authorities were the Defence R&D Canada Human Research Ethics Committee (approved as Revised Protocol L-586) as well as the National Research Council's Ottawa Research Ethics Board (approved as Application 2007-01).

3.2 Trial design

Three experienced Leopard 2C crew members volunteered as test subjects on five consecutive test days. The first four test days were conducted using temperatures and solar heat levels recommended in NATO STANAG 2895, i.e. 44°C and 1120 W/m^2, respectively. A fifth test day, using a less extreme and more frequently encountered summer temperature in Afghanistan (i.e. 35°C) was added with a view to testing the robustness of the cooling system over a more prolonged period. Thus, the test days were as follows:

a. Test Day I - No Cooling Vehicle Unshielded (NCVU): subjects did not wear the LCG and the vehicle did not have a solar protection covering, at 44°C;

b. Test Day II - Active Cooling Vehicle Unshielded (ACVU): subjects wore the LCG and the vehicle did not have a solar protection covering, at 44°C;

c. Test Day III – No Cooling Vehicle Shielded (NCVS): subjects did not wear the LCG and the vehicle was fitted with the solar protection covering, at 44°C;

d. Test Day IV – Active Cooling Vehicle Shielded (ACVS): subjects wore the LCG and the vehicle was fitted with the solar protection covering, at 44°C;

e. Test Day V – Active Cooling Vehicle Shielded 35°C (ACVS35): subjects wore the LCG and the vehicle was fitted with the solar protection covering. Testing occurred at an external ambient temperature of 35°C.

3.3 Test location

All testing occurred in the vehicle climatic chamber located at the National Research Council Centre for Surface Transportation Technology (CSTT) in Ottawa. The test subjects occupied crew stations inside a Leopard C2 tank in the chamber.

3.4 Test procedures

Subjects followed identical procedures for all trials. After their arrival at the test location, their resting blood pressure and heart rate were measured using an automated electronic device after a 10 minute sitting period to identify any abnormal responses. Abnormal was defined for this study as a systolic blood pressure >140 mmHg, diastolic blood pressure >90 mmHg, and/or resting heart rate >100 beats per minute. These procedures resulted in the identification of one test subject who became ill after the second test day and could not participate thereafter.

After inserting their own rectal thermistor for measurement of internal body temperatures subjects were weighed both nude and clothed prior to commencing the trial. Subjects were then instrumented with skin thermistors, data logger, and a heart rate transmitter, and donned a tee-shirt, the LCG if it was a test day involving the LCG, their crew vehicle uniform, helmet, gloves and fragmentation vest. They then entered the tank and assumed their crew position. They carried out simulated normal crew duties associated with a nominal 6 hour tank mission with the vehicle exposed to an external dry bulb temperature controlled at 44ºC (Test Days I-IV) or 35°C (Test Day V), simulated solar radiation fixed at 1120 W/m^2 (generated by a bank of high intensity lights), 10-20% relative humidity, and no wind. This exercise was planned to continue for up to 6 hours or until one of the following end-point criteria were reached:

a. rectal temperature reached 38.5ºC;
b. heart rate reached or exceeded 95% of the individual's age-predicted maximum value (220 – age) for 3 consecutive minutes;
c. nausea or dizziness precluded further activity;
d. the investigator or subject terminated the session.

As the subject approached one of these end-point criteria their responses were monitored more frequently to ensure that the exposure was ended at the appropriate time. Subjects drank 5 ml/kg body mass (approximately 400 ml) of water or Gatorade® prior to beginning each trial and were instructed to drink *ad libitum* throughout the test. Both water and Gatorade® were available for drinking in the tank.

During the "Active Cooling" trials on Test Days II, IV, and V, the subjects wore the LCG, of appropriate size and fit, similar to that shown in Figure 1. The vest was worn directly over an inner-most T-shirt but otherwise the subjects dressed in their standard uniform as described above. The liquid coolant supply/return lines to/from the vest were located and secured so as to minimize any interference with normal crewman activities. Whenever the turret was occupied by fewer than three subjects (Test Days IV-V, and after a subject's run ended), an unmanned LCG was connected at the vacant crew position(s) so that the DC250 essentially always delivered cooling to three LCGs.

For trials on Test Days III, IV, and V, a specially designed solar protection shield was fitted to the exterior of the tank. It was designed to reduce the solar radiation component of the heat strain to which the tank is exposed; no associated change to the human testing procedures described above was required. This shield is shown fitted to the tank in Figure 5.

3.5 Crew activities

Once they entered the chamber the subjects immediately entered the tank. During the trials where the cooling system was employed they immediately connected their LCGs to the tethered line attached to the chiller/pump unit and, except for brief intervals to change positions, remained connected for the duration of their trial. The subjects carried out the serial activities described in Annex A. When they were not engaged in the execution of those activities they remained passive in their crew position. Even during the firing exercises described in Annex A, it was only the Loader (see 3.5.1) who engaged in physical exertion levels which could be classified as high intensity and which only lasted for a few minutes.

3.5.1 Loader activities

In accordance with the timelines outlined in Annex A, the Loader engaged in high intensity exertion which involved loading of ammunition rounds for a "gun fire" engagement. The standard for the rate of firing is six rounds in a minute. During this trial the gun did not fire, recoil or eject the empty casing. Therefore, the Loader's actions involved loading the six rounds at the highest rate possible. The sequence of activities by the Loader were as follows: he opened the sliding breech block by pulling on the breech lever; he picked up the 18.8 kg ammunition round from the ready rack, inserted the round into the gun chamber and pushed on the base of the cartridge until it was fully seated, which activated closure of the spring-loaded sliding breech; he then pushed the "ammo button" and reported "ready." When the Gunner pulled the firing lever and reported firing the Loader pulled the breech lever, opened the breech, partly removed the practice round and slammed it back in place, pushed the "ammo button" again and reported "ready" for firing again. This was repeated six times.

