The Application of Human Systems Integration in DoD Design

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Dedication

I would like to honor my wife with this work. Although she did not contribute directly to the content or its findings, it was through her love and support which has made this journey possible.

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Abstract of Praxis

The Application of Human Systems Integration in DoD Design

Human Systems Integration (HSI) is the process taken to integrate human considerations within a system. This discipline seeks to place human requirements on the same level as other system elements, such as hardware and software to better facilitate a "total system" approach. This paper examines the developments in human factors, in addition to a review of current literature, and the application of HSI in government programs. A methodology is proposed that will enable a user to elicit, identify, and integrate specific requirements of the HSI military standard into an explicit application. A case study is detailed to provide insight to the significance of human requirements along with the benefits that can be obtained by their application.

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Glossary of Terms

MIL-STD-1472: This standard establishes general human engineering criteria for design and development of military systems, equipment, and facilities.

FST: Full Systems Test - Set of scenarios that would typically be seen during combat situations.

ISO 9241 (06/01/1997): Provides information on the ergonomics of human-computer interaction.

MIL-HDBK-759C (07/31/1995): "Provides basic guidelines and data on human engineering design for military systems, equipment, and facilities."

ISO/IEC TR 25060 (09/01/2006): This Technical Report "describes a potential family of International Standards that document the usability of systems."

NASA/SP-2010-3407 (01/27/2010): Provides guidance on human factors and the environment.

ASTM F1166 (06/28/2011): Informs on "ergonomic design criteria from a human-machine perspective."

Human-Centered Design: A process depicted by four major activities, represented by four overlapping circles that illustrate the result of each activity can enlighten the input of another.

Chapter 1: Introduction

The human element is essential to the success of complex systems during every stage throughout its lifecycle. Within the defense industry, "Human Systems Integration (HSI) is a "comprehensive management and technical approach for addressing the human element in weapons system development" (Liu et al, 2009, p.6). Improvements in system performance have been well documented in the application of HSI as well as the solicitation of human stakeholders being utilized as system requirements. Additionally, multiple best practices have been published in a variety of case studies which highlight the effectiveness of HSI in systems engineering (Landsburg et al, 2008).

The work presented in this paper is part of an initiative to improve the console design for remote weapons in the U.S. Military using specific requirements of HSI MIL-STD-1472G. In order to accomplish that task, a partnership between the Depart of the Navy (DON) and the Department of Homeland Security (DHS) was formed to adapt a practice developed by the National Institute of Standards and Technology (NIST), to meet the specific needs of the DON. This new methodology enabled the DON to elicit and identify the specific requirements of MIL-STD-1472G needed to improve remote weapon performance. Using the adapted methodology, the research conducted in a military HSI laboratory identified 24 elements (requirements) of MIL-STD-1472G with the highest probability to improve the time between target acquisition and target termination by HSI advancements. It is proposed that the 24 requirements identified within MIL-STD-1472G can reduce the time between target acquisition and target termination, when applied to the design early in development. A Full Systems Test

(FST) was conducted on a console prototype which included the 24 requirements of MIL-STD-1472G. Each FST is comprised of 14 different wartime scenarios which were completed by nine different weapon operators.

1.1 Significance of HSI in remote operations

Human Engineering, also known as ergonomics or Human Factors Engineering (HFE), is literally the science behind the application of information on human characteristics into a systems design for human use. Advancements by multiple countries in the field of HFE and HSI are credited with the evolution in this field, but this research will focus on the activity within the U.S. Military. The U.S. Military addresses HSI in a plethora of documentation. The two highest level documents are "DoDD 5000.01, *Defense Acquisition System*, which states the application of human systems integration, and DoDI 5000.02, *Operation of the Defense Acquisition System*, which defines HSI and identifies its domains" (Foxx et al, 2006).

Even though the domains of HSI are listed in the Operation of the Defense Acquisition System, each military branch maintains their own archives and classifications of HSI domains. These differences exist to help the integration of HSI into the different services (military branches), but do not present a disagreement about the importance or meaning of HSI. Since the Navy supported the research accomplished in this paper, we use the Navy's definition of the HSI domains. The seven domains are: human factors engineering (HFE), training, personnel, manpower, environment, safety, occupational health (ESOH), survivability and habitability.

The majority of models perceived in the remote weapon setting have been carried over from the piloted cockpit environment. Human factors in aerospace medicine involve "ensuring humans have both the physical and mental capacity to perform under conditions associated with aerospace operations" (Pope & Bogart, 1992, p.64). Interest in aerospace HSI is increasing as scientific improvements alter the roles of human operators, with the realization that "the considerable base of human factors knowledge derived from cockpit experience may have limited applicability to future systems" (Tvaryanas, 2006, p.36). While the previous statement was speaking to Remotely Piloted Aircraft (RPA), the same concern exists within improvements in the remote weapon environment. The following chapters will address the commonality between the two, and the steps that have been taken to address console improvements for remotely controlled weapons.

In conclusion of this research, I identify specific HSI requirements derived from MIL-STD-1472G which were determined to improve operator efficiency in remote weapon applications. The requirements are tested and measured with the development of a prototype which integrates these requirements into a model design.

1.2 MIL-STD-1472G

According to the Military Standard (MIL-STD) 1472G, its purpose is to "establish the criteria for design and development of military systems, equipment, and facilities" (MIL-STD-1472G, 2012, p.2). The information contained in military standards represent 'guidelines' to create consistency throughout their use in a variety of applications (Fortune & Valerdi, 2012). MIL-STD-1472 establishes "general human engineering criteria for design and development of military systems, equipment and facilities" (MIL-STD-1472G, 2012, p.2). "Human engineering is one of seven domains of Human-systems integration (as defined in the DoD 5000 series) and is synonymous with Human factors engineering" (Eusgeld, Nan, & Dietz, 2011, p.9).

MIL-STD-1472 is the human engineering standard and was developed and approved for "use by all departments and agencies of the Department of Defense (DOD)" community (MIL-STD-1472G, 2012, p.2). This standard alone was developed 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" (MIL-STD-1472G, 2012, p.2).

MIL-STD-1472 has remained, in large part, technically unchanged since the 1980s. Revision "D" was circulated in March 1989 and addressed technology levels that existed around 1987-1988. In 1996 revision "E" was issued to cosmetically improve the document by reducing space by changing font. Then in 1999 revision "F" mainly consisted of relocating the measurement of human individual data from MIL-STD-1472 to MIL-HDBK-759 (MIL-STD-1472G, 2012).

However, the changes incorporated into revision "G" are substantial over previous revisions. For example, "the organizational structure of the standard was revamped to group similar material in the same section of the document; obsolete provisions (e.g. dot-matrix printers) were deleted, out-of-date provisions were updated to reflect the latest research, and new provisions were added to address emerging technologies" (MIL-STD-1472G, 2012, p.2).

This paper presents its work in five sections. The Introduction will detail the significance of HSI in remote operations and the importance it plays in engineering management and systems engineering. The introduction of HSI Military Standard MIL-STD-1472 is also outlined. The Literature Review will address the origins of HSI and its growth in and throughout the military. A review of current literature will also detail the systems integration of unmanned systems and methods for remote weapon design. The third section will outline the Methodology that was used to identify the requirements that would be incorporated into a prototype console design. The fourth section will provide the results from the Full Systems Test (detailed in Chapter 4) and this paper will conclude with future applications and a summary of the research.

Chapter 2: Literature Review

Since the introduction of advanced remote controlled weapons is still a relatively new technology, their console designs have been largely adapted from the more familiar cockpit environment. As such, this literature review seeks to outline and origins of HSI and its growth within the military and ultimately into unmanned design.

