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Human Factors Evaluation of an Experimental Locomotive Engineer Crewstation

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13. ABSTRACT (Maximum 200 words)
A human factors evaluation of an experimental engineer control system was conducted by the Volpe Center using a locomotive research simulator—the Federal Railroad Administration Cab Technology Integration Laboratory (CTIL). The primary objective was to find the areas of the crewstation where it may provide (or deny) benefit to engineers from a human factors perspective. This was done by performing an initial evaluation with human factors experts to define major areas of concern; a comparison of the experimental crewstation (and the existing AAR-105 control stand in CTIL) to human factors design standard MIL-STD-1472G; an evaluation using an anthropometric modeling tool, to look at reachability, comfort, visibility and arm support; and a usability test with experienced engineers in the simulator. The evaluation found an increased level of comfort and reachability in the controls, and usability test subjects found the experimental system easy to use. However, we also found issues with the chair which may require adapting the specifications, such as unstable monitors, lack of writing space, and visibility of signals while standing. We also found issues which could easily be fixed in future iterations of the current system. Possibilities for future research regarding current control stands are also considered.

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ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °Φ = y °Χ

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

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1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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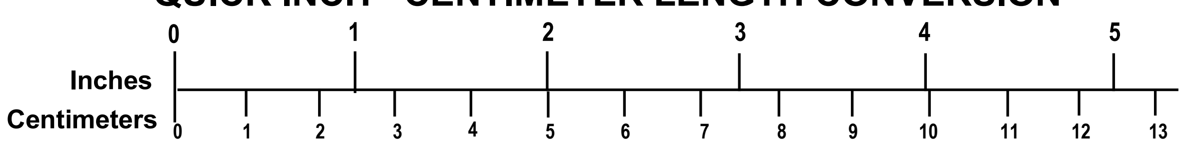

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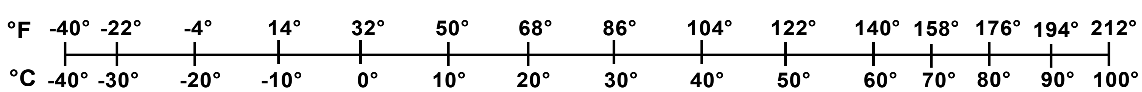

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Executive Summary

This report documents the human factors evaluation performed by the John A. Volpe National Transportation Systems Center (the Volpe Center) during August 2014 to September 2015, of an experimental engineer locomotive control environment that was commissioned by the Federal Railroad Administration (FRA) and built by QinetiQ North America Technology Solutions Group. The aim of this experimental crewstation design was to demonstrate an alternative crewstation concept and design approach by integrating the displays and controls into the seat so that they could be accessed when the chair rotates, offering standing and seated ("sit/stand") train operation capabilities, and providing ergonomic improvements and comfort to the rail control environment.

To perform this assessment we utilized the Cab Technology Integration Laboratory (CTIL) rail simulator, owned by FRA and stationed at the Volpe Center in Cambridge, MA. Integrating the experimental crewstation enabled us to use performance data from real engineers on a simulated version of real track. CTIL additionally provided us with a conventional control stand and seat (the Association of American Railroads [AAR]-105 control stand) against which we were able to compare interface features. We used this control stand implementation to better understand how the experimental crewstation may provide (or deny) benefit to engineers, should it ever be implemented in an actual train.

The first step of the evaluation effort was a preliminary design evaluation, in which we identified design flaws in the experimental crewstation based on our first impressions which stemmed from general usability practices. We performed this task to gain an understanding of the scope of its potential problems from a high-level, and to drive the general direction of later activities.

The second step of the evaluation effort was an ergonomic assessment, which evaluated the extent to which the experimental crewstation met existing human factors and ergonomic standards through two tasks: *standards comparison* and *anthropometric modeling*. In the standards comparison, we evaluated both the AAR-105 control stand and the experimental crewstation against the military human factors design criteria standard MIL-STD-1472G (DoD, 2012). In the anthropometric modeling task, we evaluated the key operations tasks performed on both workstations using a computer tool to help determine the accessibility of controls and assess engineers' physical stress and discomfort.

The final step of the evaluation was a usability test, where we asked experienced engineers to accomplish a series of tasks with the experimental crewstation so that we could apply scientific measurement to support or refute concerns we had raised in earlier tasks. This task also provided engineers with a chance to give feedback about the experimental crewstation design.

The evaluation unveiled three major problems with the crewstation which may make any fully integrated sit/stand concept infeasible in current locomotives, at least in the near term:

- Standing position puts users' eyes above (or too close too) the top of the front window, such that it is extremely difficult to see high signals.
- A low profile chair required for sit/stand operation leads to unstable and hard-to read displays.
- There is no obvious place for engineers to write notes or store paperwork.

Future iterations of the design may require either moving away from attached displays (less integration), or moving away from the sit/stand feature (less operator flexibility) in order to address these issues.

Additionally, usability test data showed that engineers overall thought the seat was easy to use. Also, as can be expected with the first iteration of any system, we found many areas in which the experimental workstation can be improved. The vast majority of these issues are correctable in future iterations of the crewstation. These issues can be found ordered by severity in Appendix B.

Engineers who visited the Volpe Center for the usability test noted that many railroads have poorly featured, damaged, or inadequately maintained seats. Additionally, we learned that not all AAR-105 control stands are the same; some may be positioned closer to the seat than the one in CTIL. Control accessibility in the AAR-105 is dependent on how well the seating lets engineers orient themselves to the stand, and how close the seat is to it. It is possible that providing guidance about control stand and seat positioning, FRA could encourage increased control accessibility and a decrease in repetitive stress injuries in a cost-effective manner.

With this information, it would be useful to repeat the tasks in this evaluation plan for all these AAR-105 configurations. This would provide railroads with direct guidance on which configurations are best for use. In addition to control configuration, the study could also examine optimal display placement. This may identify low-cost upgrades for existing locomotives that address integration issues and increase their serviceable life as more automation tools for train handling come online over the coming decades.

Lastly, it would be useful to conduct a time-motion study to more deeply understand control use frequencies in various types of operations. Understanding how uncomfortable it is to use a control stand is only half of the story in determining whether it needs to be redesigned. The other half is knowing the frequency of their use by job type and the tolerable dosage of these positions in terms of long term injury. A better understanding of these impacts could lead to focusing on improving the locations of key controls, rather than building comprehensive new design concepts which affect all of them at once.

1. Introduction

This document describes the human factors analysis activities performed on an experimental crewstation design developed by QinetiQ North America Technology Solutions Group for the Federal Railroad Administration (FRA) in summer 2014. Researchers at the John A. Volpe National Transportation Systems Center (Volpe Center) in Cambridge, MA, performed the evaluation beginning in winter 2014 through spring 2015 using the Federal Railroad Administration's (FRA) Cab Technology Integration Laboratory (CTIL).

1.1 Background

Conventional control stands for operating trains, such as the one from the Association of American Railroads (called the Association of American Railroads [AAR]-105), have evolved from models of locomotives dating back to the 1950s such as the Electro-Motive Diesel (EMD) GP20. Despite multiple systematic improvements and alternative designs (such as desktop-style controls), "cab seating and its associated controls and display configuration still seems to be a problem today and is critical to crew performance. Concerns about crew health, safety, and performance related to current workstation designs persist" (Federal Railroad Administration, 2013).

Moreover, the AAR-105 control stand was developed in a time when extensive automation and computer displays were not yet part of the operating environment. The existence of such features today increases the scope of the train operation interface and indicates a need for a more involved design approach that includes Human Systems Integration (HSI) and human factors engineering as part of the systems engineering process.

In response to this issue, FRA released a Request for Proposal (RFP) under identification number DTFR53-12-D-00009, *Engineer's Crewstation Design*, in 2013. The proposed goal was to design and build a new control system for a locomotive cab that takes into consideration design problems from older systems, and to install it in CTIL rail simulator for evaluation.

Specifically, FRA wanted to explore a concept that would enhance both the ergonomics and the functionality of the workspace. The criteria for the new design included a number of special features:

- The ability for engineers to view and operate displays and controls from 180 degrees of chair rotation.
- The capability for both standing and seated (i.e., "sit/stand") train operation.
- "A baseline array of controls and displays that enable the same capabilities as existing cabs, but are not constrained by existing designs" (QinetiQ, 2013).
- Ergonomic improvements to the rail control environment
- Reconfigurable controls
- Enhanced comfort

FRA hoped that the design and evaluation of this integrated ergonomic crewstation would allow for an assessment of not only the crewstation itself, but also of the usefulness of human-in-the-loop testing of new cab designs using CTIL. Even if the results of this study suggested that the experimental crewstation were unfit for use or redesign, FRA hoped that this evaluation procedure could serve as a roadmap for the evaluation of future cab technologies of all kinds.

Figure 1. The experimental crewstation

FRA awarded the contract to design and build this combined seating-and-controls system (Figure 1), which we refer to in this document as the experimental crewstation, to QinetiQ North America Technology Solutions Group. The experimental crewstation was installed in CTIL in late summer of 2014, at which point we began evaluating its effectiveness in key areas related to FRA's goals.

1.2 Objectives

FRA contracted us to evaluate the effectiveness of the experimental crewstation. We assessed and documented any aspects of its design that could lead to confusion or mistakes in operation, and evaluated whether engineers found it intuitive and easy to use. Additionally, FRA asked for improvement recommendations that can be incorporated into future prototypes.

FRA asked us to use CTIL for this evaluation because of its ability to easily integrate new displays and controls into the simulated operating environment. Using CTIL also allowed us to make use of its suite of ergonomic analysis tools.

1.3 Scope

We evaluated the experimental crewstation through a series of activities, including:

- A preliminary design evaluation
- A comparison to human factors design standards
- An assessment of key body positions using various body sizes
- A functional evaluation with experienced locomotive engineers

These tasks allowed us to examine the control and seating configuration of the experimental crewstation from human factors and end user perspectives.

Our evaluation focused on the placement and physical characteristics of the controls and labels as well as their accessibility as made available by the seating. We also evaluated the adjustability of the seating. To provide additional context to the evaluation of the experimental crewstation, and in keeping with the goal of using CTIL for the assessment, we also conducted some of the evaluation tasks using the AAR-105 control stand and chair which were installed in the simulator when the manufacturer (Alion Science) delivered it to FRA in 2009. In this way we enumerated areas in which the experimental crewstation may offer improvements to this existing control stand.

Although CTIL allowed us to get insight into many aspects of the experimental crewstation, there were some elements that we were unable to evaluate due to using CTIL for our evaluation:

- The seat's vibration dampening capabilities were not evaluated for effectiveness because CTIL does not have a motion base to replicate the motion experienced in a real train.
- Because CTIL provides only one version of the AAR-105 control stand, we were unable to account for variations in AAR-105 configurations which exist between trains and railroads.
- The AAR-105 control stand was the only conventional control stand compared because CTIL is not equipped with a desktop-style control configuration.

Section 2 provides a more detailed discussion of these limitations.

1.4 Organization of the Report

This document was organized as such:

- Section 1 describes the nature and scope of the experimental crewstation evaluation.
- Section 2 briefly compares the key features of the conventional control stand (AAR-105) and experimental crewstation.
- Section 3 describes the overall approach to evaluating the crewstation.
- Section 4 describes the issues found during the initial high-level evaluation of the crewstation.
- Section 5 describes the standards comparison and anthropometric modeling activities performed during the evaluation.
- Section 6 details the activities performed during a functional evaluation of the crewstation using experienced locomotive engineers.
- Section 7 summarizes the findings from the experimental crewstation evaluation and discusses potential areas for further research.
- Appendix A prioritizes human factors workstation issues that designers should address.
- Appendix B includes a spreadsheet version of our findings from the standards comparison task.
- Appendix C includes tables from the military standard which were referenced in the standards comparison task.
- Appendix D includes figures from the military standard which were referenced in the standards comparison task.
- Appendix E shows the full set of comfort analysis results for both positions and control systems.
- Appendix F includes the complete set of documents, tasks and questionnaires used during the usability tests.

2. Workstation Designs

The following sections summarize the designs of the AAR-105 control stand and the experimental crewstation to give readers an understanding of the fundamental differences between them.

2.1 AAR-105 Control Stand

Figure 2 shows the AAR-105 control stand installed in CTIL.

Figure 2. The AAR-105 control stand in CTIL

In this control configuration, the controls are mounted vertically on a large rectangular surface. This "control stand" houses all of the physical controls that engineers need to access quickly. The control stand provides access to the controls, listed in Table 1.

Table 1. Controls on the AAR-105 control stand in CTIL

Control System	Manner of Control
Throttle	Lever with detents for stop, idle, and eight numbered positions.
Dynamic brake	Lever with detents for the off and setup positions. Continuous past setup through marked positions 1-8.
Automatic brake	Lever with detents for release, minimum service, full service, suppression, handle off, and emergency positions. Continuous between minimum service and full service for accurate braking.
Independent brake	Lever with detent for release. Continuous past release through full service.
Bail	Independent brake lever; press downward for activation.
Reverser	Lever with detents for reverse, neutral and forward.
Bell	Large metal switch. Engineers must move switch to turn it off.
Horn	Large spring-loaded metal switch. It returns to the off position when released.
Intercom unit	Button for talking. Speaker for listening. Knob for volume.
Sand	Metal switch for sanding/lead truck control. Button for manual sanding.
End-of train emergency	Small metal switch with a protection device; protection must be lifted to access the switch.
Various engine and traction systems	Breakers.
Headlights	Large knobs with detents for different intensities.
Alerter response button	Large yellow push button.

CTIL’s AAR-105 installation also features a desk underneath the front window which has a cup holder.

Above the desk are two interactive computer monitors. CTIL also supports a third monitor which sits on top of the shelf near the top of the control stand next to the horn.

The control stand has interlocks to prevent accidental activation of the throttle, dynamic brake and reverser. Specifically, if the throttle or dynamic brake is in use, the reverser will not move. Also, the dynamic brake and throttle cannot be operated simultaneously.

To access the control stand, engineers sit in a chair beside it. The control stand is placed to the left side of the engineer to allow for clear viewing out the front window. Since the control stand is to the left of the engineers, it is angled at 45 degrees to better face to them.

Since the seat and control stand are not the same unit, it is possible to use a variety of seats, and each may have its own features. CTIL uses a seat with a moderate amount of adjustability and cushioning alongside the AAR-105 Control Stand. Its armrests fold upward to facilitate entrance into the seat past the control stand, but do not adjust upwards, downwards, forwards or backwards. The seat has the ability to slide forward and backward, and can be rotated through 45 degrees of motion. It has a locking pin at 45 degrees (facing the control stand) and 0 degrees (facing forward). Figure 3 shows the seat in the 45-degree locked position, facing the control stand. The seat has a high back but no headrest.

Figure 3. CTIL-provided seat angled toward the AAR-105 control stand in the simulator

Since different seats can be paired with the control stand, this one serves merely as an example of the type of seating that may exist in locomotives. In keeping with the goal of using CTIL for analysis of the experimental crewstation effectiveness, we used the above described seat for all comparisons of AAR-105 control stand to that of the experimental crewstation.

CTIL's AAR-105 control stand also features a non-adjustable footrest which is attached to its base.

2.2 Experimental Crewstation

Figure 4 shows the experimental crewstation installed in CTIL. It features the same control systems as the AAR-105 does, but instead of being mounted on a panel the controls are mounted to the armrests. The controls are smaller than the ones on the AAR-105 to accommodate this change. Additionally, control types for some of the control systems are different, as listed in Table 2.

Figure 4. Experimental crewstation with integrated controls and displays

Table 2. Control types the AAR-105 control stand and the experimental crewstation

Control System	AAR-105 in CTIL	Experimental crewstation
Throttle	Horizontal lever	Vertical lever with horizontal grip. Combined with dynamic brake
Dynamic brake	Horizontal lever	Vertical lever with horizontal grip. Combined with throttle
Automatic brake	Horizontal lever	Vertical lever
Independent brake	Horizontal lever	Vertical lever
Bail	Independent brake lever; press downward for activation	Button on top of independent brake
Reverser	Horizontal lever	Vertical lever
Bell	Large metal switch. Engineers must move switch to turn it off	Small round white button. Button must be pressed again to turn it off
Horn	Large spring-loaded metal switch. Releasing the switch turns it off	Small round blue button. Releasing the button turns it off
Intercom unit	Button for talking. Speaker for listening. Knob for volume	Button for talking. No speaker or volume knob
Sand	Metal switch for sanding/lead truck control. Button for manual sanding	Small round white button for sanding/lead truck (press to switch functions). Small round blue button for manual sanding (release to turn off)
End-of train emergency	Small metal switch with red protection device	Small metal switch with red protection device
Various engine and traction systems	Breakers	Small square black buttons. The buttons stay depressed after activation. Pressing again deactivates them.
Headlights	Large knobs with detents for different intensities	Small knobs with detents for different intensities
Alerter response button	Large yellow push button	Small round yellow push button

One notably different control type in the experimental crewstation is a single lever for both the throttle and dynamic brake functions (see Figure 5) rather than separate interlocked levers. The other main design difference for the controls themselves is that many controls which were switches or breakers on the AAR-105 control stand exist as push buttons on the experimental crewstation.

Figure 5. Combined dynamic brake and throttle on the experimental crewstation

The experimental crewstation displays are mounted on a post that connects to the right armrest, allowing the armrests to move when engineers rotate the seat. The seat's allowable rotation in the cab is approximately 180 degrees.

The experimental crewstation offers increased cushioning and vibration dampening, compared to the chair provided alongside the AAR-105 control stand in CTIL. It includes a built-in footrest and allows forward-backward adjustment of the armrests (although not upwards or downwards). It also allows for a small amount of vertical adjustment (approximately 1.75 inches), but does not allow for height adjustment relative to the footrest.

Another unique feature of the experimental crewstation is its sit/stand capability, shown in Figure 6. This is designed to allow engineers to reach the controls from a standing position while gaining back support from the backrest.

Figure 6. Experimental crewstation configured for seated operation (left) and standing operation (right)

3. Evaluation Strategy

To provide a thorough examination of the experimental crewstation while also allowing for input from human factors specialists and locomotive engineers, we used three evaluation methods:

- In the **preliminary design evaluation**, we determined design flaws in the experimental crewstation based on our first impressions, which stemmed from general usability practices. We performed this task to gain an understanding of the scope of its potential problems from a high-level, and to drive the general direction of later activities.
- The **ergonomic assessment** evaluated the extent to which the experimental crewstation met existing human factors and ergonomic standards through two tasks: *standards comparison* and *anthropometric modeling*. These tasks supported (or refuted) our initial concerns from the preliminary design evaluation and provided a thorough investigation of the crewstation from a variety of human factors perspectives. In the standards comparison, we evaluated both the AAR-105 control stand and the experimental crewstation against the military human factors design criteria standard MIL-STD-1472G (DoD, 2012). In the anthropometric modeling task, we evaluated the key operations tasks performed on both workstations using a computer tool to help determine the accessibility of controls and assess engineers' physical stress and discomfort.
- In the **usability test** we asked experienced engineers to accomplish a series of tasks with the experimental crewstation so that we could apply scientific measurement to support or refute concerns about the experimental crewstation, which we had raised in earlier tasks. We also evaluated whether the experimental crewstation's controls map properly to common train operation tasks as judged by engineers. The usability test also provided engineers with a chance to give open-ended feedback about the experimental crewstation design.

3.1 Task Flow

The main output from each task in this evaluation was a list of "human factors issues," aspects of the experimental crewstation's design that may result in engineer confusion or may contribute to critical mistakes in operation. We ordered these issues based on our perception of their importance, but the crewstation's designers as well as FRA and other stakeholders may feel that a different prioritization is more prudent. Ultimately any decision on improving the design, should FRA consider its design a useful one, should incorporate all relevant perspectives and not just ours.

In some cases, however, the activities revealed areas of the crewstation where we lacked the data or guidance at the time to allow us the confidence to consider them as issues. We called each of these findings a "potential issue" and forwarded it to a later task for further analysis.

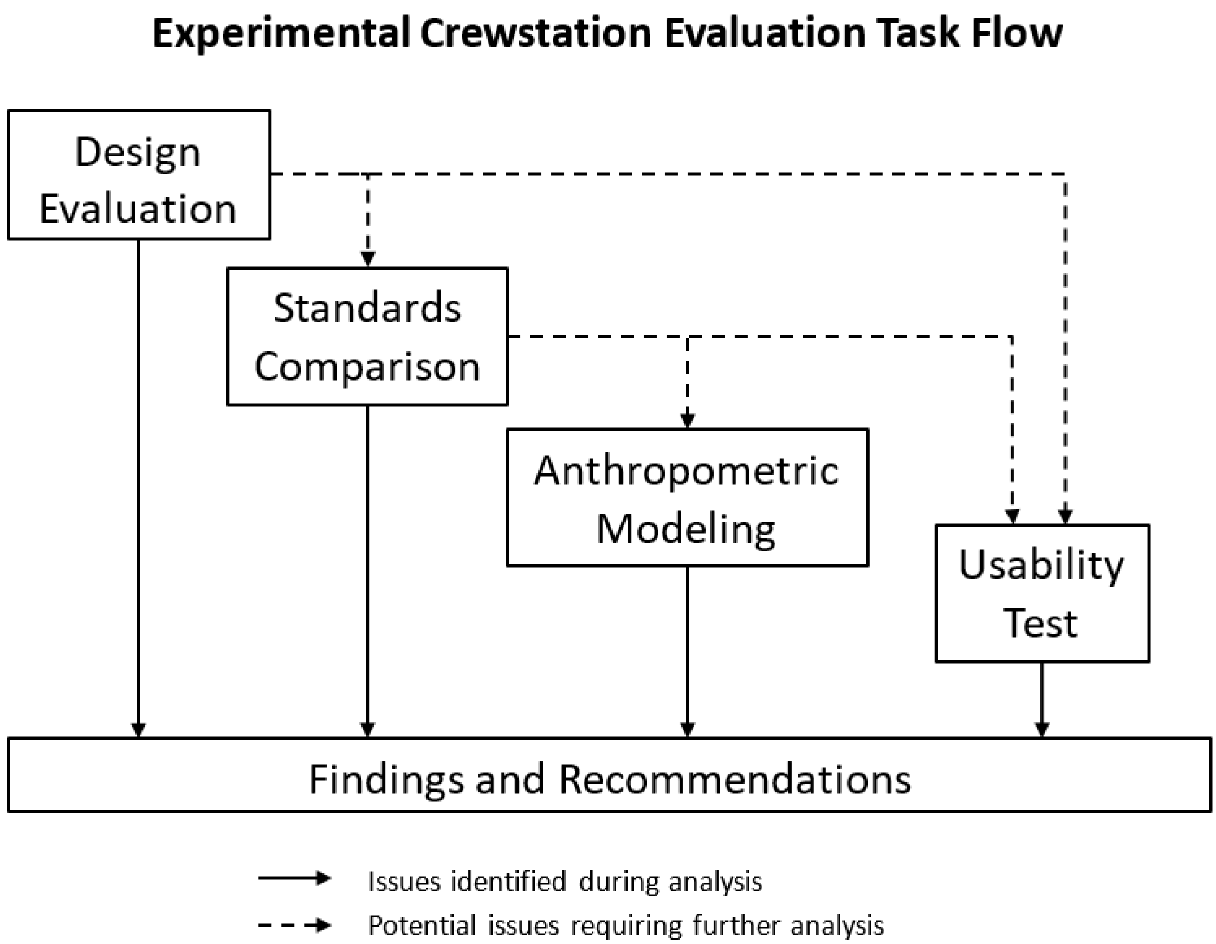

Figure 7. Task flow diagram

Figure 7 shows that each potential issue found support or refutation in one of the subsequent tasks. In this way, we supported each human factors issue we found with at least one of the following:

- Design criteria from Military Design Criteria Standard 1472G
- Computer-Aided Design (CAD) based anthropometric modeling data
- Performance, behavior and comments from target users (i.e., experienced engineers)

3.2 Use of Simulators

FRA's rail simulators housed at the Volpe Center were instrumental for the evaluation. Below is a description of how each of them was used.

3.2.1 The Cab Technology Integration Laboratory

CTIL is a rail simulator which was purchased by FRA in 2009 and is housed at the Volpe Center in Cambridge, MA (see Figure 8). CTIL's purpose is to provide "a platform for prototyping the human-machine interface of new locomotive cab technologies to assess their integration and impact on crew performance. As new capabilities emerge in the marketplace or are mandated to meet safety, cost and security requirements, CTIL can help to identify and mitigate risks and costs of technology integration in the locomotive cab by addressing risks associated with human performance" (Jones, M., Plott, C., and Olthoff, T., 2010).

Figure 8. CTIL Simulator housed at the Volpe Center

CTIL's key features include:

- A re-configurable cab interior
- Four large displays: two that display the forward view, one that displays the left side view, and one that displays the right-side view
- Three interior monitors with multiple choices for engineer information displays
- Realistic simulation software provided by an industry leader in the field (CORYS)
- Two hundred miles of simulated track in freight and passenger environments which exist in the real world, facilitated by a Memorandum of Understanding (MOU) between FRA and Burlington Northern Santa Fe Railway (BNSF)
- Video capture from multiple angles, and a tool to analyze the video for behavioral trends (Noldus Observer)
- Audio capture
- Intercom to simulate radio communications
- Data capture of control stand and simulation state variables up to 10 Hz

- An anthropometric modeling tool which enables evaluation of CAD versions of cab configurations using simulated engineers (RAMSIS)

FRA required that the experimental crewstation be integrated into the CTIL for evaluation. We used CTIL to evaluate the experimental crewstation because its features enabled us to collect human performance data with real engineers. CTIL enabled us to test the features of the experimental crewstation in ways which might otherwise be difficult or dangerous to do in the field, such as checking engineers' reactions to emergency situations and looking at how the automatic brake's design might encourage inaccurate use.

Additionally, CTIL also features an AAR-105 control figuration. We used this configuration in portions of our analysis to provide readers with a means for understanding how the experimental crewstation may provide (or deny) benefit to engineers compared to a familiar control configuration.

3.2.2 The Research and Locomotive Evaluator/Simulator (RALES)

The Volpe Center is also home to an older locomotive simulator owned by FRA, the Research and Locomotive Evaluator/Simulator (RALES). RALES is an exact, full-scale replica of an SD40-2 cab (see Figure 9) which contains an AAR-105 control stand and seat. Since RALES is not as easily reconfigured as CTIL and lacks some of CTIL's newer research capabilities, we used RALES only minimally in our evaluation.

Figure 9. RALES Simulator housed at the Volpe Center

In particular, RALES was used as an example of:

- Cab dimensions, including window height, for a line of sight analysis
- Variability in cab configurations using the AAR-105 control stand

The availability of this second simulator allowed us an additional data point for these sections and supplemented our use of CTIL, which was used for the majority of our evaluation.

3.3 Limitations

This section describes the elements of our approach that were left out or limit the generalizability of our findings: other control configurations, AAR-105 variability, simulator use and the prototype nature of the experimental crewstation.

3.3.1 Other Control Configurations

Since we used CTIL to evaluate the effectiveness of the experimental crewstation, we compared the system to the simulator's already installed AAR-105 during the standards comparison and anthropometric analysis tasks. We did this to provide readers with a means for understanding how the experimental crewstation may provide (or deny) benefit to engineers, compared to a familiar control configuration.

This expanded evaluation resulted in a major limitation, however, in that the AAR-105 is not the only common control configuration. A control configuration also commonly exists in which the controls are mounted horizontally on a desk, as shown in Figure 10. We did not evaluate this "desktop-style" control configuration because one was not available to us in CTIL.

Figure 10. Desktop-style control configuration (Transportation Safety Board of Canada, 1997)

If we had been able to use a desktop-style control configuration as an additional benchmark against the experimental crewstation, we likely would have found a different set of potential improvements. Moreover, a full understanding of any prototype control configuration requires an in-depth evaluation of all common current configurations.

3.3.2 AAR-105 Variability

The AAR-105 control configuration in CTIL, which we used for comparison against the experimental crewstation, is set 35 inches from the right-hand window of the cab. This distance allowed FRA to place two display monitors underneath the front window. The accompanying seat is centered in the space between the control stand and the right window.

Although CTIL features a setup with two forward displays, this configuration is not necessarily common in locomotives. RALES, for example, has the control stand positioned only 24 inches from the side window. This location forces the controls closer to the user (though it may also make it significantly more difficult to get in and out of the seat). Trains with configurations like this may have only one forward monitor, or two monitors mounted on the shelf adjacent to the horn, or other setups.

Additionally, the chair that we used for evaluations such as the one in the anthropometric analysis was the one that FRA purchased when CTIL was installed. It has an array of adjustability features (listed in Section 2 of this report) that other seats may not have, such as forward and backward adjustability. Conversations that we have had with engineers reveal that due to railroads buying differing equipment to support their employees and simply due to old or un-replaced equipment, seating in a locomotive can mean anything from a fully adjustable chair to a fixed. This variation in chair types can have a significant impact on the comfort of operating the AAR-105 control stand.

It is important for railroaders reading this report to understand that their railroad's particular control stand placement likely has a significant impact on how generalizable some of our conclusions are. If these railroaders believe their control configuration is different enough from CTIL's to invalidate some of these conclusions, they should keep in mind that the method we used to reach them could be applied to their own specific configuration.

In fact, this notion of generalizability due to control stand and seat configurations is an indicator that a study of common AAR-105 control stand setups and their benefits and drawbacks may be an extremely beneficial one for the community of cab designers.

3.3.3 Simulator Use

The use of CTIL simulator was very valuable because it provided us with a controlled environment to take measurements, and enabled us to get experienced engineers to use the controls and provide us with extremely useful insights.

Though there were many tangible benefits to using this approach, there were a number of limitations that arose as a result of using a simulated locomotive environment as the sole environment for this type of work:

- Due to the absence of a motion base in CTIL, it was impossible to replicate the vibration, rocking, or sudden onset forces that may occur in real operating environments. We understand that these issues are important ones and attempted to note where they may influence the findings. Since we did this work in the simulator, however, we did not have the ability to record real train cab data about these issues to further support them.
- The simulators do not have a rear view screen or mirrors, so it was not possible to simulate the view out the rear of the train. This made determining rearview window

placement difficult and limited the ability to collect detailed engineer data for how the chair would perform reverse maneuvers.

If the crewstation was evaluated in an actual operation environment, these issues could be examined, but many of the cost and safety advantages of using simulation would be lost.

3.3.4 Prototype Nature of the Experimental Crewstation

It is important to note that QinetiQ of North America, designed and built the experimental crewstation under an FRA contract to design and build the crewstation to demonstrate an alternative design approach and to gain an understanding about the human factors benefits and drawbacks of this alternative approach. Therefore, some materials issues identified, such as ones related to durability or materials types, may be due to choices made in prototyping that would be changed if this were a production-level device. We also have included this type of issue in our findings to ensure designers are aware of the need to address these limitations if the crewstation was ever built for production; however, they do not reflect on the quality of the design.

4. Preliminary Design Evaluation

This section describes the method and findings from the preliminary design evaluation we conducted on the experimental crewstation.

4.1 Method

In this phase of the evaluation, we identified flaws that may negatively affect the operability of the experimental crewstation, based on general usability practices. We used this evaluation to determine whether the experimental crewstation follows general usability principles, and to identify areas of its design that may lead to confusion or failure to perform key tasks. We performed this task to rapidly get a sense for where to focus our efforts in greater detail during later tasks. To perform the preliminary design evaluation, we examined the experimental crewstation and created a list of the potential major human factors issues, based on our own expertise and experience.

The preliminary design evaluation focused entirely on finding the major potential flaws in the crewstation, to guide later tasks in our evaluation. Those tasks provided a more in depth and rigorous look at the crewstation's benefits and flaws, as well as evidence supporting or refuting the concerns listed here.

4.2 Findings

This section describes the issues we found during the preliminary examination of the experimental crewstation. We have ordered the issues so that the ones we considered most important are listed first. The designers can manage limited resources for making updates to the chair by using this order as a prioritization.

4.2.1 Display Mount Instability

One of the most significant concerns we found was the potential for high levels of display motion. The experimental crewstation's displays are mounted on a vertical post which extends forward from the end of the right armrest (see Figure 11). The armrest is connected to the back of the chair at only one point. Since the weight of the three displays is 32 inches away from the point where it is attached to the chair, any motion of the engineer is amplified through the armrest and display mounts and results in a great deal of swaying. At times the displays may sway several inches to the left and right, sometimes causing them to knock against the side window. This display motion has several consequences that were concerning to us:

- Frequent banging of the displays against the window, which could potentially damage either the displays or the window
- Gradual damage to, or breakage of, the pole due to mechanical fatigue
- Impaired readability of any information displayed on the screens

Figure 11. Display mount on right armrest

It should be noted that we witnessed these complications in a simulated cab environment. This environment did not subject the experimental crewstation to the levels of shaking and rocking that it would experience on an actual locomotive. Since we were unable to simulate that kind of motion, we did not test the readability of the displays under those conditions. However, the degree of swaying is significant, and we expect that in an actual locomotive cab these forces acting on the mounting arm represent even greater potential for readability problems and equipment breakage.

4.2.2 Lack of Work and Storage Space

Locomotive engineers carry lots of paper with them to support their work, such as:

- Operations bulletins
- Temporary speed restriction bulletins
- Timetables
- Track warrants
- Booklets to record changes to train operations which arise during operation (called Form D's in NORAC rules, or Form B's in General Code of Operating Rules [GCOR] rules)

In previous studies using CTIL, we have seen that engineers use these notes frequently, write on them, and ultimately rely on them as reminders for speed changes or necessary, upcoming tasks. In fact, because of these needs, other researchers have begun looking at electronic methods for accessing this information (Liu, A. M., Oman, C. M., and Voelbel, K., 2014). Given some familiarity with these needs, we were concerned that the experimental crewstation may not adequately support engineers' use of paperwork due to its lack of any writing surface or storage, described below.

Figure 12 illustrates the storage and writing space differences between the AAR-105 control stand in CTIL and the experimental crewstation. The AAR-105 lacks storage space, but includes a small desk which is sufficient for jotting down notes and keeping paperwork easily accessible.

In contrast, the experimental crewstation has no place for paperwork, nor does it come equipped with a writing surface or desk of any kind, making the situation worse when compared to the AAR-105 in CTIL.

Figure 12. Engineer's view and workspace. AAR-105 control stand with desk space for worksheets (left), experimental crewstation without desk (right)

Some automation systems that exist in train cabs, such as Trip Optimizer and ACSES, allow for computerization of some of the tasks for which engineers currently use paper (U.S. Patent No. 20,100,023,190, 2010). As mentioned above, some prototype electronic systems (like one on an iPad, developed by MIT) are attempting to address the issue. It is possible that future cabs will be able to completely preclude the need for paperwork. Current systems, however, still require paperwork and we anticipated that the complete absence of workspace and storage space in the experimental crewstation would cause engineers a great deal of difficulty in current train cab implementations.

4.2.3 Risks of Standing in a Moving Locomotive

While standing operation would allow engineers a break from the discomfort that comes from being seated for long periods, it may be hard to maintain a standing position in a locomotive cab without robust securement. Locomotives occasionally encounter sudden heavy forces such as those from coupler breakage, hard coupling and decoupling operations, and simple run-ins from cars behind the locomotive.

Currently the seat only has a simple two-point seatbelt, but for standing operations a harness or three-point or five-point seatbelt may necessary to avoid falling when the locomotive experiences sudden jolts, and to raise the probability that these forces are distributed across joints rather than muscles and organs. Acceleration forces may be considerably more difficult to withstand while the engineer is in standing positions compared to experiencing them while being seated, though existing research notably does not account for back support when determining standing tolerances (Lewis, M. E., 2006).

Also, while an examination of the effectiveness of the experimental workstations vibrational dampening was beyond the scope of our evaluation, we did have one concern about its application. A locomotive cab environment is prone, of course, to a large amount of movement and vibration due to track conditions. The experimental crewstation's seat was designed to dampen these vibrations. This is a unique feature not found in current engineers' seats. However, this dampening benefit is only present during seated operation because the dampener exists between the seat and the floor. During standing operation, the impacts of cab motion will continue to present vibration risks. Engineers operating the experimental crewstation in a standing position will be exposed to vibration more directly via the floor, which may result in damage to their knees, hips, and spine. To mitigate these effects it may be beneficial to include a cushioned mat for standing operation.

4.2.4 Absence of Locking Ability

We noted that the experimental crewstation lacks the AAR-105's removable reverser feature we mentioned in Section 2. Removing the lever locks the locomotive in situations when:

- The locomotive is not being used.
- The locomotive is being used in series with multiple locomotives at the head end.
- The locomotive is being used with distributed power, where locomotives exist at various locations throughout the length of the train. This provides power for long trains and redistributes the forces in between cars.

This locking feature is important because inadvertent use of the reverser in these situations could result in damage.

The experimental crewstation does not include this feature. As a result, the design makes the locomotive vulnerable to accidental reverser actuation when being used in the scenarios listed above. For consistency with existing workstations and reduced risk of inadvertent control actuation, we recommend incorporating a locking capability into any future workstation designs.

4.2.5 Configuration of Frequently-Used Controls

Generally, controls that are frequently used should be the easiest to find and actuate. We believe that experimental crewstation's functionality could be enhanced by increasing the size of the frequently-used buttons and changing the position of the alerter.

Firstly, we determined that an increase in the size of frequently used buttons would maximize their accessibility. A user's ability to quickly reach buttons is mainly a function of the buttons' distance and size (Fitts, P. M., 1964). The experimental crewstation's alerter, horn and bell buttons are all closer to the user's resting hand than on the AAR-105 in CTIL. However, the buttons are only 0.5 inches wide, compared to 1.5 inches on the AAR-105 for the alerter (other controls are not buttons but have large targets for grasping). We believe that the experimental crewstation buttons' sizes may be unnecessarily limiting the effectiveness gained from making them more easily reachable. Designers could maximize speed of activating frequently used buttons by making them larger. The control boxes could tolerate larger buttons while maintaining proper separation by moving them closer to the edge of the boxes.

Secondly, the alerter is located far back on the armrest control panel, alongside the wiper controls. Our evaluators noticed that activating it was somewhat difficult, because their elbows were blocked by the backrest, as shown in Figure 13. To account for this, we recommend moving this frequently-accessed button forward on the button panel.

Figure 13. Posture required to actuate the alerter on the experimental crewstation (left), and natural hand position (right)

4.2.6 Lack of Intercom Speaker

We noted that the experimental crewstation does not include a location for an intercom speaker or accompanying volume control knob. It is likely that this was an oversight in the prototype. However, the intercom is presently used to communicate critical information to and from the engineer, such as:

- Information about issues that affect train operation and have emerged since the crew and train departed, such as bridge strike orders (to go slow over a bridge which had been struck by a passing truck) or so-called "stop and protect" orders to verify that grade crossing equipment is functional
- Communications between the conductor and engineer that occur during reverse operations and maximize the accuracy of the engineer's movements, such as car counts or distance to a goal
- Communication from dispatchers about emergencies that require the engineer to stop the train, such as a runaway railcar

We recommend adding a speaker and volume control for the intercom and conducting a test of the intercom system's operability and usability.

4.2.7 Seat Adjustability

We noted a number of potential issues regarding the fit and adjustability of the experimental crewstation seat:

- The seat does not allow vertical adjustment relative to the footrest, or vertical or lateral adjustment of the armrests. One of our smaller evaluators noted that it was hard for her to reach the footrest and that the armrests were uncomfortably far apart.
- One of our larger evaluators noted that in standing position he had no arm support.
- One guest engineer visiting our CTIL facility noted to us that some railroads encourage engineers to nap if they are confined to the train between shifts. The backrest cannot be reclined to support napping and may thus be an inconvenient place to nap. While it is important to note that the seat for the AAR-105 control stand in CTIL also does not recline, it appears to be a feature that may benefit engineers.