3.6 Measurements

3.6.1 Test subject measurements

During each of the test sessions, rectal temperature and skin temperatures were monitored using thermistors and recorded every 5 minutes. Heart rate was monitored using telemetry and recorded every 10 minutes. Fluid loss was calculated from changes in nude weight before and after the trial corrected for fluid intake and urine output during the trial. Sweat evaporation was estimated from changes in dressed weight. Subjects were asked to provide two subjective ratings of their thermal comfort generally every 15 minutes using the table in Annex B: a rating of whole body thermal comfort and the thermal comfort of the torso under the cooling vest. They were also asked to subjectively rate their overall perceived exertion. Standardized scales were used for this purpose and subjects communicated their ratings to trials staff in the control room over the radio. The subjects were also asked about the effects of the cooling system on their ability to do their jobs in the tanks, and their past experience with operations in the Leopard 2C or other armoured vehicles in hot temperatures.

Figure 5. Solar shield prototype fitted to tank

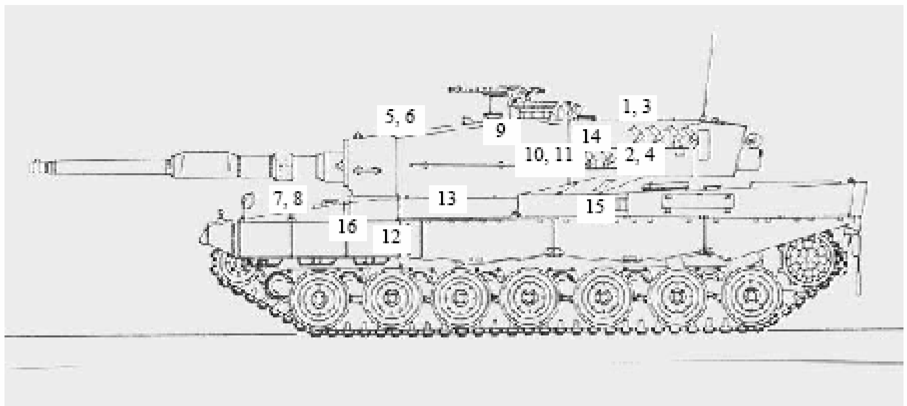
3.6.2 Cooling system measurements

Thermistors were mounted on the surface of the supply and return lines near the LCG and were externally insulated. These thermistors were used to measure LCG inlet and outlet temperatures.

3.6.3 Tank and chamber temperature measurements

Thermocouples, thermistors, humidity sensors, and digital data loggers were used to monitor and record ambient air temperature and humidity in the chamber, inside of the tank adjacent to each crew position, and on both the external and internal tank surfaces at several locations. The locations of the various temperature probes on the tank are depicted in Figure 6.

TEMERATURE MEASUREMENT SITES



Surface Outside Turret
1 Top-left
2 Top-left (45° slant)
3 Top-right
4 Top-right (45° slant)
5 Top-center, on cover
6 Top-center, under cover

Surface Outside Hull
7 Top-right
8 Top-left

Surface Inside Turret
9 Top-centre
10 Top-right (45° slant)
11 Top-left (45° slant)
12 Hydraulic Pump

Ambient Inside Turret
13 Left of Gunner seat
14 Left-aft-above Crew Commander seat
15 Left-aft of Loader seat

Ambient Inside Hull
16 Left-aft-above Driver seat

Figure 6. Location of surface and ambient air temperature measurements.

3.6.4 Solar heat simulation

The standardized simulation of solar heat was achieved using 500 W halogen work lamps modified to mount in racks above the test area. Approximately 300 lamps were required. The protective glass was removed from the lamps to permit greater intensity. The lamps were arranged with a spacing that facilitated uniform light distribution across the sample area. The minimum distance from the lights to the top of the tank turret was 6 – 7 feet. The measurement device for the solar component was an Eppley Radiometer (model Precision Spectral Pyranometer), which is a broad band device used to measure total solar intensity. It was located on top of the turret just in front of the crew commander position. Light intensity does vary with distance from the lamps, thus the intensity at the hull was lower than the 1120 W/m^2 measured at the device location on top of the turret. Light intensity from the lamps was adjusted by fine tuning of the voltage to the lamps. The spectrum of the lamps used is higher in the infra-red region than natural sunlight, however this should not have confounded results where the objective is to generate solar heat.

4 Results

4.1 Test subjects characteristics

DASPM was able to recruit three male Leopard 2 C operators from CFB Gagetown. They were briefed about the protocol, all associated risks and discomforts and provided with informed consent forms. All three volunteered as test subjects; one subject became ill after the second test day and was not able to participate in the remaining three trials. The subjects nominal crew position, age (years), height (metres), and weight (kilograms) were, respectively: Gunner, 30, 1.68, 100.6; Crew Commander, 33, 1.85, 95.2; Loader, 24, 1.73, 98.2.

4.2 External ambient temperature

The targeted climatic chamber ambient dry bulb temperature was 44°C for the first four test days and 35°C on the last test day. The measured mean values and ranges of air temperature outside of the tank during each test days are shown below in Table 2. The Wet Bulb Globe Temperature (WBGT) is considered a composite heat stress index which incorporates the effects of air temperature, relative humidity, wind and solar radiation. It is considered a more valid indicator of thermal stress to humans than ambient air temperature alone. The mean WBGT measurements in the chamber were around 34.5°C for the NCVU, ACVU, NCVS, and ACVS trials , and 28.3°C for the ACVS35. Such WBGT levels are considered severe and the severity is compounded because of the added heat burden associated with wearing a fragmentation vest (Cadarette et al. 2005). Under such conditions Canadian Forces (CFMO 40-2, 1997) and US Army guidelines (Montain et al. 1999) limit moderate intensity work to 20 minutes per hour to prevent internal body temperature from exceeding 38.5ºC. With the aid of a heat strain model, Cadarette et al. (2005) predicted that core temperature would rise to 38.4ºC after 100 minutes of performing light work (225 W) at a WBGT of 32.0ºC when soldiers were dressed in their normal battle dress uniform and wore body armour. When the WBGT was increased to 35.0ºC the predicted rise in core temperature increased to 38.7ºC. Although core temperature increases to 40ºC can be physiologically tolerated by many individuals (Selkirk and McLellan, 2001), cognitive performance can be affected at much lower core temperatures (Hancock and Vasmatzidis, 2003), with the most complex decision making tasks being impacted with rates of increase in core temperature as low as $0.055ºC{\cdot}h^{-1}$. In the current trial, the rates of increase in core temperature were greater than this value for all subjects when cooling was not provided (see Section 4.7) again substantiating the severity of the environmental conditions inside the tank and the need for cooling.