A review of current literature details the history of HSI and its recent growth in the government and industry, and as an essential element of system design. Legacy console design problems are evaluated in the literature and evaluated for prospective improvement.

This review of current literature will detail the following areas of HSI: when and how was HSI originally began; the development of HSI within the U.S. Military; Systems Integration of HSI into an unmanned environment, and current methods for unmanned design.

2.1 Origins of HSI

The origin of HSI actually falls into the field of Human Factors Engineering (HFE). According to (Nardi, 1997), "Human Factors is the science of understanding the properties of human capability and the application of this understanding to the design and development of systems and services." Arguably, human factors have been considered since scientific research first began. It wasn't until the Industrial Revolution that we began to see advancements in the interaction between humans and machines. Additionally, improvements in work management were also made during that period, and those advancements were characterized as Industrial Engineering at the time (Nemeth, 2004).

During the first and second World Wars, industrial challenges and requirements grew significantly. In response to this growth, funding efforts by the U.S. and UK were introduced to understand human impacts on performance" (Booher, 2003). Due to the fact that HFE has been documented over the course of the 20th century, sometimes under different names, it's difficult to pinpoint the true beginning of HFE (Meister, 2000).

In the early 1980's, the "U.S. General Accounting Office (since renamed the Government Accountability Office) released reports calling on the U.S. Army to improve the integration of Manpower, Personnel, and Training (MPT)" (Stanton et al, 2013, p.7). In 1986 the Manpower and Personnel Integration (MANPRINT) program was developed by the US Army, which then became the official Directorate for HSI (Army, 2007). Since that time, HSI has seen tremendous growth in systems which require the human element.

2.2 HSI in the Military

The Army MANPRINT program was able to overcome the limitations of previous government attempts to influence the acquisition process and demonstrate mojor cost, performance, and safety enhancements (Booher and Minninger, 2003). Since then, HSI programs, modeled after MANPRINT, have been institutionalized in the U.S. Navy (SEAPRINT), U.S. Air Force (AIRPRINT), and Ministry of Defence (United Kingdom Human Factors Integration). To a lesser degree, HSI has been introduced into other U.S. agencies and other countries, and increasingly to private commercial activities. Within non-DoD agencies, the Federal Aviation Agency (FAA) has produced the most comprehensive guidelines to integrate human factors into the acquisition process (Swallom, 2003).

Although the HSI discipline is relatively new, it has developed principles, methods, and technological advancements that can be useful in integration inherent limitations and strengths of people into the systems engineering and management processes. This comes at a time when government cultures are beginning to appreciate the challenges and advantages of designing and operating complex system, which include full consideration of the roles of people throughout the systems engineering process.

HSI is unique as a discipline within the human-centered systems design, and development approaches that currently exist. HSI makes it possible for an organization to achieve significant increases in system performance, productivity, and safety, particularly with complex systems (Zigler & Weiss, 2003). To the degree this new discipline is applied at national levels, HSI can also help provide dramatic increases in technological effectiveness, including such aspects as reducing waste and protecting citizens from harm when a person, machine, or organization fails.

The need to consider the human element as a critical component is supported by systems engineering and systems management philosophies. People, technology, and organizations make up the three top-level components of any complex system (Sage and Lynch, 1998, p.57).

2.3 Unmanned (Military) Systems Integration

Modern military technologies make our enemies deadlier, exponentially exacerbating the dangers inherent with personnel involvement in a non-permissive environment (Liu et al, 2015). Even in the face of competitor capabilities, it is very unlikely that an American force would be repelled. The real danger lies in the enemy's exploitation of one of America's critical vulnerabilities: casualty aversion. Casualty aversion is only one factor among many that affect the political will to support military operations (Haskins, 2010). The access of information the populous has today regarding American casualties has marked a paradigm shift in one area of military technology: unmanned systems. Such systems will reduce the cost in life and limb that must be risked when executing military operations. In turn, this reduction will mitigate the risk presented by American casualty aversion (Andresen & Gronau, 2005).

The public reaction to casualties is a highly complex phenomenon, and must also take into account the public expectation of success. The human factor will remain paramount in war, and boots on the ground will always be needed to fully compel our adversaries, but the proportional risk to life and limb that must be assumed to shape the battlespace is changing at an exponential rate (Paez et al, 2005). Unmanned aerial vehicles, ground vehicles, surface ships, and now weaponry are proliferating, and it is likely that they will one day disproportionately represent combat power in every domain.

2.4 Methods for Unmanned (Remote) Design

The consoles that have been developed for today's remotely controlled weapons closely mirror the blueprint of a remotely piloted aircraft. According to (Tvaryanas et al, 2006), the qualitative difference between manned and unmanned aviation presents a natural aeromedical separation of hazards (e.g. vibrations, acceleration, etc.). Regardless of these differences, human performance continues to remain an essential part for the success of these systems. According to (Rieger et al, 2009, p.28) "RPAs have historically suffered mishap rates 1-2 orders of magnitude greater than those of manned aviation with various studies attributing 17-69% of these mishaps to human factors." Additionally, weak HSI was identified as the leading cause of RPA calamities by the U.S. Air Force Scientific Advisory Board.

Given the environmental difference between remotely manned aircraft and manned aircraft, the remote weapons practitioner is constantly challenged to address HSI issues in yet another new application and environment. With current remote weapon consoles being forced to accept the shortfalls in cockpit design, new programs are forced to respond by augmenting other domains in which they have more control, such as the training or the personnel domain (Rinaldi, Peerenboom, and Kelly, 2001).

Since the militaries newest weapons are designing towards remote operation, the urgency involving improvements to the remote console design have been growing within the ranks of the military. This urgency materialized when this research began by leveraging MIL-STD-1472 for HSI improvements over the current remote weapon design criteria.

Chapter 3: Methodology & Methods

3.1 Methodology

According to (Andresen & Gronau, 2005) a methodology that "could identify critical human requirements in different systems would rewrite the book on human systems integration." This approach took steps in that direction to meet needs of the DON and improve the identification of HSI system requirements for our system design and application.

The advancements seen in today's state of the art remote weaponry have prompted the U.S. government to fund research to leverage the HSI requirements contained within MIL-STD-1472. To accomplish this, the DON set out to investigate and identify specific requirements that could improve the operators console for remote controlled weapons. Collaboration with the DHS allowed for the adaptation of a procedure developed by the NIST, which enabled this research to identify the requirements within MIL-STD-1472 to achieve these improvements. The result was a set of 24 specific HSI requirements that could reduce target acquisition and termination time by a remote weapons operator.

Many of the Federal standards that exist to form the Human Engineering and HSI criteria for systems within the government are very domain-centric and focus on particular functions, populations, and systems. In contrast, the approach by the NIST (the Baseline User-Centered Design (UCD), was based on user populations whose features are varied. The baseline UCD encompasses a variety of public, state, and other personnel outside of Federal civil servants. In order for this approach to be useful to the DON, a modification was necessary to fit a finite range of user abilities, dimensions, and characteristics within the context of a remote weapon environment. The new UCD methodology centered itself on requirements for a remote weapon console, and is referred to as 'Baseline 2' in this research.

3.1.1 Identification of HSI Elements

The first phase of this research was to recognize and examine existing HFE and HSI standards, best practices, and procedures for the current cockpit setting. Concluding a Baseline 2 review, the current cockpit environment was mapped to existing standards while other areas that required further evaluation were mapped to specific requirements of MIL-STD-1472. This resulted in a spreadsheet illustration which coordinated the reviewed standards to the gaps that were identified during phase 2. This illustration can be seen in section 3.1.3 of this research paper.

