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An Assessment of the Emergency Egress Characteristics of the U.S. Army Airborne Command and Control System (A2C2S)

by Thomas J. Havir and Richard W. Kozycki

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14. ABSTRACT
The U.S. Army Airborne Command and Control System (A2C2S) is a command and control (C2) system consisting of an A-kit and a B-kit and will be hosted by the utility helicopter (UH)-60L (and newer) Blackhawk. The A2C2S Product Manager (PM) requested the U.S. Army Research Laboratory's (ARL's) Human Research and Engineering Directorate to perform an evaluation of the emergency egress characteristics of the A2C2S to help support the low rate initial production (LRIP) milestone decision. ARL and the PM developed a plan to evaluate the emergency egress characteristics of the A2C2S using a combination of human figure modeling and egress testing. The evaluation plan used human figure modeling to perform a detailed analysis of all egress routes to identify whether the larger end of the male Soldier population, with equipment, could fit through the egress routes and to identify design characteristics of the A2C2S that enhance or degrade the Soldier's ability to egress the aircraft. The emergency egress test was used to validate the results of the model, verify that the egress could meet the time requirements, and identify additional safety concerns that may be encountered during actual egress trials. The results of the egress modeling identified some shortcomings with the egress characteristics of the A2C2S; however, the results were favorable. The results of the egress testing validated the modeling that was performed. In addition, all egress trials successfully met or exceeded the 30-second time standard for emergency egress. The results and recommendations from the modeling and testing were provided to the PM to help drive design modifications that, if implemented, could enhance the emergency egress characteristics of the A2C2S.

15. SUBJECT TERMS
A2C2S; emergency egress; human factors

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1. Introduction

1.1 Description of System

The Army Airborne Command and Control System (A2C2S) (see figure 1) is a command and control (C2) system consisting of an A-kit and a B-kit and will be hosted by the utility helicopter (UH)-60L (and newer) Blackhawk. The A-kit is permanently affixed to the airframe and consists of antennas, wiring, and aircraft interfaces (e.g., power, structural, etc.) that enable the B-kit to be installed in the airframe.

Figure 1. A2C2S.

The B-kit, or mission equipment package (MEP), consists of operator workstations, computer systems, and the communications devices necessary to support the digital C2 process.

The A2C2S will host the following Army Battlefield Command System (ABCS) software to support continuous situation awareness: Maneuver Control System (MCS), Maneuver Control System–Light (MCS-L). All-Source Analysis System-remote work station (ASAS-RWS), ASAS-Light (ASAS-L), Advanced Field Artillery Tactical Data System (AFATDS), air and missile defense work station (AMDWS), Battle Command Sustainment and Support System (BCS3), command and control personal computer (C2PC), and Force XXI Battle Command Brigade and Below (FBCB2), including Blue Force Tracking (BFT).

Commanders will use the A2C2S to command and control units engaged in military operations ranging from humanitarian support and homeland security through high-intensity conflict. The

A2C2S will allow the commander and staff to quickly traverse the battlefield while exercising command and control over forces in joint, interagency, and multi-national environments.

1.2 Background and Purpose

The A2C2S Product Manager (PM) requested the U.S. Army Research Laboratory's (ARL's) Human Research and Engineering Directorate to perform an evaluation of the emergency egress characteristics of the A2C2S to help support the low rate initial production (LRIP) milestone decision.

The addition of the A2C2S B-kit, which occupies a large volume of the aircraft cabin, results in a very restricted work space. Since the early design stages of the A2C2S, the manpower and personnel integration (MANPRINT) working group (WG) has identified many potential hazards regarding emergency egress and has recommended that formal egress testing be accomplished to ensure that all hazards are identified and mitigated.

Several documents govern emergency egress requirements and testing procedures. The primary document that discusses egress requirements is the Aircraft Crash Survival Design Guide (ACSDG). This report identifies two factors that determine emergency egress requirements. They are (a) the amount of available time before the post-crash conditions exceed human tolerance limits and (b) the attitude and condition of the aircraft structure after it comes to rest. Research has shown that the available escape time from a helicopter involved in post-crash fires is only 7 to 16 seconds. Based on this research, occupants must evacuate the aircraft within about 10 seconds if they are to survive. The ACSDG allows this evacuation time to be extended to 30 seconds for aircraft with crash-resistant fuel systems. In addition to establishing the time standard for emergency egress, the ACSDG also sets a requirement to use only half of the available exits to simulate blocked or unusable exits. Therefore, emergency egress escape provisions should allow the maximum number of aircraft personnel to evacuate in 30 seconds with only half of the aircraft exits available for egress. The evacuation times should be demonstrated by actual tests (Johnson, Robertson, & Hall, 1989).

The U.S. Army Test and Evaluation Command (ATEC) has published a test operations procedure (TOP) that governs test procedures for ingress, emergency egress, and emergency evacuation of Army aircraft (ATEC, 1991). TOP 7-3-529 specifies several test conditions that are important to highlight:

- The aircraft configuration to be tested shall most closely resemble the normal operational characteristics of that particular type of aircraft.
- Participants must be appropriately attired to reflect the worst case conditions in a variety of mission scenarios.

- Uniforms selected for ingress/egress testing will address the most extreme operational conditions, which is likely a combination of cold weather and nuclear, biological, and chemical protective clothing.
- Representative personnel should be used who meet the first percentile female to the 99th percentile male population. To simulate a worst case scenario, the largest available personnel should be used for emergency egress and emergency evacuation.

TOP 7-3-529 does not specifically address environmental conditions that should be used during egress testing or whether testing should be conducted during the day or at night; however, it does tell us to have the crew members make subjective judgments about the ability to reach and open exits for emergency egress during varying conditions.

Finally, the Department of Defense (DoD) Design Criteria, MIL-STD-1472F (Department of Defense, 1999) includes many design standards for systems, which affect egress. This design standard addresses passageways, hatches, ladders, stairways, platforms, inclines, handholds, and other provisions for ingress, egress, and passage during normal, adverse, and emergency conditions.

The A2C2S operational requirements document (Training and Doctrine Command Program Integration Office, 2002) states the following regarding egress:

- The space provided for stowage of these items (load-bearing equipment, protective mask and a small amount of personal gear) in the UH-60 cabin must not impede emergency egress.

The purpose of this study was to evaluate the emergency egress characteristics of the A2C2S, identify design characteristics that result in a negative impact on emergency egress, and to verify that personnel can egress the A2C2S within the 30-second time standard.

2. Method

2.1 Evaluation Strategy

ARL and the PM developed a plan to evaluate the emergency egress characteristics of the A2C2S using a combination of human figure modeling and egress testing. This method of evaluation was selected on the basis of the most cost-effective method available. The evaluation plan used human figure modeling to perform a detailed analysis of all egress routes to identify (a) whether the larger end of the male Soldier population, with equipment, could fit through the egress routes and (b) design characteristics of the A2C2S that enhance or degrade the Soldier’s ability to egress the aircraft. The emergency egress test was used to validate the results of the model, verify that the egress could meet the time requirements, and identify additional safety concerns that may be encountered during actual egress trials.

2.2 Modeling and Simulation

Modeling and simulation have become an integral part of the engineering process in many modern military systems and will assume an even greater role in the years ahead. The DoD initiatives, such as simulation-based acquisition (SBA), often mandate the central role of simulation in systems design and engineering. As an example, the Future Combat Systems (FCS) program is envisioned as an SBA program, which the Defense Advanced Research Projects Agency (DARPA) will implement as the Simulation and Modeling for Acquisition, Requirements, and Training (SMART) program. This will maximize the use of modeling and simulation (M&S) throughout its life cycle to optimize the force, define requirements, demonstrate performance, reduce risk, and reach a balance of performance and cost (both acquisition and life cycle). Through M&S, industrial and Government teams are able to assess tough questions early and continuously throughout the process.

