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INSULATED CONTAINERS FOR BOTTLED WATER (ICB) – PERFORMANCE EVALUATION

by
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Final Report
July 2013 – January 2014

Approved for public release; distribution is unlimited

U.S. Army Natick Soldier Research, Development and Engineering Center
Natick, Massachusetts 01760-5000

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14. ABSTRACT

This report describes an evaluation of the thermal performance, blast durability, operational durability, and flammability of four insulated containers for bottled water (ICB) recently developed by the Natick Soldier Research, Development and Engineering Center (NSRDEC). This testing was conducted or contracted by NSRDEC from July 2013 through January 2014 in support of PM MRAP efforts to reduce unrestrained stowage in vehicles while providing palatable drinking water for mounted Soldiers. The ICBs are lighter, require less storage space, and have more effective tie-down characteristics than coolers often used to carry bottled water in vehicles. The performance of the ICBs and a commonly used cooler was assessed to determine whether the easier-to-stow ICBs would be as effective and durable as the coolers. The four ICBs provide three options in size and capacity and two choices of insulation r-value and cost. Hot ambient temperature tests were conducted to assess thermal performance. Improvised explosive device (IED) simulations were used to assess blast durability. Drop tests, vibration tests, and abrasion tests were conducted to assess operational durability. Flash oil fire tests were conducted to assess flammability. All the ICBs survived the blasts test and the drop test while the cooler did not survive either one. All the containers survived the vibration tests. Though the cooler maintained bottled water under 72 °F much longer than the standard insulation ICB of the same capacity and the smaller ICB, the higher R-value (more costly) ICB of similar size maintained the temperature 8 h longer than the cooler, and the largest standard insulation ICB maintained temperature as long as the cooler when filled with water bottles and 6 h longer with a 5-gal water bag.

15. SUBJECT TERMS

WATER	STOWAGE	PROTOTYPES	BOTTLED WATER	HIGH TEMPERATURE
WEIGHT	EJECTION	CONTAINERS	DRINKING WATER	THERMAL INSULATION
BOTTLES	HYDRATION	HOT REGIONS	COMBAT VEHICLES	TEST AND EVALUATION
COOLERS	INSULATION	LIGHTWEIGHT	GROUND VEHICLES	AMBIENT TEMPERATURE
COOLING	DURABILITY	WATER COOLERS	MILITARY VEHICLES	
STORAGE	PROJECTILES	WATER COOLING	IMPROVISED EXPLOSIVE DEVICES	

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Preface

This report describes an evaluation of the blast durability, thermal performance, operational durability, and flammability of a set of prototype insulated containers for bottled water (ICB) developed by the Natick Soldier Research, Development and Engineering Center (NSRDEC) in July 2013 as an easier-to-restrain-and-stow alternative to the coolers commonly used to carry bottled water on mounted operations. The testing and analysis was conducted or contracted by NSRDEC (under project number OMA-423829) from July 2013 through January 2014 in support of Joint Program Office Mine Resistant Ambush Protected (JPO-MRAP)-funded efforts to reduce unrestrained stowage in vehicles. The purpose of this study was to assess the performance of four ICBs and a commonly used commercially available cooler to determine whether the easier-to-restrain-and-stow ICBs would be as effective and durable as the coolers. The blast durability assessment was conducted by Johns Hopkins University Applied Physics Laboratory, and the abrasion testing portion of the operational durability assessment was conducted by Taber Industries.

The author acknowledges the valuable contributions of the other four members of the NSRDEC evaluation team: John Gildea, Laurra Winter, Brian Grady, Will Feather.

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INSULATED CONTAINERS FOR BOTTLED WATER (ICB) PERFORMANCE EVALUATION

1. Introduction

In places such as Iraq and Afghanistan, average ambient temperatures can be anywhere between 95 °F and 120 °F. Under these conditions, heat-induced ailments can negatively affect Warfighter combat effectiveness through reduced endurance and cognitive function. These negative side effects can prove detrimental to mission success. Examples of such heat-induced ailments include heat syncope, heat exhaustion, heat stroke, and dehydration. Drinking cold water can drastically thwart off heat-related ailments, as well as improve cognitive function and endurance. When compared to drinking warm water, cold water can increase exercise endurance capacity by 23 ±6%[1], as well as reduce heart rate and psychological strain.

As part of an overall effort to combat the effects of extreme heat on the Warfighter, in July 2013, the Natick Soldier Research, Development and Engineering Center (NSRDEC) completed development of a set of insulated containers for bottled water (ICB). This report describes an evaluation of the blast durability, thermal performance, operational durability, and flammability of four newly developed prototype ICBs and a commercial off-the-shelf (COTS) cooler conducted or contracted by NSRDEC between July 2013 and January 2014. Both the development and evaluation projects were funded by PM-MRAP as part of an effort to reduce unrestrained stowage in vehicles, and bottled water is the most common unrestrained item in all vehicles. These newly developed ICBs are intended to provide thermal retention performance comparable to commercially available coolers while reducing the comparative storage space and weight and improving the comparative durability and tie-down characteristics. A more durable ICB with more secure tie-downs will reduce the likelihood of damage to the container contents and harm to the vehicle's occupants caused by release of the container or ejection of its contents in an improvised explosive device (IED) scenario.

The four prototype ICBs provide three options in size and capacity and two choices of insulation R-value and cost. The objectives of this performance testing included:

1) Determine and compare the ability of each prototype ICB and a COTS cooler to survive and remain restrained during an in-vehicle IED scenario.
2) Determine and compare the thermal performance of each prototype ICB and a COTS cooler.
3) Determine and compare the durability during drop testing of each prototype ICB and a COTS cooler.
4) Determine and compare the ability of each prototype ICB and a COTS cooler to be effectively restrained during normal vehicle operation.
5) Determine and compare the abrasion resistance of the materials of each prototype ICB and a COTS cooler.
6) Determine and compare the flammability of each prototype ICB and a COTS cooler.

1.1 Background

Realizing the benefits of drinking cold water, vehicle-mounted Soldiers in Iraq and Afghanistan started utilizing commercially available insulated coolers to prolong the palatability of their water. This

[1] Jason K.W. Lee; Susan M. Shirreffs; Ronald J. Maughan, "Cold Drink Ingestion Improves Exercise Endurance Capacity in the Heat," Medicine and Science in Sports and Exercise®. 2008;40(9):1637-1644. © 2008 American College of Sports Medicine

utilization of COTS coolers came about because "War-fighters are required to remain static inside their tactical vehicles from 6 to 48 hours. The War-fighter and the bottled water that they carry become warm due to extremely high ambient temperatures, solar radiation, and the heat from the vehicles. Neither warm nor hot water is palatable; thereby reducing the voluntary intake of water."[2]

The Operational Forces Interface Group conducted a survey of 230 Warfighters from various units to gauge their interest for a Vehicular Mounted Combat Cooling System (VMCCS) in November 2008. The complete report is provided in Appendix A. The survey questioned Warfighters on drinking water quality in hot environments, as well as drinking water habits. Some of the findings include:

- Slightly under fifty percent of Warfighters stated they have witnessed disposal or have personally disposed of bottled water because it was warm.
- Seventy-seven percent of Warfighters stated the bottled water that they were supplied with became hot or warm during their mission.
- Forty-seven percent of Warfighters stated they did not consume enough water because their drinking water became too hot.

Participants were also asked if they felt there was a need for chilled water, whereby three-quarters (73.0%, n=168/230) of the Soldiers responded that there is a need for chilled bottled water within their vehicle to support increased hydration, morale, and combat effectiveness while slightly over one-quarter (27.0%, n=62/230) said "No". From those who said "Yes," the following comments were received:

- Cold water is more refreshing (n=22).
- Cools core body temperature (n=22).
- Morale and combat effectiveness (n=21).
- Increases hydration with cool water (n=19).
- It would be nice to have a cold drink (n=19).
- Hot water hard to drink (n=6).
- Increases energy (n=5).
- Decrease dehydration with cold water (n=4).
- More convenient (n=2).

Currently there is no military-developed solution to insulate bottled water and prolong its initial cold temperature. While COTS coolers are being utilized, they cannot be effectively restrained, are heavy, and take up a significant amount of space. These factors play into the unrestrained stowage issue, whereby vehicle-mounted Soldiers are ineffectively mounting commercially available coolers and they, as well as the bottles they contain, are becoming projectile hazards during improvised explosive device (IED) scenarios. Examples of some of these COTS coolers and their being ineffectively restrained/stowed can be seen in Figure 1.

Fielding a unique high-performance military cooler for vehicle-based applications would not only allow Soldiers to safely restrain one of the most common items stowed in a vehicle, but would also improve the mounted Soldiers' physical stamina, health and morale by sustaining cold bottled water for the entire duration of the mission, whether it be an 8-h patrol or a 4-day scouting mission.

[2] Jessica Harshman, "Operational Forces Interface Group - Vehicular Mounted Combat Cooling System (VMCCS)," Natick Soldier Research, Development and Engineering Center, January 8, 2009.

Figure 1: Ineffectively Restrained Coolers

The Alpha prototype suite of ICBs consists of a small, medium, and large version with standard commercial off the shelf (COTS) double bubble heating, ventilation, and air conditioning (HVAC) insulation and a medium version with Aerogel insulation. Each version (which is specified and pictured in Section 1.3) has an integrated access flap that can be lifted up to access the bottled water, Modular Lightweight Load-carrying Equipment (MOLLE) webbing to accommodate various attachments, and integrated handles for ease of transport. The medium and large ICBs also have integrated high-strength 2,000-lb straps to keep the bag closed during an in-vehicle IED detonation scenario. The high-strength straps coupled with the MOLLE webbing allow the ICBs to easily tie down in any vehicle and mitigate the threat of unrestrained bottled water or other small personal gear in an IED scenario. The medium and large ICBs also include a double flip-top design, which allows the entire volume to be accessed when loading, as well as a removable waterproof liner which attaches with Mil-SPEC snaps.
The COTS double bubble insulation is cost effective, easy to work with, and can be sewn through. Aerogel insulation, in contrast, is relatively expensive and difficult to work with, but it provides the best performance available in the market today. Different construction techniques had to be used in order to accommodate the Aerogel insulation, but the ICB is the same size as the double bubble medium ICB.

1.2 Descriptions of Tested Containers

The four ICB prototypes were tested along with a Coleman 30-qt cooler (as the baseline container) to compare the performance of each prototype with a standard cooler. This cooler was selected because it represented the generic, hard-walled plastic coolers that had been seen in the field, held the same number of bottles (15) as the medium ICBs, and was small enough to store in a vehicle with minimal room. Larger coolers would have to be secured to the outside of the vehicle; therefore, medium or small sized coolers should be more common and would apply to a larger user group. The physical characteristics of the four ICBs and the cooler are listed in Table 1, various views of the ICBs are shown in Figure 3, and the cooler and its contents are pictured in Figure 3. As listed in Table 1, the large ICB is also capable of accommodating the High Stress Collapsible Water Bag (HSCWB) 5-gal water bladder, allowing the HSCWB's detachable faucet to protrude through the integrated grommet on the side of the large ICB so that secondary containers can be easily filled. The large ICB also has a rubberized base for added traction and abrasion resistance.

Table 1: Physical Characteristics of Tested Containers

Feature		ICB Small	ICB Medium		ICB Large	COTS Cooler
Insulation		Double Bubble	Double Bubble	Aerogel Spaceloft	Double Bubble	Air Gap
R Value		3	3	10.3	3	5
Dimensions (in)		15 x 3 x 11	15 x 10 x 11”		16 x 21 x 11	17 x 15 3/8 x 12
Weight (lb)		1.38	3.88		8.98	6
Space to Store - Empty		.138 ft^3	.260 ft^3	.434 ft^3	.583 ft^3	1.815 ft^3
Space to Store - Full		.286 ft^3	.955 ft^3		2.139 ft^3	1.815 ft^3
Capacity		5 700-mL Bottles	15 700-mL Bottles		36 700-mL Bottles	15 700-mL Bottles
		3 Legacy MREs	8 Legacy MREs		24 Legacy MREs	
		3 New MREs	11 New MREs		28 New MREs	
					HSCWB	
Construction	Body	Cordura	Cordura		Cordura	PE Plastic
	Base	Cordura	Plastic Wrapped Cordura		Rubberized traction pad	PE Plastic
	Liner	No	Yes		Yes	No
Safe Tie-Down Capability		Yes	Yes		Yes	No
Easy Access when Tied Down		Yes	Yes		Yes	No

Figure 2: Alpha Prototype ICBs: (a) Small; (b) Medium; (c) Medium Aerogel; (d) Large.

Figure 3: Medium-Size COTS Cooler

2. Methods and Procedures

Six performance tests were conducted in four categories:

- Blast Durability - IED Simulation Test (Section 2.1)
- Thermal Performance - Hot Ambient Temperature Test (Section 2.2)
- Operational Durability (Section 2.3)
    - Drop Test
    - Vibration Test
    - Abrasion Test
- Flammability - Flash Oil Fire Test (Section 2.4)

Each of the five containers was subjected to each test except for abrasion testing; only component materials of the ICBs (not in-tact containers) were subjected to the abrasion tests.

2.1 Blast Durability

The blast durability testing consisted of laboratory simulations of IED explosions using the Vertically Accelerated Load Transfer System (VALTS), which is an underbody blast (UBB) simulator (Figure 4) owned and operated by the Johns Hopkins University Applied Physics Laboratory (JHU/APL). The testing was conducted by JHU/APL under contract to NSRDEC, and JHU's full report on the testing is reprinted as Appendix B. VALTS is a multiple impact vertical test platform used to simulate roadside mine blasts. It features controlled accelerative impulse (which simulates global rigid body motion) and controlled deceleration impulse (which simulates slam-down impact of the vehicle) to the test specimen body. The system is constructed with a 50 in x 60 in high-strength aluminum table top surface (carriage) with threaded inserts on a 4-inch grid pattern allowing for attachment of a variety of seat systems and simulated vehicle structures. It also has a stationary carriage and test specimen design for the following advantages: full control of the Device-Under-Test (D.U.T.) prior to the onset of the pulses, a lack of acceleration and velocity influences upon the D.U.T. prior to the shock impulses, and the best representation of "real world" acceleration conditions.

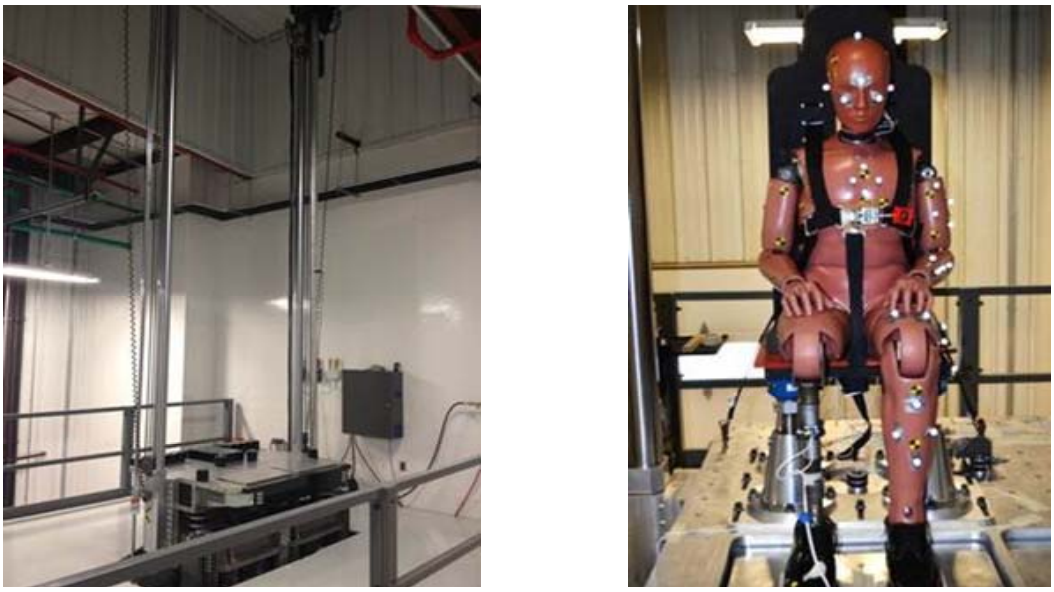


Figure 4: APL VALTS. Left: Structure; Right: Example Test Specimen Setup

VALTS achieves high-level impact energies by propelling precision-guided ballistic masses (Figure 5) into both the lower leg and the stationary carriage. Programming materials are placed between the ballistic

mass and stationary carriage to produce the desired pulse duration with the pressure level controlling the impact speed. The VALTS controller module allows for complete control of setup and operation. The control software has a manual control mode that allows different loading conditions to operate independently, providing a wide range of loading conditions. Achieved velocity for VALTS ranged from 2 to 10 m/s with durations of 10 to 40 ms for the carriage and 7 to 16 m/s with durations of 2 to 10 ms.

Figure 5: VALTS Guided Ballistic Masses

A test fixture (Figure 6) was provided to JHU/APL to hold the test articles and allow them to be tied down using the prescribed tie-down procedures. This fixture was rigidly mounted to the VALTS. The test fixture was instrumented with accelerometers (Endevco 2262A) attached to Low Frequency Foam Isolated (LOFFI) mounts similar to those used in live-fire testing. Exposure severity was determined by the response of this sensor. Response data was sampled at 100 kHz using a Dewetron data acquisition system. The collected data allowed for the verification of the test exposure. High speed imaging was installed on the test sled, as well as off-board, allowing evaluation of the test article response.

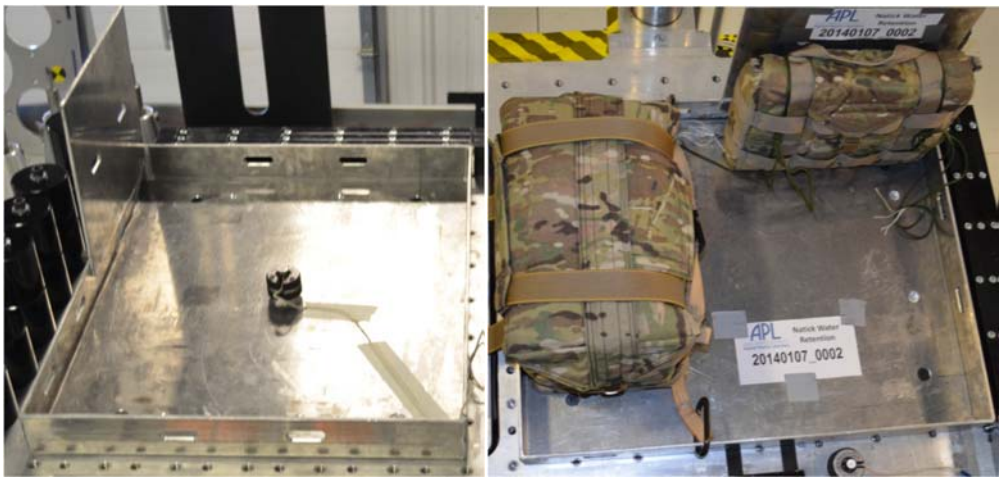


Figure 6: Test Fixture. Left: Fixture Mounted to VALTS; Right: ICBs Mounted to Fixture

Onboard video data was collected using a Phantom Miro3 camera (0.5 megapixel at 1000 fps). The recorded response provided insight into the response of the various systems under loading REDD-2014, and could allow for some measurements of deflection and translation during the test. Initial tests also included two off-board Phantom v10 cameras (0.5 megapixel at 4700 fps).