Before the HSI requirements could be determined, a review of all standards applicable to the remote console environment was reviewed and followed a synthesis, or more specific, Delphi review for selection. An explanation of the requirement selection process is detailed herein. The result of this review identified five standards that would be used to determine the HSI requirements that needed to be addressed by MIL-STD-1472G.

3.1.2 Delphi Method

In traditional group discussion methods, effective communication is sometimes inhibited by the disadvantages inherent in groups. These include many psychological factors, problems with dominant individuals, and the consequent problem that all points of view are not heard, and the lack of documented, concise statements about what actually happened in the group dialogue (Archer, Headley, & Allender, 2003).

The procedure known as Delphi was developed by the Rand Corporation and eliminates many of the disadvantages of group dialogue (Blanchard et al, 1990). The Delphi approach does this because of three features not found in either classic brainstorming or brainwriting. These are anonymity, iteration with controlled feedback, and statistical group response.

Although a Delphi exercise is really a modification of both brainstorming and brainwriting, there are two primary variations that make it different (Sage & Lynch, 1998). First, there are simultaneous individual contributions from each participant at every step, without participants having knowledge of inputs supplied by others for that particular step. Second, the sources of all inputs are anonymous. This anonymity of input is maintained though the entire Delphi dialogue.

The Delphi approach tries to minimize the biasing effect of irrelevant dialogue between individuals and of group pressure toward conformity. Delphi helps to ensure that group interactions about the issue at hand compensate for the biases of individuals, and that the knowledge of several members of the group will compensate for ignorance on the part of others (Landsburg et al, 2008).

3.1.3 National Institute of Standards and Technology (NIST)

NIST conducts research in HSI to develop and improve the technical bases for standards related to procedures and specifications, while remaining objective for organizations and users in industry (Liu et al, 2015). The process developed by NIST for the DHS was based upon a three phase approach which consisted of a review of existing standards; the application of a User-Centered Design to map the standards to DHS needs; and to determine where new or modified HSI requirements need to be addressed in order to meet DHS organizational requirements. Details of the UCD are outlined herein.

This three phase approach was adopted in this research, but modified to meet the requirements explicit for our application. The first phase remained largely unchanged, which included a thorough review and identification of existing human factors, standards, and practices that were applicable to the DON for remote weapon console designs. The first phase followed a synthesis (compare and contrast)/Delphi review process, and concluded with five standards relevant in the research application.

The following is a brief description of the contents each standard has to offer; ISO 9241 includes guidance on software accessibility. MIL-HDBK-759C provides "basic guidelines and data on human engineering design for military systems, equipment, and facilities" (MIL-HDBK-759C, 1995, p.3). The outputs of the UCD process are outlined in ISO/IED TR 25060. Specifically, it normalizes the documented information types in a detailed report which measures effectiveness, efficiency, and satisfaction. NASA/SP-2010-3407 includes content around application to designs, and ASTM F1166 addresses data limitations. These five standards created the scope for the elements that would be identified and used from MIL-STD-1472.

The second and third phases of the NIST approach were essentially combined, which applied the UCD to map the needs of the DON to those standards that were identified in phase 1. Fundamentally, this phase also identified the gaps in those standards which lead to the identification of areas that could be addressed by MIL-STD-1472 in this research.

3.1.3.1 Phase 1, Standards Review

Phase 1 completion of the Baseline 2 review consisted of a Delphi research process, from which 34 federal standards were evaluated that are applicable in the capacity of HSI. The research group was composed of specialists (practitioners) that had a strong knowledge and understanding of our system requirements and standards development. The group also consisted of several experienced operators with backgrounds in aviation cockpit arrangements, as well as hands on experience with that environment, in both government and industry.

The use of highly qualified practitioners is the strongest indicator for a specific system that HSI is being recognized (Esugeld et al, 2011). Practitioners are the most reliable witnesses to how well human factors issues are being addressed in a system. Expert practitioners are needed to apply most of the tools and techniques used within the systems acquisition process. Our researchers relied on their own ability to infer relationships from one or more sources such as; observations, articles, requirements, standards, etc. Clearly, the experience and background of each team member was vital in performing a review of standards that would be applicable in this research application.

The selection and use of specifications and standards was an iterative process (Landsburg et al, 2008). At the outset of system design, there should be relatively few fixed specification and standards, except those that define the customer’s requirements. During the development process, it should be determined if specifications and standards already exist that would define the requirements. Additionally, one factor considered when evaluating the specifications was that they must be balanced against cost, schedule, risk, and the overall need. At the end of the process was a set of defined, tailored specifications and standards that would establish the scope for which requirements would be utilized.

Following the Delphi process paired with our own expertise in HSI and high level understanding of the unmanned environment, we were able to identify five existing standards and best practices that were determined to be the most relevant to the unmanned weapon environment. The following five standards were identified at the conclusion of the Delphi review of applicable standards:

1. ISO 9241 (06/01/1997) – Originally titled *Ergonomic requirements for office work with visual display terminals*, this standard provides the requirements for human-centered design principles within the human-computer interaction.
2. MIL-HDBK-759C (07/31/1995) – This handbook outlines the basic guidelines on the design of military system with data on human engineering within the Department of Defense.
3. ISO/IEC TR 25060 (09/01/2006) – Provides the scope of common industry standards to document the requirements needed for the development of a useable system.
4. NASA/SP-2010-3407 (01/27/2010) – This handbook is a resource for implementing requirements and provides guidance on deriving and implementing program-specific requirements.

5. ASTM F1166 (06/28/2011) – The objective of this practice is to provide ergonomic design criteria for maritime vessels and structures to ensure compliance with human performance requirements.

3.1.3.2 Phase 2, User-Centered Design Process

After the applicable standards were identified, the UCD process was applied to identify what areas of HSI are currently addressed in the standards that were selected. This review also recognized capacities that weren't comprehensive in the standards, which would be required to be addressed by MIL-STD-1472.

The review was structured around the framework outlined by ISO 9241-210. This is one of the three standards that make up the UCD process. The framework identified in ISO 9241-210 is independent of specific processes and provides a perspective that can be integrated into different designs in a way that is context appropriate (Nemeth, 2004). This standard is identified by four major activities: understanding and specifying the context of use; specifying the user requirements; providing design solutions; and evaluating designs against the requirements.

The first activity captured the scope of our review; to understand and specify the context of use for HSI requirements within the DON. The entire UCD is comprised of supporting standards ISO/IEC 25062 and TR 25060. These additional standards focus on evaluations reporting and reporting detailed results to measure efficiency, effectiveness, and satisfaction. Figure 3.1.3.2 illustrates the four major activities of the Human-Centered Design process. Each activity is represented by a circle, which overlaps each other to represent the impact one process can have on another. This illustration reflects a non-linear sequence with no starting or stopping points. Figure 3.1.3.2 also illustrates that the requirements of the user are always located at the center of each activity.