2.2.1 Human Figure Modeling

One of the many types of modeling and simulation software available include three-dimensional (3-D) human figure modeling software that is used for the purpose of performing ergonomic analyses. Computer-based graphical human figure models have been used to perform ergonomic analyses of work place designs since the late 1960s (Das & Sengupta, 1995) and have gained widespread acceptance over the past two decades as designers have migrated from traditional paper drafting methods to the use of computers and computer-aided design (CAD) software. These human figure modeling programs have proved to be an effective tool for evaluating the human-in-the-loop interaction between the operator and the crew station.

2.2.2 Jack

The Jack[1] human figure modeling software was used to perform the A2C2S egress modeling analysis. The Jack software is an interactive tool for modeling, manipulating, and analyzing human and other 3-D articulated geometric figures (Badler, Phillips, & Webber, 1993). The software also contains a utility for importing anthropometric data that are used to build and size the human figure models. This aspect of the software allows the human factors analyst to tailor the models to represent a specific user population for whom the equipment design is targeted.

In order to assess a worst case egress scenario, a large male figure derived from the U.S. Army 1988 anthropometric survey (Gordon, Bradtmiller, Churchhill, Clauser, McConville, Tebbetts, & Walker, 1989) was used. This figure was selected from the extreme large end of a manikin set that represents an accommodation boundary for the central 90% of the combined male and

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[1] Jack is a registered trademark of Unigraphics, Inc.

female Soldier population. The anthropometric dimensions of the large male figure are presented in appendix A. These boundary figures represent “worst case” extremes of body size and body proportions that must be accommodated in order to capture the desired percentage of users (Bittner, Glenn, Harris, Iavecchia, & Wherry, 1987).

The U.S. Army Natick Soldier Center, Natick, Massachusetts, supplied the data set used to generate the boundary forms that were then used to construct the human figure models for this analysis by the principal components analysis (PCA) method. Some human figure boundary models are shown in figure 2.

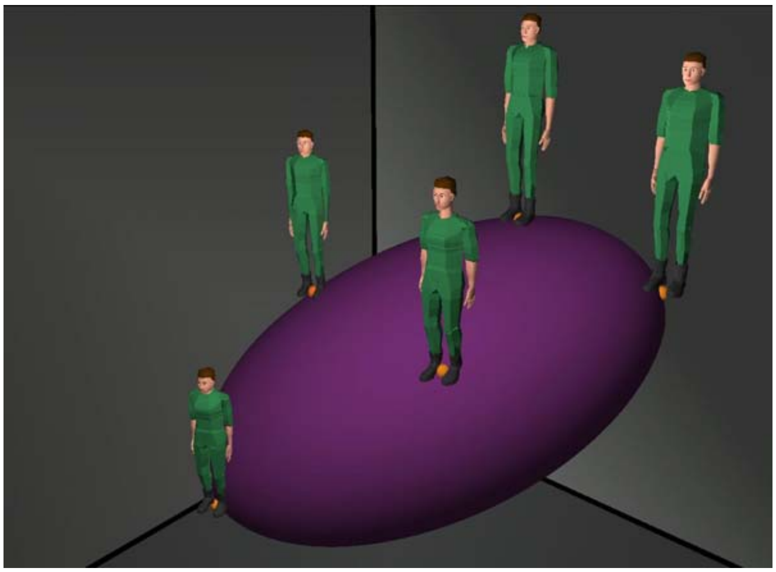

Figure 2. Boundary models representing an accommodation envelope.

PCA reduces the dimensionality of the accommodation envelope from n-space (where n is the number of body dimensions that are critical for the design accommodation) to a smaller number of dimensions that account for a large proportion of the original variation with the use of linear combinations of the original measurements. Further, PCA identifies important “large-small” body dimension combinations when they are important in the covariance structure, and the method generally creates one or more principal components that actually measure such extremes of shape.

2.2.3 Digitized Clothing and Equipment Models

Typically, unclothed human figure models are used to analyze a work space design. However, for this assessment, bulky clothing and equipment worn by the Soldier, which may have a detrimental effect on egress, also had to be taken into account. Over the past several years, ARL has built a library of digitized Soldier clothing and equipment items such as helmets, vests, packs, and individual Soldier weapons, in addition to specialized gear developed for the Air Warrior program. For clothing such as jackets, coats, and pants, the items were digitized in several different sizes and in a variety of different postures. Most of these models are kept to a resolution of about 3,000 to 5,000 polygons. The models are also segmented at the shoulders, elbows, waist, hips, and knees. This procedure allows for real-time movement of the human figure when fitted with the clothing models, and the clothing can also be scaled to fit a range of body sizes.

In addition to the battle dress uniform (BDU) shirt and trousers, a personal armor system for ground troops (PASGT) vest and helmet along with a load-bearing vest (LBV) were added to the human figure model. Figure 3 illustrates a comparison of clothed and unclothed human figure models used for this analysis.

Figure 3. Clothed and unclothed human figure models.

2.2.4 Human Figure Modeling Analysis

The human figure analysis consisted of examining a series of likely body postures for the large male figure throughout each egress path to determine if sufficient body clearance would exist in order to exit the aircraft successfully. Any "bottlenecks" that would hamper an egress task were documented. There was, however, no attempt to discern if each egress task could be performed within a certain time limit.

The following five egress tasks were examined:

- Egress from the right rear workstation position with an exit through the left side cargo door (an assumed inoperable right side cargo door or a blocked right side cargo door opening).
- Egress from the right front workstation position over the top of the center console with an exit through the left side cargo door (assuming again an inoperable right side cargo door or a blocked right side cargo door opening).

- Egress from the front left workstation position by the Soldier crawling over the top of the workstation with the flat panel monitor rotated downward into the horizontal stowed position and then exiting through the front of the aircraft.
- Egress from the front left workstation position by the Soldier crawling under the workstation platform and exiting through the front of the aircraft.
- Egress from the front left workstation position with an exit through the left side cabin door window opening (assuming an inoperable left side cargo door).

For each egress task examined, there are numerous exit strategies incorporating nearly an unlimited combination of possible body postures and positions that the workstation operator could employ to successfully accomplish the goal. However, the objective of this modeling and simulation effort was to determine if the target Soldier population could perform each of the egress scenarios successfully and, if so, construct a likely motion sequence that would demonstrate how this could be accomplished and provide any recommendations for improvement.

2.3 Emergency Egress Test

The egress test was conducted by the PM in an aircraft hanger at the 1-227th Aviation at Fort Hood, Texas, on February 25, 2004. ARL and the Aviation Engineering Directorate (AED) of the U.S. Army Research Development and Engineering Command also assisted the PM in conducting the test. Representatives from AED served as timekeepers and helped organize the trials. ARL personnel also served as timekeepers, collected demographic and anthropometric data, and administered post-test surveys to observers and participants (see appendix B). Seven Soldiers participated as the test participants (see figure 4).

Figure 4. Test participants.

Six Soldiers were members of the 2-4 aviation battalion, Fort Hood, Texas, and one Soldier was a member of the U.S. Army Operational Test Command. The Soldiers ranged in rank from Specialist (E-4) to Sergeant First Class (E-7) and ranged in age from 24 to 36 years. Table 1 shows the anthropometric data collected for the test participants.

Table 1. Test participant anthropometric data.

	Mean	**Median**	**Range**	**Percentile Range**
Stature (cm)	181.25	180.57	175.90 to 189.43	52.41 to 98.12
Bideltoid Breadth (cm)	50.35	50.09	46.33 to 56.57	13.77 to +100
Chest Depth (cm)	27.47	28.09	23.07 to 32.30	29.17 to +100
Buttock Depth (cm)	30.17	30.39	25.73 to 33.03	67.26 to +100
Buttock-Knee Length (cm)	60.46	61.08	56.47 to 63.27	3.61 to 71.04

The test was conducted in three phases. Phase 1 consisted of four egress trials with no exits blocked. The purpose of Phase 1 was to orient the participants with the A2C2S and egress routes and to establish a baseline for egress time with no exits blocked. Phase 2 consisted of four trials conducted with the purpose of determining if the operators could safely egress the A2C2S, with half of the exits blocked, within 30 seconds. One trial was conducted for practice and three trials were conducted for record. Finally, Phase 3 consisted of eight additional egress trials. In these eight trials, the conditions were varied in order to examine several egress scenarios that were identified as potential hazards. The purpose of Phase 3 was to identify hazards when Soldiers egressed during these conditions.