Table 2. External chamber ambient temperatures

Test Condition	NCVU	ACVU	NCVS	ACVS	ACVS35
Mean °C	43.7	44.6	43.5	45.0	35.8
Range °C	41.5-45.3	42.8-45.4	41.7-45.4	41.6-45.9	33.6-37.0

Condition Legend
NCVU= No Cooling Vehicle Unshielded
ACVU= Active Cooling Vehicle Unshielded
NCVS= No Cooling Vehicle Shielded
ACVS= Active Cooling Vehicle Shielded
ACVS35= Active Cooling Vehicle Shielded 35°C

4.3 Tank internal temperatures

Internal ambient temperature was monitored at locations adjacent to each crew position. In general, the temperatures crept upwards gradually and progressively and would have continued to do so if the trial had continued past the point in time where the subject with the longest tolerance time was stopped. The initial and final temperatures on each test day are shown below in Table 3.

Table 3. Internal tank ambient temperatures (°C) at each crew position and test condition

	Driver		Gunner		Crew Cmdr		Loader	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
NCVU	41.2	48.6	46.4	52.8	49.8	57.0	39.8	51.0
ACVU	48.8	55.0	52.0	58.8	55.6	64.2	47.8	55.6
NCVS	45.3	48.1	48.0	52.0	50.3	54.7	48.6	52.4
ACVS	47.3	52.3	48.6	55.6	49.9	56.8	46.8	55.1
ACVS35	39.8	46.6	43.9	48.6	44.6	51.2	39.4	46.6

Condition Legend
NCVU= No Cooling Vehicle Unshielded
ACVU= Active Cooling Vehicle Unshielded
NCVS= No Cooling Vehicle Shielded
ACVS= Active Cooling Vehicle Shielded
ACVS35= Active Cooling Vehicle Shielded 35°C

4.4 Tank surface temperatures and the solar shield

The mean values for the tank surface temperatures are shown in Table 4. Without the solar shield, the temperatures on the external surface of the top of the turret reached in excess of 80°C. The shield had a marked effect on external and internal vehicle surface temperatures which were 10-25°C lower with the shield (Figure 7), but this did not have a similar or noticeable effect on ambient air temperature inside of the tank (Table 3). The lack of effect on air temperature is likely due to the open hatches which permitted free air flow through the vehicle from outside of the tank. Hatches remained open to simulate what usually occurs in theatre.

Table 4. Mean External and Internal Tank Surface Temperatures (°C)

Site	**Locator in Figure 6**	**NCVU**	**ACVU**	**NCVS**	**ACVS**	**ACVS35**
External Surfaces						
Right top turret	3	77	82	58	61	53
Left top turret	1	74	78	57	60	54
Right turret slant	4	65	67	51	54	47
Left turret slant	2	65	69	51	55	48
Right top hull	7	59	64	49	51	44
Left top hull	8	43	49	43	46	38
Internal Surfaces						
Right turret slant	10	54	61	49	53	46
Left turret slant	11	53	61	49	54	49
Turret top	9	76	84	57	61	57

Legend
NCVU= No Cooling Vehicle Unshielded
ACVU= Active Cooling Vehicle Unshielded
NCVS= No Cooling Vehicle Shielded
ACVS= Active Cooling Vehicle Shielded
ACVS35= Active Cooling Vehicle Shielded 35°C

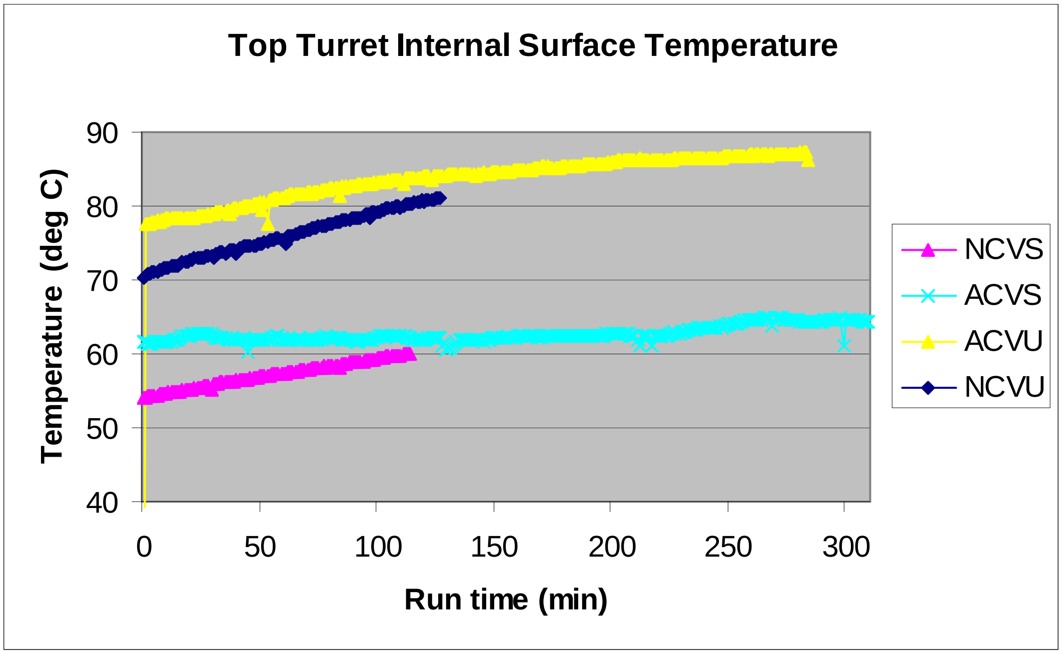


Figure 7. Effect of solar shield on surface temperature on top of turret inside of tank

