2012 NDIA GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM
MODELING & SIMULATION, TESTING AND VALIDATION (MSTV) MINI-SYMPOSIUM
AUGUST 14-16, MICHIGAN

Effect of Heat on Wounded Warriors in Ground Combat Vehicles: Insights from the Army Medical Community, and the Simulation of a Novel Method for Soldier Thermal Control

Nathan Tison, Ph.D.
ESI US
Ann Arbor, MI

Rob E. Smith, Ph.D.
TARDEC CASSI Analytics
Warren, MI

ABSTRACT

Ground combat vehicles can operate in regions characterized by various types and severities of injuries – resulting from improvised explosive devices (IEDs), gunfire or heat illness – as well as extreme climates such as desert environments. Because of the wounded warrior's compromised physical condition, their thermal surroundings within the vehicle are especially important. This paper presents insights gleaned from the Army medical community, as well as a simple study of the effect of heat on soldiers in a ground combat vehicle using CFD / thermal modeling and simulation tools and methodologies. In particular, an Army-patented method for controlling body temperature via skin temperature feedback together with a cooling vest and pants ensemble is employed.

INTRODUCTION

Wounded warriors, as compared with non-injured soldiers, are generally less tolerant to the effects of heat. Because their injuries often degrade their thermoregulatory capability, the outcome for wounded warriors is affected by their thermal surroundings – especially severe thermal conditions. Such severe thermal conditions can exist within ground combat vehicles; although these vehicles are generally equipped with heating, ventilation, and cooling (HVAC) systems, the HVAC systems often lack sufficient cooling capacity under conditions of thermally severe weather, open-hatch operations for situational awareness purposes, and a significant amount of on-board electronics. The effect of heat on wounded warriors within ground combat vehicles is the subject of this paper. This paper has two purposes: (1) to provide insights gleaned from the Army medical community, and (2) to simulate a novel method for soldier thermal control.

INSIGHTS FROM THE ARMY MEDICAL COMMUNITY

The insights gleaned from the Army medical community can be organized into four categories: casualty transport, type, care, and simulation.

Casualty Transport

Casualty transport can be discussed in terms of the transport starting point, en route medical treatment, and treatment philosophy. Regarding the transport starting point, the transport can be described as evacuation or shuttling. Evacuation describes the transport of a casualty from the point of injury (or some casualty collection point) to a care facility. Shuttling, on the other hand, describes the transport of a casualty from one care facility to another. Evacuation is the more urgent of the two, since the casualty is less likely to be stable at the beginning of the transport. However, because most casualty evacuations are transported by air (because of the lack of roads, etc.), ground evacuations are relatively infrequent [1].

Regarding the transport en route medical treatment, In a similar way, two methods of casualty transport can be considered: "medical" transport of casualties on dedicated vehicles which are both equipped and staffed for purposes of administering en route medical care, and "non-medical" transport of casualties on non-dedicated vehicles which are neither equipped nor staffed for purposes of administering en route medical care; in the context of evacuation, the two aforementioned concepts are respectively termed "medevac" and "casevac" [1, 2].

Regarding the transport philosophy, the transport can be described as a "stay and play" approach involving comprehensive treatment on-site with consequently delayed transport to a care facility, and a "scoop and run" approach involving immediate transport to a care facility with only basic treatment en route. Reasons favoring the latter approach include the fact that it would be difficult to transport an operating room-like setting – including the staff, equipment, supplies (blood products, etc.) – to the casualty, which would be important to have during the critical first hour after injury [3]. The Army ground evacuation doctrine is generally based upon a "scoop and run" approach.

In light of the above, the simulation study of this paper will be concerned essentially with only shuttling transport involving only very limited medical care.

Casualty Types

It was originally intended to consider casualty scenarios which vary in the following respects: (1) the type / severity of the casualty, (2) the frequency of the casualty on the battlefield, (3) criticality with respect to the life of the soldier (considering the available care), and (4) thermoregulatory significance. More specifically, it was desired to focus on four main classes of injury: heat (exhaustion and stroke), ballistic (blunt and penetrating / perforating), pressure / blast (limb loss, paralysis, organ rupture), and burn. However, physiological and or thermoregulatory data associated with such injuries is generally not readily available (exceptions do exist, such as the locally augmented metabolic activity associated with burn injuries) [4]. Therefore, the simulation study was generally limited to healthy soldiers, but soldiers suffering from heat injury were considered as well.

Heat injuries represent a significant problem on the battlefield and in training. In 2005, 1,700 heat injuries occurred in the U.S. Army [5], with the incidence rate of heat stroke in particular increasing from 1.8 per 100,000 soldiers in 1980 to 14.5 per 100,000 soldiers in 2002 [6]. With ongoing operations in Iraq, Afghanistan, and other hot climates, the heat injury rates seem unlikely to significantly drop soon.