All trials began with the doors closed, black-out curtain installed, headsets worn and plugged in, seat belts fastened, monitors up, and keyboards extended. During the egress trials, the participants wore BDUs, body armor, LBVs, and Kevlar[2] helmets. In addition, one trial in Phase 3 consisted of an operator wearing mission-oriented protective posture (MOPP) IV. Time was recorded for all trials. The time began when the test officer announced the command "go". The time stopped when the last Soldier placed both feet on the ground and no part of his body was in contact with the aircraft. This procedure varied slightly from the guidelines in the ATEC TOP that suggest using a demarcation line approximately 5 feet from the aircraft to stop timing.

[2]Kevlar is a registered trademark of E.I. DuPont de Nemours & Co., Inc.

3. Results and Discussion

3.1 Results of the Human Figure Modeling Analysis

3.1.1 Egress From the Right Rear Operator Workstation

The first egress task examined simulated the operator seated at the right rear workstation position (figure 5) and exiting through the left side cargo door. This scenario assumes an inoperable right side cargo door or a blocked right side cargo door opening.

Figure 5. Human figure model seated at the right rear workstation.

There are two egress strategies that the workstation operator would probably employ for this scenario. The first would involve the operator using the seat pans of the two adjacent seats as crawling surfaces and traversing the aircraft from right to left in this manner. The rear seat pan to ceiling dimension is 37.0 inches and the seatback to workstation distance (with the center workstation keyboard folded back into the stowed position) is 24.25 inches. This crawl space area of 37.0 by 24.25 inches would provide sufficient space for a large male to crawl across the seats and exit through the left side cargo door (see figure 6).

The other egress strategy would have the operator maintain a seated posture and slide the hips across the other two adjacent seats (see figure 7).

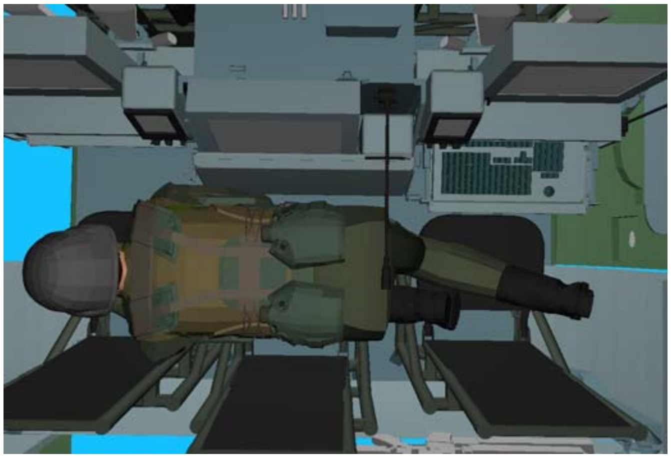

Figure 6. Human figure model leaving over rear seats.

Figure 7. Human figure model sliding across rear seats.

Figure 7 also shows that the operator has retracted the right and left keyboards and folded the center workstation keyboard into a stowed position in order to maximize the available space during this type of egress. With these keyboards moved out of the way, sufficient space does exist for the operator to perform the egress in this manner. One possible problem area noted when this type of egress is performed is shown in figure 8. Large males could have a problem with their heads striking the upper left-hand corner of the flat screen monitor just before they exit the aircraft through the left cargo door opening.

Figure 8. Human figure model sliding across rear seats.

3.1.2 Egress From the Right Front Operator Workstation

The next egress task examined was an egress from the right front workstation position (see figure 9) over the top of the center console with an exit through the left side cargo door. Once again, this scenario assumes an inoperable right side cargo door or a blocked right side cargo door opening.

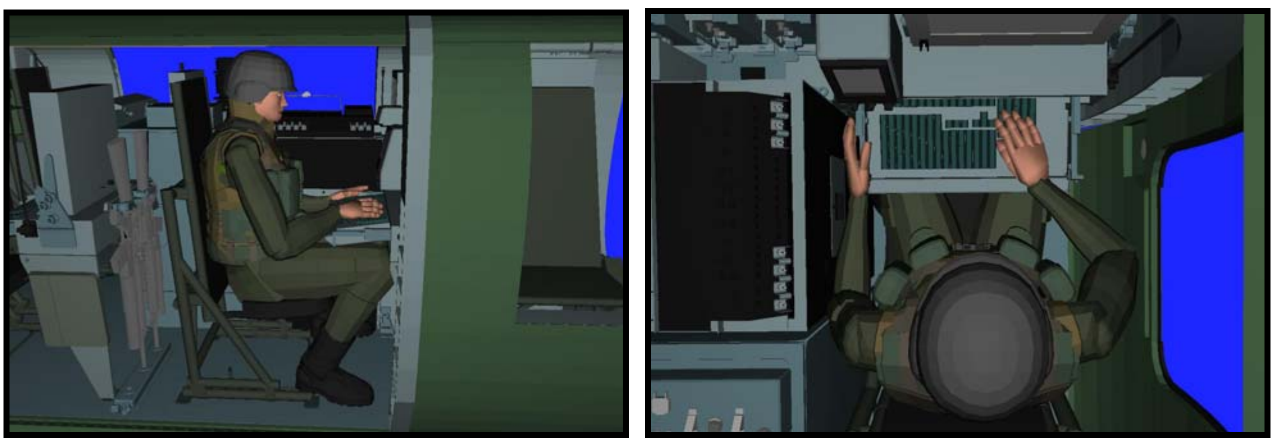

Figure 9. Side and top views of the large male figure seated at the right front workstation.

There are three likely egress strategies from the front right workstation position in a scenario where the right side cargo door is inoperable or the right side cargo door opening is blocked. Two of these strategies, which would involve the Soldier going over the top of the workstation or going under the workstation and exiting through the front of the aircraft, are covered later in this report when we examine egress from the front left crew station position. This evaluation focuses on the third likely strategy which would have the operator attempt to climb over the center console and exit the left side of the aircraft.

The difficulty with this egress route is the limited clearance available to the operator to use for a crawl space over the top of the center console (see figure 10).

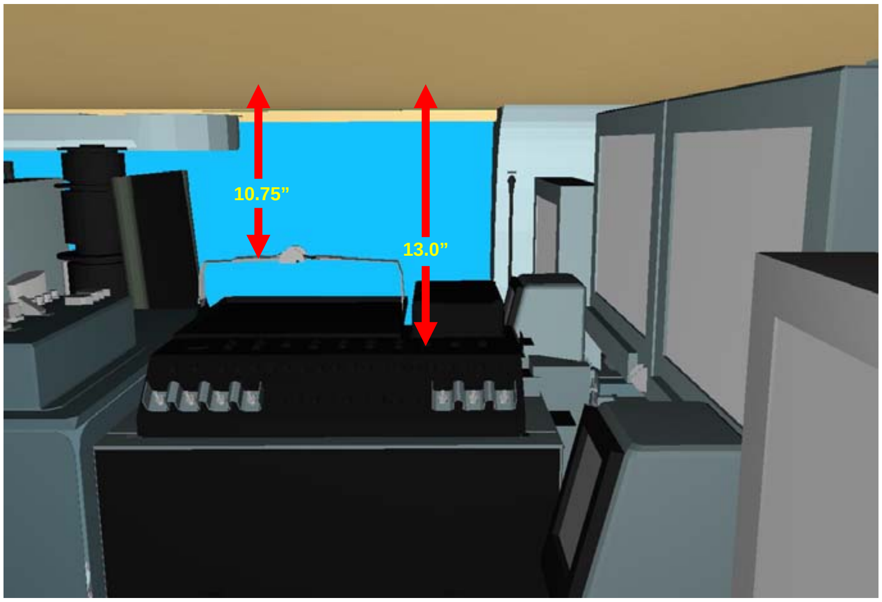

Figure 10. Clearance dimensions above center console.