Legend
NCVU= No Cooling Vehicle Unshielded
ACVU= Active Cooling Vehicle Unshielded
NCVS= No Cooling Vehicle Shielded
ACVS= Active Cooling Vehicle Shielded

4.5 Crew member tolerance times

With data available for only two or three volunteers, no statistical analysis can be conducted, but individual subject data reveal substantial information about the efficacy of the cooling vest. All three volunteers participated in the NCVU and ACVU trials. Only two of the volunteers completed the remaining trials. The total trial duration for the subjects as well as the reason for stopping each trial are shown in Table 5 below. Volunteers were stopped because of one or more of the following pre-determined criteria: the upper threshold for rectal temperature (38.5°C) was reached, voluntary cessation because of severe head-ache or nausea, and, in the case of the ACVS35 trial, the trial was halted for Subject #1 ("Gunner") for logistical reasons. At the time of stopping the ACVS35 trial, Subject #1 was subjectively comfortable and his rectal temperature had been stable 37.4°C for the entire 5.5 hours trial duration. With the exception of that logistically limited trial, all subjects were close to the point of becoming heat casualties at the time their trial was stopped. The cooling garment approximately doubled tolerance time for the trials conducted at 44°C and, in the case of Subject #1, he could have likely continued for at least another 1-2 hours longer than the 5.5 hours he comfortably tolerated during the trial at 35°C.

Table 5. Duration of each trial and the reason for stopping the trial.

	Subject #1 Gunner		**Subject #2 Crew Commander**		**Subject #3 Loader**	
Trial	***Duration (min)***	***Reason***	***Duration (min)***	***Reason***	***Duration (min)***	***Reason***
NCVU	127	voluntary, in distress	91	voluntary, in distress	63	voluntary
ACVU	283	rectal temperature limit	161	voluntary, headache, nausea	123	rectal temperature
NCVS	104	rectal temperature limit	114	rectal temperature limit		
ACVS	310	rectal temperature limit	206	voluntary, headache		
ACVS35	330	Logistical, subject could have continued	185	voluntary, severe headache		

Condition Legend
NCVU= No Cooling Vehicle Unshielded
ACVU= Active Cooling Vehicle Unshielded
NCVS= No Cooling Vehicle Shielded
ACVS= Active Cooling Vehicle Shielded
ACVS35= Active Cooling Vehicle Shielded 35°C

4.6 Crew member internal body temperatures

A key indicator of thermal strain is the rate of rise in internal body temperature. Here again, with data available for only two or three volunteers no statistical analysis can be conducted. Individual subject data, however, reveal substantial information about the efficacy of the cooling vest. The average rate of rise in rectal temperature is depicted in the Figure 8 below as the change in rectal temperature during the trial divided by the duration of the trial in minutes. It should be noted that this variable was calculated to facilitate a comparison across trials and should not be interpreted as implying that there was a continuous and linear increase in body temperature over the duration of the trials. In Figure 8, a lower rate of rise indicates less physiological strain. The rate of rise in internal body temperature was reduced by approximately 50% with the LCG. It should also be noted that although the volunteers remained for the most part in their designated positions, they did switch positions intermittently as described in the listing of serial activities in Annex A.

4.7 Crew commander position

The Crew Commander reported serious headaches on four of the five trials. With only one subject it is difficult to assess the relative importance of the position itself vs. this specific individual's response to the heat stress incurred in the Crew Commander's position. It is well established, however, that in addition to ambient dry bulb air temperature and relative humidity, the heat from solar radiation is a very significant component in determining heat stress. With hatches open, and in contrast with the other crew positions, the Crew Commander will incur more heat stress from the solar radiation. Thus, any strategies to protect the Crew Commander from the effects of solar heat radiation would likely be advantageous. Examples might include a canopy that shades the position, head cooling with passive cooling systems, or an appropriate form of insulation covering the helmet or between the helmet and the head. More research would be required to validate whether the symptoms of the Crew Commander in this study are generic to the position in the vehicle, as well as to validate the efficacy of COTS head cooling technologies.

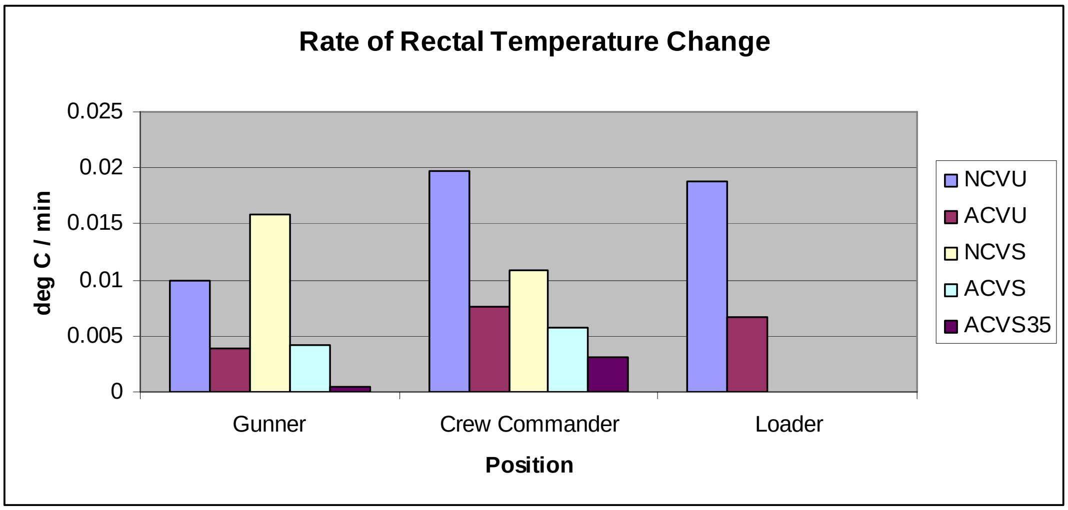


Figure 8. Average rate of rise of rectal temperature, calculated as the difference between the initial and final rectal temperature divided by the elapsed time.

