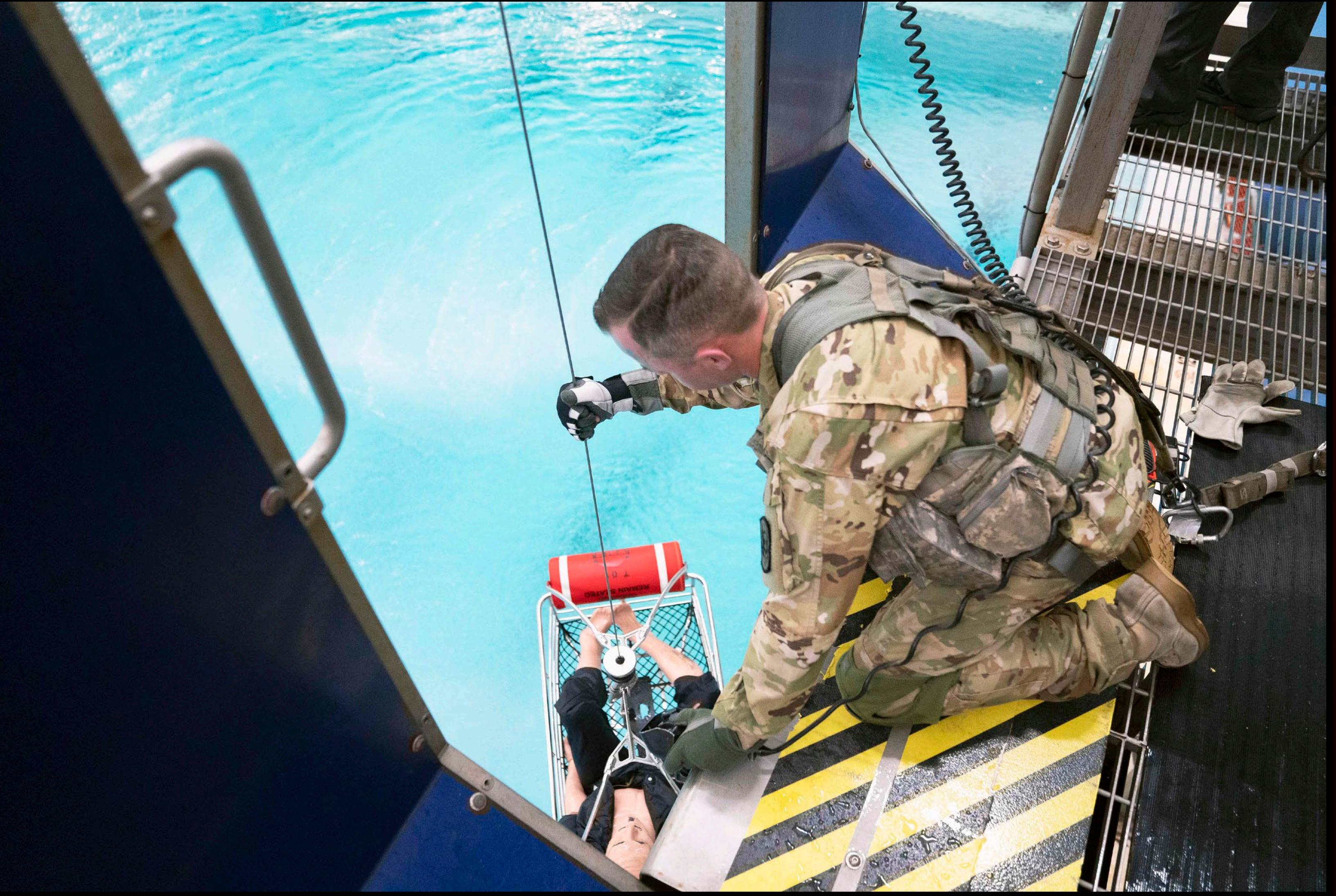

Enhanced Rescue Hoist Glove

Operational Field Assessment Report

September 2020

Homeland Security

Science and Technology

NUSTL®
NATIONAL URBAN SECURITY TECHNOLOGY LABORATORY

Approved for Public Release

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FOREWORD

The National Urban Security Technology Laboratory (NUSTL) is a federal laboratory organized within the U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T). Located in New York City, NUSTL is the only national laboratory focused exclusively on supporting the capabilities of state and local first responders to address the homeland security mission. The laboratory provides first responders with the necessary services, products, and tools to prevent, protect against, mitigate, respond to and recover from homeland security threats and events.

DHS S&T works closely with the nation's emergency response community to identify and prioritize mission capability gaps, and to facilitate the rapid development of critical solutions to address responders' everyday technology needs. DHS S&T gathers input from local, tribal, territorial, state and federal first responders, and engages them in all stages of research and development—from building prototypes to operational testing to transitioning tools that enhance safety and performance in the field—with the goal of advancing technologies that address mission capability gaps in a rapid time frame, and then promoting quick transition of these technologies to the commercial marketplace for use by the nation's first responder community.

As projects near completion, NUSTL conducts an operational field assessment (OFA) of the technology's capabilities and operational suitability to verify and document that project goals were achieved.

NUSTL's publicly released OFA reports are available at www.dhs.gov/science-and-technology/frg-publications. OFA reports deemed sensitive are available on a case-by-case basis, and can be requested by contacting NUSTL@hq.dhs.gov.

Visit the DHS S&T website, www.dhs.gov\science-and-technology\first-responder-technologies, for information on other projects relevant to first responders.

Visit the NUSTL website, www.dhs.gov/science-and-technology/national-urban-security-technology-laboratory, for more information on NUSTL programs and projects.

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EXECUTIVE SUMMARY

Rescue hoist gloves protect emergency responders' hands during specialized helicopter hoist rescue operations. To improve the durability and performance of these gloves, the U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) First Responders and Detection, Office of Mission Capability and Support sponsored the research and development of abrasion-resistant glove materials and alternative glove designs. This effort resulted in two prototype fingerless glove designs.

The two gloves, denoted Glove B and Glove C, are made from a "SuperFabric" material coated with resin to create abrasion-resistant dots. While both gloves use the resin-coated fabric on the palm and a stretchable fabric on the back, other design elements differed. Glove B incorporates a second layer of finer-grained material to provide additional abrasion resistance and a wear-indicator feature on the palm, a rubber pad on the heel of the hand, and reflective fabric at the wrist cuff and closures. Glove C has an additional padded layer over the purlicue—the area between the thumb and index finger—and part of the palm region, with leather on the fingers and wrist area. Both gloves have Velcro straps and a loop at the wrist as well as leather finger pulls.

DHS S&T's National Urban Security Technology Laboratory (NUSTL) conducted an operational field assessment (OFA) where five responders from the fire services and members of the uniformed services evaluated the gloves at the U.S. Coast Guard's Aviation Technical Training Center located in Elizabeth City, North Carolina. To replicate manual tasks typically associated with rescue missions, the evaluators used hoist platforms equipped with safety harnesses, rescue gurneys holding weighted mannequins, stationary helicopters, carabiner and various other gear. Equipment at the training center was able to mechanically generated wind and rain to simulate conditions encountered during hoist rescue operations.

The evaluators found that the SuperFabric material used in the enhanced gloves had different properties than the leather in their current gloves, which effected operational activities. The enhanced glove material was found to have low friction, which allowed the hoist cable to glide with less contact, but also reduced the palm grip typically used to maneuver themselves on the helicopter floor. Evaluators found that excess fabric bunching in the palm of the gloves could negatively affect comfort and functionality. Modifications to the glove design were suggested to improve usability and comfort, including reduction of fabric in the palm by using a curved design that models a natural hand shape; reduction in the length of the cuff for improved compatibility with flight suit sleeves; refinement of shape and position of the rubber pad in Glove B and addition of a similar leather or rubber pad to Glove C; and re-location of seams from high-wear areas in the purlicue to the back of the hand. No significant differences were found between using the gloves in dry or wet conditions. Evaluators valued the gloves' special features such as the wrist loop (both gloves), wear indicator (Glove B) and extra padding (Glove C), which would be particularly helpful for maintenance, protection and comfort, respectively.

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1.0 INTRODUCTION

Rescue hoist gloves protect emergency responders' hands during specialized helicopter hoist rescue operations, and may be worn on only one hand. Gloves may be either a full coverage style or a fingerless over-glove style that does not cover the fingertips. The fingerless over-glove style may be worn over a separate, thinner full-coverage glove that provides thermal protection and covers the fingertips. Responders performing these specialized rescue operations wear the hoist glove primarily to protect the palm side of the hand that manually guides a steel hoist cable during descents and ascents. Responders have found that these gloves degrade quickly due to friction with the cable. In addition to the loss of hand protection, fragments of material from a damaged glove—typically leather—can get caught between strands of the hoist cable and may shorten the useable life of the cable or hoist system. Other types of rescue hoist missions requiring hand protection may involve ropes rather than steel cables such as cave, whitewater and dive rescue operations.