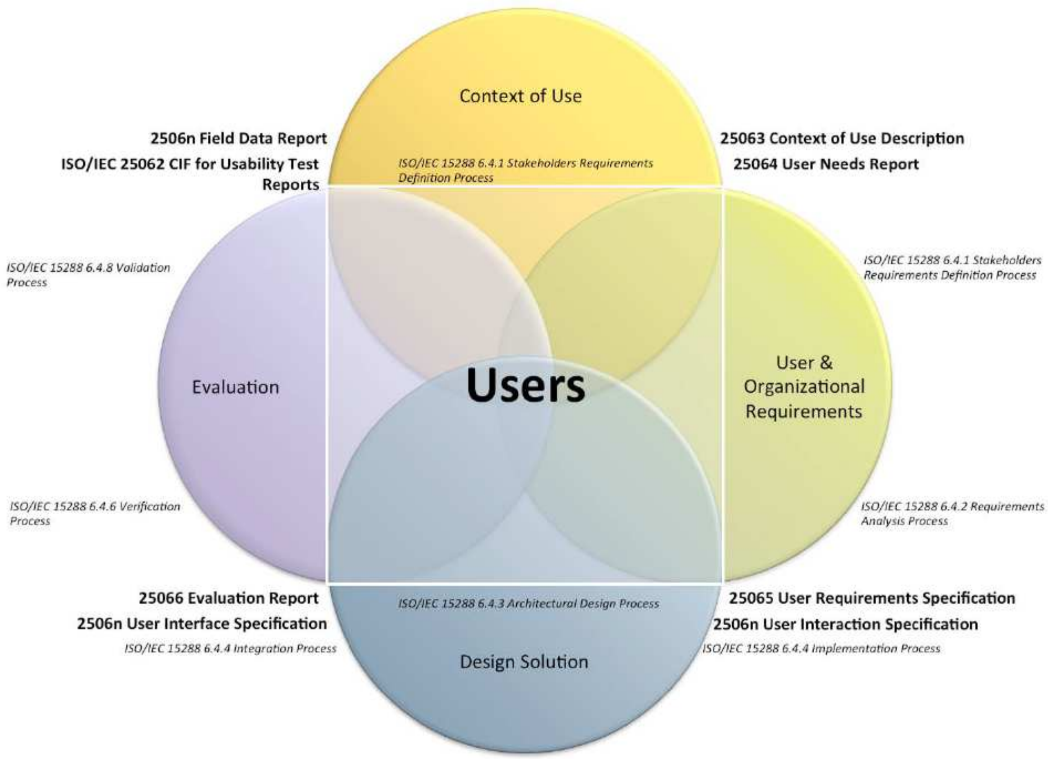


Figure 3.1.3.2 **Human-Centered Design Process (NISTIR 7889, 2014)**

3.1.3.3 Phase 3, Requirement Selection Process

According to Sage & Rouse (2009), the primary problem associated with the use of military standards in the systems engineering process is misuse. Standards and specifications are simply tools that can be used to provide solutions for technical problems. Unfortunately they are sometimes used as substitutes for good engineering analysis.

Three of the more common pitfalls found when implementing multiple standards were identified by Sage & Rouse. These included locking yourself into a set of detailed specifications and standards too early in the design and development process. The next two concerns were addressed by the Standard Review group created for this research. The first is over-specifying; where there is a tendency to cite more specifications and standards than are needed in order to meet a requirement. The second is citing an entire specification when all the requirements within the referenced document are not applicable. Oftentimes, a mil-spec can be tailored to focus on only those requirements that apply. Sage & Rouse (2009) indicate that when a small portion of a specification or standard is needed, it is usually better to extract the applicable sentences or paragraphs rather than cite the entire document. These concerns were addressed by the Standards Review Team.

The research team formed to conduct the review was comprised of diverse individuals, each with backgrounds that created a wide scope of expertise within the research area. The team leveraged that knowledge throughout the review of all pertinent standards, and with the application of the UCD began to map the relevant areas that would need to be addressed by MIL-STD-1472.

Throughout the review, areas that were potentially applicable to the remote weapon environment were categorized and sorted. The focus was the substance within each standard that presented a direct focus on the immediate use for the remote environment. Components within the standards that were determined to be irrelevant to the job were eliminated during the review. For example, MIL-STD-1472G 5.6.8 *Trailers, vans, and intravehicular connections* address general requirements for intravehicular coupling devices and therefore was determined irrelevant for this research. Any section that was omitted from a standard followed a ‘compare and contrast’ process to ensure it had no relevance to the research application.

Given the expertise of the review team, it is unlikely that the discarded standard components would apply. Thus, the selected standard components were organized by categories found across the standards. Table 3.1.3.3 illustrates this by cross-referencing the reviewed standards with the categories that were determined to have relevance in the remote weapon environment. Table 3.1.3.3 below identifies the requirements that were addressed by MIL-STD-1472G:

Elements to be addressed by MIL-STD-1472G	ISO 9241	MIL-HDBK-759C	ISO/IEC TR 25060	NASA/SP-2010-3407	ASTM F1166
Grouping & Arrangement	X	X		X	
Mechanical Controls		X	X		X
Equipment Simplicity	X		X	X	
Computer Controls	X	X			X
Design Factors	X	X	X	X	
Eye & Head Based Controls		X		X	X
Standardization		X	X		X
Legibility/Visibility	X		X	X	X
Training	X	X	X	X	X
Coding	X		X		X
Visual Displays	X	X	X	X	X
Controls & Displays	X	X	X		X
Irrelevant Information	X		X	X	
Content Display		X	X	X	
Glare	X	X		X	X
Order of Precedence		X		X	X
System Compliance	X		X	X	X
Illuminance	X	X		X	
Items Within Units	X	X	X		X
Workstation Design	X	X		X	X
Special Purpose Design	X	X	X		
Design for Remote Handling		X	X		X
Seated Operations	X	X	X		X
Gunner Tracking Performance	X		X	X	X

Table 3.1.3.3 **<u>Elements by Standards Representation</u>**

3.2 Methods

A critical goal of this research was the identification of requirements within MIL-STD-1472 that were determined to improve system efficiency. The second was their successful implementation into a prototype design to test the elements in an operational environment. The following section details an explanation of each requirement that was adopted into the new design criteria.

3.2.1 Elements of MIL-STD-1472G

MIL-STD-1472G is comprised of literally hundreds of elements (requirements) identified as paragraphs regarding HSI methodologies. This section focuses on 24 'requirements' of MIL-STD-1472G which were utilized to form the foundation of the new console design criteria. The following is a description of each requirement that was identified and used, as well as the impact it had on the new console design. Due to the confidential nature of these improvements, a sanitized explanation of each element is provided below:

3.2.1.1 Requirement 4.4.7 <u>Design Factors</u>

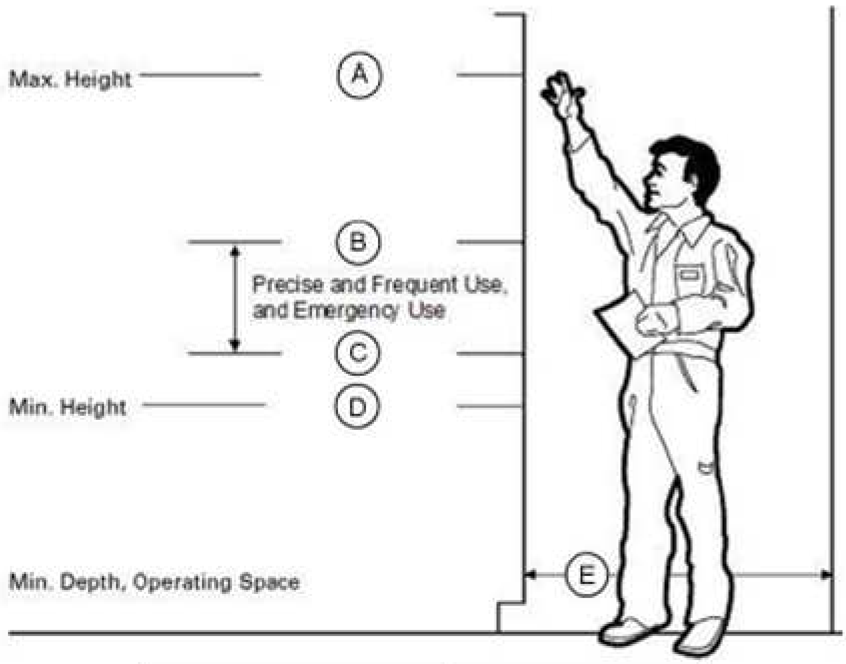
The overall design of the console was to reflect the factors that influence human performance; which include:

1. "Efficient arrangement of operation and maintenance workplaces, equipment, controls, and displays" (MIL-STD-1472G, 2012, p.11).
2. "Adequate natural or artificial illumination for the performance of operation, control, training, and maintenance" (MIL-STD-1472G, 2012, p.11).
3. "Design features to assure rapidity, safety, ease and economy of operation, and maintenance in normal, adverse, and emergency conditions" (MIL-STD-1472G, 2012, p.11).