Condition Legend
NCVU= No Cooling Vehicle Unshielded
ACVU= Active Cooling Vehicle Unshielded
NCVS= No Cooling Vehicle Shielded
ACVS= Active Cooling Vehicle Shielded
ACVS35= Active Cooling Vehicle Shielded 35°C

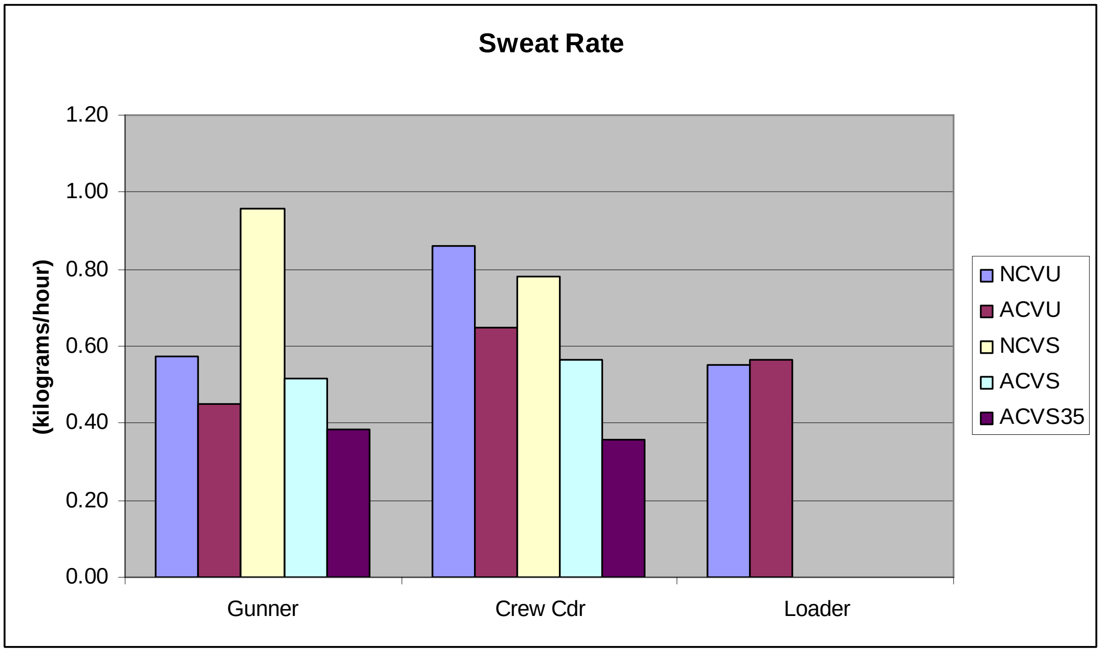


Figure 9. Calculated sweating rates

Legend
NCVU= No Cooling Vehicle Unshielded
ACVU= Active Cooling Vehicle Unshielded
NCVS= No Cooling Vehicle Shielded
ACVS= Active Cooling Vehicle Shielded
ACVS35= Active Cooling Vehicle Shielded 35°C

4.8 Crew member sweating rates

Sweating rates were estimated based on the difference between initial and final nude body weights, corrected for the volume of fluid the subjects ingested and the volume of urine excreted during the trial. The calculated sweating rates for each subject are shown in Figure 9. The mean sweating rates (in kg/h) were 0.66, 0.55, 0.87, 0.54, and 0.37 for the NCVU, ACVU, NCVS, ACVS, and ACVS35 trials, respectively. The observed sweating rates were consistent with expectations for low to moderate levels of physical exertion. Maximal sweating rates in large individuals can be 2 – 3 times the observed levels during hard physical exertion in hot conditions. The volunteers were instructed to drink freely during the trials and were provided with a choice of water or a commercial rehydration beverage (Gatorade®). Nude body weight was the same or, on some occasions, even somewhat higher after the trial which indicates that the subjects drank sufficiently to avoid dehydration.

4.9 Crew member heart rates

As expected, resting heart rate increased progressively with time throughout the trials. There were also acute rapid increases to levels of 140-180 beats/min that were associated with the increased intensity of physical activity during the firing drills, particularly in the Loader position. For the Gunner and Crew Commander positions the increases in heart rates were slower and can be primarily attributed to the cardiovascular strain associated with the body's normal thermoregulatory processes. There was no permanently designated volunteer who sat in the Driver position but the Gunner did, at times, move to that position and his heart rate response was similar to when he was in the Gunner position.

4.10 Crew member subjective thermal stress

The thermal comfort ratings indicated that the volunteers subjectively perceived whole body thermal strain as lower while wearing the LCG, particularly after the first hour (Figure 10). They also found the area of the torso immediately under the LCG to be a more comfortable temperature while wearing it.

4.11 User comments

The volunteers found the LCG to be comfortable and that it did not interfere with their normal crew activities, nor with their entry into or egress from the vehicle. No difficulties were reported regarding connecting or disconnecting the LCG to or from the chiller supply and return lines. The volunteers reported that they perceived the magnitude of the cooling effect to be less in the Crew Commander's position than in the other positions. Since all volunteers shifted at one time or another to the crew commander position, the lower perceived cooling can not be attributed to the vest but is more likely due to a restriction of unknown cause which reduced coolant flow through the tethered lines to this particular position.