The dimensions taken from the CAD model show that the clearance between the top of the center console and the interior aircraft ceiling narrows to as little as 10.75 inches. Therefore, the two most critical body dimensions that must be examined are the chest depth and buttock depth. The large male figure used in this analysis has a chest depth dimension of 11.26 inches and a buttock depth of 11.40 inches. However, these are standing dimensions and when a person assumes a crawling position, one could expect significant soft tissue compression along with a compression of the chest cavity so that even a large male Soldier should be able to squeeze through the limited space available over the center console if the standard BDU clothing worn did not include any additional equipment. On the other hand, an LBV such as the one worn by the large male human figure in this analysis, can add 4 to 5 inches to the chest depth measurement and would make egress over the center console very difficult, if not impossible, for the larger end of the male Soldier population (see figure 11).

Figure 11. Large male figure attempting egress over the center console.

3.1.3 Egress From the Left Front Operator Workstation

The last series of egress tasks examined is from the front left workstation position (see figure 12). Although the results for these series of analyses pertain to the front left workstation position, because of the symmetry of the A2C2S design, similar results could be expected for the front right workstation position as well.

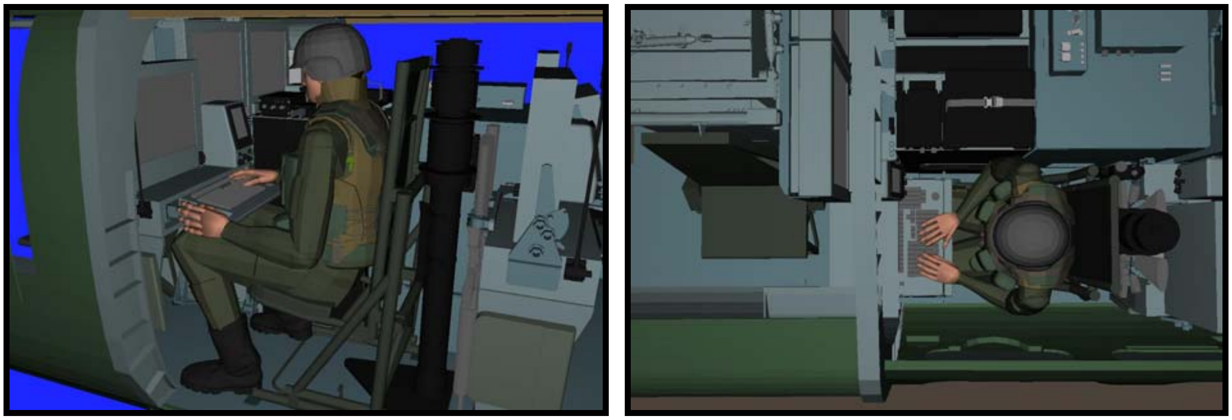

Figure 12. Side and top views of the large male figure seated at the left front workstation.

The next two egress scenarios from the front left crew station position assumed a blocked left side cargo door opening which would necessitate an exit through the front or right side of the aircraft. An egress from the front left workstation with an exit through the right side of the aircraft would again require the operator to climb over the center console. This egress route was addressed in the analysis and therefore, the likely egress strategy for this scenario was by exiting through the front of the aircraft. This, in turn, requires the operator to crawl over the top of the workstation or crawl underneath of the workstation platform in order to exit through the front of the aircraft.

Performing egress by crawling over the top of the workstation first requires that the keyboard tray be retracted into the platform and the monitor folded down into the stowed horizontal position, in order to maximize the available space for this egress path. Even with the monitor folded down into a stowed horizontal position, the available space over the top of the workstation is limited to a maximum height of 18.5 inches and a maximum width of 22.0 inches (see figure 13).

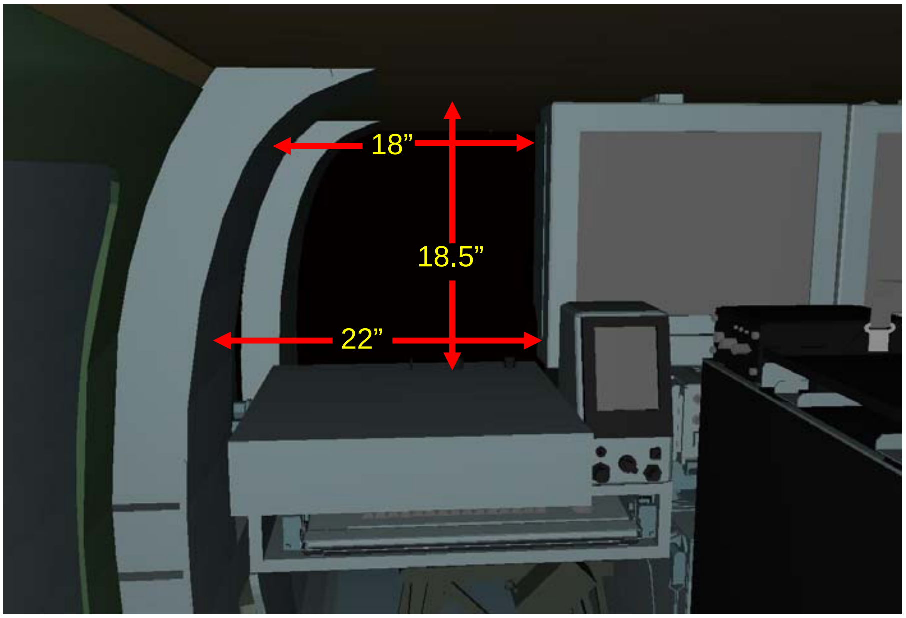

Figure 13. Dimensions over the front left workstation with the monitor folded down.

The body dimensions of most concern for this egress route are the shoulder width (bideltoid breadth), chest depth, and buttock depth. The bideltiod breadth for the large male figure used for this evaluation is 21.25 inches and the chest depth and buttock, which were mentioned earlier, are 11.26 inches and 11.40 inches, respectively. This bideltoid breadth dimension slightly exceeds the available space dimensions if the operator were to perform the egress with his chest lying on top of the monitor. However, if instead, a strategy is employed whereby the torso is rotated to the left or right by about 45 degrees, the operator would then have enough room to clear the shoulders through the opening and successfully perform the egress (see figure 14).

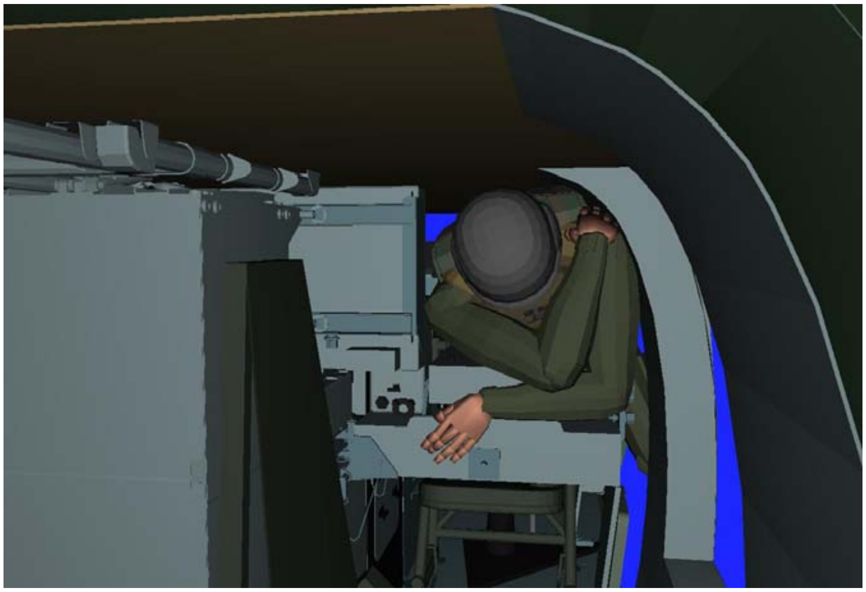

Figure 14. Large male figure positioning shoulders to leave over workstation.

Once the shoulders have cleared, sufficient room exists, even for the large male wearing the added clothing and equipment items, to clear the rest of the body through the opening (see figure 15).

Figure 15. Aft and forward facing views of large male figure clearing shoulders through workstation.