We decided to inspect these issues further in the standards comparison and anthropometric analysis tasks to learn about how the chair fits into the guidelines for these issues.

4.2.8 Risks of Seat Adjustment

Since the experimental crewstation was intended to convert easily from seated mode to standing mode, we were concerned with the process of adjusting the seat and the risks of injury to engineers while doing so. In converting the seat of the experimental crewstation from seated to standing operation, the engineer must pull a lever that drops the seat pan down. Since the footrest is attached to the seat pan, pulling this lever causes the two to lower in unison. This raises several issues:

- If the footrest is not raised enough before pulling the lever, there is a chance that it will fall to the floor when the lever is pulled. The instructions for the experimental crewstation state that the engineer should maintain a grip on the footrest before pulling the lever (see Figure 14). However, if engineers forget this step they could injure their feet if the footrest falls.
- There is a risk that the engineer may trip while attempting to leave the seated position to make an adjustment, or for that matter during rapid evacuation of the cab. Since the footrest is positioned between the engineer's legs and is several inches off the ground, it is possible that an engineer may trip over it if their right foot is caught while exiting the seat. This could result in an injury.
- Since the footrest is attached to the seat, engineers must use two hands to convert it to standing mode. Therefore, we believe that it would be unsafe to change the seat position while the train is in motion. We recommend that the engineer only change the seat position when the train is stopped.

Figure 14. Experimental crewstation seat conversion step showing engineer holding the footrest (right hand) while pulling the seat pan's drop lever (QNA Transportation Group, 2014)

It may be worthwhile to examine alternate adjustment methods, or safety measures that could mitigate the risks of adjusting the experimental crewstation.

4.2.9 LED Display Feedback

We observed that the combined throttle and dynamic brake position indicator in the experimental crewstation may not provide sufficient feedback to the engineer in certain situations.

In the experimental crewstation, the position of the combined throttle and dynamic brake lever is indicated by an array of colored LEDs, summarized in Table 3.

Table 3. LED light indications for throttle or dynamic brake

Lever Position	LED Lights Displayed
Throttle notches	One green LED light for each notch: for example, six green LED lights are shown when the throttle is in notch six
Idle	Solid white LED light
Setup	Blinking Blue LED light. Light turns solid when setup is complete
Dynamic brake	Red LED lights representing eight evenly spaced locations on the brake's continuous path between lowest and highest application of the brake

For engineers to understand their throttle position, they must count the green (or red) lights. While these lights may be easy to count when there are fewer than four lights illuminated, they may be more difficult to count quickly in the higher ranges. Additionally, since the dynamic brake is continuous, it is possible for the brake to be located between two notches, which cannot be displayed by these LEDs. To allow engineers to more quickly read the position of the dynamic brake or throttle, and to better reflect the position of the dynamic brake when it is between notches, we recommend that designers test out some alternative readouts, such as an analog numerical readout similar to the AAR-105, or a digital numerical readout for the throttle, or a higher-resolution line of LEDs for the dynamic brake.

4.2.10 Accidental Application of Automatic Brake and Emergency Functions

Another concern was that the experimental crewstation's automatic brake may allow for more frequent or over-applications of the automatic brake compared to the one in the AAR-105 in CTIL.

The Automatic brake in CTIL's AAR-105 control stand was designed based on the New York Air Brake model 26-L (see Figure 15). It has detents for the release position and minimum service, then a 3.28-inch arc of continuous movement to provide different application levels of the brake.[1] After this application range are detents for full service, suppression, handle off, and emergency positions. The range of movement between minimum and full service allows engineers to make small adjustments in braking to accurately control the train in different environments and scenarios.

[1] Range was determined by measuring the direct distance between minimum service and full service at the end of the brake handle, and then calculating the arc length geometrically.

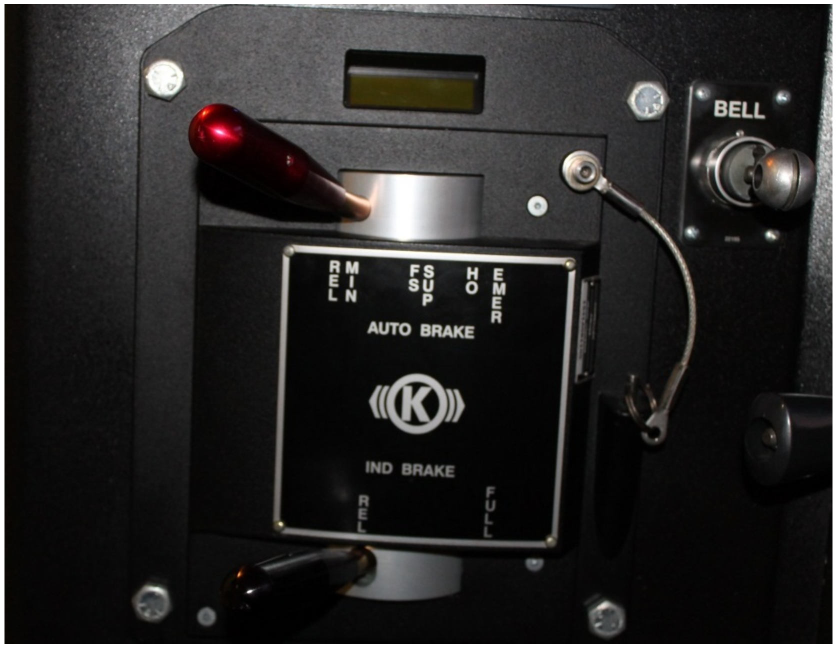

Figure 15. Automatic brake in CTIL's AAR-105 control stand, modeled after New York Air Brake model 26-L

The continuous service portion of experimental crewstation's automatic brake extends only 1.76 inches. We were concerned that this small range of movement might lead engineers to accidentally apply heavier braking than intended. The worst case for this type of error would be an accidental application of full service braking, an action that costs railroads money over time (due to replacement cost for brakes).

This action could also be dangerous because in direct release braking used in freight operations, the engineer cannot make an adjustment to lower a braking application without first releasing the brake. An accidental full service application of the automatic brake at the wrong time could lead to train damage; an unnecessary release of the brakes at an inopportune time could also result in acceleration of the train. If noticed, this acceleration could lead the engineer to force the train to stop to wait for the brakes to recharge. On the other hand, an unnoticed acceleration could lead a train to be extremely difficult for an engineer to control.

Since our concerns in this area we decided to explore them more in our usability test.

4.2.11 Throttle and Dynamic Brake Orientation

Upon this initial review, we had some concerns about the direction of the throttle and dynamic brake on the experimental crewstation. Figure 16 shows the throttle and dynamic brake in the AAR-105 control stand and the experimental crewstation.

Figure 16. Dynamic brake and throttle levers on the AAR-105 control stand (left) and on the experimental crewstation (right)

The throttle in the AAR-105 control stand is positioned at a 45 degree angle to the plane of motion of the train. In the experimental crewstation, the throttle has been combined with the dynamic brake and repositioned so that the lever is operated parallel to the plane of motion.

In the current design of the experimental crewstation, QinetiQ made the throttle “pull to power” for consistency with the AAR-105 throttle. However, because the throttle is aligned with the motion of the train, it is possible that users will not expect the “pull to power” orientation and will instead expect to push the lever forward to move the train forward (i.e., they may expect consistency of the direction of motion, rather than consistency with existing controls).

Since it is unclear whether the “pull to power” throttle orientation will be beneficial or lead to confusion, we decided to examine this issue during the usability test.

4.2.12 Shallow or Fragile Detents

We noticed that the detents for the combined throttle were particularly weak and could lead to inadvertent actuation. We were concerned that it may be easy for an engineer to move through multiple notches without realizing that is happening. This may lead to the engineer using more or less throttle than intended and to additional head-down time as the engineer determines where the throttle is positioned.

Further, the detents weakened over time. Over the course of approximately 80 hours of use, the detented controls that received the most use (such as the throttle) became noticeably smoother and shallower than the ones that received less use (such as the reverser). We attributed this change in detent depth to the construction materials used in the controls.

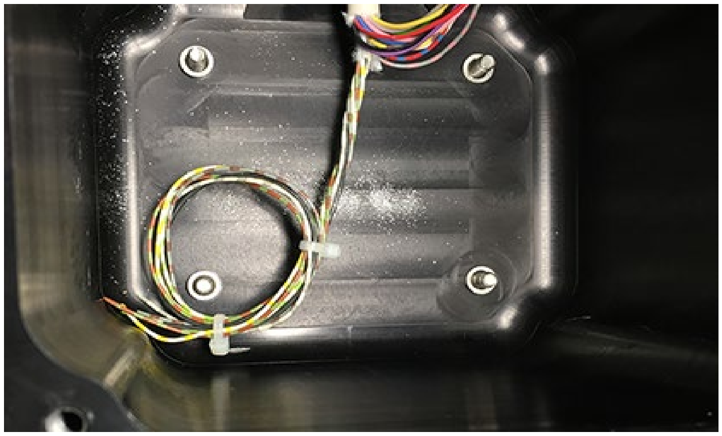

Figure 17. The silver powder-like crystals shown inside of the throttle control box are aluminum shavings from the detent housing caused by wear from the control lever's steel ball bearing

The detented control levers on the experimental crewstation consist of two pieces: a housing with hemispherical indentations attached to the control casing, and a ball bearing and spring attached to underside of the lever. As the lever moves, the ball bearing slides along the housing and into the indentations, which are aligned with the labeled lever positions.

The experimental crewstation's detent housings are aluminum, and the ball bearings are stainless steel. As a result, the ball bearing wore down the housing (see Figure 17). While it was understood that the experimental crewstation is a conceptual prototype that may not yet have been put through the mechanical rigor necessary for field implementation, it occurred to us that a materials engineering mismatch like this could be easily overlooked.

4.2.13 Rear and Side Visibility

We were concerned with the impact that the use of this chair may have on the operation of the train in reverse.

In a conventional seat, the engineer is often seated very close to the right window of the locomotive cab. This allows engineers to easily turn and look out the back of the cab or, with more difficulty, to lean out the window and look at the ground or the rear of the train. These are both actions that may be performed during reverse moves.

There are several factors in the experimental crewstation's design that may impede an engineer's access to the rear view:

- The experimental crewstation's right armrest does not fold up because the arm that holds the displays is mounted to it. This design impedes the engineer from leaning out the window to view the train's rear, and is exacerbated by the chair's more central position as mentioned above.
- The two displays on the right side of the mount may block an engineer's access to the cab's rearview mirrors.

The second issue may be remedied by simply moving the mirrors, but mirror sizes may dictate the feasibility of doing so, and they vary depending on the locomotive. Figure 18 shows a full size rearview mirror, but the Amtrak Acela is equipped with a small pneumatically controlled mirror that folds out when an engineer needs it.

Figure 18: Rearview mirror on a freight locomotive from a previous Volpe Center study

Since CTIL cannot model rearview mirror locations we recommend further study to determine where the mirror could be placed. Another option would be a rearview camera whose video could be displayed on one of the display monitors.

4.3 Summary

The preliminary design evaluation identified thirteen issues which may influence the effectiveness of the experimental crewstation, listed in Table 4.

Table 4. Summary of issues identified in the preliminary design evaluation

Issue	Summary of issue	Sections containing further analyses or discussion
Display mount instability	Displays are mounted to the right armrest with a single point of attachment, leading to dangerous levels of movement that impair readability and could damage the screens or window.	Standards Comparison
Lack of work and storage space	The experimental crewstation includes neither a desk nor storage space for paperwork, which engineers use frequently.	Standards Comparison; Usability Test
Risks of standing in a moving locomotive	The ability of standing persons to withstand shock and vibration may present problems for standing	None

Issue	Summary of issue	Sections containing further analyses or discussion
	operation. The crewstation seatbelt is unlikely to provide adequate support for these problems.	
Absence of locking mechanism	The reverser cannot be removed to prevent inadvertent damage, as is typical in other control configurations.	None
Configuration of frequently used controls	The size and placement of some of the most frequently used controls could be improved to allow for faster actuation and slightly more comfortable arm positioning.	Standards Comparison; Usability Test
Lack of intercom speaker	There is no intercom, which is essential to many tasks.	None
Seat adjustability	Some aspects of the seat, such as armrest height, are not fully adjustable for all users, particularly the tallest subset of the population. These issues appear to be worsened in standing position.	Standards Comparison; Anthropometric Modeling
Risks of seat adjustment	Conversion between the seated position and the standing position may cause injury if performed improperly.	Usability Test
LED display feedback	Throttle and dynamic brake positions are indicated by a series of LEDs which may be difficult to read and do not accurately reflect the continuous nature of the dynamic brake. Feedback can also be made clearer during dynamic brake set-up.	Standards Comparison; Usability Test
Accidental application of the automatic brake and emergency functions	The service range of the automatic brake is shorter than typical and it requires less force to actuate, increasing the risk of accidental brake applications or over-braking. There is also a related risk of accidentally actuating the emergency brake function contained in the automatic brake lever.	Standards Comparison; Usability Test
Throttle orientation	The "pull-to-power" orientation of the throttle and dynamic brake was designed for consistency with the obliquely-oriented AAR-105 control stand. This design may be different enough from the AAR-105 that pulling to throttle may be counterintuitive.	Standards Comparison; Usability Test
Shallow or fragile detents	Control lever detents are very weak relative to those in the AAR-105 control stand, and seem to be	Standards Comparison

Issue	Summary of issue	Sections containing further analyses or discussion
	weakening over time, increasing the risk of inadvertent actuations. This may be simply a prototyping issue.	
Rear and side visibility	The fixed right armrest and display screens may prevent access to the side window and mirrors.	Standards Comparison; Usability Test

Several potential issues were specifically addressed in our subsequent tasks, which take a more thorough look at the crewstation according to standards, anthropometric analysis and engineer performance data.

5. Ergonomic Assessment

This section details the analysis that we conducted during the ergonomic assessment of the prototype crewstation.

We assessed the degree to which the seat, controls, and display interface features and locations maximize engineer access and minimize repetitive stress and discomfort. In the standards comparison task, we did this by comparing these elements against a detailed standard for human factors. In the anthropometric analysis task, we did it by using RAMSIS, a three-dimensional CAD ergonomics tool.

5.1 Standards Comparison

In this analysis, we evaluated the experimental crewstation against the established human factors design criteria contained in the Department of Defense Design Criteria Standard for Human Engineering, MIL-STD-1472G. This standard provides specific recommendations on topics including design of controls, visual displays and labeling, ground vehicles, physical accommodations, maintenance accessibility, and workspace design, among others.

Our analysis revealed a number of strengths of the experimental crewstation that were consistent with the goals that shaped its design. The standards comparison task also revealed areas where designers can do further work to facilitate the health, safety, and performance of train crews. We summarize the purpose, approach, methods and results for this task below.

5.1.1 Purpose

The stated purpose of MIL-STD-1472G is “to present human engineering design criteria, principles, and practices to optimize system performance with full consideration of inherent human capabilities and limitations as part of the total system design trade space to more effectively integrate the human as part of the system, subsystems, equipment, and facilities to achieve mission success” (DoD, 2012). Consistent with this purpose, our analysis sought to identify areas where the experimental crewstation violated the standard and to put forward recommendations to address the most serious concerns to improve system performance and safety.

5.1.2 Approach

We tailored our analysis to the specific context of the experimental crewstation. Of the 15 sections of recommendations in the standard, there were six that we deemed relevant to our analysis:

- 5.1 Controls
- 5.2 Visual Displays
- 5.4 Labeling
- 5.6 Ground Vehicles
- 5.8 Physical Accommodations
- 5.10 Workspace Design

- 5.9 Maintenance Accessibility[2]

Each criterion within the relevant sections of the military standard served as a benchmark to examine the experimental crewstation and the AAR-105 control stand in CTIL. To present findings of the comparison in a thorough and organized fashion, we created a table for each relevant section of the standard, and identified whether each workstation complied with the standard according to Table 5.

Table 5. Rubric for standards comparison task

Status	Description
Conflict	Items which clearly and unambiguously violated the requirements of the standard in a way that we anticipated to have a significant negative impact on safety or efficiency
Minor Conflict	Items which violated the requirements of the standard but which we expected to have a less serious impact than other conflicts
Potential conflict	Items which were evaluated further in other phases of the crewstation evaluation for one of the following reasons: • The item may or may not have violated the standard depending on the findings of other, potentially conflicting criteria. • The item was in violation of the standard but may or may not present issues in practice due to specifics of locomotive operations not accounted for by the writers of the standard.
No conflict	Items that complied with the standard
Not applicable	Items that did not apply to the locomotive crewstation
Beyond scope	Items which apply to the locomotive crewstation but could not be evaluated in the simulator environment, or were not evaluated due to the crewstation's prototype nature

Once we had examined each relevant section of the military standard and added to the spreadsheet, we ordered any conflicts, minor conflicts, and potential conflicts that we identified according to our impression of their importance. We explored any items that we labeled "potential conflict" in more depth in later tasks.

[2] Maintenance accessibility was examined only for the experimental crewstation. Since maintenance issues are not the primary concern of this evaluation, this was done only to identify major issues related to the overall maintainability of the crewstation concept. It would not have been fair to compare it to the AAR-105, since the crewstation is in a prototype phase and maintenance issues have likely not yet been given full consideration. It is included last in this list due to this difference from the other sections analyzed.

5.1.3 Method

This section describes the criteria, tools, and limitations associated with the standards comparison task on the experimental crewstation and AAR-105 control stand.

5.1.3.1 Design Criteria

Out of many standards and handbooks that we examined, the Volpe Center chose MIL-STD-1472G for its comprehensive and detailed recommendations. It incorporates guidelines from the Department of Defense Handbook for Human Engineering Design Guidelines, MIL-HDBK-759C, and was last updated in 2012 to include the most recent technical and human factors knowledge. As a precedent for its use in transportation systems, MIL-STD-1472G has served as the backbone for other standards, including FAA's Human Factors Design Standard (HFDS), identification number DOT/FAA/CT-03/05 HF-STD-001.[3]

5.1.3.2 Tools

We used several different tools to support this analysis (see Table 6).

Table 6. Tools used to support the standards comparison task

Tool	Purpose
Extech 475044 handheld force gauge	Used to measure forces required to actuate controls; see Figure 19
Precision calipers	Used to measure small distances such as the spacing between controls or the height of label characters
Measuring tape	Used to measure large distances such as the height of the cab windows or dimensions of the workstation seats

[3] Other standards exist which have overlap with the MIL-STD01472G that may be beneficial as well. One such document is the Human Factors Engineering Data Guide for Evaluation (HEDGE). This standard was not used for our evaluation because it is geared around testing for the purposes of preparing for an implementation. We chose MIL-STD—1472G instead because of its easy application of design guidelines, which fits well for understanding the drawbacks in an experimental system.

Figure 19. An evaluator using the handheld force gauge to measure the automatic brake in AAR-105 control stand in CTIL

5.1.3.3 Limitations

Since the military standard allows for very thorough examination of many kinds of systems, some aspects of it do not apply to this crewstation evaluation.

There are some criteria that apply to trains, but not to this crewstation, such as heating and ventilation. Other criteria do not pertain to trains at all, such as criteria for weapon systems. We labeled these “not applicable” in our comparison. It is important to note that if the experimental crewstation is implemented inside a train cab, designers should ensure that it does not interact with other in-train systems in ways that violate the criteria of the standard.

Also, several other criteria could not be evaluated using CTIL, as described in Section 2. For example, the lighting conditions in the simulator cannot accurately replicate the range of lighting conditions that an engineer would encounter in operation. Therefore, we marked these items as “beyond scope” in the analysis tables. Designers should ensure that these criteria are met through further evaluation if the experimental crewstation is to be implemented in a train cab.

5.1.4 Results

The standards comparison revealed some ways in which the experimental crewstation may offer benefits as compared with CTIL’s implementation of the AAR-105 control stand and seat. It also found some areas in which the experimental crewstation is less effective than the AAR-105 in CTIL.

The major potential benefits and issues that we found are detailed below. For each area that we highlighted, relevant criteria from MIL-STD-1472G are included in table format for quick reference. Where it was relevant, we included figures demonstrating both the AAR-105 control stand in CTIL and the experimental crewstation to aid readers in visualizing these issues.

5.1.4.1 Significant Potential Benefits

FRA commissioned the experimental crewstation's design in an attempt to improve crew safety and performance. In some cases, it may meet the requirements of MIL-STD-1472G in areas where the AAR-105 control stand in CTIL did not. The criteria for which the experimental crewstation performed better than CTIL's AAR-105 control stand are listed in Table 7, and are discussed in further detail below.

Table 7. Design criteria from MIL-STD-1472G pertaining to the anticipated benefits of using the experimental crewstation rather than the AAR-105 control stand

Design Criteria
5.1.1.2.3 User-control orientation. Controls shall be oriented with respect to the user. Where a vehicle user may use two or more stations, the controls shall cause movement oriented to the user at the effecting station, unless remote visual reference is used.
5.1.4.3 High-force controls.
5.1.4.3.1 Use. Controls requiring user forces exceeding the strength limits of the lowest segment of the expected user population shall not be used. High-force controls shall not be used except when the user's nominal working position provides proper body support or limb support or both, e.g., seat backrest, foot support. Sustained (i.e., durations longer than 3 seconds) high-force requirements shall be avoided.
5.8.4.1.8 Range of motion. Table XXXVI[4] of MIL-STD-1472G (DoD, 2009) gives the ranges, in angular degrees, for all voluntary movements the joints of the body can make, as illustrated on Figure 54.[5] The designer should remember that these are maximum values; since they were measured with nude personnel, they do not reflect the restrictions clothing would impose. The lower limit shall be used when personnel must operate or maintain a component. The upper limit shall be used in designing for freedom of movement.
5.6.5.2.3 Field restriction. The visual field restriction shall not exceed 20 degrees of subtends with one eye.
5.8.5.2 Operability. The strength and endurance performance characteristics of weakest personnel performing the actual or equivalent task shall be accommodated to ensure operability. The maximum force that can be applied will depend on such factors as the type of control, the body member used to operate it, the position of this body member during control operations, the general position of the body, and whether or not support is provided by backrests. Because human strength and endurance are specific to the task performed, accommodation of operability must be based on performance of the equivalent activity. Where accommodation is based on strength or endurance of a different activity, there must be a valid relation between the performance of the two activities.

[4] See Appendix D.

[5] See Appendix E.

Design Criteria
5.8.6.1 Exerted forces. The maximum amount of force or resistance designed into a control shall be determined by the greatest amount of force that can be exerted by the weakest person likely to operate the control. The maximum force that can be applied will depend on such factors as the type of control, the body member used to operate it, the position of this body member during control operations, the general position of the body, and whether or not support is provided by backrests.   **5.10.3.2.6 Compatibility**. Work seating shall provide an adequate supporting framework for the body relative to the activities that must be carried out. Chairs to be used with sit-down consoles shall be operationally compatible with the console configuration.   **5.10.2.1 Provision of workspace**. Workspace shall be provided to perform all operational and maintenance tasks by the central 90 percent accommodation for whatever specific range and type of user population is specified by the procuring organization (see Section 6.2 of MIL-STD-1472G [DoD,2009]) while wearing the appropriate (e.g., winter or PPE) clothing and using the required tools.   **5.10.2.2 Consideration of personnel**. In establishing the workspace, consideration shall be given to the number of personnel required to perform the work and the body positions required to do the work.   **5.10.2.12.4 Reach limitations**. Maximum effective forward reach (i.e., able to grasp and turn/push/pull) shall be 610 millimeters (24 inches) from the front of the user's body.   **5.10.2.12.5 Lifting forward reach**. Jobs requiring the user to lift more than 3.0 kilograms (7.0 pounds), or produce torque (e.g., turning a wrench), shall be kept within 305 millimeters (12 inches) of the front of the user's body. If a hazard (e.g., hot surface, electrical contact) exists within these reach envelopes, it must be guarded, removed, or moved beyond the maximum reach of the user.   **5.6.2.7 Head restraints**. For occupant vehicles, the headrest shall be attached to the seat bucket so that it moves with the seat bucket during stroking of the energy absorption mechanism so as to support and protect the head. The headrest shall be contoured to provide energy absorption qualities to minimize whiplash injuries for the desired range of the expected, clothed, occupant population. The headrest cushioning material shall also be resilient, durable, comfortable, and will not lump during use. The headrest shall not interfere with the ingress or egress of an occupant wearing a back-type parachute.

Overall, the experimental crewstation may be a substantial improvement over traditional control stands in terms of ergonomics, comfort, and operability.

The AAR-105 control stand is a large unit that was originally devised to house the large equipment needed to operate the controls. This large unit also allows controls to be very robust and resistant to breakage. Since the unit are a large size, it had to be placed to the left of the seat and angled toward the engineer to enable access. This means that to access the controls with both hands, engineers need to orient themselves to the controls, rather than have the controls oriented to them. Thus, engineers essentially have two points of orientation: the control stand and the front window (see Figure 20).

Figure 20. AAR-105 control stand with seat oriented toward controls (left); experimental crewstation with seat and integrated controls oriented toward the front window (right)

The experimental crewstation utilizes newer technology that is considerably smaller than that which was available when the AAR-105 control stand was originally designed. This allows for control placement surrounding the engineer and simplifies operation by providing just one physical point of orientation. In this sense the experimental crewstation successfully meets many of FRA's initial goals including:

- "While operating, all controls and displays shall be ergonomically accessible for use."
- "The crewstation shall be designed to ergonomically accommodate crew health…and reach requirements."
- "The crewstation shall accommodate primary and critical control features user accessible at/on positions." (Federal Railroad Administration, 2013)

By integrating the controls into the armrests in a forward-facing position, the experimental crewstation offers an improvement according to the criterion for User-Control Orientation.[6]

Additionally, the AAR-105 control stand incurs some variability in that any seat can be paired with it. Some seats, like the one in CTIL, may be installed somewhat further away from the controls due to the control stand's proximity to the window. Other seats may be nonadjustable and greatly limit access to the controls. In this sense integrating the controls into the seat ensures their compatibility with the seat, which is an improvement to the compatibility criterion listed in Table 7. This integration admittedly comes at a cost though, because it is difficult to replace seating without replacing controls, and also begs the question of whether providing better seating alongside AAR-105 control configurations can improve control access in a cost-effective manner.

Though some ergonomic issues remain, the experimental crewstation takes into consideration the positions required to operate the locomotive and allows for more comfortable positions on the whole than the AAR-105 control stand (see criteria for Provision of Workspace and

[6] The desktop-style control stand, which we did not evaluate, has this advantage as well.

Consideration of Personnel). As an example, Figure 21 illustrates the uncomfortable wrist positions required to operate several of the controls in the AAR-105 control stand; these positions are eliminated in the experimental crewstation.

Figure 21. A 50th percentile female evaluator operating the automatic brake in the AAR-105 control stand in CTIL (left), and the experimental crewstation (right)

Additionally, the experimental crewstation accommodates users' range of motion better than the AAR-105 control stand, as required by the criterion for Range of Motion. Placing controls along the armrests ensures that users are not required to operate controls beyond the 24 inch reach limitations specified limitations (see the criterion for Reach Limitations), and furthermore, that they are not required to produce torque by operating levers outside the specified 12-inch lifting reach envelope (see the criterion for Lifting Forward Reach). Some of the farthest controls in the AAR-105 control stand in CTIL, such as the breaker switches on the far right of the control stand, are in violation of these requirements. We also conducted further exploration of the ergonomic benefits of the experimental crewstation during the anthropometric modeling task.

Controls in the experimental crewstation are not only easier to reach, but also easier to activate. Unlike the AAR-105 control stand, which nears the maximum force criteria for some controls such as the automatic brake (see Appendix B and Appendix C), none of the controls in the experimental crewstation require high forces to operate. Therefore, it may better accommodate the weakest personnel as required in the criteria for High Force Controls, Operability, and Exerted Forces.

By improving the placement and operability of controls and addressing a number of ergonomic requirements not met by the AAR-105 control stand in CTIL the experimental crewstation successfully meets many of FRA's initial goals (Federal Railroad Administration, 2013) including:

- "While operating, all controls and displays shall be ergonomically accessible for use."
- "The crewstation shall be designed to ergonomically accommodate crew health…and reach requirements."

- “The crewstation shall accommodate primary and critical control features user accessible at/on armrest positions.”

Lastly, the experimental crewstation includes a headrest to reduce whiplash injuries, which is a feature that the AAR-105 seating in CTIL does not have.

Despite these advantages, the experimental crewstation has plenty of room for improvement according to the standard. In the following sections, we detail the issues identified in this standards comparison, as well as potential improvements that could bring the experimental crewstation even closer to meeting FRA’s design goals and maximizing engineers’ safety and performance.

5.1.4.2 Human Factors Issues

In addition to noting the potential improvements the experimental crewstation offers, we identified a series of issues that we believe will affect the performance of engineers using it. These issues are ordered below, with the most severe ones listed first.

Display Vibration

We had identified display motion as a serious issue in the preliminary design evaluation task. MIL-STD-1472G guidance, listed in Table 8, supports this as an issue because it specifically requires that display vibration must not interfere with the operator’s ability to read onscreen content.

Table 8. Criteria from MIL-STD-1472G that addresses display vibration

Design Criteria
5.2.1.1.6 Vibration of display. Vibration of visual displays or of observers shall not degrade user performance below the level required for mission accomplishment (see Section 5.5.5 of MIL-STD-1472G [DoD, 2009]). In a mobile environment, vibration of visual displays or of observers shall not degrade user performance below the level required for mission accomplishment.

We had identified in the preliminary design evaluation that the displays are mounted on a post that extends outward from the right armrest, and any movement of the chair is amplified through it (see Figure 11). Given that the vibration caused by the engineer’s motion leads to significant motion and reduced readability, we are confident that this issue would be significantly worse in an actual locomotive. This is a violation of the Vibration of Display requirement.

It is extremely important to note that this single-attachment design is a vital part of FRA’s goal for the experimental crewstation. To facilitate integration of displays (which is important with the advent of automation systems), FRA wanted the displays to move if the seat was rotated. Satisfying this requirement while also allowing engineers to get into the seat dictates that the display mount be attached only on one side of the seat, and this by definition will incur instability.

If this requirement is vital to FRA's goals, we recommend additional research into stabilizing the displays with additional points of attachment on the right side. Elimination of vibration or motion may not be possible with this particular crewstation. Ideally the display mounts would be small, strong, and feature shock absorption of some kind. Most importantly, it should extend from a large base that is very stable. The chair selected for the experimental crewstation does not have this base.

On the other hand, separating the displays from the chair and mounting them on a post attached to the floor and ceiling would stabilize the monitors, but would not allow them to move with the seat. It may be possible to provide a single small attached monitor to the experimental crewstation that only displays a small subset of information, for use when the seat is turned substantially, but a more involved series of studies would be needed to figure out what should be displayed and whether it can be displayed on a small enough screen that would not suffer from vibration effects. Alternatively, head-up displays might be embedded in the windshield; these might be adjusted vertically by electronics in accordance with the user's eye point, but would also lack the ability to rotate with users.

Resolving these issues would improve the success of the experimental crewstation to provide improved human performance and safe operation of the train.

Lack of Work and Storage Space

The preliminary design evaluation task revealed the need for engineers to reference paperwork in their day-to-day operations. Several criteria in MIL-STD-1472G support this need; these are listed in Table 9.

Table 9. Criteria from MIL-STD-1472G that address work and storage space

Design Criteria
5.10.2.8 Storage space. Adequate space shall be provided on consoles or immediate work space for storing manuals, worksheets, and other required materials to include basic operational equipment.
5.10.3.1.2 Work surface. Unless otherwise specified (see Section 6.2 of MIL-STD-1472G [DoD, 2009]), work surfaces to support documents such as job instruction manuals or worksheets shall be 90 to 93 centimeters (35.4 to 36.6 inches) above the standing surface. If the work surface is being used for locating certain types of controls (joystick, track ball, and keyboards), it shall be 102 to 107 centimeters (40.1 to 42.1 inches) above the standing surface. Care shall be taken, when combining a horizontal workspace and a control panel, to ensure that users will have adequate workspace (minimum of 25 centimeters (9.8 inches) deep) and that they will be able to reach the control panel (maximum of 40 centimeters (15.7 inches) deep).
5.10.3.2.3 Writing surfaces. If consistent with user reach requirements, writing surfaces on equipment consoles shall be not less than 40 centimeters (16 inches) deep and 61 centimeters (24 inches) wide.

We noted in the preliminary design evaluation that the experimental crewstation has neither writing nor storage space. These criteria offer a confirmation of those findings.

Though the writing surface in the AAR-105 control stand in CTIL is relatively small, it is sufficient to meet the Work Surface and Writing Surface criteria where the experimental crewstation does not.

Notably, both workstations tested fail to meet the Storage Space criterion, but the AAR-105's desk space is available for engineers to keep paperwork during train operation, and there are many spaces in CTIL near the control stand and desk were a folder system could be installed. The experimental crewstation's attached controls and displays, on the other hand, restrict access to forward wall where folders could be installed.

We deemed this lack of workspace in the experimental crewstation a major concern because of the frequency with which engineers are required to reference paperwork. It is conceivable that future train cabs will provide sufficient automation that using paperwork is not an important component of train operation, but that it is not currently the case.

We recommend incorporating a workspace to allow engineers to write notes, and to provide storage space so that engineers can easily keep track of the necessary papers. While we considered ideas such as a fold-out table similar to college auditorium desks and hooks for clipboards on the vertical display mount, each of these ideas had major drawbacks. Extending desk space is temporary and makes it hard to get out of the seat, for example, and clipboards hanging on a hook are prone to swinging. This may be a difficult issue to resolve with the current experimental control configuration.

Failing to address this issue may result in significant safety risks, such as failure of engineers to adhere to speed restrictions listed on misplaced paperwork or increased head-down time while engineers struggle to store or retrieve paperwork in makeshift storage locations.

Accidental Actuation of Automatic Brake and Emergency Functions

The preliminary design evaluation noted the potential for inadvertent actuation issues in the experimental crewstation. MIL-STD-1472G includes a number of criteria addressing the proper protection of controls from accidental actuation, particularly emergency controls. These criteria are listed in Table 10.

Table 10. Criteria from MIL-STD-1472G that address accidental actuation of emergency controls

Design Criteria
5.1.1.3.9 Emergency shutoff controls. Emergency shutoff controls shall be accessible, not hidden, located to prevent accidental activation, and positioned within easy reach of the user (see Section 5.1.1.7 and 5.1.1.8 of MIL-STD-1472G [DoD, 2009]).
5.1.1.8 Prevention of accidental actuation.
5.1.1.8.1 Location and design. Controls shall be designed and located so that they are not susceptible to being moved accidentally or inadvertently, particularly critical controls where such operation might cause equipment damage, personnel injury, system performance degradation, or system shutdown of mission critical equipment where a reboot period is necessary to restart the equipment.

Design Criteria
5.1.1.10.2 Consistency of use. A control used for a critical/emergency use function shall be dedicated to that function only. **5.6.3.4 Control of hazardous operations**. The operation of switches or controls which initiate hazardous operations shall require the prior operation of a locking control.

According to the criterion for Emergency Shutoff Controls, these should be used exclusively in emergency situations, but in current locomotive control stations this is not the case; emergency braking is done by increasing the application of the automatic brake beyond a certain point. Because so many trains operate this way, recommending that the experimental crewstation follow these criteria rather than matching existing control stations could lead to negative transfer effects. Therefore, in this case, consistency between workstations may be more important than adherence to the Consistency of Use criterion.

In contrast to the emergency brake, the end-of-train (EOT) emergency device is an example of a control used exclusively for emergencies and properly protected from inadvertent actuation in both workstations. It is properly protected from inadvertent actuation with a cover and is only used for emergency functions in accordance with criteria for Control of Hazardous Operations and Consistency of Use. Though it is covered, it remains easily accessible when needed as stated in the criterion for Emergency Shutoff Controls. The EOT Emergency switch is shown in Figure 22 on the experimental crewstation, and is comparable in the AAR-105 control stand, though it is located farther away.

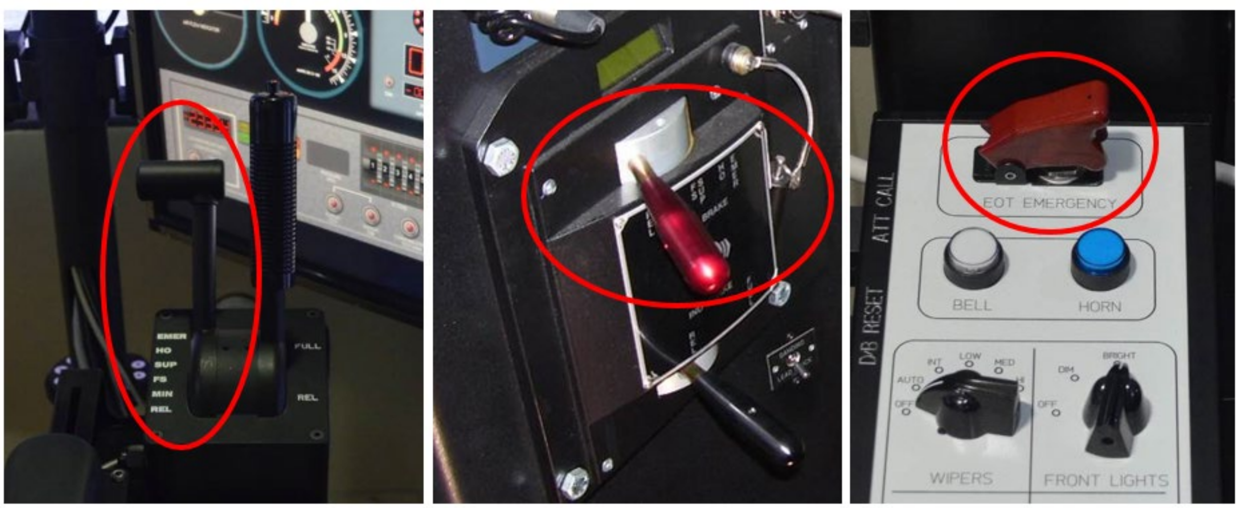

Figure 22. Emergency controls. Automatic brake lever with emergency brake function in the experimental crewstation (left), automatic brake lever with emergency brake function in the AAR-105 control stand (center), and end of train emergency device on the experimental crewstation

Continued protection of the EOT switch from inadvertent actuation and improved differentiation of the emergency functions of the automatic brake will help prevent accidental actuation of emergency controls in the experimental crewstation.

In the preliminary design evaluation, we also noticed that the automatic brake in the experimental crewstation is at a higher risk of inadvertent actuation compared to the AAR-105 control stand in CTIL. (See Figure 22 for an illustration of emergency controls in both workstations.) In the AAR-105 control stand, strong detents and a moderate travel range between minimum and full service minimize the risk the automatic brake lever from being accidentally moved into the emergency braking position. However, in the experimental crewstation there may be an increased risk of accidental actuation due to the shallow detents and the shorter travel range of the lever.

In addition to this risk, it is possible that emergency braking could be actuated if the brake were bumped accidentally. This bumping is less likely to occur in the experimental crewstation because engineers not need to pass by the controls on their way to sitting in the seat, but it remains a possibility with serious consequences. The consequences of accidentally applying the emergency brake may risk the safety of the train with possible outcomes such as brake damage or derailment depending on the circumstances in which it occurs.

According to the standard, controls that are directly in front of users, especially when supported by armrests, are the most apt to accept high forces for actuation. Sue to this, we recommend strengthening detents and/or increasing the distance that the control must travel to activate emergency braking to reduce the risk of accidental actuation.