Each container was blast tested with its capacity (as listed in Table 1) of frozen 700-mL water bottles: 36 for the large ICB, 15 for each medium ICB and the COTS cooler, and 5 for the small ICB. Each container was tested using two different restraint methods, but only one method per test. The ICBs were secured by either of two restraint systems provided by NSRDEC: Standard Tie Downs (STDs) or Universal Tie Downs (UTDs). The STD was 550 Paracord pre-cut to a specific length; it was the NSRDEC in-house rigger's recommended restraint system because it was readily available in the field. The UTD included a center buckle and two carabineers that attached to the tray; it was tested at the request of the sponsor (JPO MRAP). The COTS cooler was secured using either a UTD or a standardized strap which soldiers in the field readily procure and use from their PXs (rubber bungee cord), instead of an STD. Use of the restraints and the application to the various test samples followed the provided installation procedures, which were developed by NSRDEC's in-house rigger and are available from NSRDEC upon request.

Fourteen blast test events (detailed in Table 2) were executed at maximum accelerations of 7 m/s and 9 m/s with proprietary acceleration profiles. Three tests were run at each test event for the small, medium double bubble, and large ICBs to determine repeatability of the results. Only one test per event was run for the COTS cooler and the medium Aerogel ICB due to concerns with failure and expense, respectively, of the systems.

Table 2: Blast Test Matrix

Test Event	Exposure Severity (m/s)	System	Restraint
1	7	Medium Double Bubble ICB	STD
2	9	Medium Double Bubble ICB	STD
3	7	Medium Double Bubble ICB	UTD
4	9	Medium Double Bubble ICB	UTD
5	7	Small ICB Medium Aerogel ICB	STD UTD
6	9	Small ICB Medium Aerogel ICB	STD UTD
7	7	COTS Cooler Large ICB	UTD STD
8	9	COTS Cooler Large ICB	UTD STD
9	7	Large ICB	UTD
10	9	Large ICB	UTD
11	7	Small ICB Medium Aerogel ICB	UTD STD
12	9	Small ICB Medium Aerogel ICB	UTD STD
13	7	COTS Cooler	Standardized Strap
14	9	COTS Cooler	Standardized Strap

2.2 Thermal Performance

The thermal performance testing consisted of hot ambient temperature testing in NSRDEC's Doriot Climatic Chambers tropic climate chamber. The temperature was set at 120 °F, the relative humidity (RH) was set to fluctuate between 20% and 40%, the wind speed was set at 5 mph, and the solar radiation lamps were turned on above the ICBs to simulate daytime sunlight conditions at the equator (approximately 800 W/m^2). This test was conducted to simulate a worst case scenario by taking the highest temperature from MIL-STD-801G's hot dry test and the highest RH from MIL-STD-810G's basic hot test (120 °F/40% RH). This specific climate chamber is not capable of testing to a diurnal cycle, hence the need to set the test parameters to a steady state condition. However, since the climate chamber could not be left on overnight, the heat input, wind, and solar radiation lamps were shut down every day at approximately the same time, resulting in a diurnal cycle of sorts whereby the ICBs were subjected to a worst case daytime scenario (120 °F/40% RH) for approximately 8 h and then subjected to a lower ambient evening/nighttime/early morning temperature between 100 °F-115 °F for approximately 16 h.

Each container was tested with its capacity (as listed in Table 1) of frozen 700-mL water bottles: 36 for the large ICB, 15 for both medium ICBs and the COTS cooler, and 5 for the small ICB (Section 2.2.1). Additionally, the large ICB was tested with an HSCWB filled with water and frozen (Section 2.2.2). (The large ICB was the only container that could accommodate an HSCWB.)

2.2.1 700-mL Water Bottle Tests

Prior to testing, eighty six 700-mL bottles of water were frozen to a temperature of 0 °F ± 10 °F. Prior to being frozen, one thermocouple was placed into nine of the bottles (total of nine thermocouples). The thermocouples were inserted into the bottles via a .25-inch hole which was drilled through each bottle's cap, as seen in Figure 7. One thermocouple was also placed on the outside handle of each ICB and COTS cooler to monitor the ambient temperature. The thermocouple for the COTS cooler was wrapped around the cooler handle and the cooler handle was positioned vertically above the cooler as seen in Figure 8.

Figure 7: Thermocouple Installation into Water Bottles

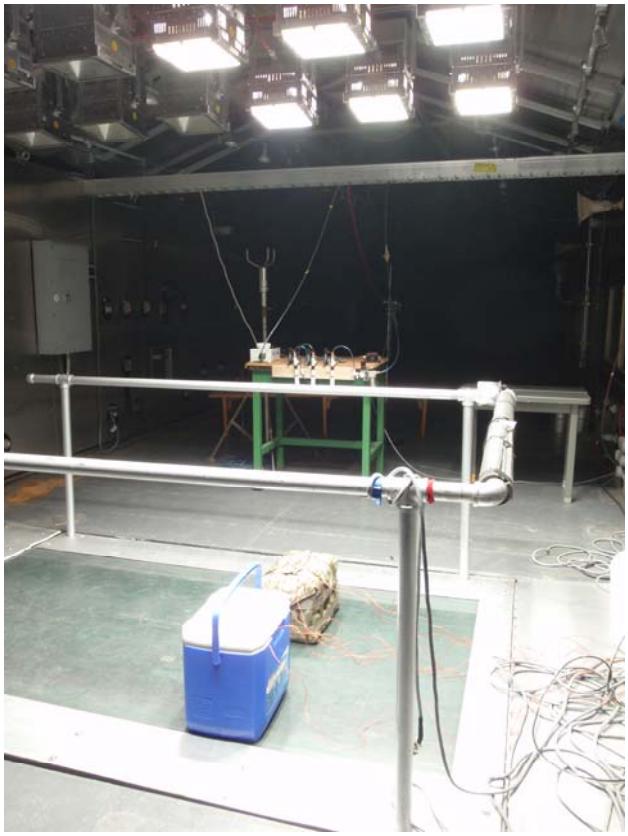


Figure 8: COTS Cooler Thermocouple Placement

The bottles were then placed into the five containers in their respective capacities. The bottles equipped with thermocouples, designated by yellow caps, were placed in the positions shown in Figure 9, Figure 10, and Figure 11. Positions were chosen to correspond to the center of the bag, at least one corner of the bag, and the center of at least one wall of the bag.

Figure 9: Large ICB Thermocouple Positions

Figure 10: Medium ICB and Cooler Thermocouple Positions

Figure 11: Small ICB Thermocouple Positions

Each loaded ICB was then closed and placed on the climate chamber floor directly below the solar radiation lamps as seen in Figure 12. Each ICB's front facing wall (access port side) was also positioned to face the wind being generated in the chamber. One thermocouple was also positioned in the middle of the ICBs to record the ambient temperature at the level of the ICBs. The thermocouple wires were then run to a Graphtec GL200A data logger, which can be seen in Figure 13.

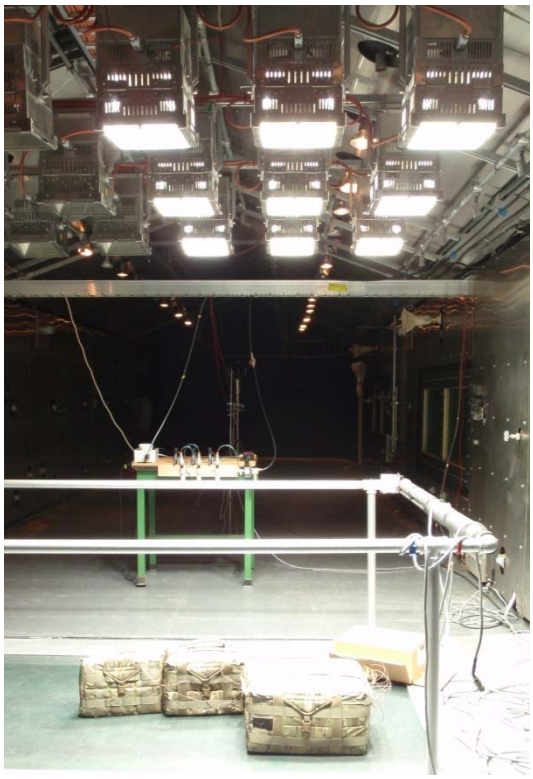


Figure 12: ICB Test Placement in Climate Chamber

Figure 13: Graphtec GL200A Data Logger

Temperature readings were then recorded every minute until all bottled water temperature readings were above 71.6 °F. Recording was stopped once all bottles exceeded 71.6 °F, as any temperature above that is outside of the TB MED 577/NAVMED P-5010-10/AFMAN 48-138_IP palatable water acceptability range, which is between 59 °F and 71.6 °F.

2.2.2 HSCWB in Large ICB Test

This test was conducted to determine the thermal performance difference between the HSCWB and water bottles when stored in the large ICB. Prior to testing, two HSCWBs were filled with approximately 5 gal of water each and frozen to a temperature of 0 °F ± 3 °F. Prior to being frozen, two thermocouples were inserted into each HSCWB through its cap. The HSCWBs were then placed in a freezer to allow each HSCWB to freeze in place in a large ICB, as can be seen in Figure 14.

Figure 14: HSCWB Frozen in Large ICB

2.3 Operational Durability

Three types of tests were conducted to assess durability: drop tests and vibration tests with each container filled with its respective capacity (as specified in Table 1) of 700-mL water bottles and abrasion tests of three materials used in the various ICBs.

2.3.1 Drop Tests

The drop test was conducted in accordance with ASTM D5276 (Standard Method for Drop Test of Loaded Containers by Free Fall) by using a non-interfering free fall machine (Figure 15). This machine is capable of raising a container up to 15 ft off the ground and releasing it for free fall without interference, allowing it to hit the ground on the downward face of the container completely parallel to the ground.

Figure 15: Drop Test Machine

Each container, loaded with its capacity of 700-mL water bottles (as specified in Table 1), was dropped from a height of 96.5 inches, which represents the floor height of the MRAP troop entrance floor plus the height of a 95th percentile male's elbow. This drop test is meant to represent a 95th percentile male dropping the bag from the MRAP troop entrance onto the ground. Each bag was dropped once on each of its faces.

Prior to testing, approximately 86 700-mL bottles of water were frozen to a temperature of 0 °F ±10 °F and placed in each bag as described in Section 2.2.1 without the thermocouples. After each drop the container was opened and inspected for damage.

2.3.2 Vibration Tests

The vibration test was conducted in accordance with ASTM D999 (Standard Test Methods for Vibration Testing of Shipping Containers). A custom-made tray was used to tie down the containers as they would be tied down in the field. Two tie-down methods described in section 2.1 (STD and UTD) were used to test each container (shown in Figure 15). The tie-down procedures were determined by a professional rigger; a video of the procedures is available from NSRDEC upon request.

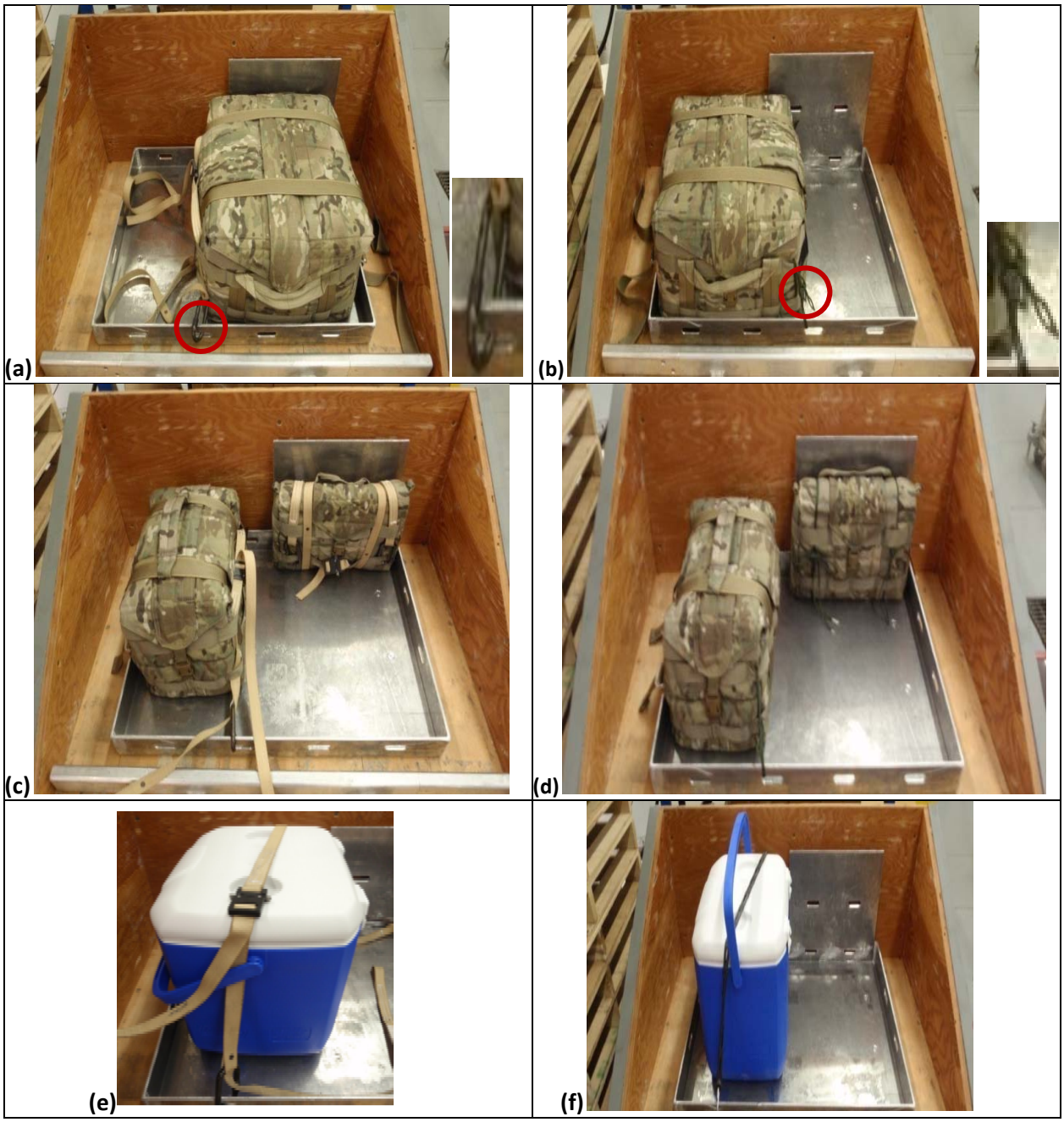


Figure 16: Vibration Test Tie-Down Methods on Containers: (a) Large ICB-UTD; (b) Large ICB-STD; (c) Medium and Small ICB-UTD; (d) Medium and Small ICB-STD; (e) Cooler-UTD; (f) Cooler-STD

Prior to testing, 86 bottles of water were frozen to a temperature of 0 °F ± 10 °F and placed in each container as described in Section 2.2.1 without the thermocouples. The tray was then fastened to the vibration table with four bolts, which went through the tray to the underside of the vibration table where they were fastened with nuts and washers. The bolts used to hold the tray to the vibration table were countersunk so as not to interfere with the bottom of the containers.

Each container was tested twice, once using each method. As mentioned in Section 2.1 for the blast testing, the STD method utilized standard 550 paracord, which was selected by the professional rigger,

as it is readily available in the field, and the UTD strap was requested by the sponsor JPO-MRAP for testing. The integrated heavy duty straps on the medium and large ICBs were used for fastening along with the method strap (STD or UTD) for those ICBs. The small ICB and COTS cooler did not have integrated straps; therefore, only the STD or UTD was used to fasten them.

2.3.3 Abrasion Tests

The abrasion testing consisted of rotary tests and linear tests. Three separate materials were tested in each test: camouflage Cordura, rubber traction pad, and SuperFabric™. The goal of this testing was to determine durability of the current ICB materials being used (Cordura/rubber traction pad) compared to SuperFabric or any other prospective construction materials. SuperFabric™ is being considered as an alternate base material for the large bag to replace the currently used rubber traction pad due to its light weight and flame resistant properties. Cooler materials were not relevant to this testing goal.

The rotary abrasion testing (shown in Figure 17) was conducted to simulate overall wear of the materials used in the construction of the ICBs and was conducted in accordance with ASTM D3389 "Standard Test Method for Coated Fabrics Abrasion Resistance (Rotary Platform Double-Head Abrader)". The linear testing (shown in Figure 18) was conducted to simulate dragging of the ICBs back and forth. It was also conducted based upon ASTM D3389 because there is no standard for linear testing of coated fabrics. The abrasion testing was conducted independently, under contract to NSRDEC, by Taber Industries, and their full report on the testing is reprinted as Appendix C.

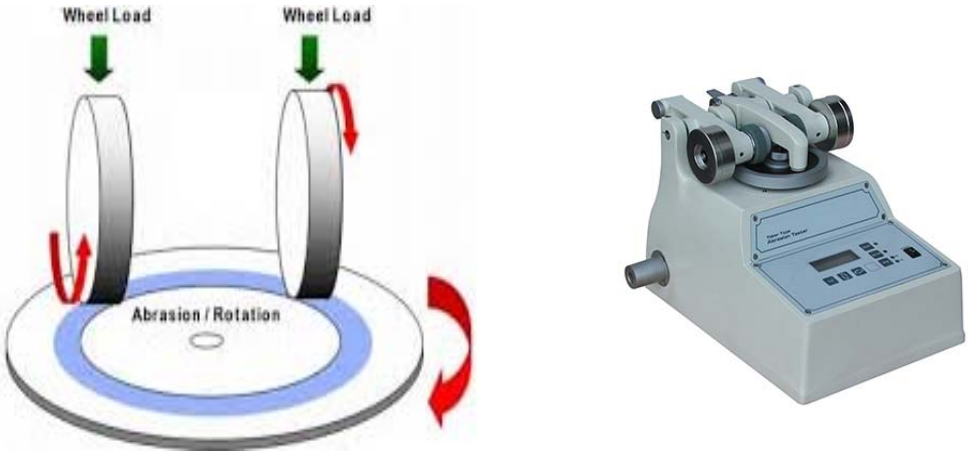


Figure 17: Rotary Abrasion Test Equipment

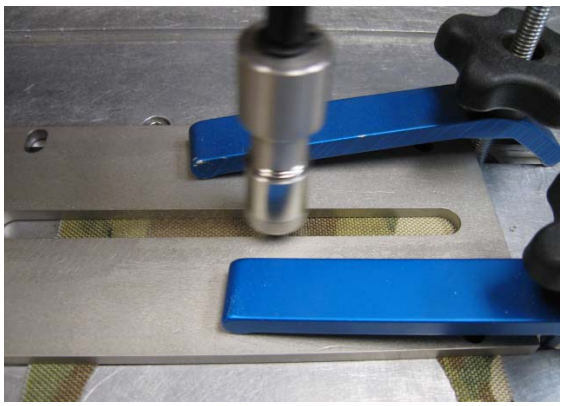


Figure 18: Linear Abrasion Testing

2.4 Flammability

Flammability of the five containers was assessed by conducting flash oil fire tests at NSRDEC's Ouellette Thermal Test Facility (TTF). The testing used a "mid-scale" test procedure/equipment that is being developed at TTF; it is based on ASTM F1930 (Standard Test Method for Evaluation of Flame Resistance Clothing for Protection Against Fire Simulations Using an Instrumented Manikin). The mid-scale test subjects the item being tested to the same heat flux as ASTM F1930, but allows for testing of objects other than those that are intended to be worn on a person.

To date there are only four ASTM F1930 test systems operational in North America, and each test set up varies slightly – room size, manikin, number of sensors, type of sensors, number of burners used in testing, building systems, propane delivery systems, and burn injury models used. The mid-scale test system is being developed to fill the gap which currently exists between swatch-level testing and full-scale manikin testing. The goal is to correlate this test with ASTM F1930 to enable testing of different items (pouches, bags, etc.) and fabrics that are not capable of being tested on a manikin in order to assist in the final prototype designs and fabric selections and/or layering schemes. It is also intended to be used in testing isolated instrumented manikin body parts (head and hand). In this particular test, the test apparatus was altered to test the ICBs, as well as the COTS cooler.