The displays that were required for system operation were already dictated by weapon design. Existing console environments had similar displays located in conventional locations based on legacy arrangements. This was the first area addressed in the new design criteria.

In order to determine the new arrangement, methods including task analysis, storyboarding, sailor interviews, heuristic evaluation and an eye tracking study was accomplished with 60+ operators to determine the new location of each display, based on combat condition situations.

There were multiple prototypes developed based on the above methods. Each one was slightly different based on the information collected. The eye tracking study was conducted on each console design to determine the final GUI placement. The results of each eye tracking study would either confirm or identify the need to relocate a GUI from its current location. The goal of this exercise was to centrally locate the highest utilized display to the front of the operator, based on eye fixation time. Controls within the new console were measured to ensure their placement fell within the requirements of Figure 3.2.1.1, as indicated below.



Dimension	Value
Maximum height (A)	188 cm (74 in)
Preferred max. height [1/] (B)	139.7 cm (55 in)
Preferred min. height [1/] (C)	86.4 cm (34 in)
Minimum height (D)	76.2 cm (30 in)
Preferred min. depth [2/] (E)	106.77 cm (42 in)
Minimum depth (E)	94 cm (37 in)

NOTES:

[1/] Preferred dimensions are for those controls that require precise, frequent, or emergency use.

[2/] The dimensions listed accommodate the central 90 percent of the anticipated user population.

Taken from: MIL-STD-1472G, 11 January 2012

Figure 3.2.1.1 Control Mounting Height

3.2.1.2 Requirement 4.6.1 Equipment Simplicity

The console equipment was to conform to the simplest design consistent with the functional requirements during combat operations. The design of the controls and displays were intended to mirror legacy cockpit controls to help alignment with experienced operators and to aid responsive habit from time spent in conventional console environments.

This effort to prevent reinventing the wheel included the use of legacy controls commonly found similar operations. The requirement for equipment simplicity was maintained without introducing new equipment which would require additional training and cost.

3.2.1.3 Requirement 4.6.2 Training

The console was designed to be "operated and maintained" within its functioning environment with minimal training by personnel. Here again, legacy concepts and designs were utilized as much as possible to help reduce the need for additional training with the introduction of a new design. The changes that were introduced were done so based on minimalizing the requirement for additional training by the operator.

Training is also categorized by the budget typically allocated to it. For the purpose of this research, cost was not the preeminent factor in this area. This focus of this research instead, focused on the speed at which operators could navigate using legacy designs and equipment.

3.2.1.4 Requirement 5.1.1.3 Grouping and Arrangement

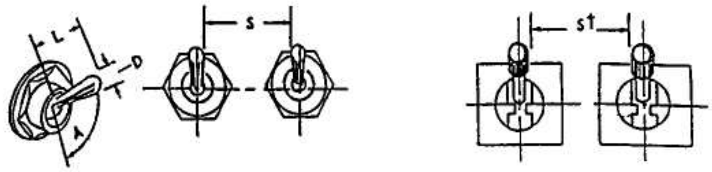
The controls in the console that work together was grouped together which builds on legacy platforms. In cases where multiple steps can be selected by a single control, the steps were designed to minimize cycling through unnecessary steps (e.g., the ON/OFF position. Sequential operations were designed to follow a fixed pattern to improve efficiency during operation. This included a left-to-right/top-to-bottom configuration. The controls utilized most frequently or demanding fine settings were designed with the most auspicious location for access. The minimum spacing requirements between controls outlined in MIL-STD-1472G are illustrated in Table 3.2.1.4.

	Toggle Switches	Push buttons [2]	Continuous Rotary Controls	Rotary Selector Switches	Discrete Thumbwheel Controls
Toggle Switches	3.2.1.4.A	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)	3.2.1.4.B	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 (0.5in)	3.2.1.4.C	25 mm (1 in)	19 mm (0.75 in)
Rotary Selector Switches	19 mm (0.75 in)	13 mm (0.5 in)	25 mm (1.0 in)	3.2.1.4.D	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)	3.2.1.4.E

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 3.2.1.4 Minimum, edge-to-edge separation distances for controls

Figures 3.2.1.4.A-E represent the arrangement each control, button, or switch followed during its installation into the prototype console, as referenced from Table 3.2.1.4:



	Dimensions			Resistance	
	Arm length (L)		Control Tip (D)	Small switch	Large switch
	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)

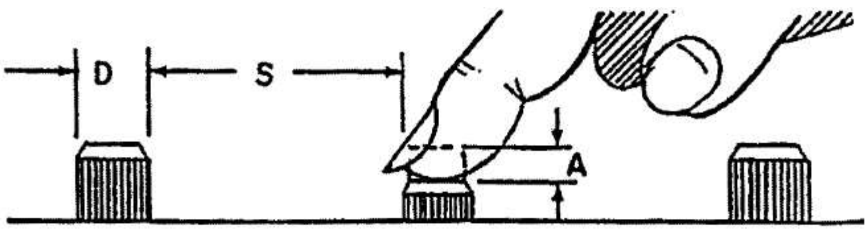
	Displacement between positions	
	Two positions	Three positions
Minimum	30 deg	17 deg
Maximum	80 deg	40 deg
Preferred	--	25 deg

	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)

Toggle switches.

Taken from: MIL-STD-1472G, 11 January 2012

Figure 3.2.1.4.A Toggle Switches



	Dimensions (D, Diameter)						Resistance		
	Fingertip		Thumb		Palm				
	Bare hand	Gloved hand [1/]	Bare hand	Gloved hand [1/]	Bare hand	Gloved hand [1/]	Single finger	Different fingers [2/]	Thumb/palm
Minimum	10 mm (0.4 in)	19 mm (0.75 in)	19 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)

	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)

	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)	--	13 mm (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-2874E)), add 5.0 mm (0.2 in) to Diameter (D) of bare hand dimension.

[2/] Actuated at same time.

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

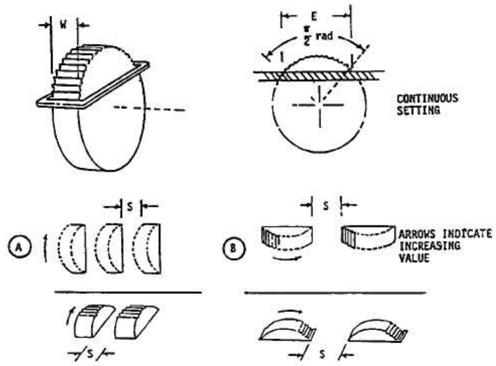
NOTE:

1. Figure 14 does not apply to keyboards (see 5.1.3.2).

Push button (finger- or hand-operated).