Control Distribution and Interference

The optimized configuration of controls was one of the primary goals in the design of the experimental crewstation. In the course of this standards comparison we identified several concerns regarding the position of the controls due to the potential for control interference or unequal distribution of workload. The criteria from MIL-STD-1472G relevant to these issues are listed in Table 11.

Table 11. Criteria from MIL-STD-1472G that address control interference and distribution of workload

Design Criteria
5.1.1.1.2 Distribution of workload. Controls shall be selected and distributed so that none of the user's limbs will be overburdened.
5.1.1.3.8 Control interference. The size, shape, and location of controls shall be designed to ensure that the operation of any one control does not interfere with the user's ability to use other controls and to perform other duties.

The current distribution of controls places the throttle, dynamic brake, bell, horn, and alerter (see Figure 23) all on the left-hand side. This may lead to the overburdening of the left arm at times when the user may want to operate several of these controls either concurrently or in quick succession, in violation of the Distribution of Workload criterion. Additionally, due to the placement of levers slightly laterally to the armrest, the closer levers may occasionally block the outer ones depending on their position. In particular, the automatic brake may sometimes be positioned such that it is difficult to reach the independent brake and bail. Such control interference violates the criterion for Control Interference.

Figure 23. Left hand side controls including throttle and dynamic brake, reverser, end-of-train emergency switch, horn, bell, lights, and alerter (left). Right hand side controls including automatic brake, independent brake, sand buttons, engine run, generator field, fuel control, grid reset, and lights (right)

In contrast to this, the AAR-105 does not suffer from such effects. Despite the fact the users need to orient themselves to the controls by turning away from the front view, the wide panel of the control stand affords two handed operation in many different situations.

To resolve these issues in the experimental crewstation, it may be beneficial to consider optimizing the control layout to allow for such two-handed operations. Additionally, we recommend moving the levers on the crewstation so that they are in front of the armrests, rather than to the sides, or angling them slightly to minimize the interference that occurs. Moving the levers would allow designers to provide a bigger button panel, which would provide added space for the duplicated controls.

The degree of control interference may not immediately compromise the safety of the train; however, easily reachable controls that allow concurrent operation may reduce frustration and allow the crew to maintain greater situational awareness.

Location of Frequently-Used Controls

In addition to the control interference issues associated with the distribution of controls in the experimental crewstation, we deemed the location of primary controls a human factors issue. Though this experimental crewstation remains a notable improvement over traditional control stands in this aspect, it could be further improved to maximize the ergonomic benefits to crew comfort and health. Relevant criteria from MIL-STD-1472G are listed in Table 12.

Table 12. Criteria from MIL-STD-1472G that address the position of primary controls

Design Criteria
5.1.1.3.3 Location of primary controls. The most important and frequently used controls (particularly rotary controls and those requiring fine settings) shall have the most favorable position for ease of reaching and grasping.
5.1.4.2.2 Continuous adjustment linear controls. Continuous adjustment linear controls shall meet the following:
(a) Levers
(4) Limb support. When levers are used to make fine or continuous adjustments, support shall be provided for the appropriate limb segment as follows:
(a) For large hand movements – elbow
(b) For small hand movements – forearm
(c) For finger movements – wrist

As discussed in the preliminary design evaluation, some of the most frequently used controls are not in what could be considered an optimum position, even though the placement of primary controls within users' range of motion is a significant improvement over the AAR-105 control stand.

Additionally, the experimental crewstation may not meet the criterion for Continuous Adjustment Linear Controls, which requires forearm support for the use of levers. The location of control levers lateral to the armrest means that engineers can only rest their elbows, not their entire forearms, while using the controls. We believe that if the levers were moved inward so that they were at the end of the armrests where the engineers' hand normally rests, the engineer could make better use of the crewstation's forearm support while making continuous lever adjustments in keeping with the criteria listed above.

Figure 24. Use of experimental crewstation levers with limited forearm support (left), suggested position of levers to improve utilization of armrests (right)

Movement of the control levers closer to the natural resting position of the engineers' hand as shown in Figure 24 could also facilitate the relocation of control boxes, enhancing the overall accessibility of controls.

Use of Push Buttons

The standards comparison also found that the selection of control types needs improvement. In particular, the designers used push buttons for several controls where another control type would be better suited according to MIL-STD-1472G. Table 13. includes the criteria related to use of push buttons.

Table 13. Criteria from MIL-STD-1472G that address the use of push buttons

Design Criteria
5.1.1.8.1 Location and Design. Controls shall be designed and located so that they are not susceptible to being moved accidentally or inadvertently, particularly critical controls where such operation might cause equipment damage, personnel injury, system performance degradation, or system shutdown of mission critical equipment where a reboot period is necessary to restart the equipment.
5.1.4.2.1 Discrete adjustment linear controls. Discrete adjustment linear controls shall meet the following: a. Push buttons (finger- or hand-operated). Push buttons shall meet the following: (1) Use. Push buttons shall be used when a control or an array of controls is needed for momentary contact or for actuating a locking circuit, particularly in high-frequency-of-use situations. Push buttons shall not be used for discrete control where the function's status is determined exclusively by a position of the switch, e.g., an on-off push button that is pressed in and retained to turn a circuit on and pressed again to release the push button and turn the circuit off. (2) Shape. The push button surface shall be concave (indented) to fit the finger. When a concave surface is impractical, the surface shall provide a high degree of frictional resistance. Large hand- or fist-operated, mushroom-shaped buttons shall be used only as EMERGENCY STOP controls. (3) Positive indication. A positive indication of control activation shall be provided (e.g., snap feel, audible click, or integral light). Tactile feedback shall be the primary form of positive indication. Other means for positive indication (e.g., audible click, light) shall be used in addition to tactile feedback and in cases where tactile feedback is not possible. (4) Channel or cover guard. A channel or cover guard shall be provided when accidental actuation of the control must be prevented. When a cover guard is in the open position, it shall not interfere with operation of the protected device or adjacent controls. (5) Dimensions, resistance, displacement, and separation. Except for use of push buttons in keyboards, control dimensions, resistance, displacement, and separation between adjacent edges of finger- or hand-operated push buttons shall conform to the criteria on Figure 14.
5.1.1.9 Feedback. There shall be no discernible time lag between a change in a system condition being controlled or monitored and its indication on a display. If a time lag between control actuation and ultimate system state is unavoidable, the system shall provide immediate feedback to the user of the process and direction of parameter change. Feedback shall indicate (without ambiguity, uncertainty, or error) to the user that the control is properly actuated, that the desired response is achieved, and when the desired response is complete. Critical control functions, such as those entered by keyboard, shall provide feedback to the user prior to entry to ensure that the keyed entry is errorless and is the one that the user desires to enter.

Table 14 shows the different ways the experimental crewstation implements push buttons.

Table 14. Push buttons on the experimental crewstation

Control	Push Button Details
Engine Run, Generator Field, Fuel Control	Square black push button with "click feel." Down position means that it is on. Pushing the button again disengages it
Ground Relay Reset	Square black push button. Releasing the button disengages it
Bell, Sanding/Lead Truck	Round blue push button with no "click feel." Pushing the button a second time disengages it
Horn, Sand	Round white push button. Releasing the button disengages it
Alerter	Round yellow push button. Releasing the button disengages it

Push buttons on the experimental crewstation control panels are used for several on-off functions. The criterion for Discrete-Adjustment Linear Controls states that push buttons shall not be used for on-off functions, and upon examining these push buttons the reasoning for this becomes clear: it is difficult to determine whether the push buttons on the experimental crewstation are in the down position ("on") or the up position ("off"). Figure 25 shows the push buttons used in the experimental crewstation and several of the slide switches used in the AAR-105 control stand for the same functions.

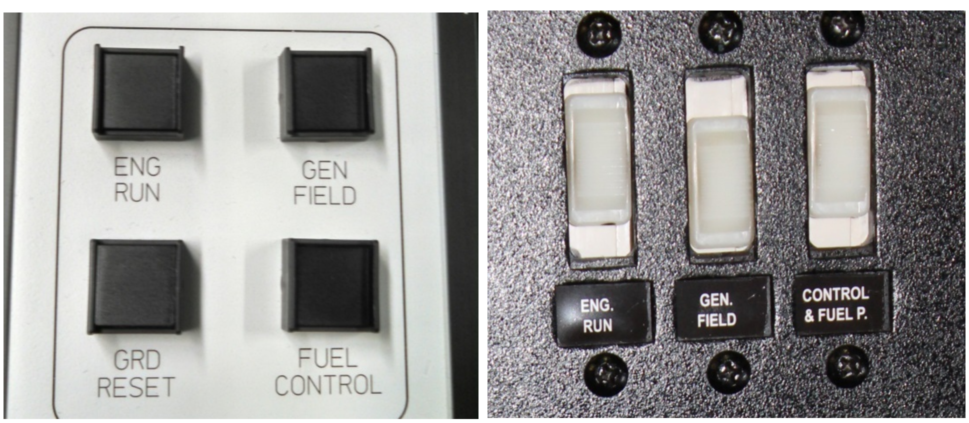

Figure 25. Experimental crewstation push buttons (left) are shown in the down position with the exception of "GRD RESET." AAR-105 control stand switches (right) are up with the exception of "GEN. FIELD"

The push buttons on the experimental crewstation also demonstrate why these criteria exist because similar-looking buttons do not always perform similar tasks. For example the ground relay reset button looks identical to the generator field, engine run and fuel control. Conversely, different buttons also perform the same mechanical tasks: the generator field, engine run and fuel control work the same as the bell, but the buttons work differently. Additionally, these push buttons are at risk of accidental actuation according to the criterion for Location and Design.

We recommend following the standard by using switches and breakers instead of push buttons because they are less likely to be confusing and are potentially harder to bump.

Another issue with this implantation is the lack of feedback. The AAR-105's controls for these functions successfully communicate information at a glance. If push buttons absolutely *must* be used, the control should give feedback in the form of "snap feel" an audible click, or illuminated light so that users know that they have activated the control (even this has its drawbacks, as a broken light can communicate the wrong information). This feedback should be implemented in the same manner for all push buttons.

We recommend using some form of toggle, rocker, or slide switch for on-off controls in place of push buttons. These control types allow for clear and reliable visual feedback, enabling users to more quickly note the position of controls.

This issue is unlikely to directly impact the safety of the train because many of these controls are used at the beginning of a route and not often afterwards. However, this issue is important to address because it has the potential to contribute to confusion and delayed situation awareness.

The criterion for Discrete Adjustment Linear Controls also provided support for the concern we raised in the preliminary design evaluation about button size. For fingertip-actuated buttons, the recommended size range is 0.4–1.0 inches in width for bare-handed use, but it specifies a minimum of 0.75 inches for designs where users might be wearing gloves. Given that freight trains are often run in cold and exposed conditions it is likely that engineers would sometimes wear gloves. Increasing the button size would help activation speeds, as we discussed earlier, but would also better accommodate gloved hands.

Coding of Emergency Controls

Coding allows users to quickly differentiate between controls and select the proper action. In emergency situations, it is particularly important for users to quickly select the proper control; therefore, it is critical for emergency controls to adhere to the criterion from MIL-STD-1472G shown in Error! Reference source not found..

Table 15. Criteria from MIL-STD-1472G that address coding of emergency controls

Design Criteria
5.1.1.4 Coding. **5.1.1.4.1 Methods and requirements**. The use of a coding mode (e.g., size and color) for a particular application shall be governed by the relative advantages and disadvantages of each type of coding (see Table IV).[7] Where coding is used to differentiate among controls, application of the code shall be uniform throughout the system and other systems expected to be operated by the user.

There are several emergency use controls in the experimental crewstation, including the automatic brake which accesses the emergency brake function, and the end-of-train emergency switch.

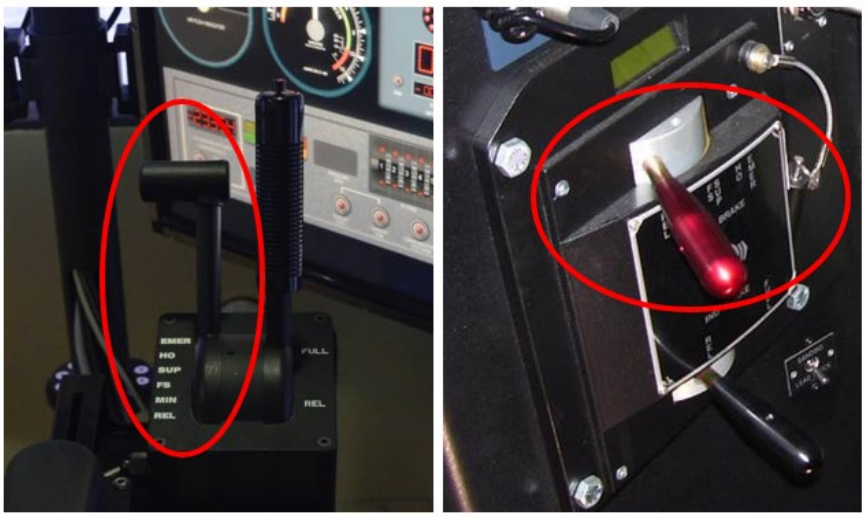

Figure 26. Automatic brake lever with emergency brake function in the experimental crewstation (left), automatic brake lever with emergency brake function in the AAR-105 control stand (right)

According to MIL-STD-1472G Table XVIII, color coding of lights, and MIL-STD-1472G Table XV (DoD, 2009), common color association meanings, the color red typically indicates "emergency," "severe threat," "stop," or "failure."[8] Therefore, it makes sense for emergency controls to be colored red.

In the AAR-105 control stand, emergency controls are coded properly with both the automatic brake lever and the EOT switch colored red, but in the experimental crewstation the automatic brake lever is black. See Figure 26 for an illustration of the automatic brake in each workstation. Engineers may use a variety of existing control stands, which may lead to confusion. In an

[7] See Appendix D.

[8] See Appendix D.

emergency situation, engineers may look for a familiar red lever to activate the emergency brake. Therefore, it is recommended to color the automatic brake lever red in all locomotive workstations, including the experimental crewstation, if only for the sake of consistency.

We separated this coding issue from other, more minor issues because it applies to the emergency controls. It is critical to minimize the time that it takes to recognize and activate the proper control when it needs to be done in an emergency. Due to the possible safety impact, coding of emergency controls is particularly essential to reduce confusion and allow for maximized situational awareness.

Seating Dimensions and Adjustability

Improper seating increases the risk of ergonomic injuries and discomfort. Though the majority of ergonomic issues are addressed in the anthropometric modeling task, several issues were found during this standards comparison that violated the MIL-STD-1472G criteria listed in Table 16.

Table 16. Criteria from MIL-STD-1472G that addres seat adjustability and dimensions

Design Criteria
5.6.2 Vehicle seating. **5.6.2.1 Dimensions and clearances**. Vehicle operator seating dimensions and clearances shall be in accordance with Figure 41, Figure 42, and Table XXX of MIL-STD-1472G (DoD, 2009), as applicable.[9] [10] **5.6.2.2 Vertical adjustment**. Vertical adjustment of a seat to a higher position shall also increase leg room and footrest angle. **5.8.4.1.5 Adjustable dimensions**. Seats, restraint systems, safety harnesses, belts, controls or any equipment that must be adjusted for the comfort or performance of the individual user shall be adjustable for the range of personnel using them. **5.10.3.2.7 Seat pan and vertical adjustment**. Seat pan and vertical adjustment shall meet the following: a. The seat pan shall have an adjustable height of 38 to 54 centimeters (15 to 21 inches) in increments of no more than 3.0 centimeters (1.0 inch) each. b. If the seat height exceeds 53 centimeters (21 inches), a footrest shall be provided. c. Single-pedestal seats shall have a five-legged base. d. The seat pan shall have a 0- to 7.0-degree adjustable tilt rearward, be between 38 and 46 centimeters (15 and 18 inches) wide and not more than 40 centimeters (16 inches) deep. e. Where exclusive use by male personnel is specified (see Section 6.2 of MIL-STD-1472G [DoD, 2009]), the adjustable height of 40 to 54 centimeters (16 to 21 inches) shall be used. **5.10.3.2.10 Armrests**. Unless otherwise specified (see Section 6.2 of MIL-STD-1472G [DoD, 2009]), armrests shall be provided. Armrests that are integral with users' chairs shall be at least 5.0 centimeters (2.0 inches) wide and 20 centimeters (8.0 inches) long. Modified or retractable armrests shall be provided when necessary to maintain compatibility with an associated console. Armrests shall be adjustable from 19 to 28 centimeters (7.5 to 11 inches) above the compressed sitting surface. Distance between armrests shall be not less than 46 centimeters (18 inches).

[9] See Appendix D.

[10] See Appendix E.

Design Criteria
5.6.2 Vehicle seating. **5.10.3.2.12 Footrests**. Whenever the users must work for extended periods in seats higher than 46 centimeters (18 inches) or with work surfaces higher than 76 centimeters (30 inches), footrests shall be provided. Footrests, where provided, shall contain nonskid surfaces. Footrests shall be adjustable from 2.5 to 23 centimeters (1.0 to 9.0 inches) above the floor, not less than 30 centimeters (12 inches) deep, and 30 to 40 centimeters (12 to 16 inches) wide. Footrest inclination shall be 25 to 30 degrees.

The dimensions and adjustability of the seat pan are a major factor in the comfort of a seat. MIL-STD-1472G recommends an adjustable height range of at least 6 inches in the Seat Pan and Vertical Adjustment criterion; however, the experimental crewstation only allows 1.75 inches of vertical adjustment due to seating specifications that allow it to compress and extend to deal with forces on the vertical axis. The exact amount of adjustability varies depending on the weight of the operator, as it functions by allowing air to release from the pneumatic vibration dampening system. Also, the tilt of this seat cannot be adjusted.

It is also important to note that the seat height does not adjust at all relative to the attached footrest. This is contrary to the requirements in the listed criteria for Vertical Adjustment and for Footrests.

The experimental crewstation also has adjustability problems related to standing height. Firstly, its adjustable range is far too short to bring the chair's back high enough in the standing position; for most people, standing height is considerably higher than seated height. Secondly, the height adjustment button is located underneath the seat pan and inaccessible during standing mode.

The armrests in the experimental crewstation, while providing for more adjustability than the seat in CTIL's AAR-105 configuration, also pose a number of issues related to seat adjustability and fit, in violation of the criterion for Armrests. Though they do allow fore-aft adjustments, they do not allow any lateral or vertical adjustment. The armrests in the experimental crewstation are a somewhat wide 25 inches apart, which is three inches wider than the seat for the AAR-105 in CTIL and seven inches wider than the minimum requirement. Lateral adjustments may benefit smaller users who may find the current position of the armrests too wide (and the standard does not specify a maximum value), but vertical adjustment is by far the more critical. Figure 27 shows that when operating the crewstation in a standing position, the lack of vertical adjustability becomes immediately apparent.

Figure 27. An approximately 95th percentile male (left) and 50th percentile female (right) during standing operation demonstrate the lack of armrest adjustability

For smaller users, this lack of adjustability may not be problematic, but it is impossible for taller users to reach the armrests without slouching or leaning against the seatback with their legs extended forward. Because the criteria in the standard does not reference armrest height for standing operations we decided to explore that further in the anthropometric modeling tasks; for the remaining adjustability issues, the design standard alone is enough to conclude that the experimental crewstation needs improvement.

Seating adjustability is a human factors issue because of the likelihood of moderate ergonomic issues and discomfort over prolonged use. It is recommended to increase the vertical adjustability of the seat and of the footrest relative to it, as well as the height and width of armrests, which will greatly increase the comfort of users and will have substantial implications for their physical health.

Labeling for Dark Adaptation

Whenever equipment is operated at night, it is important to ensure that the operator is able to maintain adequate visibility and situational awareness. Several criteria in MIL-STD-1472G address the need for illuminated displays and dark adaptation, as outlined in Table 17.

Table 17. Criteria from MIL-STD-1472G that address labeling for dark adaptation

Design Criteria
5.1.2.1.6 Illumination. Adjustable illumination shall be provided for visual displays (including display, control, and panel labels and critical markings) that must be read under darkened conditions. Illumination shall be continuously adjustable or permit adjustment to a minimum of 30 increments throughout the full operational range from full bright to full off.
5.4.6.2 Dark adaptation. Where dark adaptation is required, the displayed letters or numerals shall be visible without impairing night vision (e.g., white on a dark background).
5.2.3.10.3 Intensity Control. The dimming of LEDs shall be compatible with the dimming of incandescent lamps.
5.2.3.13.14 Luminance Control. When displays will be used under varied ambient illuminance, a dimming control shall be provided. The range of the control shall permit the displays to be legible under all expected ambient illuminance. The control shall be capable of providing multiple step or continuously variable illumination. Dimming to full OFF may be provided in noncritical operations, but shall not be used if inadvertent failure to turn on an indicator could lead to critical user failures, i.e., failure to detect or perform a critical step in an operation.

In the AAR-105 control stand in CTIL, there is no adjustable illumination for the visual displays. However, white text is used for all control labels, per the criterion for Dark Adaptation.

When it comes to the experimental crewstation, the controls are labeled in a way that is inappropriate for darkened conditions according to the criteria for Illumination and Dark Adaptation (see Figure 28). The black text on a grey background may be difficult to read in dim lighting, and the lighter background may impair night vision according to these criteria.

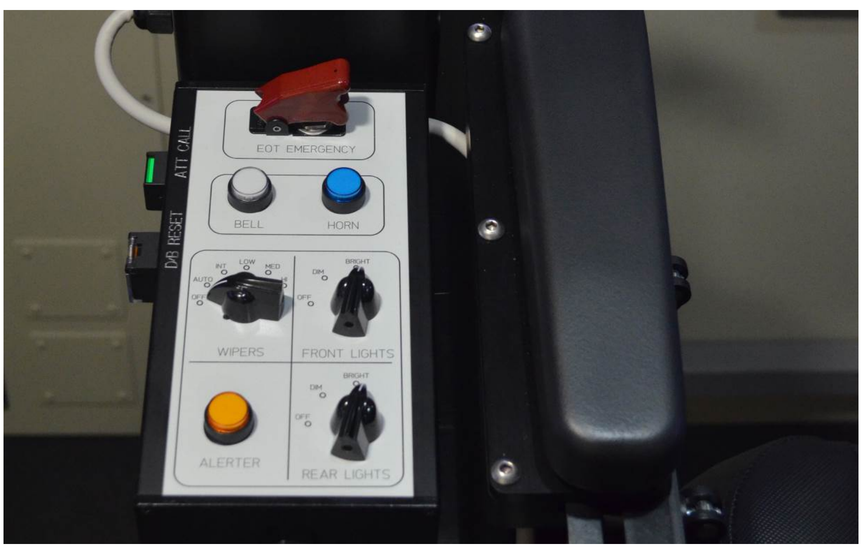

Figure 28. Left armrest control box with labels written in black text on a light gray background

One additional area where both the experimental crewstation and the AAR-105 control stand in CTIL fall short is control of the brightness of the labeling lights. Criteria for Intensity Control (for LEDS) and Luminance Control (for other labels) indicate that this lighting should be adjustable to account for different lighting conditions.

To improve readability in darkened conditions, it is recommended to use white text on a black background to minimize the impairment of night vision, and to provide adjustable illumination or backlighting for the labels. Only backlighting or self-luminous controls with dimmers would be acceptable in a locomotive cab, because of the need to preserve dark adaptation in many situations. Addressing this issue will improve the readability of the control labels without compromising night vision and will promote safe, efficient operations.

5.1.4.3 Potential Human Factors Issues

Some concerns were raised during this standards comparison that could not be easily addressed within the scope of this assessment. These issues required either more thorough ergonomic assessment or evaluation by users with greater familiarity with locomotive operations. Therefore, we assigned these concerns to the anthropometric modeling and usability test tasks to gain further information about them.

LED Display Feedback

In order for users to operate a system correctly, they must understand its current state and the outcome of their actions. We identified a number of these issues in the experimental crewstation during this standards comparison. Relevant criteria from MIL-STD-1472G are listed in Table 18.

Table 18. Criteria from MIL-STD-1472G that address feedback issues

Design Criteria
5.1.1.9 Feedback. There shall be no discernible time lag between a change in a system condition being controlled or monitored and its indication on a display. If a time lag between control actuation and ultimate system state is unavoidable, the system shall provide immediate feedback to the user of the process and direction of parameter change. Feedback shall indicate (without ambiguity, uncertainty, or error) to the user that the control is properly actuated, that the desired response is achieved, and when the desired response is complete. Critical control functions, such as those entered by keyboard, shall provide feedback to the user prior to entry to ensure that the keyed entry is errorless and is the one that the user desires to enter.
5.1.2.1.4 Feedback. a. Use. Feedback shall be provided which presents status information, confirmation, and verification of input throughout system interaction. b. System-status. Users shall be provided at all times with system-status information regarding operational modes and availability, either automatically or by request as needed. c. Computer response. Every input by a user shall produce a consistent, perceptible response output from the computer. In applications where the system intentionally produces no visual feedback as an indicator of invalid user input, an alternative form of feedback (e.g., different audio sound) shall be produced to ensure the invalid action is recognized by the user. d. System response time. Maximum system response times for real-time systems (e.g., fire control systems, command, and control systems) shall not exceed the values of Table V of MIL-STD 1472G (DoD, 2009).[11] Non-real-time systems may permit relaxed response times. System response times for real-time and non-real-time systems shall not exceed the response time of the equivalent existing or predecessor system. If computer response time will exceed 1.0 second, the user shall be given a message indicating that the system is processing (for remotely handled automated systems, see Section 5.12 of MIL-STD-1472G [DoD, 2009]). e. Task performance time. The time required to accurately complete a standard time sensitive action or sequence of actions (including system response time) shall not exceed the time to complete the same action(s) on the equivalent existing or predecessor system. f. Time-consuming processes. The system shall give warning information when a command is invoked which will be time consuming or resource-intensive to process
5.2.3.13.4 Equipment response. Lights, including those used in illuminated push buttons, shall display equipment response and not merely control position.
5.2.3.13.6 Positive (active) feedback. Changes in display status shall signify changes in functional status rather than results of control actuation alone.
5.2.3.15 Simple indicator lights.

[11] See Appendix D.

Design Criteria
5.2.3.15.1 Use. Simple indicator lights shall be used when design considerations preclude the use of legend lights. **5.2.3.13.6 Positive (active) feedback**. Changes in display status shall signify changes in functional status rather than results of control actuation alone

We had identified during the preliminary design evaluation that it may be somewhat difficult for engineers to identify which notch they are in by simply glancing at the array of LEDs, especially as more lights are illuminated and the time to count them is increased. We noted that a simple numerical readout may be preferable, since it would be easier to read at a glance. This notion is supported by the criterion for Simple Indicator Lights, which indicates that legend lights (in this case, numbers) should be used in place of simple indicator lights when possible.

Figure 29. Combined throttle and dynamic brake in a series of positions: set up (left), dynamic notch 5 (center), and dynamic notch 8 (right)

The combined throttle could also provide improved feedback during the dynamic brake set up period (see Figure 29). Currently, the experimental crewstation flashes a blue LED for 10 seconds, then ceases blinking and displays a solid blue light to indicate that the system is done with setup. If the lever is moved into a braking position during the 10 second window, setup will continue until the system is ready at which point the dynamic brake will engage; however, the blue LED disappears and is replaced by red LEDs to indicate the dynamic brake position. This conflicts with the Positive Feedback criterion. A simple improvement would be to continue to flash the blue light in addition to illuminating the red dynamic brake lights while the lever is in a dynamic braking position if the system is still in set up. This would more accurately reflect the system response rather than the control position, as required by the criteria listed for Feedback and Equipment Response.

In contrast to the experimental crewstation's LED lights, the AAR-105 control stand in CTIL uses numerical readouts to indicate notch and dynamic brake position, which is in agreement with the criteria presented in the table. Additionally, the operator receives tactile, kinesthetic, auditory, and visual indications when the dynamic brake is in set up.

Though it seems likely that using a numerical readout would be preferable to the LED display, it is unclear how difficult engineers will find the LED display to use in practice. Therefore, we examined this issue in the usability test as well.

Throttle and Dynamic Brake Orientation

The issue of throttle and dynamic brake orientation which we identified in the preliminary design evaluation is particularly complicated because several of the requirements that pertain to this issue, found in Table 19, are seemingly contradictory. The orientation that is most consistent with the AAR-105 control stand and other conventional workstations is the opposite of the orientation that seems most intuitive and is recommended by several criteria in the standard.

Table 19. Criteria from MIL-STD-1472G that address orientation of the throttle and dynamic brake

Design Criteria
5.1.1.2.1 Consistency of movement. Direction of control movement shall be consistent with the related movement of an associated display, equipment component, or vehicle. In general, movement of a control forward, clockwise, to the right, up, or pressing a control, shall turn the equipment or component on, cause the quantity to increase, or cause the equipment or component to move forward, clockwise, to the right, or up. Valve controls are excluded (see Section 5.1.1.2.4 of MIL-STD-1472G [DoD, 2009]).
5.1.1.3.4 Consistency. The arrangement of functionally similar, or identical, primary controls shall be consistent from panel to panel throughout the system, equipment, or vehicle, and other systems expected to be operated by the user (e.g., a movement of a control to the right or left shall result in a corresponding movement of a displayed element to the right or left).
5.1.2.3.7 Digital displays. Clockwise movement of a rotary control or movement of a linear control forward, up, or to the right shall produce increasing values in digital displays.
5.1.2.3.9 Common plane. Direction of control movements shall be consistent with related movements of associated displays, equipment components, or vehicles.
5.1.2.3.13 Arrays of indicator lights. A bottom-to-top or left-to-right movement in an array of indicator lights shall represent increasing values.

As discussed in the preliminary design evaluation the combined throttle on the experimental crewstation is oriented so that pulling back on it moves the train forward (so-called "pull-to-throttle") for consistency with the AAR-105 control stand. This is in keeping with criterion for Consistency, which requires the arrangement of controls to be consistent among systems operated by the same user. Since engineers may operate many different locomotives, each with different control stations, it is valuable for the experimental crewstation to behave similarly to existing control stands.

However, orienting the dynamic brake and throttle this way is contrary to several criteria in MIL-STD 1472G. Criteria for related Consistency of Movement and Common Plane advise that moving the control forward should correspond to a forward movement of the train and vice versa, which would require exchanging of the throttle and the dynamic brake. Criteria for Digital Displays and Arrays of Indicator Lights recommend that forward movements or bottom-to-top arrays of lights should correspond to increasing values, or in this case, an increased speed, which is also consistent with reversing the throttle and brake.

It was unclear whether in this case it is better to maintain the orientation for consistency with the AAR-105 control stand, or to reverse the orientation for compliance with the criteria, and perhaps with engineers' intuition. Therefore, we explored this issue in the usability test.

Additionally, there is an inconsistency with the displays due to the prototype nature of the chair. When the experimental crewstation was built, FRA determined that the content of the displays was beyond the scope of its design. There is a bar graph on the display that shows throttle position consistent with the direction of the AAR-105 controls (left to right). In the experimental crewstation, displays should be updated to show the graph vertically to match the orientation of the control.

Upward Visibility

While operating the experimental crewstation from a standing position, the engineer's viewpoint is substantially higher than when the engineer is seated. This raised some potential issues regarding upward visibility as addressed by criteria in Table 20.

Table 20. Criteria from MIL-STD-1472G that address upward visibility

Design Criteria for Upward Visibility
5.6.5.2.2 Upward visibility. Upward visibility shall extend to not less than 15 degrees above the horizontal.
5.10.3.1.1. Window placement. The lower edge of the window shall be no more than 1.32 meters (52 inches) and the upper edge no less than 1.85 meters (74 inches) above the deck, except for forward bridge windows which shall be no less than 1.98 meters (79 inches) above the deck. Where reflection from window glass could be a problem, the window shall be angled from the vertical, top-out, and bottom-in 15 degrees, but in no case shall the angle be less than 8.0 degrees or more than 25 degrees.

The window in CTIL is approximately 64 inches high, 10 inches less than is required for standing workspaces according to the criterion for Window Placement. While CTIL may not be representative of all locomotive cabs, it is worthwhile to note that cab windows were not designed with standing operation in mind, and may be lower than the Upward Visibility criterion requires. This may have particularly serious implications for engineers, who must be able to see signals up until the train passes them. If windows are too low for standing operation, upward visibility could be significantly impaired.

Therefore, we chose to explore this issue in more detail in the anthropometric modeling task.

Rear Visibility

In the preliminary design evaluation, we noted that the position of the crewstation and mounted displays may impede rear visibility. Several criteria from MIL-STD-1472G regarding rear visibility are listed in Table 21.

Table 21. Criteria from MIL-STD-1472G that address rear visibility

Design Criteria
5.6.5.3.1 Rear (vehicle). Side and rear enclosures shall be designed to permit the operator to view the rear of the vehicle (directly or by use of mirrors or DVE) in order to observe the load and to facilitate trailer attachment and backing maneuvers.
5.6.5.3.2 Rear view (road). A glare-proof, flat, elongated mirror and convex spotter-rearview mirror shall be provided on each side of the cab, located in such a manner as to afford the operator rearward vision from the normal operating position.

As we previously discussed in the preliminary design evaluation, the experimental crewstation may make it difficult to perform certain operations that require looking out the side or rear of the locomotive. The right hand armrest cannot be raised, which makes leaning out the window likely impossible, and the seat faces forward, which may increase the difficulty of looking out the rear of the cab.

Unfortunately, CTIL does not include a rear view or mirrors, so it was difficult to assess the extent to which rear visibility would be impaired if the experimental crewstation were installed in a real locomotive, rather than in a simulator. Therefore we added a reverse operations task to the usability test so that we could learn more about how engineers felt the chair would affect backup operations.

Shallow or Fragile Detents

The use of detents is an important method of preventing accidental control activation. Criteria from MIL-STD-1472G related to this issue are listed in Table 22.

Table 22. Criteria from MIL-STD-1472G that address shallow or fragile detents

Design Criteria
5.1.1.1.4 Detent controls. Detent controls shall be selected whenever the operational mode requires control operation in discrete steps.
5.8.5.3 Break strength. Where critical items may be damaged by the exertion of large forces, the break strength shall be not less than can be exerted by the strongest person.
5.9.1.14 Delicate items. Items susceptible to maintenance-induced damage, (e.g., rough handling, static electricity, abrasion, contamination) shall be clearly identified and physically and procedurally guarded from abuse.

The experimental crewstation uses a number of control levers, some of which were noted to have shallow or fragile detents during the preliminary design evaluation. Specifically, we noted that the detents for the throttle were quickly eroding with use due to the materials used to prototype the experimental crewstation. Due to this erosion issue, the experimental crewstation can be considered in violation of criteria for Break Strength and Delicate Items.

However, since these issues are likely due to the prototype nature of the crewstation, we have included this section to show that standards exist to support our earlier findings during the preliminary design evaluation, and to ensure that this issue (and any other issue related to durability) is not overlooked if future iterations of the experimental crewstation are considered for field implementation. Operator chairs exist in construction equipment, for example, which appear to be very durable (see Figure 30).

Figure 30. JR Merritt Controls, Inc. adjustable operator chair (Merritt Controls, 2015)

5.1.4.4 Minor Human Factors Issues

Our standards comparison revealed minor human factors issues that are too numerous to describe in detail here; rather, they are included in full in Appendix C. However, a summary of these issues provides insight into their nature and the value of addressing them.

- *Control grouping*. The majority of controls in the experimental crewstation are properly grouped according to the criterion for Grouping listed below; however, the crewstation contains two separate sets of lighting controls (see Figure 23). It may increase the intuitiveness of the crewstation's control layout if these controls were placed together. Relevant criterion from MIL-STD-1472G include:
    - *5.1.1.3.1 Grouping*
- *Control spacing.* Some controls fall slightly short of standards for control spacing, listed in MIL-STD-1472G Table III and in the criteria below.[12] Specifically, the control levers are slightly too close together, as are the rotary controls for windshield wipers and headlights, and the push buttons for cab lights. Increasing the spacing of these controls would aid in disambiguation and discourage accidental actuations. Additionally, the placement of controls may create interference, where access to a control is blocked by the user's body or another control. Relevant criteria from MIL-STD-1472G include:
    - *5.1.1.3.7 Spacing*

[12] See Appendix D.

- *5.1.4.2.2a(7) Displacement and separation*
- *5.1.1.3.4 Control interference*

- *Control coding.* We classified issues related to coding of non-emergency controls as minor issues because they do not immediately impact the safety of the train. However, improved use of coding methods may accelerate distinction of controls and reduce the likelihood of incorrect control actions.

  Currently, the crewstation uses a combination of coding methods. Due to the limited size of the experimental crewstation's control panels, the criterion for Location Coding suggests that it is not a viable coding method. Therefore, size, shape and color coding should be prioritized. Shape coding is used to distinguish levers and sets of push buttons (Figure 23). To address the criterion for Blind Operation, designers should provide greater tangible distinction between controls such as the horn and bell.

  The criterion for Color Coding recommends using it as a secondary method of coding, which is done in this crewstation. However, there are some minor issues with the use of color coding. Horn, bell, and sand push buttons are coded in white and blue, but the meaning of this coding is unclear; these controls may be better disambiguated using shape coding, or by using different control input types as detailed in the standards comparison. Additionally, the use of white and blue in the throttle LED display is contradictory to the standard's criteria according to MIL-STD-1472G Table XVIII, color-coding of lights; to improve the clarity of this LED display, white should be used for set-up to indicate "action in progress." [13]

  Relevant criteria from MIL-STD-1472G include:

  - *5.1.1.4 Coding*
  - *5.1.1.4.1 Methods and requirements*
  - *5.1.1.4.2 Location-coding*
  - *5.1.1.4.3 Size-coding*
  - *5.1.1.4.4 Shape-coding*
  - *5.1.1.4.5 Color-coding*
  - *5.1.1.7 Blind operation.*
  - *5.2.3.15.5 Simple indicator lights: Coding*

- *Maintenance accessibility.* Given that we examined a prototype version of the experimental crewstation, many issues related to its maintenance were beyond the scope of this analysis. However, some issues, which were believed to be innate risks of this type of control station, were analyzed and deemed minor issues. We noted that due to the size of the control boxes, it may be difficult to maintain the components contained within them. In particular, it may be necessary to remove a functioning part to maintain a malfunctioning one in violation of the criterion for Removal of Functioning Components or Parts. It may also be difficult to access parts for maintenance, particularly printed circuit boards within the control boxes, in violation of criteria for Ease of Access and

[13] See Appendix D.