Casualty Care Equipment

The equipment associated with care of the casualty can be described in terms of three aspects: the vehicle, the litter, and the casualty coverings. The traditional ground medical vehicle has been the M113. It has been described as small, uncomfortable, low-armor, cold war era, and having low-maneuverability [1]. The M113 is starting to be supplanted by up-armored High Mobility Multipurpose Wheeled Vehicles (HMMWVs) and Mine Resistant Ambush Protected (MRAP) vehicles; it has been noted that ground transport of casualties must be armored, given the level of threats to which the vehicle can (or is likely to) be subjected [1]. The HVAC systems of medical vehicles are generally insufficient as it relates to air cleanliness, humidity, ventilation, and temperature [1].

The patient litter is an item which must be transported along with the patient; therefore, it ought to be light, easily movable, robust, and cleanable [1]. These desired litter characteristics tend to preclude incorporation of thermal control.

The casualty covering could range from a simple blanket to a sophisticated thermal garment. The standard issue blanket is made of wool, and has been noted to not be very effective [1]. Mylar blankets, due to their highly insulative characteristics, have been used to assist in thermoregulation for casualties with low core temperatures [1]; a survey of other methods can be found in the literature [7]. For casualties with elevated core temperatures, a thermal garment or blanket can be used to provide active cooling; the garment or blanket can be air- or liquid-cooled.

Casualty Care Controversy

The thermal care associated with wounded warriors can be described in terms of the controversy associated with the best thermal state for the wounded warrior, as well as the challenges associated with providing the best thermal environment. Because most ground medical vehicles shuttle casualties (rather than evacuate them), the casualties generally ought to be stable on the vehicles [1].

The care of casualties within ground combat vehicles varies depending upon the vehicle, but certain thermal aspects are described here. Traditionally, the guidance has been to keep casualties warm via a blanket or other means [1]. The rationale for this guidance is that many trauma injuries involve blood loss, which is generally attended by a decrease in core temperature. Sufficiently reduced core temperature is generally associated with coagulopathy – a condition which is detrimental to bleeding casualties because of the associated hindrance of wound blood clotting. Fluid requirements are generally increased and recovery times are generally longer for patients with reduced core temperature. Multiple studies conclude that hypothermia, especially unregulated hypothermia, is harmful within the context of trauma injuries [8, 9, 10, 11, 12]. Along with acidosis (associated with anaerobic metabolism) and coagulopathy, hypothermia is a member of the "deadly triad" which marks patients as being near the end of their physiologic reserve [10]. As it relates to trauma, the hypothermia which can occur ranges from regulated (body-controlled) hypothermia, which is likely good because of its potentially protective nature, and unregulated hypothermia, which can be bad (as described above) [13]. A regulated increase in body temperature – i.e., a fever – resulting from the body's response to the injury could be beneficial [14].

However, there also could be benefits associated with not warming the casualties. For a casualty with reduced core temperature, the body's thermoregulatory system naturally tends to shunt blood flow to the body core via peripheral vasoconstriction, thus potentially decreasing peripheral blood loss. Conversely, keeping the casualty too warm via a blanket could cause more blood to be diverted to the body's periphery via vasodilatation; for normal subjects, skin blood flow can range as a percentage of cardiac output from nearly about 5% for normothermic conditions to as much as 60% for maximum heat stress caused vasodilation [15]. Such vasodilation puts greater strain on the heart [16, 17], and generally augments the cardiovascular problems from any hypovolemia associated with the injury-related blood loss and dehydration [14], or hypothermia-induced cold diruesis. Another benefit of decreased core temperature is the resulting decrease of metabolic activity, with the attendant decreased respiratory and cardiac activity as well as blood perfusion needs [3, 12]. Because casualties are often characterized by significant blood loss – approximately 85% of potentially survivable KIAs are due to hemorrhaging [1] – as well as decreased blood pressure (including a decreased capacity to control blood pressure), the effects of a decreased core temperature may be beneficial. The use of intentional hypothermia during surgery for the purpose of tissue preservation and reduction of blood flow and oxygenation needs is well established.

Regarding this ongoing controversy associated with the ideal thermal state for casualties, it can be said that a near-normothermic state should be the goal [13, 14]. The thermal state of casualties is probably best assessed via the body's core temperature; probably the best metric for core temperature, all things considered, is the rectal temperature [16]. However, monitoring of core temperature within a medical vehicle is generally not performed [1] or possible. Perhaps the measurement of rectal temperature within medical vehicles could become standard practice, given the importance of awareness of the casualty's thermal state to the treatment approach and the casualty's recovery.