The propane test chamber in the TTF houses a propane delivery system, as well as alarms and an exhaust system. All building systems are controlled from within the control room and include a wet scrubber system, fire alarm/wet deluge system, propane delivery system, underground storage tank, data acquisition system, and system software to safely run the test. During this project, the mid-scale test was run manually, but will be run through the Human Machine Interface (HMI) upon finalization of the test design.

The gas system used included a vaporizer outside the building to supply the proper gas flow rate to the burners for testing. In the modified test apparatus used, two burners were positioned to obtain a direct impingement of the flame on the test sample, as illustrated in Figure 19, to simulate a flash oil fire scenario. Propane gas was sent from the supply system to the burners. The burner system used pilot lights to ignite the propane gas. As specified in ASTM F1930, the average heat flux used for testing was 2 cal/cm^2/s or 84 kW/m^2. This heat flux was calibrated by using the flat plate test apparatus: a 13-in by 13-in surface area containing 13 sensors. This plate was set 35 in from the floor, as can be seen in Figure 20, and the distance from the burners to the plate was adjusted until the required heat flux was achieved, which was 38 in. A steel mesh box was then used to elevate the test article to the required height, and the front face of the test article was positioned to the front of the mesh box/rack, which was precisely 38 in away. The burners were L.B. White Propane Torches, manufacturing model Big Bertha.

Once the test article was in position, it was subjected to three separate burns: an initial 4-s burn, a second 4-s burn, and a final 10-s burn. The initial burn was the only burn required for the ASTM test. The second burn was done to determine the damage, if any, caused by a repeatedly impinging oil fire. The final burn was done to determine the time necessary to ignite the test article.

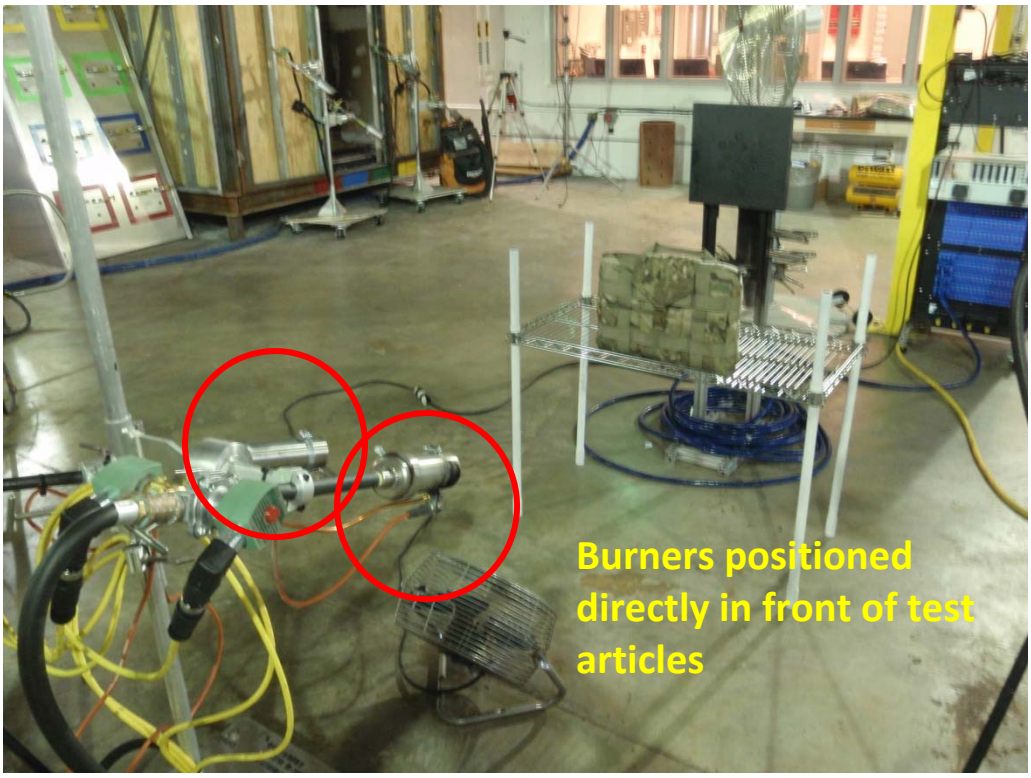


Figure 19: Flash Oil Fire Test Setup: Burner/Test Article Position

Figure 20: Flash Oil Fire Test Setup: Calibration Plate

3. Results and Discussion

The results of each of the six test types are summarized in Table 3. All the ICBs survived the blasts test and the drop test while the cooler did not survive either one. All the containers survived the vibration tests. The medium-size COTS cooler maintained bottled water under 72 °F much longer than the medium and small double bubble ICBs. However, the more costly medium Aerogel ICB maintained the temperature 8 h longer than the cooler, and the large ICB maintained temperature as long as the cooler when filled with water bottles and 6 h longer when tested with an HSCWB. The Aerogel ICB also outperformed the other containers in the flammability tests, though all the containers performed acceptably. The abrasion tests were not applicable to the cooler. Detailed results of these tests are presented for the four categories of blast durability, thermal performance, operational durability, and flammability in Sections 3.1, 3.2, 3.3, and 3.4, respectively.

Table 3: Summary of Results for Each Test

Test Criterion	ICB Small	ICB Medium	ICB Aerogel	ICB Large	COTS Cooler
IED Blast Survival	Yes	Yes	Yes	Yes	No
Time Water Remained under 72 °F	17 h 3 min	29 h 40 min	56 h 30 Min	47 h 18 min 54 h 10 min*	48 h
Drop Test Survival	Yes	Yes	Yes	Yes	No
Normal Off-Road Vibration Survival	Yes	Yes	Yes	Yes	Yes
Abrasion Cycles Survived	1392 Linear 2000 Rotary	1392 Linear 2000 Rotary	1392 Linear 2000 Rotary	17950 Linear 7000+ Rotary)	NA
Flammability Performance	Survived multiple 4-s exposures	Survived multiple 4-s exposures	Survived multiple 4-s exposures and 10 s exposure	Passed ASTM test with one exposure	Survived multiple 4-s exposures

*HSCWBs, instead of water bottles

3.1 Blast Durability

Table 4 summarizes the IED simulation testing using VALTS and gives the achieved exposure conditions for each of the tests. Where multiple tests were completed, an average achieved severity and standard deviation are also provided. Tests that involved two containers are also indicated with the corresponding restraint system. Additional details on the results of the blast durability testing can be found in JHU/APL's report, which is reprinted as Appendix B.

Table 4: Blast Durability (IED Simulation) Test Result Summary

Test Run	Exposure Severity (m/s)	Achieved Severity (m/s)	System	Restraint	Notes
1	7	6.8 ± 0.2	Medium ICB	STD	STD appeared to be loose posttest, retightened pre-test.
2	9	9.1 ± 0.0	Medium ICB	STD	STD appeared to be loose posttest, retightened pre-test.
3	7	6.8 ± 0.2	Medium ICB	UTD	UTD strap came unbuckled during final test.
4	9	9.1 ± 0.0	Medium ICB	UTD	UTD strap came unbuckled for two of the three tests, unbuckled and re-buckled prior to testing.
5	7	6.6 ± 0.4	Small ICB Aerogel ICB	STD UTD	UTD strap came unbuckled during final test.
6	9	8.9	Small ICB Aerogel ICB	STD UTD	No failures detected.
7	7	6.8	COTS Cooler Large ICB	UTD STD	UTD strap came unbuckled during test; Cooler came open.
8	9	8.9	COTS Cooler Large ICB	UTD STD	UTD strap remained buckled during test; Cooler came open.
9	7	6.9 ± 0.1	Large ICB	UTD	No failures were detected.
10	9	9.3 ± 0.2	Large ICB	UTD	No failures were detected.
11	7	6.8	Small ICB Aerogel ICB	UTD STD	Fully loaded Small ICB difficult to install with UTD.
12	9	9.0	Small ICB Aerogel ICB	UTD STD	Fully loaded Small ICB difficult to install with UTD.
13	7	6.7	COTS Cooler	Standardized Strap	No failures were detected.
14	9	9.0	COTS Cooler	Standardized Strap	Cooler came open during test.

3.2 Thermal Performance

As mentioned in Section 2.2, the thermal performance evaluation consisted of two sets of hot ambient temperature tests: one using 700-mL water bottles in each of the five containers and the other using an HSCWB in a large ICB. The results are presented in Sections 3.2.1 and 3.2.2, respectively

3.2.1 700-mL Water Bottle Tests

The average water bottle temperatures for the three double-bubble ICBs during the 50-h hot ambient temperature test described in Section 2.2.1 are shown in Figure 21. As can be seen, the more bottled water stored, the longer the average bottled water temperature remained below 72 °F. This is because the larger the thermal mass, the longer it takes to change temperature; therefore, the largest ICB took the longest to have its water bottles heat up.

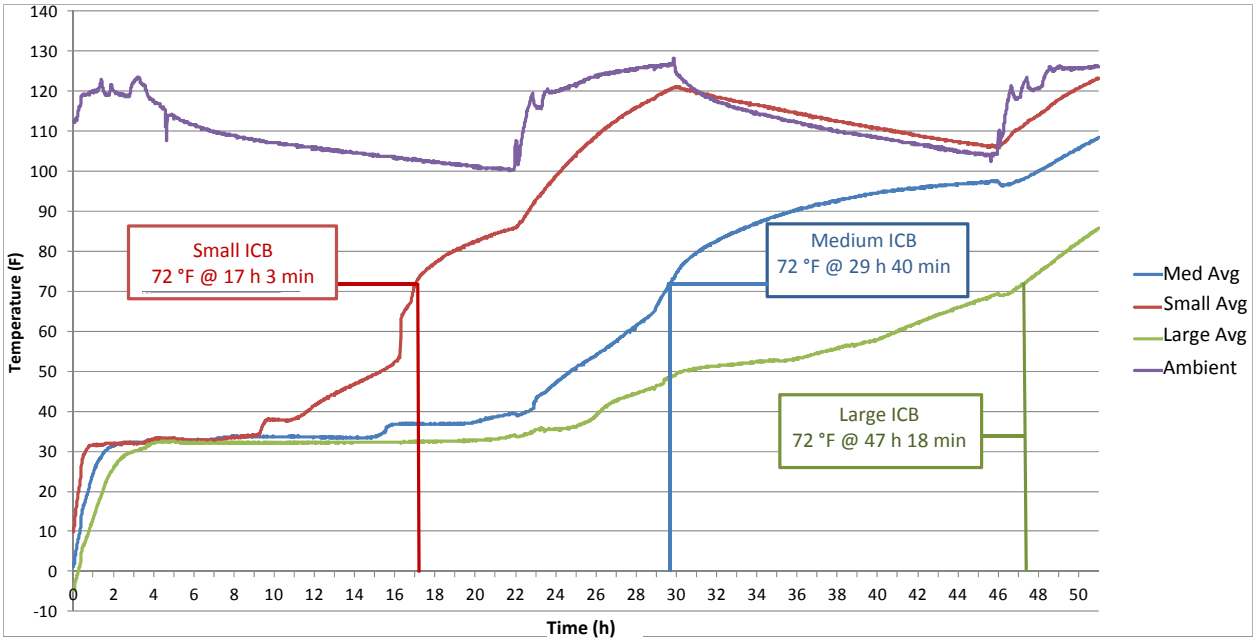


Figure 21: Hot Ambient Temperature Test - Double Bubble ICB Average Bottled Water Temperatures

The variations in the bottled water temperatures at different locations in the small, medium, and large ICBs are shown in Figures 22, 23, and 24, respectively.

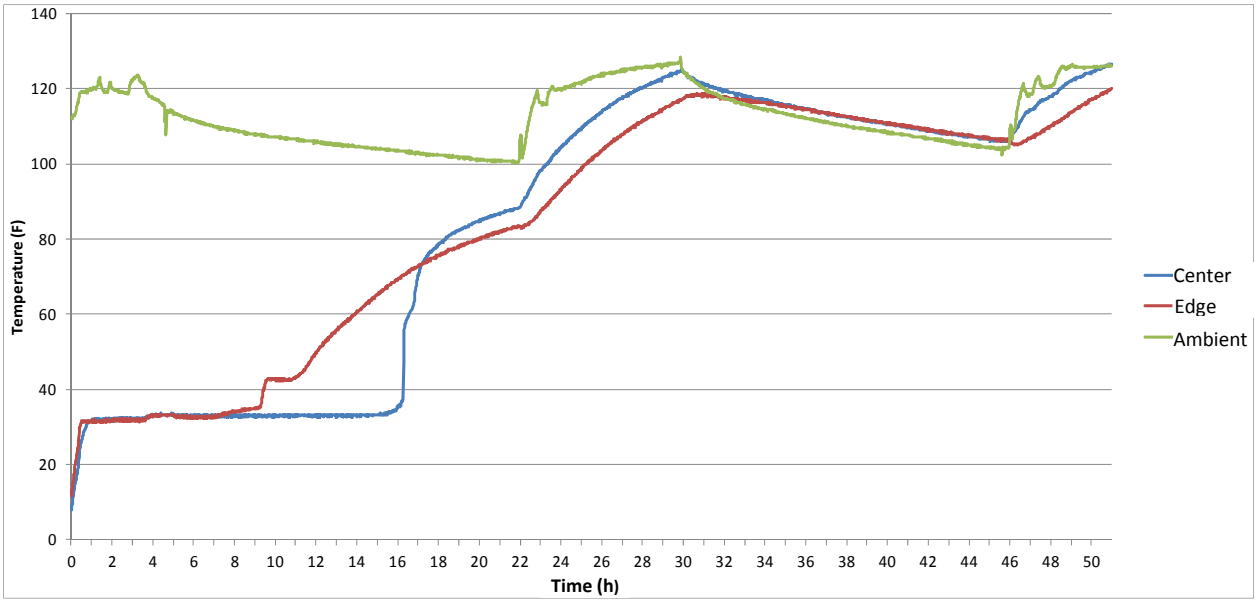


Figure 22: Hot Ambient Temperature Test – Small ICB Bottled Water Temperatures

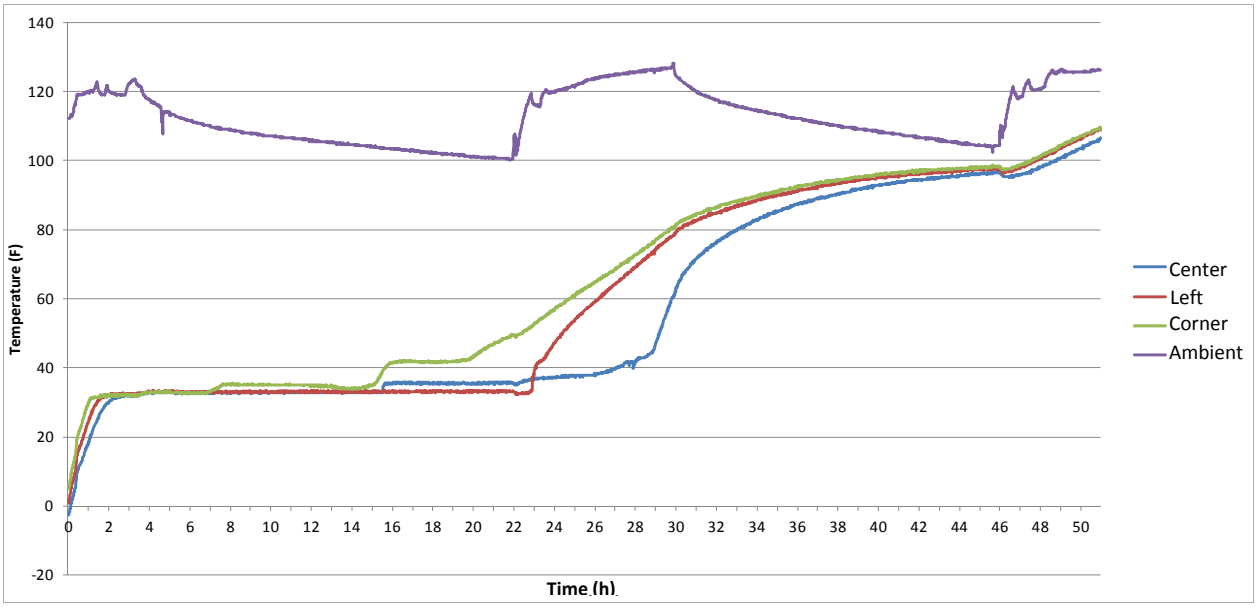


Figure 23: Hot Ambient Temperature Test – Medium ICB Bottled Water Temperatures

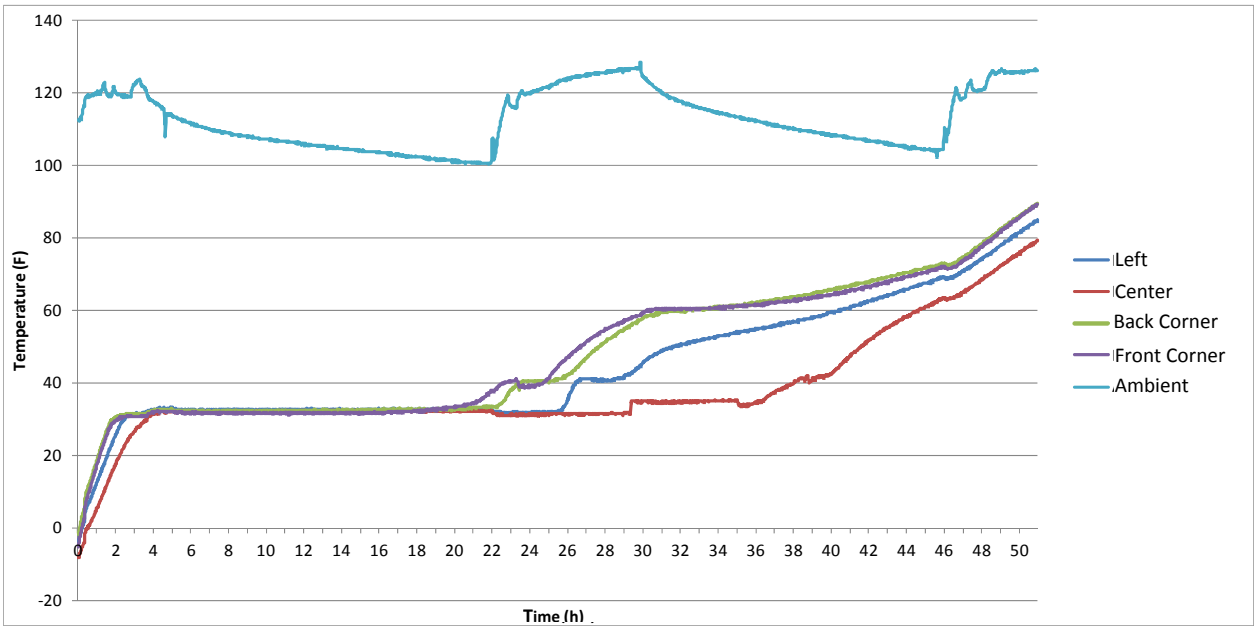


Figure 24: Hot Ambient Temperature Test – Large ICB Bottled Water Temperature

Figure 25 shows the average bottle temperature in the Aerogel ICB and COTS cooler throughout the 80 h of testing. The COTS cooler had similar performance to that of the large ICB, as shown in Figure 24. This was most likely due to the COTS cooler's foam insulation, which had a higher R-value (of about 5 per in) than the ICB double bubble insulation (about 3 per in). The COTS cooler's white plastic lid also allowed for a higher reflectivity of solar radiation than any of the ICBs, aiding in its cold storage hold time performance.