Mounting of Printed Circuit Boards. We recommend taking these issues into consideration if FRA decides to pursue future iterations of this experimental crewstation. There are likely to always be some access difficulties when working with small areas, but designers should strive to minimize these difficulties. This issue may not immediately impact the safety of the train, but it will have a long term impact on the durability of the system and engineers' confidence in its use. Relevant criteria from MIL-STD-1472G include:

  - *5.9.1.12 Ease of access*
  - *5.9.2.1.2 Removal of functioning components or parts*
  - *5.9.19.1 Printed circuit boards: Mounting*

- *Label placement.* Some minor issues stem from the placement of labels in the experimental crewstation. First, it bears mentioning that some items are not labeled, particularly the brake levers and throttle, in conflict with the criterion for Use of Labels. Additionally, in some positions, the users' body or the position of other controls may make the labels on control panels difficult to read, violating the criterion for Obscuration. Since all controls in the experimental control station are below eye level, labels should be placed above the controls according to the criterion for Placement: At or Below Eye Level; moving labels to above the controls will meet this criterion and may reduce obscuration issues. Resolving these labeling issues may help improve cognitive processing time, allowing engineers to operate more efficiently. Relevant criterion from MIL-STD-1472G include:
  - *5.4.1.1 Use of labels*
  - *5.4.3.2 Location: Obscuration*
  - *5.4.3.5.2 Placement: At or below eye level*
- *Label readability.* A number of control labels in the experimental crewstation do not meet the criteria of MIL-STD-1472G for Stroke Width and Character Height Versus Viewing Distance. Additionally, some of the labels as seen in Figure 28, which are printed in black text on a gray background, may lack sufficient contrast for readability as required by the criterion for Visibility and Legibility and the criterion for Label Contrast. Though precise measurements of label contrast were not taken, it is believed to be a potential minor issue. Addressing the criteria for labeling for dark adaptation as discussed earlier in this standards comparison task would likely address these issues. Increasing the readability of labels may reduce engineers' cognitive processing time and allow for more efficient operations, much in the same way as addressing the placement of labels. Relevant criterion from MIL-STD-1472G include:
  - *5.4.5.5 Visibility and legibility*
  - *5.4.5.10 Label contrast*
  - *5.4.5.8 Label mounting*
  - *5.4.6.3.7 Stroke width*
  - *5.4.6.3.13 Character height versus viewing distance*

- *Handles and grasp areas.* There is no clear grasp area defined on the footrest. It affords grasping by shape and texture, but users may be injured if they let go of it, causing it to drop suddenly.
    - *5.8.6.5.3 Handles and grasp areas*

5.1.5 Summary

The standards comparison task was beneficial in that it identified a number of issues that corresponded with the findings of the preliminary design evaluation on as well as a number of issues that were not caught by the Volpe Center human factors evaluators. It also showed areas where the AAR-105 control stand provides better adherence to the standard than the experimental crewstation. The use of MIL-STD-1472G allowed for a thorough, rigorous analysis of many aspects of the experimental crewstation, and identified many human factors issues, some of which were identified for further examination using anthropometric modeling or during the usability test. These issues are summarized in Table 23.

Table 23. Summary of issues identified in the standards comparison task

Issue	Summary of issue	Sections containing further analyses or discussion
D	Displays are mounted such that their vibration may impair readability to dangerous levels.	
Lack of work and storage space	The experimental crewstation includes neither a desk nor storage space for necessary paperwork.	Usability Test
A au em	The automatic brake requires less force to actuate than in the AAR-105 control stand, increasing the risk of accidental brake applications or over-braking, as well as accidentally actuating the emergency brake, which lacks recommended protections.	
Control distribution and interference	The placement of frequently used controls may not evenly distribute the workload between the left and right arms. Additionally, the placement of some levers may occasionally block access to others.	Usability Test
L u	Some of the most frequently used controls could be moved to encourage more comfortable arm positioning and use of forearm support.	
Use of push buttons	Push button state is ambiguous for “on/off” functions. Other control types which provide better feedback, especially visual, would be preferable.	Usability Test
C co	The emergency brake in the experimental crewstation should be colored red for consistency with other emergency controls and workstations.	

Issue	Summary of issue	Sections containing further analyses or discussion
Seating dimensions and adjustability	Some dimensions, such as seat and armrest height, are not fully adjustable for all users as required.	Anthropometric Modeling
Labeling for dark adaptation	Not all labels meet requirements for dark adaptation (white text on a black background) nor is adjustable backlighting provided.	None
LED display feedback	Throttle and dynamic brake positions are indicated by a series of LEDs where a numeric readout or other more precise display type would be preferable. Dynamic brake set-up feedback could be improved.	Usability Test
Throttle and dynamic brake orientation	The "pull-to-power" orientation of the throttle was designed for consistency with the AAR-105 control stand, but because it is inconsistent with the train's direction of motion, may be counterintuitive.	Usability Test
Upward visibility	The experimental crewstation places users' much higher in both seated and standing positions than the AAR-105 control stand, and may restrict upward visibility to less than the 15 degrees required.	Anthropometric Modeling
Rear visibility	The fixed position of the right armrest and display screens may restrict rear visibility.	Usability Test
Shallow or fragile detents	Control lever detents are very weak relative to the AAR-105 control stand levers, and seem to be weakening over time, increasing the risk of inadvertent actuations. This may be simply a prototyping issue.	None
Minor human factors issues	There is room for minor improvement in several areas, such as: • Grouping, spacing, and coding of non-emergency controls • Accessibility for maintenance • Placement and readability of labels • Clearly defined grasp areas for seat adjustment	None

Therefore, the standards comparison task made a substantial contribution to the overall assessment of the effectiveness of the experimental crewstation.

5.2 Anthropometric Modeling

This section describes the anthropometric modeling task we performed for the Ergonomic Assessment phase of the experimental crewstation evaluation. The purpose of this activity was to evaluate the experimental crewstation from the perspectives of control accessibility support, physical comfort, muscular fatigue, and available visibility. Purpose, approach, methods and results for this task are described below.

5.2.1 Purpose

In general, it is good design practice to ensure that equipment's physical characteristics and operations fit the population of personnel that will use it (e.g., engineers, maintenance staff). This notion is supported by the criteria from MIL-STD-1472G listed in Table 24.

Table 24. Criteria from MIL-STD-1472G supporting anthropometric analysis

Design Criteria
5.8.1.1 Systems, equipment, and facilities. Systems, equipment (including life support and emergency escape), and facilities used by operators, maintainers, and supporters shall be designed for full use by the range of service personnel with applicable operational clothing, protective clothing, and specialized equipment.
5.8.2.2.2 Selected populations. Where equipment will be used, inclusively or exclusively, by selected or specialized segments of the military population (e.g., Air Force flight crews, Navy divers, disabled), the characteristics of the job population may be used in lieu of the requirements in 5.8.4 of MIL-STD-1472G (DoD, 2009).
5.8.3.1 General design criteria. General design criteria. Design shall ensure physical accommodation, compatibility, operability, and maintainability for all physical factors (size, weight, reach, strength, and endurance) by the central 90 percent of the target user population as identified in 5.8.2 of MIL-STD-1472G (DoD, 2009).
5.8.4.1 Use of anthropometric data. Use of anthropometric data. Use of anthropometric data as design criteria shall consider all the following: a. The nature, frequency, safety, and difficulty of the related tasks to be performed by the user or wearer of the equipment. b. The position of the body during performance of these tasks. c. Mobility or flexibility requirements imposed by these tasks. d. Increments in the design-critical dimensions imposed by the need to compensate for obstacles and projections.
5.10.2.1 Provision of workspace. Workspace shall be provided to perform all operational and maintenance tasks by the central 90 percent accommodation for whatever specific range and type of user population is specified by the procuring organization (see Section 6.2 of MIL-STD-1472G [DoD, 2009])) while wearing the appropriate (e.g., winter or PPE) clothing and using the required tools.
5.10.2.2 Consideration of personnel. In establishing the workspace, consideration shall be given to the number of personnel required to perform the work and the body positions required to do the work.

These criteria require control systems to accommodate the central ninety percent of users in terms of size, reach and performance. They also require consideration of body positioning, task frequency, and body mobility. We performed the anthropometric modeling task to understand how the experimental crewstation satisfies these general requirements. It also aided us in evaluating the crewstation against more specific criteria regarding reach, comfort, visibility, and arm support, which are detailed in the analysis section below.

5.2.2 Approach: Computerized Modeling

We used anthropometric modeling software called RAMSIS to assess how well the experimental crewstation and the AAR-105 control stand (as it is installed in CTIL) accommodate the user population and to reveal any potential problem areas in the designs. We chose this software-based approach because of its low complexity and expense compared to traditional methods, which require thorough measurement of both the equipment and the body dimensions of the user population. FRA purchased RAMSIS in 2009 as part of the CTIL program.

After inputting CAD versions of the two workstations, we used RAMSIS to draw reach envelopes and identify the most natural body positions for key tasks. This job was directly facilitated by the software's automated tools. To accomplish this, the software created models for engineers of varying size (called "mannequins") to determine how well the workstations accommodate the central-ninety percent of users as required by the design criteria standards.

5.2.3 Method

This section describes the tools and simulated user physical dimensions we used for the anthropometric modeling task.

While performing the standards comparison, we identified criteria that specifically required anthropometric modeling to analyze. Since multiple criteria could be evaluated with the same method in the modeling software, we grouped them according to the software's automated analysis capabilities. We used the results of these automated analyses to determine whether each workstation passed or failed to pass each criterion from the standards. We listed aspects of the experimental crewstation which failed to meet criteria as human factors issues.

As we did in the standards comparison task, we performed the same anthropometric modeling tasks using the AAR-105 control stand and seat installed in CTIL. We did this to give insight for how the experimental crewstation may provide (or deny) benefit to engineers. This comparison is subject to the limitations we noted in Section 2.

5.2.3.1 RAMSIS Analysis Tools

The main modeling tasks in RAMSIS informed our findings for every requirement we reviewed:

- A **reach analysis**, in which RAMSIS generated images showing the extents of mannequins' reach in three dimensions overlaid on the CAD drawings of the workstations.
- A **comfort analysis**, in which we used RAMSIS's built-in Discomfort Assessment Score to determine the degree to which the two systems supported key operator positions from the perspective of ergonomic comfort.

- A **line-of-sight analysis**, which focused on the experimental crewstation's ability to allow engineers to see out the front window in both seated and standing positions.
- An **engineer height analysis**, which focused on how the armrests in the experimental workstation support engineers in sitting and standing positions.

5.2.3.2 Selected Population

FRA's Human Factors Guidelines for Locomotive Cabs (1998) recommends that "user population sizes should be used to design the cab with the male 95th percentile dimensions used to set clearances and the female 50th percentile dimensions used to set reach envelopes." Since engineers are predominantly male we used this as the "central ninety percent" detailed in the military design standard.

Using the RAMSIS-provided database, which contains data generated by the U.S. Public Health Service National Health and Nutrition Estimation Survey (Center for Disease Control, 2009), we created mannequins for 95th percentile male and 50th percentile female to use as test cases in the anthropometric modeling analyses. We used these test cases because if the two extremes of the population are satisfied, it is reasonable to conclude that all sizes in between would also be satisfied.

Using these test cases, we conducted analyses on both the AAR-105 control stand and seat in CTIL and the experimental crewstation to understand both the areas where the experimental crewstation resolves existing problems and the areas where it falls short of requirements.

5.2.4 Results

The results of the analyses are below.

5.2.4.1 Reach Analysis

Table 25 shows findings based on our evaluation of the RAMSIS-generated reach envelopes for both workstations as specified by military design criteria. In short, the criteria indicate that the control unit should "be oriented with respect to the user," that "the most important and frequently used controls…shall have the most favorable position for ease of reaching and grasping; have emergency shutoffs which are "accessible, not hidden" and "located to prevent accidental actuation," and that the controls be reachable "by at least 95 percent of female users without moving the torso." These criteria are important because they allow for accurate control while minimizing repetitive stress and unnecessary movement.

Table 25. Reach analysis criteria summary

Criterion from MIL_STD-1472-G	AAR-105	Experimental crewstation
5.1.1.2.3 User-control orientation. Controls shall be oriented with respect to the user. Where a vehicle user may use two or more stations, the controls shall cause movement oriented to the user at the effecting station, unless remote visual reference is used.	Potential Conflict	Passed
5.1.1.3.3 Location of primary controls. The most important and frequently used controls (particularly rotary controls and those requiring fine settings) shall have the most favorable position for ease of reaching and grasping.	Conflict	Passed
5.1.1.3.9 Emergency shutoff controls. Emergency shutoff controls shall be accessible, not hidden, located to prevent accidental activation, and positioned within easy reach of the user (see Sections 5.1.1.7 and 5.1.1.8 of MIL-STD-1472G [DoD, 2009]).	Potential Conflict[14]	Passed
5.10.4.1.2 Panel angle. The left and right segments shall be angled from the frontal plane of the central segment such that they can be reached by at least 95 percent of female users without moving the torso.[15]	Conflict	Passed

To evaluate the extent to which each workstation meets these requirements, we used RAMSIS to determine reach envelopes for the large (95th percentile male) and small (50th percentile female) test cases in both control systems. RAMSIS determined these reach envelopes by tracing the fingertip extents of each test case seated in the chair, without leaning forward.

AAR-105 Control Stand in CTIL

As we mentioned in the preliminary design evaluation, there are two points of user orientation in the AAR-105 control stand: the forward view and the control stand. We drew the reach envelopes with the test cases in both of these positions.

For the first set of reach envelopes (facing forward) we positioned the seat at the back of the operational range for the 95th percentile male and at the front of the range for the 50th percentile female. The resulting images in Figure 31 indicate that that when users of all sizes face the forward window, none of the controls can be reached with the right hand without leaning forward or twisting.

[14] "Easy reach of the user" may be influenced by chair's orthogonal distance to control stand.

[15] 50th percentile female, rather than 5th percentile female based on FRA guidance.

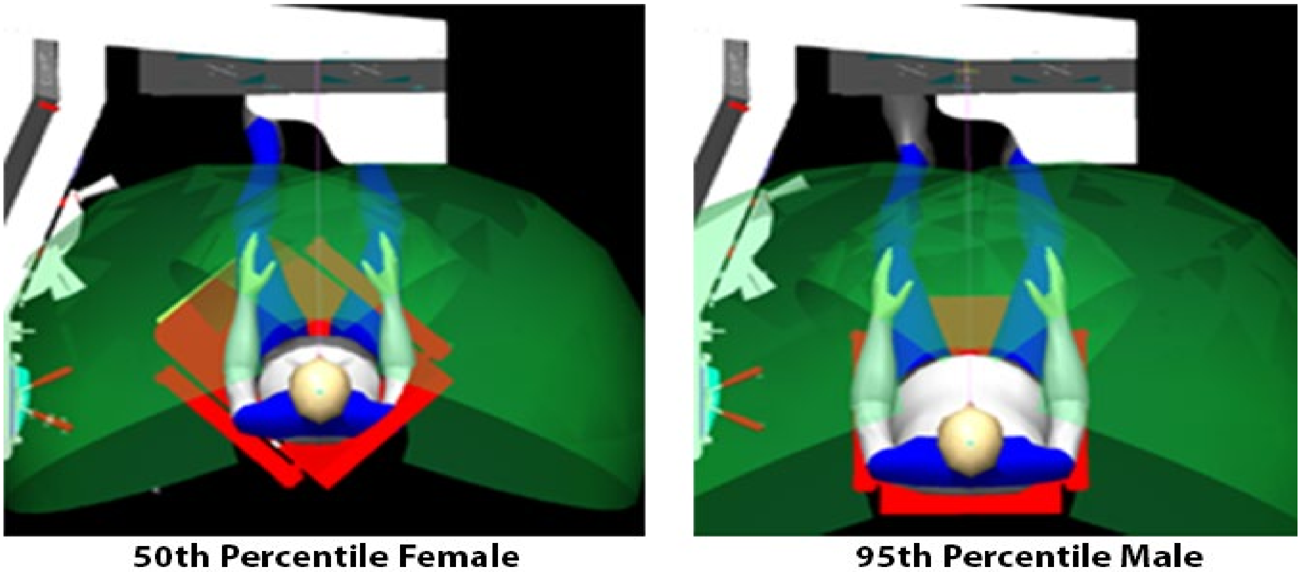

Figure 31. Reach envelopes in the AAR-105 control stand while facing forward

The reach extents in the forward facing position also show that for the 50th percentile female, much of the controls are at the edge of the reach extents. Given this great distance, it is highly likely that smaller users would need to sit close to the edge of the seat to operate controls if they choose to face forward while operating, though doing so does not provide back support.

The relative position of the automatic brake and throttle pose another problem for small users. Figure 31 shows that the brake is near the back of the reach envelope of the left hand, which means that as users slide forward in the chair or move the chair forward, it will become more difficult for them to access the brake.

Given that the majority of the population is right-handed and the forward-facing body position in the AAR-105 control stand does not allow for easy access to controls with the right hand, we expect that users of all sizes may turn toward the control stand to operate it. This notion is supported by the photo in Figure 32, which taken during a previous study on vibration that the Volpe Center conducted.

Figure 32. Engineer facing the control stand in a real locomotive

Due to this, we repositioned the test cases to face the controls and performed another reach extents analysis (Figure 33) using RAMSIS. To understand the best possible scenario for reachability, both test cases were positioned with the seat in the forward-most position. This new position facing the control stand brings the right-hand reach envelopes closer to the controls for both test cases. Even here, though, Figure 33 shows that small engineers must bend forward to reach the throttle when it is positioned in the low ranges.

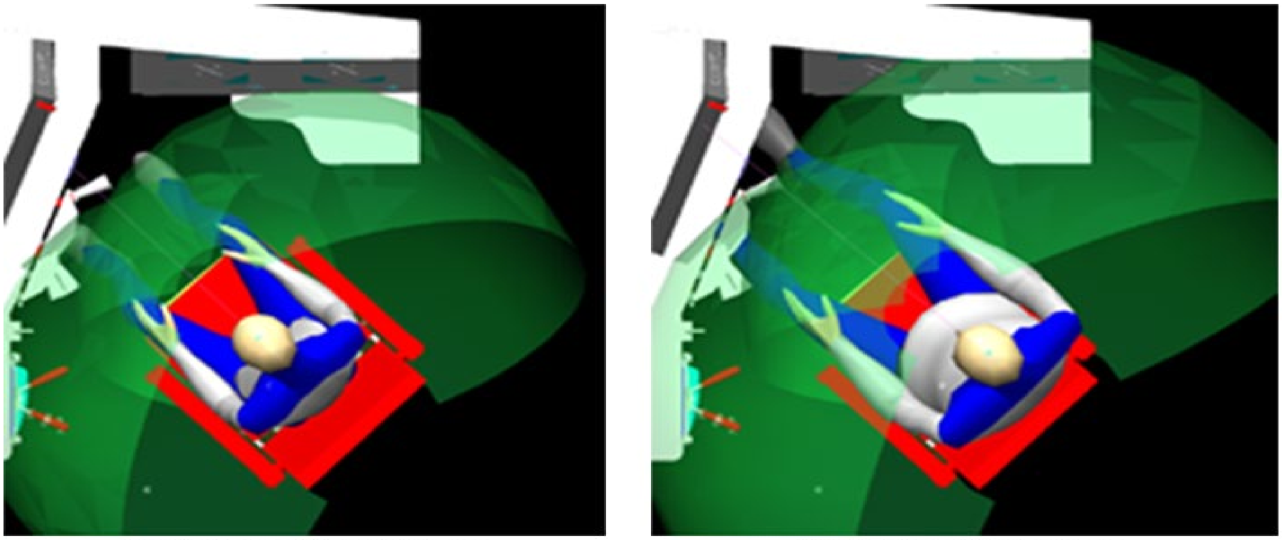

Figure 33. Reach envelopes in the AAR-105 control stand while facing the controls

In this seat position, it is nearly as easy for both test cases to reach the throttle in low position with the left hand as with the right. This makes two-handed operation somewhat easier. There are many situations in which two-handed control operations are preferred or even necessary, such as:

- Stretch braking, where the throttle may not be in idle when the automatic brake is first engaged (Association of American Railroads, 1973)
- Manipulating the dynamic brake and automatic brake while intermittently engaging the bail to prevent independent brake engagement (Association of American Railroads, 1973)
- Keeping one hand on the controls while sounding the bell and horn through a grade crossing

It should be noted that when the user's body is angled toward the control stand, users must turn their necks to look out the windows, including when simply looking forward and especially when spotting wayside signals, many of which are to the right of the field of view. Additionally, placement of the controls to the left of the engineer means that the engineer does not have access to them while turning to look out the window.

Because engineers must turn to face the crewstation to operate it in CTIL, and because no controls are really definable as "easy to reach," we rated this implementation of the control stand as in conflict or potentially in conflict with the criteria in this section. Control stands that are closer to the side window than the setup in CTIL likely would have more reachable controls. A more detailed study of all control stand types, including a survey of railroads to understand the distribution of configurations, would be necessary to make a broad statement about the accessibility of all AAR-control stands in this way.

Experimental Crewstation Reach Analysis Results

Ideally, engineers would have access to all of the controls and visibility out the forward window without needing to shift or twist their bodies. Having the same level of access to controls no matter the direction the chair is facing would also be beneficial. This was one of the goals of the experimental crewstation's design. We determined the extent to which the experimental crewstation met this goal by drawing reach envelopes using RAMSIS (see Figure 34). The experimental crewstation's armrests (and attached controls) were positioned all the way forward for the large test case, and all the way back for the small test case.

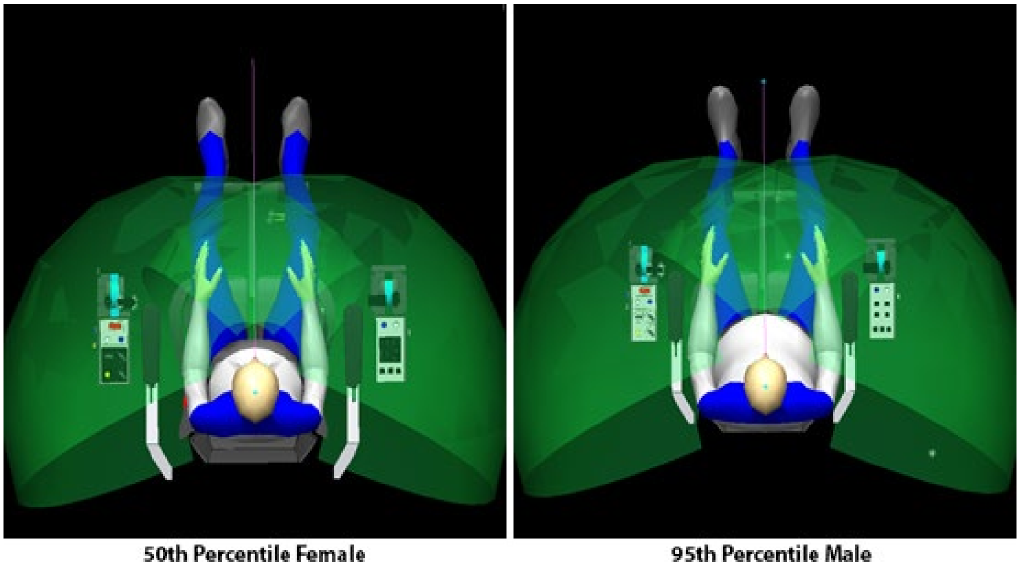

Figure 34. Reach envelope for both test cases positioned in the experimental crewstation. All controls are within the reach envelope of one hand[16]

According to the reach envelopes provided by RAMSIS, the experimental crewstation's control configuration shows significantly improved reachability over the configuration of the AAR-105 control stand because all controls are well within reach. Additionally, the position of the seat allows users of all sizes to face the forward window while using the controls. Finally, since the controls are mounted to the chair, accessibility does not change if the engineer decides to face another direction while operating.

Since the accessibility of controls is greatly improved in the experimental crewstation, the RAMSIS Reach Analysis did not reveal any suggested improvements to its design. All controls are substantially more reachable in this design than in the conventional AAR-105 control stand configuration.

5.2.4.2 Comfort Analysis

Table 26 shows the military design criteria and findings for the Comfort Analysis task below, which require natural body movement, proper placement of high-force controls, accessibility from comfortable postures, and compatibility of seating with the tasks that must be performed.

[16] The image on the left does not reflect the actual adjustment mechanism. In reality, the cushion and control boxes slide backward in the track visible in the image. However, this could not be easily accomplished using our 3D models, so for the sake of this analysis the entire armrests were moved backward an equivalent distance.

Table 26. Criteria summary for the comfort score analysis

Criterion from MIL_STD-1472-G	AAR-105	Experimental crewstation
5.1.4.2.2 Location, position, direction, and range of movement. The location, position relative to the user, and direction and range of lever movement shall be compatible with user reach, mobility, natural movements, and strength capabilities. When high forces are required of the user, the lever handle shall be located between waist and shoulder levels. For high-force applications the force will typically be applied in a pulling direction.	Potential Conflict	Passed
5.1.4.3.1 Use. Controls requiring user forces exceeding the strength limits of the lowest segment of the expected user population shall not be used. High-force controls shall not be used except when the user's nominal working position provides proper body support or limb support or both, e.g., seat backrest, foot support. Sustained (i.e., durations longer than 3 seconds) high-force requirements shall be avoided.	Potential Conflict	N/A (high force controls not used)
5.1.4.3.2 Arm, hand, and thumb-finger controls. Where arm, hand, and thumb-finger controls requiring high control forces are to be used, the maximum force requirements shall not exceed those specified on Figure 23,[17] and corrected, where applicable, for females. Two thirds of each value shown is considered to be a reasonable adjustment.	Potential Conflict	N/A (high force controls not used)
5.10.2.11 Control/display accessibility. All controls and displays shall be reachable and readable from the normal work body postures or positions without having to assume awkward or uncomfortable postures.	Conflict	Potential conflict
5.10.3.2.6 Compatibility. Work seating shall provide an adequate supporting framework for the body relative to the activities that must be carried out. Chairs to be used with sit-down consoles shall be operationally compatible with the console configuration.	Conflict	Passed

Method

To assess the degree to which the two control configurations meet these criteria, we configured them based on earlier findings using RAMSIS. We then placed the mannequins in each control

[17] See Appendix E.

paradigm and let RAMSIS automatically position them for each task and their comfort. These steps are described below.

Seat Positioning – We determined the positions for two control stands' seats and armrests using conclusions from the Reach Analysis:

- The AAR-105 seat yielded best results for both test cases when rotated 45 degrees toward the control stand and positioned in the forward-most position.
- The experimental crewstation yielded best results when armrests (and attached controls) were positioned all the way forward for both mannequins due to the alerter access issue mentioned in the preliminary design evaluation (access to the button is somewhat impeded by the seatback when the armrest is in the back position). Additionally, we positioned the test cases' bodies at the back of the seat to make proper use of the back support when calculating all comfort scores.

Mannequin Positioning – After positioning the test cases in each seat, we issued commands through RAMSIS for the mannequins to reach for the primary controls at the edge of their sitting reach envelopes: the automatic brake and throttle. RAMSIS then automatically determined the most comfortable body position required to accomplish each task. To do so, RAMSIS computed all of the body positions from our positional commands and chose the ones expected to be most comfortable based on its built-in overall Body Discomfort Score described below.

Discomfort Rating – RAMSIS determined comfort automatically through its built-in Body Discomfort Score. The Body Discomfort Score is derived from a study conducted by RAMSIS where automobile drivers rated their own physical discomfort for each body part. The score allows designers to find awkward and potentially painful postures for the neck, shoulders, back, buttocks, left and right legs, and left and right arms (Meulen, P., and Speyer, H., 2006).[18] RAMSIS also generates a total discomfort score, which is derived from the score of all body parts. The scale for each Body Discomfort Score ranges from 0 to 8, with 8 being the most uncomfortable. When comparing two scores, a difference of 1 constitutes a statistically significant difference in comfort, based on the study that RAMSIS used to derive the score.

Limitations

The scores we calculated are subject to the limitations of seat type and control stand placement described in Section 2. Relative placement of the seat to the control stand can have a large effect on the results.

Additionally, the Body Discomfort Scores only tell part of the story when it comes to understanding pain and repetitive stress. Specifically, the frequency with which these tasks are performed is a large factor in determining how much impact an uncomfortable position may have on an engineer. The results from this assessment are useful for understanding how uncomfortable positions are, but not the frequency. A study that evaluates the acceptable dosage rate for

[18] The RAMSIS Discomfort Assessment also includes a score for "fatigue," defined by them as the amount of physical fatigue one may feel while holding a specific position for up to four hours. We did not include this score in our analysis because we found it unlikely that engineers will hold positions for a long time.

uncomfortable positions would be extremely beneficial to the cab design community, but it is beyond the scope of the crewstation evaluation.

The results of the Comfort Analysis for each control stand are below.

Results for AAR-105 Control Stand in CTIL

As implied by the Reach Analysis, the Comfort Analysis highlights and further details the problems engineers might encounter operating high-frequency and important controls.

As noted in the reach analysis, users may attempt to use the throttle with either the left hand or the right. Comparison of the Body Discomfort Score results for each test case did not reveal a significant difference between operation with the left-hand and operation with the right-hand, as can be seen in Table 27. For each analysis and pictorial comparison in this report, we used the most comfortable overall score for throttle operation: right-hand operation for the 95th percentile male and left-hand operation for the 50th percentile female.

Table 27. Overall discomfort scores for throttle operation on the AAR-105 control stand in CTIL

Mannequin	Left-hand	Right-Hand
95th Percentile Male	5.7	5.1
50th Percentile female	5.7	6.1

Figure 35 shows the optimal body positioning for accessing the automatic brake, throttle, and both controls simultaneously for the large and small mannequins in the AAR-105 control stand. If positioned in the chair to make use of its back support, mannequins must bend at the waist and extend their arms to grasp the throttle.

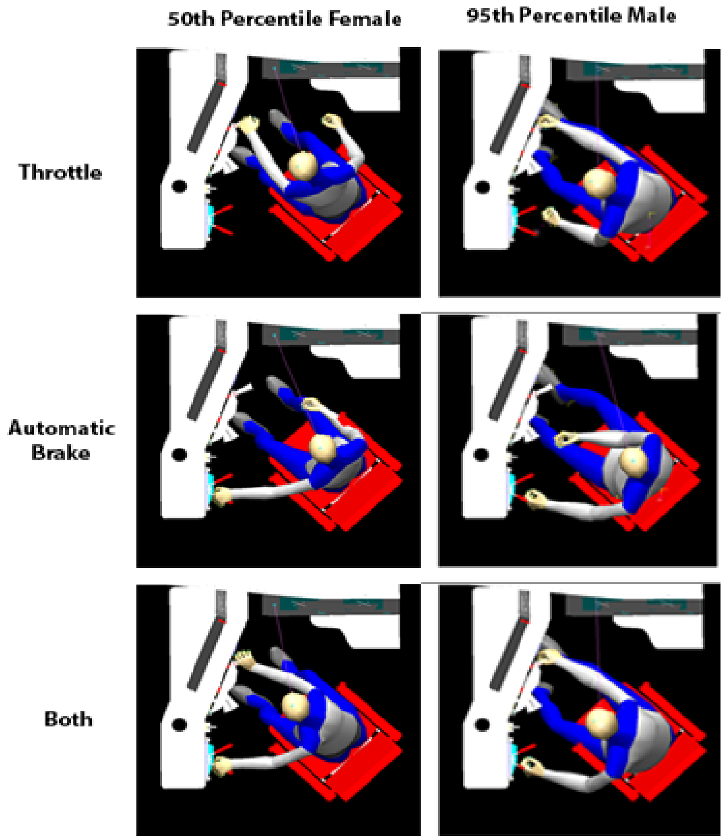

Figure 35. Side-by-side comparison of the small and large test case for the three analyzed control operations

Figure 35 shows that this extension worsens if the user also reaches for the automatic brake, as may occur in situations such as stretch-braking, and it does so substantially for small users; the discomfort scores for the two different mannequins are only significantly different for the simultaneous operation of the two controls. In that operation, the discomfort score is significantly higher for the small test case in the neck (6.7 for the small test case and 5.4 for the large test case) and shoulders (5.4 for the small test case and 4.2 for the large test case).

Problems due to the positioning of the throttle and automatic brake at the end of users' reach range may be especially critical because of the controls' deep detents. We cannot say with certainty that the automatic brake qualifies as a high force control since the exact force required to operate it depends on how recently it has been maintained. However, the force required to actuate the automatic brake on the AAR-105 control stand in CTIL was measured at approximately 8 pounds of force, which is at the upper end of the criteria for a user with 60 to 90 degree shoulder extension and may exceed these limits once the criteria are adjusted to accommodate both male and female users. Therefore, we consider the AAR-105 control stand's automatic brake potentially in conflict with the military design criteria for Use and Arm, Hand, and Thumb-Finger Controls listed in Table 26.

It should be noted, though, that these scores may be somewhat dependent upon the seat used and the control stand's distance relative to it. A seat located (orthogonally) closer to the control stand than the one we tested would have its controls closer to the reach envelope, or within it, and reduce bending and twisting. However, since the control stand is simply a vertical surface from the floor to the top of the controls, moving the seat closer to the controls could theoretically result in the legs being "crowded" and encourage users to adopt a forward-facing posture, and worsen the amount twisting required to reach the automatic brake.

Experimental Crewstation Results

Figure 36 shows side-by-side comparisons of the AAR-105 control stand in CTIL and the experimental crewstation using the small mannequin for the three test scenarios: grasping the throttle, grasping the automatic brake, and grasping both simultaneously. The experimental crewstation's design greatly improves access to these controls. The RAMSIS body positions show that users use much more comfortable body positions to access the controls compared to the AAR-105 control stand. Additionally, the controls, while not in this case requiring high forces, are oriented closer to the engineer's center of gravity, which allows engineers to generate more force if necessary. This may become critical if designers choose to deepen the control detents based on other findings in this report.

RAMSIS body positioning shows that mannequins used a slight back rotation in the most comfortable position for control access. This occurred because the controls are not directly in front of the armrest, and therefore RAMSIS judged rotating the back would yield slightly better overall discomfort scores than keeping the back stationary and moving only the arms.

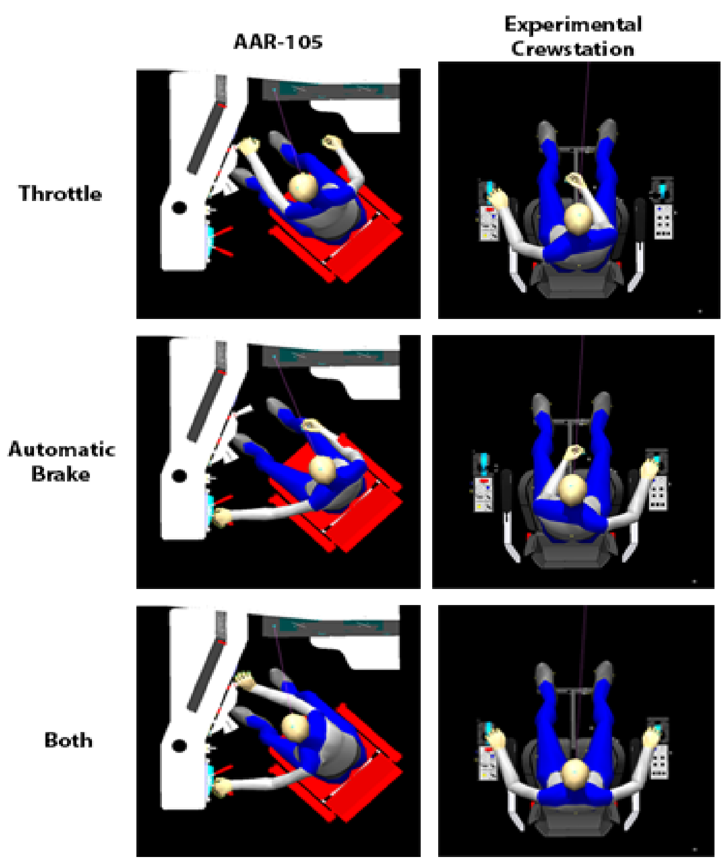

Figure 36. Differences in body positioning between the AAR-105 control stand and the experimental crewstation, for 50th percentile female

Additionally, the overall comfort score for the experimental crewstation is significantly better in all three tested control scenarios because the arm extension and neck twisting found in the AAR-105 are not necessary. This yielded significant improvement for the overall Body Discomfort Score in all three control operation scenarios (see Figure 37 and Figure 38). For the full list of these improvements by body part, refer to Appendix A.

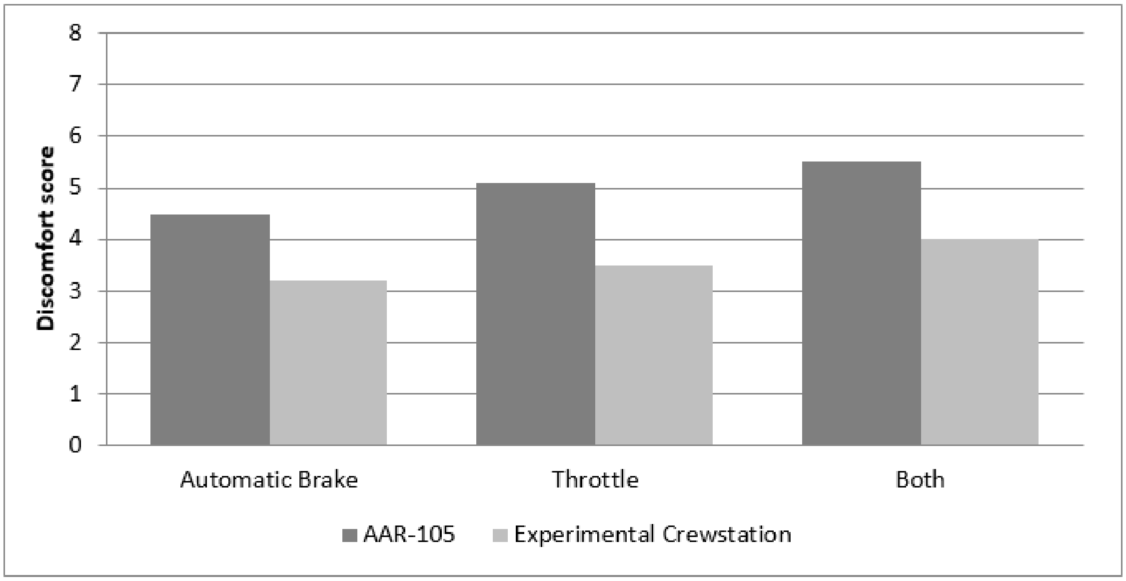

Figure 37. Overall discomfort scores for 95th percentile male

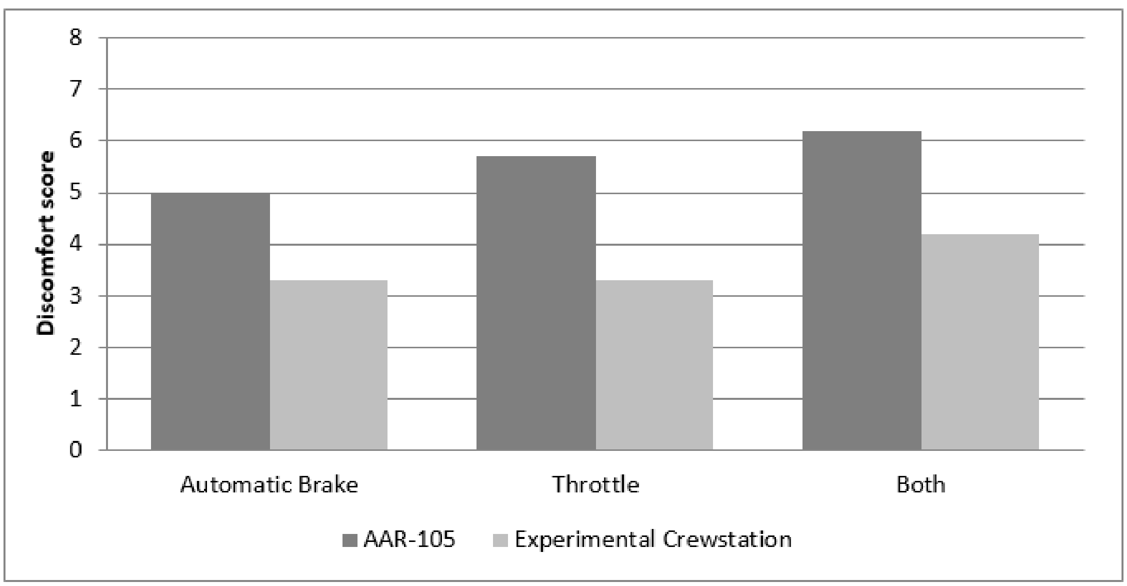

Figure 38. Overall discomfort scores for 50th percentile female

Overall, due to the improved access to the tested controls and the low forces required to operate them, we judged the experimental crewstation to have passed many of the applicable criteria under this analysis, with the exception of alerter access (noted in the preliminary design evaluation).