Casualty Care Challenge

The availability of electrical power on vehicles is often in high demand and always limited. Therefore, the use of power to provide cooling for wounded warriors or heat-affected soldiers ought to be efficient. The power is used most efficiently when the cooling directly provided to the soldiers via microclimate cooling [14]. Unfortunately, a common method for direct cooling of the soldiers – surface cooling – can cause cutaneous vasoconstriction, which effectively increases the insulation of the soldier, thereby making cooling more difficult (less efficient); this vasoconstriction generally begins at skin temperatures between 32 and 33 degrees Celsius [18, 19]. However, the intermittent application of cooling to warm, vasodilated skin has been found to decrease these insulative effects of vasoconstriction [18]. The optimal skin temperature range within which vasoconstriction is minimized – in such a way that thermoregulatory and cardiovascular strain are not significantly increased, and the required power is decreased – was determined to be between 33 and 35 degrees Celsius [18]. A related patent was obtained for a cooling / heating method in which it was hypothesized that the most efficient method of cooling (or heating) would use this same temperature range for skin temperature feedback control [20]. Using the skin temperature feedback control method proposed, cooling is only applied when the skin temperature has surpassed the range upper limit and, subsequently, has not yet dipped to the range lower limit [20]. Compared with constant cooling, the skin temperature feedback method was found to allow a 46% reduction in cooling power requirements [20]. It was also found that such intermittent cooling methods require a smaller amount of body surface area for cooling, and that the time period or frequency associated with the intermittent cooling did not significantly affect the cooling performance [18]. This suggests that the magnitude of the cooling is not an important factor, so long as it is sufficiently high so that the range lower limit can be reached in a reasonably timely fashion. For wounded warriors, a skin temperature range between 30 and 33 degrees Celsius was deemed optimal [14]. While this range may require more cooling and electrical power, the health benefits to the wounded warrior would be greater; the simulation study within this report intended to quantify this relationship.

Casualty Simulation

Various tools exist which facilitate the modeling and simulation of the human body from a thermoregulation perspective. Examples of some of these tools include Thermoanalytics' Human Comfort module used together with its RadTherm solver, and P+Z Engineering's Fiala-FE module used together with its Theseus-FE solver. Fiala's active and passive models comprise the segmental thermo-physical predictive capability for these tools.

Currently, there is insufficient understanding to model the relative changes of thermoregulation mechanisms for injured soldiers relative to healthy soldiers for any type or severity of battlefield injury; however, "a comprehensive model … is both laborious and expensive, but very much needed" [4]. This kind of modeling would require "formulating a de novo model based on sub-human data (archival or actual experimentation) and simulating such responses on the human" [4]. In the absence of appropriate data, it would be safe to say that "any modeling of thermoregulatory control and injury would be misdirected" [14]. It was also stated that Fiala's passive and active models were "not designed to answer the ballistic, pressure, and burn consequences" [4]. A model associated with military working dogs which was developed by Dr. Larry Berglund at the U.S. Army Research Institute of Environmental Medicine (ARIEM) could be leveraged for such purposes, as well as rat models [4].

SIMULATION OF A NOVEL METHOD FOR SOLDIER THERMAL CONTROL

The aforementioned skin temperature feedback control method, patented by the U.S. Army for efficient soldier thermal control, is the focus of this simulation study. This study can be discussed in terms of the simulation scenario (including the environmental, vehicle, patient, and cooling garment considerations), methodology (in terms of its solution process, metrics, and parameters), and results.

Simulation Scenario

A severe thermal environment involving high solar loading of 1,120 W/m^2 without cloud cover, an effective sky temperature of 20^{o}C, a hot ambient air temperature of 54.4^{o}C (130^{o}F), and a vehicle headwind speed of 2.23 m/s (5.0 mph) was simulated. Steady-state conditions were assumed.

The ground combat vehicle simulated was a medical Mine Resistance Ambush Protected (MRAP) vehicle – the Caiman medical vehicle. Both the interior and exterior flow / thermal conditions of the vehicle were simulated under steady-state conditions. The vehicle was modeled as moving at a speed of 8.94 m/s (20 mph). While it was intended to simulate the vehicle's mobility performance, the focus of the study was the vehicle interior, and so the details associated with the vehicle's mobility characteristics are not presented here. And to force severe thermal conditions inside the vehicle, reduced HVAC performance was simulated.

The interior HVAC system includes a front unit and a rear unit. The front unit was modeled to recirculate air at a rate of 0.195 m^3/s (413 ft^3/min), and to reject only 500W of thermal energy; it does not draw in fresh air from ambient. The rear unit was modeled to recirculate air at a rate of 0.290 m^3/s (613 ft^3/min), and draw in fresh air from ambient at a rate of 0.100 m^3/s (211 ft^3/min); the rear unit was modeled to reject only 1,500W of thermal energy. These reduced cooling rates were imposed for the purpose of forcing more severe thermal conditions within the vehicle in a simple way.