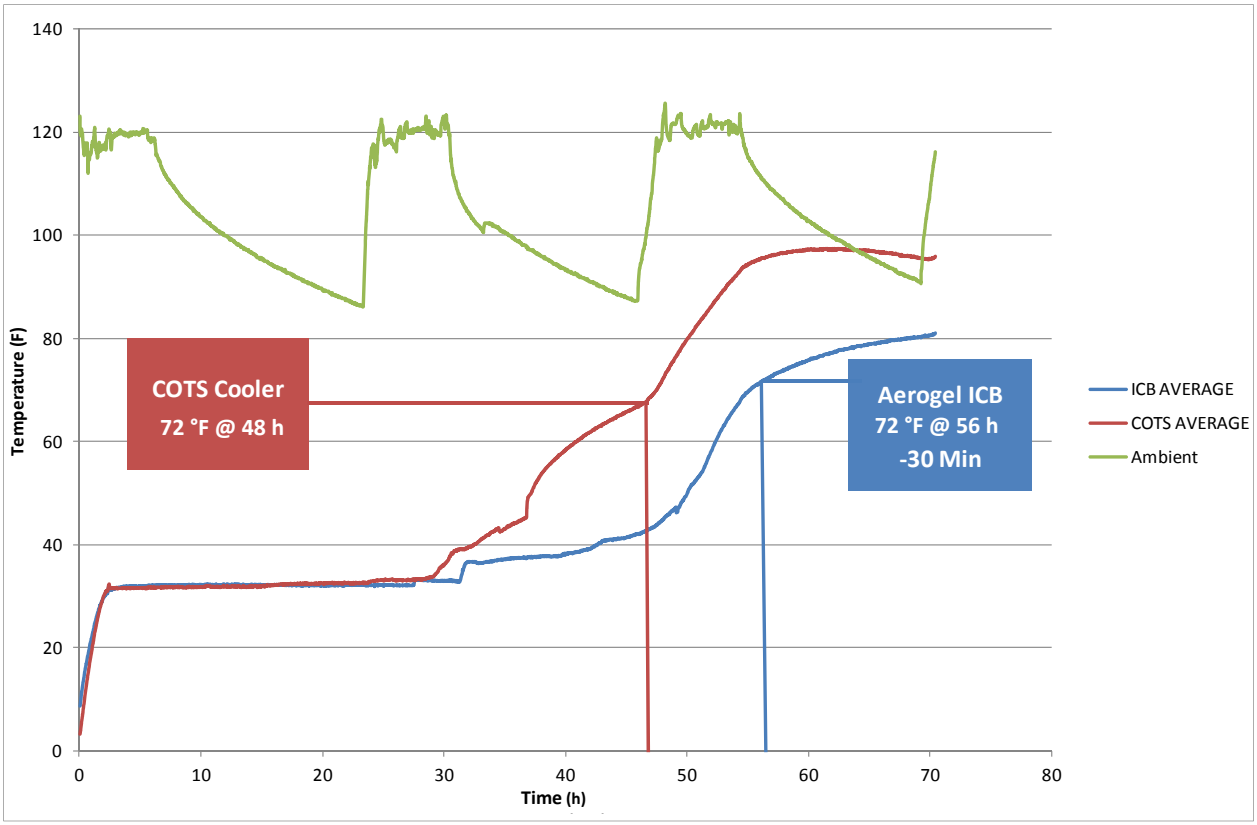


Figure 25: Hot Ambient Temperature Test –Aerogel ICB and COTS Cooler Average Bottled Water Temperatures

The Aerogel ICB performed the best of all the containers tested, no matter what size. It provided a cold storage hold time which was 26 h and 50 min more than the comparably sized medium double bubble ICB and 8 h and 30 min more than the comparably sized COTS cooler. This increase in cold storage hold time performance is solely due to its Aerogel insulation, which had an R-value of 10.3.

3.2.2 HSCWB in Large ICB Test

The average temperatures recorded from the hot ambient temperature test described in Section 2.2.2 are shown in Figure 26 from each HSCWB for nearly 70 h of testing. During this test the HSCWBs were positioned one on top of the other, hence the "Top HSCWB" and "Bottom HSCWB" readings. As can be seen when comparing the data in Figure 26 with that in Figure 24, the HSCWBs stored in the large ICB were able to remain below 72 °F for well over 6 h longer than the bottled water in the large ICB (6 h 27 min longer for the top HSCWB and 6 h 50 min longer for the bottom HSCWB). This reinforces the thermal mass principle mentioned in Section 3.2.1: the more frozen water that is stored, the longer that water will take to heat up.

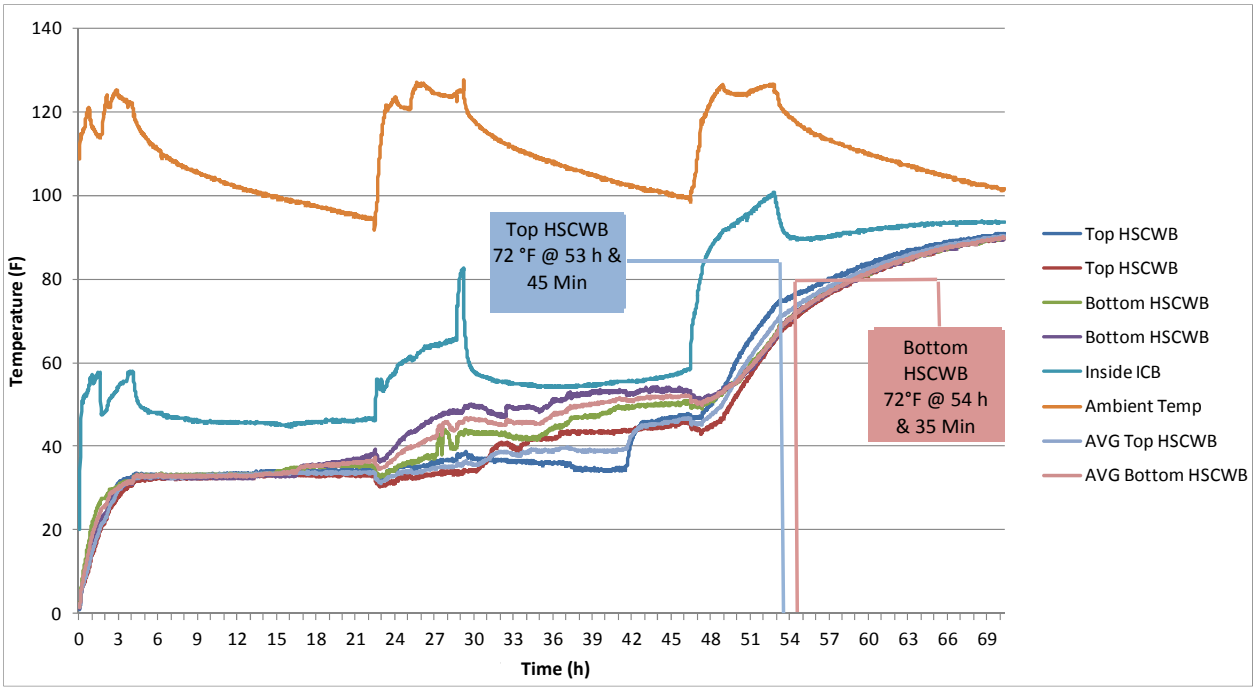


Figure 26: Hot Ambient Temperature Test – Large ICB HSCWB Water Temperatures

3.3 Operational Durability

As mentioned in Section 2.3, the operational durability evaluation consisted of three types: drop tests, vibration tests, and abrasion tests. The results are presented in Sections 3.3.1, 3.3.2, and 3.3.3, respectively.

3.3.1 Drop Tests

Images demonstrating the outcome of each container's drop test can be seen in the corresponding sections. Video documenting the drop tests for each container is available on request.

3.3.1.1 Large ICB

The large ICB was opened and inspected after each drop to document the extent of the damage to the bottles. Any external damage to the bag was also noted. No bottles escaped from the bag during any of the large ICB drops.

The initial drop with the bag bottom facing down (Figure 27) caused only minor damage/cracking on three of the bottles contained within. No damage to the bag was noted.

Dropping the bag with the top facing down (Figure 28) caused damage to all the bottles' caps, causing them to break off or be crushed.

Figure 27: Large ICB Drop Test with Bag Bottom Facing Down

Figure 28: Large ICB Drop Test with Bag Top Facing Down

Dropping the bag with the access flap facing down (Figure 29) caused the access flap's buckle to break. It should be noted that these buckles are replaceable without tools.

Figure 29: Large ICB Drop Test with Access Flap Facing Down

Subsequent drops on the remaining three sides (Figure 30) caused additional damage to the bottles, resulting in about 50% of the bottles being destroyed. No additional damage to the bag was noted. No damage to the internal liner was noted.

Figure 30: Large ICB Drop Test, Subsequent Drops

3.3.1.2 Medium ICB

The medium double bubble ICB was opened and inspected after each drop to document the extent of the damage to the bottles. Any external damage to the bag was also noted. No bottles escaped from the bag during any of the drops during the medium ICB drop test.

The initial drop with the bag bottom facing down (Figure 31) showed only minor damage/cracking on two of the bottles contained within. No damage to the bag was noted.

Figure 31: Medium ICB Drop Test with Bag Bottom Facing Down

Dropping the bag with the top facing down (Figure 32) caused damage to all the bottles' caps; they either broke off or were crushed. A couple of the bottles also cracked at the neck

Figure 32: Medium ICB Drop Test with Bag Top Facing Down

Dropping the bag with the access flap facing down (Figure 33) caused the access flap's buckle to break. It should be noted that these buckles are replaceable without tools.

Figure 33: Medium ICB Drop Test with Access Flap Facing Down

Subsequent drops on the remaining three sides (Figure 34) caused some additional minor damage to a couple of the bottles. No additional damage was noted on the bag or the liner.

Figure 34: Medium ICB Drop Test, Subsequent Drops

3.3.1.3 Small ICB

The small ICB was opened and inspected after each drop to document the extent of the damage to the bottles. Any external damage to the bag was also noted. No bottles escaped from the bag during any of the drops during the small ICB drop test.

The initial drop with the bag bottom facing down (Figure 35) showed only minor damage/cracking on the bottom of the center bottle. No damage to the bag was noted.

Figure 35: Small ICB Drop Test with Bag Bottom Facing Down

Dropping the bag with the top facing down (Figure 36) caused damage to all the bottles' caps; they either broke off or were crushed.

Figure 36: Small ICB Drop Test with Bag Top Facing Down

Subsequent drops to the remaining four sides (Figure 37) resulted in the center bottle sustaining more damage. No damage to the bag was noted. The buckle did not break as it did on the other large and medium ICBs.

Figure 37: Small ICB Drop Test, Subsequent Drops

3.3.1.4 COTS Cooler

The COTS cooler was opened and inspected after each drop to document the extent of the damage to the bottles. Any external damage to the cooler was also noted. Bottles escaped from the cooler in every drop except for the first drop when the bottom of the container was facing down.

The initial drop of the COTS cooler with the bottom facing down (Figure 38) resulted in minor crushing of the bottom corners of the cooler. No damage to the bottles was noted. No bottles escaped the cooler.

Figure 38: COTS Cooler Drop Test with Bottom Facing Down

Dropping the COTS cooler with the top facing down (Figure 39) resulted in damage to all but two of the bottles' caps. All but three bottles were ejected from the cooler upon impact. One of the hinges on the cooler's lid also broke upon impact.

Figure 39: COTS Cooler Drop Test with Top Facing Down

Subsequent drops on the remaining four sides (Figure 40) caused some internal damage to the cooler in the form of dents. The other hinge did not break, but was warped somewhat due to the asymmetrical mounting of the lid. No substantial additional damage to the bottles was noted on the subsequent drops.

Figure 40: COTS Cooler Drop Test, Subsequent Drops

3.3.1.5 Aerogel ICB

The medium Aerogel ICB was opened and inspected after each drop to document the extent of the damage to the bottles. Any external damage to the bag was also noted. No bottles escaped from the Aerogel ICB during any of the drops.

The initial drop of the Aerogel ICB with the bottom facing down (Figure 41) resulted in no damage to the ICB or bottles.

Figure 41: Aerogel ICB Drop Test with Bag Bottom Facing Down, Initial Drop

Subsequent drops with the bottom facing down (Figure 42) caused no damage to the bag and only minor damage to only one bottle; the cap was blown off, but was undamaged and was re-threaded.

Figure 42: Aerogel ICB Drop Test with Bag Bottom Facing Down, Subsequent Drops

Dropping the Aerogel ICB with the top facing down (Figure 43) which was the final drop, destroyed all of the bottles' caps, but none of the bottles themselves were damaged. No damage to the Aerogel ICB's buckles was seen. This lack of damage to the buckles, in contrast to the damage that was seen on the

double bubble ICBs, can only be explained by the Aerogel insulation's physical properties. The thicker material may have absorbed more impact than the double bubble insulation.

Figure 43: Aerogel ICB Drop Test with Bag Top Facing Down (Final Drop)

3.3.2 Vibration Tests

When the UTD method was used, the large ICB sustained minor abrasion and stretching on its integrated tie-down straps (Figure 44a). The carabiners attached to the UTD straps also sustained minor abrasion wear in the areas that were contacting the mounting tray (Figure 44b). All bottles remained in the container throughout the test.

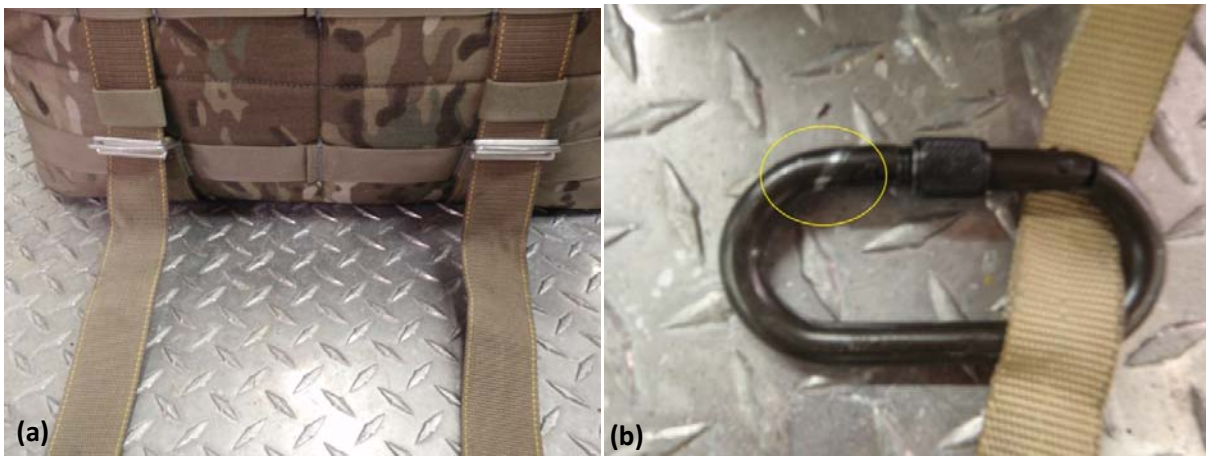


Figure 44: Vibration Test Results for Large ICB using UTD Method: (a) Abrasion on Tie-Down Straps; (b) Abrasion on Carabiners

With the STD method, some abrasion wear and scuffing were noted on the bottom of the ICB (Figure 45a). Some additional stretching was noted on the bag's MOLLE webbing (Figure 45b) and on the integrated tie-down straps (Figure 45c). This was most likely due to the additional give of the 550 paracord. All bottles remained in the container throughout the test.

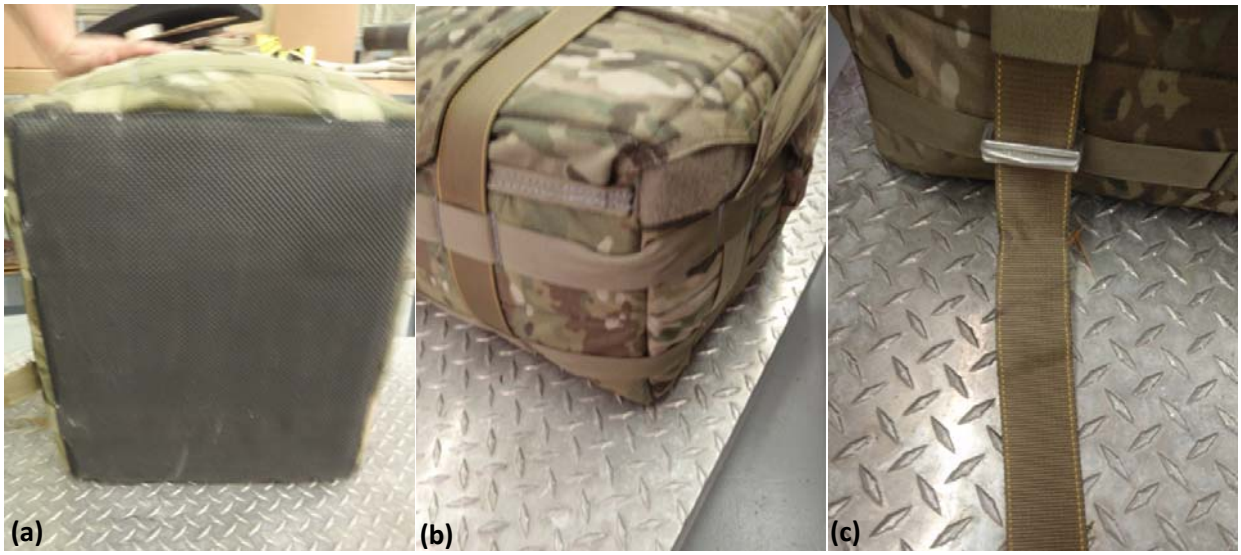


Figure 45: Vibration Test Results for Large ICB using STD Method: (a) Abrasion on Bottom of ICB; (b) Stretching on MOLLE Webbing; (c) Stretching on Straps

No damage or stretching was seen during the medium and small ICB test using the UTD method (Figure 46). All bottles remained in the containers throughout the test.

Figure 46: Vibration Test Results for Medium and Small ICBs using UTD Method

When using the STD method, however, minor abrasion wear was seen on one of the integrated tie-down straps of the medium ICB (Figure 47a). The small ICB also had some moderate deformation of the top row of webbing on the back of the ICB (Figure 47b). All bottles remained in the containers throughout the test.

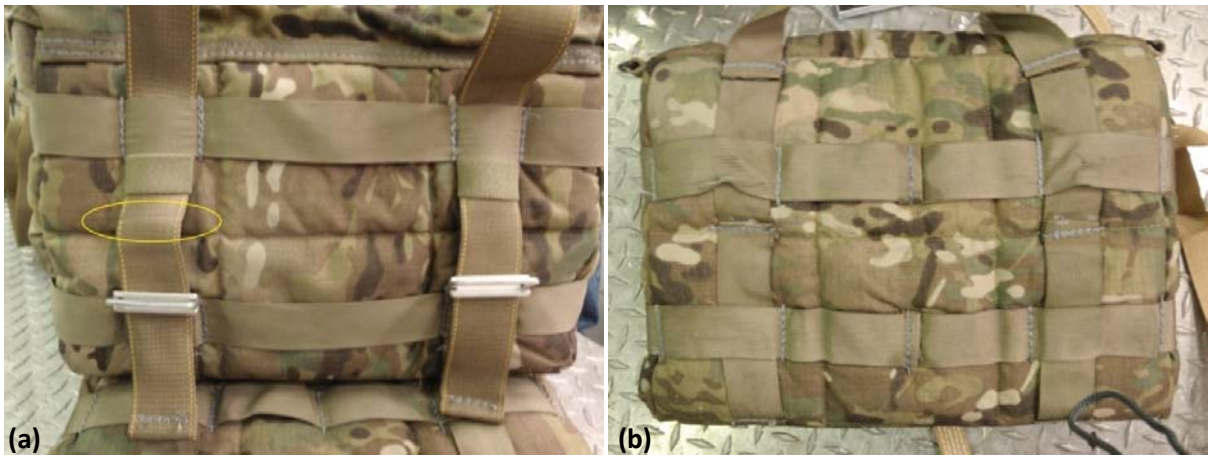


Figure 47: Vibration Test Results for Medium and Small ICBs using STD Method: (a) Abrasion on the Straps of Medium ICB; (b) Deformation on Back Webbing of Small ICB

No damage to the COTS cooler was noted during the UTD test (Figure 48). All bottles remained in the container throughout the test.