5.2.4.3 Line of sight analysis

There is one criterion from the military design standard that required a line-of-sight analysis using RAMSIS (Table 28). Upward visibility is an important requirement for operation of a locomotive because many signals, such as ones on bridges or cantilevers, are located above the height of the train; scale drawings provided by a local railroad indicated that the height of the top aspect of a three-aspect signal on a signal bridge is approximately 40 feet (Safetran, 2005).

Table 28. Criteria summary for the line of sight analysis

Criterion from MIL_STD-1472-G	AAR-105	Experimental crewstation
5.6.5.2.2 Upward visibility. Upward visibility shall extend to not less than 15 degrees above the horizontal.	Passed	Conflict

CTIL's seat alongside the AAR-105 control stand meets the requirements for upward visibility with ease, but the experimental crewstation is considerably higher. Designers may have intended this height to better accommodate the standing functionality of the chair, since the chair does not have a large window for vertical adjustment. We were concerned that this higher vantage point would make it more difficult for engineers to see overhead signals.

The top of the front window in CTIL is located at a height of 63.50 inches from the floor. Since locomotives can vary in configuration, we decided to use the Volpe Center's other rail simulator, RALES, as a second point of reference; is a scale model of an SD40 with a front window whose header is located 60.50 inches from the floor.

The Shockwave seat provided with the experimental crewstation is built for compression forces in maritime environments. Therefore it can move a great deal (8 inches, measured) in compression, but in terms of ride height settings only has an adjustable range of 1.75 inches. The back of the seat pan measures between 31.00 and 32.75 inches depending on this range.

We drew user height data from the RAMSIS database to determine the seated and standing heights for the large and small mannequins (95th percentile male and 50th percentile female). Because we were concerned that window height may be a very important issue we also drew user height information for and additional test case for the 50th percentile male, which may be closer to typical users' height. To determine the position of the eye from the top of the head, we subtracted an estimated distance of 5 inches from the seated and standing heights. We then added this value to the height of each chair (as measured at the back of the seat pan) to determine the eye-height values seen in Table 29.

Table 29. Approximate eye height while using experimental crewstation[19]

Test Case	Approximate Seated Eye-Height Including Chair (in)	Approximate Standing Eye-Height (in)
95th Percentile Male	65.25 – 67.00	69.68
50th Percentile Male	62.68 – 64.43	64.94
50th Percentile Female	60.32 – 62.07	59.69

Using a distance of 41.50 inches between users and the front window we calculated the upward visibility angle in the seated and standing positions for both locomotives (Table 30). None of the positions tested met the 15 degree upward visibility requirement in the military standard.

Table 30. Degrees of upward visibility using the experimental crewstation

Test Case	RALES, Seated	RALES, Standing	CTIL Seated	CTIL Standing
95th Percentile Male	0 degrees	0 degrees	0 degrees	0 degrees
50th Percentile Male	0 degrees	0 degrees	1.13 degrees	0 degrees
50th Percentile Female	0.24 degrees	1.12 degrees	4.38 degrees	5.25 degrees

These values for eye height do not take into consideration the compression effects of the seat cushion or air suspension when the engineer is seated, which are both determined by the engineer's weight. However, it is worth noting that to achieve 15 degrees of upward visibility the eye-height in CTIL would need to be 52.38 inches from the floor, while in RALES it would need to be 49.38 inches from the floor. This height disparity between goal number and actual height is too large to be accounted for with these cushioning variabilities.

Based on this comparison, it is clear that neither seated nor standing operation would afford the upward visibility required in the standard. Engineers would likely be required to bend downward to see overhead signals at close range in most cases.

5.2.4.4 Armrest Support

During the preliminary design evaluation and standards comparison tasks we became concerned that the armrests for the experimental crewstation did not support users of varying sizes. Table 31 reiterates the criteria that were being examined.

[19] We used an estimated distance of 5 inches for the distance from top-of-head to the eye.

Table 31. Criteria summary for armrest adjustability

Design Criteria
5.10.3.2.10 Armrests. Unless otherwise specified (see Section 6.2 of MIL-STD-1472G, [DoD, 2009]), armrests shall be provided. Armrests that are integral with users' chairs shall be at least 5.0 centimeters (2.0 inches) wide and 20 centimeters (8.0 inches) long. Modified or retractable armrests shall be provided when necessary to maintain compatibility with an associated console. Armrests shall be adjustable from 19 to 28 centimeters (7.5 to 11 inches) above the compressed sitting surface. Distance between armrests shall be not less than 46 centimeters (18 inches).

To determine how well the chair would provide vertical armrest support, we drew user data from the RAMSIS database and compared that information to the available armrest heights in the experimental crewstation. A properly adjusted armrest should touch the engineers' forearms when they are bent at a 90-degree angle.

The armrests on the experimental crewstation do not adjust separately from the chair; they are a fixed nine inches above the back of the seat pan. Height adjustment of the chair does affect the armrests in the standing position, giving an operable range between 40.5 and 42.25 inches from the floor.

We compared these numbers to the test cases' elbow height using the best possible case for chair adjustment. Table 32 shows the difference between these values and the armrest positions.

Table 32. Elbow distance from armrests

Test case	Distance above armrests while seated (in.)	Distance above armrests while standing (in.)
50th percentile female	3.70	0.60
95th percentile male	5.72	5.76

Our calculations showed that while the experimental crewstation is capable of supporting small users in the standing position, the armrests fall short everywhere else. Notably, large engineers are the least supported members of the user group, with a distance of approximately 5.7 inches between their elbows and the armrests (Figure 27). Based on this finding we recommend providing independently adjustable-height armrests for engineers.

5.2.5 Summary

The findings from the anthropometric modeling task indicate that the experimental crewstation would provide a significant increase in control accessibility and overall comfort for engineers while reducing fatigue related to body positioning.

The analysis also uncovered that in some circumstances, the height of the chair in both the seated and standing positions may pose some problems for visibility, as shown in Table 33. These problems should be directly addressed by FRA before any rollout of the experimental crewstation that may be considered.

Table 33. Summary of issues identified in the anthropometric modeling task

Issue	Summary of issue
Excessive standing height	Standing operation will affect the engineer's ability to maintain contact with high signals due to the height of train cab windows restricting upward visibility. FRA should decide on whether this affects the safety of standing operation, and whether other safety measures are necessary such as requiring cabs with standing functionality to have in-cab signaling installed.
Excessive seated height	To allow adequate upward visibility, it is very important to lower the operational height of the seat or to consider another, lower seat. Note, though, that this change will not affect standing height.
Inadequate armrest height	The armrests do not provide proper support for the full range of users because they do not adjust while in seated position, and have too short an adjustable range for the standing position. We suggest adding vertical armrest adjustment to provide this support.

6. Usability Test

This section details the activities performed during the usability test phase of the experimental crewstation evaluation. We performed this to judge how well the crewstation's controls are mapped to the functions required for train operations.

We conducted this usability test with experienced locomotive engineers in the CTIL simulator at the Volpe Center in Cambridge, MA, during May 2015.

A usability test is a type of functional evaluation where users are asked to accomplish a series of tasks with a system or piece of equipment to apply scientific measurement and judge key issues. We performed this activity using the experimental crewstation to evaluate whether the crewstation's controls map properly to common train operation tasks as judged by engineers, as well as to ascertain the extent to which the controls allow for consistent and accurate use. The usability test also provided engineers with a chance to give feedback about the crewstation's design.

The usability test was focused on observing operation of the crewstation by end users to further examine aspects of its design, which previous tasks identified as potential concerns. In focusing the test this way, experimenters hoped to be able to determine the expected frequency and impact of these potential issues.

Findings from the usability test clarified earlier potential human factors issues and identified several new ones. This portion of the document details the methods and findings related to this task.

6.1 Methods

To assess the experimental crewstation's usability and find human factors issues systematically, we conducted a usability test with experienced engineers. The test allowed these users to give constructive feedback in a controlled environment to provide additional data for concerns raised by the evaluation team. It also provided a comfortable setting for engineers to voice opinions on the crewstation that they might omit in more public settings.

This section describes the test's participants, tasks, data collection procedure, and data analysis employed while conducting the usability test of the experimental crewstation.

6.1.1 Control Stands

We chose to focus our usability test on elements of the experimental crewstation's design that needed engineer input before classifying as issues. By doing this we were able to answer many questions that were raised in earlier tasks.

We did not explore the same issues in the AAR-105 control stand because engineers have a great deal of experience with it and we were concerned that any comparative performance data between it and the experimental crewstation would reflect experience more than usability.

CTIL is equipped to handle these types of performance comparison between systems, but these are involved studies by nature. In this case, it would require that either the participants receive extensive training and experience on the experimental crewstation, or that participants be chosen from a pool of engineers with no experience on the AAR-105. Given that we planned this usability test to evaluate the first iteration of a design, we decided a more straightforward look at the new design alone was sufficient for understanding where its flaws might be.

6.1.2 Participants

This study included eight locomotive engineers who were familiar with train operations in the AAR-105 control stand. We recruited these participants from a population of engineers from a local commuter railroad and regional freight railroads. Four current passenger engineers and four current freight engineers participated in the study. One of the passenger engineers also had past experience as a freight engineer.

We used an independent recruiter (a former railroad engineer and union member) to find our participants. To do this, the recruiter called union chapters to determine the availability and interest of engineers. The recruiter then sent a follow-up email to interested engineers to inform them about the study and schedule a time to participate.

The vast majority of locomotive engineers are male; therefore, the available participant pool reflected that gender imbalance. Our goal was to include one to two female participants in the study but because of the extremely low availability of female engineers, all eight engineers who participated in the study were male.

6.1.3 Tasks

The tasks for the usability test were centered on issues that we identified in the preliminary design evaluation and ergonomic assessment phases of the crewstation evaluation. We prepared the task scenarios to address the following questions:

- Are engineers likely to engage the throttle by pushing it forward (i.e., incorrectly)?
- Will engineers be able to easily read and understand the state of push button controls?
- Will engineers be able to tell which notch the throttle (or dynamic brake) is in, based on the LEDs beside the control?
- What problems do engineers encounter when switching operation modes between sitting and standing?
- What problems do engineers encounter when operating in standing mode?
- Do engineers exhibit any over-braking behaviors while operating the train?
- When engineers are asked to make specific braking applications, are they able to do so?
- What problems do engineers expect to encounter while operating the train in the reverse direction?
- Can engineers effectively put the automatic brake into the emergency position?

We organized these questions into six tasks to be performed by the engineers in the simulator. We gave the engineers instruction sheets describing the train composition and exact performance requirements; these can be found in Appendix F. A brief description of each task is included in Table 34.

Table 34. Summary of usability test tasks and scenarios

Task	Purpose	Scenario Summary
1	Collect the engineers' first impressions of the chair	Engineers were not told the locations or orientations of the controls. They were asked to perform a brake set and running test, and then depart their initial terminal at track speed (50 mph for the entire experiment). They were required to meet a temporary speed restriction of 20 mph. Afterwards, signal indications guided the engineers to bring the train to a stop.
2	Evaluate the push-button controls	Participants were instructed to depart and follow signal indications. However, before departure the engine became disabled and we instructed the engineers to use the crewstation to find the control error which is responsible for the issue (a fuel control button incorrectly set to the "off" position).
2a	Evaluate the LED feedback of the throttle and dynamic brake; to evaluate the emergency controls	This task was designed to take place after restarting the engine in Task 2, but to avoid waiting the time necessary to bring the train up to speed, we separated it into its own scenario. The scenario began with the train already at 30 mph, with an unsigned speed restriction of 20 mph starting a mile later. The train continued through undulating terrain that required use of the dynamic brake. At predetermined points in the scenario, the experimenter paused the simulator and asked the engineers to use the controls to determine their throttle (or dynamic brake) position. After these throttle checks were completed, the engineer encountered a signal that turned from green to red as they approached it, encouraging them to pull the emergency brake handle. The scenario ended after the engineer brought the train to a stop.
3	Evaluate seated and standing operation in passenger operations; evaluate feasibility of working with papers	Engineers operated a passenger train through three passenger stops. The engineer started with the crewstation in a seated position and at each station stop they adjusted the seat from a seated position to a standing position (or vice versa). We also gave the engineer a Form D while in the standing position. The simulation ended at the final stop.
4	Evaluate the accuracy with which engineers were able to apply the automatic brake	We presented the participants with a stationary train. Participants were then asked to make four applications of the automatic brake as quickly and accurately as possible (applications were of minimum service, 15 and 20 pounds, and full service).We randomized the order of these applications for each participant. We set the train's brakes to

Task	Purpose	Scenario Summary
		direct release for this task, to reveal whether engineers made braking applications that were too large.
5	Evaluate the crewstation's performance during backup operations	Participants were asked to perform a reverse operation maneuver. Since CTIL does not have a rear view, engineers were asked to describe in detail to the experimenter how they would perform this maneuver in the real world (how to work with the conductor, how and where outside the cab they would look to judge speed or distance, etc.).

6.1.4 Data Collection Procedure

Before beginning the experiment, we read each participant an introduction explaining the goal of the usability test and asked each one to sign a consent form to acknowledge the volunteer nature of the study and that they were being recorded.

Following this, we administered a background information questionnaire, which asked questions pertaining to their operational experience and garnered opinions about existing workstations. The main goal of the questionnaire was to get participants comfortable with talking to the experimenter and expressing opinions.

Afterwards, we used the experimental crewstation's user manual to describe the seat and its conversion process from sitting to standing operation. The subjects were then taken into the CTIL simulator, where the experimenter demonstrated the process of adjusting the seat. We did this because the preliminary design evaluation indicated that there was at least some risk of injury during this task if done improperly and we wanted to ensure their safety. We then adjusted the armrests to whatever position the engineer found most comfortable.

Before operating the simulator, we gave subjects an Operations Bulletin which described the differences between the field signage they are used to and the signage in the simulator. These differences are summarized below:

- Due to a bug we found in the permanent speed restriction signage in the simulator, we instructed subjects to disregard the permanent speed restriction signs along the right-of-way. This is consistent with past experiments in CTIL. Instead, one permanent speed restriction of fifty miles per hour was in effect for the entire track in all scenarios.
- The field signage for temporary speed restrictions followed GCOR rules, which include a blank yellow rectangular warning board two miles in advance of the point of restriction, followed by *no signage* at the start of the restriction, and a blank green rectangular board at the end of the restriction.
- The field signage for work areas also followed GCOR rules, which include a yellow and red rectangular warning board two miles in advance of the work area, followed by a red rectangular board at the start of the work area, and a green rectangular board at the end of the work area.

We then asked the participants to complete the previously summarized tasks with the experimenter watching from within CTIL. We asked them to audibly state their intents and actions while accomplishing these tasks in order for us to better understand their thought processes.

We recorded audio of the participants' voice and video of the simulation for each session. The video included the engineer's front view, a view of the engineer's face, a view of the controls, and the engineer's information display. We transcribed the recordings after all sessions were completed for subsequent analysis.

After completing the tasks, we asked each participant to rate the experimental crewstation's usability on the System Usability Scale (SUS), an industry standard scale for measuring usability. The SUS scores system usability on a scale of 0-100, with higher ratings attributed to more usable systems. The mean score of the scale based on an analysis of 1180 SUS studies is 70.91 (s = 11.87), and the top quartile score range is 78.51–93.93 (Bangor, A., Kortum, P. T., and Miller, J. T., 2008). More than comparing to other systems however, we intended the SUS to provide a consistent benchmark for measuring usability in this and any future iterations of the crewstation.

Finally, subjects responded to a debriefing questionnaire in which they rated the difficulty of performing the tasks and using key controls.

Subjects were compensated with $350 in Amazon.com gift certificates.

6.1.5 Data Analysis

This section describes the forms of data analysis that were performed for the usability test on the experimental crewstation.

6.1.5.1 Binomial Probability

The main performance measures in this study were the frequency of engineer mistakes and the frequency of successful task completion. We used binomial probability to determine the expected frequency of these mistakes in the user population. Failure rates were separated into three groups with 95 percent confidence: behaviors that are expected to be exhibited by greater than 5 percent of the population ("small minority"), those that are expected to be exhibited by greater than 20 percent of the population ("substantial minority"), and ones expected to be exhibited by greater than 50 percent of the population ("majority").

Table 35. One-tailed probability matrix for a sample size of eight, used to determine thresholds for population behavior rate

Population Behavior Rate	Probability of Subject Failures 0 subjects	1 subject	2 subjects	3 subjects	4 subjects	5 subjects	6 subjects	7 subjects	8 subjects
5%	1.000	.337	.057	**.006**	.000	.000	.000	.000	.000
20%	1.000	.832	.497	.203	.056	**.010**	.001	.000	.000
50%	1.000	.996	.965	.855	.637	.363	.145	**.035**	.004

Using Table 35, we determined that:

- **Three out of eight** subjects exhibiting a behavior would correspond to a small minority of engineers (>5%, p=0.006).
- **Five out of eight** subjects exhibiting a behavior would correspond to a substantial minority of engineers (>20%, p=0.010).
- **Seven out of eight** subjects exhibiting a behavior would correspond to a majority of engineers (>50%, p=0.035).

6.1.5.2 Tabulation of Comments

We used transcripts of the video recordings to tabulate issues, audible mistakes and complaints. We did this because in certain instances:

- Engineers revealed concerns about the chair that could potentially cause injury. Despite a potential low frequency of occurrence, these issues' repercussions mean that a frequency of zero is the only acceptable goal for the design.
- Engineers exhibited behaviors that further supported usability test findings or previously mentioned human factors issues.
- Engineers voiced concerns that should be reported in this document, despite not being strictly human factors issues.

6.1.5.3 System Usability Scale and Debriefing Questionnaire

We tabulated means and standard deviations for the debriefing questionnaire items and the total SUS score.

Because we did not examine the AAR-105 control stand in this usability test, there is not a SUS or debriefing questionnaire score with which to compare the experimental crewstation's scores. However, the SUS score can serve both as a general measure for usability and as a benchmark for future iterations of the crewstation, should there be any.

6.2 Findings

This section describes the usability test findings, organized by the issues Volpe Center researchers aimed to investigate.

6.2.1 System Usability Scale Results

The mean score for the SUS survey based on the tasks performed during the usability test was 83.71 ($s = 8.8$). There is no other relevant SUS score to compare this to because we did not conduct an equivalent evaluation of the AAR-105 control stand using this scale. However, this score puts the experimental crewstation in the top quartile of systems rated on the SUS, which indicates that overall the workstation was very well received by the engineers (Bangor, A., Kortum, P. T., and Miller, J. T., 2008).

One additional factor to take into consideration is that half of the questions on the SUS were written in a "reversed" style (i.e. questions for which a rating of "strongly agree" corresponds to a worse score for the system). Two subjects may have been confused by these reversed questions; we compared the subjects' responses to these questions to their other responses on the SUS and to their transcripts and concluded that these responses were made by mistake. These possible mistakes accounted for three question responses in all, across seventy questions answered by all subjects. Adjusting these responses to reflect what the subjects likely intended (using the opposite end of the rating scale) resulted in an adjusted SUS mean of 86.57 ($s = 9.57$). Therefore, the end result (regardless of whether these reversed items were incorrectly answered) was the same—the workstation was well received.

Additionally, one subject indicated in the debriefing that he was under the mistaken impression that he was supposed to use the SUS to rate the CTIL simulator and not the experimental crewstation. We removed this subject's results from the analysis.

6.2.2 Debriefing Questionnaire

Table 36 summarizes the results from the debriefing questionnaire, in which subjects rated the difficulty of performing the listed tasks on a scale of 1–5 (higher numbers indicate higher difficulty).

Table 36. Debriefing questionnaire results

Task	Mean difficulty	Standard deviation
Find the problem with the Fuel Control button	4	1.07
Determine your throttle notch	2.88	0.83
Find button controls without looking down	2.63	1.6
Operate the automatic brake	1.88	1.25
Switch the chair from sitting to standing	1.63	0.74

Task	Mean difficulty	Standard deviation
Read the information displays	1.63	0.74
Engage the alerter response button	1.5	0.76
Switch the chair from standing to sitting	1.5	0.76
Engage the dynamic brake	1 .38	0.74
Operate the throttle	1.38	0.52
Engage the emergency brake	1.13	0.35

The tasks that were notably rated as difficult include finding the problem with the Fuel Control button and determining the throttle notch. Another point of interest is that the participants were divided over the ease of finding button controls without looking down; two engineers rated this action a 5 out of 5, while five of the engineers rated it at a 2 or below.

Beyond these three ratings, the results from the debriefing scale seem to indicate an overall high level of ease in using the controls and performing the core functions that were examined in the usability test. This finding is consistent with the implications of the SUS score results.

6.2.3 Findings based on performance Data

We reached the findings below using the performance data measured by the Volpe Center experimenters during the usability test of the experimental crewstation.

6.2.3.1 Throttle directionality

After reading instructions for Task 1 and conducting a "brake set" procedure, participants departed from the initial terminal without any instruction on how to operate the throttle. We did this so that we could examine the participants' natural inclination for directionality of the controls. We hypothesized that a large number of engineers would push the control forward to move the train forward.

Only two of eight subjects pushed the control forward when asked to depart. This number does not meet the threshold of confidence that even 5 percent of the user population would perform the same way. Furthermore, after the initial mistake we found no evidence of directional confusion of the throttle from any engineer in this or any subsequent task.

Further discussion with the passenger engineers revealed that they use two different types of control stand: the AAR-105 and a desktop-style control stand that features a combined throttle and dynamic brake that is oriented like the one on the experimental crewstation.

Given the performance data and the information that similar inverted throttle designs currently exist, it is not expected that pulling the throttle backwards to power the train is a cause for concern despite our concerns in our initial evaluation and despite that it is not strictly compatible with military design standards. There may also be negative transfer effects if the directionality of the throttle were to be reversed, since current engineers may have experience with “pull-to-throttle” controls. [20]

6.2.3.2 Push buttons

In Task 2, we required participants to find the cause of a disabled engine, which was that the Fuel Control push button was improperly set to the “off” position. We asked the engineers to use the experimental crewstation to find this issue.

Despite all engineers checking the Engine Run, Fuel Control, and Generator Field buttons to ensure they were all in the “on” position, seven out of eight engineers were unable to find the problem. The probability matrix in Table 35 indicates that this failure would occur in a majority of the population of engineers. This failure was due to an inability to distinguish between the Fuel Control button’s “off” and “on” positions, an explanation that is further supported by the debriefing questionnaire, which indicated a high difficulty score for finding the problem as well as comments from engineers in the study (sample comments below):

- “Normally [the fuel control button will] be a switch that will be up or down. If it was lighted it would say, you know, active or passive.”
- “On a locomotive, I mean we have an F40, we have a switch, down and up; up is engaged. So your eye would automatically scan that. There’s nothing here to scan, it’s just a black button.”
- “… I wasn’t thoroughly familiar, it’s easier you know with the switches there, you can just visually look at them and see everything’s up as opposed to having to check, that I don’t totally like, you’ve got to feel for it, you can’t visually see so much what the issue is.”

One subject did mention that a problem with the fuel control is a somewhat unexpected scenario because the engine would only cut out due to such an issue if the button had been bumped. However, he also noted that finding the issue should still have been an easy task because a simple visual search of the button states should have been able to uncover the problem.

These findings support the notion from the standards comparison that button type and feedback is of critical concern to the design of the experimental crewstation. This issue can cause oversights and mistakes by engineers in addition to confusion.

6.2.3.3 LED Display Readout

During Task 2a, we periodically prompted each participant to tell us the position of the throttle based on the LEDs on the experimental crewstation. We did this only three times due to time constraints. Our expectation was that engineers would be unable perform the task to 100 percent

[20] This conclusion assumes that the automatic brake and independent brake follow the same directional conventions (push forward to brake) in both current and future workstations.

accuracy, given the expected difficulty of counting the glowing lights as we mentioned in the standards comparison.[21]

The mean accuracy of engineers in determining their throttle location was 87.5 percent (s = 17.25%), with no participant responding incorrectly more than one time. There were three incorrect responses out of twenty-four total trials. In all three cases the incorrect throttle check was due to a mismatch between the finite nature of the LED on the dynamic brake and its continuous use. That is, the dynamic brake allows for very fine adjustment, but its LED is incapable of showing that the brake is between any of its eight indicated positions.

Responses in the debriefing questionnaire also indicated that participants experienced a moderate amount of difficulty in determining their throttle notch.

Based on the performance and debriefing data it is reasonable to conclude that a displayed numerical range may offer an improvement in accuracy and a decrease in user frustration.

6.2.3.4 Over-braking

We asked the engineers to make four braking applications using the automatic brake: two applications of minimum and full service, which are aligned with detents, and two continuous applications of 15 and 20 pounds under direct release. Their goal was to make them as quickly and accurately as possible.

Since we were especially concerned during the preliminary design evaluation about users making braking applications that are too large, we analyzed the data from that perspective; we categorized any braking application greater than the target as a failed attempt.

Four of eight engineers failed to make 15-pound braking applications without going over; the probability matrix indicates this would occur in a small minority of the population (greater than 5 percent). Five of eight engineers failed to make the 20-pound application without going over; this corresponds with a large minority of engineers (greater than 20 percent). Only one engineer was able to achieve both of these braking targets successfully. See Table 37 for a summary of brake application failures and their expected frequencies.

Table 37. Findings based on usability test performance data for over-braking

Task	Failures	Expected Frequency Based on Probability Matrix
Minimum service application	0 out of 8	Not significant (less than 5%)
Full service application	0 out of 8	Not significant (less than 5%)
15 pound application	4 out of 8	Small minority (greater than 5%)

[21] Since the difficulty of reading the LED display may depend on the position of the throttle, and we were unable to control the notch that engineers were in during operation, we felt that it did not make sense to use binomial probability for this task. Instead, each participant's accuracy was determined by the number of successful readings divided by three, and then we took an average of these scores.

Task	Failures	Expected Frequency Based on Probability Matrix
20 pound application	5 out of 8	Large minority (greater than 20%)

Discussion with the participants after conducting the task and at other points in the usability test supported the notion that the braking window between minimum and full service was too short:

- "For only going 5 pounds [from Release to Minimum Service] it seemed you go a very long way. And there, that's full service, and that's another what, 20 pounds, in less distance than what you go to minimum."
- "It's a very short distance to travel…I run a 30 [desktop control stand]. The distance to travel with the handle is longer. So I didn't, I had a little bit of a hard time feeling that, feeling where I was in the brake. I think I had to look down a couple of times…between the minimum and the full service it just seemed a little short."
- One engineer used the AAR-105 control stand in the LETS cab simulator to show a braking technique that he and other engineers use with the 26L brake. When needing to make small changes to the braking application, he would put the brake just past minimum service and gently tap the brake handle until achieving the right amount of air. He was concerned that a much shorter braking window would make this operation impossible.[22]

As mentioned in the preliminary design evaluation, the cost for over-braking is high. Therefore these findings indicate the need to redesign the automatic brake handle to allow for a longer, more forgiving service range.

6.2.4 Findings from comments or other noted behaviors

The following findings were reached by analyzing the comments and notable behaviors of participants in the usability test.

6.2.4.1 Sit/Stand Conversion

Engineers did not experience any problems during the conversion of the chair from seated to standing operation. In fact, eight out of eight engineers were able to complete the conversion tasks without error. However, two comments related to pinch points and feedback were of particular interest to us.

One engineer was concerned that his hand might get caught between the footrest and the cushion that shields it while converting the workstation to standing position. We contend that while the pad is made of soft material, the footrest's shape affords grasping and accidental hand insertion may still cause users' hands to get pinched if they happen to be at the wrong angle.

[22] A quote is not provided because voice data was not captured for this demonstration. It was shown by the engineer outside of the CTIL, in another Volpe Center rail simulator that had the conventional controls installed.

Another engineer noticed that there was no audible click when he raised the seat pan back into the seated position. This is in violation of the military design criteria regarding feedback, though it is a minor issue.

6.2.4.2 Standing Operation

To solicit comments about operating in the standing position, we gave engineers a chance to operate the train between two station stops while standing.

We noted a number of body positions that appeared to be uncomfortable. However, these positions varied considerably by participant. Given the small sample set of the usability test, there was not enough performance data to analyze these postures rigorously. Nonetheless, it appears that these body behaviors were all due to a common cause: the pedestal on which the experimental crewstation sits.

Engineers wishing to stand upright in the crewstation with their backs against the seatback found their feet partially on the crewstation's steel pedestal mount (see Figure 39). The steel pedestal mount is approximately 0.5 inches thick, and the circular unit about which the chair rotates lies just beyond its edge, measuring 0.75 inches. Additionally, the entire chair sits on CTIL's adapter plate, which is also 0.75 inches thick, with a 45 degree chamfer.[23]

Figure 39. The base of the experimental crewstation

[23] It should be noted that the adapter plate exists because the manner in which the crewstation was installed in CTIL; FRA required that its installation should be minimally invasive to the simulator. In an actual train, an adapter plate may not be necessary.

This relatively large ridge meant that engineers had difficulty finding a comfortable standing position, which led to frequent shifting for the participants. Some of the positions engineers adopted included:

- Standing with their feet at a potentially uncomfortable angle, half on the pedestal and half on the ground, in order to stand straight and make use of the backrest.
- Stepping forward and leaning back at an awkward angle to make use of the backrest.
- Standing with their legs split far out to the left and right to avoid the pedestal base, which lowered the engineer's stance enough to use the backrest and armrests but was noted to be uncomfortable.
- Stepping forward and standing straight without use of the backrest or armrests, which reduced the reachability of the control boxes and may not be possible in an actual moving locomotive due to the lack of support.

Engineers noted their discomfort with each of these positions. One engineer commented: "To stand up, your feet almost have to be so far forward. Otherwise you try to stand on the pedestal." Another who stood with his legs splayed on either side of the footrest noted that he would not like to operate in the standing position very long.

If this crewstation is ever to be installed in an actual locomotive, the pedestal should be countersunk into the floor if at all possible. If this cannot be addressed, this issue should be considered a primary concern to designers.

6.2.4.3 Operating in Reverse

In Task 5**,** we asked participants to perform a reverse operation maneuver. Since CTIL does not have a rear view, we asked engineers to describe in detail to us how they would perform the maneuver in the real world (how to work with the conductor, where outside the cab they would look to judge speed or distance, etc.). We did this to gain more knowledge about how the crewstation would perform in reverse operations.

During this task, all eight engineers reported that they primarily rely on their conductor to know their exact position. Typically the conductor gets out of the train and provides the engineer with a "car count," a measure of how close the train is to arrival, as measured by the number of cars remaining before it is necessary to stop. This measure is especially useful to engineers because with long trains it is typically impossible to know the location of the train's rear. One exception to this was the opinion of an engineer who worked for a local rail yard assembling train consists; he contended that rear window accessibility is a necessity because of the frequency and duration with which he is required to run in reverse. This is an ability that the experimental crewstation can fulfill, due to its rotation feature.

Engineers reported that understanding whether the train was moving, even if very slowly, is key to operating in reverse; when the locomotive is behind the load rather than in front, it takes time to remove the slack in the train, which results in slow and intermittent locomotive movement that is hard to perceive. Engineers reported that they look for signs of this movement either by looking at their speed indicator or by looking at the ground just outside their window.

Participants who indicated that looking at the ground was a useful tool also indicated that looking straight down was not necessary; they believed they could get the information by looking at the ground slightly further away. It is important to note that parallax may play a part in reducing the fidelity of the observed speed despite participants' comments, since objects that are further away appear to move less than ones that are closer. However, the issue of the impact of parallax on fine movements in locomotive cabs is not one that CTIL is equipped to study deeply.

Given that engineers have a multitude of tools and personnel to aid them in backup operations, it does not appear that the position of the seat will cause a significant problem for backup operations under current operating conditions. As such, the issue noted in the preliminary design evaluation is retracted.

6.2.4.4 Emergency Braking

The goal of this portion of the test was to force engineers into a situation where they needed to use the emergency brake. However, when presented with a sudden unexpected red signal, only two engineers put the train into emergency service. All other train engineers brought the train to a safe stop without emergency braking.

Conversations with engineers led us to believe that a sudden unexpected red signal is not always cause for an emergency brake, especially in a freight environment where trains may be carrying hazardous materials. In the case of this particular scenario, the train was travelling at 20 mph when engineers were presented with the red signal. Therefore we believe that the infrequent emergency use can be attributed to the engineers' ability to stop safely, rather than with any issue with the control. Based on this, there is not enough information to indicate whether the automatic brake control is a problem in emergency situations. Future studies should use situations where emergency braking would be more likely to occur, such as an obstruction hidden by a blind turn.

The questionnaire responses of the two engineers who used the emergency indicate a best-possible score of 1 for its operation. However, the low sample size is likely not enough to make a determination of how salient the emergency brake is on the experimental crewstation. We recommend falling back on the standards comparison for any improvements to the design, such as making the automatic brake handle red to follow convention and to indicate its emergency use. These changes may speed up recognition in critical situations.

6.2.4.5 Writing Surface

We determined during the preliminary design evaluation and standards comparison tasks that the lack of a writing surface was a human factors issue. Therefore engineers' behaviors related to a lack of a writing surface were not planned to be explored more in the usability test. In fact, we were concerned that a lack of a place to write or to put papers would be too distracting; therefore, subjects were given a clipboard to aid them. The participants were allowed to use and store the clipboard however they wished. Despite all this, we witnessed some behaviors during the test that underscored the writing surface issue and decided they were worth highlighting in these findings.

Left without a place to store the clipboard, participants found their own solutions, some of which can be seen in Figure 40. Engineers attempted to store their paperwork by placing it (clockwise from top right):

- Perched on the extension arm mounted on the right armrest, leaning against the displays.

- On their laps, forcing them to sit tip-toed to balance it.
- On the shelf in front of the forward view where it was out of their reach.
- Removed from the clipboard, folded and placed atop the display mount.

None of these locations, nor any of the other locations engineers attempted, would work in a real cab environment.

Figure 40. Four places engineers attempted to store usability test paperwork while operating the train

Some participants suggested that a foldout desk arm (similar to those sometimes found in auditorium seating) or a hook for the clipboard might help with writing tasks or clipboard storage, respectively. While these solutions each have their own drawbacks, these behaviors and participant suggestions serve to greatly underscore the importance for including space for writing and storing paperwork. Without such a space, it is clear that engineers are forced to come up with solutions that are ineffective due to lack of affordances, may result in a great deal of physical discomfort, and/or may block some portion of the screen or out-the-window view.

6.2.4.6 Reverser Interlock

The AAR-105 control stand has a number of interlocks to prevent actuation that could lead to locomotive damage. One such interlock operates between the throttle and the reverser; under no circumstances will the reverser lever move when the throttle is beyond the idle position.

During Task 5 of the usability test one subject accidentally moved the reverser to neutral before putting the throttle in idle. By doing so he discovered that the experimental crewstation does not have the necessary interlocks to prevent its improper actuation. While only one subject encountered this issue, it should be given high priority because accidental actuation in this manner has a very high potential of damaging the locomotive.

6.2.4.7 Two-handed Operation

Two subjects suggested that there are certain operations that engineers may attempt to perform using both hands where designers of the crewstation did not intend for this.

The first issue is related to the placement and actuation of the horn. During the usability test, two engineers attempted to sound the horn with their right hand while keeping their left hand on the throttle (see Figure 41). One engineer stated that keeping one hand on the throttle control was a typical operation while going through grade crossings.

Figure 41. Two-handed operation for simultaneous use of the horn and throttle

Secondly, since use of the automatic brake is often immediately followed by using the bail, these same engineers found it awkward to move their hand to the adjacent independent brake to do so. While they did not demonstrate the behavior, they both voiced the desire to actuate the bail with their left hand while keeping their right hand on the automatic brake.

Both of these actions are easily afforded by the AAR-105 control stand; due to its vertical orientation, engineers are able to access multiple controls without crossing hands (though they still may find considerable discomfort, as noted in the Anthropometric Modeling section of this report).

These actions, though infrequent, support concerns we had noted in the standards comparison. Engineers suggested mounting an additional horn button on the throttle lever and an additional bail button on the automatic brake lever to reduce unnecessary hand motion and arm crossing. Another suggestion from an engineer would be to put copies of the horn on both sides of the control stand to discourage arm crossing.

6.2.4.8 Maintenance and Breakage

Our conversations with the participants allowed them to voice concerns about the durability of the chair from maintenance and breakage perspectives.

Several engineers were concerned that the maintenance requirements of the chair were too high. According to conversations with these engineers, maintenance crews do not often spend time servicing cab elements that are not controls. These engineers worried that the seat conversion process would be compromised as a result:

- "I know some of the old seats have a lever [for back support] on the side and of course when they get rusty, they wouldn't [spring load it], wouldn't adjust it, it wouldn't lift up so they'd be leaned over pulling on it and yanking on it and stuff."
- "Not so much on the main track but if you're on a local or a switch engine or something like that, that's where the older engines are and you have armrests that don't work, or one is broken or the adjusters don't work so one's up this way and the other one's falling down that way. So, you know, a requirement would have to be that the seat would now have to be part of a daily inspection, and all of this stuff would be a requirement to actually work, you know."

Additionally, one engineer who has been involved with training and discipline reported that seating is often damaged by frustrated engineers. His concern about the fragility of the monitor mounts reinforces findings in this report from previous tasks:

- "Well, I just look at it and it's got too many moving parts. I've got people that I work with that are, using it very generally here, people are going to get up and they're going to smash that side, going to push that aside, I think a fixed [mount] thing would be much more beneficial, just in terms of maintenance and not having destruction."

This participant was also particularly concerned about the quick-release locks that allow for armrest adjustment.

Both of these observations support our concerns about the fragility of chair elements and display motions, and we suggest using sturdy elements wherever possible and minimizing easily accessible moving parts. We recommend replacing quick-release units with spring loaded pins, securing the monitor mounts in multiple locations, and making an overall attempt to damage-proof the system.

6.2.4.9 Dirty Environment

One engineer mentioned that working on a train is a messy endeavor; engineers routinely interact with oil, dirt and grease that gets on their boots and clothes. This participant anticipated that the footrest would be extremely dirty, and that it would benefit to have a handle accessible so that engineers do not need to grab the dirty footrest to convert the seat from sitting to standing.

6.3 Summary

The usability test task was successful in resolving potential issues found during earlier phases of the evaluation. Additionally it revealed a small set of issues that we had not yet discovered. Lastly, data from the study allowed us to retract some issues that we had considered potential concerns, but that were not supported by these findings. In accomplishing these tasks, the usability test provided great value to the evaluation and also provided engineers with the chance at early stage input.

6.3.1 Human Factors Issues by Importance

We created a list of human factors concerns from the usability test findings. It is ordered in Table 38 by perceived importance; however, other prioritization schemes may be used.