The vehicle can accommodate four patient litters in the rear of the vehicle: an upper and lower litter on either side, left and right, of the central vehicle aisle. The four patients are resting in supine positions; there are also soldiers lightly active in sitting positions in the vehicle crew positions. Because of the lack of wounded warrior data, the patients are assumed to be healthy with normal thermoregulation capability, and generally starting with a normal core body temperature.

To facilitate cooling of the soldiers, individual cooling garments were modeled. The cooling garment was modeled as cooling pads wrapped around the soldiers torso and thighs, from just above the knees up to the neck (excluding the arms but including the shoulders). While it is understood that some wounded warriors may be unable to have cooling pads wrapped around them in this way, this method can be thought of as representative of whatever cooling method would actually be feasible given the specific injuries. Probably a more effective cooling scenario would involve a cooled pad on which the soldiers lie, with cool air blown between the patient and a covering [21]. The patient's cooling garment ensemble was modeled as having a thermal resistance of approximately 0.069 m^2-K/W, evaporative resistance of 0.014 m^2-kPa/W, a clothing area factor of 1.28, clothing insulation of 0.45 clo, and vapor permeation efficiency of 0.3. A cooling rate of 540W – high because of the severe thermal conditions modeled – was used for each patient. The details associated with the cooling device – such as the liquid pump, heat exchanger, etc. – were not considered in the overall modeling. For the skin temperature feedback method, temperature measurement was performed for only the cooled skin.

Simulation Methodology

The solution process involved: (1) performing a steady-state solution for the scenario described above, but with the thermal state of the soldiers' bodies (but not their clothing ensembles) being fixed at normothermic conditions; and (2) performing a subsequent transient solution for the same scenario, but with the soldiers being able to thermally respond to their surroundings, both passively and actively (via thermoregulation). For the transient solution, the convective heat transfer coefficients and flow reference temperatures from the steady-state solution – and associated with a higher y+ value of 100 – were used; this was based on the assumption that the effect of the soldiers' thermal changes on the surrounding air would be small.

The method used for solving the flow and temperature fields, both inside and outside the vehicle, involved iterative solving between a thermal solver, MuSES v.10.3.0, and a CFD solver, Star-CCM+ v.7.02.008. For purposes of decreasing model size, two separate CFD models were generated: one involving the exterior flow and the other involving the interior flow. Heat transfer coefficient and flow reference temperature data were passed from the CFD solver to the thermal solver, and wall temperatures were passed from the thermal solver to the CFD solver; this was performed until solution convergence was obtained. A script which facilitated this data passing and the iterative solving was used.

The main metrics used to assess the effect of heat on wounded warriors include skin temperature, skin blood flow and vasomotion, and cardiac output (the volumetric flowrate of blood from the heart). The parameters thermally influencing the wounded warrior can be categorized in terms of soldier thermal <u>conditions</u> and soldier thermal <u>control</u>. The soldier thermal conditions include: (1) the thermal <u>boundary</u> conditions, which involve the thermal characteristics of the surroundings associated with each soldier individually, including the local convection and radiation heat transfer characteristics; and (2) the thermal initial conditions, which involve the thermal characteristics of the beginning (initial) state of the soldiers.

The soldier thermal control involves the cooling control type and the cooling control set points. The cooling control types investigated include no cooling and skin-temperature feedback control. For the skin-temperature feedback control, it is intended to maintain the skin temperature between the upper and lower set points. When the skin temperature surpasses the upper set point, cooling is continuously applied until the skin temperature dips below the lower set point. As the temperature rises and again surpasses the upper set point, cooling is applied again until the temperature dips below the lower set point (and so on). Two set point ranges – corresponding to the two ranges previously discussed – were considered: a “low cooling” range from 33^{o}C to 35^{o}C, and a “high cooling” range from 30^{o}C to 33^{o}C. A script which accomplishes the skin temperature feedback cooling control was developed and implemented into the thermal model.

Simulation Results – Steady-State

Results from the steady-state simulation are displayed here. Figure 1 shows the exterior heat transfer coefficient distribution associated with the moving vehicle. Higher heat transfer coefficient regions include the spinning wheels and vehicle leading edges; lower heat transfer coefficient regions include the roof area over which the main flow separated because of the gunner assembly, as well as the vehicle rear exposed to the vehicle wake.

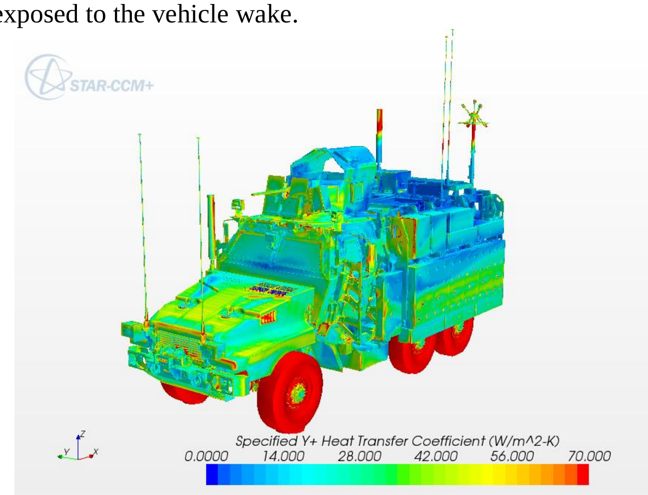

Figure 1: Heat Transfer Coefficients from CFD Model, Which Are Mapped to Thermal Model.