Taken from: MIL-STD-1472G, 11 January 2012

Figure 3.2.1.4.B Push Button Requirements



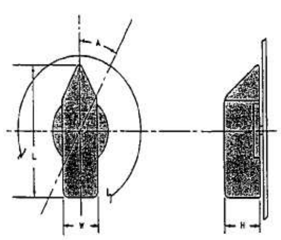
	E, Rim exposure	W, Width	S		Resistance
			A	B	
Minimum	25 mm [1/] (1.0 in)	3 mm [1/] (0.125 in)	25 mm (1.0 in), add 13 mm (0.5 in) for gloves	50 mm (2.0 in), add 25 mm (1.0 in) for gloves	To minimize effects of inadvertent input if user subject to motion
Maximum	100 mm (4.0 in)	23 mm (0.875 in)	N/A	N/A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

NOTE:
[1/] Preferred. Some miniature applications may require less.

Continuous adjustment thumbwheel.

Taken from: MIL-STD-1472G, 11 January 2012

Figure 3.2.1.4.C Thumbwheel Requirements



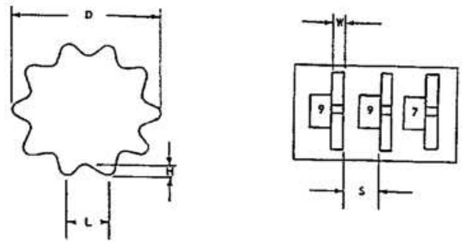
	Dimensions			Resistance
	L, Length	W, Width	H, Depth	
Minimum	25 mm (1.0 in)	--	16 mm (0.625 in)	115 mN x m (1.0 in-lb)
Maximum	100 mm (4.0 in)	25 mm (1.0 in)	75 mm (3.0 in)	680 mN x m (6.0 in-lb)
	Displacement [1/], A		**Separation**	
	--	[2/]	One-hand random	Two-handed operation
Minimum	262 mrad (15 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.

Rotary Selector Switch

Taken from: MIL-STD-1472G, 11 January 2012

Figure 3.2.1.4.D Rotary Selector Switch Requirements



	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)

Discrete thumbwheel control.

Taken from: MIL-STD-1472G, 11 January 2012

Figure 3.2.1.4.E Discrete Thumbwheel Requirements

3.2.1.5 Requirement 5.1.1.4 Coding

As show in Table 3.2.1.5, 1472G specifies that "the use of coding (e.g., size and color) for a particular application shall be governed by the relative advantages and disadvantages of each type of coding" (MIL-STD-1472G, 2012, p.19). The standard goes on to state that "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" (MIL-STD-1472G, 2012, p.19).

Legacy control locations were replicated into the new design when similar functions were identified. The new design included no more than three different sizes to code controls used by the operator. When similar functions are replicated on different equipment, similar sized controls were used for continuity. Specifically, when the diameter of the knob "specifies the coding parameter, the differences between diameters shall be not less than 13 millimeters and when the knob thickness is to coding parameter, the differences between thicknesses shall be not less than 10 millimeters" (MIL-STD-1472, 2012, p.19).

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 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 3.2.1.5 Advantages/Disadvantages of various types of control coding

3.2.1.6 Requirement 5.1.3 <u>Computer Controls</u>

In some cases touch-screen controls can be used to "provide an overlaying control function to a display where direct visual reference is desired" (MIL-STD-1472, 2012, p.29). Touch-screens were also used for the selection of devices or targets illustrated on Heads Up Displays (HUD). Advantages and disadvantages of touch-screen use, according to standard 1472 are provided in Table 3.2.1.6.

The design ensures touch-screens provide a clear and readable display in the operational environment. According to (MIL-DTL-1472G, 2012) the response time of the display shall not exceed more than 100 milliseconds." The new console design ensures characteristics of touch-interactive devices won't degrade the quality of the visual display or reduce performance.

When touch-screen controls were used for critical tasks the system response required an additional action to ensure that the selection was intended (MIL-STD-1472, 2012). In other words, it's important that the contact of the fingertip on the touch-screen is able to control the function as intended.

Another important design improvement is the viewing angles of the touch screens in the new console design. (MIL-STD-1472G, 2012, p.29) states that "a reduced viewing angle, less than 90 degrees from horizontal, may reduce arm fatigue for frequent actions; however, changes to viewing angles shall be evaluated in relation to the negative impact on parallax, specular glare, and readability." Reach design improvements met the following requirements of MIL-STD-1472 (2012):

a. "Touch-screens shall be mounted to ensure the central 90 percent of the anticipated user population can reach and actuate all areas of the screen including corners of the display"
b. "Touch-screens shall be located so as to avoid full arm extension"
c. "Touch-screens shall be located so as to avoid upward reach"
d. "Elbow support shall be provided where possible to minimize arm fatigue"

Advantages	Disadvantages
No separate input device	Slower alphanumeric data entry
Programmable interface	Arm fatigue
Fast access	Finger may obstruct view
Direct manipulation of targets	Fingerprints or other debris may obscure screen
Input/output in same location	Larger buttons required for finger use
Intuitive	Pointing is not very accurate
Natural pointing action	User must be within reach of screen
Generally no additional desk space required [1/]	No tactile feedback provided [3/]
Generally no training required [2/]	Unable to rest finger on target without actuation [3/]
	Accuracy degraded by vehicle movement and vibration.
	Gloved operation may be incompatible with some touch-screen technology.
	Controls must be deactivated for cleaning.

NOTES:

[1/] If incorporated as part of an existing primary display.

[2/] Application-dependent.

[3/] If a tactile feedback membrane is not incorporated.

Table 3.2.1.6 Advantages/Disadvantages of touch-screen use

3.2.1.7 Requirement 5.1.4 <u>Mechanical Controls</u>

The controls involved in the movement, control, and firing of the weapon were designed to provide ‘feed-back’ into the control. This provides the operator with a controlled ‘feel’ of the weapon. Similar technologies have already been incorporated into controls for online and video gaming, such as controlled vibrations. While the introduction of ‘feed-back’ into controls isn’t a new technology, its use in the unmanned weapon environment does represent a new addition to the design.

3.2.1.8 Requirement 5.1.6 Eye- and Head-based Controls

According to (MIL-STD-1472G, 2012, p.81), "eye- and head-based controls can be used for a variety of tasks including teleoperations, instrument selection on a panel and visual search tasks." An example of this technology includes certain eye or head movements in a particular pattern to access or control different applications in the console. Retinal tracking of the operator, for the purpose of command selection provided an improvement in console operations.

3.2.1.9 Requirement 5.2 Visual Displays

Visual displays were used to provide the user with equipment and system conditions. Another improvement is that the face of each display is now flush with the surface of the panel in which it was installed. 1472G also indicates the "combined effects of all geometric distortion shall not displace any point on the display from its correct position by more than 5.0 percent of the picture height" (MIL-STD-1472G, 2012, p.82). The display refresh rate and other parameters are also required to provide a flicker free display.

In a mobile environment the vibration of visual displays can degrade user performance below the threshold to ensure mission success. This console was designed on a flex-deck platform with shock isolators specifically designed to reduce or eliminate vibration from a mobile environment.

3.2.1.10 Requirement 5.2.2 Displays – Content

According to (MIL-STD-1472, 2012, p.85) "computer programs and equipment interfaces shall provide a functional interface between the system for which they are designed and users (operators/maintainers) of that system." It goes on to say this "interface shall optimize compatibility with personnel and shall minimize conditions which can degrade human performance or contribute to human error" (MIL-STD-1472, 2012, p.85).

The console was designed to display sufficient information to enable the user to execute the intended mission and limit the amount of information required to make decisions. A review of the task analysis dictated the information requirements that are displayed. Redundant information is not displayed unless it's required for special purposes.