Table 38. Summary of issues identified in the usability test

Issue	Summary of issue	Supporting evidence
Push buttons	Performance data indicate that engineers had a great deal of difficulty determining the current button state due to lack of visual feedback.	Seven out of eight engineers failed this task, meaning that this issue would occur in the majority of the population (50%) Debriefing questionnaires also revealed that engineers had difficulty with this task
Automatic brake service window	Performance data show a risk of over-braking due to the brake's short window between minimum and full service applications.	Four out of eight engineers failed to make a 15-pound braking application and five out of eight failed to make a 20-pound application, indicating that these tasks would occur in a small minority (greater than 5%) and large minority (greater than 20%) of the population, respectively
Standing discomfort	The experimental crewstation's pedestal and mount create uncomfortable foot positions while standing. If this seat is implemented in a real locomotive, care should be taken to countersink the pedestal into the floor.	Engineers' comments and behaviors

Issue	Summary of issue	Supporting evidence
Reverser interlock	The experimental crewstation does not have the proper interlocks to ensure the reverser is not actuated while the throttle is engaged.	Engineers' comments and behaviors
LED display readout	Engineers indicated that reading the LEDs was somewhat difficult, and performance data show that a mismatch between discrete LED indicators and continuous dynamic brake controls can cause mistakes in identifying dynamic brake positioning.	Mean accuracy for this task was 87.5% (*s* = 17.25%) Debriefing questionnaires also revealed that engineers had difficulty with this task
Two-handed operation	Engineers noted the need for simultaneous use of the throttle and horn, and disliked the need to frequently move from the automatic brake to the bail. The AAR-105 control stand allows for two-handed operation in both of these cases.	Engineers' comments
Maintenance and breakage	Some engineers commented that the design of the seat means it may become substantially less functional over time, due to lack of maintenance and intentional breakage by engineers.	Engineers' comments
Pinch point	There was concern from one engineer that the footrest and seatback create a pinch point. We contend that this is a somewhat minor pinch point, but since it could conceivably result in injury it must be considered an important concern.	Engineers' comments
Dirty footrest	A dirty cab environment might discourage engineers from converting the chair to standing position, due to engine grease and dirt on the footrest.	Engineers' comments
Seat pan feedback	When returning the seat pan to seated position, there is no indication (aural or otherwise) that it is engaged and in position.	Engineers' comments

6.3.2 Retracted Issues

Data from the usability test resulted in the retraction of two earlier concerns from the Crewstation Evaluation, listed in Table 39.

Table 39. Summary of issues retracted following the usability test

Issue	Summary of issue and evidence for retraction
Throttle directionality	While the "pull to power" concept conflicts with the military design criteria standard, data from engineers failed to show that even 5% of the population would encounter problems with directionality upon initial use. Furthermore, switching the throttle direction may incur negative transfer effects. Throttle directionality concerns are hereby retracted so long as future designs consider that all brakes should operate in the same direction.
Reverse operations	Evaluators were initially concerned that the seat would block critical access to mirrors and the outside of the train. Conversations with engineers revealed this to not be the case.

7. Conclusion

Overall, our evaluation revealed some important positive qualities of the experimental crewstation:

- The standards comparison task revealed great improvement in the design's adherence to human factors criteria when compared to the AAR-105 control stand.
- The anthropometric modeling task supported the standards comparison findings by showing the extent to which the experimental crewstation improves engineer's access to controls and reduces engineers' physical discomfort.
- The usability test showed that engineers judged the crewstation to have a high degree of usability overall.

These qualities are in line with FRA's goals as listed in the RFP.

However, in addition to these findings, the crewstation evaluation process uncovered many issues that need to be rectified in order for a design like this one to move forward both from a safety perspective and for full acceptance by those in the railroad industry. It is not uncommon for evaluators to encounter a variety of issues in the first iteration of a system, and for designers to address them in subsequent iterations. It does pay to note, though, that a subset of these issues would be inherent to the design of any workstation of this type:

- The design of the display mounts leaves the displays very unsteady in the simulator, and they would be considerably more so in a real locomotive. In-train forces dictate that the display mounts should be short, strong, and attached to an extremely stable base. The experimental crewstation seat does not provide this, and it may be difficult for any standing unit to provide it. Solutions we suggested call for abandoning the standing nature of the chair or detaching the monitors from it, which would deny access to them or place them further away from engineers in certain chair positions. Overall, any mounted display needs rigorous testing in a locomotive to determine whether it is stable enough for use.
- Standing operation does not provide the required 15 degrees of upward visibility out the forward view, which may make high signals extremely difficult, if not impossible, to see. If FRA is committed to the idea of standing operation it would require taller locomotive windows, which is an involved design change.
- There is no space for writing down information or storing paperwork, and no obvious solution for a place to put it. This may be an issue that becomes obsolete with future computer tools, but it is untenable based on current train operation needs.

Before any further pursuit of a sit-stand control configuration with displays and controls mounted on the armrests, we suggest deep consideration as to how to first address these issues or, alternatively, not including some of these things as *requirements* of the integrated workstation given the significant problems that may be introduced as a result.

We arrived at all these findings by using a series of dependable human factors evaluation tasks that included preliminary design evaluation, standards comparison, anthropometric modeling and a usability test with railroad engineers. By allowing the results of each task to inform the goals of subsequent ones, we were able to quickly find high-level concerns and verify them rigorously. This same approach could also be used for evaluating any future crewstation concept.

Using CTIL was extremely beneficial to the evaluation. It allowed us to collect engineer performance data to better understand how the chair might be used in the real world and enabled us to use its AAR-105 control stand as a benchmark for standards compliance.

During this process we determined that there are several areas of research that would greatly benefit evaluations of future cab control designs:

- Learn the details about the types of AAR-105 control configurations, including their placement relative to the window and seat as well as number of displays and their locations in the cab. This could be done by surveying railroads or by visiting engine terminals and taking measurements. This task would enable researchers to make more complete and accurate evaluations of other conceptual control configurations, and allow the findings to be more generalizable to railroads.
- Learn about the types of seats currently in use and their relative distribution by surveying railroads about their equipment. Engineers who visited the Volpe Center for the usability test noted that many railroads have poorly featured, damaged, or inadequately maintained seats. Control accessibility in the AAR-105 is dependent on how well the seating lets engineers orient themselves to the stand. It is possible that providing guidance to railroads about seating could increase control stand accessibility and decrease repetitive stress injuries in a cost-effective manner.
- Use the design standards and anthropometric modeling tools outlined in this document to evaluate AAR-105 control stand configurations and seating from the above survey information. This would provide railroads with direct guidance on which configurations are best for use. In addition to control configuration, the study could also examine optimum display placement in the AAR-105, which is major issue that FRA attempted to resolve via the experimental crewstation. This may identify low-cost upgrades for existing locomotives that resolve major issues and increase their serviceable life as more automation tools for train handling come online over the coming decades.
- Conduct a time-motion study to more deeply understand control use frequencies in various types of operations. Understanding how uncomfortable it is to use a control stand is only half of the story in determining whether it needs to be redesigned. The other half is knowing the frequency of their use and the tolerable dosage of these positions in terms of long term injury. A better understanding of these impacts could lead to focusing on improving the locations of key controls, rather than attempting to come up with design concepts that affect all of them at once.
- Use the design standards and anthropometric modeling tools outlined in this document to evaluate desktop-style configurations and seating in use in the United States and abroad. This would provide railroads with direct guidance on the advantages and drawbacks of this style of control stand compared with the AAR-105. Since desktop-style control stands are often used in passenger operations, this task would provide a similar benefit to passenger railroads as this document does for freight systems.

These research areas speak to the notion that while the experimental crewstation does attempt to address key issues of control access and display integration, it does not do so with regard to the entire possible set of requirements for train operation. It may be prudent to enumerate a full set of requirements that all control configurations should strive to resolve, be they human factors-related or beyond, and then aim to design a workstation that addresses them. The resultant system may include a workstation with some similar features to the one we tested, but it importantly would also allow railroads to address their own unique needs by not limiting them to a single design solution. These requirements could also be used to guide changes in existing workstations which would be cost-effective and straightforward for railroads.

In all though, the creation and evaluation of the experimental crewstation was valuable because it encouraged out-of-the-box design thinking and led to an evaluation method that can be applied to any future system. In doing so FRA, QinetiQ, and the Volpe Center worked together to ultimately contribute to the goal of enhanced railroad engineer safety and the future of cab design.

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Appendix A. Human Factors Issues by Importance

The following table is a list of all issues found during our evaluation of the experimental crewstation. We ordered these issues based on our perception of their importance, but the crewstation's designers as well as FRA and other stakeholders may feel that a different prioritization is more prudent. Ultimately any decision on improving the chair, should FRA consider its design a useful one, should incorporate all relevant perspectives and not just ours.

Table A1: Human factors issues found while examining the experimental crewstation, in descending order of importance

Issue	Summary of issue	Evidence
Unstable display mounts	Displays are mounted to the right armrest with a single point of attachment, leading to dangerous levels of movement that impair readability and could damage the screens or window.	Observation of monitors swaying with engineer movement in a simulator without motion; design standards criteria[24] for display vibration; comments from engineers during usability test
Lack of workspace and storage space for papers	The experimental crewstation includes neither a desk nor storage space for paperwork, which engineers use frequently.	Design standards criteria require a work surface and storage space; behaviors from engineers during usability test
Absence of reverser interlock	The experimental crewstation does not have the proper interlocks to ensure the reverser is not actuated while the throttle is engaged.	Comparison of interlocks on AAR-105 and experimental crewstation; comments from engineers in usability test
Standing position too high to see overhead signals from distance	Standing operation will affect the engineer's ability to maintain contact with high signals due to the height of train cab windows restricting upward visibility. FRA should decide on whether this affects the safety of standing operation, and whether other safety measures are necessary such as requiring cabs with standing functionality to have in-cab signaling installed.	Line-of-sight analysis using anthropometric data
Seated position too high to see overhead signals from distance	To allow adequate upward visibility, it is very important to lower the operational height of the seat or to consider another, lower seat. Note,	Line-of-sight analysis using anthropometric data

[24] "Design Standards Criteria" refers to specific criteria from MIL-STD-1472G (DoD, 2012), which was our main point of reference for the standards comparison task.

Issue	Summary of issue	Evidence
	though, that this change will not affect standing height.	
Standing in a locomotive leaves engineers vulnerable to run-in forces	The ability of standing persons to withstand shock forces may present problems for standing operation. The crewstation seatbelt is unlikely to provide adequate support for these problems.	Comparison of sitting versus standing g-force tolerance (literature research)
No intercom speaker	There is no intercom, which is essential to many tasks.	Knowledge of communications content from previous CTIL experiments
Small braking window may lead to over-applications of automatic brake	Performance data show a risk of over-braking due to the brake's short window between minimum and full service applications.	Usability test performance data
Standing vibrational effects	The ability of standing persons to withstand vibration may present problems for standing operation.	Literature research
Fragile detents	Control lever detents are very weak relative to the AAR-105 control stand levers, and seem to be weakening over time, increasing the risk of inadvertent actuations. This may be simply a prototyping issue.	Observation of aluminum flaking from detent housings
Buttons for frequently used controls are too small	Enlarging some of the most frequently used controls may allow for faster actuation.	Design standards criteria for users wearing gloves
Alerter position too far back on panel	The size and placement of the alerter could be improved to allow for faster actuation and slightly more comfortable arm positioning.	Observation of users being impeded by the chair back when actuating the button
Armrests not adjustable white sitting, and not adjustable enough while standing	The armrests do not provide proper support for the full range of users because they do not adjust while in seated position, and have too short an adjustable range for the standing position. We suggest adding vertical armrest adjustment to provide this support.	Anthropometric analysis shows lack of forearm support
Footrest low and non-adjustable	The height of the footrest relative to the seat is not adjustable and is too low for the smallest users.	Design standards criteria

Issue	Summary of issue	Evidence
Push buttons used in place of breakers or switches	Performance data indicate that engineers had a great deal of difficulty determining the current button state due to lack of visual feedback. Other control types which provide better feedback would be preferable.	Design standards criteria; usability test performance data
Risk of falling footrest	Conversion between the seated position and the standing position may cause injury if performed improperly.	Experimental crewstation manual
Control distribution may overload left hand	The placement of some of the most frequently used controls may not evenly distribute the workload between the left and right sides of the body.	Design standards criteria; observation of usability test subjects crossing their arms to aid their left hands.
No forearm support for use of levers (due to controls not being forward of the armrest)	The placement of some levers could be improved to allow for more comfortable arm positioning and use of forearm support.	Design standards criteria require forearm support for small hand movements
Automatic brake not coded red for emergency use	The emergency brake in the experimental crewstation should be colored red for consistency with other emergency controls and workstations.	Design standards criteria
Labels not designed for dark adaptation	Not all labels meet requirements for dark adaptation (white text on a black background) nor is adjustable backlighting provided.	Design standards criteria
Confusion over throttle and dynamic brake notch due to LEDs instead of numeric readouts	Throttle and dynamic brake positions are indicated by a series of LEDs which are difficult to read and do not accurately reflect the continuous nature of the dynamic brake. Feedback can also be made clearer during dynamic brake set-up.	Usability test performance data; design standards criteria
Chair base makes standing operation uncomfortable	The experimental crewstation's pedestal and mount create uncomfortable foot positions while standing.	Behavioral observations from usability test
Chair's central location means changing rearview mirror placement	The fixed right armrest and display screens may prevent access to the side window and mirrors.	Comments from engineers during usability test

Issue	Summary of issue	Evidence
Dirty environment might make footrest adjustment inconvenient	A dirty cab environment might discourage engineers from converting the chair to standing position, due to engine grease and dirt on the footrest.	Comments from engineers during usability test
Equipment is somewhat fragile and prone to breakage from rail environment and occasional delinquent engineers	Some engineers commented that the design of the seat means it may become substantially less functional over time, due to lack of maintenance and intentional breakage by engineers.	Comments from engineers during usability test
Control spacing slightly crowded	The size and placement of some of the most frequently used controls could be improved to allow for faster actuation and slightly more comfortable arm positioning.	Design standards criteria
Other minor issues:	Buttons rely on color coding rather than size, shape and style	Design standards criteria
	Maintenance accessibility may be difficult with small controls and casings	Design standards criteria
	No clear grasp area on footrest other than the unit itself	Design standards criteria
	Some items not labeled, others placed below controls instead of above them	Design standards criteria
	Label font sizes vary and stroke width too small	Design standards criteria
	Labels may have inadequate contrast with background	Not tested (beyond scope of CTIL)

Appendix B. Standards Comparison Tables for Relevant Sections

B.1: Controls

Table B1: Standards Comparison table for MIL-STD-1472G's Section 5.1.1: General Criteria (DoD, 2009)

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.1.1.1 Selection	*Not applicable.*	-	*Not applicable.*	-
5.1.1.1.1 Compatibility with users	**Potential conflict.**	Many important or frequently used controls including throttle, dynamic brake, and alerter are on the left armrest. Though this arrangement does not require awkward twisting, it may still place an excessive burden on the left (often non-dominant) hand at times. We discussed this more in the usability test findings.	**Potential conflict.**	All controls are to the left of the user, which may be problematic for right-handed users and require users to orient themselves to face the control stand. This is examined in the anthropometric modeling task.
5.1.1.1.2 Distribution of workload	**Potential conflict.**	Several frequently used controls are located on the left armrest, including the throttle and dynamic brake. To promote a more equal distribution of workload to the right and left arms, it may be beneficial to relocate some of these controls.	**Potential conflict.**	If operator turns to face the control stand, they may use both hands to operate the controls. However, the left arm may be overburdened due to the placement of the stand to the left of the operator. This is examined in the anthropometric modeling task.
5.1.1.1.3 Multirotation controls	*Not applicable.*	-	*Not applicable.*	-
5.1.1.1.4 Detent controls	No conflict.	-	No conflict.	-
5.1.1.1.5 Stops	No conflict.	-	No conflict.	-
5.1.1.1.6 Power assist	*Not applicable.*	-	*Not applicable.*	-

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.1.1.2.1 Consistency of movement	**Potential conflict.**	The throttle is activated by pulling it backward, while the dynamic brake is activated by pushing forward. This criterion suggests that the opposite configuration is more correct. The current configuration is modeled after the AAR-105 stand, and will be further examined in our usability test.	**Potential conflict.**	The throttle is activated by pulling it left (backward), while the dynamic brake is activated by pushing it right (forward). Since the control station is oriented obliquely, it is unclear whether these should be classified as forward/backward motions, in which case they should be reversed according to this criterion.
5.1.1.2.2 Multidimensional operation	*Not applicable.*	-	*Not applicable.*	-
5.1.1.2.3 User-control orientation	No conflict.	-	**Potential conflict.**	The user must rotate his or her body to face the controls. This issue will be examined in more depth using anthropometric modeling.
5.1.1.2.4 Valve controls	*Not applicable.*	-	*Not applicable.*	-
5.1.1.3.1 Grouping	**Minor conflict.**	Lighting controls exist separately on both left and right armrest panels; according to this criterion it may be preferable to group these together.	No conflict.	-
5.1.1.3.2 Sequential operation	No conflict.	-	No conflict.	-
5.1.1.3.3 Location of primary controls	**Potential conflict.**	Most primary controls are readily accessible, but the alerter reset button may be difficult to reach. This issue will be examined using anthropometric modeling.	**Potential conflict.**	Some primary controls such as the automatic brake may be difficult to reach. This issue will be examined using anthropometric modeling.

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.1.1.3.4 Consistency	**Potential conflict.**	The directionality of the throttle and dynamic brake was designed for consistency with the AAR-105 control stand but conflicts with other criteria. See Sections 5.1.1.2.1, 5.1.2.3.7, 5.1.2.3.9, and 5.1.2.3.13 of MIL-STD-1472G (DoD, 2009) for additional discussion.	No conflict.	-
5.1.1.3.5 Remote controls	*Not applicable.*	-	*Not applicable.*	-
5.1.1.3.6 Maintenance and adjustment	No conflict.	-	No conflict.	-
5.1.1.3.7 Spacing	**Minor conflict.**	The horn and bell are adequately spaced for fingertip actuation, but not for palm. The push button lighting controls are also inadequately spaced. The separation of rotary controls is slightly less than the requirement.	No conflict.	-
5.1.1.3.8 Control interference	**Minor conflict.**	Controls on the armrest panels may be obscured by the users' body while the user operates other controls, particularly the throttle and brake levers. See section 5.4.3.2 of MIL-STD-1472G (DoD, 2009) for label obscuration issues.	**Minor Conflict.**	Some controls may be obscured by the controls above them, including the reverser, throttle, and headlights. There is also an interlock to prevent the simultaneous use of the throttle and dynamic brake; this is done deliberately for safety purposes. See Section 5.4.3.2 of MIL-STD-1472G (DoD, 2009) for label obscuration issues.

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.1.1.3.9 Emergency shutoff controls	**Conflict.**	The emergency brake is not located separate from other controls to prevent accidental actuation; it is actuated by the automatic brake lever.	**Conflict.**	The emergency brake is not located separate from other controls to prevent accidental actuation; it is actuated by the automatic brake lever. It also may not be within easy reach of the user.
5.1.1.4.1 [Coding] Methods and requirements	**Minor conflict.**	Coding type depends on how the controls will be distinguished. For controls that are not in the user's field of view, shape or size coding would be best. All controls are labeled, and some are color coded. Use of color coding can be improved. At the present, many RHS controls are too similar and closely located to distinguish other than by label.	**Minor conflict.**	Controls are distinguished primarily by shape and labeling. Controls are inadequately spaced for location coding, and consistency of color coding could be improved.
5.1.1.4.2 Location-coding	**Minor conflict.**	Controls should be a minimum of 250 mm (10 inches) apart for location coding. None of the controls in the workstation meet this requirement. Given the space restrictions created by this type of workstation, location coding is likely not an ideal choice.	**Minor conflict.**	Most controls are not 10 inches apart; therefore if location coding is the desired means of coding, it is not sufficient. While exact placement appears to vary slightly from stand to stand, the stand in CTIL has its automatic and independent brakes 8" apart rather than 10.
5.1.1.4.3 Size-coding	**Minor conflict.**	Size coding is not used; however, it would be an effective way of disambiguating controls.	*Not applicable.*	-
5.1.1.4.4 Shape-coding	**Minor conflict.**	Controls are large enough to be shape coded; however, a wider variety of shapes could be used to aid disambiguation.	No conflict.	-

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.1.1.4.5 Color-coding	**Minor conflict.**	A secondary means of coding must be used any time color coding is used. According to the suggested color meanings, the blue and white lights on the throttle/dynamic brake may need to be reversed.	**Minor conflict.**	Label for Dynamic brake is coded red, but has a different meaning than the EOT emergency switch and the automatic brake, both of which contain emergency actions.
5.1.1.5 Labeling of controls	**Potential conflict.**	See Section 5.4 of MIL-STD-1472G (DoD, 2009) for detail.	**Potential conflict.**	See Section 5.4 of MIL-STD-1472G (DoD, 2009) for detail.
5.1.1.6 Compatibility with handwear	**Potential conflict.**	Some characteristics of the crewstation, such as push button spacing, may be incompatible with users' handwear.	No conflict.	
5.1.1.7 Blind operation	**Minor conflict.**	Tangible distinction is not provided between all controls.	**Minor conflict.**	Tangible distinction is not provided between all controls.
5.1.1.8.1 [Accidental Actuation] Location and design	**Conflict.**	Emergency brake may be actuated due to weak detents and reduced spacing versus the AAR-105's emergency brake. Push buttons are located where they could be accidentally bumped by a hand or elbow and are not shielded.	No conflict.	-
5.1.1.8.2 Internal controls	*Not applicable.*	-	*Not applicable.*	-
5.1.1.8.3 Rapid operation	No conflict.	-	No conflict.	-
5.1.1.8.4 Methods	No conflict.	-	No conflict.	-
5.1.1.8.5 Weapon control/actuation	*Not applicable.*	-	*Not applicable.*	-
5.1.1.8.6 Dead man controls	*Not applicable.*	-	*Not applicable.*	-

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.1.1.8.7 Foot-operated controls	*Not applicable.*	-	*Not applicable.*	-
5.1.1.9 Feedback	**Conflict.**	It is difficult to determine whether a push button control is in an "on" or "off" state. This criterion suggests the use of indicator lights in addition to a "click" or "snap feel" Additionally, the dynamic brake set-up phase is indicated by a flashing light; however, this light does not persist if the lever is moved beyond the set-up position. It would be clearer if the set up LED continued flashing so long as set-up is in effect, regardless of lever position, to indicate the current system state.	**Conflict.**	No feedback exists on the control stand showing when the Setup procedure is complete.
5.1.1.10.1 Interlocks and warnings	No conflict.	-	No conflict.	-
5.1.1.10.2 Consistency of use	**Conflict.**	Controls for emergency/critical use should be used for only that function, though this is not the case for the emergency brake in either workstation, though it is the case with the EOT switch. It may be preferable to maintain consistency with the AAR-105 workstation rather than to meet this criterion.	**Conflict.**	Controls for emergency/critical use should be used for only that function. This is not the case with the emergency brake in either workstation—it is the case with the EOT switch.

Table B2: Standards Comparison table for MIL-STD-1472G's Section 5.1.2: Control/display Integration (DoD, 2009)

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.1.2.1.1 Relationship and location	No conflict.	-	No conflict.	-
5.1.2.1.2 Design	No conflict.	-	No conflict.	-
5.1.2.1.3 Complexity and precision	No conflict.	-	No conflict.	-
5.1.2.1.4 Feedback	**Conflict.**	The dynamic brake set-up period has a delay of longer than 1s, so the user should be informed of time remaining; this is done with a flashing light but the feedback is lost if the control is moved. (See Section 5.1.1.9 of MIL-STD-1472G [DoD, 2009] for additional detail.)	No conflict.	-
5.1.2.1.5 Error management	*Beyond scope.*	-	*Beyond scope.*	-
5.1.2.1.6 Illumination			**Conflict.**	The dynamic brake, throttle, and switches are backlit; however, this backlighting is not adjustable.
5.1.2.1.7 Simultaneous access	*Not applicable.*	-	*Not applicable.*	-
5.1.2.2 Position relationships	No conflicts		No conflicts	
5.1.2.3.1 Lack of ambiguity	No conflict.	-	No conflict.	-
5.1.2.3.2 Display response time	No conflict.	-	No conflict.	-

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.1.2.3.3 Moving-pointer circular scales	No conflict.	-	No conflict.	-
5.1.2.3.4 Moving-pointer linear scales	*Not applicable.*	-	*Not applicable.*	-
5.1.2.3.5 Fixed-pointer circular scale	*Not applicable.*	-	*Not applicable.*	-
5.1.2.3.6 Fixed-pointer linear scale	*Not applicable.*	-	*Not applicable.*	-
5.1.2.3.7 Digital displays	**Potential conflict.**	Forward movements of the dynamic brake and backward movements of the throttle correspond to increasing speeds; this criterion suggests that these controls should be reversed. See Sections 5.1.1.2.1 of MIL-STD-1472G (DoD, 2009) for additional explanation.	**Potential conflict.**	Throttle movements left correspond to increasing speed values; this criterion suggests that this directionality should potentially be reversed. See Sections 5.1.1.2.1 of MIL-STD-1472G (DoD, 2009) for additional explanation.
5.1.2.3.8 Direct linkage	*Not applicable.*	-	*Not applicable.*	-
5.1.2.3.9 Common plane	**Potential conflict.**	The direction of throttle movement is inconsistent with the related movement of the locomotive. See Sections 5.1.1.2.1 and 5.1.2.3.7 of MIL-STD-1472G (DoD, 2009) for additional detail.	**Potential conflict.**	The direction of throttle movement may be considered inconsistent with the related movement of the locomotive. See Sections 5.1.1.2.1 and 5.1.2.3.7 of MIL-STD-1472G (DoD, 2009) for additional detail.
5.1.2.3.10 Parallel movement	*Not applicable.*	-	*Not applicable.*	-
5.1.2.3.11 Labeling	**Potential conflict.**	See Section 5.4 of MIL-STD-1472G (DoD, 2009) for detail.	**Potential conflict.**	See Section 5.4 of MIL-STD-1472G (DoD, 2009) for detail.

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.1.2.3.12 Movement direction	*Not applicable.*	-	*Not applicable.*	-
5.1.2.3.13 Arrays of indicator lights	**Potential conflict.**	The current configuration displays additional lights from top to bottom as the throttle application is increased and bottom to top as the dynamic brake is applied. This criterion recommends displaying increases from bottom to top, consistent with the findings in Sections 5.1.1.2.1, 5.1.2.3.7, and 5.1.2.3.9 of MIL-STD-1472G (DoD, 2009) which suggest flipping the position of these controls.	*Not applicable.*	-
5.1.2.4 Control/display movement ratio	*Not applicable.*	-	*Not applicable.*	-
5.1.2.5 Signal precedence	*Beyond scope.*	-	*Beyond scope.*	-

Table B3: Standards Comparison table for MIL-STD-1472G Section 5.1.4: Mechanical Controls

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.1.4.1.1 Discrete adjustment rotary controls	No conflict.		**Minor conflict.**	The rotary selector switches used for headlights require 8.72 N to actuate, exceeding the maximum criterion (6 N).
5.1.4.1.2 Continuous adjustment rotary controls	*Not applicable.*	-	*Not applicable.*	-
5.1.4.2.1 Discrete adjustment linear controls	**Conflict.**	This workstation uses push buttons for many on/off functions where another control type such as switches would be preferable, including the bell, sand, and lighting control. These buttons also lack an indication of activation such as a snap feel, click, or light.	No conflict.	-
5.1.4.2.2 Continuous adjustment linear controls			**Conflict.**	No hand, elbow, or forearm support for is provided for use of levers.
5.1.4.3.1 High force controls: Use	*Not applicable.*	-	**Potential conflict.**	The seat may lack adequate back and arm support for use of the automatic brake, which

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
				may be considered a high force control. See the anthropometric modeling analysis for discussion of body positions.
5.1.4.3.2 Arm, hand, and thumb-finger controls	*Not applicable.*	-	**Potential conflict.**	According to Figure 23 in MIL-STD-1472G, for 60–90-degree arm extension of the left arm, the maximum force should be between 8 and 13 N for outward and inward motion respectively. Two thirds of this limit should be used for female personnel, which makes the automatic brake possibly in violation of this standard. The precise amount of force required varies depending on the last time the control was oiled, but is approximately 8 N.
5.1.4.3.3 Foot controls	*Not applicable.*	-	*Not applicable.*	-
5.1.4.4 J-Handles	*Not applicable.*	-	*Not applicable.*	-

B.2: Visual Displays

Table B4: Standards Comparison table for MIL-STD-1472G's Section 5.2.1: Installation of Visual Displays (DoD, 2009)

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.2.1.1.1 Use of visual displays	No conflict.	-	No conflict.	-
5.2.1.1.2 Display face flush with panel	*Not applicable.*	-	*Not applicable.*	-
5.2.1.1.3 Geometric distortion	*Beyond scope.*	-	*Beyond scope.*	-
5.2.1.1.4 Preventing flicker of electronic visual displays	*Beyond scope.*	-	*Beyond scope.*	-
5.2.1.1.5 Geometric stability (jitter) of visual displays	*Beyond scope.*	-	*Beyond scope.*	-
5.2.1.1.6 Vibration of display	**Conflict.**	The way in which displays are mounted is unstable and creates significant vibration, which would undoubtedly hinder users' performance.	No conflict.	-
5.2.1.2.1 Display location	No conflict.	-	No conflict.	-
5.2.1.2.2 Access to display	No conflict.	-	No conflict.	-
5.2.1.2.3 Orientation of display	No conflict.	-	No conflict.	-

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.2.1.2.4 Orientation to reduce parallax	No conflict.	-	No conflict.	-
5.2.1.3 Luminance considerations for visual displays	*Beyond scope.*	-	*Beyond scope.*	-
5.2.1.4 Display illumination and light distribution	*Beyond scope.*	-	*Beyond scope.*	-
5.2.1.5 Contrast of displays	*Beyond scope.*	-	*Beyond scope.*	-
5.2.1.6 Displays for night operations	*Beyond scope.*	-	*Beyond scope.*	-

Table B5: Standards Comparison table for MIL-STD-1472G's Section 5.2.3: Displays-hardware (DoD, 2009)

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.2.3.1 Electronic displays	No conflict.	-	**Conflict.**	Viewing distance exceeds the specified maximum 70 cm (28 in).
5.2.3.2 Large-screen displays	*Not applicable.*	-	*Not applicable.*	-
5.2.3.3 Small-screen displays	*Not applicable.*	-	*Not applicable.*	-
5.2.3.4 Handheld displays	*Not applicable.*	-	*Not applicable.*	-
5.2.3.5 Three-dimensional (3-D) displays	*Not applicable.*	-	*Not applicable.*	-
5.2.3.6 Head-up displays (HUDs)	*Not applicable.*	-	*Not applicable.*	-
5.2.3.7 Helmet-mounted displays (HMDs)	*Not applicable.*	-	*Not applicable.*	-
5.2.3.8 Liquid crystal displays (LCDs)	No conflict.	-	No conflict.	-
5.2.3.9 Plasma displays	*Not applicable.*	-	*Not applicable.*	-
5.2.3.10.1 Light Emitting Diodes (LEDs): General	**Potential conflict.**	See Section 5.2.3.13 of MIL-STD-1472G (DoD, 2009) for detail.	**Potential conflict.**	See Section 5.2.3.13 of MIL-STD-1472G (DoD, 2009) for detail.
5.2.3.10.2 LEDs: Use	No conflict.	-	No conflict.	-
5.2.3.10.3 LEDs: Intensity control	**Conflict.**	Dimming of LEDs is not provided.	**Conflict.**	Dimming of LEDs is not provided.

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.2.3.10.4 LEDs: Color-coding	**Potential conflict.**	See Section 5.2.3.15.5 of MIL-STD-1472G (DoD, 2009) for detail.	**Potential conflict.**	See Section 5.2.3.15.5 of MIL-STD-1472G (DoD, 2009) for detail.
5.2.3.10.5 LEDs: Lamp testing	*Beyond scope.*	-	*Beyond scope.*	-
5.2.3.11 Other displays (CRTs, electroluminescent displays, others)	*Not applicable.*	-	*Not applicable.*	-
5.2.3.12 Dot-matrix/segmented displays	*Not applicable.*	-	*Not applicable.*	-
5.2.3.13.1 General types of transilluminated displays	No conflict.	-	No conflict.	-
5.2.3.13.2 Use	No conflict.	-	No conflict.	-
5.2.3.13.3 Transilluminated displays: Use of transilluminated displays for maintenance	*Beyond scope.*	-	*Beyond scope.*	-
5.2.3.13.4 Transilluminated displays: Equipment response	No conflict.	-	No conflict.	-
5.2.3.13.5 Transilluminated displays: Limited	No conflict.	-	No conflict.	-

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
use of lights and indicators				
5.2.3.13.6 Transilluminated displays: Positive (active) feedback	**Conflict.**	Changes in display status should indicate functional status changes rather than simply control actuation. This is relevant to the indicator lights for the DB when set up is in effect - display should show blue flash until set up is no longer in effect, rather than terminating when control is moved beyond setup.	*Not applicable.*	-
5.2.3.13.7 Transilluminated displays: Absence of signal usage	No conflict.	-	No conflict.	-
5.2.3.13.8 Transilluminated displays: Powered off signal	*Not applicable.*	-	*Not applicable.*	-
5.2.3.13.9 Transilluminated displays: Grouping	*Not applicable.*	-	*Not applicable.*	-
5.2.3.13.10 Transilluminated displays: Location	No conflict.	-	No conflict.	-
5.2.3.13.11 Transilluminated displays: Location of critical functions	*Not applicable.*	-	*Not applicable.*	-

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.2.3.13.12 Transilluminated displays: Luminance	*Beyond scope.*	-	*Beyond scope.*	-
5.2.3.13.13 Transilluminated displays: Glare	*Beyond scope.*	-	*Beyond scope.*	-
5.2.3.13.14 Transilluminated displays: Luminance control	**Conflict.**	Dimming is not provided for transilluminated displays; see also Section 5.2.3.10.3 of MIL-STD-1472G (DoD, 2009).	**Conflict.**	Dimming is not provided for transilluminated displays; see also Section 5.2.3.10.3 of MIL-STD-1472G (DoD, 2009).
5.2.3.13.15 Transilluminated displays: False indication or obscuration	No conflict.	-	No conflict.	-
5.2.3.13.16 Transilluminated displays: Contrast within the indicator	*Beyond scope.*	-	*Beyond scope.*	-
5.2.3.13.17 Transilluminated displays: Color-coding	**Potential conflict.**	See Section 5.2.3.15.5 of MIL-STD-1472G (DoD, 2009) for detail.	**Potential conflict.**	See Section 5.2.3.15.5 of MIL-STD-1472G (DoD, 2009) for detail.
5.2.3.14.1 Legend Use	*Not applicable.*	-	No conflict.	-
5.2.3.14.2 Legend lights: Positive versus negative legend - dark adaptation	*Not applicable.*	-	No conflict.	-

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.2.3.14.3 Legend lights: Positive versus negative legend	*Not applicable.*	-	*Not applicable.*	-
5.2.3.14.4 Legend lights: Contrast reversal	*Not applicable.*	-	*Not applicable.*	-
5.2.3.14.5 Legend lights: Legibility in high illumination	*Not applicable.*	-	No conflict.	-
5.2.3.14.6 Legend lights: Lettering	*Not applicable.*	-	**Potential conflict.**	See Section 5.4.6.3 of MIL-STD-1472G (DoD, 2009).
5.2.3.14.7 Visibility and Legend lights: legibility	*Not applicable.*	-	No conflict.	-
5.2.3.14.8 Legend lights: Multi-function legends	*Not applicable.*	-	*Not applicable.*	-
5.2.3.14.9 Legend lights: Stacked legends	*Not applicable.*	-	*Not applicable.*	-
5.2.3.14.10 Legend lights: Design	*Not applicable.*	-	No conflict.	-
5.2.3.14.11 Legend lights: Interchanging legends	*Not applicable.*	-	*Beyond scope.*	-

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.2.3.14.12 Legend lights: Legend border	*Not applicable.*	-	*Not applicable.*	-
5.2.3.14.13 Legend lights: Visual contrast	*Not applicable.*	-	No conflict.	-
5.2.3.14.14 Legend lights: Illumination	*Not applicable.*	-	No conflict.	-
5.2.3.14.15 Legend lights: Light leakage	*Not applicable.*	-	No conflict.	-
5.2.3.14.16 Legend lights: Redundancy	*Not applicable.*	-	*Beyond scope.*	-
5.2.3.14.17 Legend lights: Malfunctions	*Not applicable.*	-	*Beyond scope.*	-
5.2.3.15.1 Simple indicator lights: Use	**Conflict.**	The throttle and dynamic brake use simple indicator lights to indicate the current notch; this must be determined by counting LEDs. It may be preferable to use legend lights.	No conflict.	-
5.2.3.15.2 Simple indicator lights: Spacing	No conflict.	-	No conflict.	-
5.2.3.15.3 Simple indicator lights: International conventions and standards	No conflict.	-	No conflict.	-

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.2.3.15.4 Simple indicator lights: Brightness	No conflict.	-	No conflict.	-
5.2.3.15.5 Simple indicator lights: Coding	**Minor conflict.**	Blue and white lights on throttle could potentially be switched, as white indicates action in progress and blue is simply advisory according to Table XVIII of MIL-STD-1472G (DoD, 2009). See Table XV of MIL-STD-1472G (DoD, 2009) for a detailed description of color associations.	**Minor conflict.**	Simple indicator lights for "pcs open" and "brake warn" indicators are properly coded in solid red and orange respectively. Other indicators such as "wheel slip" are white but could potentially be coded in red to indicate a malfunction. See Table XVIII and Table XV of MIL-STD-1472G (DoD, 2009) for a detailed description of color associations.
5.2.3.16 Transilluminated panel assemblies	*Not applicable.*	-	*Not applicable.*	-

B.3 Labeling

Table B6: Standards Comparison table for MIL-STD-1472G's Section 5.4.1: General Labeling (DoD, 2009)

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.4.1.1 Use of labels	**Minor conflict.**	Not all controls are labeled in this workstation; the brake levers and throttle are not labeled.	**Minor conflict.**	Not all controls are labeled in this workstation; the positions of the reverser are not labeled.
5.4.1.2 Label characteristics	**Potential conflict.**	Some label characteristics do not meet the design practices specified in this section regarding orientation, size, etc.	**Potential conflict.**	Some label characteristics do not meet the design practices specified in this section regarding orientation, size, etc.
5.4.2 Orientation	**Minor conflict.**	ATT CALL, D/B RESET, and PTT labels are an unacceptable orientation. They should be labeled with characters readable from an upright orientation. However, since they are to the side, they may be in an upright orientation relative to the user. This requires further consideration.	No conflict.	-

Table B7: Standards Comparison table for MIL-STD-1472G Section 5.4.3: Labeling location (DoD, 2009)

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.4.3.2 Obscuration	**Minor conflict.**	Labels on the armrest panels may be obscured by the users' body while the user operates other controls, particularly the throttle and brake levers. See Section 5.1.1.3.8 of MIL-STD-1472G (DoD, 2009) for control obscuration issues.	**Minor conflict.**	Several labels may be obscured by the controls above them, including the label for the reverser, throttle, and headlights. See Section 5.1.1.3.8 of MIL-STD-1472G (DoD, 2009) for control obscuration issues.
5.4.3.3 Movable controls	*Not applicable.*	-	*Not applicable.*	-
5.4.3.4 Adjacent label	No conflict.	-	No conflict.	-
5.4.3.5.1 Viewing	No conflict.	-	No conflict.	-
5.4.3.5.2 At or below eye level	**Minor conflict.**	Labels are located beneath controls; however, this criterion requires that labels at or below eye level should be located above the controls.	**Minor conflict.**	Most labels are above the controls they describe, with the independent brake, sand, and ground reset relay, and slide switches as the only exceptions.
5.4.3.5.3 Above eye level	*Not applicable.*	-	*Not applicable.*	-
5.4.3.6 Redundant labeling	*Not applicable.*	-	*Not applicable.*	-
5.4.3.7 Standardization	No conflict.	-	**Minor conflict.**	Label locations are inconsistent: most labels are located above controls, but some are located below. See Section 5.4.3.5.2 of MIL-STD-1472G (DoD, 2009) for detail.
5.4.3.8 Overhead items	*Not applicable.*	-	*Not applicable.*	-
5.4.4.1 Equipment functions	No conflict.	-	No conflict.	-
5.4.4.2 Abbreviations	No conflict.	-	No conflict.	-

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.4.4.3 Irrelevant information	No conflict.	-	**Minor conflict.**	Equipment may include trade names or logos (e.g., the "K" on the automatic brake).
5.4.5.1 Brevity	No conflict.	-	No conflict.	-
5.4.5.2 Familiarity				
5.4.5.2.1 Considerations	No conflict.	-	No conflict.	-
5.4.5.2.2 Special markings and symbols	*Not applicable.*	-	*Not applicable.*	-
5.4.5.3 Comprehension	No conflict.	-	No conflict.	-
5.4.5.4 Consistency	No conflict.	-	No conflict.	-
5.4.5.5.1 Accurate reading	**Potential conflict.**	Labels are readable under typical conditions; however, there are several issues that ought to be addressed related to contrast (MIL-STD-1472G Section 5.4.5.10) and dark adaptation (MIL-STD-1472G Section 5.4.6.2) (DoD, 2009).	**Potential conflict.**	Labels are readable under typical conditions; however, there are several issues that ought to be addressed related to contrast (MIL-STD-1472G Section 5.4.5.10) and dark adaptation (MIL-STD-1472G Section 5.4.6.2) (DoD, 2009).
5.4.5.5.2 Considerations	**Potential conflict.**	There are some minor character style issues that hinder readability (see Section 5.4.6.3). Additionally, there may be some issues related to label contrast (see Section 5.4.5.10).	**Potential conflict.**	There are some minor character style issues that hinder readability (see Section 5.4.6.3). Additionally, there may be some issues related to label contrast (see Section 5.4.5.10).
5.4.5.6 Access	*Not applicable.*	-	*Not applicable.*	-
5.4.5.7 Cables	*Beyond scope.*	-	*Beyond scope.*	-
5.4.5.8.1 Attachment	*Not applicable.*	-	*Not applicable.*	-
5.4.5.8.2 Non-removable	No conflict.	-	No conflict.	-

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.4.5.8.3 Wear and dirt	No conflict.	-	No conflict.	-
5.4.5.8.4 Mounting alternatives	No conflict.	-	No conflict.	-
5.4.5.9 Label surface	*Not applicable.*	-	*Not applicable.*	-
5.4.5.10 Label contrast	**Potential conflict.**	Some labels on the armrest panels may lack adequate contrast with the grey background; however, taking precise measurements of this contrast is beyond our scope due to the variation in cab illumination that cannot be replicated in our simulator.	**Potential conflict.**	Some labels, such as those for the automatic brake in our workstation, may lack proper contrast. However, taking precise measurements of this contrast is beyond our scope due to the variation in cab illumination that cannot be replicated in our simulator and the variation in cab equipment.
5.4.5.11 Label background	*Not applicable.*	-	*Not applicable.*	-
5.4.6.1 Black characters	*Beyond scope.*	-	*Beyond scope.*	-
5.4.6.2 Dark adaptation			**Conflict.**	Dark adaptation is required; therefore all text should be white on a black background. This also allows for proper backlighting (see Section 5.1.2.1.6 of MIL-STD-1472G [DoD, 2009]). Some labels in our workstation do not meet this requirement, including those for the automatic brake, though this may vary depending on the equipment in a particular locomotive cab.
5.4.6.3.1 Style of characters	**Potential conflict.**	See Sections 5.4.6.3.7 and 5.4.6.3.13 of MIL-STD-1472G (DoD, 2009) for details.	**Potential conflict.**	See Sections 5.4.6.3.3, 5.4.6.3.4, and 5.4.6.3.11 of MIL-STD-1472G (DoD, 2009) for details.