Figure 2 shows the interior heat transfer coefficient distribution associated with the patients, along with the streamlines (colored on a flow velocity basis) of the flow moved by the HVAC units. Here it can be seen that the surfaces closer to the HVAC outlet flow are characterized by higher heat transfer coefficients, increasing the thermal variability of the patients.

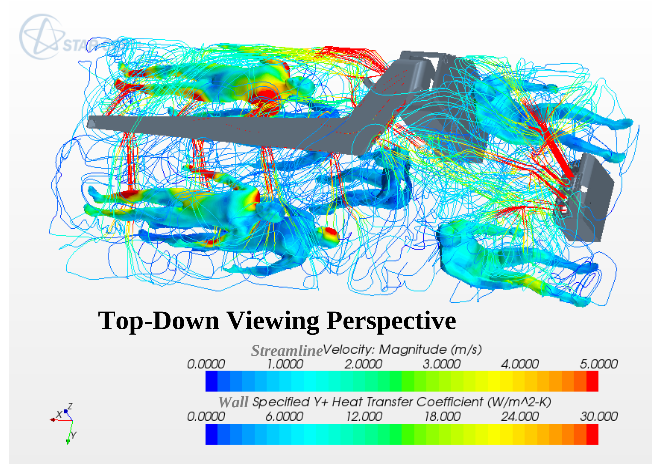

Figure 2: Effect of Vehicle HVAC Flow on Soldier Heat Transfer Coefficients.

Figure 3 shows the temperature distribution of the vehicle. Higher temperature regions include the engine compartment, as well as the flow-separated, solar-exposed roof region near which roof-mounted electronics cooling fan flow is exhausted.

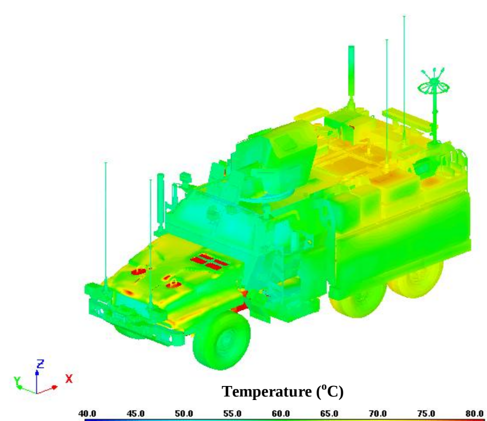

Figure 3: Wall Temperatures from Thermal Model, Which Are Mapped to CFD Model.

Table 1 shows the variation of the thermal conditions associated with the patients’ surroundings. The higher patients, because of their closer proximity to the HVAC flow outlets, are characterized by higher “whole body” heat transfer coefficients as reported by MuSES’ Human Thermal Module.

Table 1: Variation of the Thermal Conditions of the Patients' Surroundings.

Patient Location	"Whole Body" Heat Transfer Coefficients (W/m^2-^oC)	
	Radiative	Convective
Top-Left	5.45	36.9
Top-Right	5.42	36.9
Bottom-Left	5.28	30.8
Bottom-Right	5.22	30.6

Simulation Results – Transient

For the transient simulations, in which the soldier temperatures were solved, the effect of the patient cooling method was under focus. The cooling methods considered include "no cooling", "low cooling" (involving the skin temperature feedback control within a skin temperature range between 33°C and 35°C), and "high cooling" (involving the skin temperature feedback control within a skin temperature range between 30°C and 33°C). Because the results for each patient show similar trends, only results for the patient in the top-left litter will generally be shown. Figure 4 shows the effect of the cooling method on the mean temperature of the patient's cooled skin. Both cooling methods stay within their respective set points.