3.2.1.11 Requirement 5.4.3.7 Standardization

In cases where an action in the console is replicated, care was given to ensure consistency throughout the system. For example, the location of a label is placed at the same location for all components with a label (see also Section 3.1.13). There were 4 items modified from legacy designs to conform to this standardization. The changes that were made are currently restricted from publication.

3.2.1.12 Requirement 5.4.4.3 Irrelevant Information

The remote weapons console is comprised of a variety of components and displays which are required for operational functionality. The names and other irrelevant information, such as the manufacturers name were removed from all equipment in the console. Only information that's required for the operator is visible. Additionally, when certain information is selected, a display time was also introduced with this element.

3.2.1.13 Requirement 5.4.5.5 Visibility and Legibility

Labels were located to promote accurate reading during operation. The following factors of MIL-STD-1472 were taken into consideration:

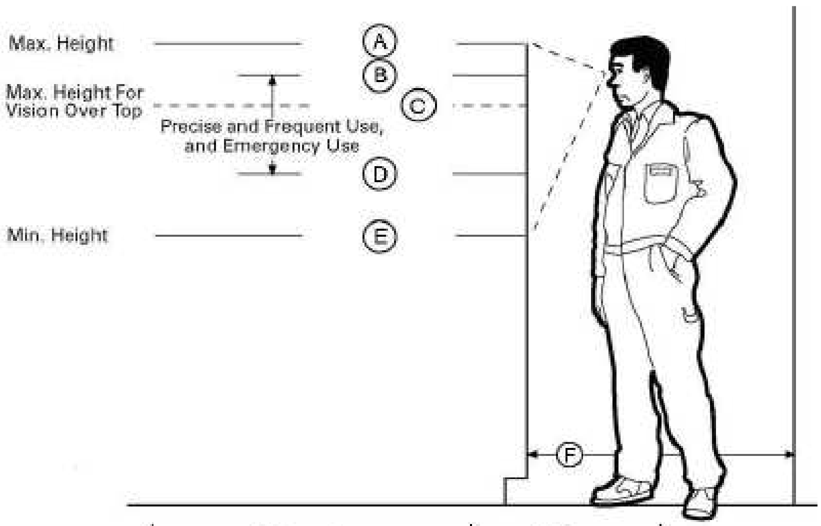
a) "Contract between the lettering and its immediate background" (MIL-STD-1472, 2012, p.134).
b) "Height, width, stroke width, spacing, and style of letters and numerals, and size of detail for other abstract or pictorial symbols" (MIL-STD-1472, 2012, p.134).
c) "Relative legibility of alternate words that might be used to convey the same meaning" (MIL-STD-1472, 2012, p.134).
d) "Specular reflection" (MIL-STD-1472, 2012, p.134).

The application of this element closely followed the MIL-STD definition. Its contents were also applied with the following element, 'Controls and Displays'.

3.2.1.14 Requirement 5.4.7.2 Controls and Displays

The labeling of the controls and displays followed a simplistic design with basic information for proper identification. Labels on the controls and displays provided verbal meaning in the most direct manner possible. Each display and control was labeled by its function and similar names were avoided for different controls and displays with similar functions. Specifically, it was the naming convention of the labels that provided improvement for this element.

Each display in the new console followed a strict maximum and minimum threshold regarding their arrangement height and placement. These threshold values were dictated by MIL-STD-1472G as indicated in Figure 3.2.1.14.



Dimension	Value
Maximum height (A)	177.8 cm (70 in)
Preferred max. height [1/] (B)	165.1 cm (65 in)
Maximum lookover height [1/] (C)	150.1 cm (59 in)
Preferred min. height [1/] (D)	139.7 cm (55 in)
Minimum height (E)	104 cm (41 in)
Preferred min. depth (F)	104 cm (41 in)
Minimum depth (F)	94 cm (37 in)

NOTES:

[1/] Preferred dimensions are for those controls that require precise, frequent, or emergency use.

Display mounting height.

Taken from: MIL-STD-1472G, 11 January 2012

Figure 3.2.1.14   Display Mounting Height Requirements

3.2.1.15 Requirement 5.5.3 Illuminance

The new console was designed to ensure that illumination is attuned with each mission situation. Lighting controls are illuminated in areas that are frequently dark. The illumination is distributed to reduce reflection and glare. Flickering light sources were also absent from of the console design. Color patterns based on function were also implemented into the console criteria.

3.2.1.16 Requirement 5.5.3.3 Glare

The console was designed to meet the following general glare requirements of MIL-STD-1472:

a) "Glare avoidance: Lighting shall be designed and located to avoid glare from working and display surfaces as viewed from the normal working position" (MIL-STD-1472, 2012, p.149).
b) "Maximum luminance ratio: The maximum luminance ratio between any two different sources of luminance light within an operator or maintainer's field of view shall not exceed 5:1" (MIL-STD-1472, 2012, p.149).
c) "Non-reflective work surfaces: To reduce glare, non-reflective or matte finished surfaces shall be provided on consoles, panels, and other work surfaces" (MIL-STD-1472, 2012, p.149).
d) "Non-reflective surfaces within field of view: Placement of smooth, highly polished surfaces within 60 degrees of a person's normal visual field shall be avoided" (MIL-STD-1472, 2012, p.149).

3.2.1.17 Requirement 5.5.4.3 Total System Compliance

This paragraph of the standard provides instruction for an "acoustical environment that will not cause personnel injury, interfere with voice or any other communications, cause fatigue, or in any other way degrade system effectiveness" (MIL-STD-1472, 2012, p.151). The new design includes an environment that eliminates ambient noise while providing essential information and communication from the weapon and other required personnel.

3.2.1.18 Requirement 5.7.1.1 Order of Precedence

The order of precedence outlined in 1472G are as follows:

a) "Design for minimum risk" (MIL-STD-1472, 2012, p.179).

b) "Incorporate safety devices" (MIL-STD-1472, 2012, p.179).

c) "Provide warning devices" (MIL-STD-1472, 2012, p.179).

d) "Provide procedures and training" (MIL-STD-1472, 2012, p.179).

All aspects of the new design followed the aforementioned order of precedence. As such, future console designs will follow these adopted instructions. While this requirement didn't represent a very large percentage in the reduction of time for target termination, it did provide an improvement in the overall design as determined through the Delphi review process.

3.2.1.19 Requirement 5.9.2 Mounting of Items Within Units

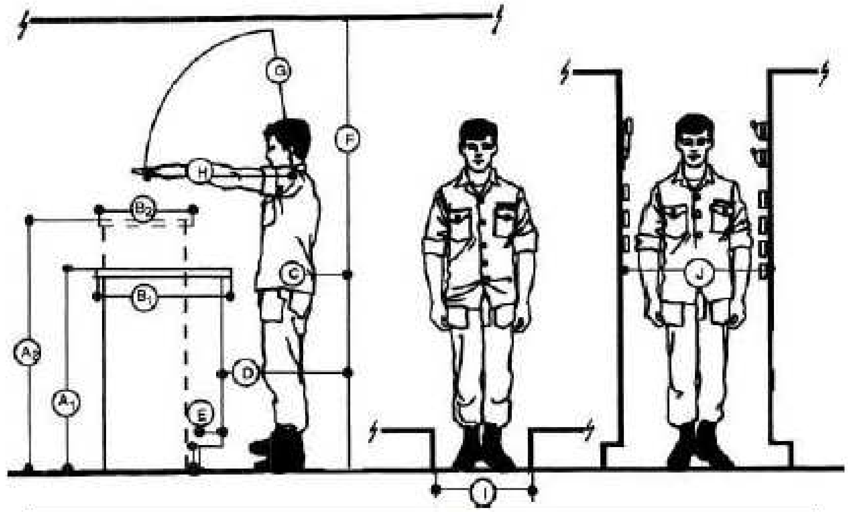
The equipment was located such that pre-determined information/parameters were 'grouped' together within the console. An eye tracking study was accomplished to identify and group the most commonly viewed information together. This was accomplished by multiple tests conducted on a variety of prototype arrangements. The final locations were determined following a 'trial-and-error' approach regarding the implementation of changes concluded from each eye tracking study.