One other point to note about this egress route is that once the operator is able to clear the torso through the opening, the seat on the other side of the workstation can be used for support, in addition to providing a structure that can be used to pull the rest of the body through the opening (see figure 16).

The conclusion drawn from the analysis of this egress route was that the space available over the top of the workstation, although it would be tight for the larger end of the population, should be sufficient to allow the egress to be successfully performed.

Figure 16. Large male figure using the crew chief for support.

The other egress route that was examined for this scenario (inoperable door and left side cargo door opening blocked) had the operator crawling under the workstation platform. Figure 17 shows the dimensions of the space available for egress under the workstation platform.

The analysis performed for this egress route assumed that the operator's initial steps would be to fully retract the keyboard into the workstation platform, lift the seat pan into the vertical stowed position, and then proceed to crawl under the workstation platform on hands and knees. The key body dimensions that one would want to consider for this egress route are bideltoid breadth as well as the buttock-knee length and the chest depth. As noted earlier, the bideltoid breadth dimension of the large male figure was 21.25 inches and so the width of the crawl space is adequate to accommodate large male Soldiers even with additional clothing and equipment. However, the buttock-knee dimension of the large male figure was 26.4 inches and the height of the crawl space is only 25.25 inches. This means that although the larger male Soldiers would not be able to crawl under the workstation platform with the arms fully extended and legs upright, enough space does exist so that, with a slightly lower profile crawling posture, these Soldiers could get through (see figure 18).

As seen on the left side of figure 18, upon emerging from under the workstation platform, the Soldier will have to negotiate around the seat directly in front of the platform. Whereas this seat assists the Soldier when he is performing the egress maneuver over the top of the workstation platform, it is clearly an obstacle in the path when the Soldier is attempting to egress underneath. The analysis showed that although this seat would not prevent the larger Soldiers from completing the egress, it could make this route a much more time-consuming option versus going over the top of the workstation.

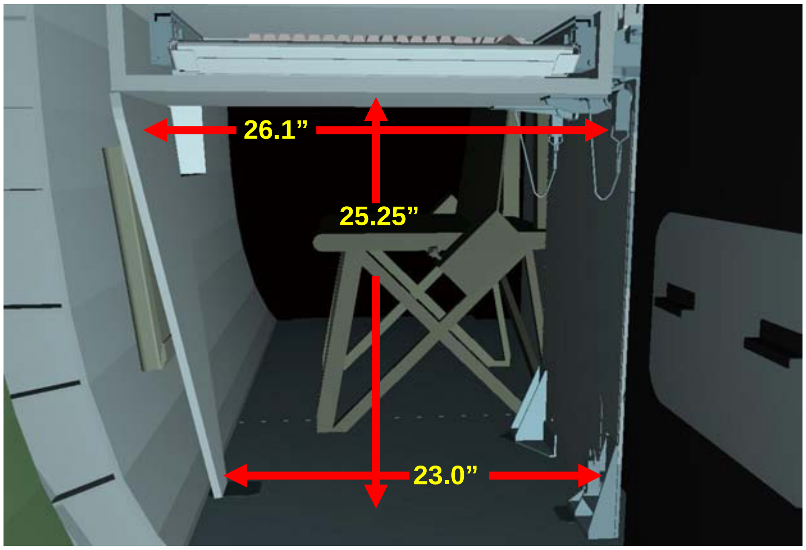

Figure 17. Dimensions of crawl space under the front left workstation.

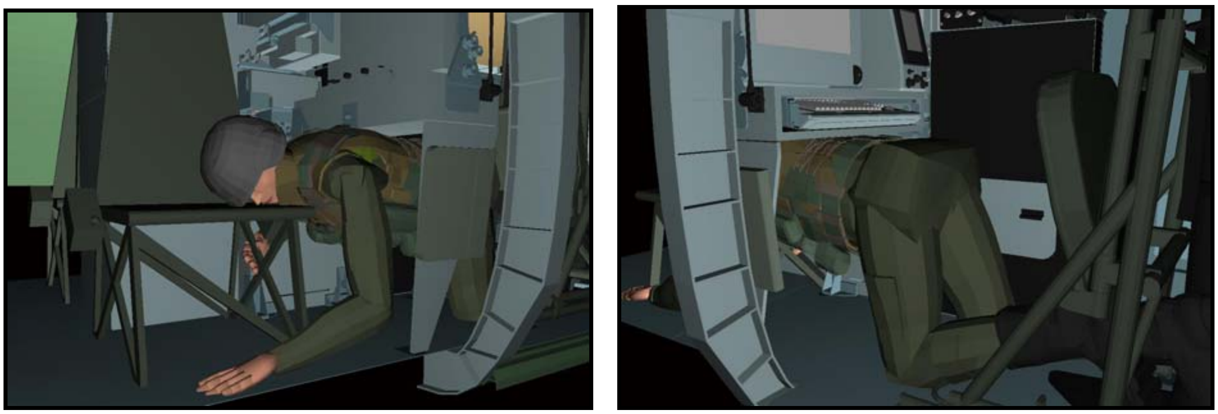

Figure 18. Aft and forward facing views of large male figure crawling under the workstation.

3.1.4 Egress From the Left Front Operator Workstation, Cargo Door Window

The final egress scenario examined began with the operator seated at the front left workstation position and assumed an inoperable left side cargo door but with an unobstructed left side cargo door window opening. The likely egress path in this case would be an exit through the front window opening of the left cargo door. With the keyboard tray retracted and the seat pan folded into the upright position, the operator has a clear unobstructed path to the window opening. The dimensions of the window opening are shown in figure 19.

The size of the cargo door window openings is adequate for even the larger end of the population to use for emergency egress (see figures 20 and 21).

The analysis of this scenario concluded that the A2C2S equipment would not obstruct access to the side cargo door window openings and, provided that the windows can be safely removed, emergency egress via this route can be successfully accomplished by the entire spectrum of the Soldier population.

Figure 19. Dimensions of side cargo door window openings.

Figure 20. Interior view of the large male figure leaving through left front cargo door window.

Figure 21. Exterior view of the large male figure leaving through left front cargo door window.

3.2 Results of Actual Emergency Egress Testing

The first phase of trials included emergency egress with no exits blocked. This set included four trials intended to familiarize the test participants with the egress process and the steps that would need to be completed to egress (i.e., how to stow the keyboard, open the doors, etc.), and to record the egress time required to egress the aircraft during these conditions. The recorded times for these trials averaged 8.5 seconds.

The second phase of egress trials included blocking the exits on the left side of the aircraft to simulate an aircraft on its side or otherwise blocked exits. During these trials, the three rear operators maneuvered across the back row of workstations and exited through the right cargo door. The front right operator also exited through the right cargo door. The operator seated at the left front workstation was the large male participant. This operator exited the aircraft by lowering the workstation monitor, crawling over the workstation into the crew chief station, and exiting through the right gunner's window. Figure 22 shows the opening over the workstation provided when the monitor is folded down. The operator was unable to egress over the center console because of the restricted space between the center rack and the cabin roof. Figure 23 shows the space restriction caused by the height of the center rack. The recorded times for these three trials ranged from 17 to 23 seconds, and the average egress time was 19.3 seconds.

Figure 22. Egress route over workstation.

The participants were surveyed after the first two sets of egress trials. Five participant responses rated egress as moderately easy on a 5-point Likert rating scale. One participant rated egress very easy and one participant rated egress borderline. The participants also were asked to provide suggestions for design changes that could improve the ability to egress the A2C2S. The most common comment provided was to allow the rear center keyboard to lock into the "up" position during egress. Currently, the design and location of the intercommunication system (ICS) connector prohibits the keyboard from being locked in the up position when the ICS cord is connected. A complete summary of results and comments is presented in appendix C.

The final phase of trials included seven scenarios that were performed when the left or right cargo doors and gunner's windows were blocked. These scenarios were designed to simulate an aircraft landing that would restrict the use of these exits. The egress times and conditions for each trial are listed in table 2.