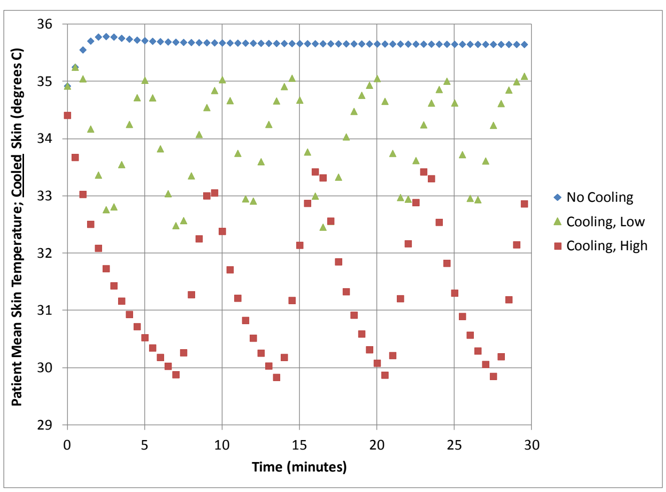

Figure 4: Effect of Cooling Method on the Mean Temperature of the Patient's Cooled Skin.

Figure 5 shows the effect of the cooling method on the mean temperature of all the patient's skin. Because these mean skin temperature values include uncooled skin, the values are higher relative to those of Figure 4.

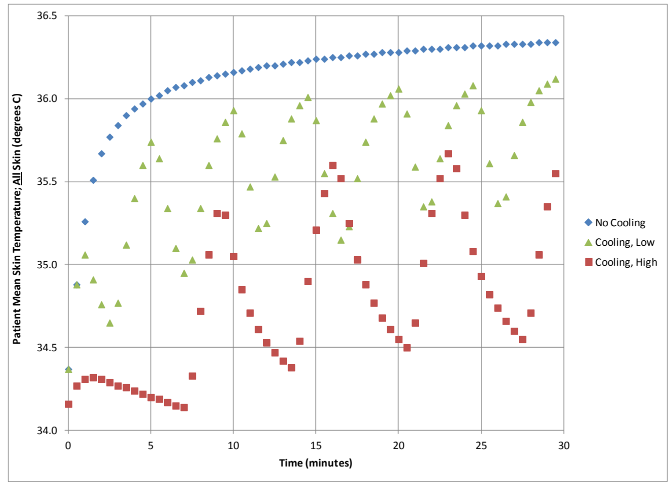

Figure 5: Effect of Cooling Method on the Mean Temperature of the Patient's Skin (All).

Figure 6 shows a comparison for the two mean skin temperature values, involving all of the skin and just the cooled skin, for the "high cooling" method. It is safe to say that, the greater the amount of cooled skin, the closer the two values would be.

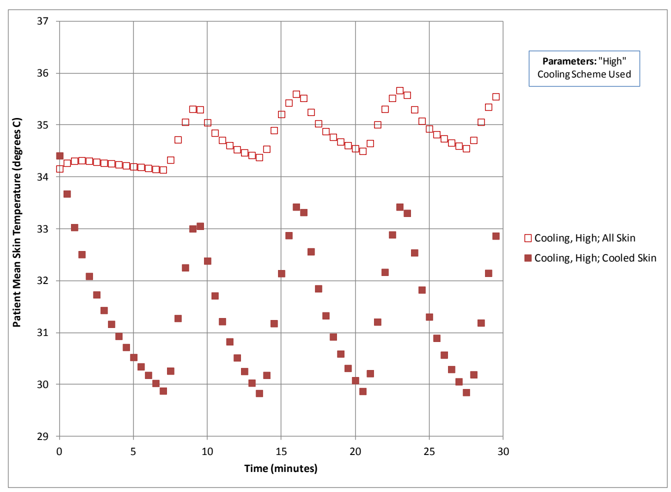

Figure 6: Comparison of Effect of the High Cooling Method on the Mean Temperature of the Patient's Cooled Skin vs. All of the Skin.

Figure 7 shows the effect of the cooling method on skin blood flow. For greater amounts of applied cooling, skin blood flow decreases. For patients with peripheral injuries, lower skin blood flow – brought about by greater cooling – could be preferred for wounded warriors.

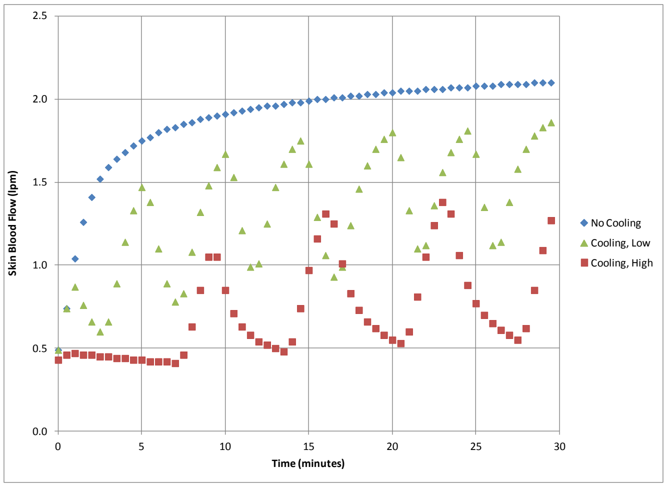

Figure 7: Effect of Cooling Method on Skin Blood Flow.