Figure 48: Vibration Test Results for COTS Cooler using UTD Method

No damage to the COTS cooler was noted during the STD test (Figure 48) either. All bottles remained in the container throughout the test.

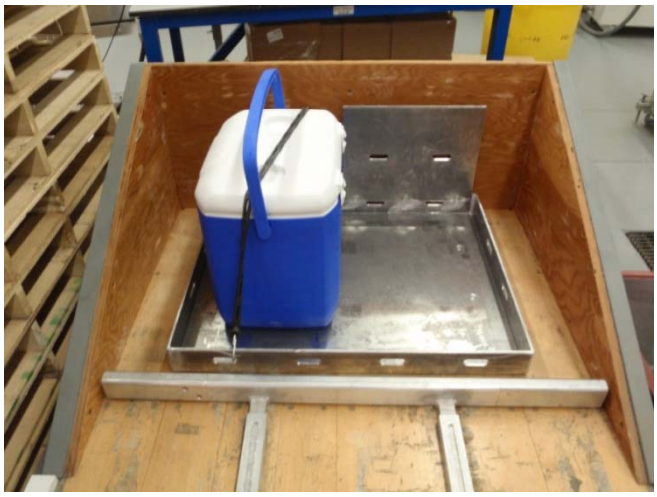


Figure 49: Vibration Test Results for COTS Cooler using STD Method

After the Aerogel ICB test using the UTD method, minor wear was seen on the ends of the UTD strap where the carabiner was attached (Figure 49a). Minor wear was also seen on the carabiner itself (Figure 49b). No damage to the Aerogel ICB was noted during this test. All bottles remained in the container throughout the test.

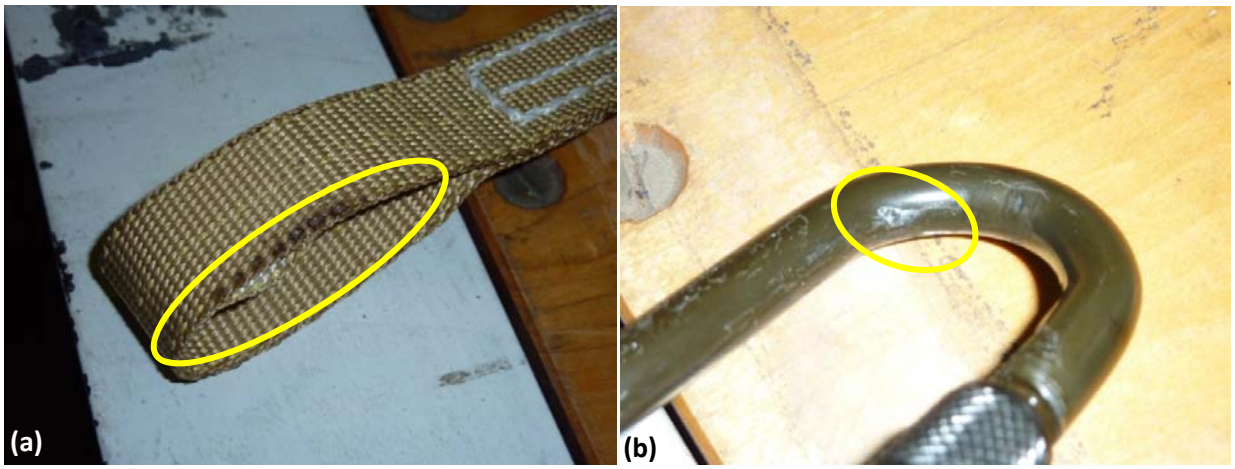


Figure 50: Vibration Test Results for Aerogel ICB using UTD Method: (a) Wear on End of UTD Strap; (b) Wear on Carabiner

During the test using the STD method, minor wear was seen on the Aerogel ICB's integrated straps, which fastened to the tray (Figure 51). This was most likely due to the play inherently given by the 550 paracord, which allows for more vertical motion than the UTDs.

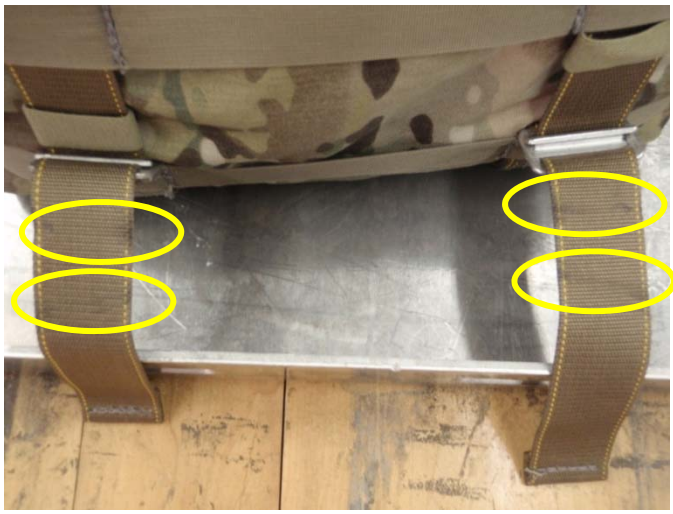


Figure 51: Vibration Test Results for Aerogel ICB using STD Method

3.3.3 Abrasion Tests

Table 5 summarizes the rotary abrasion testing, and Table 6 summarizes the linear abrasion testing. As can be seen, the rubberized base material which is currently used on the large ICB was the most durable of the three materials tested in both the rotary abrasion test and the linear abrasion test. While the rubberized material was the most durable material tested by far, especially in regards to linear abrasion and overall material loss, it was also the heaviest and least flexible. Nevertheless, it provided the most traction and was considerably cheaper than SuperFabric. Cordura was the least expensive material tested by far; however, it provided minimal wear resistance compared to the other materials. The complete Taber Industries report containing the abrasion test results is reprinted in Appendix C.

Table 5: Rotary Abrasion Testing Summary

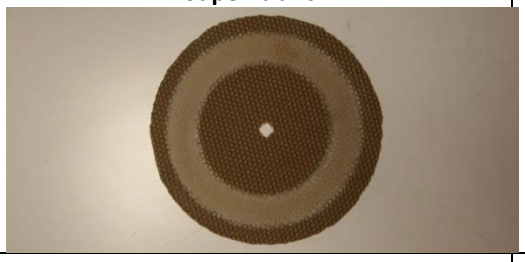
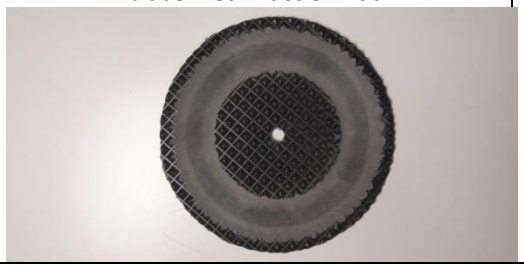
Test Material	Cycle Count	Breakthrough	Start Weight	End Weight
Cordura 	2000	2000	6.9358	6.3910 (7.85% loss of material)
SuperFabric 	5000	No Break Through	5.0156	3.9144 (21.9% loss of material)
Rubberized Traction Pad 	7000	No Break Through	24.2625	22.4235 (7.5% loss of material)

Table 6: Linear Abrasion Testing Summary

Test Material	Cycle Count	Breakthrough
Cordura 	1392	1392
SuperFabric 	1725	1725
Rubberized Traction Pad 	17950	No Break Through

3.4 Flammability

As described in Section 2.4, the flammability evaluation consisted of flash oil fire testing. Images before testing and at various points during testing and description of the conditions during testing of the small, ICB, medium ICB, Aerogel ICB, large ICB, and COTS cooler are presented in Sections 3.4.1 through 3.4.5, respectively.

3.4.1 Small ICB

The setup of the flash oil fire test for the small ICB is shown in Figure 52a. After the initial 4-s burn, minor charring and fabric contraction were noted on the body of the ICB (Figure 52b). The ICB flap saw the most fabric contraction due to the heat buildup under the flap. Some areas in the center of the body saw the external layer of Cordura burn through to the insulation. No complete burn through was seen. Ignition was not sustained, most likely due to the aluminized insulation which dissipated the heat. The buckle still operated. This WOULD NOT be a fire hazard during a flash oil fire scenario.

The subsequent 4-s burn caused additional external layer burn through, as well as additional fabric contraction on the flap (Figure 52c). Ignition was still not sustained. This WOULD NOT be a fire hazard during a flash oil fire scenario with multiple separate impingements.

After 8 s of flame impingement, ignition was sustained. Complete burn through occurred and can be seen in Figure 52d, and minor damage was done to the center water bottle (Figure 52e).

Figure 52: Small ICB Flash Oil Fire Test Results: (a) Test Setup; (b) After Initial 4-s Burn; (c) After Second 4-s Burn; (d) After Final 10-s Burn; (e) Damage on Bottles after 10-s Burn

3.4.2 Medium ICB

The setup for the medium double bubble ICB flash oil fire test is shown in Figure 52a. During the initial 4-s burn, little to no charring and fabric contraction were noted on the body of the ICB (Figure 52b). The ICB flap saw the most damage with a single spot of burn through of the external layer of Cordura. No complete burn through was seen. Ignition was not sustained, most likely due to the aluminized

insulation which dissipated the heat. The buckle still operated. This WOULD NOT be a fire hazard during a flash oil fire scenario.

After the second 4-s burn, additional external layer burn through was seen, as well as additional fabric contraction on the flap and body (Figure 52c). Ignition was still not sustained. This WOULD NOT be a fire hazard during a flash oil fire scenario with multiple separate impingements.

After 8 s of flame impingement, ignition was sustained with the leading accelerant being the plastic insert in the base of the ICB. The insert combusted the fastest and was the most difficult material to put out on this ICB. Complete burn through was noted (Figure 52d). No damage to the bottles was seen.

Figure 53: Medium ICB Flash Oil Fire Test Results: (a) Test Setup; (b) After Initial 4-s Burn; (c) After Second 4-s Burn; (d) After Final 10-s Burn

3.4.3 Aerosol ICB

Setup for the medium Aerogel ICB flash oil fire test is shown in Figure 53a. During the initial 4-s burn, no charring, burn through or loss of functionality was noted (Figure 53b). The buckle still operated. This WOULD NOT be a fire hazard during a flash oil fire scenario.

After the second 4-s burn, minor fabric contraction was seen on the flap (Figure 53c). No other damage was noted. Ignition was still not sustained. This WOULD NOT be a fire hazard during a flash oil fire scenario with multiple separate impingements.

Ignition was NOT sustained after 10 s of flame impingement. Severe fabric contraction and minor charring was noted. Some small areas had burn through of the external layer of Cordura (Figure 53d). The inner layer of Cordura, which houses the Aerogel insulation, was not penetrated. No damage to the bottles was seen. The flap buckle was non-functional due to being warped. This increase in fire retardation over the double bubble ICBs was most likely due to the Aerogel insulation's ability to absorb and internally disperse extreme amounts of thermal energy. This was also apparent in the physical temperature of the bag, which was noticeably hotter to the touch than the double bubble ICBs which were tested, indicating that the Aerogel ICB absorbed more of the thermal energy. This WOULD NOT be a fire hazard during an extended flash oil fire scenario.

Figure 54 Aerosol ICB Flash Oil Fire Test Results: (a) Test Setup; (b) After Initial 4-s Burn; (c) After Second 4-s Burn; (d) After Final 10 s Burn

3.4.4 Large ICB

The setup for the large ICB flash oil fire test is shown in Figure 54a. The part of the buckle attached to the flap was not used during the flash oil fire testing, as it broke during drop testing and could not be reattached for this test. After the initial 4-s burn, minor charring was seen on the upper portion of the

bag, as well as on the flap. Small patches of burn through were seen on the center face of the bag, as well as on the bottom leading edge of the bag (Figure 55b). The plastic grommet also immediately shrunk and distorted from the heat. Ignition was not sustained. This ICB WOULD NOT be a fire hazard during a flash oil fire scenario.

During the second 4-s burn, sustained ignition was initiated from the rubberized base of this particular ICB (Figure 55c). No other ICB had a rubberized base. While extensive fabric contraction and some additional burn through were seen on the center face of the bag, no other portion of the bag sustained ignition. Once ignited, the rubberized base continued to burn and ignite the rest of the ICB on the left side, causing the plastic grommet to immediately ignite and aid in the spread of the fire. Complete burn through was noted in this area (Figure 55d), and several bottles on the interior of the ICB were damaged. The internal liner of the bag also acted as an accelerant, ignited from the flames which quickly reached inside the ICB through the hole where the plastic grommet once was (Figure 55e). The rubberized base and plastic grommet also dripped flaming material when combusted. This flaming material remained lit on the floor once it dripped off the ICB. This ICB COULD BE a fire hazard if exposed to multiple flash oil fire scenarios. While it is important to note that this test was above and beyond what is required by the ASTM test, it may be prudent to take into account expected fire scenarios when considering this particular bag design. A 10-s test was not conducted, since sustained ignition was achieved during this test.

Figure 55: Large ICB Flash Oil Fire Test Results: (a) Test Setup; (b) After Initial 4-s Burn; (c) Sustained Ignition During Second 4-s Burn; (d) After Second 4-s Burn; (e) Interior after Second 4-s Burn

3.4.5 COTS Cooler

The setup for the flash oil fire test with the COTS cooler is shown in Figure 56a. The initial 4-s burn resulted in minor charring of the COTS cooler and partial melting of the label on the front face of the cooler and a small spot on the top right face of the cooler near the lid (Figure 56b). Ignition was not

sustained. No serious damage or loss of functionality was noted. This COTS cooler WOULD NOT be a fire hazard during a flash oil fire scenario.

During the second 4-s burn, some additional charring of the front face of the cooler was seen, especially near the bottom edge (Figure 56c). The label on the front face sustained no additional damage. An additional medium sized spot sustained some mild melting on the right center of the front face of the cooler, as well as along the bottom front face edge. No loss of functionality or serious damage was seen. Ignition was not sustained. This COTS cooler WOULD NOT be a fire hazard in a flash oil fire scenario with multiple impingements.

During the 10-s burn, extensive melting was seen across the front face of the cooler, especially in the center. This was primarily caused by the label, which after 7 s of being exposed to the flame ignited and sustained ignition until the immediate surrounding area sustained ignition as well (Figure 56d). The entire front face of the cooler was also in a state of plasticization, whereby if touched it would stick to the user's hands and cause severe burns. Flaming melted plastic also dripped from the ignited area of the cooler onto the ground and remained burning for some time. The cooler after the ignition is shown in Figure 56e. No bottles were damaged during this test (Figure 56f), and the cooler was not allowed to burn through, but would have if not extinguished. This COTS cooler WOULD BE a fire hazard, as well as a potentially dangerous burn hazard during an extended flash oil fire scenario.

Figure 56: COTS Cooler Flash Oil Fire Test Results: (a) Test Setup; (b) After Initial 4-s Burn; (c) After Second 4-s Burn; (d) Sustained Ignition during 10-s Burn; (e) After 10-s Burn; (f) Undamaged Bottles with Damaged COTS Cooler after 10-s Burn

4. Conclusions

The purpose of this study was to assess and compare the performance of the prototype ICBs and a COTS cooler to determine whether the ICBs (which as can be seen in Table 1) are lighter, have better thermal insulation performance, require less storage space, and have more effective tie-down characteristics than commonly used COTS coolers. Per the results summarized and detailed in Chapter 3, it can be concluded that all of the ICBs would be viable alternatives to a COTS cooler of a similar size in mounted operations because, in addition to their storage and restraint advantages, they can keep water under 72 °F longer than a COTS cooler of a comparative size. The ICBs also survived blast tests and drop tests that the cooler did not survive, making ICBs the much safer and more reliable vehicle mounted cooler solution. Specific conclusions drawn from the various test results are presented for the four categories of blast durability, thermal performance, operational durability, and flammability in Sections 4.1, 4.2, 4.3, and 4.4, respectively.

4.1 Blast Durability

The blast durability testing presented in Section 3.1 allows for the following conclusions:

1) All of the containers subjected to high rate vertical loading remained operational after testing with the exception of the COTS cooler. All ICBs tested were undamaged even if the restraint system failed. The COTS cooler sustained crushing damage at high loading rates and failed to remain sealed regardless of restraint system or loading rate.
2) The most reliable and effective restraint system was the STD (550 Paracord). The UTD became unbuckled with all of the containers except for the large ICB. The standardized strap, which was used exclusively with the COTS cooler, did not prevent motion or unsealing of the COTS cooler upon impact.

4.2 Thermal Performance

The thermal performance testing data presented in Section 3.2 allows for the following conclusions:

1) The larger the cooler's size, and therefore the more water stored, the longer the contained water's average temperature will remain below 72 °F. This means that, while the small, medium, and large double bubble ICBs were all constructed in a similar fashion, the large ICB performed the best of the three. This has to do with Newton's law of cooling, which describes how a larger mass of ice will predictably take longer to melt. Therefore, the more frozen water bottles, water bladders, or just general water mass is stored, the longer that water will take to heat up. This conclusion is comparable only across ICBs or COTS coolers with the same insulation and similar construction. It is not directly comparable across different coolers because different insulation and different construction techniques, such as those used in the medium Aerogel ICB, will affect thermal performance.
2) The Aerogel ICB had the best thermal performance followed by the COTS cooler and then the double bubble ICBs. The Aerogel ICB's increased performance over the other ICBs was strictly due to the insulation's high R-Value of 10.3 compared to the double bubble ICB insulation's R-Value of around 3. The COTS cooler performed better than the double bubble ICBs, not only because of its insulation, which had a higher R-Value of 5, but also because of the lid, which was semi-reflective and white. The lid definitely reflected more of the solar load and aided in its performance. However, both the COTS cooler and Aerogel ICB weigh more than the double bubble ICBs, the Aerogel ICB would cost considerably more than those ICBs, and the COTS cooler would cost considerably less than any ICB. Thus, these tradeoffs would have to be considered.

3) Storing HSCWBs in any cooler will allow the user to maintain a lower water temperature longer than bottled water. This is because of the increased volume of water that is able to fit into a given container with an HSCWB, as well as the reduction in surface area exposed to the air within the cooler it is stored in. The material the HSCWB is constructed of is also thicker and therefore provides more insulation than the thin plastic of a water bottle.

4.3 Operational Durability

4.3.1 Drop Testing

The drop testing data presented in Section 3.3.1 allows for the following conclusions:

1) Both the double bubble ICBs and the Aerogel ICB can be dropped from elbow height out of an MRAP troop entrance door full of bottles of water without suffering any catastrophic failures. The only damage to be expected may be a broken buckle, which is replaceable.
2) The COTS cooler cannot be dropped from elbow height out of an MRAP troop entrance door full of bottles of water without sustaining severe damage and/or a catastrophic failure of the lid hinges.
3) The COTS cooler cannot contain the bottles of water when dropped.
4) No bottles will be ejected from any ICB during a drop event of similar or less magnitude.
5) Dropping any of the tested containers from the height tested will result in some damage to the water bottles inside.
6) The more water bottles stored in any of the tested containers, no matter what type, the more damage will be done to the water bottles and the container. This is due to the weight involved in the drop event.
7) Dropping any of the tested containers with the lid/access side facing down causes the most damage to its water bottles.
8) Less damage was sustained to the medium Aerogel ICB and its bottles of water (no broken buckles/fewer damaged bottles) than to the medium double bubble ICB and its bottles. This may be a statistical anomaly, since the test was not repeated multiple times, but it may also have something to do with the thicker insulation used in the Aerogel ICB, which adds some padding that may somewhat cushion the bag's fall.