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.4.6.3.2 Plain style	No conflict.	-	No conflict.	-
5.4.6.3.3 Capital versus lower case	No conflict.	-	**Minor conflict.**	All labels are written in all capital letters. Long instructions should be written with blended capitalization.
5.4.6.3.4 Letter width	No conflict.	-	**Minor conflict.**	Text uses less than the necessary width
5.4.6.3.5 Numeral width	*Not applicable.*	-	No conflict.	-
5.4.6.3.6 Wide characters	*Not applicable.*	-	*Not applicable.*	-
5.4.6.3.7 Stroke width	**Minor conflict.**	Labels do not use consistent stroke widths. Some are too wide (automatic brake, independent brake, and reverser labels) while others are too narrow (d/b reset and headlight knob labels).	**Minor conflict.**	Labels do not use consistent stroke widths. Some are too wide (automatic brake, independent brake, horn, bell, throttle and dynamic brake labels) while others are too narrow (alerter label).
5.4.6.3.8 Stroke continuity	No conflict.	-	No conflict.	-
5.4.6.3.9 Character spacing	No conflict.	-	No conflict.	-
5.4.6.3.10 Word spacing	No conflict.	-	No conflict.	-
5.4.6.3.11 Line spacing	No conflict.	-	**Minor conflict.**	Line spacing is 1/4 character height. 1/2 character height is the requirement
5.4.6.3.12 Character height versus luminance	*Beyond scope.*	-	*Beyond scope.*	-
5.4.6.3.13 Character height versus viewing distance	**Minor conflict.**	Characters for brake labels are slightly too large for non-critical markings (5.08 mm). Small labels on wiper control are too small (2mm). See table XXI of MIL-STD-1472G (DoD, 2009).	**Minor conflict.**	Many labels are too large for non-critical markings (automatic and independent brake, bell, dynamic brake and throttle labels).

Section	Experimental Workstation: Result	Experimental Workstation: Notes	AAR-105 Control Stand: Result	AAR-105: Notes
5.4.6.4 Pictorials and symbols	*Not applicable.*	-	*Not applicable.*	-
5.4.6.5 Borders	No conflict.	-	No conflict.	-
5.4.5.5 Use of color	*Not applicable.*	-	*Not applicable.*	-

B.4 Ground Vehicles

Table B8: Standards Comparison table for MIL-STD-1472G's Section 5.6.1: Ground vehicles - General (DoD, 2009)

Section	Experimental crewstation: result	Experimental crewstation: notes	AAR-105 control stand: result	AAR-105 control stand: notes
5.6.1 General	**Potential conflict.**	Some aspects of vehicle operation may not accommodate the full central range of users—the remainder of this section elaborates on such issues.	**Potential conflict.**	Some aspects of vehicle operation may not accommodate the full central range of users—the remainder of this section elaborates on such issues.

Table B9: Standards Comparison table for MIL-STD-1472G's Section 5.6.1: Ground vehicle seating (DoD, 2009)

Section	Experimental crewstation: result	Experimental crewstation: notes	AAR-105 control stand: result	AAR-105 control stand: notes
5.6.2.1 Dimensions and clearances	**Conflict.**	The distance from seat pan to footrest is too large (18 inches instead of 15 inches) according to Table XXX and Figure 41 of MIL-STD-1472G (DoD, 2009).	**Conflict.**	The seat in the CTIL 105 control stand is too high according to Table XXX and Figure 41 of MIL-STD-1472G (DoD, 2009).
5.6.2.2 Vertical adjustment			**Conflict.**	The seat in the CTIL 105 control stand does not adjust vertically.

Section	Experimental crewstation: result	Experimental crewstation: notes	AAR-105 control stand: result	AAR-105 control stand: notes
5.6.2.3 Horizontal adjustment	*Not applicable.*	-	No conflict.	-
5.6.2.4 Back-rest angle	No conflict.	-	No conflict.	-
5.6.2.5 Seat padding	No conflict.	-	No conflict.	-
5.6.2.6 Safety restraints	*Not applicable.*	-	*Not applicable.*	-
5.6.2.7 Head restraints	No conflict.	-	**Conflict.**	Head restraints are not provided.

Table B10: Standards Comparison table for MIL-STD-1472G's Section 5.6.3: Vehicle controls (DoD, 2009)

Section	**Experimental crewstation: result**	**Experimental crewstation: notes**	**AAR-105 control stand: result**	**AAR-105 control stand: notes**
5.6.3.1 Dynamic effects	No conflict.	-	No conflict.	-
5.6.3.2 Steering	*Not applicable.*	-	*Not applicable.*	-
5.6.3.3 Pedals	*Not applicable.*	-	*Not applicable.*	-
5.6.3.4 Control of hazardous operations	**Conflict.**	The EOT emergency device is properly locked or shielded, but the emergency brake does not have any such locking device.	**Conflict.**	The EOT emergency device is properly locked or shielded, but the emergency brake does not have any such locking device.

Table B11: Standards Comparison table for MIL-STD-1472G's Section 5.6.5: Vehicle visibility (DoD, 2009)

Section	**Experimental crewstation: result**	**Experimental crewstation: notes**	**AAR-105 control stand: result**	**AAR-105 control stand: notes**
5.6.5.1 Lateral visual field	No conflict.	-	No conflict.	-
5.6.5.2.1 Forward visibility	*Not applicable.*	-	*Not applicable.*	-
5.6.5.2.2 Upward visibility	**Potential conflict.**	Upward visibility may be limited; this is explored in the anthropometric modeling analysis.	No conflict.	-
5.6.5.2.3 Field restriction	No conflict.	-	**Conflict**	The control stand itself obstructs greater than 20 degrees of the users' visual field.
5.6.5.3.1 Rear (vehicle)	**Potential conflict.**	There is a possibility that rear view is restricted by the placement of the workstation and displays; this will be evaluated further in our usability test.	No conflict.	-
5.6.5.3.2 Rear view (road)	**Potential conflict.**	There is a possibility that rear view is restricted by the placement of the workstation and displays; this will be evaluated further in our usability test.	No conflict.	-
5.6.5.3.3 Adjustability	*Beyond scope.*	-	*Beyond scope.*	-
5.6.5.3.4 Bracing	*Beyond scope.*	-	*Beyond scope.*	-
5.6.5.3.5 Mirrors as handholds	*Beyond scope.*	-	*Beyond scope.*	-
5.6.5.4 Glare	*Beyond scope.*	-	*Beyond scope.*	-

Section	Experimental crewstation: result	Experimental crewstation: notes	AAR-105 control stand: result	AAR-105 control stand: notes
5.6.5.5 Windshields and windows	*Beyond scope.*	-	*Beyond scope.*	-
5.6.5.6 Windshield wipers and washers	*Beyond scope.*	-	*Beyond scope.*	-
5.6.5.7 Lighting systems	*Beyond scope.*	-	*Beyond scope.*	-
5.6.5.8 Night operation	*Beyond scope.*	-	*Beyond scope.*	-
5.6.5.9 Lighting for dark adaptation	*Beyond scope.*	-	*Beyond scope.*	-

B.5 Physical Accommodations

Table B12: Standards Comparison table for MIL-STD-1472G's Section 5.8.1: General physical accommodations (DoD, 2009)

Section	Experimental crewstation: result	Experimental crewstation: notes	AAR-105 control stand: result	AAR-105 control stand: notes
5.8.1.1 Systems, equipment, and facilities	**Potential conflict.**	There may be issues in accommodating the desired range of personnel. See the remainder of this section, Section 5.10 of MIL-STD-1472G (DoD, 2009), and anthropometric modeling analysis for details.	**Potential conflict.**	There may be issues in accommodating the desired range of personnel. See the remainder of this section, Section 5.10 of MIL-STD-1472G (DoD, 2009), and anthropometric modeling analysis for details
5.8.1.2 Clothing and personal equipment	*Not applicable.*	-	*Not applicable.*	-

Table B13: Standards Comparison table for MIL-STD-1472G's Section 5.8.2: Target populations (DoD, 2009)

Section	Experimental crewstation: result	Experimental crewstation: notes	AAR-105 control stand: result	AAR-105 control stand: notes
5.8.2.1 Regular populations	No conflict.	-	No conflict.	-
5.8.2.2.1 Male only populations	*Not applicable.*	-	*Not applicable.*	-
5.8.2.2.2 Selected populations	No conflict.	-	No conflict.	-
5.8.2.2.3 Foreign military personnel	*Not applicable.*	-	*Not applicable.*	-
5.8.2.2.4 Joint service personnel	*Not applicable.*	-	*Not applicable.*	-

Section	Experimental crewstation: result	Experimental crewstation: notes	AAR-105 control stand: result	AAR-105 control stand: notes
5.8.2.3 Maintenance and support personnel	No conflict.	-	No conflict.	-

Table B14: Standards Comparison table for MIL-STD-1472G's Section 5.8.3: Design limits (DoD, 2009)

Section	Experimental crewstation: result	Experimental crewstation: notes	AAR-105 control stand: result	AAR-105 control stand: notes
5.8.3.1 General design criteria	No conflict.	-	No conflict.	-
5.8.3.2 Special situations	*Not applicable.*	-	*Not applicable.*	-

Table B15: Standards Comparison table for MIL-STD-1472G's Section 5.8.4: Anthropometric design (DoD, 2009)

Section	Experimental crewstation: result	Experimental crewstation: notes	AAR-105 control stand: result	AAR-105 control stand: notes
5.8.4.1.1 Safety and health considerations	*Beyond scope.*	-	*Beyond scope.*	-
5.8.4.1.2 Adjustments	*Not applicable.*	-	*Not applicable.*	-
5.8.4.1.3 Clearance dimensions	*Not applicable.*	-	*Not applicable.*	-
5.8.4.1.4 Limiting dimensions and dynamic characteristics	*Beyond scope.*	-	*Beyond scope.*	-

Section	Experimental crewstation: result	Experimental crewstation: notes	AAR-105 control stand: result	AAR-105 control stand: notes
5.8.4.1.5 Adjustable dimensions	**Conflict.**	This seat is not adjustable for the full range of personnel. The height of the footrest relative to the seat does not adjust, and the armrest height and width are fixed as well.	**Conflict.**	This seat is not adjustable for the full range of personnel. The height does not adjust and may be unsuitable for the smallest users.
5.8.4.1.6 Multiple dimension accommodation	No conflict.	-	No conflict.	-
5.8.4.1.7 Other application limits	*Not applicable.*	-	*Not applicable.*	-
5.8.4.1.8 Range of motion	No conflict.	-	**Potential conflict.**	Some controls may be outside users' range of motion; see the anthropometric modeling section for details.
5.8.4.2 Whole body	*Not applicable.*	-	No conflict.	-

Table B16: Standards Comparison table for MIL-STD-1472G's Section 5.8.5: Strength (DoD, 2009)

Section	Experimental crewstation: result	Experimental crewstation: notes	AAR-105 control stand: result	AAR-105 control stand: notes
5.8.5.1 Guidance	No conflict.	-	No conflict.	-
5.8.5.2 Operability	No conflict.	-	**Potential conflict.**	The smallest personnel may have difficulty operating some controls; see RAMSIS analysis for details.
5.8.5.3 Break strength	**Potential conflict.**	The break strength of controls may present an issue; however, this may also be due to the prototype nature of this workstation. The resistance of controls may be able to be increased because controls are located within comfortable reach.	No conflict.	-

Table B17: Standards Comparison table for MIL-STD-1472G's Section 5.8.6: Human strength and handling capacity (DoD, 2009)

Section	Experimental crewstation: result	Experimental crewstation: notes	AAR-105 control stand: result	AAR-105 control stand: notes
5.8.6.1 Exerted forces	No conflict.	-	**Potential conflict.**	Some controls may exceed the strength limitations of the weakest personnel; see Section 5.1.4.3.2 of MIL-STD-1472G (DoD, 2009) for details.
5.8.6.2 Load carrying	*Not applicable.*	-	*Not applicable.*	-
5.8.6.3.1 Lifting limits	No conflict.	-	No conflict.	-
5.8.6.3.2 Lifting frequency	*Not applicable.*	-	*Not applicable.*	-
5.8.6.3.3 Load size	No conflict.	-	No conflict.	-

Section	**Experimental crewstation: result**	**Experimental crewstation: notes**	**AAR-105 control stand: result**	**AAR-105 control stand: notes**
5.8.6.3.4 Twisting	*Not applicable.*	-	*Not applicable.*	-
5.8.6.3.5 Obstacles	*Not applicable.*	-	*Not applicable.*	-
5.8.6.3.6 Lifting team designations	*Not applicable.*	-	*Not applicable.*	-
5.8.6.3.7 Carrying limits for distances up to 10 meters	*Not applicable.*	-	*Not applicable.*	-
5.8.6.3.8 Carrying limits for distances over 10 meters	*Not applicable.*	-	*Not applicable.*	-
5.8.6.3.9 Carrying frequency	*Not applicable.*	-	*Not applicable.*	-
5.8.6.3.10 Object carry size	*Not applicable.*	-	*Not applicable.*	-
5.8.6.3.11 User population	No conflict.	-	No conflict.	-
5.8.6.3.12 Labeling	*Not applicable.*	-	*Not applicable.*	-
5.8.6.4 Hand trucks and wheeled dollies	*Not applicable.*	-	*Not applicable.*	-
5.8.6.5 Push and pull forces				
5.8.6.5.1 Horizontal	*Not applicable.*	-	*Not applicable.*	-
5.8.6.5.2 Vertical	No conflict.	-	*Not applicable.*	-
5.8.6.5.3 Handles and grasp areas	**Minor conflict.**	There is no clear grasp area defined on the footrest. It affords grasping by shape and texture, but users may be injured if they let go, causing the footrest to drop suddenly.	*Not applicable.*	-
5.8.6.5.4 Mounting	*Not applicable.*	-	*Not applicable.*	-

B.6 Workspace Design

Table B18: Standards Comparison table for MIL-STD-1472G's Section 5.10.1: General Workspace Design (DoD, 2009)

Section	Experimental crewstation: result	Experimental crewstation: notes	AAR-105 control stand: result	AAR-105 control stand: notes
5.10.1 General	No conflict.	-	No conflict.	-

Table B19: Standards Comparison table for MIL-STD-1472G's Section 5.10.2: Workspace provision (DoD, 2009)

Section	Experimental crewstation: result	Experimental crewstation: notes	AAR-105 control stand: result	AAR-105 control stand: notes
5.10.2.1 Provision of workspace	**Potential conflict.**	There are several issues in accommodating the desired range of personnel. See the remainder of this section, Section 5.8 of MIL-STD-1472G (DoD, 2009), and RAMSIS analysis for details.	**Potential conflict.**	There are several issues in accommodating the desired range of personnel. See the remainder of this section, Section 5.8 of MIL-STD-1472G (DoD, 2009), and RAMSIS analysis for details.
5.10.2.2 Consideration of personnel	**Potential conflict.**	Some tasks may not adequately accommodate comfortable body positions for personnel. The remainder of this section elaborates on these issues.	**Potential conflict.**	Some tasks may not adequately accommodate comfortable body positions for personnel. The remainder of this section elaborates on these issues.
5.10.2.3 Kick space	No conflict.	-	**Minor conflict.**	The kick space provided is slightly too shallow (3.5 inches rather than 4 inches).
5.10.2.4 Guards	*Not applicable.*	-	*Not applicable.*	-
5.10.2.5 Handles	*Not applicable.*	-	*Not applicable.*	-
5.10.2.6 Flushing, draining, and venting	*Beyond scope.*	-	*Beyond scope.*	-
5.10.2.7 Work space	*Beyond scope.*	-	*Beyond scope.*	-

Section	Experimental crewstation: result	Experimental crewstation: notes	AAR-105 control stand: result	AAR-105 control stand: notes
5.10.2.8 Storage space	**Conflict.**	No storage space is provided for manuals, worksheets etc.	**Conflict.**	No storage space is provided for manuals, worksheets etc.
5.10.2.9 Pull space	*Not applicable.*	-	*Not applicable.*	-
5.10.2.10 Skid layout	*Not applicable.*	-	*Not applicable.*	-
5.10.2.11 Control/display accessibility	No conflict	-	**Potential conflict.**	Some controls including the automatic brake may not be reachable without assuming uncomfortable postures. This will be analyzed using anthropometric modeling.
5.10.2.12.1 Eliminate interference among crewmembers	No conflict	-	No conflict.	-
5.10.2.12.2 Avoid simultaneous tasks	No conflict.	-	No conflict.	-
5.10.2.12.3 Workbench location	No conflict.	-	No conflict.	-
5.10.2.12.4 Reach limitations	No conflict.	-	**Conflict**	When the user is seated, many controls (particularly the breaker switches on the right side of the control stand) are more than 24 in. in front of the user.
5.10.2.12.5 Lifting forward reach	No conflict.	-	**Conflict**	Many controls are located outside the 12 inch lifting/torque reach envelope, including the automatic brake lever.

Table B20: Standards Comparison table for MIL-STD-1472G's Section 5.10.3: Workstation design (DoD, 2009)

Section	Experimental crewstation: result	Experimental crewstation: notes	AAR-105 control stand: result	AAR-105 control stand: notes
5.10.3.1.1 Standing: Window placement	**Potential conflict.**	The upper edge of the window is less than the required 74 inches above the floor (approximately 64 inches), suggesting that this workspace may not be suitable for standing operation.	*Not applicable.*	-
5.10.3.1.2 Standing: Work surface	**Conflict.**	No workspace is provided.	*Not applicable.*	-
5.10.3.1.3 Standing: Display placement, normal	No conflict.	-	*Not applicable.*	-
5.10.3.1.4 Standing: Display placement, special	*Not applicable.*	-	*Not applicable.*	-
5.10.3.1.5 Standing: Control placement, normal	*Not applicable.*	-	*Not applicable.*	-
5.10.3.1.6 Standing: Control placement, special	*Not applicable.*	-	*Not applicable.*	-
5.10.3.1.7 Standing: Overhead reach	*Not applicable.*	-	*Not applicable.*	-

Section	Experimental crewstation: result	Experimental crewstation: notes	AAR-105 control stand: result	AAR-105 control stand: notes
5.10.3.1.8 Standing: Control mounting height	*Not applicable.*	-	*Not applicable.*	-
5.10.3.1.9 Standing: Display mounting height	*Not applicable.*	-	*Not applicable.*	-
5.10.3.1.10 Standing: Dimensions	No conflict.	-	*Not applicable.*	-
5.10.3.2.1 Seated: Work surface width and depth	*Not applicable.*	-	*Not applicable.*	-
5.10.3.2.2 Seated: Work surface height	*Not applicable.*	-	**Conflict.**	Work surface is 27 inches off the floor; less than the recommended 29–31.
5.10.3.2.3 Seated: Writing surfaces	**Conflict.**	A writing surface is not provided.	**Conflict.**	A writing surface is provided; however it is not an adequate depth (should be 16 in. rather than 5–10 in.)
5.10.3.2.4 Seated: Seating	**Potential conflict.**	Seating may not be completely appropriate for all users due to low footrest.	**Potential conflict.**	Seating may not be completely appropriate for all users to reach and operate all controls; see anthropometric modeling analysis for details.
5.10.3.2.5 Seated: Window placement	No conflict.	-	No conflict.	-
5.10.3.2.6 Seated: Compatibility	No conflict.	-	**Potential conflict.**	Seating may not be compatible with the control panels; see anthropometric modeling analysis for details.
5.10.3.2.7 Seated: Seat pan	**Conflict.**	Seat tilt is not adjustable and vertical adjustment is very limited. See Section	**Conflict.**	Seat tilt is not adjustable and vertical adjustment is not possible. See Section

Section	Experimental crewstation: result	Experimental crewstation: notes	AAR-105 control stand: result	AAR-105 control stand: notes
and vertical adjustment		5.8.4.1.5 of MIL-STD-1472G (DoD, 2009) for additional details.		5.8.4.1.5 of MIL-STD-1472G (DoD, 2009) for additional details.
5.10.3.2.8 Seated: Backrest	No conflict.	-	No conflict.	-
5.10.3.2.9 Seated: Cushioning and upholstery	No conflict.	-	No conflict.	-
5.10.3.2.10 Seated: Armrests	**Conflict.**	Armrests lack vertical adjustability.	**Conflict.**	Armrests lack vertical adjustability.
5.10.3.2.11 Seated: Seat base	No conflict.	-	No conflict.	-
5.10.3.2.12 Seated: Footrests			**Conflict.**	The current footrest is not adequately deep (12 in. minimum required), nor is it height adjustable from 1 to 9 inches (current height is 6in.), and the angle is too extreme (should be 25–30 degrees rather than 45).
5.10.3.2.13 Seated: Temporary seats	*Not applicable.*	-	*Not applicable.*	-
5.10.3.2.14 Seated: Knee room	*Not applicable.*	-	No conflict.	-
5.10.3.2.15 Seated: Display placement, normal	No conflict.	-	No conflict.	-

Section	Experimental crewstation: result	Experimental crewstation: notes	AAR-105 control stand: result	AAR-105 control stand: notes
5.10.3.2.16 Seated: Display placement, special	No conflict.	-	**Minor conflict.**	Frequently used displays should be 8 to 29 inches above the sitting surface. The lower display screens could be raised by 2–3 inches to fully meet this requirement.
5.10.3.2.17 Seated: Warning displays	No conflict.	-	**Minor conflict.**	Warnings should be at least 22.5 inches above sitting surface - none of the displays are this height.
5.10.3.2.18 Seated: Control placement, normal	No conflict.	-	**Minor conflict.**	Controls should be 8–34 inches above seat. Many controls are too low, but none are too high.
5.10.3.2.19 Seated: Control placement, special	No conflict.	-	**Minor conflict.**	Frequently used controls should be 8–29 inches above seat. Many controls are too low, but none are too high.
5.10.3.3 Mobile workspace	*Not applicable.*	-	*Not applicable.*	-
5.10.3.4 Work benches	*Not applicable.*	-	*Not applicable.*	-
5.10.3.5 Kneeling workspaces	*Not applicable.*	-	*Not applicable.*	-
5.10.3.6 Squatting workspaces	*Not applicable.*	-	*Not applicable.*	-
5.10.3.7 Control Surfaces	*Not applicable.*	-	*Not applicable.*	-

Table B21: Standards Comparison table for MIL-STD-1472G's Section 5.10.4: Special-purpose console design (DoD, 2009)

Section	**Experimental crewstation: result**	**Experimental crewstation: notes**	**AAR-105 control stand: result**	**AAR-105 control stand: notes**
5.10.4.1.1 Horizontal wraparound: Panel width	*Not applicable.*	-	**Potential conflict.**	Controls may not be accessible to the full range of users; see anthropometric modeling analysis for details.
5.10.4.1.2 Horizontal wraparound: Panel angle	*Not applicable.*	-	**Potential conflict.**	Controls may not be accessible to the full range of users; see anthropometric modeling analysis for details.
5.10.4.1.3 Horizontal wraparound: Dimensions (vision over top)	*Not applicable.*	-	No conflict.	-
5.10.4.1.4 Horizontal wraparound: Dimensions	*Not applicable.*	-	**Potential conflict.**	Left panel width is approximately 48 inches, which exceeds the 24 inches recommended. This may lead to excessive twisting, examined in the anthropometric modeling analysis.
5.10.4.1.5 Horizontal wraparound: Viewing angle	*Not applicable.*	-	No conflict.	-
5.10.4.2.1 Vertical segments: Panel division	*Not applicable.*	-	*Not applicable.*	-
5.10.4.2.2 Vertical segments: Height	*Not applicable.*	-	*Not applicable.*	-
5.10.4.2.3 Vertical segments: Sit-stand consoles	No conflict.	-	*Not applicable.*	-

B.7 Maintenance Accessibility

Note: There were a large number of items in this section that were beyond scope for this investigation, including lubrication, casings test connectors and others. These were omitted from this document.

Table B22: Experimental crewstation standards table for MIL-STD-1472G's Section 5.9.1: General maintenance accessibility (DoD, 2009)

Section	Result	Notes
5.9.1.1 Standardization	*Beyond scope.*	-
5.9.1.2 Part selection	*Beyond scope.*	-
5.9.1.3 Tools	No Conflict	-
5.9.1.4 Securing tools	*N/A*	*Not applicable.*
5.9.1.5 Grip span	*N/A*	*Not applicable.*
5.9.1.6 Modular replacement	*Beyond scope.*	-
5.9.1.7.1 Removal and replacement of stowed items	*Beyond scope.*	-
5.9.1.8 Separate adjustability	No Conflict	-
5.9.1.9 Malfunction identification	*Beyond scope.*	-
5.9.1.10 Operational environment	*Beyond scope.*	-
5.9.1.11.1 Error-proof design: Physical features	*Beyond scope.*	-
5.9.1.11.2 Error-proof design: Absence of physical features	*Beyond scope.*	-
5.9.1.11.3 S Error-proof design: Any form and function	No Conflict	-
5.9.1.11.4 Error-proof design: Different form and function	*Beyond scope.*	-
5.9.1.11.5 Error-proof design: Connectors	*Beyond scope.*	-
5.9.1.11.6 Error-proof design: Prevent damage to equipment	*Beyond scope.*	-
5.9.1.12 Error-proof design: Ease of access	**Minor conflict.**	Control boxes are small and may present ease of access issues.
5.9.1.13 Error-proof design: Safety	*Beyond scope.*	-
5.9.1.14 Error-proof design: Delicate items	**Potential Conflict.**	Current component, including detents, may be somewhat delicate, but due to the prototype nature of this workstation it is impossible to determine whether this would remain an issue.
5.9.1.15 Error-proof design: Work from ladders	*Beyond scope.*	-
5.9.1.16 Error-proof design: Maintenance of elevated structures	*N/A*	*Not applicable.*

Table B23: Experimental crewstation standards table for MIL-STD-1472G Section 5.9.2: Mounting of items within units

Section	Result	Notes
5.9.2.1.1 Accessibility of components	*Beyond scope.*	-
5.9.2.1.2 Removal of functioning components or parts	**Minor conflict.**	Control boxes for the throttle and reverser are tied together, as are the control boxes for automatic brake and independent brake; therefore functioning components must be removed to replace others.
5.9.2.1.3 Components maintained by the same technician	*N/A*	*Not applicable.*
5.9.2.1.4 Frequent access	*N/A*	*Not applicable.*
5.9.2.1.5 Safety	*N/A*	*Not applicable.*
5.9.2.2 Stacking avoidance	*N/A*	*Not applicable.*
5.9.2.3 Similar items	No Conflict	-
5.9.2.4 Hinge-mounted units	*N/A*	*Not applicable.*
5.9.2.5 Frames and structural members	*Beyond scope.*	-
5.9.2.6 Fuses	*N/A*	*Not applicable.*

Table B24: Standards Comparison table for MIL-STD-1472G's Section 5.9.4: Access and accessibility

Section	Result	Notes
5.9.4.1.1 Panels, cases, and covers	*Beyond scope.*	-
5.9.4.1.2 Mounting provisions	No Conflict	-
5.9.4.2 Large items	*N/A*	*Not applicable.*
5.9.4.3 Use of tools and test equipment	*Beyond scope.*	-
5.9.4.4 Rear access	*N/A*	*Not applicable.*
5.9.4.5 Relative accessibility	*Beyond scope.*	-
5.9.4.6 High-failure-rate items	*Beyond scope.*	-
5.9.4.7 Skills	*Beyond scope.*	-
5.9.4.8.1 Workspace features	No Conflict	-
5.9.4.8.2 Workspace: Visual inspection	No Conflict	-
5.9.4.9.1 Access to items and components	No Conflict	-
5.9.4.9.2 Access openings	No Conflict	-
5.9.4.9.3 Physical access	No Conflict	-
5.9.4.9.4 Access: Guarding hazardous conditions	*Beyond scope.*	-

Table B25: Experimental workstation standards table for MIL-STD-1472G's Section 5.9.19.1: Printed circuit boards (DoD, 2009)

Section	Result	Notes
5.9.19.1 Mounting	**Minor conflict.**	**Due to the limited size of control boxes, some circuit boards are located in tight areas and may be difficult to remove.**

Appendix C. Tables from Military Design Criteria Standard 1472G

The following tables are taken from MIL-STD-1472G and included here for reference.

We used Table III and the affiliated figures to determine appropriate separation distances for controls. Table XV (Common color association meanings) and Table XVIII (Color-coding of lights) were used in our analysis of color coding. Table XXX (Recommended clearances around vehicle operator's station to accommodate a soldier dressed in arctic clothing) was not used in our analysis because it is not relevant to our context; however, we have included it because it was cited by criterion in MIL-STD-1472G that we addressed through other means. Similarly, we did not use Table XXXVI (Range of motion) because we were able to use data from RAMSIS which was more representative of our user population.

Table C1: MIL-STD-1472G's Table III. Minimum, edge-to-edge separation distances for controls (DoD, 2009)[1]

Initial Control	Toggle Switches	Push Buttons [2/]	Continuous Rotary Controls	Rotary Selector Switches	Discrete Thumbwheel Controls
Toggle Switches	See Figure 16.	13 mm (0.5 in)	19 mm (0.75 in)	19 mm (0.75 in)	13 mm (0.5 in)
Push Buttons [2/]	13 mm (0.5 in)	See Figure 14.	13 mm (0.5 in)	13 mm (0.5 in)	13 mm (0.5 in)
Continuous Rotary Controls	19 mm (0.75 in)	13 mm (0.5 in)	See Figure 12 of MIL-STD-1472G (DoD, 2009).	25 mm (1.0 in)	19 mm (0.75 in)
Rotary Selector Switches	19 mm (0.75 in)	13 mm (0.5 in)	25 mm (1.0 in)	See Figure 6.	19 mm (0.75 in)
Discrete Thumbwheel Controls	13 mm (0.5 in)	13 mm (0.5 in)	19 mm (0.75 in)	19 mm (0.75 in)	See Figure 8 of MIL-STD-1472G (DoD, 2009).

NOTES:

[1/] All values are for one-hand operation. All values are for bare-handed operation.

[2/] For push buttons not separated by barriers.

Table C2: MIL-STD-1472G's Table IV: Advantages and disadvantages of various types of control coding (DoD, 2009)

Advantages	Type of coding					
	Location	Shape	Size	Mode of Operation	Labeling	Color
Improves visual identification	X	X	X		X	X
Improves nonvisual identification (tactile and kinesthetic)	X	X	X	X		
Helps standardization	X	X	X	X	X	X
Aids in identification under low levels of illumination and colored lighting	X	X	X	X	(When trans-illuminated)	(When trans-illuminated)
May aid in identifying control position (settings)		X		X	X	X
Requires little (if any) training; is not subject to forgetting					X	
Disadvantages						
May require extra space	X	X	X	X	X	
Affects manipulation of the control (ease of use)	X	X	X	X		
Limited in number of available coding categories	X	X	X	X		X
May be less effective if user wears gloves		X	X	X		
Controls must be viewed (i.e., must be within visual areas and adequately illuminated)					X	X

Table C3: MIL-STD-1472G's Table V. Acceptable system response times (DoD, 2009)

System Interpretation	Response Time Definition	Time (seconds)
Key response	Key depression until positive response, e.g., "click"	0.1
Key print	Key depression until appearance of character	0.2
Page turn	End of request until first few lines are visible	1.0
Page scan	End of request until text begins to scroll	0.5
XY entry	From selection of field until visual verification	0.2
Pointing	From input of point to display point	0.2
Sketching	From input of point to display of line	0.2
Local update	Change to image using local data base, e.g., new menu list from display buffer	0.5
Host update	Change where data is at host in readily accessible form, e.g., a scale change of existing image	2.0
File update	Image update requires an access to a host file	10
Inquiry (simple)	From command until display of a commonly used message	2.0
Inquiry (complex)	Response message requires seldom used calculations in graphic form	10
Error feedback	From entry of input until error message appears	0.2

Table C4: MIL-STD-1472G's Table XV. Common color association meanings (DoD, 2009)

Color	Maps and tactical meaning	Classification meaning	Alarm, alert, warning, threat meaning	Equipment meaning	Other common meaning
Red	Red alert Forces or situation at critical condition Hostile target identification	Secret	Critical consequences Danger or unsafe Severe threat Emergency Alarm	Closed/stopped Oxygen Malfunction Ordnance handling	Stop Heat or fire Failure OFF (as opposed to ON)
Orange		Top Secret	Alarm, alert, or hazard High Threat		Value between red and yellow
Yellow	Forces or situation at marginal condition Unknown target affiliation CBRNE areas		Warning, caution, or hazard Elevated threat Approaching critical Extreme Caution Impending Danger	Oil	Abnormal state Delay Check/recheck
Green	Non-alert Neutral target affiliation Obstacles Forces or situation at acceptable condition	Unclassified	Normal Safe Low threat	Open/flowing	Maintenance personnel ON (as opposed to OFF) Intolerance/acceptable Ready, proceed, satisfactory
Blue	Friendly target affiliation Deep water		Safe Guarded threat	Noncritical items Water or flooding Nitrogen	Cool or cold
Cyan (turquoise, light blue)	Friendly target affiliation		Advisory	Aerated water	Cool

Color	Maps and tactical meaning	Classification meaning	Alarm, alert, warning, threat meaning	Equipment meaning	Other common meaning
Dark blue (navy blue)			Advisory	Untreated water	
Magenta (pink, light purple)			Alarm state Radiation hazard		
Purple (violet)				Aviation fuels	
White			Advisory	Steam	Medical personnel Empty Functional or physical position Action in progress
Black	Political boundary Image or figure edge				Outline or border
Gray				Smoke	Inactive/unavailable options or actions

Table C5: MIL-STD-1472G's Table XVIII. Color-coding of lights (DoD, 2009)

Size/type	**Color**				
	Red	**Yellow**	**Green**	**White**	**Blue**
>=25mm (1 in), flashing (3 to 5 sec)	Emergency condition (impending personnel or equipment disaster)				
>=25 mm (1 in), steady	Master summation (system or subsystem)	Extreme caution (impending danger)	Master summation (system or subsystem)		
<=13mm (0.5 in), steady	Malfunction; action stopped; failure; stop action	Delay; check; recheck	Go ahead; in tolerance; ready	Functional or physical position; action in progress	Advisory

Table C6: MIL-STD-1472G's Table XXX. Recommended clearances around vehicle operator's station to accommodate a soldier dressed in arctic clothing (DoD, 2009)

Body Part or Dimension	Recommended Clearance
A. Elbow (dynamic)	91 cm (36 in)
B. Elbow (static)	71 cm (28 in)
C. Shoulder	58 cm (23 in)
D. Knee width (minimum)	46 cm (18 in)
E. Knee with (optimum)	61 cm (24 in)
F. Boot (provide adequate clearance to operate brake pedal without inadvertent accelerator operation)	15 cm (6.0 in)
G. Pedals (minimum)	5.0 cm (2.0 in)
H. Boot (provide adequate clearance to operate accelerator without interference by brake pedal)	15 cm (6.0 in)
1. Head (seat reference point (SRP) to roof line)	107 cm (42 in)
2. Abdominal (seat back to steering wheel)	41 cm (16 in)
3. Front of knee (seat back to manual controls on dash)	74 cm (29 in)
4. Seat depth (SRP to front edge of seat pan)	41 cm (16 in)
5. Thigh (underside of steering wheel to seat pan)	24 cm (9.5 in)
6. Seat pan height	38 cm (15 in)
7. Boot (front of seat pan to heel point of accelerator)	36 cm (14 in)
8. Minimum mitten clearance around steering wheel	8.0 cm (3.0 in)
9. Knee-leg-thigh (brake/clutch pedals to lower edge of steering wheel)	66 cm (26 in)

NOTE: See Figure 42[25]

[25] See Appendix E.