The U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) funded Higher Dimension Materials Inc. (HDM) and the North Carolina State University Textile Protection and Comfort Center (TPACC) to conduct research and development of advanced abrasion-resistant glove materials and alternative glove designs. HDM and TPACC worked with commercial glove manufacturers to produce prototype gloves using high-performance materials. The goal of this effort was to develop enhanced rescue hoist gloves with improved durability and longevity, while allowing sufficient dexterity for rescue helicopter personnel to perform requisite tasks without damaging the hoist cable. This research effort was managed by DHS S&T First Responders and Detection (FRD), Office of Mission Capability and Support (MCS).

The research and development effort began in 2017 and resulted in two prototype glove designs, designated Glove B and Glove C in this document. Both are designed to be worn over an under-glove, and their palms are made from a SuperFabric material that is coated with resin to create abrasion resistant dots (called guardplates) that cover the surface. Glove B incorporates a second layer of finer-grained SuperFabric material under the top layer that is intended to provide additional abrasion resistance and is constructed of contrasting color layers that to provide a visual wear indicator as the glove degrades over time. Glove C uses a single type of SuperFabric with an additional layer over the purlicue—the area between the thumb and index finger—and part of the palm region and also includes leather components at the palm and on the finger pulls, which is intended to provide additional traction.

On behalf of DHS S&T FRD MCS, the National Urban Security Technology Laboratory (NUSTL) was tasked with conducting an operational field assessment (OFA) to evaluate the enhanced rescue hoist gloves' suitability for use by emergency responders. NUSTL conducted the OFA at the U.S. Coast Guard's Aviation (USCG) Technical Training Center (ATTC) located in Elizabeth City, North Carolina. This report describes the evaluators' feedback obtained during the operational test activities that simulated conditions encountered during rescue missions.

1.1 Purpose

The purpose of the OFA was to assess the enhanced rescue hoist glove models for operational suitability for first responders in a simulated operational environment.

1.2 Objectives

The OFA assessed glove performance related to:

- Fit and Comfort–overall fit and feel, as well as compatibility to work with other personal protective equipment and standard uniforms
- Functionality–ability to not interfere with operational tasks. This objective also includes:
  - Durability–ability to withstand repeated use without significant degradation in protection or shedding fragments that could damage hoist cables
  - Usability–ease of donning and doffing in wet and dry conditions, and availability of gloves in an appropriate range of sizes
- Protection–effectiveness in shielding the hand from contact with a hoist cable
- Dexterity–adequate flexibility to allow for the full range of hand motion to enable the operation of typical equipment, such as radios, carabiners, harnesses and similar equipment.

1.3 Participants

Table 1-1 lists the OFA participants. Five evaluators from three different agencies participated, along with OFA team members, the technology developer and observers.

Table 1-1 OFA Participants

Role	Organization
Evaluators	• North Carolina National Guard • San Diego Fire and Rescue (California) • U.S. Coast Guard (Alabama)
Venue Host	U.S. Coast Guard Aviation Technical Training Center
Program Managers and Support Staff	U.S. Department of Homeland Security, Science and Technology Directorate
OFA Test Director and Data Collectors	U.S. Department of Homeland Security, Science and Technology Directorate, National Urban Security Technology Laboratory
Technology Developer	Higher Dimension Materials Inc.
Observers	• U.S. Coast Guard Aviation Technical Training Center • U.S. Coast Guard Research and Development Center
Photographer and Videographer	U.S. Department of Homeland Security, Science and Technology Directorate, Communications and Outreach Division

1.4 Requirements

Table 1-2 summarizes requirements that the enhanced rescue hoist glove models were expected to meet and the manner by which those requirements were tested during the OFA. These requirements were drawn from the *U.S. Department of Homeland Security Notice of Funding Opportunity Protective Equipment for Responders,* which described the critical capabilities and requirements for enhanced rescue hoist gloves. The FRD Program Manager identified the requirements to be addressed at the OFA.

Table 1-2 Enhanced Rescue Hoist Glove Requirements and Activities Matrix

Category	Requirement	OFA Test Activities
Protection/Durability	• Provide adequate protection to the hand guiding the cable during rescue operations. • Not transfer heat from friction created by a hoist cable to the hand. • Provide increased durability and longevity over existing gloves, either as a single unit or unit with replaceable parts.	• Evaluators dropped and guided steel hoist cables and pulled up a line[i] attached to various types of gurneys and carriages with various contents, such as a mannequin or weighted objects. • Evaluators guided a cable under varying environmental conditions, including calm air and mechanically generated wind and rain.
Dexterity	• Have adequate flexibility and dexterity to allow for the full range of hand motion to enable normal operations of radios, carabiners and similar equipment.	• Evaluators performed intricate manual tasks such as: ○ Attaching and detaching self-locking carabiners ○ Adjusting buckles ○ Operating helicopter doors, operation panels, controls or keyboards
Functionality	• Not produce fibers or other loose materials during use or as a result of wear. • Features of the glove do not interfere with operations (e.g., snag points, cuff, hooks, etc.), allowing for use when performing other duties.	• Shedding of fragments assessed after cable handing scenarios described in the Protection/Durability OFA Test Activities listed above. • Potential interference assessed during the same cable handing scenarios described in the Dexterity OFA Test Activities listed above.
Usability	• Relative ease of donning and doffing in wet and dry conditions. • Available in a range of sizes.	• Evaluators donned and doffed dry hoist gloves with: ○ Dry hands and dry under-gloves (as applicable) ○ Wet hands and wet under-glove ○ Wet hands and dry under-glove. • Evaluators donned and doffed wet hoist gloves over wet hands/under-gloves.
Compatibility	• Be compatible with personal protective equipment and standard uniforms for rescue operations.	• Evaluators were asked to bring their current flight suit or uniform to verify compatibility during donning, doffing and the activities in each scenario.

[i] The enhanced rescue hoist gloves are intended to withstand being used to guide steel cables, which was the primary focus of the OFA. However, some USCG operations may involve other types of lines or ropes, a potential alternate use-case for the hoist gloves. A trail line activity was included at the OFA for USCG evaluators; their assessment of the potential use of the gloves for trail line operations are reported in Appendix A.

1.5 System Description

The two prototype styles of enhanced rescue hoist gloves are shown in Figure 1-1, designated Glove B and Glove C. Both gloves incorporate an exterior palm layer made from a gray-colored, resin-coated SuperFabric material with smooth guard plates for improved abrasion resistance. Designated by the number 700665, the SuperFabric employs a 70/08-400 resin pattern imprinted on a Polyester 600 Denier guardplate construction. The 70/08 sequence represents measurement parameters in units of mils (thousandths of an inch), where 70 is the diameter of the guardplates and 08 refers to the size of the gap between the guardplates. The number proceeding the dash specifies the height of the guardplates as 400 microns (thousandths of a millimeter). Gloves B and C offer different components using different formats and materials, as detailed below. Figure 1-1 depicts key characteristics of the two designs.

Glove B

Views of palm side (top) and back of hand (bottom). The rubber heel on palm is intended to prevent slipping. An additional underlayer of abrasion resistant material (not visible) indicates wear, becoming visible with use.

Glove C

Views of palm side (top) and back of hand (bottom). An additional panel of abrasion-resistant material is visible on the palm side, covering the purlicue and extending to a region of the central palm along the thumb.

Figure 1-1 Two Enhanced Rescue Hoist Glove Models

The small dots visible on the palm side of each model serve to resist abrasion and are called guardplates. Loops at the wrist and leather finger pulls aid donning and doffing and Velcro closures allow users to adjust the fit.

1.5.1 Glove B

Figure 1-2 Close-up of the rubber heel on Glove B.

Glove B was designed by HDM and produced by Lucky Zone Inc. HDM is based in Oakdale, Minnesota. Lucky Zone Inc.'s U.S. headquarters is in New York City, while its manufacturing facility is in China. Glove B includes an additional inner pad (not visible in the photos) made of orange-colored, resin-coated fabric (designated 700538) with 50/05-200 guard plates imprinted into an orange base material. The base material is specified according to a unit of measure of the fiber-thickness of individual threads or filaments in the material, called the "Denier" number, designated by an integer followed by an uppercase "D," such that the higher the Denier number, the thicker the fabric. The orange fabric used for Glove B is 100D, which is a relatively lightweight fabric. It is then laminated to another 100D fabric that is coyote (brown) in color. The smaller, thinner guardplates of the orange fabric and the lightweight 100D fabric are intended to provide additional abrasion protection, while maintaining flexibility. This color and fabric combination also serves as a visual indicator of wear conditions. If the user sees the orange guardplates, it indicates that the glove can be used for up to an additional 20 lifts; however, when the brown fabric is showing, the user should discard and replace the glove. Glove B is also outfitted with a rubber heel on the palm (Figure 1-2) to prevent slippage.