4.12 Calculations of cooling power

The total cooling power specified for the DC250 chiller unit is approximately 600 W, or 200 W for each of three crewmen. From LCG coolant flow rate (1/3 of chiller flow = 0.7 litres/min) and water/glycol mixture heat capacity (0.85 cal/° C/mL), the cooling power delivered to the LCG is estimated at 41 W/°C difference between the LCG inlet and outlet temperatures. The LCG inlet/outlet temperature difference as measured in these trials was about 1- 4 °C corresponding to roughly 40-164 W (20-82% of chiller output) reaching the LCG. This of course implies significant losses occurred from the chiller and supply lines to the extreme environment, or perhaps lower than expected performance of the chiller in the environment. It must be remembered that these calculations of cooling power reflect the total system’s efficiency.

After reaching the area to be cooled, the effectiveness of the coolant is a direct function of several factors, including the surface area of the body that is in direct contact with the coolant-containing tubes embedded into the LCG. In light of the tube geometry only about half of the LCG cooling capacity can be exploited with the remaining cooling directed outwards through the fragmentation vest and to the environment.

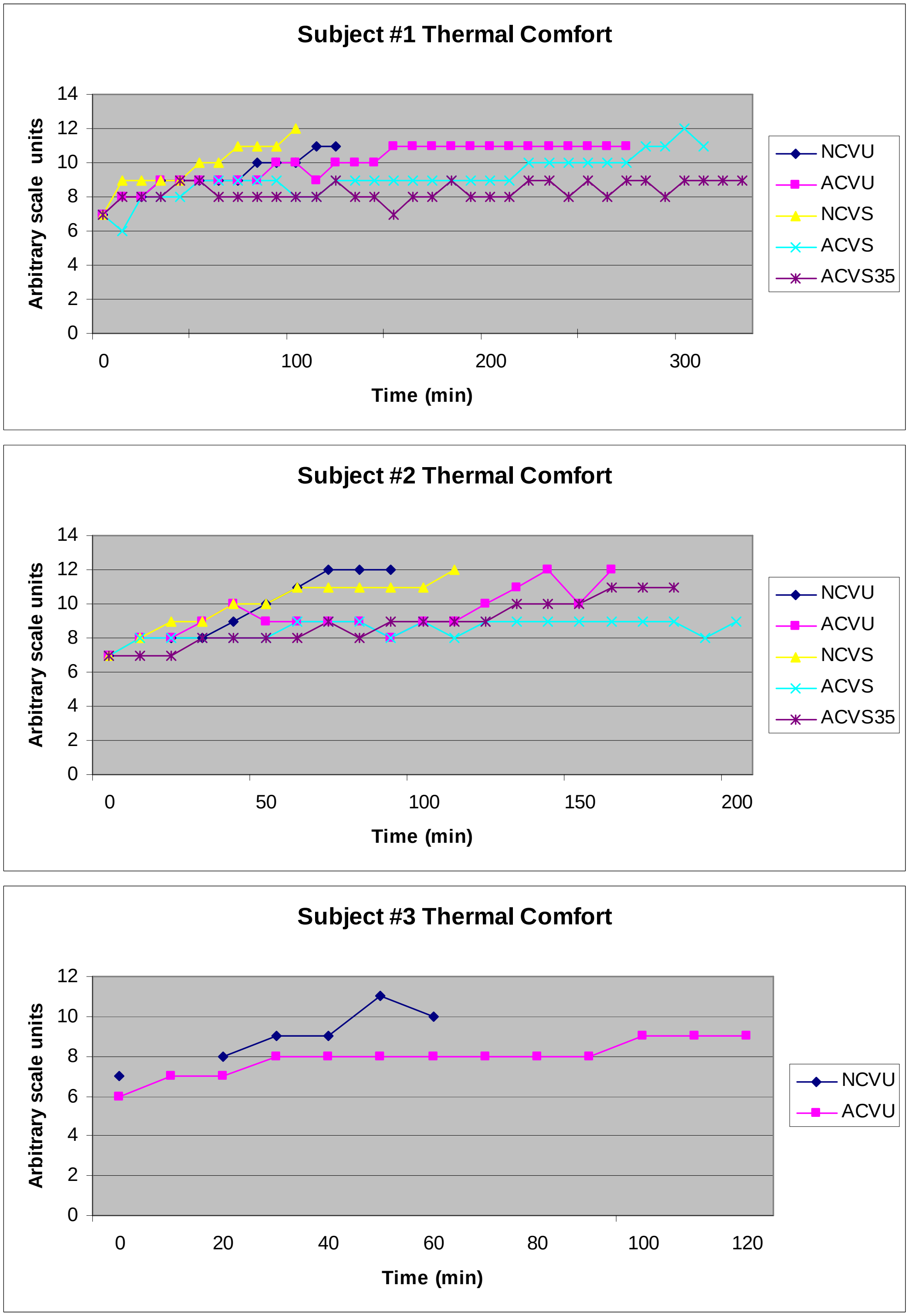


Figure 10. Subjective ratings of whole body thermal comfort. See Annex B for a description of the ratings.

5 Conclusions

5.1 Requirement for heat stress mitigation

These results suggest that without mitigation of the heat stress, the extreme sunny, daylight conditions chosen to mimic the warmest days in the Kandahar region of Afghanistan would likely render Leopard crew members as operationally impaired within 1-2 hours, and as heat casualties soon thereafter. It should be noted that this conclusion applies to individuals who are well hydrated. Dehydration will exacerbate the problem.