Several issues were identified during Phase 3 of the egress test. The participants and observers noted that the rear center keyboard would not remain in the stowed position because of interference with the ICS hookup. Another issue identified during the egress testing was the location of "quick connect" cables on the back of the workstation monitors. These connections caused snag hazards when the front operators were forced to egress over the top of the workstation. During the second trial of Phase 3, the large male participant was attempting to egress under the front workstation. In the process, the Soldier's butt pack became snagged on the left keyboard retaining nut. As a result, the egress trial was unsuccessful and had to be run again. Observers corrected the problem and the trial was repeated without incident. Finally, during the fifth trial of Phase 3, the left rear operator folded down his monitor to lean over the workstation and open the cargo door. After successfully opening the door, the operator leaned back into his seat and attempted to egress the aircraft with his monitor still folded down. The clearance between the folded down monitor and the aft edge of the cargo door was not sufficient to allow successful egress. After several seconds, the participant recognized the problem, folded the monitor back up, and successfully egressed the aircraft.

Figure 23. Restricted space above center rack.

Table 2. Egress test conditions and egress times - phase 3.

Trial	Conditions	Egress Time (sec)
1	Right exits blocked. Right front operator egressed over right workstation	28.5
2	Left exits blocked. Left front operator egressed under the workstation.	26
3	Left exits blocked. Left front operator egressed over workstation. Crew chief was unconscious (simulated).	29
4	Right exits blocked. Crew chief opened left cargo door from over the front workstation.	13.5
5	Right exits blocked. Left rear operator opened left cargo door.	23
6	Right exits blocked. Left rear operator unconscious (simulated).	19.5
7	Left exits blocked. Left front operator in MOPP IV egressed over workstation.	14

4. Recommendations

4.1 Recommendations Derived From Human Figure Modeling

The following recommendations are derived from the human figure modeling analysis. These recommendations are design changes for the A2C2S workstations, which would improve safety or egress time.

The first recommendation pertains to egress from the rear workstation positions or, more specifically, the first type of egress analysis addressed in the results section. As noted in the results section, larger Soldiers could have problems with head contact to the upper outboard section of the flat screen monitor at the right or left rear workstation positions. A solution that would provide extra headroom would be to allow the flat screen monitors to rotate back beyond the full upright position. The current rotation back seems to be limited to about 20 degrees because of weapon stowage in back of the right and left rear workstation positions. However, even this limited rotation of the monitors could provide the additional space to make egress from the rear workstation positions easier for the larger Soldiers (see figures 24 and 25).

Figure 24. Restricted head space with monitor positioned upright.

Figure 25. Additional head space provided by rotating monitor backward 20 degrees.

The next recommendation applies to an egress that would require the Soldier to traverse the center console between the right and left front workstation positions. The modeling analysis showed that although a larger Soldier may be able to squeeze through the space currently available over the center console, if additional bulky clothing and equipment were being worn, egress for this route might be very difficult, if not impossible. Therefore, it is recommended that the profile of this center rack of equipment be lowered by at least 5 to 6 inches to accommodate larger Soldiers who may be wearing equipment such as body armor, LBVs, cold weather or MOPP IV ensembles.

A third recommendation applies to an egress from the front left or right workstation positions where the path would involve crawling under the workstation platform. As shown previously in figure 18, sufficient space does exist under the platform even for larger Soldiers to crawl under the workstation platform. However, the seat directly in front of the workstation positions could significantly slow egress. A quick release that would allow the seat to be moved or rotated away from the workstation would provide much needed additional space and would allow this egress maneuver to be performed more easily.

The last recommendation again applies to an egress performed from the front left or right workstation positions. The need to crawl over or under the workstation platform could be eliminated if the platforms themselves were modified in such a way that the entire platform could be collapsed and folded down. Figure 26 shows the dimensions of space that would be available for egress if the platform could be folded down.

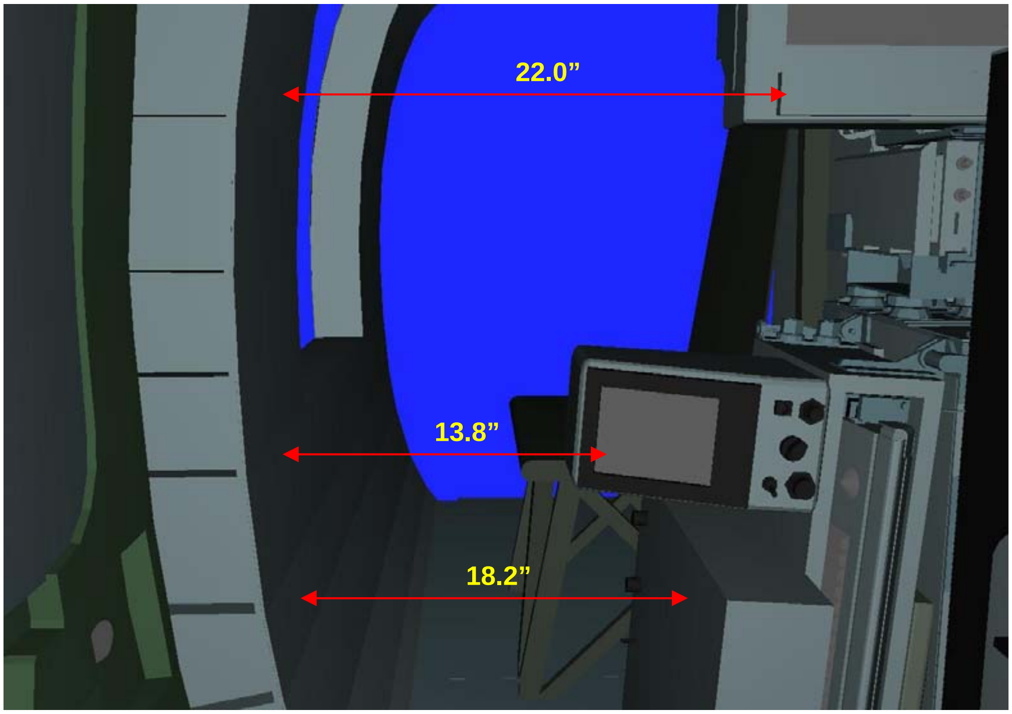

Figure 26. Egress dimensions with left front workstation folded down.

Figure 27 shows the clear benefit provided by the additional space created when the workstation platform collapses. This potential design alternative would provide ample space for even large male Soldiers to use for an egress path and would be much more preferable than their having to climb over or crawl underneath the workstation.

Figure 27. Large male figure leaving through space provided when workstation is folded down.

4.2 Recommendations Derived From Emergency Egress Testing

Several recommendations were made by the test participants and observers, which if adopted, could enhance egress from the A2C2S. Some of these recommendations mirror those identified by the human figure modeling analysis, emphasizing the importance of conducting modeling and simulation early in the design stages of an acquisition program.

The first recommendation was to modify the design of the rear center keyboard to allow it to remain in the upright, stowed position when folded up. Currently, the keyboard tray interferes with the ICS cord and cannot be locked in the stowed position. Correcting this problem would likely reduce the egress time from the rear workstations.

Several personnel made recommendations regarding the seat design. One participant suggested that the seat pans should flip up on their own when weight is removed from them. Another participant noted that allowing the seats to lock in the upright position would enhance egress. Both of these suggestions may benefit egress when a front seat operator is attempting to egress under the workstation or across the rear workstations.

Another recommendation that resulted from the egress test was to reposition the cable connections on the back of the monitors. For egress from the front workstations, with a cargo door blocked or inoperable, the preferred egress route is over the top of the workstation. This egress route would require an operator to fold the monitor down, which would position the back of the monitor upright with the connectors facing up. In this situation, these connectors provide a snag hazard and can reduce the effectiveness of this egress path.

The final recommendation that was made was to teach egress to A2C2S operators. Many good lessons were learned from this egress test. One example is that the preferred egress route from the front workstation with a blocked cargo door is over the top of the workstation. This recommendation is made, based on the potential interference from the crew chief seat (identified in the Jack study) and the problems noted by test participants and observers during the actual egress test. Another lesson learned was that attempting to egress from the rear workstations with the side workstation monitor folded down could be very difficult and time consuming. Teaching egress to operators would allow the operators to be aware of the best egress paths and potential egress problems before they have to execute a real-world emergency egress. Such training could save the lives of A2C2S operators in an emergency situation.