Two adjustable Velcro® straps on the back of the glove allow the user to fit it snugly to their hand. The material on the back of the hand is bright orange stretch Cordura®. The color aids visibility, while the material's ability to stretch—along with a wrist pull and two finger pulls—aid in donning and doffing. Reflective fabric is incorporated in the wrist cuff and closures, and an additional layer of SuperFabric 700665 is used in the purlicue for increased protection. Kevlar® thread is used throughout the glove.

1.5.2 Glove C

Figure 1-3 Close-up on additional layer of fabric on Glove C.

Glove C was designed and produced by Hyunjin Inc., a Korean company, and was made in Vietnam. Glove C incorporates SuperFabric 700665 in the high-wear area of the glove's purlicue for user protection, along with an additional layering of SuperFabric in the purlicue area (Figure 1-3), which extends to the middle of the palm. The material on the back of the hand is black Spandex®, with two adjustable Velcro straps on the back of the glove, allowing the user to fit it snugly to their hand. White leather is used on the fingers and wrist area. The glove also has a wrist pull and leather finger pulls to aid donning and doffing.

2.0 OPERATIONAL FIELD ASSESSMENT DESIGN

2.1 Event Design

During this OFA, five evaluators--first responders from the fire service and members of the uniformed services from California, North Carolina and Alabama-- assessed the gloves' durability, functionality, dexterity, usability, compatibility with other equipment and the protection provided in simulated rescue hoist scenarios. The OFA was conducted at the USCG ATTC, located in Elizabeth City, North Carolina, where evaluators participated in various activities at two stationary hoist platforms. The prototype gloves were assessed under calm conditions, as well as with simulated wind and rain; and the evaluators donned and doffed the gloves when they were wet and dry. Degradation testing also occurred.

Evaluators were grouped into two teams and data collectors from NUSTL were assigned to each team. The data collectors facilitated the test activities, recorded observations and comments during each activity and used a questionnaire to gather feedback from each evaluator following the completion of each activity station. Following the completion of all activities, additional feedback was solicited from the evaluators during a group debrief session. Observers from the USCG ATTC (North Carolina) and USCG Research and Development Center (Connecticut) watched the OFA activities.

2.2 Scope

The OFA consisted of the following components:

Classroom Presentation and Technology Familiarization

The OFA began with an introductory session providing evaluators with an overview of the OFA process, how the capability gap was identified, planned activities for the OFA and a site safety briefing. HDM provided an overview of the enhanced rescue hoist gloves in the classroom, which included background on the development of the technology and a familiarization session. During this session, evaluators were able to try on the gloves while HDM guided them through the specifications of each model.

Figure 2-1 Evaluators examine the gloves during the technology familiarization session

Assessment Activities

After the familiarization session, the evaluators performed the activities listed in Figure 2-1, with the two teams working simultaneously throughout simulated rescue operations. After completing the activities for each circuit, they provided direct feedback in response to questions from NUSTL data collectors. NUSTL data collectors also noted any candid observations and comments from the evaluators during the activities. Full details of the event design are described in the Enhanced Rescue Hoist Glove Operational Field Assessment Plan (U.S. Department of Homeland Security (DHS), Science and Technology Directorate, December 2019).

Table 2-1 Enhanced Rescue Hoist Glove OFA Activity Descriptions

Activity Title	Activity Description	Purpose
Donning and Doffing	Evaluators donned and doffed dry and wet gloves. When donning and doffing the wet gloves, evaluators followed a predefined procedure where they would wet their bare (or under-gloved) hand for 10 seconds, then don the enhanced rescue hoist glove and submerge their gloved hand for two minutes.	These activities assessed the ease of donning and doffing in both dry and wet conditions.
Dexterity	With dry and wet gloves, evaluators performed manual tasks requiring motor skills and/or grip (i.e., manipulating carabiners, opening and closing latches or buckles, etc.). Dry and wet gloves were used for this activity.	These activities gauged dexterity and flexibility.
Calm Hoist	With dry gloves, evaluators worked with a gurney or carriage device, where they lowered the equipment to just above the surface of the water in calm conditions, hoisted it back to the starting point and repeated as needed to assess the gloves.	These activities gauged the usability, functionality, dexterity and compatibility with personal protective equipment and standard uniforms for rescue operations.
Rain and Wind Hoist	With wet gloves, evaluators worked with a mannequin on a gurney or in a carriage. With rain and wind generators turned on, evaluators lowered the mannequin into the water, hoisted it back to the starting point and repeated as needed to assess the gloves.	These activities gauged the usability, functionality, dexterity and compatibility with personal protective equipment and standard uniforms for rescue operations.
Degradation Testing	All evaluators began the OFA with brand new gloves. Following the operational activities, NUSTL data collectors photographed the gloves B and C to track durability. This was followed by additional durability tests involving guiding a weighted hoist cable continuously for at least one minute.	Continuously guiding the cable allowed the evaluators to assess the durability and functionality of the gloves.

Figure 2-2 Evaluators using the gloves during activities meant to assess dexterity.

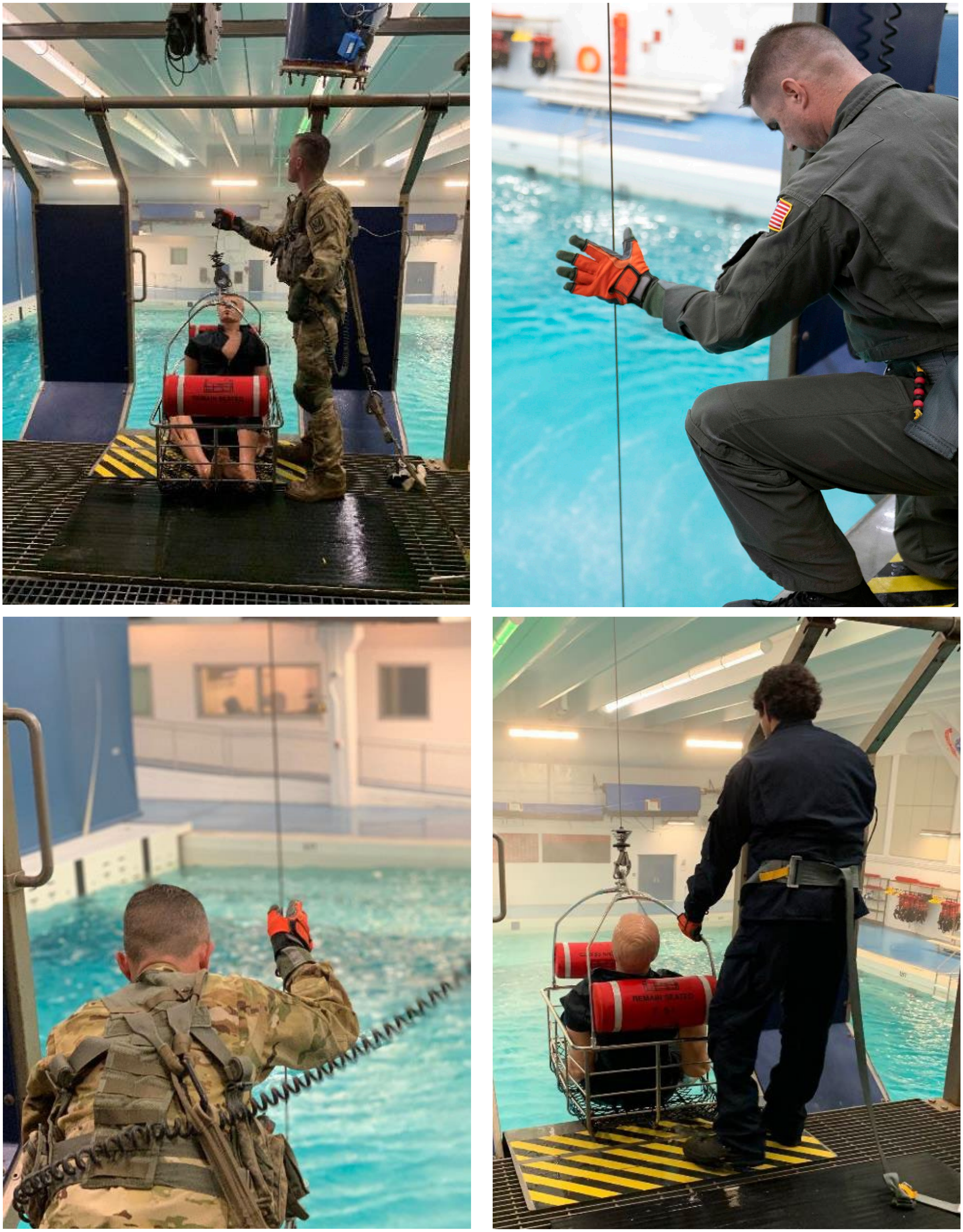

Figure 2-3 Evaluators wearing Glove B while performing hoist operations.