5.2 Would vehicle air conditioning suffice? Probably not.

Whole vehicle air conditioning was not considered as a viable option because of advice that the available power was not sufficient for such retrofitting. Thus, this investigation focused on the advantages of microclimate cooling for crew members. We have considered, though, whether an air conditioning unit for the entire vehicle would be sufficient, of and by itself, to adequately mitigate the heat stress that is experienced by the crew members. The results from previous studies conducted with vehicles such as the Light Armour Vehicle III (LAV III) and the Air Defence Anti-Tanks System (ADATS) have shown that air conditioning can reduce interior temperatures by 5º-10ºC under similar environmental conditions as were used in the present study (Hanna, 2005a). However, interior temperatures in these studies still exceeded 35ºC and in some locations were still above 40ºC. At higher environmental temperatures of 49ºC and high solar load (1120 $W \cdot m^{-2}$) temperatures in the driver's area of the LAV III were above 45ºC with the air conditioning unit operating with an outlet air temperature of 20º-25ºC (Hanna, 2005b). Thus, although the use of air conditioning will effectively lower internal vehicle temperatures, it is highly unlikely that this approach would be successful in controlling the thermal strain experienced by crew members for prolonged periods especially when exposed to the extreme conditions in Afghanistan during the summer months. However, tapping into vehicle air conditioning in order to provide air-cooled micro-climate conditioning, in addition to vehicle cooling, is an effective heat stress mitigation approach for crew members that has been successfully integrated in tank systems such as the Israeli Merkava, M1 Abrams, and other Leopard tank models. Such an approach is recommended for consideration to meet future combat vehicle air conditioning requirements.

5.3 One viable solution

A review of COTS technologies suggests that the most viable solution in the available timelines is one involving a powered active-cooling system capable of delivering a continuous and constant 150W of cooling to each crew member.

The results of this trial should be considered as "proof of concept" that the liquid perfused micro-climate cooling system evaluated can mitigate the heat stress to the extent that crew members would likely be able to at least double their operationally effective duration when outside temperature is as high as 44°C. In the more frequently encountered 35°C temperature conditions, crew should be able to avoid debilitating heat strain for at least 3-5 hours, depending on the activity level while in the vehicle. A system with higher cooling capacity would be commensurately more effective than that evaluated in this trial.

5.4 Micro-climate conditioning: air cooled vs. liquid cooled garments

Our review of micro-climate cooling technologies for armoured vehicles indicates that cooling garments that use cool air are at least as effective, and may be more effective, than the liquid cooled garments (Vallerand et al., 1991; McLellan et al., 1998, 1999; Laprise et al., 2005). Moreover, such cooling is typically evaluated as more comfortable by users, at least partly due to dissipation of sweat. For future reference, there are related commercial technologies available, including those that have already been integrated with more modern versions of the Leopard tank. The power and timeline constraints precluded recommending such technology to DASPM for the CF Leopard 2C. Scientific consensus about the benefits and efficacy of air-linked micro-climate cooling is such that there would be no requirement to do another laboratory trial to demonstrate "proof-of-principle"; field trials, however, would be recommended to demonstrate effective integration of a cooling system with the other vehicle systems and the crew.

Previous work conducted at DRDC Toronto has shown that both air- and liquid-cooling vests are effective in reducing the thermal strain of wearing NBC protective clothing in hot environments (McLellan et al., 1999). Additional recent work (McLellan, T. Personal communication) has also shown that the use of an air-cooling vest, with inlet temperatures controlled at around 20ºC, and with a flow of around 440 litres per minute, was sufficient to control the thermal strain for subjects exposed to either a desert (49ºC and 10% relative humidity) or tropical (35ºC, 70% relative humidity) environment and dressed in identical clothing and protective equipment as was used in the current investigation. Without cooling, the rate of increase in core temperature was 0.01ºC$\cdot$min^{-1} (0.6ºC$\cdot$h^{-1}). These rates of increase are comparable to those observed in the present study and would suggest that either air- or liquid-cooling vests could provide sufficient cooling for crew members.

5.5 Solar shield

The solar shield fitted to the exterior of the vehicle, while markedly reducing the interior surface temperature of the vehicle, had no apparent effect on the ambient air temperature inside of the tank, probably because hatches were open allowing external air to flow freely through the vehicle. Thus, there was no advantage in terms of the tolerance times of the volunteers during those trials with the shield.

5.6 Crew position

Although individuals vary widely in their response to, and tolerance of heat stress, the results of the present trial suggest that crew position is also a critical factor. The relatively higher level of metabolic heat production associated with the activities of the "loader" should be considered a significant limiting factor. Also, the exposure in the open hatch of the "Crew Commander's" helmet-covered head may also result in more significant and more rapid heat strain than in other positions. For the latter position in particular, consideration should be given to evaluating the benefits that may be afforded by shading the position, even intermittently. Although there are head-cooling technologies that are commercially available there is no scientific consensus as to their efficacy.

5.7 Crew hydration

We were impressed with the hydration awareness of the volunteers in this evaluation. Without prompting they voluntarily consumed sufficient fluids during the trial to compensate for their sweat losses and avoid dehydration. During operations of durations similar to this trial either water or commercially available electrolyte/carbohydrate rehydration solutions are effective and safe methods of maintaining hydration status. If requested, we can provide further information about the volume and formulation of rehydration drink that would be most effective for sustained crew operations; this is a mature area of physiology and no related trials would be needed to provide such guidance.

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Annex A Crew activities

Serial	Time of the event in Minutes	Event	Crews' actions		
			Crew Commander (CC)	Loader	Gunner
1	32	Action Drill.	Orders his crew into action.	Verifies the main armament and switches on the hydraulic system.	Switches on the fire control system and activates the hydraulic system. He warms up the hydraulic system by elevating and depressing the main armament repeatedly twenty times.
2	37	Six HESH rounds Gun Fire Engagement.	Issues a Fire Order and supervises his crew. Once the engagement is terminated he issues a Contact Report using the radio.	Picks up a training round from the ammunition ready rack and loads the round into the main gun. He then opens the breech and reloads the ammunition until the CC stops the engagement (six times for this engagement).	Points his fire control system onto the simulated target and fires the gun on the CC orders.