Figure 8 shows the effect of the cooling method on cardiac output. Greater cooling results in less cardiac output, and thus cardiovascular strain.

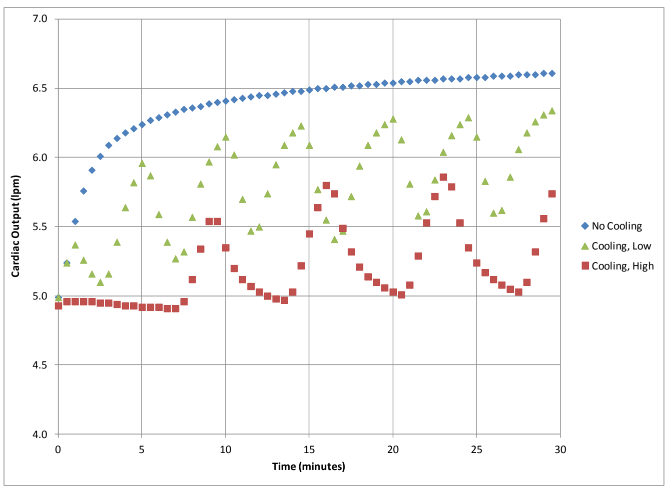

Figure 8: Effect of Cooling Method on Cardiac Output.

Figure 9 shows the effect of the cooling method on steady-state thermal sensation. The greater the cooling, the lower the thermal sensation – and the greater the thermal comfort.

Table 2 shows, for the simulated intermittent, 540W per patient cooling, the cooling duty cycle required for each cooling method. Although significantly more power would be required for more cooling, the benefits of reduced cardiovascular strain and skin blood flow may outweigh the required vehicle performance burdens.

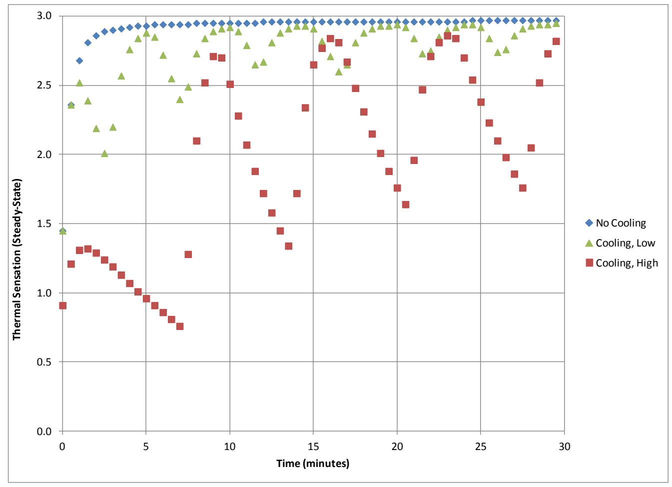

Figure 9: Effect of Cooling Method on Thermal Sensation.

Table 2: Required Cooling for Various Cooling Methods and for Different Soldier Initial Thermal States.

Cooling Condition	Cooling Duty Cycle (%)	
	Normothermic Initial State	Hyperthermic Initial State
None	0	0
Low	34.7	49.6
High	64.0	69.1

CONCLUSIONS

Based upon the insights gleaned from the Army medical community, as well as some of the results of simulation study presented here, various conclusions related to the thermal conditions within ground combat vehicles can be drawn: (1) Cooling a greater surface area of the body – as well as proportioning the cooling to parts of the body such that a more uniform surface temperature results – would generally decrease local vasoconstriction and increase cooling efficiency; (2) higher cooling capacity for patients would present a burden, but may be outweighed by the patient benefits; (3) implementation of a skin temperature feedback control method – with “low cooling” for healthy soldiers, and “high cooling” for wounded warriors – would improve efficiency; (4) implementing core temperature monitoring would provide the best metric of the patient’s thermal state; (5) obtaining wounded warrior physiological and thermoregulatory data, and developing appropriate predictive models with user ability to have more control over the human physiology and thermoregulation throughout the body, may be warranted; (6) interaction with Army combat casualty care personnel could yield the desired, ideal HVAC conditions for wounded warriors; and (7) future work could involve simulation of dust entrainment into the crew / patient areas, vehicle overpressure characteristics, and many other health-related aspects of ground combat vehicles.

ACKNOWLEDGMENTS

The authors are extremely grateful for the time and insights from the following people within the Army medical community: Drs. Michael N. Sawka, Richard R. Gonzalez, Reed Hoyt, Andrew Cap, and Victor Convertino, Mr. Brad Laprise, and Mr. Walter Teal. The authors are also grateful for the assistance of intern Steve McCarty, who generated the MuSES-Star iterative solving script which greatly facilitated the simulations contained within this report, as well as for the assistance of Josh Pryor (at Thermoanalytics, Inc.) in support of the development of the MuSES script used to implement the skin-temperature feedback cooling.