4.3.2 Vibration Testing

Based on the vibration testing data presented in Section 3.3.2, it can be concluded that all the ICBs and the COTS cooler can be tied down, using the UTD method, and can successfully store bottled water during off-road driving. Although minor stretching/wear was seen on ICB webbing and UTD straps/carabineers and the rubberized base of the large ICB, none of that would be indicative of a pending material failure. However, significantly more movement of the ICBs during testing was noticed when the ICBs were tied down using the STD (550 paracord) method. This would ultimately lead to an increase in wear and reduction in the overall usable life of the cooler.

4.3.3 Abrasion Testing

The abrasion testing data presented in Section 3.3.3 show that the rubberized material tested was the most abrasion resistant, followed by the SuperFabric and then the Cordura. The following specific conclusions can also be drawn from that data:

1) The rubberized material will last about 10 times longer than SuperFabric and 13 times longer than Cordura when subjected to linear abrasion. Since linear abrasion is the most common type of abrasion (e.g., dragging across pavement and shifting back and forth when tied down in a

vehicle) these ICBs will be experiencing, the rubberized base would extend the ICB's life (when only subjected to normal wear and tear) by at least 10 times when compared to Cordura or SuperFabric.

2) Constructing the rest of the ICB out of SuperFabric could extend the ICB's usable life (if only exposed to normal wear and tear) by at least 2.5 times, based on the rotary abrasion results, Rotary abrasion (e.g., rubbing against a wall in a vehicle when tied down, equipment being stored on top of the bag) would be the most common type seen on the side and top of the ICB.

4.4 Flammability

The flash oil fire testing data presented in Section 3.4 concludes that the double bubble ICBs, the Aerogel ICB, and the COTS cooler all passed the standard ASTM flash oil fire test and can be excluded as a fire hazard during a flash oil fire scenario. All items tested could continue to be used after the first burn, but it would be recommended that they be replaced after the second burn since the outer layer of Cordura on the ICBs and plastic on the COTS cooler were substantially damaged and most likely prone to accelerated degradation. The following conclusions can also be drawn from the data in Section 3.4:

1) The large ICB cannot sustain multiple 4-s flame impingements without being ignited. This is solely due to the rubberized base which, once heated from an initial flame impingement during testing, easily ignited and caught the rest of the large ICB on fire.
2) The small and medium double bubble ICBs and COTS cooler are capable of sustaining at least two separate 4-s flame impingements without sustaining ignition and becoming a fire hazard.
3) The double bubble ICBs and COTS cooler are not able to withstand over 7-8 s of flame impingement without sustaining ignition.
4) The Aerogel ICB is capable of sustaining multiple 4-s flame impingements and then at least 10 s of flame impingement without sustained ignition.

This document reports research undertaken at the U.S. Army Natick Soldier Research, Development and Engineering Center, Natick, MA, and has been assigned No. NATICK/TR- 17/013 in a series of reports approved for publication.

Appendix A:
Operational Forces Interface Group
Vehicular Mounted Combat Cooling System (VMCCS)

(Reprint of original)

OPERATIONAL FORCES INTERFACE GROUP

Vehicular Mounted Combat Cooling System (VMCCS) Fort

Irwin, California

National Training Center (NTC)

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8 January 2009

Natick Soldier Research, Development and Engineering Center (NSRDEC)
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EXECUTIVE SUMMARY

The VMCCS background survey completed at Fort Irwin, California was useful for obtaining and documenting feedback on Soldiers' thoughts and perceptions of the concept of a VMCCS for military use. It is important to keep in mind; participants did not use the VMCCS, but were asked questions relevant on how often they would or might use the VMCCS, and to help determine what they are currently using to meet hydration requirements. This was a background survey to determine user needs. Most Soldiers reported they typically ride in a HMMWV and that they are carrying bottled water on a mission. They also estimated that they are consuming an average of 7 bottles of water per day in a hot arid climate. Nearly half of the Soldiers reported that they have personally witnessed or have participated in disposing of water because it was too hot. Two-thirds of the participants feel that there is space available for a cooling device inside their vehicle and three-fourths feel there is a need for actively chilled bottled water inside their vehicle to ensure hydration and combat effectiveness. It seems obvious from the data received that future development of the VMCCS should continue.

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Background

The Natick Soldier Research, Development and Engineering Center (NSRDEC) conducted a background survey for a Vehicular Mounted Combat Cooling System (VMCCS) in November 2008 with Soldiers from various units at the National Training Center (NTC), Fort Irwin, California. One of the purposes is to get more (cool) water into the War-fighters conducting combat operations inside tactical vehicles in hot and arid climates. War-fighters are required to remain static inside their tactical vehicles from 6 to 48 hours. The War-fighter and the bottled water that they carry become warm due to extremely high ambient temperatures, solar radiation, and the heat from the vehicles. Neither warm nor hot water is palatable; thereby reducing the voluntary intake of water.

A total of 230 Soldiers at Fort Irwin participated in the background survey on the VMCCS and were asked specific questions on their thoughts of the model and relevant questions pertaining to their current hydration needs, accessibility and if they think the VMCCS would be appropriate to use. The goal of this background survey was to inform Soldiers on the importance of hydration and to obtain feedback from them on their opinion of the concept of the VMCCS. Data obtained and interpreted from the Soldiers will be utilized for future development and improvement of the VMCCS. A copy of the questionnaire used is included as an attachment.

Survey Sample

A total of 230 Soldiers participated in the data collection with an average time in the military of 64 months and the average age was 26 years old. The survey group was mostly male (97.8%, n=224/229) while five were female (2.2%). Soldiers reported a wide variety of Military Occupation Specialties (MOSs), with the most common Career Management Fields being: Transportation (n=70), Infantry (n=38), Combat Engineer (n=32) and Vehicle Maintenance (n=15). Ranks were as follows: E-1 – E-3 (n=66), E-4 – E-6 (n=138), E-7 – E-8 (n=17), O-1 – O-2 (n=3), O-2 – O-4 (n=5) and WO-4 (n=1). Participants reported being assigned to their unit for an average of 19 months.

Data Handling and Data Analysis

The statistics cited for any particular question are based on the number of respondents who answered for the section. Statistics used to describe the questionnaire data are the number of valid responses (n) to a "yes - no" or multiple-choice question, or the arithmetic mean for a scale-ended question.

Vehicle

Slightly over three-quarters of participants (77.8%, n=179/230) indicated they typically ride in the High Mobility Multipurpose Wheeled Vehicle (HMMWV). In addition many respondents also identified another vehicle (43.0%, n=99/230). Presented in Table 1. are a list of HMMWV Variants identified, and in Table 2. are a list of "Other" vehicles.

Table 1.

HMMWV Variants

- M1151 (N=47)
- M1114 (N=19)
- M998 (N=12)
- M1181 (N=3)

Table 2.

Other Vehicles

- FAMILY OF MEDIUM TACTILE VEHICLES (FMTV) (N=72)
  FMTV SPECIFIC VARIANTS
- HEAVY EXPANDED MOBILITY TACTILE TRUCK (HEMTT) (N=34)
- FMTV (N=19)
- LOAD HANDLING SYSTEM (LHS) (N=13)
- PALLETIZED LOAD SYSTEM (PLS) (N=6)

- MINE RESISTANT AMBUSH PROTECTED (MRAP) VARIANTS (N=38)
- LIGHT MEDIUM TACTILE VEHICLES (LMTV) (N=14)
- 5 TON (N=2)
- M916 (N=2)
- M113 (N=2)

Approximately eighty percent of Soldiers stated they are required to stay inside their tactical vehicle for extended periods of time in warm and or hot climates to support mission requirements (81.3%, n=187/230). Of those who responded "Yes," Soldiers estimated an average of 7 hours as the time required to be spent inside the vehicle without exiting.

Bottled Water Supply and Consumption

Approximately three-quarters of participants responded in the affirmative that they are supplied with bottled water (76.5%, n=176/230) while slightly under one-third did not (23.5%, n=54/230). Of those who answered "Yes," Soldiers were asked how much they carry inside their vehicle to support missions in hot or arid climates and the following table displays their responses.

Table 3.

Amount of Water Carried Inside Vehicle to Support Missions in Hot/Arid Climates

GALLONS

- 1-5 GALLONS (N=9)
- 5-10 GALLONS (N=2)

BOTTLES

- 2-10 BOTTLES (N=11)
- 10-20 BOTTLES (N=30)
- 20-30 BOTTLES (N=9)
- 30-40 BOTTLES (N=2)
- 40+ BOTTLES (N=10)

CASES

- 1-5 CASES (N=51)
- 5-10 CASES (N=2)

LITERS

- 24 LITERS (N=8)
- 3 LITERS (N=2)
- 2 LITERS (N=2)

COOLERS

- 2 COOLERS
- 1 COOLER

Approximately fifty percent of Soldiers (51.7%, n=119/230), stated 1 Quart or Liter (32 ounces) as the size bottles they typically carry inside their vehicles while slightly over one-third (27.4%, n=63/230) stated 1 Pint (16 ounces). Slightly over three-quarters of participants stated the bottled water that they are supplied with became hot or warm during their mission (77.0%, n=177/230). Of the participants who answered "Yes," slightly under fifty percent of participants said they believed they were not consuming enough water because it is warm (46.9%, n=83/177). Soldier comments can be seen in the following table.

Table 4.

Soldier Comments on Why They Are Not Consuming Enough Warm Water

- DO NOT LIKE TO DRINK HOT WATER (N=23)
- MAKES ME WANT TO DRINK LESS WATER WHEN IT IS HOT (N=14)
- TOO HOT TO DRINK HOT WATER (N=10)
- COLD WATER HELPS COOL CORE BODY TEMPERATURE - MORE INCLINED TO HYDRATE WITH COLD WATER (N=9)
- I DRINK WHEN I NEED TO REGARDLESS TO TEMPERATURE (N= 6)
- ICE MELTS (N=5)
- COOLERS ONLY WORK FOR SO LONG (N=3)
- DOES NOT REFRESH AND QUENCH MY THIRST (N=2)

Bottled Water Transportation Methods

A typical mission was estimated to be an average of 48 hours and Soldiers estimated drinking approximately 6 bottles of water per day to stay hydrated while conducting their missions. When a hot and arid climate was specified participants estimated that they drank an average of 7 bottles of water per day. The following table displays current water transportation methods as identified by Soldiers.

Table 5.

Current Water Transportation Methods

- COOLER (N=100)
- INSIDE VEHICLE (N=42)
- CAMELBAK (N=31)
- BOX (N=14)
- ASSAULT PACK (N=8)
- RUCKSACK (N=5)
- BOTTLED WATER (N=5)
- CANTEEN (N=4)
- WATER JUGS (N=2)

Participants estimated that they carried an average of 7 bottles of water per man for a mission. Soldiers were asked how much water they are transporting with them while conducting vehicular related missions and the following table displays their responses.

Table 6.

Amount of Water Transported on Vehicular Related Missions

BOTTLES

- 2-10 BOTTLES (N=7)
- 10-20 BOTTLES (N=7)
- 20-30 BOTTLES (N=9)
- 30-40 BOTTLES (N=8)
- 40+ BOTTLES (N=18)

GALLONS

- 1-10 GALLONS (N=13)
- 10-20 GALLONS (N=2)

CASES

- 1-5 CASES (N=39)
- 5-10 CASES (N=5)
- 10-15 CASES (N=1)

LITERS

- 1-10 LITERS (N=17)
- 20-30 LITERS (N=4)
- 10-20 LITERS (N=2)

Hydration Requirements

Slightly under fifty percent of Soldiers stated they have personally witnessed or disposed of bottled water because it was warm (44.0%, n=101/230) while slightly over fifty percent stated they did not (56.0%, n=129/230). The following table displays comments received.

Table 7.

Comments on Water Disposal Due to Warmth of Water

- TOO HOT TO DRINK (N=36)
- DID NOT HYDRATE AS MUCH (N=6)
- NOBODY WANTS TO DRINK HOT WATER (N=6)
- PEOPLE THROW AWAY BECAUSE IT IS WARM (N=5)
- USED TO WASH WINDOWS (N =4)
- TASTED POOR AFTER HEATED (N=3)
- FOR COLD WATER FROM WATER BUFFALO (N=2)
- HAD WATER COME FRESH FROM ANOTHER SOURCE (N=2)
- WATER TOO AND HOT PLASTIC BECOMES CONTAMINATED (N=2)

Two-thirds of participants reported they know what their hydration requirements are (66.5%, n=153/230) while one-third stated they did not (33.5%, n=77/230). Of those who stated "Yes," the following table displays comments received on what Soldiers think their hydration requirements are.

Table 8.

Soldier Comments on Their Perception of Hydration Requirements

- 1 QUART PER HOUR (N=31)
- KEEP URINE CLEAR (N= 7)
- STAY HYDRATED (N=7)
- 1 GALLON PER DAY (N=6)
- 2 QUARTS EVERY HOUR (N=4)
- 2 GALLONS PER DAY (N=4)
- 1 BOTTLE PER HOUR (N=3)
- 64 OUNCES A DAY (N=3)
- DEPENDS ON ENVIRONMENT (N=2)
- 1 BOTTLE PER HOUR (N=2)
- 2 BOTTLES (N=2)
- 10 QUARTS A DAY
- 2 CAMELBAKS PER DAY
- 2 PER HOUR ON MISSION
- 20 BOTTLES PER DAY
- 3 BOTTLES A DAY OR CAMELBAK
- 6 BOTTLES
- 6 WATER 2 OTHER
- FOLLOW WORK CHART
- NEED SOMEWHAT COOLED WATER

Approximately eighty percent of participants felt they are meeting their hydration requirements (81.3%, n=187/230) while slightly under twenty percent said "No" (18.7%, n=43/230). Of those who said they feel they are not meeting their hydration requirements, the following comments were received: "do not drink enough" (n=18) and "mission dependant" (n=3).

Access to Bottled Water during Missions

Sixty percent of Soldiers stated during their missions they are allowed to exit the vehicles to access bottled water (61.0%, n=140/230), while slightly under forty percent said "No," they are not allowed (39.1%, n=90/230). Of those who said "Yes," the following comments were received on how often during their missions Soldiers are allowed to exit the vehicles to access bottled water.

Table 9.

Comments on How Often During Missions Soldiers Exit Vehicles to Access Bottled Water

- WHEN NEEDED (N=46)
- WHEN STOPPED (N=24)
- MISSION DEPENDANT (N=10)
- AS LONG AS AREA IS SAFE (N=5)
- A FEW TIMES PER MISSION (N=5)
- AT EVERY FOB (N=4)
- 5 HOURS (N=3)
- 1 HOUR (N=3)
- 3 HOURS (N=3)
- OFTEN (N=3)

Soldiers estimated that there is an average of 3 personnel inside their vehicle for a mission. Slightly under two-thirds of participants responded that there is space available inside their vehicle to place a small bottled water cooling device (65.7%, n=151/230) while approximately one-third stated there was not (34.3%, n=79/230). Those who answered "Yes," were queried what size would they recommend and where. As a reminder slightly under eighty percent of our respondents identified the HMMWV as the vehicle that they typically ride in. The following are their responses.

Table 10.

Comments on What Size and Where Soldiers Recommend Placing a Small Bottled Water Cooling Device

COOLER (N=35)

COOLER SPECIFICATIONS

- 48 QUARTS IN TRUNK
- 5 GALLONS
- 6 PACK
- THERE IS A SPACE BEHIND GUNNER'S FEET FOR A COOLER

BACK OF VEHICLE (N=14)

BACK SPECIFICATIONS

- BACK
- DEPENDING ON SIZE IT COULD INTERFERE WITH THE GUNNER IF IN THE MIDDLE
- HOOD MIDDLE
- MIGHT ALSO TAKE UP A LITTLE OF THE TRUNK
- REAR SEATS
- SHORT AND NARROW
- TRUNK

5 GALLONS (N=13)

5 GALLON SPECIFICATIONS

- ANYWHERE
- BEHIND SEATS
- BY THE TAILGATE
- CENTER CONSOLE
- FLOORBOARD
- JUG BACKSIDE UNDER GUNNER
- REAR OF THE VEHICLE OR IN THE TRUNK AREA
- SOMEWHERE ACCESSIBLE
- UNDER GUNNER

AVERAGE OR REGULAR SIZE (N=12)

AVERAGE OR REGULAR SIZE SPECIFICATIONS

- BACK REAR
- BEHIND FRONT PASSENGER SEAT
- BEHIND GUNNER BETWEEN PASSENGERS
  BETWEEN 2 BACK SEATS
- BETWEEN PASSENGERS IN THE BACK
  DEPENDS ON TRUCK
- IN MIDDLE
- WITH 3 OR 4 BAGS OF ICE

SMALL (N=10)

SMALL SPECIFICATIONS

- 12 BOTTLE CAP
- BEHIND GUNNER PLATFORM
- BETWEEN THE BACK SEATS
- IN THE MIDDLE OF THE SOLDIERS
- SQUARE BEHIND GUNNER STORAGE
- UNDER THE FEET OF 3 PASSANGERS
- UNDERNEATH BACKSEAT

RANDOM SPECIFICATIONS (N=8)

- 1 FOOT X 2 FEET (N=5) (ONE SAID MIDDLE SEAT, ONE SAID BETWEEN TWO REAR PASSENGERS BEHIND GUNNER)
- 1 FOOT X 1 FOOT (N=5) (ONE SAID CENTER)
- 2 FEET X 2 FEET X 2 FEET (N=2)
- 2 FEET X 3 FEET (N=2)
- BEHIND DRIVER SEAT (N=2)
- CENTER CONSOLE (N=2)
- EXTRA SEAT (N=2)
- UNDER GUNNER (N=2)

PASSENGER SEAT SPECIFICALLY NOTED (N=6)

- 30 QUARTS BETWEEN REAR PASSENGER SEATS
- 32 QUARTS IN PASSANGER FRONT SEAT
- ABOVE OR BEHIND PASSENGER SEAT
- BETWEEN PASSENGER SEATS
- FRONT PASSANGER SET
- PLACED ON BATTERY BOX WHEN PASSENGER SEAT REMOVED

LENGTH, WIDTH AND HEIGHT SPECIFICATIONS (N=5)

- 2 FEET LENGTH X 3 FEET WIDTH X 2 FEET HEIGHT (N=2) (ONE SAID IN THE MIDDLE)
- 2 FEET LENGTH X 1 FOOT WIDTH X 1FOOT HEIGHT. WE WOULD HAVE TO SACRIFICE SOME OTHER EQUIPMENT
- 3 FEET LENGTH X 2 FEET WIDTH X 1 FOOT HEIGHT
- 3 INCHES LENGTH 18 WIDTH IN THE AREA BETWEEN DRIVER AND TROOP AREA

MEDIUM (N=5)

MEDIUM SPECIFICATIONS

- BEHIND THE PASSANGER SEAT
- IN BACK
- ON THE BACK SEAT
- ON THE BATTERIES WE REMOVED FRONT PASSENGER SEAT
- PASSANGER SIDE OF VEHICLE

LARGE (N=4)

LARGE SPECIFICATIONS

- BEHIND DRIVER OR PASSENGER SEAT
- IN TRUNK
- PASSANGER FRONT
- REAR MIDDLE

Slightly under sixty percent of Soldiers stated they have a 24 volt Direct Current (DC) vehicle power receptacle (i.e. NATO receptacle) in their vehicle to potentially power a water cooling device (58.7%, n=135/230) while slightly over forty percent said "No" (41.3%, n=95/230). Soldiers were asked approximately how much water they would need inside their vehicle per mission and the following table displays their responses.