Serial	Time of the event in Minutes	Event	Crews' actions		
			Crew Commander (CC)	Loader	Gunner
3	39	Unload Clear Gun.	Orders the crew to unload the gun.	Opens the breech and removes the practice round from the gun's chamber and replaces it into the ammunition ready rack.	Inputs the start mode values into his fire control system and carries on with observation.
4	41	Two SABOT rounds engagement	Same as serial 2.	Same as serial two although only two rounds are fired for this engagement.	Same as serial 2.
5	43	Unload Clear Guns.	Same as serial 3.	Same as serial 3.	Same as serial 3.
6	72	Two SABOT rounds engagement where the second round is a misfire	Same as serial 2; however, he must supervise his crew performing a misfire drill and he must report this condition using the radio.	Same as 2.	Same as 2 with the addition of performing a misfire drill where he must verify the correct position of key components of the firing mechanism.
7	84	CC and Loader trade places	Orders the hydraulic system to be turned off and pulls himself out of his position and jumps into the loaders position.	Turns off the hydraulics and pulls himself out of his position and jumps into the commander's seat.	Turns off the hydraulics and waits for instructions.

Serial	Time of the event in Minutes	Event	Crews' actions		
			Crew Commander (CC)	Loader	Gunner
8	96	Unload Clear Guns. Replenish.	From the loader's position he opens the breech and removes the round and places it into the ready rack. Form the 39 rounds bin he removes three practice rounds and places them into the ready rack.		
9	120	The Gunner is moved from his seat to the Drivers seat.	Orders Hydraulics to be turned off. Ounce the Loader and the Gunner are out of the turret he returns to his original position, sitting in the crew commander's seat.	Pulls himself out of the CC position and returns to his original place.	Pulls himself out of the turret, opens the Driver's hatch, positions himself into the driver's seat and closes the hatch.
10	180	The Gunner returns to his initial position.	Orders the hydraulics off and pulls himself out of the turret for the gunner to regain his position.	Turns off the hydraulics.	Opens the Driver's hatch, removes himself from the seat and closes the hatch. He then returns to his original position into the Gunners seat.
11	212	The serials are repeated			

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Annex B Scale of thermal comfort ratings

Rating	*Description*
1	So cold I am helpless
2	Numb with cold
3	Very cold
4	Cold
5	Uncomfortably cool
6	Cool but fairly comfortable
7	Comfortable
8	Warm but fairly comfortable
9	Uncomfortably warm
10	Hot
11	Very hot
12	Almost as hot as I can stand
13	So hot I am sick and nauseated

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List of symbols/abbreviations/acronyms/initialisms

A	ampere
ADATS	Air Defence Anti-Tanks System
ACVS	Active Cooling Vehicle Shielded (one of the test conditions)
ACVS35	Active Cooling Vehicle Shielded at 35°C (one of the test conditions)
ACVU	Active Cooling Vehicle Unshielded (one of the test conditions)
cal	calories
CF	Canadian Forces
CFMO	Canadian Forces Medical Orders
COTS	Commercial off-the-shelf
CSTT	Centre for Surface Transportation Technologies
DASPM	Directorate Armament Sustainment Project Management
deg C ºC	degrees Celsius
DRDC	Defence Research and Development Canada
h	hour
kg	kilograms
LAV	Light Armoured Vehicle
LCG	Liquid Cooled Garments
m	metres
min	minutes
ml mL	millilitres
mm Hg	millimetres of mercury
NATO	North Atlantic Treaty Organization
NBC	Nuclear, Biological and Chemical
NCVS	No Cooling Vehicle Shielded (one of the test conditions)
NCVU	No Cooling Vehicle Unshielded (one of the test conditions)
R&D	Research & Development
STANAG	Standardization Agreement
TOPP	Threat-Oriented Protective Posture (classification system for chemical/biological agent protective garments)

US	United States
VDC	volts direct current
W	watts
WBGT	Wet Bulb Globe Temperature

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The Directorate Armament Sustainment Programme Management (DASPM) requested Defence R&D Canada (DRDC) support with the investigation and recommendation of "...technologies available to mitigate the effects of the heat stress expected for Leopard 2C crews operating in the Kandahar region of Afghanistan in summer." DRDC was asked to focus "...on technologies that are likely to be able to be delivered and installed by the beginning of June 2007."

Candidate heat stress mitigation strategies, technologies, technical reports, scientific reports, and commercial product specifications were reviewed in light of the timelines and engineering constraints. It was decided to test a vapour compression liquid circulating product as a "proof of concept" that personal micro-climate cooling would significantly mitigate the anticipated heat stress challenge in theatre. In addition, a specially designed solar heat dissipation textile was fitted to the exterior of the tank. The effects of these products were evaluated by monitoring the tank temperatures, the tank crew members' body temperatures, physiological and perceptual responses to a standardized heat stress. The heat stress involved exposure of the tank and crew members in the tank to an external air temperature of 44°C or 35°C and a simulated solar heat load of 1120 W/m2 in accordance with NATO STANAG 2895 which provides guidance on meteorological conditions that should be used for testing of materiel in accordance with the location in the world where the equipment will be deployed.

The crew members were exposed to the heat stress on five consecutive days, either with or without the cooling or the solar shield. The cooling system consisted of a chiller unit and a worn distribution vest (liquid cooling garment or LCG) which interfaced via thick-walled supply and return lines. It was estimated that 40-164 W of cooling reached the LCG.

The results suggest that without mitigation of the heat stress, the warmest days in the Kandahar region of Afghanistan would likely render Leopard crew members as operationally impaired within 1-2 hours, and heat casualties soon thereafter. The technology review indicated that the most viable solution in the available timelines involves a powered active-cooling system capable of delivering a continuous and constant 150W of cooling to each crew member. The LCG evaluated in this trial can mitigate the heat stress to the extent that crew members would likely be able to at least double their operationally effective duration when outside temperature is as high as 44°C. In the more frequently encountered 35°C conditions, crew should be able to avoid debilitating heat strain for at least 3-5 hours.

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[cooling; micro-climate conditioning; thermal stress; tank crew; human performance]

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