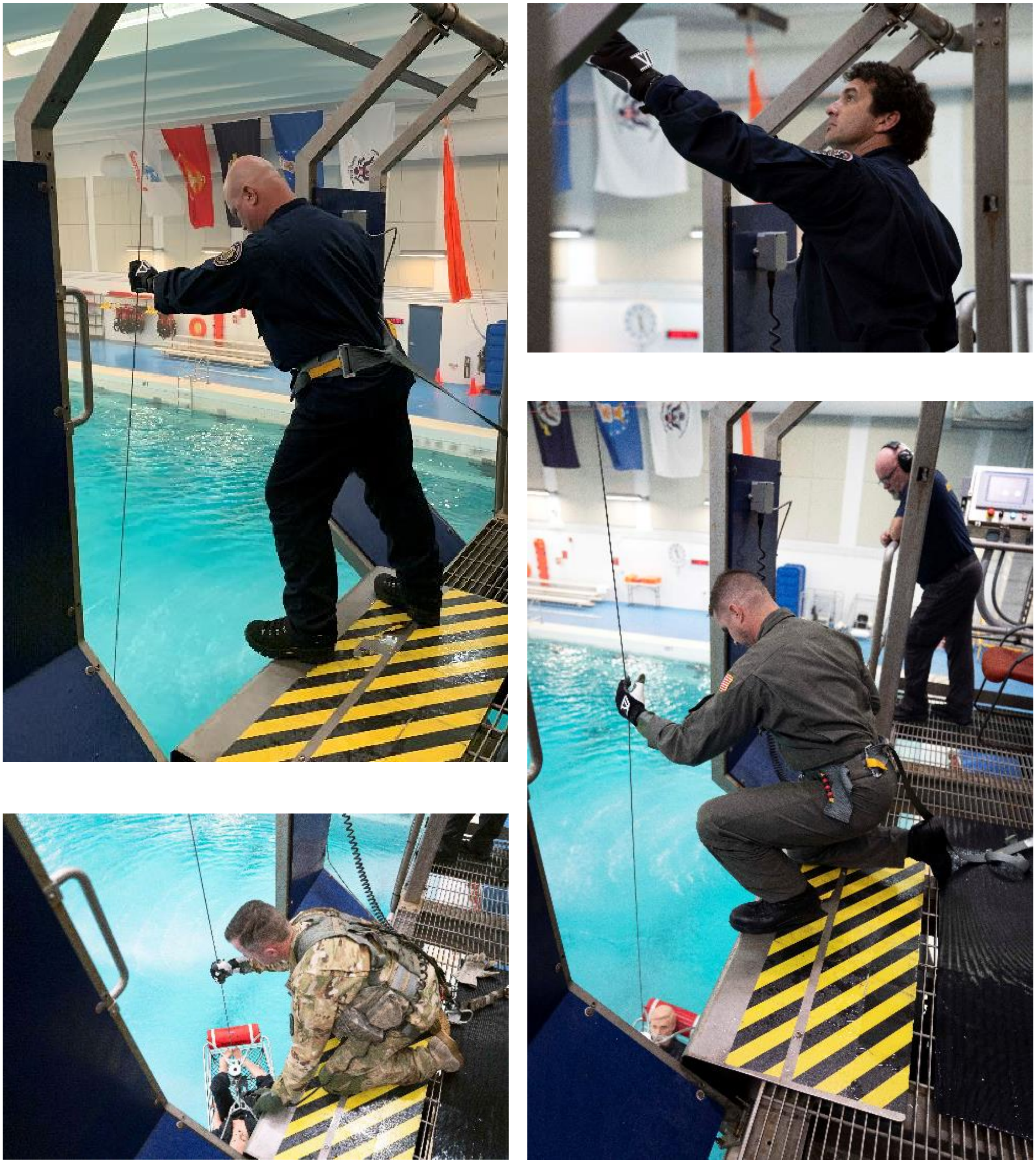

Figure 2-4 Evaluators wearing Glove C while performing hoist operations.

Debrief

A debrief session, facilitated by the NUSTL OFA test director, was held at the conclusion of all activities with all OFA participants. During this session, evaluators provided comments to elaborate on their numerical ratings.

2.3 Limitations of and Deviations from the Test Plan

2.3.1 Limitations

Degradation assessment was limited because the one-day OFA timeframe did not allow long-term use of the prototype enhanced rescue hoist gloves over an extended period.

Another limitation was the individual variability in hand shape, which naturally affects fit and glove performance. Two evaluators would have preferred a smaller size.

Finally, simulated operations do not encompass the extreme environmental conditions that responders may encounter while performing their duties.

2.3.2 Deviations

There were minor deviations from the Enhanced Rescue Hoist Glove Operational Field Assessment Plan (2019) related to the test procedures. The ATTC is outfitted with two hoists, but only one is capable of generating wind and rain. As a result, the rain and wind scenarios were combined, and occurred at one hoist. Though not described in the assessment plan, two stationary MH60 and MH65 helicopters were made available to the evaluators to facilitate additional dexterity tests. The evaluators were able to use the prototype gloves while scooting on the floor of helicopters, grabbing handles, buckling safety belts and using toggle switches/levers inside the cockpit. Finally, while the evaluators were provided with, or brought, their current issued hoist gloves to the OFA, assessment of current gloves is not included in the results analysis.

Figure 2-5 Stationary Helicopters used for Dexterity Testing
MH60 (Left), Evaluators in the MH65 during dexterity testing (Right)

3.0 RESULTS

This section contains evaluators' feedback gathered from questionnaires and group discussions and includes their suggestions for enhancements to the gloves that may improve functionality. The section is organized into sections on fit and comfort, functionality, protection, durability and opportunities for improvement. Section 3.1 covers overarching feedback that pertains to and compares both prototypes, while sections 3.2 and 3.3 report feedback specific to Glove B and Glove C, respectively.

The OFA questionnaire was structured so that, when prompted with a statement related to an activity they performed, evaluators selected a response of strongly agree, agree, disagree or strongly disagree and provided comments to explain their selection. There were a few instances where a response of not applicable (N/A) in response to the statement were received from evaluators.

3.1 Comparative Analysis and Feedback For Glove B and Glove C

During the assessment, there were instances where evaluators provided overarching feedback that pertained to and compared Gloves B and C. This information is captured below.

3.1.1 Fit and Comfort

The evaluators identified two primary issues with the fit of both gloves. First, all of the evaluators agreed that the cuffs on Gloves B and C were too long (shown in Figure 3-1) and would interfere with their dry suits and potentially with operations. The lower section of Velcro on both gloves (circled in Figure 3-1) was viewed as unnecessary and cumbersome; one evaluator suggested that the cuff on either glove be shortened to the wrist line and should have a single Velcro strap. Another evaluator suggested improving the straps by narrowing the opening on both gloves and changing the angle at which the Velcro lays. Additional suggestions included considering a closed-loop strap design or an elastic cuff.

Figure 3-1 Length of Glove Cuffs B (Top) and Glove C (Bottom)

Second, most evaluators determined that the overall fit and feel of both gloves was cumbersome due to excess fabric in the palm area. Three of the five evaluators noted that the fabric bunched up in the palm area, (Figure 3-2), which decreases their ability to feel the cable and extend their fingers during manual tasks, affecting safety during hoist operations. It was suggested that the gloves incorporate enhanced structure to account for the natural C-shape curvature of a hand.

Another evaluator did not have a problem with fabric bunching in the palm area of the gloves and said both gloves had a good fit when worn with the under-glove. The evaluators also added that there needed to be a more precise and accurate sizing chart available to assist with ensuring an appropriate fit.