Table 11.

How Much Water Soldiers Feel They Need Inside Their Vehicle Per Mission

GALLONS

- 1-10 GALLONS (N=39)
- 10-20 (N=1)

BOTTLES (APPROXIMATE NUMBER OF)

- 3-10 BOTTLES (N=15)
- 10-20 BOTTLES (N=20)
- 20-30 BOTTLES (N=8)
- 30-40 BOTTLES (N=10)
- 40+ BOTTLES (N=10)

Table 11.

How Much Water Soldiers Feel They Need Inside Their Vehicle Per Mission

(continued)

CASES

- 1-5 CASES (N=39)
- 5-10 CASES (N=4)
- 10-15 CASES (N=1)

QUARTS

- 20-30 QUARTS (N=5)
- 2-10 QUARTS (N=3)

LITERS

- 20-30 LITERS (N=4)
- 4-10 LITERS (N=2)
- 10-20 LITERS (N=1)

Need for Chilled Bottled Water within Vehicle

Participants were asked how fast they would need their water chilled if they were using a VMCCS in their vehicle. The average estimate was 26 minutes. Slightly under three-quarters of Soldiers felt there is a need for actively chilled bottled water within their vehicle to support increased hydration, morale and combat effectiveness (73.0%, n=168/230) while slightly over one-quarter said "No" (27.0%, n=62/230). Of those who said "Yes," the following comments were received.

Table 12.

Soldier Comments on Why They Feel Actively Chilled Bottled Water Would Increase Hydration, Morale and Combat Effectiveness

- COLD WATER IS MORE REFRESHING (N=22)
- COOLS CORE BODY TEMPERATURE (N=22)
- MORALE AND COMBAT EFFECTIVENESS (N=21)
- INCRASES HYDRATION WITH COOL WATER (N=19)
- IT WOULD BE NICE TO HAVE A COLD DRINK (N=19)
- HOT WATER HARD TO DRINK (N=6)
- INCREASES ENERGY (N=5)
- DECREASE DEHYDRATION WITH COLD WATER (N=4)
- MORE CONVENIENT (N=2)

DISCUSSION

The VMCCS background survey completed at Fort Irwin, California was useful for obtaining and documenting feedback on Soldiers' thoughts and perceptions of the concept of a VMCCS for military use. It is important to keep in mind; participants did not use the VMCCS, but were asked questions relevant on how often they would or might use the VMCCS, and to help determine what they are currently using to meet hydration requirements. This was a background survey to determine user needs.

Most Soldiers reported they typically ride in a HMMWV and that they are carrying bottled water on a mission. They also estimated that they are consuming an average of 7 bottles of water per day in a hot arid climate. Nearly half of the Soldiers reported that they have personally witnessed or have participated in disposing of water because it was too hot. Two-thirds of the participants feel that there is space available for a cooling device inside their vehicle and three-fourths feel there is a need for actively chilled bottled water inside their vehicle to ensure hydration and combat effectiveness. It seems obvious from the data received that future development of the VMCCS should continue.

Attachment - Vehicular Mounted Combat Cooler System (VMCCS)

The Natick Soldier Research Development & Engineering Center (NSRDEC) is conducting an assessment for the Vehicular Mounted Combat Cooler System to develop a strategy that will allow for all units in hot arid climates to easily maintain and distribute cold bottled water to manned mobile units. Your responses to the following questions will influence the potential development of a material solution to support bottled water chilling capabilities, so please consider each question before answering. The information that you provide will be used only for this assessment; your answers will remain confidential. If you have any questions regarding this form, or the assessment in general, ask the representative present. Thank you in advance for your participation.

When answering each question, please explain your answers.

Last name?_____ Time in the military? _____ years _____months

Rank? E-____ O-____ WO-____ MOS? _____

What is your gender? Ⓜ Ⓕ Unit _____

How old are you? _____years

How long have you been assigned to this unit? _____ months

What type of vehicle do you usually ride in? Ⓐ Bradley (specify type_____)

Ⓑ Stryker

Ⓒ M-1 Abrams Tank

Ⓓ HMMWV (specify type_____)

ⒺOther (specify type _____)

1. Are you required to stay inside your tactical vehicle for extended periods of time in warm/hot climates to support mission requirements?

Ⓨ Ⓝ

If YES, how long is the average time required to be spent inside your vehicles without exiting? _____hours

Privacy Act Statement
Purpose(s):
To evaluate clothing and individual equipment under development or consideration by the Army; to determine acceptability of clothing and equipment items in consideration of procurement. To locate individual/s who participate in a user assessment or evaluation at the end of the test period, to complete a questionnaire on the test item.

Routine uses of records maintained in the system, including categories of users and the purposes of such uses:
In addition to those disclosures generally permitted under 5 U.S.C. 552a(b) of the Privacy Act. These records or information contained therein will not be disclosed outside the DoD. Reports published on findings do not contain any personal information, but lists demographics in the aggregate. The `Blanket Routine Uses' set forth at the beginning of the Army's compilation of systems of records notices apply to this system.

2. Are you supplied bottled water? Ⓨ Ⓝ

If YES, approximately how much are you carrying inside your vehicle to support missions in hot/arid climates? _____

3. What size(s) bottles do you typically carry inside your vehicles?

Ⓐ 1 Pint (16 ounces)

Ⓑ 1 Quart/Liter (32 ounces)

Ⓒ ½ Gallon (64 ounces)

Ⓓ 1 Gallon (128 ounces)

Ⓔ Other (_____)

4. Does the bottled water that you are supplied with become warm/hot during your mission?

Ⓨ Ⓝ

If YES, do you believe you are not consuming enough water because it is warm?

Ⓨ Ⓝ

If YES, please explain.

5. Approximately how much bottled water do you drink per day to stay hydrated while conducting your missions? _____bottles (approximately)

How many bottles of water to do you drink per day in hot and arid climates? _____days

6. How long is your typical mission? _____

7. How do you currently transport bottled water?

8. Approximately how much bottled water do you carry per man per vehicles?
_____bottles per man

9. Approximately how much water are you transporting with you while conducting vehicular related missions?

10. Have you personally witnesses or disposed of bottled water because it was warm?

Ⓨ Ⓝ

If YES, please explain.

11. Do you know what your hydration requirements are? Ⓨ Ⓝ

If YES, what are your hydration requirements?

12. Do you feel you are meeting your hydration requirements? Ⓨ Ⓝ

If NO, please explain.

13. During your missions, are you allowed to exit the vehicles to access bottled water?

Ⓨ Ⓝ

If YES, how often?

14. Approximately how many Soldiers are usually in the vehicle with you?
_____Soldiers

15. Is there space available inside your vehicle to place a small bottled water cooling device?

Ⓨ Ⓝ

If YES, what size would you recommend and where?

16. Do you have 24 VDC vehicle power (i.e. NATO receptacle) in your vehicle to potentially power a water cooling device?

Ⓨ Ⓝ

17. Approximately how much water would you need to carry inside your vehicle per mission?

18. Approximately how fast would the water need to be chilled? _____ minutes

19. Do you feel there is a need for actively chill bottled water within your vehicle to support increased hydration, morale, and combat effectiveness?

Ⓨ Ⓝ

If YES, please explain.

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Appendix B:
Blast Durability Tests Performed by Johns Hopkins University - Applied Physics Laboratory Using Vertically Accelerated Load Transfer System (VALTS)

(Reprint of original)

Science and Technology Support for the U.S. Army Natick Soldier Systems Center
Monthly Status Report

Contract No. N00024-13-D-6400

Submitted by,
The Johns Hopkins University Applied Physics Laboratory 11100 Johns Hopkins Road, Laurel, MD 20723-6099

To: Mr. Benjamin Williams
U. S. Army Natick Soldier Research, Development and Engineering Center

From: Mr. Kyle A. Ott, Project Manager
Mr. Andrew Merkle, Program Manager
Ms. Catherine Carneal, Assistant Program Manager Biomechanics & Injury Mitigation Systems

Reporting Period: October 1, 2013 to February 28, 2014

Executive Summary

Supporting the primary objective of The Natick Soldier Research Development and Engineering Center-Combat Feeding Directorate to evaluate the performance of new vehicle-borne water retention systems, the structural integrity of the five cooler systems and three separate retention systems when exposed to under body blast loading conditions was evaluated in a laboratory setting. All test articles subjected to high rate vertical loading and performed well, being able to remain operational after exposure to these types of loadings. The exception was the COTS cooler system which did not remain sealed or in-place for the duration of the tests. Further, the COTS sustained damage at high loading rates and failed to remain sealed regardless of restraint system or loading rate.

The most reliable and effective restraint system was found to be the 550 Paracord. The UTD came unbuckled during some of the tests. The standardized strap which was used exclusively with the COTS did not prevent motion or unsealing of the COTS upon impact. A summary of the findings can be found in the bulleted list below:

1) All Insulated Container for Bottled (ICB) water remained operational through testing
2) COTS cooler came open and showed signs of sustained damage due to testing
3) Universal Tie Down (UTD) came unbuckled during some of the tests
    - UTD was able to restrain system with buckle failure
4) 550 Paracord was found to be effective in restraining all ICBs

1. Objective

A primary objective of The Natick Soldier Research Development and Engineering Center-Combat Feeding Directorate is to evaluate the performance of new vehicle-borne water retention systems when exposed to under body blast (UBB) loading conditions. The Johns Hopkins University Applied Physics Laboratory (JHU/APL) has a unique test device which is able to simulate representative live-fire UBB loads in a laboratory environment. The objective of this study is to evaluate the structural integrity of the five cooler systems and three separate retention systems when exposed to under body blast loading conditions representing two levels of severity.

2. Methods

2.1 Test Articles

The Natick Soldier Research Development and Engineering Center provided the mounting fixtures and test articles used in this study. The ICBs were a canvas material with an insulated lining of three different sizes. There were no noted structural differences between the medium ICB and the Aerogel cooler. The COTS cooler was a standard hard plastic cooler.

1.1.1 Test Trays – Provided by U.S. Army Natick Soldier Research, Development and Engineering Center, these trays provide the base boundary condition for the test articles. All restraint systems were attached to these test trays.

1.1.1.1 1 Back Plate for one of the trays to mount the small ICB to the test tray

1.1.2 Test Articles

1.1.2.1 Large ICBs – Designed to contain 36 700 ml water bottles

1.1.2.2 Medium ICBs – Designed to contain 15 700 ml water bottles

1.1.2.3 Small ICBs – Designed to contain 5 700 ml water bottles

1.1.2.4 Aerogel ICBs – Designed to contain 15 700 ml water bottles

1.1.2.5 COTS

1.1.3 Restraint Systems:

1.1.3.1 Universal Tie Downs (UTDs) - Provided by U.S. Army Natick Soldier Research, Development and Engineering Center, this tie down included a center buckle and two carabineers that attached to the tray.

1.1.3.2 550 Paracord - Provided by U.S. Army Natick Soldier Research, Development and Engineering Center, pre-cut to specific lengths

Each test article included a full complement of 700 ml water bottles. Test samples were secured using either a Universal Tie Down (UTD) or 550 Paracord with the exception of the Commercial-Off-The-Shelf (COTS) cooler which was secured using either a UTD or standardized strap. Use of the restraints and the application to the various test samples followed the provided installation procedure.

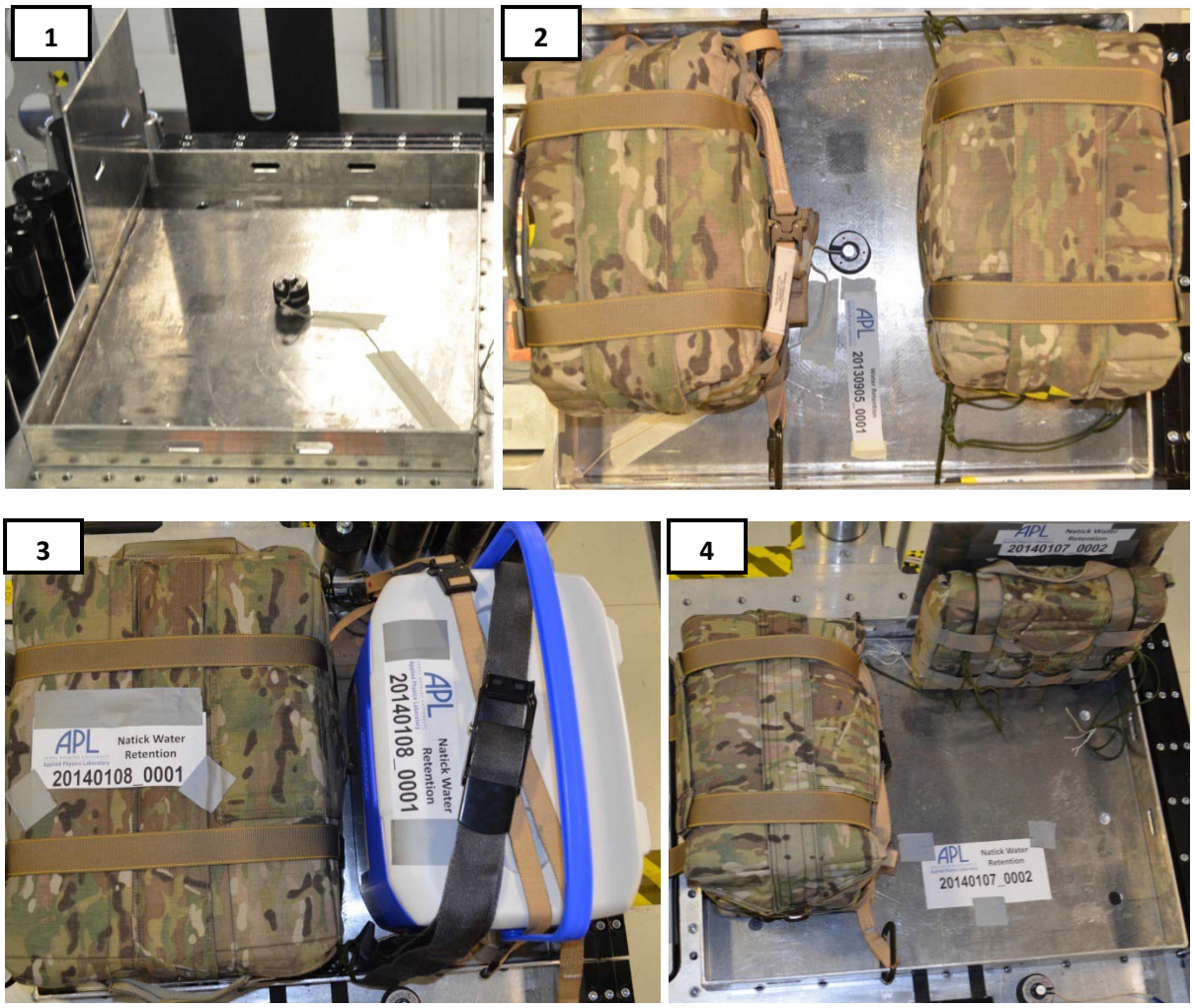

Figure 1: Test Tray with Back Plate Installed, LOFFI Accelerometer Shown (1), Medium ICB with UTD (Left) and 550 Paracord (Right) (2), Large ICB (Left) and COTS (Right) (3), Aerogel (Left) and Small ICB (Right) (4)

2.2 Test Apparatus

All tests performed on the Insulated Container for Bottled (ICB) water systems involved use of the Vertically Accelerated Load Transfer System (VALTS). The VALTS system is used to replicate high intensity vertical loading. The system was designed to achieve velocities and accelerations indicative of the modern warfighter environment, but has applications in other areas of research as well. The system utilizes high pressure nitrogen gas to accelerate massive impactors to high speeds over short time durations. The resulting imparted pulse is representative of the types of loading that is recorded during Under Body Blast (UBB) events. For this tests series, elastomers with a short pulse width were selected to represent a severe loading condition.

Test velocities achieved by the test sled were 7 and 9 m/s, again representing a severe loading condition.

Figure 2: Vertically Accelerated Load Transfer System (VALTS), Bullet mass assembly and pulse shaping elastomers (Left), mounting table and guide rods (Right). The bullet is accelerated upwards to strike the table which rides along the two vertical guide rods inducing controllable levels of UBB exposure.

2.3 Test Fixture

A test fixture was provided to JHU/APL to hold the test article. This fixture was rigidly mounted to the VALTS. The test fixture was instrumented with accelerometers (Endevco 2262A) attached to Low Frequency Foam Isolated (LOFFI) mounts similar to those used in live fire testing. Exposure severity was determined by the response of this sensor. Response data was sampled at 100 kHz using a Dewetron data acquisition system. The collected data allowed for the verification of the test exposure. High speed imaging was installed on the test sled as well as off-board allowing the evaluation of the test article response.

Onboard video data was collected using a Phantom Miro3 camera (0.5 megapixel at 1000 fps). The recorded response provided insight into the response of the various systems under loading

and could allow for some measurements of deflection and translation during the test. Initial tests also included two off board Phantom v10 cameras (0.5 megapixel at 4700 fps).

2.4 Test Matrix

The executed test matrix is shown in Table 1. For the small, medium, and large ICB systems three tests were run at each exposure condition to determine repeatability of the results. Single tests were run for tests involving the COTS system due to concerns with failure of the system. Additionally, single tests were completed for the Small and Aerogel ICB.

Table 1: Test Matrix

Test Run	Exposure Severity (m/s)	System	Restraint
1	7	Medium	Paracord
2	9	Medium	Paracord
3	7	Medium	UTD
4	9	Medium	UTD
5	7	Small Aerogel	Paracord UTD
6	9	Small Aerogel	Paracord UTD
7	7	COTS Large	UTD Paracord
8	9	COTS Large	UTD Paracord
9	7	Large	UTD
10	9	Large	UTD
11	7	Small Aerogel	UTD Paracord
12	9	Small Aerogel	UTD Paracord
13	7	COTS	Standardized Strap
14	9	COTS	Standardized Strap

3. Results

3.1 Achieved Exposure Conditions

Table 2 gives the achieved exposure conditions for each of the tests. Where multiple tests were completed an average achieved severity and standard deviation are also provided. Tests that involved two test articles are also indicated with the corresponding restraint system. Figure 3 and Figure 4 show the characteristic acceleration response for both the 7 and 9 m/s pulses as measured by the 2262 LOFFI mounted accelerometers. Both pulses have a haversine shape and are representative of the structural acceleration response measured in live fire testing [1]. From

video data, all test articles showed initial compression and then decoupling from the tray before engagement of the restraint systems.