Table C7: MIL-STD-1472G's Table XXXVI. Range of human motion (DoD, 2009)

Body member movement		Lower limit (degrees)	Average (degrees)	Upper limit (degrees)
A. Shoulder	1. Flexion	176	188	190
	2. Extension	47	61	75
	3. Lateral rotation	21	34	47
	4. Medial rotation	75	97	119
	5. Horizontal adduction	39	48	57
	6. Horizontal abduction	117	134	151
B. Elbow	1. Flexion	132	142	152
C. Forearm	1. Supination	91	113	135
	2. Pronation	53	77	101
D. Wrist	1. Flexion	78	90	102
	2. Extension	886	99	112
	3. Ulnar deviation	40	47	54
	4. Radial deviation	18	27	36
	5. Wrist carry angle	95	102	109
E. Hip	1. Flexion	100	113	126
	2. Adduction (supine)	19	31	43
	3. Abduction (supine)	41	53	65
	4. Abduction (standing)	16	23	30
	5. Adduction (standing)	15	24	33
	6. Lateral rotation (prone)	24	34	44
	7. Medial rotation (prone)	29	39	49
	8. Medial rotation (sitting)	22	31	40
	9. Lateral rotation (sitting)	21	30	39
F. Knee	1. Flexion (prone)	115	125	135
	2. Flexion (standing)	100	113	126

Body member movement		Lower limit (degrees)	Average (degrees)	Upper limit (degrees)
	4. Lateral rotation	31	43	55
	5. Medial rotation	23	35	447
G. Ankle	1. Posterior tibial angle	26	38	50
	2. Anterior tibial angle	28	35	42
H. Neck	1. Extension (backward)	44	61	88
	2. Flexion (forward)	48	60	72
	3. Lateral flexion (right)	34	41	48
	4. Lateral flexion (right)	34	41	48
	5. Rotation (right)	65	79	93
	6. Rotation (left)	65	79	93

NOTES:

1. These values are based on the nude body. The ranges are larger than they would be for clothed and mission equipped personnel.
2. Flexion: Bending or decreasing the angle between parts of the body.
3. Extension: straightening or increasing the angle between parts of the body.
4. Adduction: Moving toward the midline of the body.
5. Abduction: Moving away from the midline of the body.
6. Medial rotation: Turning toward the midplane of the body.
7. Lateral rotation: Turning away from the midplane of the body.
8. Pronation: Rotation of the palm of the hand downward.
9. Supination: Rotation of the palm of the hand upward.
10. Radial deviation: Hand moving toward the radius (bone).
11. Ulnar deviation: Hand moving toward the ulna (bone).
12. Plantarflexion: Movement that increases the angle between the foot and leg.
13. Dorsiflexion: Movement that decreases the angle between the foot and leg.

Tibial angle (posterior and anterior) is relative to a reference line formed at a right angle to the base of the foot.

Appendix D. Figures from Military Design Criteria Standard 1472G

The following figures are taken from MIL-STD-1472G and included here for reference.

Figure 6 and Figure 14 were used in our analysis of the experimental crewstation's controls. Figure 23 was used to identify appropriate forces for control levers. Figure 41 and Figure 42 were used in our analysis of appropriate seating dimensions.

Figure 8, Figure 12, and Figure 16 were not used in our analysis because the controls they depict were not used in either workstation we evaluated; however, we have included these figures because they were cited in MIL-STD-1472G criterion that we included in our analysis for other reasons. Figure 54 was not used in our analysis because we were able to address its contents through other means, using RAMSIS anthropometric modeling software.

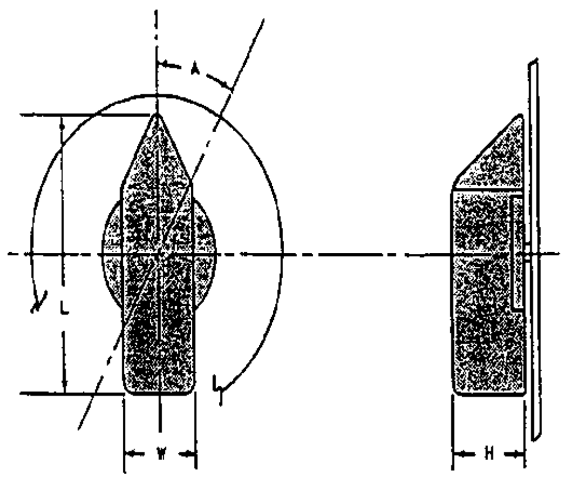

Figure D1: MIL-STD-1472G's Figure 6. Rotary selector switch (DoD, 2009)

Table D1: Dimension and resistance table for MIL-STD-1472G's Figure 6. Rotary selector switch (DoD, 2009)

	Dimensions			Resistance
	L, Length	W, Width	H, Depth	
Minimum	25 mm (1.0 in)	--	16 mm (0.625 in)	115 mN x m (1.0 in-lb)
Maximum	100 mm (4.0 in)	25 mm (1.0 in)	75 mm (3.0 in)	680 mN x m (6.0 in-lb)

Table D2: Displacement and separation table for MIL-STD-1472G's Figure 6. Rotary selector switch (DoD, 2009)

	Displacement [1/], A		Separation	
	--	[2/]	One-hand random	Two-handed operation
Minimum	262 mrad (15 deg)	525 mrad (30 deg)	25 mm (1.0 in)	75 mm (3.0 in)
Maximum	700 mrad (40 deg)	1570 mrad (90 deg)	--	--
Preferred	--	--	50 mm (2.0 in)	125 mm (5.0 in)

NOTES:

[1/] For facilitating performance.

[2/] When special engineering requirements demand large separation or when tactually ("blind") positioned controls are required.

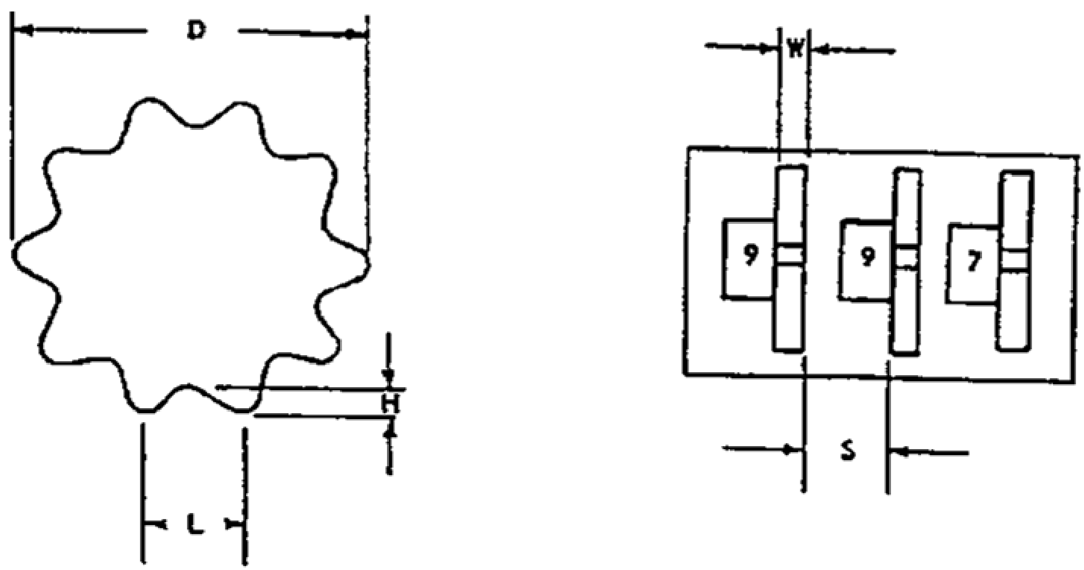

Figure D2: MIL-STD-1472G's Figure 8. Discrete thumbwheel control (DoD, 2009)

Table D3: Detail table for MIL-STD-1472G's Figure 8. Discrete thumbwheel control (DoD, 2009)

	D, Diameter	L, Trough distance	W, Width	H, Depth	S, Separation	Resistance
Minimum	29 mm (1.125 in)	11 mm (0.43 in)	3.0 mm (0.125 in)	3.0 mm (0.125 in)	10 mm (0.4 in)	1.7 N (6 oz)
Maximum	75 mm (3 in)	19 mm (0.75 in)		6.0 mm (0.25 in)		5.6 N (20 oz)

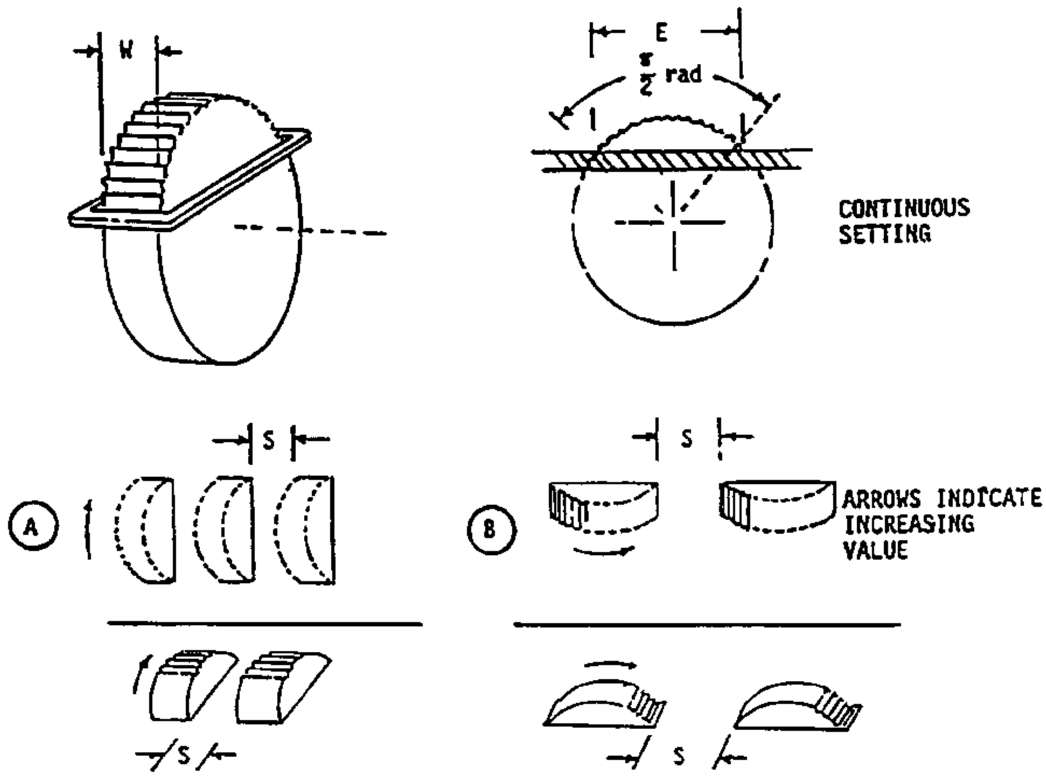

Figure D3: MIL-STD-1472G's Figure 9. Continuous adjustment thumbwheel (DoD, 2009)

Table D4: Details table for MIL-STD-1472G's Figure 9. Continuous adjustment thumbwheel (DoD, 2009)

	E, Rim exposure	W, Width	S		Resistance
			A	B	
Minimum	25 mm [1/] (1.0 in)	3 mm [1/] (0.125 in)	25 mm (1.0 in), add 13 mm (0.5 in) for gloves	50 mm (2.0 in), add 25 mm (1.0 in) for gloves	To minimize effects of inadvertent input if user subject to motion
Maximum	100 mm (4.0 in)	23 mm (0.875 in)	N/A	N/A	3.3 N (12 oz)
NOTE: [1/] Preferred. Some miniature applications may require less.					

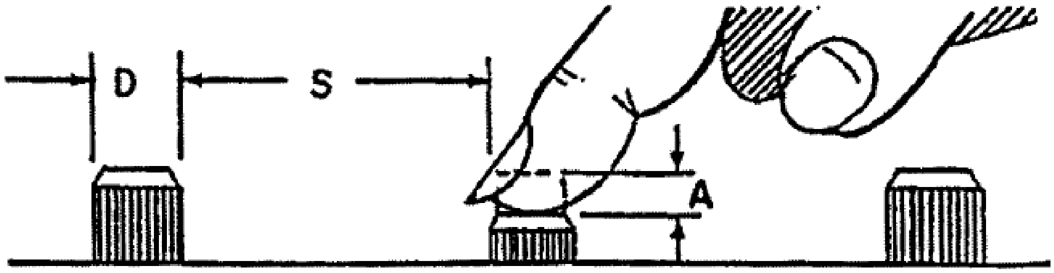

Figure D4: MIL-STD-1472G's Figure 10. Push button (finger- or hand-operated) (DoD, 2009)

Table D5: Dimensions and resistance table for MIL-STD-1472G's Figure 10. Push button (finger- or hand-operated) (DoD, 2009)

	Dimensions (D, Diameter)						Resistance		
	Fingertip		Thumb		Palm				
	Bare hand	Gloved hand 1/	Bare hand	Gloved hand 1/	Bare hand	Gloved hand 1/	Single finger	Differ-ent fingers 2/	Thumb/palm
Minimum	10 mm (0.4 in)	10 mm (0.75 in)	10 mm (0.75 in)	25 mm (1.0 in)	40 mm (1.6 in)	50 mm (2.0 in)	2.8 N (10 oz)	1.4 N (5 oz)	2.8 N (10 oz)
Maximum	25 mm (1.0 in)	--	25 mm (1.0 in)	--	70 mm (2.8 in)	--	11.0 N (40 oz)	5.6 N (20 oz)	23.0 N (80 oz)

Table D6: Displacement values for MIL-STD-1472G's Figure 10. Push button (finger- or hand-operated) (DoD, 2009)

	Displacement (A)	
	Fingertip	Thumb or Palm
Minimum	2.0 mm (0.08 in)	3.0 mm (0.12 in)
Maximum	6.0 mm (0.25 in)	38 mm (1.5 in)

Table D7: Separation values for MIL-STD-1472G's Figure 10. Push button (finger- or hand-operated) (DoD, 2009)

	Separation (S)				
	Single finger		Single finger sequential 3/	Different finger 3/	Thumb or palm 3/
	Bare	Gloved			
Minimum	13 mm (0.5 in)	25 mm (1.0 in)	6.0 mm (0.25 in)	6.0 mm (0.25 in)	25 mm (1.0 in)
Preferred	50 mm (2.0 in)	--	13mm (0.5 in)	13 mm (0.5 in)	150 mm (6.0 in)

FOOTNOTES:

[1] For standard cotton flame-resistant anti-flash gloves (i.e., Navy flash gloves (as defined in MIL-G-3874E)), add 5.0 mm (0.2 in) to Diameter (D) of bare hand dimension.

[2] Actuated at the same time.

[3] Where gloved hand criteria are not provided, minimum shall be suitably adjusted.

NOTE:

1. Figure 10 does not apply to keyboards (see Section 5.1.3.2).

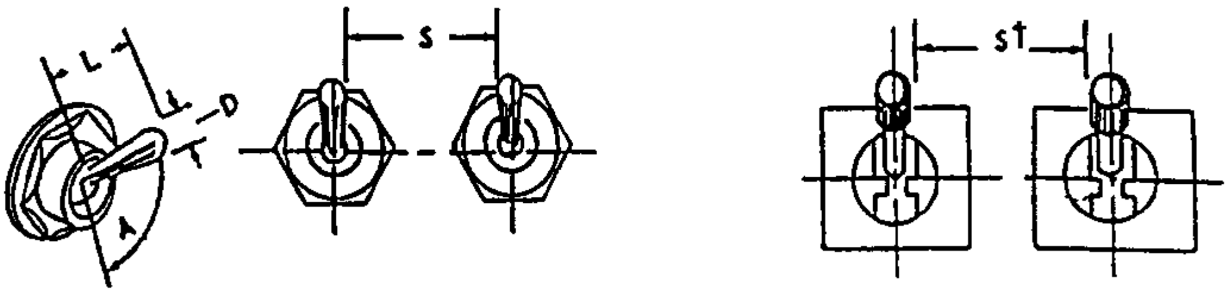

Figure D5: MIL-STD-1472G's Figure 11. Toggle switches (DoD, 2009)

Table D8: Dimensions and resistance for MIL-STD-1472G's Figure 11. Toggle switches (DoD, 2009)

	Dimensions			Resistance	
	Arm Length (L)		Control Tip (D)	Small switch	Large taxi
	Use by bare finger	Use with heavy handwear			
Minimum	13 mm (0.5 in)	38 mm (1.5 in)	3.0 mm (0.125 in)	2.8 N (10 oz)	2.8 N (10 oz)
Maximum	50 mm (2.0 in)	50 mm (2.0 in)	25 mm (1.0 in)	4.5 N (16 oz)	11 N (40 oz)

Table D9: Displacement details for MIL-STD-1472G's Figure 11. Toggle switches (DoD, 2009)

	Displacement between positions	
	Two positions	Three positions
Minimum	30 deg	17 deg
Maximum	80 deg	40 deg
Preferred	--	25 deg

Table D10: Separation details for MIL-STD-1472G's Figure 11. Toggle switches (DoD, 2009)

	Separation (S)			
	Single finger operation		Single finger sequential operation	Simultaneous operation by different fingers
	Normal	Lever lock switch		
Minimum	19 mm (0.75 in)	25 mm (1.0 in)	13 mm (0.5 in)	16 mm (0.625 in)
Optimum	50 mm (2.0 in)	50 mm (2.0 in)	25 mm (1.0 in)	19 mm (0.75 in)

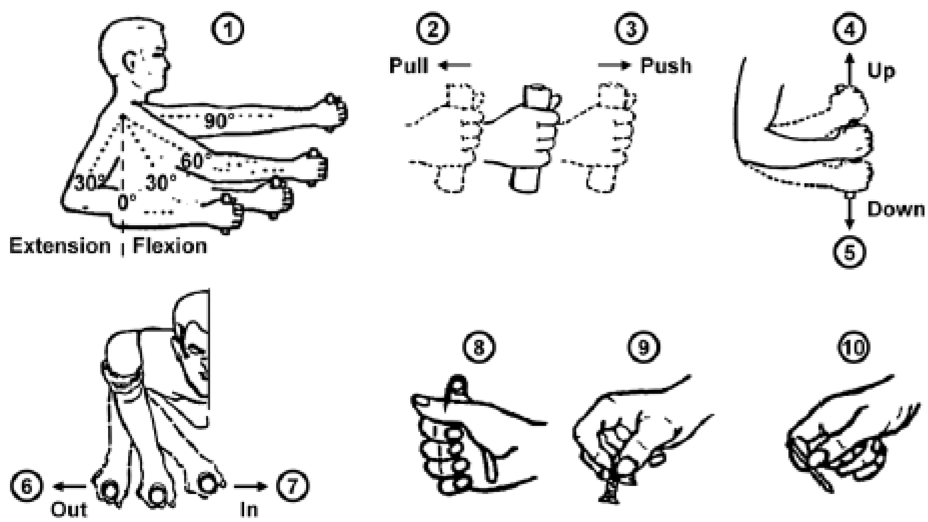

Figure D6: MIL-STD-1472G's Figure 12. Arm, hand, and thumb-finger strength (5th percentile male data) (DoD, 2009)

Table D11: Strength values for MIL-STD-1472G's Figure 12. Arm, hand, and thumb-finger strength (5th percentile male data) (DoD, 2009)

Arm Strength In Newtons (pounds of force)													
(1)	(2)		(3)		(4)		(5)		(6)		(7)	
Degree of shoulder flexion/extension	Pull		Push		Up		Down		Out		In	
	L	R	L	R	L	R	L	R	L	R	L	R
90 deg (flexion)	222 (50)	231 (52)	187 (42)	222 (50)	40 (9.0)	62 (14)	58 (13)	76 (17)	36 (8.0)	62 (14)	58 (13)	89 (20)
60 deg (flexion)	187 (42)	249 (56)	133 (30)	187 (42)	67 (15)	80 (18)	80 (18)	89 (20)	36 (8.0)	67 (15)	67 (15)	89 (20)
30 deg (flexion)	151 (34)	187 (42)	116 (26)	160 (36)	76 (17)	107 (24)	93 (21)	116 (26)	45 (10)	67 (15)	89 (20)	98 (22)
0 deg (neutral)	142 (32)	165 (37)	98 (22)	160 (36)	76 (17)	89 (20)	93 (21)	116 (26)	45 (10)	71 (16)	71 (16)	80 (18)
30 deg (extension)	116 (26)	107 (24)	98 (22)	151 (34)	67 (15)	89 (20)	80 (18)	89 (20)	53 (12)	76 (17)	76 (17)	89 (20)

Table D12: Hand strength values for MIL-STD-1472G's Figure 12. Arm, hand, and thumb-finger strength (5th percentile male data) (DoD, 2009)

Hand and pinch strength in Newtons (pounds of force)				
	(8)		(9)	(10)
	Hand grip		Palmer pinch grip	Tip pinch grip
	L	R	(Thumb pad to index & middle finger pads)	(Thumb tip to index finger)
Momentary hold	250 (56)	260 (59)	60 (13)	60 (13)
Sustained hold	145 (33)	155 (35)	35 (8.0)	35 (8.0)

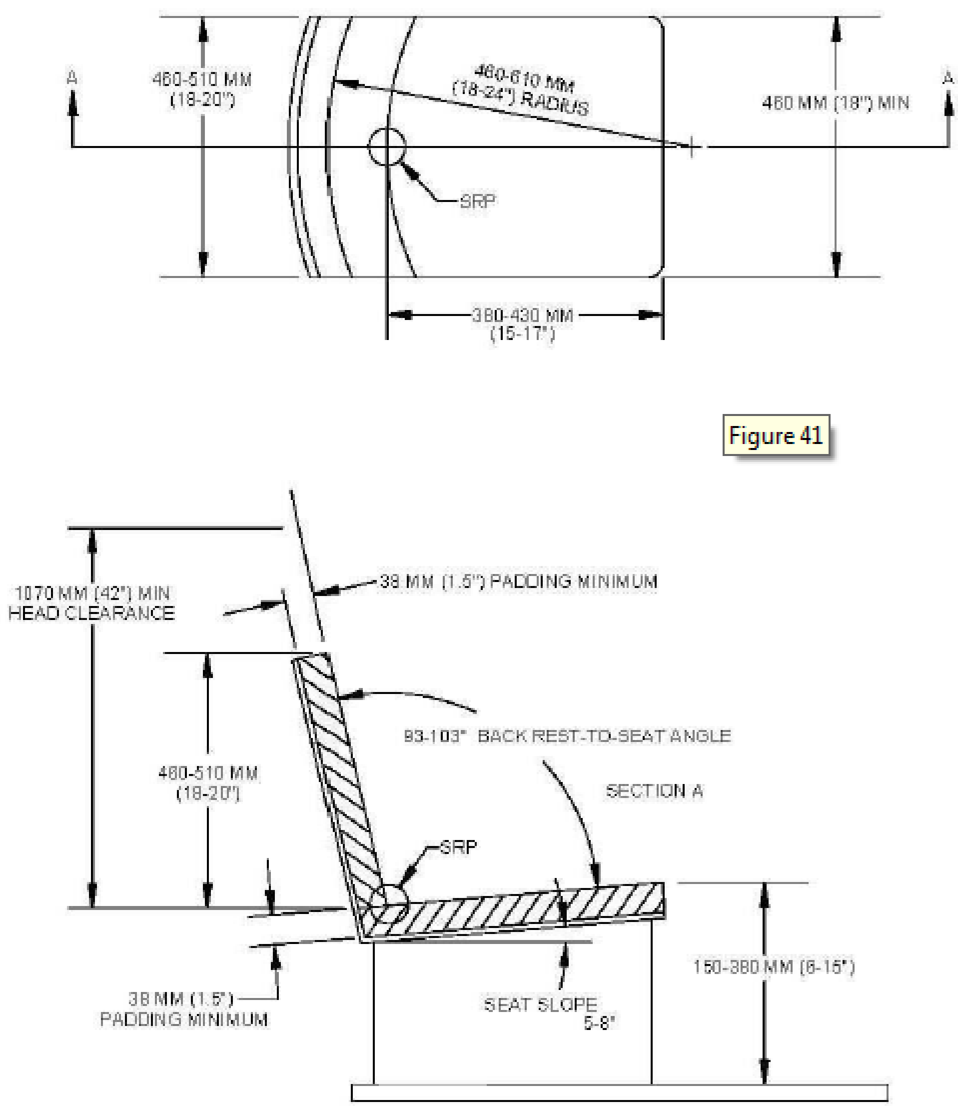

Figure D7: MIL-STD-1472G's Figure 13. Dimensions for vehicle operator's seat (DoD, 2009)

NOTE:

1. SRP = Seat Reference Point.

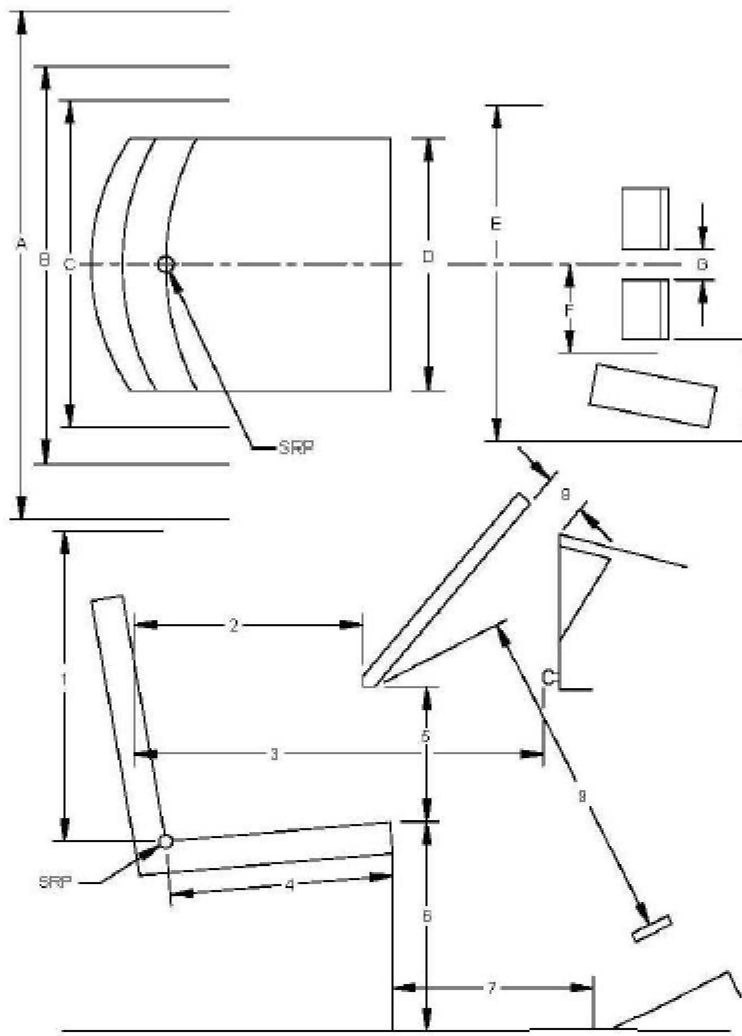

Figure D8: MIL-STD-1472G Figure 14. Measurements for clearances around equipment (DoD, 2009)

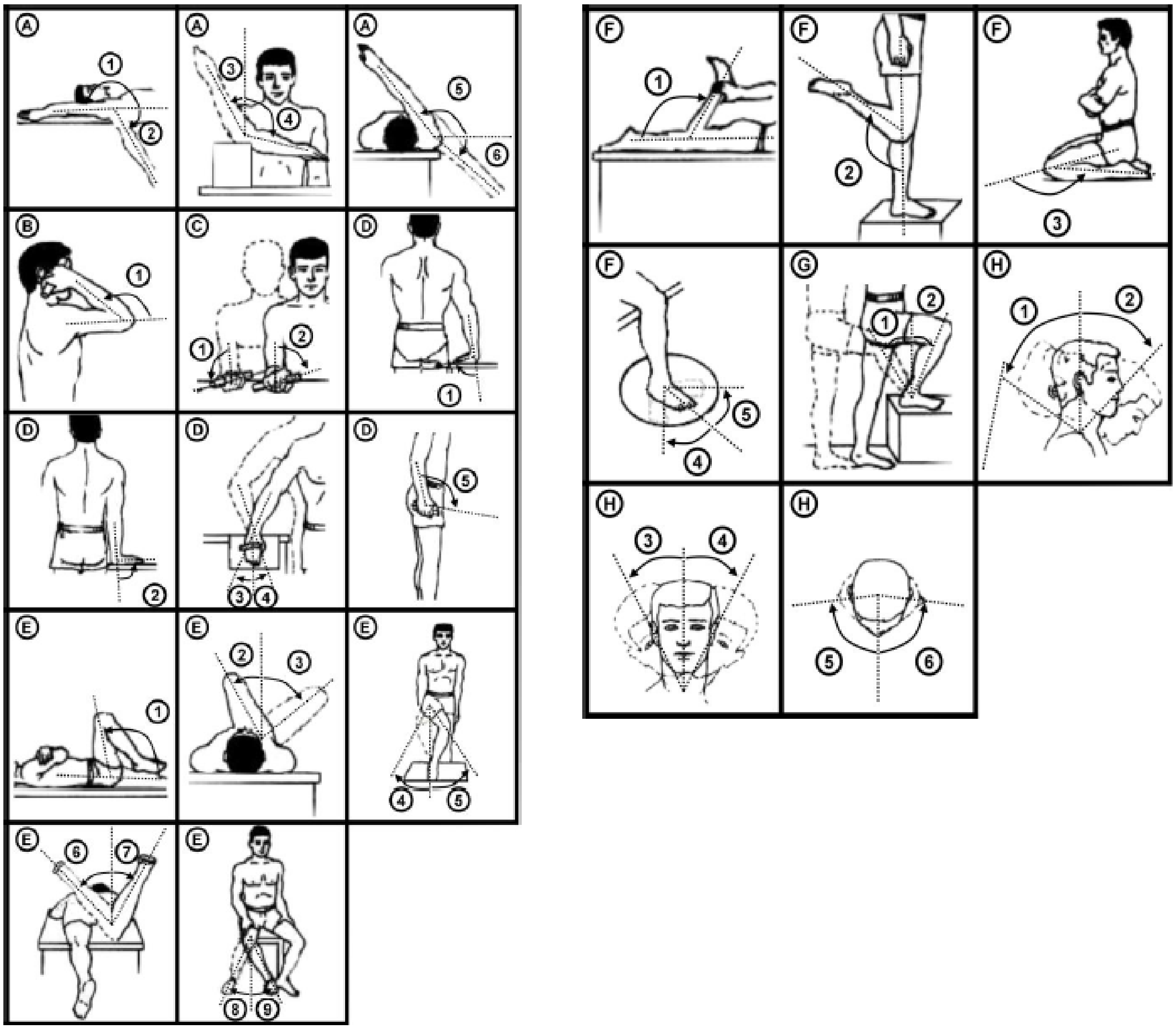

Figure D9: MIL-STD-1472G Figure 15. Range of human motion (DoD, 2009)

Appendix E. RAMSIS Body Discomfort Scores

The three tables below more thoroughly describe the comfort analysis results from the anthropometric modeling task. They compare the AAR-105 to the experimental crewstation by using the RAMSIS Body Discomfort Score for each body part as well as a score for fatigue and overall discomfort.

Lower scores represent more comfort. An asterisk is used to denote scores which are significantly better in the experimental crewstation compared to the AAR-105 (values greater than 1).

Table E1. Discomfort scores for grasping the throttle

Discomfort Type	50th Percentile Female		95th Percentile Male	
	AAR-105	Experimental crewstation	AAR-105	Experimental crewstation
Neck	5.1	2.3*	4.6	2.2*
Shoulders	3.5	2*	4	2.3*
Back	2.8	1.7*	2.4	1.8
Buttocks	2.3	1.3*	2.3	1.4
Left Leg	3.5	2.1*	2.7	2
Right Leg	3.5	1.9*	2.4	1.7
Throttle Arm	5.2	1.7*	3.9	2*
Other Arm	2.8	1.9	1.8	2
Fatigue	4.9	2.5*	4	2.7*
Overall Discomfort	6.1	3.3*	5.1	3.5*

Table E2. Discomfort scores for grasping the automatic brake

Discomfort Type	50th Percentile Female		95th Percentile Male	
	AAR-105	Experimental crewstation	AAR-105	Experimental crewstation
Neck	4	2.3*	3.4	2.1*
Shoulders	3	1.9*	2.7	2.2
Back	2.6	1.8	2.6	1.6*
Buttocks	2	1.3	2.7	1.2*
Left Leg	2.4	2	2.1	1.6
Right Leg	2.7	2	2.2	1.9
Left Arm	3.9	1.9*	3	2*
Right Arm	2.7	1.7*	2.3	1.7
Fatigue	3.9	2.6*	3.3	2.5
Overall Discomfort	5	3.3*	4.5	3.2*

Table E3. Discomfort scores for grasping throttle and automatic brake simultaneously

Discomfort Type	50th Percentile Female		95th Percentile Male	
	AAR-105	Experimental crewstation	AAR-105	Experimental crewstation
Neck	6.7	2.8*	5.4	2.5*
Shoulders	5.4	2.6*	4.2	2.8*
Back	3.3	2.4	3.3	2.1*
Buttocks	2.4	2	1.9	2
Left Leg	3.8	2.3*	3	2.1
Right Leg	4.1	2.2*	2.8	2.1
Left Arm	5.2	1.9*	2.5	2
Right Arm	6.6	2*	4	2*
Fatigue	5	3.1*	4.3	3*
Overall Discomfort	6.2	4.2*	5.5	4*

Appendix F. Usability Test Documents

Recruitment Email

Subject: Experimental Engineer Crewstation Usability Study

Dear Mr./Ms. [Engineer Name],

You are invited to participate in an important study sponsored by the Federal Railroad Administration (FRA). This study is being conducted by a team of human factors professionals from the Volpe Center, and will take place at the Cab Technology Integration Laboratory (CTIL) Locomotive Simulator in Cambridge, MA. The Volpe Center is seeking professional engineers who are familiar with the AAR-105 control stand as volunteers for this study.

This study will require volunteer engineers to operate the locomotive simulator while using an experimental crewstation. Volunteers will perform a series of typical locomotive operation tasks using the crewstation and will then be asked a series of questions about their experience to provide the human factors team with valuable perspectives on the usability of the crewstation.

This study is confidential. You will be assigned a unique participant number which will be used in place of your name, and your name will not be connected with your performance on the simulator. The data collected is only for the internal use of the human factors team to evaluate the experimental crewstation.

If you choose to volunteer for this study, you will come to the Volpe Center in Cambridge for a day of testing. It is anticipated that a typical testing day on the CTIL locomotive simulator will last approximately two hours. Should you choose to participate, you will be given a $350.00 gift certificate to Amazon.com for your time.

Benefits of this study include contributing to the body of human factors rail research. Volunteers' performance and feedback will aid in the design of future locomotive control stations which may have health and comfort benefits for future locomotive engineers. This is a unique opportunity to influence the next generation of locomotive cab work environments to ensure that future changes are beneficial to engineers like you.

If you have any questions about this study or would like more information, please contact [contact information redacted for privacy reasons in this report]

Thank you for your time and consideration.

Background Document

Note: This document is to be read aloud by the experimenter, in addition to the consent form.

Hi, my name is _____[experimenter name]____ and I'm going to be walking you through a usability test of an experimental way of operating a train.

We're asking engineers to test out this very early version so that we can see whether it works in the ways engineers expect. The session should take a maximum of two hours.

The first thing I'd like to make clear is that we're testing elements of the crewstation, and not you. Don't worry about making mistakes; as we will certainly learn a lot from any that you do make.

As you use the crewstation I'm going to ask you ask much as possible to think out loud. Say what you're looking at, what you're trying to accomplish as you're doing it, and, of course, whatever you're thinking.

Also, don't worry that you're going to hurt our feelings. We are not the designers of the crewstation, and more importantly the purpose of this is ultimately to improve train cab safety, so feel free to say whatever you feel.

If you have any questions as we progress, please ask right away. I may not be able to answer you right away, because in some cases we're most interested in how well the workstation allows people to perform when they don't have any help, but if you still have any questions when we're done I'll do my best to answer them.

I should also mention that the crewstation that we'll be working on is an early prototype. On occasion, you may notice a key element is missing or non-functional. If that happens I'll intervene to let you know that's what is going on, and let you know what to do next.

If you have any questions, you can use the contact information included on your consent form.

Opening Questionnaire

How many total years of experience do you have as an engineer?

Freight	**Passenger**
No experience	No experience
Less than 5 years	Less than 5 years
5–10 years	5–10 years
11–15 years	11–15 years
16 or more years	16 or more years

Are you currently retired? Yes or No
If so, how many years ago did you retire?_____________

Have you operated the AAR-105 control stand in a freight environment, passenger environment or both?

Freight

Passenger

Both

About how many hours per week do you spend using the AAR-105 Control Stand?

Are there any control stand designs that stand out in your mind as being really good? What did you like about them?

Please describe your relationship with technology in general. Do you consider yourself "tech savvy?"

System Usability Scale

Table F1: Usability scale administered to locomotive engineer participants

	Strongly Disagree 1	2	3	4	Strongly Agree 5
1. I would like to use this system frequently					
2. I found the system unnecessarily complex					
3. I thought the system was easy to use					
4. I think that I would need the support of a technical person to be able to use this system					
5. I found the various functions in this system were well integrated					
6. I thought there was too much inconsistency in this system					
7. I would imagine that most people would learn to use this system very quickly					
8. I found the system very cumbersome to use					
9. I felt very confident using the system					
10. I needed to learn a lot of things before I could get going with this system.					

Debrief Questionnaire

Debrief Questionnaire

On a scale of 1-5 please rate how easy-difficult you found it to:

	Easy--Hard				
• *Operate the Throttle*	1	2	3	4	5
• *Engage the Dynamic brake*	1	2	3	4	5
• *Operate the Automatic brake*	1	2	3	4	5
• *Find the problem with the Fuel Control button*	1	2	3	4	5
• *Engage the Alerter response button*	1	2	3	4	5
• *Find button controls without looking down*	1	2	3	4	5
• *Engage the Emergency Brake*	1	2	3	4	5
• *Switch the chair from sitting to standing*	1	2	3	4	5
• *Switch the chair from standing to sitting*	1	2	3	4	5
• *Read the information displays*	1	2	3	4	5
• *Determine your throttle notch*	1	2	3	4	5

What recommendations do you have for things to change, remove or add to the design? Please use the space below.

Debriefing Statement

Thank you for participating in today's usability test. As we stated earlier, your identifying information will be kept confidential and data from this session will only be used to help inform the design of future crewstations.

Engineers have been using the AAR-105 control stand for many years. With the advent of Positive Train Control systems and other automation coming to train cabs across the country, FRA and other railroads are beginning to see a need for crewstation redesigns which include space for more computer screens and better access to controls.

With this in mind, in addition to looking at improvements to existing workstations, FRA is interested in entertaining redesigns which could lead to great improvements in ergonomics as well as ease of use. One such design was built by a local transportation engineering firm and was delivered to the Volpe Center for usability testing last year. This design is the experimental crewstation which you used today.

It is important to note that there is no plan for implementing the experimental crewstation that you used today. Rather, the idea behind looking at such broad redesigns is to allow railroads, industries and governments to see how out-of-the-box thinking could affect future cab considerations.

In addition to this usability test, we have evaluated many aspects of the experimental crewstation have been evaluated to inspect whether it complies with safety, usability and ergonomic standards. The tasks you performed today will help inform concerns that were raised during earlier phases of evaluation.

If you have any questions, comments or concerns about any aspect of this experiment, please feel free to discuss them now. Or, you can contact (contact information redacted from this report) at a later time. Thanks very much for your participation!

Abbreviations and Acronyms

ACRONYMS	EXPLANATION
AAR	Association of American Railroads
BLE	Brotherhood of Locomotive Engineers
BNSF	Burlington Northern Santa Fe Railway
CTIL	Cab Technology Integration Laboratory
CAD	Computer-Aided Design
EMD	Electro-Motive Diesel
EOT	End-of-Train device
FRA	Federal Railroad Administration
HFDS	Human Factors Design Standard
HEDGE	Human Factors Engineering Data Guide for Evaluation
HFE	Human Factors Engineering
HSI	Human-Systems Integration
Volpe Center	John A. Volpe National Transportation Systems Center
LED	Light Emitting Diode
LETS	Locomotive Engineer Training Simulator
MBCR	Massachusetts Bay Commuter Railroad
MOU	Memorandum of Understanding
RALES	Research and Locomotive Evaluator/Simulator
RFP	Request for Proposal