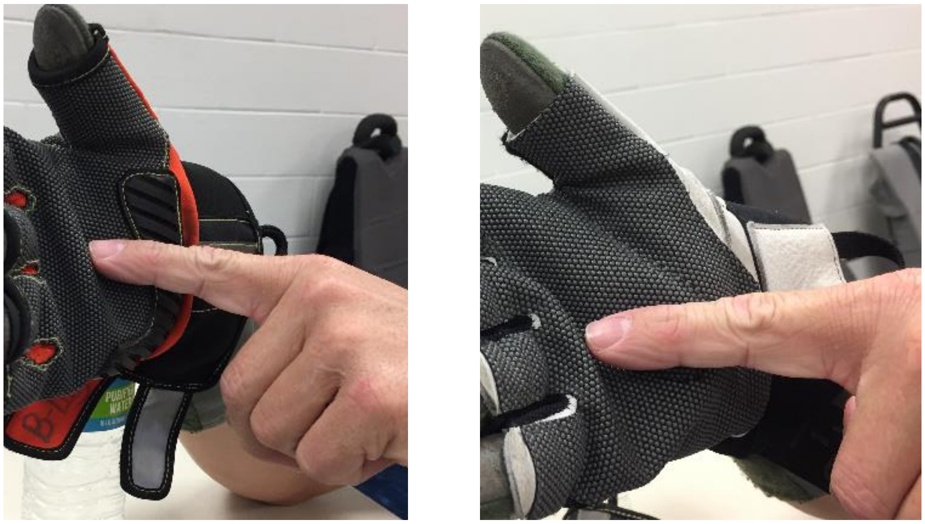

Figure 3-2 Bunched Fabric in Glove B (Left) and Glove C (Right)

3.1.2 Functionality

All of the evaluators pointed out the usefulness of the loops imbedded into the bottom of Gloves B and C. In addition to not interfering with their uniforms, evaluators anticipated that the loops would also be useful for hanging the hoist glove to dry. One evaluator also indicated that the loop was useful for donning the glove. Two evaluators stated that the pull loop on Glove C was better integrated and had a lower profile than that of Glove B, and would not be a snag hazard.

Some evaluators felt that the fingers on Gloves B and C were too long and could potentially interfere with operations, noting that those of Glove B were longer than Glove C. One evaluator suggested that the length of the glove fingers be shortened down to the second knuckle joint to allow fingers full access to manipulate hooks and other equipment. In addition, multiple evaluators did not prefer having the finger pulls present on the gloves. One evaluator felt the pulls were on the wrong fingers and could be relocated to improve doffing (i.e., adding a pull on the thumb), while another stated they would not use the pulls for doffing, regardless.

The evaluators also provided extensive feedback on the SuperFabric, the primary material of the Gloves B and C, as it differed from their current leather hoist gloves. One evaluator suggested that the low friction material of the SuperFabric would fundamentally change the way they would handle the hoist cable, noting that the material allowed for variable pressure to be applied without interrupting the cable run, which led to better cable control and management. Another evaluator agreed that controlling the cable was significantly smoother with Glove B and Glove C when compared to their current leather glove; after using the gloves the evaluator stated that the leather glove, by comparison, had a very clear drag. However, the lack of friction from the SuperFabric negatively affected other aspects of flight operations. All evaluators emphasized that Glove C did not offer sufficient grip when holding onto handles, door panels and maneuvering on the floor of a helicopter compared to Glove B. The slickness of the gloves, particularly when wet, was seen as a significant safety concern by two of the evaluators. They found it difficult to grip wet equipment during assessment operations and thought it could create dangerous conditions.

3.1.3 Protection

The evaluators had varying opinions on the level of protection the gloves provided during hoist operations. Four evaluators using Glove B noticed heat transfer from the cable to their hand during operations, while only two reported heat transfer for Glove C. Figure 3-3 displays the number of responses for the statement: "The glove did not transfer heat from friction to the hand." Four evaluators who disagreed with this statement reported that they could feel more friction transfer from the cable to their skin during testing while wearing Glove B, which was primarily attributed to the lack of extra padding in the palm and purlicue areas compared to Glove C. Some evaluators were also concerned that the purlicue coverage in both gloves was inadequate for hoist operations–three noted this for Glove B and two did so for Glove C. In addition, two evaluators suggested that some fingers be fully enclosed (i.e., the pinky and ring fingers), as they typically experience a lot of cable run up on their fingertips and wear down the under-glove fingertips quickly. One of the evaluators also stated that their hoist glove would need to be fire resistant.

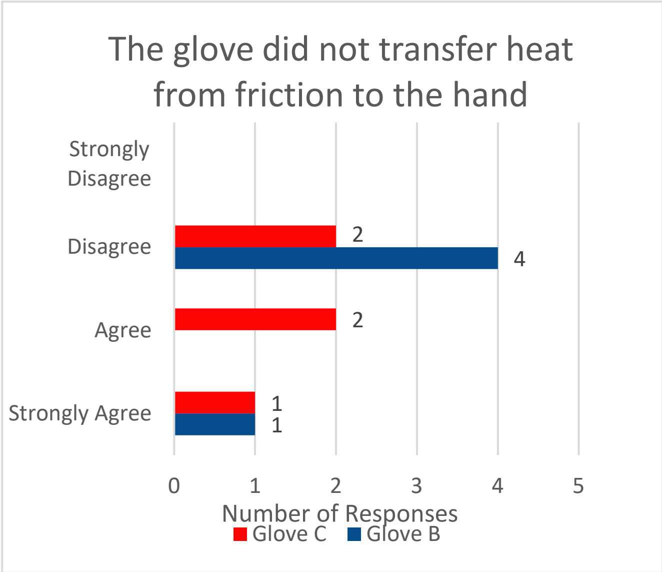

Figure 3-3 Heat Transfer Protection

3.1.4 Durability

All evaluators either agreed or strongly agreed that both prototype gloves provided sufficient durability during the assessment activities. However, as noted in the Limitations Section 2.3.1, they indicated that the gloves were not tested long enough to truly gauge their long-term durability. One evaluator stated they would need at least three to four days of testing with 10 to 12 hoists per day to more rigorously assess the durability of the gloves. The same evaluator also stated that Glove C held up better than Glove B, referencing the gloves' condition observed after testing, but noted that both were still usable. As shown in Figure 3-4, no significant degradation was observed that would require the gloves to be replaced, given the limited number of hoists conducted during this assessment.

Figure 3-4 Sample of Glove B (Left) and Glove C (Right) Following Degradation Testing

3.2 Glove B Feedback

This section covers evaluators' assessment of the fit, functionality, protection and durability of Glove B.

3.2.1 Fit and Comfort

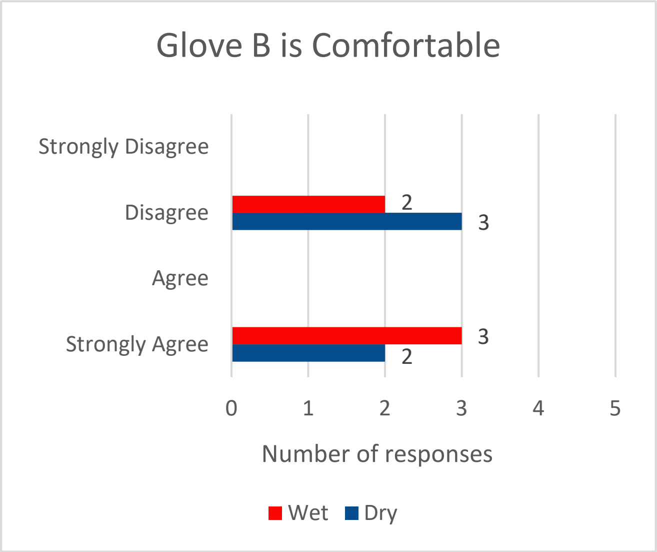

Figure 3-5 Glove B Fit and Comfort When Wet and Dry

The evaluators expressed concern regarding the fit of Glove B, when wet and dry. After trying on dry gloves in the various available sizes (large, x-large and xx-large), two evaluators determined that the overall fit of the glove was too big and needed to be adjusted. After using Glove B through all activities, the evaluators were asked about glove comfort. The results (shown in Figure 3-5) display feedback on both wet and dry gloves. Two evaluators strongly agreed that Glove B was comfortable when dry while three disagreed. When wet, three strongly agreed that Glove B was comfortable while two disagreed. One evaluator found Glove B to be more pliable when wet, therefore found it to be more comfortable than when dry. Those who disagreed attributed it to the length of the fingers as well as the length glove and where it sat on the wrist and arm, as well as fabric bunching occurring in the palm. Two evaluators determined the cuff of Glove B was too long and would get in the way of their winter dry suits. They suggested shortening the width of the Velcro by half, specifically keeping the top Velcro and replacing the bottom Velcro with neoprene or an elastic piece with a pull to tighten, and shortening the length of all fingers down to the first knuckle to improve operational use. The evaluators indicated that the fabric bunching for Glove B was minimal, but noticeable. All evaluators agreed that the overall shape of the glove was not compatible with the natural curvature of their hands, causing the extra fabric to bunch in the palm area.