REFERENCES

[1] A. P. Cap and V. A. Convertino, Interviewees, *U.S. Army Institute of Surgical Research.* [Interview]. 11 August 2010.

[2] D. L. MacDonald, "The Joint Patient Movement System, A Solution to Arrest the Erosion of an Efficient and Effective System," U.S. Army War College, Carlisle Barracks, Pennsylvania, 2004.

[3] T. Kheirbek, A. R. Kochanek and H. B. Alam, "Hypothermia In Bleeding Trauma: A Friend or Foe?," *Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine,* vol. 17, pp. 1-15, 2009.

[4] R. R. Gonzalez, *E-Mail Corresp.,* 2010 Dec. 3.

[5] M. Cates, "Heat Injury Prevention Program," Department of Army, Office of the Surgeon General, 2006, April 17.

[6] R. I. Carter, S. Cheuvront, J. Williams, M. Kolka, L. Stephenson, M. Sawka and P. Amaroso, "Hospitalizations and Death from Heat Illness in US Army Soldiers, 1980-2002," *Medicine and Science in Sports and Exercise,* vol. 37, pp. 1338-44, 2005.

[7] K. H. Polderman and I. Herold, "Therapeutic Hypothermia and Controlled Normothermia in the Intensive Care Unit: Practical Considerations, Side Effects, and Cooling Methods," *Critical Care Medicine,* vol. 37, no. 3, pp. 1101-1120, 2009.

[8] L. M. Gentilello, G. J. Jurkovich, M. S. Stark, S. Hassantash and G. E. O'Keefe, "Is Hypothermia in the Victim of Major Trauma Protective or Harmful? A Randomized, Prospecitve Study," *Annals of Surgery,* vol. 226, pp. 439-49, 1997.

[9] A. Kirkpatrick, R. Chun, R. Brown and R. K. Simons, "Hypothermia and the Trauma Patient," *Canadian Journal of Surgery,* vol. 42, pp. 333-343, 1999.

[10] Z. Arthurs, D. Cuadrado, A. Beekley, K. Grathwohl, J. Perkins, R. Bush and J. Sebesta, "The Impact of Hypothermia on Trauma Care at the 31st Combat Support Hospital," *The American Journal of Surgery,* vol. 191, pp. 610-614, 2006.

[11] E. Søreide and C. E. Smith, "Hypothermia in Trauma Victims -- Friend or Foe?," in *17th Annual Trauma Anesthesia and Critical Care Symposium*, Sydney, Australia, 2004.

[12] B. J. Tsuei and P. A. Kearney, "Hypothermia in the Trauma Patient," *Injury, International Journal of the Care of the Injured,* vol. 35, pp. 7-15, 2003.

[13] W. Winkenwerder and M. Sawka, "Disorder Due to Heat and Cold," in *Goldman's Cecil Medicine 24th Edition*, L. Goldman and I. Schaffer, Eds., Philadelphia, W. B. Saunders Company, 2011, pp. 666-670.

[14] M. N. Sawka, *E-Mail Corresp.,* 2010 Dec. 2.

[15] D. J. Kellogg, "In Vivo Mechanisms of Cutaneous Vasodilation and Vasoconstriction in Humans During Thermoregulatory Challenges," *Journal of Applied Physiology,* vol. 100, pp. 1709-1718, 2006.

[16] Headquarters, Department of the Army and Air Force, "Heat Stress Control and Heat Casualty Management Technical Bulletin Medical 507," Washington, D.C., 2003.

[17] M. Sawka and A. Young, "Physiological Systems and Their Responses to Conditions of Heat and Cold," in *ACSM's Advanced Exercise Physiology (First Edition),* C. Tipton, M. Sawka, C. Tate and R. and Terjung, Eds., Baltimore, Lippincott, Williams and Wilkins, 2006, pp. 535-563.

[18] S. Cheuvront, M. Kolka, B. Cadarette, S. Montain and M. Sawka, "Efficacy of Intermittent, Regional Microclimate Cooling," *Journal of Applied Physiology,* vol. 94, pp. 1841-48, 2003.

[19] L. A. Stephenson, C. R. Vernieuw, W. Leammukda and M. A. Kolka, "Skin Temperature Feedback Optimizes Microclimate Cooling," *Aviation, Space and Environmental Medicine*, vol. 78, pp. 377-382, 2007.

[20] S. J. Montain, T. J. Doherty, S. N. Cheuvront, M. A. Kolka, L. A. Stephenson, B. S. Cadarette, R. Carter and M. N. Sawka, "Body Thermoregulation Using Skin Temperature Feedback". USA Patent 7,837,723, 23 November 2010.

[21] R. Kenefick and W. Teal, "Microclimate Cooling Solutions to Treat Heat Injuries during Evacuation".