If future modifications of the A2C2S design include significant changes in the seats, workstations, or any other hardware that could potentially affect egress, further analyses should be conducted to determine the effect of the changes.

Finally, it is very important that the PM consider these recommendations. The egress testing did show that the A2C2S could meet the requirement set by the ACSDG; however, this test was conducted in relatively ideal conditions with adequate lighting. Many different post-crash conditions have the ability to affect this egress time. For example, when an aircraft crashes at night or is filled with dust or smoke, disorientation is likely to occur. In addition, discussions with survivors of actual aircraft accidents have indicated that many other factors are associated with the crash-fire situation that can affect the ability to escape. Examples include visual obstructions, eye and throat irritation, fire-blocked exits, panic, and heat factors associated with blowing hot air (Johnson et al., 1989). Especially in post-accident situations involving fire and water, the occupant’s survival is highly dependent on egress time. It is our responsibility to do everything reasonably possible to reduce this time through the design of the A2C2S.

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Appendix A. Large Male Human Figure Model Anthropometric Data

<u>Large Male - Extreme Form A *(90 % Accommodation Ellipse)*:</u>
<u>Variables for Human Figure Model Input</u> (all values in mm)

Acromial Height Sitting	656	Popliteal Height	481
Biacromial Breadth	425	Sitting Height	989
Buttock-Knee Length	674	Thumbtip Reach	877
Eye Height Sitting	864	Extended Thumbtip Reach	953

Acromion-Radiale Length	375	Interscye I	415
Ball of Foot Length	213	Knee Height Midpatella	551
Biceps Circ. Flexed	335	Lateral Femoral Epicondyle Height	549
Bideltoid Breadth	539	Lateral Malleolus Height	73
Bizygomatic Breadth	146	Menton-Sellion Length	127
Buttock Depth	289	Menton-Top of Head	244
Calf Circ.	386	Neck Circ	386
Cervicale Height	1656	Palm Length	120
Cervicale Height Sitting	727	Radiale-Stylion Length	289
Chest Breadth	355	Sellion-Back of Head	201
Chest Depth	286	Sellion-Top of Head	113
Ectoorbitale-Top of Head	119	Stature	191 3
Foot Breadth Horiz.	106	Tenth Rib Height	122 7
Foot Length	293	Thigh Circ.	679
Forearm Circ. Flexed	307	Thigh Clearance	190
Gluteal Furrow Height	895	Tragion-Top of Head	134
Hand Breadth	95	Trochanterion Height	101 3
Hand Circ	225	Waist Breadth	352
Hand Length	212	Waist Depth	247
Head Breadth	156	Waist Front Length Om	435
Head Length	203	Waist Height Om	116 3
Hip Breadth	374	Wrist-Center Grip Length	74
Hip Breadth Sitting	402	Wrist-Wall Length	731
Iliocristale Height	1171		

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Appendix B. Emergency Egress Test Surveys

A2C2S Egress Participant Demographics Form

PIN(1st and Last Initial, Last 4)_________________________________

Unit________________ Rank______________ Age_______

Primary MOS (include ASI's)__________________________________

Current Duty Position/Title____________________________________

Weight__________

Stature

1. __________ 2. __________ 3. __________ AVG__________

Bideltoid Breadth

1. __________ 2. __________ 3. __________ AVG__________

Chest Depth

1. __________ 2. __________ 3. __________ AVG__________

Buttock Depth

1. __________ 2. __________ 3. __________ AVG__________

Buttock-Knee Length

1. __________ 2. __________ 3. __________ AVG__________

A2C2S Egress Trial Questionnaire (Observer)

Pin # ________________ Date: ________________

Trial #: ____________________

Time it took to egress: _____________ seconds

1. Any egress problems observed or reported during trial? Yes ____ No ____
2. Any safety problems observed or reported during trial? Yes _____ No _____
3. Any damage to the mock-up? Yes _____ No _____

Description of any 1) egress problems, 2) safety problems, 3) damage to mock-up

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A2C2S Egress Questionnaire (Participant)

Pin # ________________ Date: _______________

Trial #:_______________

Clothing ensemble worn during the trial(s) you just completed: (Circle one)

Standard Gear (Body Armor, LBV, Kevlar, BDUs) / MOPP IV Gear

1. What seat did you occupy in the A2C2S? (Circle one)

Left Crew Chief **Right Crew Chief**

Left Front Right Front

Left Rear Center Rear Right Rear

2. Rate how easy or difficult it was to egress your workstation with the clothing ensemble you wore during the last trial(s).

1	2	3	4	5
Very Easy	Moderately Easy	Borderline	Moderately Difficult	Very Difficult

3. Are there any improvements that could be made to the workstations that would enhance ingress and egress?

Yes _____ No _____

If yes, describe the improvements that could be made to the workstation(s):

____

____

____

4. Do you have any suggestions for improving the method of ingress and egress that you used during this phase?

Yes _____ No _____

If yes, describe the improvements that could be made to the method that you used:

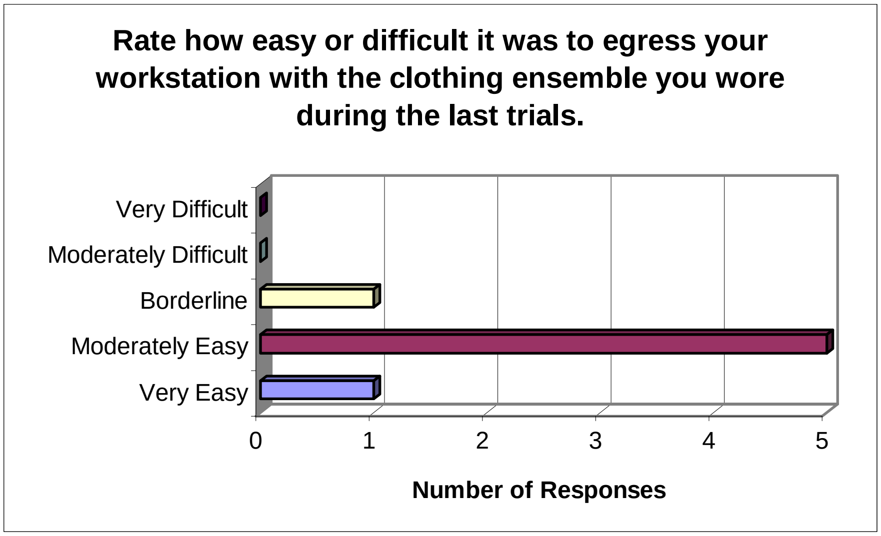
____

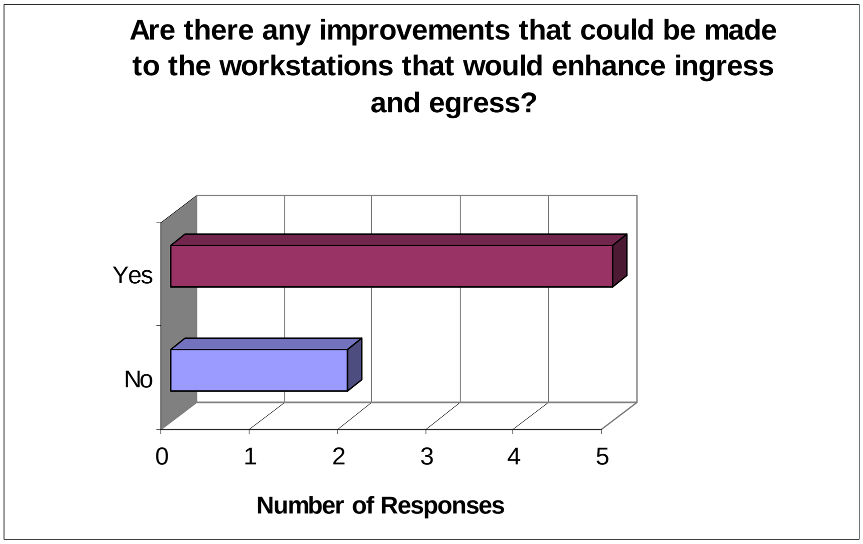
____

____

Appendix C. Emergency Egress Test Results and Comments

Participant Questionnaire

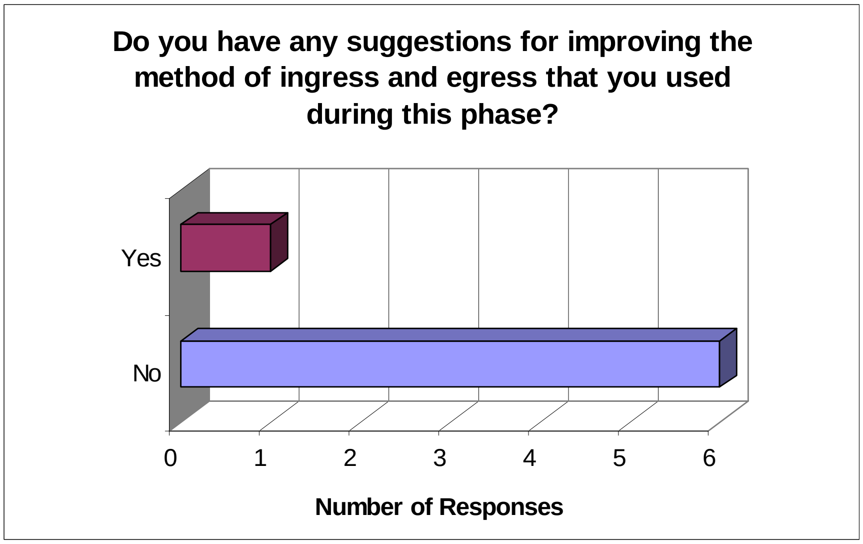




Describe the improvements that could be made to the workstations.

- Install locking mechanisms on keyboards so when you flip the keyboard up, it stays up. (center rear workstation)
- Move the keyboard and display forward. (center rear workstation)
- Lower seat back height on left and right front seats.
- Allow center-rear keyboard to lock in the up position.
- Seats lock in up position.

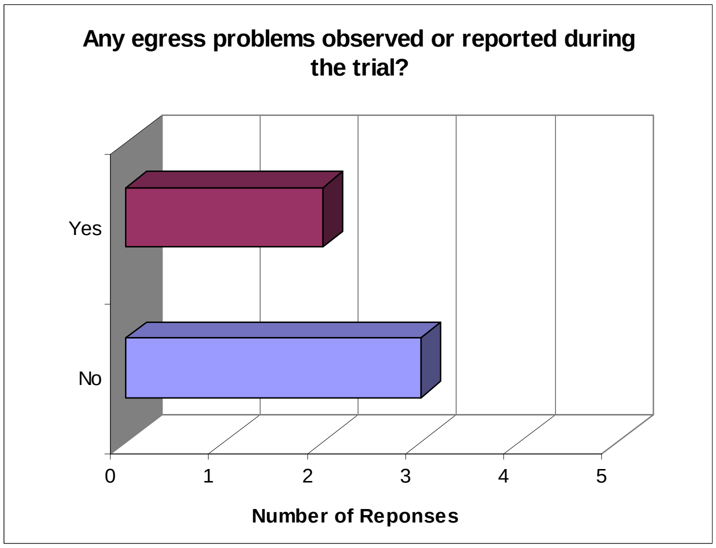
- Allow the seat to flip up on its own. It would save time for person in that workstation and those following him.
- Move quick disconnects on monitor.
- Center rear needs a larger hole in keyboard tray for ICS cord.

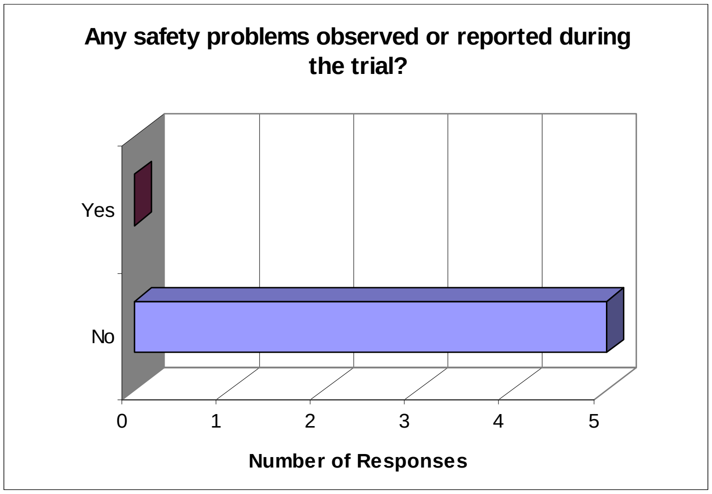


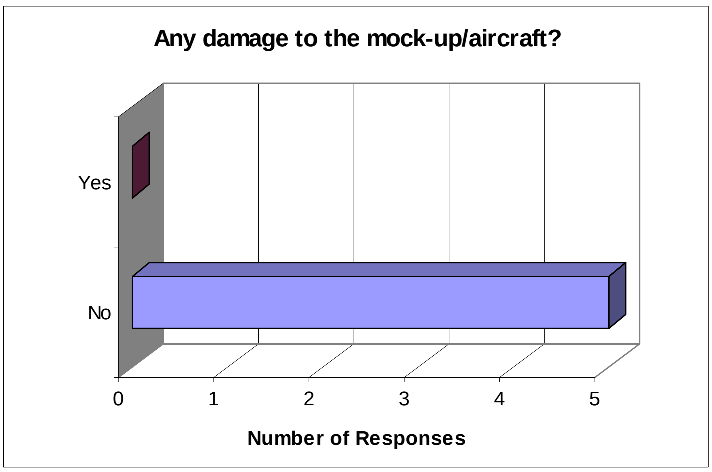
If yes, describe the improvements that could be made to the method that you used.

- Need break-out knives in back.

Observer Questionnaire







Description of any 1.) egress problems, 2.) safety problems, 3.) damage to mock-up.

- During the under-the-workstation egress trial from the left-front workstation, the participants LBV got stuck on the left keyboard retaining nut. Participant could not complete the trial without assistance. Second trial was successful. Another note was that the participant was wearing a "butt-pack" and that was the article that actually got caught, not the LBV itself.
- During one demonstration when the left-rear operator attempted to egress the back seat with his monitor stored in the full down position, he could not egress and had to re-position the monitor in the upright position to get out.
- All A2C2S operators and crew chiefs egressed the aircraft without any apparent problems. Egress should be taught at the same time aircrew egress is taught.
- During over-the-monitor egress the connectors are a problem. They need to be frangible or moved.
- Egress methods and paths must be taught.

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Glossary of Acronyms

3-D	three-dimensional
A2C2S	Army Airborne Command and Control System
ABCS	Army Battlefield Command System
AED	Aviation Engineering Directorate
AFATDS	Advanced Field Artillery Tactical Data System
AMDWS	air and missile defense work station
ARL	Army Research Laboratory
ASAS-L	All-Source Analysis System-Light
ASAS-RWS	All-Source Analysis System-remote work station
ATEC	Army Test and Evaluation Command
BCS3	Battle Command Sustainment and Support System
BDU	battle dress uniform
BFT	Blue Force Tracking
C2	command and control
C2PC	command and control personal computer
CAD	computer-aided design
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
FBCB2	Force XXI Battle Command Brigade and Below
FCS	Future Combat Systems
ICS	intercommunications system
LBV	load-bearing vest
LRIP	low rate initial production
M&S	modeling and simulation
MANPRINT	manpower and personnel integration
MCS	Maneuver Control System
MCS-L	Maneuver Control System-Light
MEP	mission equipment package
MOPP	mission-oriented protective posture

PASGT	Personal Armor System for Ground Troops
PCA	principal components analysis
PM	Product Manager
SBA	simulation-based acquisition
SMART	Simulation and Modeling for Acquisition Requirements and Training
TOP	test operations procedure
WG	working group

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