All evaluators strongly agreed that Glove B was easy to don and doff with and without an under-glove, and either strongly agreed or agreed that it was easy to don and doff wet gloves. One of the evaluators noted some difficulty doffing Glove B after wet testing (shown in Figure 3-6), as it retained water. Another evaluator suggested adding a finger pull to the thumb—the only finger without a pull—as it could assist with doffing a wet glove.

Additionally, all evaluators reported that donning and doffing is not as important as having a correct fit because emergency responders typically have enough time to don and doff gloves prior to hoist operations.

Figure 3-6 Evaluators Doffing Glove B Following Wet Testing

3.2.2 Functionality

Overall, all evaluators strongly agreed or agreed that Glove B did not interfere with operations and provided good functionality, but they provided comments that suggested additional improvements would result in an enhanced product. The evaluators pointed out that some issues with the fit of the glove affected functionality. For example, the evaluators who suggested shortening the glove's fingers said the prototype's fingers hindered manual tasks and could be an issue during operations. However, one evaluator disagreed and preferred the longer fingers on Glove B as it could provide increased protection. One evaluator reported that Glove B provided freedom of movement.

The evaluators provided feedback on the SuperFabrics' effect on hoist operations. Two evaluators determined that the SuperFabric gave them a reasonable sensation or feel of the cable; however, the lack of friction negatively affected three evaluators ability to grip the hoist. Additionally, the bunching of fabric in the palm area distracted one evaluator during hoist operations, as it forced the cable closer to the fingers rather than the padded area of the glove.

Two features of the glove, the wrist loop and the rubber heel, provided varying levels of functionality according to the evaluators. All evaluators agreed that the wrist loop on both gloves was a desirable feature, but agreed that the loop on Glove B needed to be secured more tightly to improve operational use and longevity. A lack of reinforcement in the wrist loop attachment was noticed by one of the evaluators before testing began (shown in Figure 3-7). All evaluators agreed that the rubber heel on Glove B was helpful for maneuvering about the helicopter floor and improved the overall grip of the glove on various surfaces. However, some evaluators pointed out limitations and design flaws of the rubber heel on the Glove B. One evaluator felt that the stiffness of the rubber heel limited dexterity and pushed the glove up the hand, thus interfering with operations. Another evaluator agreed, citing that the heel forced their grip on the cable to be unnatural, and limited their feel of the cable and equipment. These two evaluators suggested reshaping and relocating the rubber heel with a slimmer profile or an oval shape to improve functionality.

Figure 3-7 Glove B Wrist Loop

3.2.3 Protection

Evaluators had mixed opinions about the protectiveness provided by Glove B (shown in Figure 3-8). The majority of evaluators felt the glove provided adequate hand protection while guiding cables during hoist operations; however, most evaluators also noted that more heat was transferred to their hand while wearing Glove B. Four evaluators reported that they could feel more friction transfer from the cable to their skin during testing — this was primarily attributed to the lack of padding in the palm and purlicue areas.

To improve the overall protection that the glove provides, it was suggested that padding be added horizontally to the front of the glove from the purlicue area, across the palm, to the base of the pinky finger. Two evaluators felt additional coverage was needed in the purlicue area on the back of the glove. Additionally, evaluators informed HDM that the starting section and ending section of their hoist cables are marked with orange paint, which may transfer to gloves. They also noted that it could be difficult to distinguish orange-colored wear indications from paint transfer. As such, they suggested changing the orange color of the glove and inner wear-indicator pad.

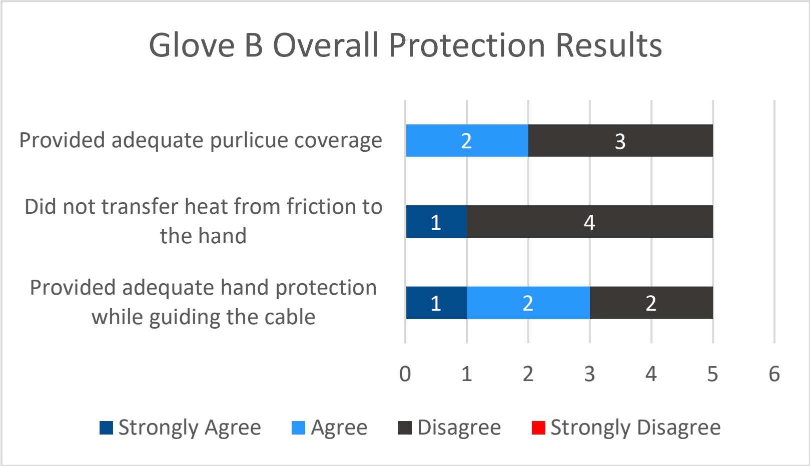

Figure 3-8 Glove B Overall Protection Results

3.2.4 Durability

After degradation testing, one evaluator noticed severe wear in the purlicue area, including worn down guard plates and torn stitching. This evaluator was not confident that the glove would remain intact after another five minutes of degradation testing, feeling that the glove would deteriorate rapidly once the guard plates flattened.

A second evaluator also had issues with the durability of the glove, noting that the stitching in the purlicue area was compromised at the conclusion of the OFA (shown in Figure 3-9). This same evaluator noted that the rubber pad showed wear after hoist operations. Both evaluators recommended enhancing and relocating stitching from the purlicue to the back of the glove, where there is minimal contact with the cable.

Figure 3-9 Varied Levels of Wear in the Purlicue of Glove B

Evaluators had varied opinions on the overall durability of Glove B (shown in Figure 3-10). Figure 3-10 also shows that evaluators did not find a difference in durability between wet and dry gloves. Three evaluators strongly agreed that the glove provided sufficient durability throughout the assessment, while two disagreed. The primary durability concerns with Glove B stemmed from the apparent wear and tear of the purlicue area–a major wear point in hoist operations.

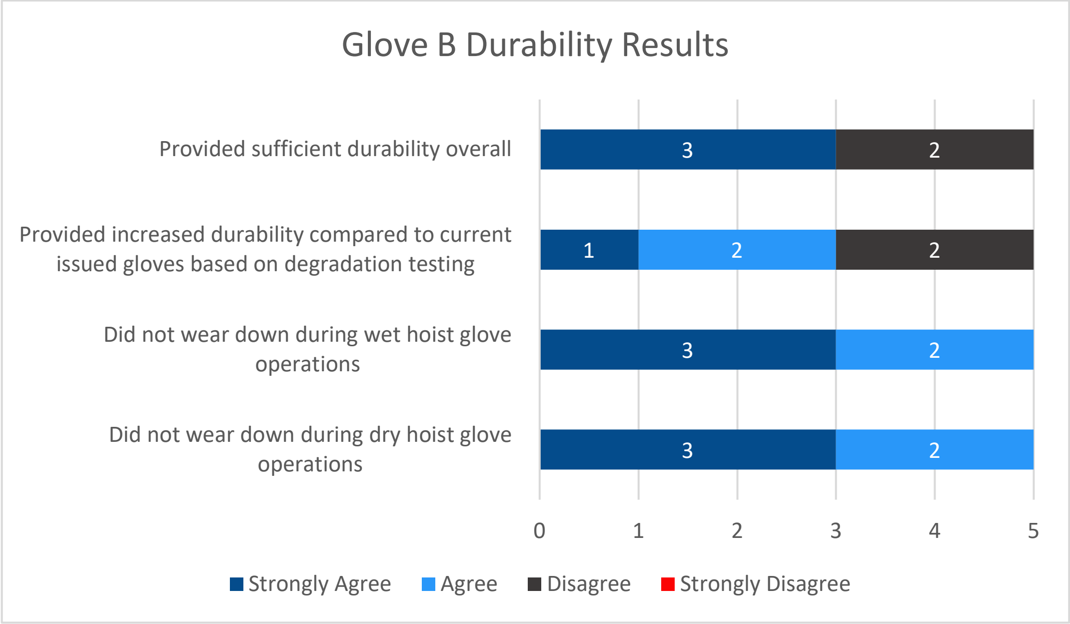

Figure 3-10 Glove B Durability Results

3.2.5 Opportunities for Improvement–Glove B

The evaluators' recommendations to enhance the design of Glove B are summarized here:

- Fit–Shorten the glove to improve comfort and avoid interference; remove the second Velcro strap at the wrist
- Design–Change the color to avoid conflating orange cable paint transfer with the glove wear indicator
- Design–Eliminate some of the Velcro and incorporate elastic around the wrist
- Design–Add a finger pull to the thumb to assist with doffing
- Durability–Move stitching to the back of the glove and away from the purlicue.