Table 2: Achieved Exposure Conditions

Test Run	Exposure Severity (m/s)	Achieved Severity (m/s)	System	Restraint	Notes
1	7	6.8 ± 0.2	Medium	Paracord	Paracord appeared to be loose posttest, retightened pre-test
2	9	9.1 ± 0.0	Medium	Paracord	Paracord appeared to be loose posttest, retightened pre-test
3	7	6.8 ± 0.2	Medium	UTD	UTD strap came unbuckled during final test
4	9	9.1 ± 0.0	Medium	UTD	UTD strap came unbuckled for two of the three tests, unbuckled and re-buckled prior to testing
5	7	6.6 ± 0.4	Small Aerogel	Paracord UTD	UTD strap came unbuckled during final test
6	9	8.9	Small Aerogel	Paracord UTD	No failures detected
7	7	6.8	COTS Large	UTD Paracord	UTD strap came unbuckled during test, COTS came open
8	9	8.9	COTS Large	UTD Paracord	UTD strap remained buckled during test, COTS came open
9	7	6.9 ± 0.1	Large	UTD	No failures detected
10	9	9.3 ± 0.2	Large	UTD	No failures detected
11	7	6.8	Small Aerogel	UTD Paracord	Fully loaded Small ICB difficult to install with UTD
12	9	9.0	Small Aerogel	UTD Paracord	Fully loaded Small ICB difficult to install with UTD
13	7	6.7	COTS	Standardized Strap	No failures detected
14	9	9.0	COTS	Standardized Strap	COTS came open during test

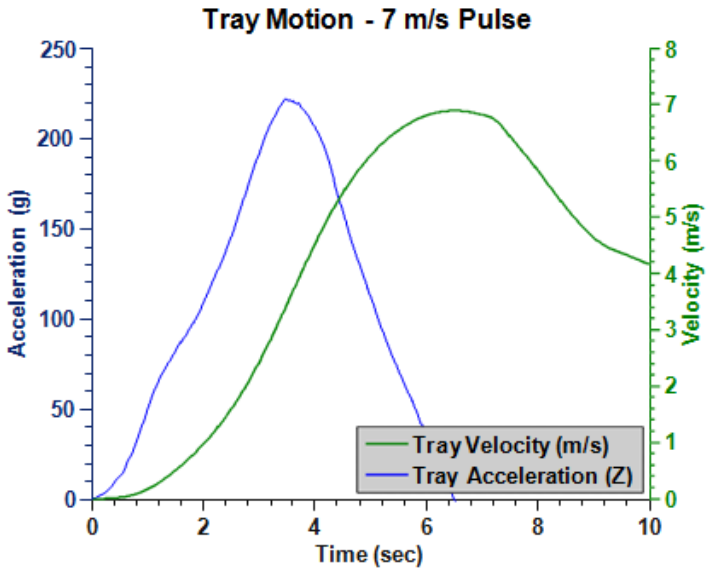

Figure 3: Characteristic acceleration and velocity response for tests targeting 7 m/s

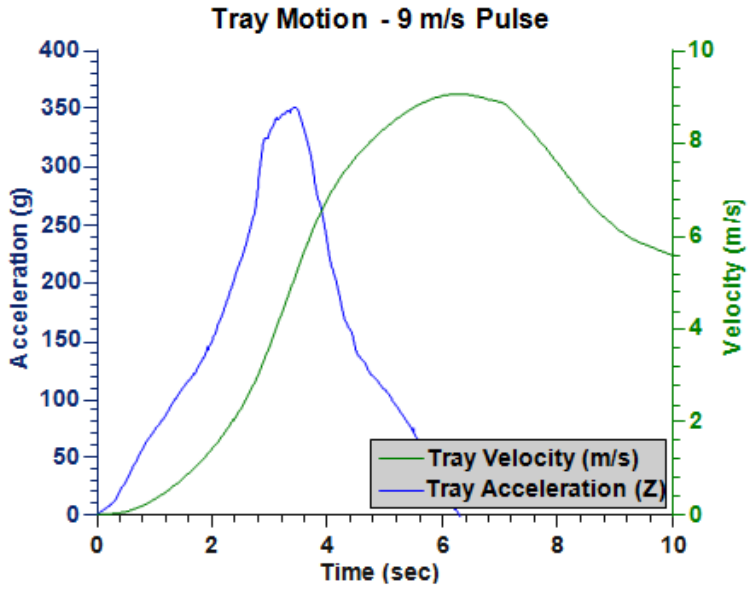

Figure 4: Characteristic acceleration and velocity response for tests targeting 9 m/s

- **Small ICB**

Figure 4 shows the pre and post-test state of the small ICB utilizing the 550 Paracord restraint techniques. No failures were noticeable across exposure rates, though the small ICB was typically tilted away from the back plate post-test. Note, pre-test the pack was secured tight

against the back plate and the Paracord was retightened after each test. High speed video showed that the system moved upwards before being restrained, this movement providing the slack in the restraint system that allowed it to end in a forward tilt position. Similar response characteristics were noted for both the 7 and 9 m/s tests.

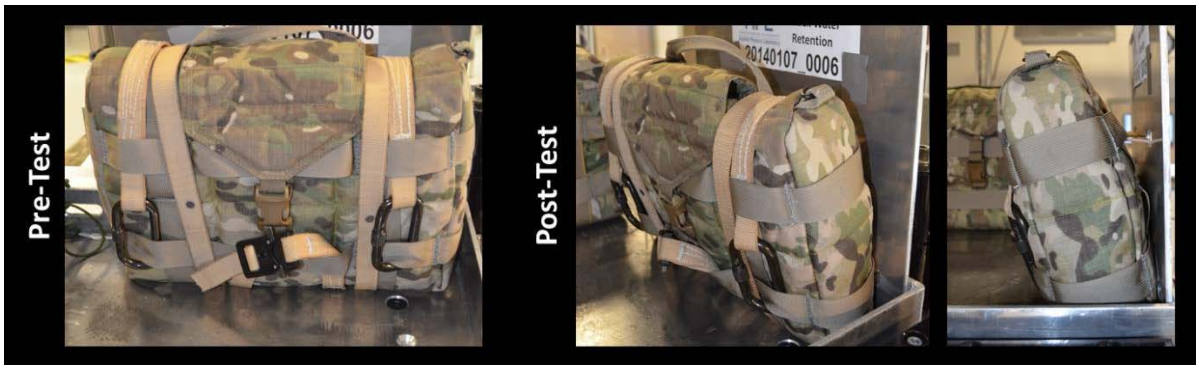

Figure 5: Small ICB with 550 Paracord pre-test (left) and post-test (right) state

Figure 5 shows the pre and post-test state of the small ICB with the UTD as the primary restraint. Though no failures were noticed, the UTD was difficult to properly attach with a fully loaded ICB. It may be possible to route the UTD differently to better facilitate mounting of the ICB system while maintaining its performance as a restraint. The UTD was inspected and reattached after each test. The small ICB was typically tilted away from the back plate post-test similar to tests involving the paracord. Similar to the tests involving the paracord, high speed video showed that the system moved upwards before being restrained, with a greater amount of displacement. Similar response characteristics were noted for both the 7 and 9 m/s tests.

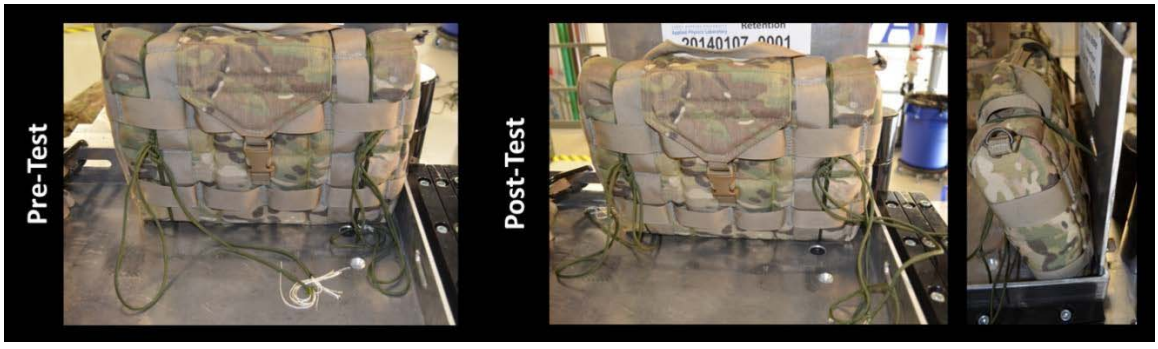

Figure 6: Small ICB with UTD pre-test (left) and post-test (right) state

- **Medium ICB**

Figure 6 shows the pre and post-test state of the medium ICB with the 550 Paracord restraints. Looseness of the Paracord was noticed post-test consistently; however the ICB remained in place and intact. The Paracord was retightened after each test. High speed video showed that the system moved upwards before being restrained, mimicking the small ICB response with a greater amount of relative displacement. Similar response characteristics were noted for both the 7 and 9 m/s tests.

Figure 7: Medium ICB with 550 Paracord pre-test (left) and post-test (right) state

Figure 7 shows the pre and post-test state of the medium ICB with the UTD restraint system. The UTD buckle became unbuckled during multiple tests; however the UTD was able to restrain the ICB due to the routing through the lateral straps. The UTD was inspected and reattached after each test. Review of the high speed video reveled that although the buckle came loose almost immediately, however, with the integrated ICB straps routed through the tray the ICB was successfully restrained. This was shown to be repeatable over multiple tests. The overall excursion of the bag from the test tray was greater than that seen by the paracord.

Figure 8: Medium ICB with UTD pre-test (left) and post-test (right) state

- **Large ICB**

Figure 9 shows the pre and post-test state of the large ICB with the 550 Paracord restraints. No failures or loosening were noted in this configuration and the Paracord was retightened after each test. High speed video shows the majority of the displacement at the center of the bag, with the overall displacement of the bag being less than what was recorded for the tests involving the medium ICB.

Figure 9: Large ICB with 550 Paracord pre-test (left) and post-test (right) state

Figure 10 shows the pre and post-test state of the large ICB with the UTD restraint. No failures or unbuckling were noted in this configuration. The UTD was inspected and reattached after each test. Similar to the tests involving the paracord, high speed video shows the majority of the displacement at the center of the bag, with the overall displacement of the bag being less than what was recorded for the tests involving the medium ICB. Unlike the medium ICB the UTD did not come unbuckled during the testing.

Figure 10: Large ICB with UTD pre-test (left) and post-test (right) state

- **Aerogel ICB**

Figure 11 shows the pre and post-test state of the Aerogel with the 550 Paracord restraints. No failures or looseness in the Paracord were noted during these tests and the Paracord was retightened after each test. High speed video showed that the system moved upwards before being restrained, similar to the medium ICB. Similar response characteristics were noted for both the 7 and 9 m/s tests.

Figure 11: Aerogel with 550 Paracord pre-test (left) and post-test (right) state

Figure 12 shows the pre and post-test state of the Aerogel with the UTD restraint. Of all the tests, only one failure of the buckle occurred. The UTD was inspected and reattached after each test. Similar to the medium ICB, review of the high speed video reveled that although the buckle

came loose almost immediately, however, with the integrated ICB straps routed through the tray the ICB was again successfully restrained.

Figure 12: Aerogel with UTD pre-test (left) and post-test (right) state

- **COTS**

Figure 13 shows the pre and post-test state of the COTS with the UTD restraint system. Multiple failure types were observed during these tests. On one test, the UTD buckle unhooked allowing the COTS to be ejected from the attachment frame. On another test where the UTD buckle remained clasped, the COTS was overturned and its contents spilled. Note, for these tests an additional strap was attached loosely to the COTS to prevent the system from becoming a projectile during testing. Review of the 7 m/s high speed video shows the COTS rotating and ejecting completely off the table with the strap still attached. For the 9 m/s test, high speed video shows the COTS rotating 180°, landing on a corner and then ejecting the water.

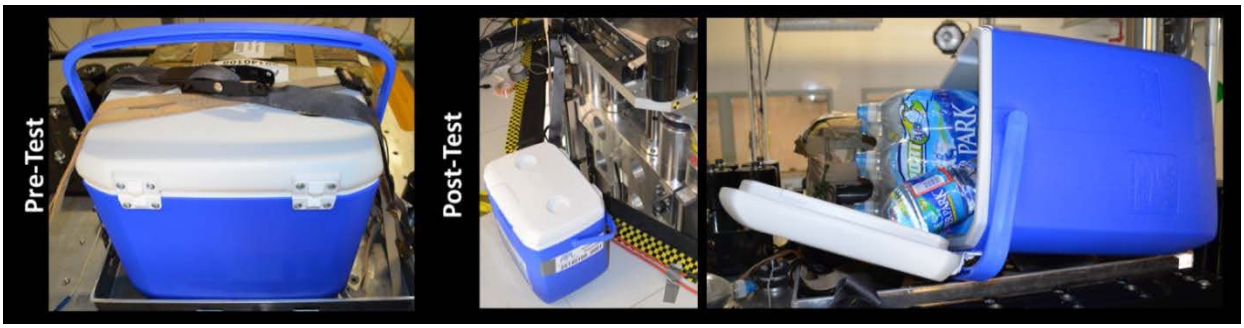

Figure 13: COTS with UTD pre-test (left) and post-test with ejection (center) and without ejection (right)

Figure 14 shows the pre and post-test state of the COTS with the standardized strap restraint. For all tests in this configuration, the COTS was overturned, but the contents were exposed only

once. In review of the high speed video, the standardized strap resisted the initial upward motion, and due to the routing induced a rotation on return to earth which caused the COTS to land on its side. The larger upward thrust during the 9 m/s tests allowed for a greater amount of rotation which induced the partial ejection of the water. Additionally, Figure 15 shows the crushing damage sustained by the COTS at the highest exposure level of 9.0 m/s.

Figure 14: COTS with standardized strap pre-test (left) and post-test without ejection (center/right) state

Figure 15: COTS sustained damage at 9.0 m/s exposure

4. Conclusions

All of the test articles subjected to high rate vertical loading were able to remain operational with the exception of the COTS. The varying size ICB's and Aerogel were undamaged even

if the restraint system failed. The COTS sustained crushing damage at high loading rates and failed to remain sealed regardless of restraint system or loading rate.

The most reliable and effective restraint system was the 550 Paracord. The UTD became unbuckled with all of the test articles except for the large ICB. The standardized strap which was used exclusively with the COTS did not prevent motion or unsealing of the COTS upon impact.

- All Iceless Cooler Bags (ICBs) remained operational through testing
- COTS cooler came open and showed signs of sustained damage due to testing
- Universal Tie Down (UTD) came unbuckled during some of the tests
  - UTD was able to restrain system with buckle failure
- 550 Paracord was found to be effective in restraining all ICBs

5. References

1. Thyagarajan, R. *End-to-end System level M&S tool for Underbody Blast Events*. in *27th Army*

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Appendix C: Abrasion Tests Performed by Taber Industries

(Reprint of original)

August 28, 2013

Ben Williams
Department of Defense-Natick Soldier R&D
Center 15 Kansas St.
Natick, MA 01760

Subject: TABER Test Request (C2324)
Reference Taber Test Report C2265

Dear Ben:
Thank you for your interest in the "Taber Test Your Sample" Program. I have performed an evaluation on the rubber, Superfabric and Cordura material samples that you submitted utilizing the Taber Model 5155 Rotary Abraser and the Taber Model 5750 Linear Abraser. The purpose of the testing is to determine which test method is used for additional sample testing. ASTM D3389 "Standard Test Method for Coated Fabrics Abrasion Resistance (Rotary Platform Double-Head Abrader)" was used for the Rotary Abraser testing.
Linear testing was *based* upon ASTM D3389. There are no specifications for linear testing of coated fabrics. The following details our test instrument set-up:

Instrument:	Taber Rotary Abraser – Model 5155
Abrasive Wheel:	H-18
Load:	500 gram/wheel
Cycles:	See Data
Vacuum Nozzle Gap:	1/8 inch
Test Conditions:	72° F, 50% RH
Test Operator:	Cliff Fee
Date:	August 23-27, 2013

Test Method:

- The Cordura Sample was adhered to S-37-1 Specimen Mounting Card before testing to ensure samples were smooth and flat and would not bunch up during the test. This also aids in consistency of testing. The Rubber and Superfabric samples were robust enough to not require adherence to a Specimen Mounting Card.
- **Sample 1 Cordura** was tested with H-18 Wheels and 500 gram load per wheel.
- The wheels were refaced prior to each test only.
- An initial weight of 6.9358 grams was recorded.
- The test was started and monitored the entire time.
- Per customer request, the test continued to 2,000 cycles where first break-through to Specimen Mounting Card was observed. A final weight was recorded as 6.3910 grams. Total weight loss is 0.5448 grams.
- See photograph below. Break through is noted at arrow.

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- **Sample 1 Rubber** was tested identically as the Cordura Sample 1.
- The wheels were refaced prior to each test.
- An initial weight of 24.2625 grams was recorded.
- The test was started and monitored the entire time.
- Per customer request, the test continued to 7,000 cycles with NO break-through. A final weight was recorded as 22.4235 grams. Total weight loss is 1.8390 grams.
- **Sample1 Superfabric** was tested identically as both of the previous samples.
- The wheels were refaced prior to test only.
- An initial weight of 5.0156grams was recorded.
- The test was started and monitored the entire time.
- Per customer request, the test continued to 5,000 cycles with NO break-through. A final weight was recorded as 3.9144 grams. Total weight loss is 1.1012 grams.

I note that the Rubber Sample appears to be the most durable followed by the Superfabric Sample and the least abrasion resistant is the Cordura Sample. This is based upon weight loss and cycle count to break- through (if any). Even though this testing does not exactly mimic field use, the direct comparison is definitely a good test.

Per the customer's request, I have also tested using a Model 5750 Linear Abraser to try and somewhat simulate the "dragging" of the samples across rough surface. Again, not exactly the same as field test but a good substitute to show a qualitative comparison.

The following details our test instrument set-up:

Instrument: Taber Linear Abraser – Model 5750 (with T-Slot Specimen Table) Abradant: ¼" H-18 Wearaser and Collet

Accessory: Narrow Slot Sample
Holder Load: 500 grams
Stroke Length: 2 inch

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Speed: 60 cycles per minute Temp/RH: 72°F, 49% RH
Operator: Cliff Fee
Date: August 23-27, 2013

- **Sample 1 Cordura** was tested per the instrument set-up above.
- The sample was held in place using the Narrow Slot Sample Holder.
- The Sample was clamped to the T-slot table. The Holder was used to secure the samples to the Linear T-slot table. A Specimen Mounting Card was not necessary as the Holder applies even pressure to secure the samples.
- Per customer request the test was set to run for one hour (= 3,600 cycles).
- The test was started and monitored the entire time.
- The test continued to 1,392 cycles where total break-through was observed.
- See photograph below.

- Sample 1 Rubber was tested identically to Sample 1 Cordura above.
- Per the customer request the test was set to two hours (7,200 cycles).
- The test continued to 7,200 cycles with no observed break-through.

The customer was contacted and he requested that the sample accomplish cycles to break-through with a time limit of an additional four hours.

- The sample accomplished a total of 17, 950 cycles with no break-through. The test was stopped due to time limit given.
- See photograph below.

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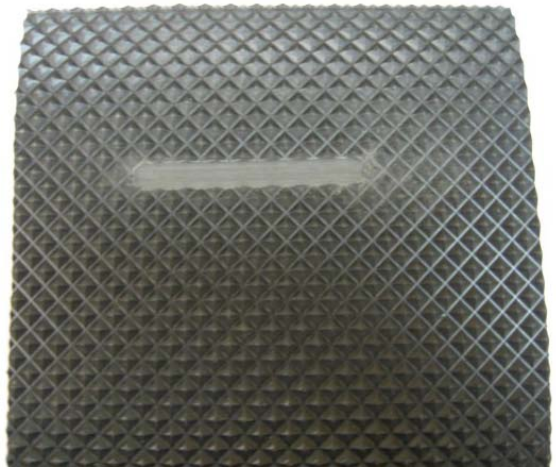

- **Sample 1 Superfabric** was tested per the instrument set-up above.
- The sample was held in place using the Narrow Slot Sample Holder.
- The Sample was clamped to the T-slot table. The Holder was used to secure the samples to the Linear T-slot table. A Specimen Mounting Card was not necessary as the Holder applies even pressure to secure the samples.
- Per customer request the test was set to run for three hours (= 10.800 cycles).
- The test was started and monitored the entire time.
- The test continued to 1,725 cycles where total break-through was observed.
- See photograph below.
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I note that the “dots” on the Superfabric wore grooves in the Wearaser. Once the “dots” were abraded through, the Wearaser abraded more on one side and wore through the fabric. EVEN if the Wearaser was refaced during the test, I do not believe the sample would have made it to 10,800 cycles

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Conclusion: The Rubber Sample again proved to be the moset abrasion resistant product based upon cycle count.

Should you have any questions about these results, please contact me at the information below.

Tested samples will be returned for the customer's further investigation.

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