3.3 Glove C Feedback

This section covers assessment of the fit, functionality, protection and durability of Glove C.

3.3.1 Fit and Comfort

All evaluators reported that the size of Glove C had an impact on the overall fit and comfort of the glove when wet and dry conditions, as shown in Figure 3-11. Three evaluators disagreed that Glove C was comfortable when dry. When wet, three strongly agreed that Glove C was comfortable while two disagreed.

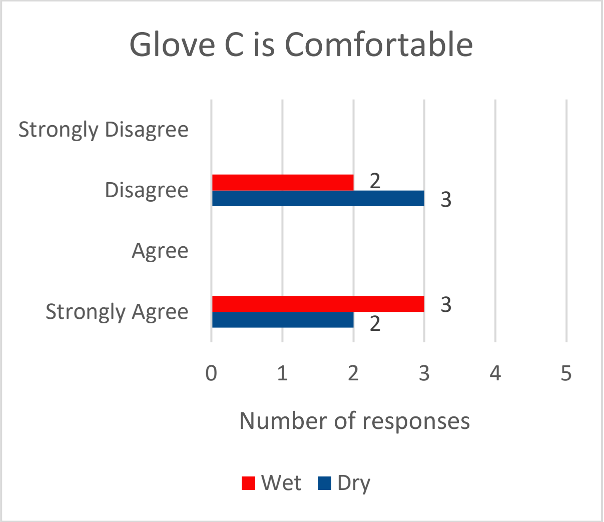

Figure 3-11 Glove C Fit and Comfort When Wet and Dry

Those who disagreed, attributed it to several factors including the glove being too big; not being compatible with their standard issued uniforms and personal protective equipment due to the length of the glove and where it sat on the wrist and arm; and bunching of fabric in the palm. Additionally, the evaluators who disagreed reported that the fit of the gloves was not ideal for operational use. In contrast, one evaluator who strongly agreed, stated that the glove felt tighter around the thumb, which allowed more feedback of the hoist cable in the hand. One evaluator found Glove C to be more pliable when wet, and therefore more comfortable than when dry. All evaluators agreed that the width of the bottom Velcro closure of Glove C was too thick and the fingers were too long. They suggested shortening the width of the Velcro by half and shortening the length of all fingers down to the first knuckle to improve operational use. All evaluators agreed that the overall shape of the glove was not compatible with natural curvature of their hands, resulting in extra fabric bunching in the palm area. However, one evaluator appreciated that the extra padding in Glove C reduced the pressure of the hoist cable against the hand and the extended padding around the thumb, which provided additional protection during hoist operations.

All evaluators stated that Glove C was easy to don and doff, with or without an under-glove, when dry. One evaluator stated that the finger pulls were useful for donning and doffing while another evaluator explained that the loop was more secure for donning. There was concern that using the finger pulls on the glove would unintendedly pull the inner glove off when doffing, which may not always be ideal.

All evaluators agreed that there was no difference between donning and doffing wet and dry gloves. Additionally, they stated that the gloves felt fine and no differences were identified, after the water bath. One evaluator indicated that Glove C was easy to take off when wet. All evaluators reported that donning and doffing is not as important as having a correct fit because emergency responders typically have sufficient time to don and doff gloves prior to hoist operations.

3.3.2 Functionality

Two evaluators reported that the glove's functionality was affected by the fit of the glove, referring to excess material bunching in the palm. Two other evaluators reported that the extra padding on Glove C helped counteract the weight of the cable while other evaluators demonstrated how the hoist cable was forced toward their fingers and away from the padded area of the glove. Other comments indicated that the length of the fingertips in Glove C affected finger flexibility when performing small tasks like opening and closing carabiners, hooks and buckles, as shown in Figure 3-12.

While conducting hoist operations, two evaluators noted that they could feel friction behind the thumb and suggested extending the patching area for further coverage.

Figure 3-12 Length of Glove C Fingertips Surpassing First Knuckle during Dexterity Activities

Another evaluator explained that bunching affects comfort and would fatigue the hand when operating devices such as radios and keyboards after constant use. All evaluators emphasized that Glove C did not have adequate traction and demonstrated that the gloves did not offer sufficient grip when holding on to handles, door panels and maneuvering on the floor of a helicopter. As such, the evaluators suggested adding patches of leather at the base of the glove palm to increase traction and enhance grip.

Some evaluators identified a difference when using wet gloves on wet equipment. All evaluators agreed that there were no differences between operating dry hoist equipment or when opening and closing carabineers or buckles with dry or wet gloves.

3.3.3 Protection

All evaluators strongly agreed or agreed that Glove C offered adequate protection of the hand during hoist operations and cable guiding (in Figure 3-13). Evaluators stated that the extra material and padding provided additional protection, but could affect operational use as extra padding and material could prevent the user from finding and feeling deformities in the hoist cable. In addition, one evaluator stated that the simulated rain and wind caused the cable to push towards the pinky and affected finger protection. Two evaluators suggested changing the direction and area coverage of the padding to include coverage around pinky and ring finger, as well as expanding the padding coverage behind the thumb for enhanced protection. Two evaluators stated that the pull loop was well integrated, and had a low profile; therefore, it would not present as a snag hazard.

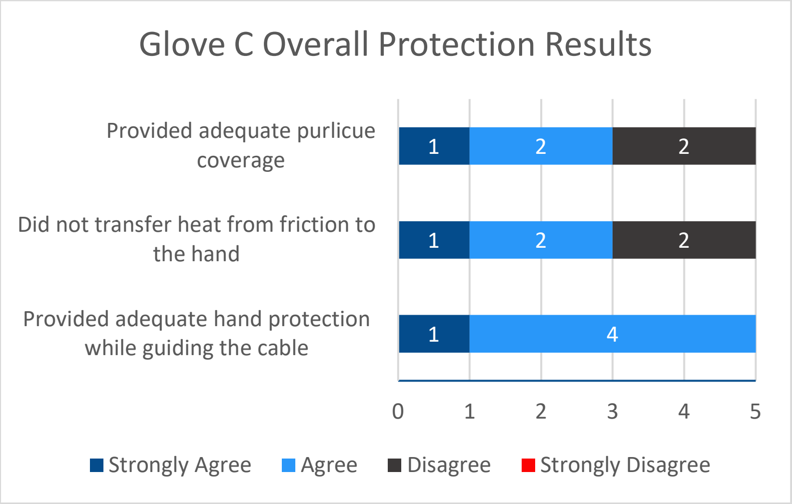

Figure 3-13 Glove C Overall Protection Results

3.3.4 Durability

Overall, the evaluators either agreed or strongly agreed that Glove C provided sufficient durability overall (as shown in Figure 3-14). There were varied responses regarding increased durability during degradation testing compared to their current hoist glove: three evaluators either agreed or strongly agreed while two disagreed.

One of the evaluators who disagreed stated that the degradation testing would need to be more extensive (additional time and/or cable distance) to truly gauge the level of durability, but stated that Glove C held up reasonably well, referencing the condition of the leather after testing.

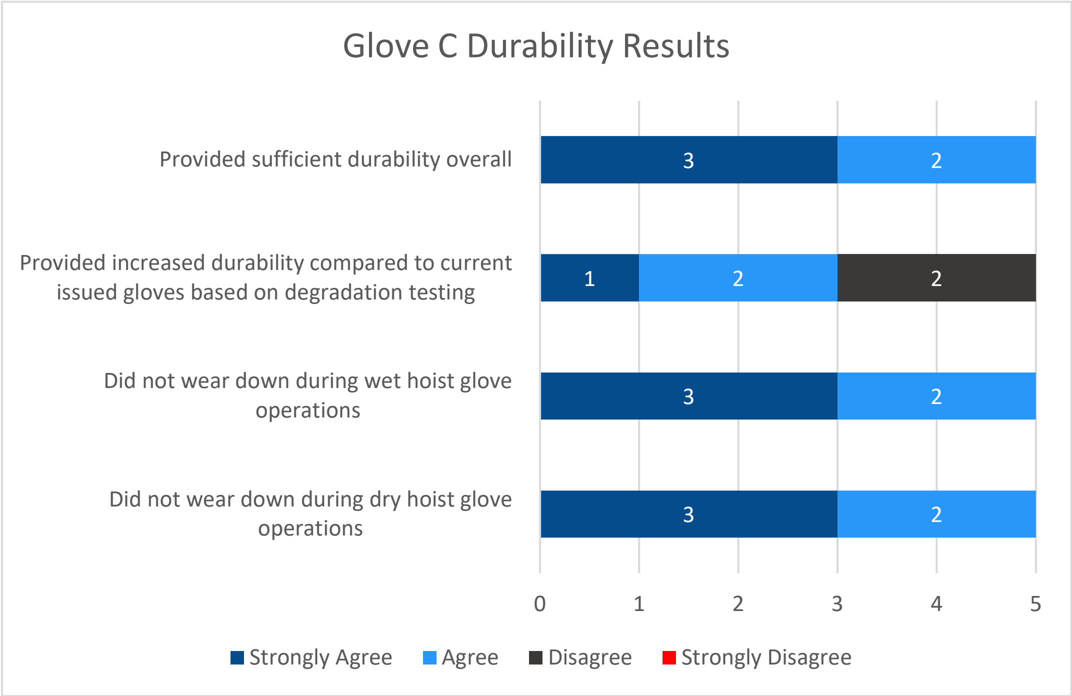

Figure 3-14 Glove C Durability Results

3.3.5 Opportunities for Improvement – Glove C

The evaluators' recommendations to enhance the design of Glove C are summarized here:

- Fit–Shorten the length of fingers to the first knuckle and reduce the cuff size by half
- Functionality–Add patches of leather at the base of the palm to increase traction and enhance grip
- Functionality–Reconfigure the padding near the palm to reduce bunching
- Protection–Expand padding behind thumb and increase the size of patching areas to include more coverage for ring and pinky fingers.

4.0 CONCLUSIONS

The objective of the OFA was to obtain feedback from first responder evaluators on the fit, comfort, functionality, protection and durability of each enhanced rescue hoist glove prototype. Throughout the OFA, evaluators suggested opportunities for improvements for each enhanced rescue hoist glove prototype to make them more suitable for use in the field.

Overall, the evaluators found that neither glove negatively affected dexterity or flexibility while performing hoist operations; although at least one evaluator found that both gloves affected their ability to complete intricate manual tasks. This was attributed to the length of the gloves' fingertips extending beyond the first knuckle of their finger.

When evaluators tested the functionality by maneuvering on helicopter flooring, they found that Glove C did not have adequate traction. This was attributed to the SuperFabric's slick palm surface area, which resulted in a limited grip. As a result, evaluators suggested adding patches of leather on the base of the palm to increase traction. Varied feedback was received for the rubber heel on Glove B: three evaluators found that the rubber heel allowed for more control while maneuvering; the other two evaluators noted it assisted with grip, but had the undesirable effect of adding pressure on the glove, which resulted in bunching and minimized sensitivity for feeling equipment in the hand. Evaluators also noted that the shape, size and placement of the rubber heel could be refined by using a shorter piece of rubber or rubber with a slimmer profile, modifying it to an oval shape, positioning it lower at the bone area of the hand or using leather in place of rubber.

Throughout the OFA, evaluators assessed the fit and comfort of the enhanced rescue hoist gloves. Evaluators varied in their feedback on fit and comfort. Three evaluators either strongly agreed or agreed that both Glove B and C were snug and fit well, but two strongly disagreed. Those who strongly disagreed cited the width of the Velcro closures, length of the cuffs and lack of a natural curve to the glove. Additionally, all evaluators strongly agreed or agreed that both Glove B and C were easy to don and doff when wet and dry, some noting that the finger pulls were of assistance.

5.0 REFERENCES

U.S. Department of Homeland Security (DHS), Science and Technology Directorate Compliance Assurance Program Office. (2020, December). Regulatory Compliance Assessment: (HSR-19-048) Operational Field Assessment of Enhanced Rescue Hoist Gloves".

U.S. Department of Homeland Security (DHS), Science and Technology Directorate. (December 2019). *Enhanced Rescue Hoist Glove Operational Field Assessment Plan.* National Urban Security Technology Laboratory. New York, NY: DHS Science and Technology Directorate.

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Appendix A. United States Coast Guard – Trail Line Considerations

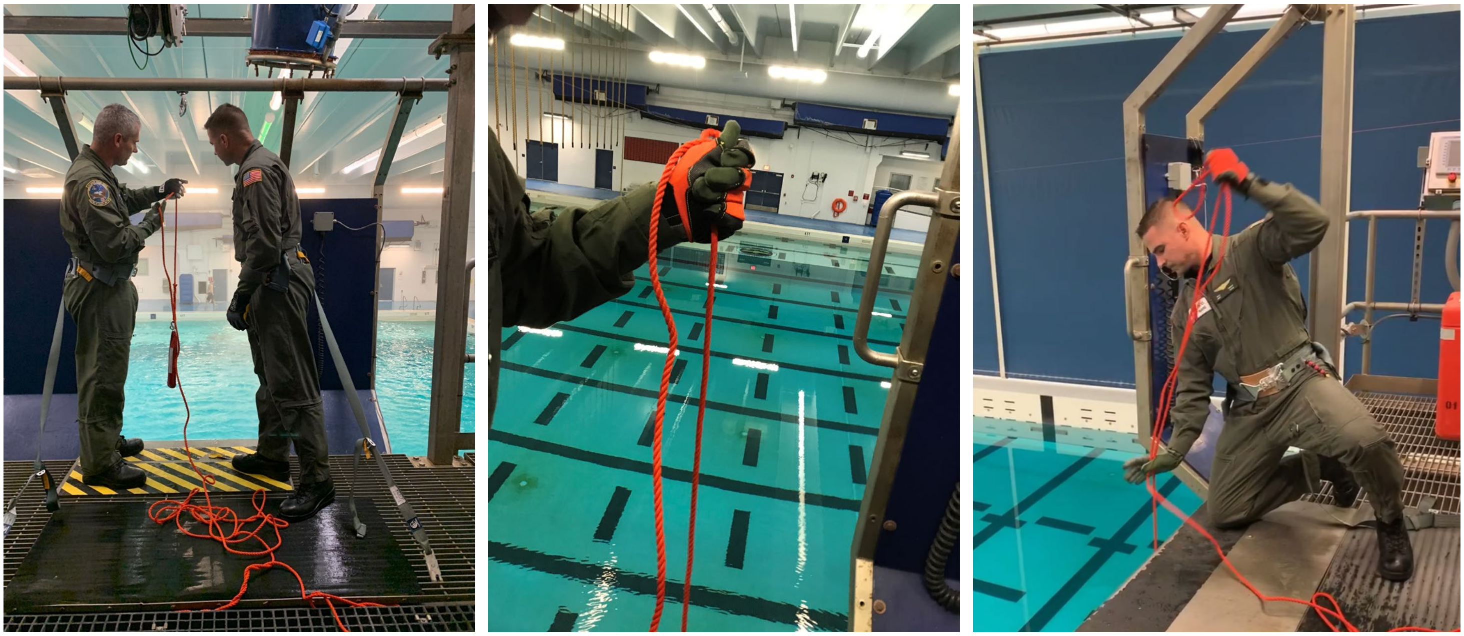
The enhanced rescue hoist gloves were designed for use with steel cables, which was the primary focus of the OFA. However, some operations involve other types of lines or ropes, presenting a potential alternate use-case for these gloves. Trail lines are used to stabilize or guide equipment or to deliver rescue devices and emergency supplies.

After hoist-specific OFA activities were completed, a trail line was set-up using a five-pound bag attached to one end of the line. Evaluators who frequently use trail lines operationally used both Glove B and C with the trail line. Activities included guiding the trail line down to the water level to gauge momentum, as well as lifting the trail line back to the platform and grabbing and then releasing the trail line every few feet to gauge grip.

Their feedback on the potential use of the enhanced rescue hoist gloves for trail line operations is summarized here:

- The material/guard plates' coefficient of friction makes it difficult to stop the trail line
- It was found necessary to manipulate the hand in a certain way (turn over wrist) to stop the trail line, and typically they would not have to do so with leather gloves
- The trail line was reported to have a different feel than the cable hoist with the glove
- The trail line slid through both glove prototypes, even while exerting a strong grip.
    - They have better grip on the trail line with their current leather glove and note that typically the trail line would not wear down a leather glove

Overall, the evaluators found that they would much prefer leather gloves for trail line operations because they successfully grab the polyethylene trail line and arrest its momentum.



Trail Line Activities
Preparing to lower trail line using Glove C (left), close up of Glove B gripping trail line (center), lifting trail line using Glove B (right)