3.2.1.20 Requirement 5.10.3 Workstation Design

(MIL-STD-1472G, 2012, p.239) indicates that "whenever possible, workspace shall be designed to users can do routing, frequent, or sort-term jobs while standing." This functionality was incorporated into the design because of the following:

a) "User's arms can apply more muscular force and make larger movements" (MIL-STD-1472G, 2012, p.239).
b) "Users can move to see and use components in areas that would be inaccessible to seated users" (MIL-STD-1472G, 2012, p.239). (see Figures 6-8)
c) "Users can change positions, to reduce fatigue and boredom; many standing tasks can be done in either a sitting or a standing position" (MIL-STD-1472G, 2012, p.239).
d) "Standing saves space; the users can use flat working surfaces, without knee room" (MIL-STD-1472G, 2012, p.239).

The new console was designed to allow the operator the same control from a seated or standing position with an adjustable console layout. An explanation of this benefit is provided in the following element 'Seated Operations'. Figure 3.2.1.19 outlines the requirements the standing workspace design had to adhere to.



Work benches				
Standard type	A.1	Height	0.91 m (2.98 feet) above floor	
	B.1	Width	0.99 m (3.24 feet)	
Podium type	A.2	Height	1.04 m (3.4 feet) above floor	
	B.2	Width	0.91 m (2.98 feet)	
Work clearances				
		Minimum	Preferred	Arctic
C.	Passing body depth	33cm (12.9 in)	38 cm (14.9 in)	38 cm (14.9 in)
D.	Standing space	76 cm (29.9 in)	91 cm (35.8)	
E.	Foot space	10 x 10 cm (3.9 x 3.9 in)		
F.	Overhead clearance	185.5 cm (73 in)	203 cm (79.9 in)	193 cm (75.9 in)
G.	Maximum overhead reach		68.5 cm (26.9)	63.5 cm (25 in)
H.	Maximum depth of reach		58.5 cm (23 in)	58.5 cm (23 in)
I.	Walking space width	30.5 cm (12 in)	38 cm (14.9 in)	38 cm (14.9 in)
J.	Passing body width	51 cm (20 in)	81 cm (31.8 in)	81 cm (31.8 in)

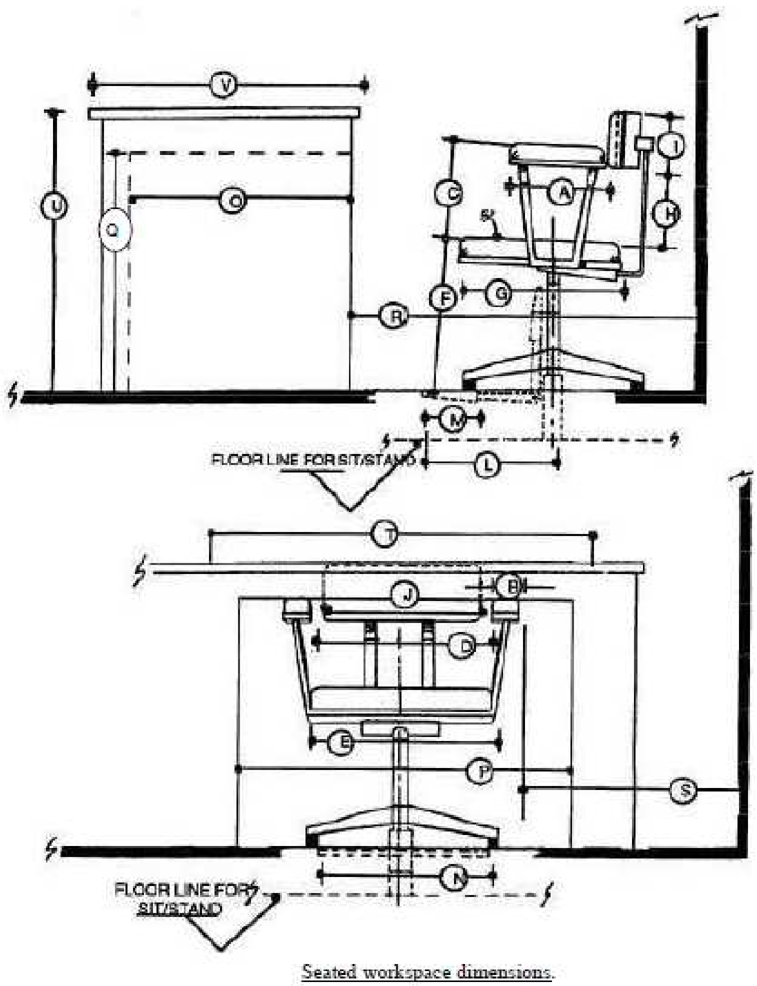
Standing workspace dimensions.

Taken from: MIL-STD-1472G, 11 January 2012

Figure 3.2.1.19 Standing Workspace Dimension Requirements

3.2.1.21 Requirement 5.10.3.2 Seated Operations

MIL-STD-1472G provides very specific dimensions regarding the seating measurement. As seen in Figure 3.2.1.21, the new design will allow the operator to "perform their mission functions without degradation of their performance" and without pain or fatigue to the user (MIL-STD-1472G, 2012, p.243). The innovation of this application is the operators ability to control the weapon from a standing or seated position based on scenario. Take for example. weapon control during high speed maneuvering compared to high altitude flight with single target orders. See Figure 3.2.1.20 below:

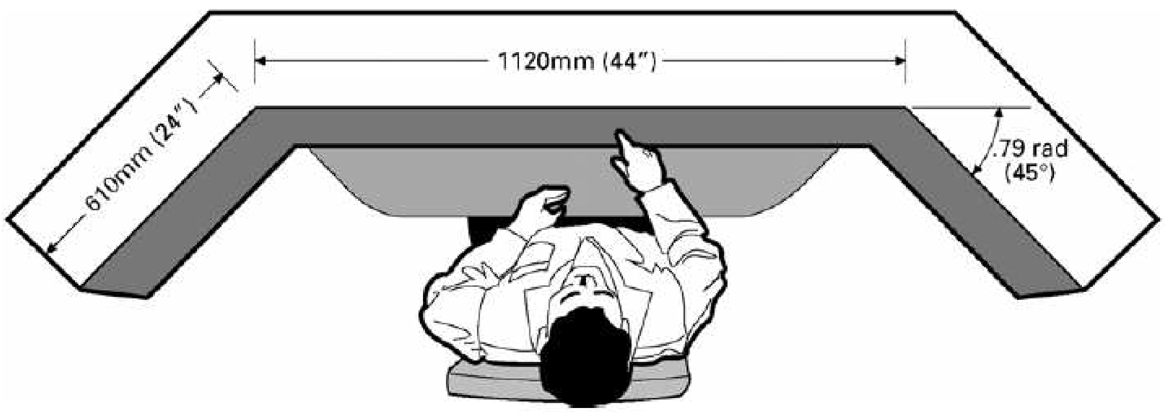


Taken from: MIL-STD-1472G, 11 January 2012

Figure 3.2.1.20 Seated Workspace Dimension Requirements

3.2.1.22 Requirement 5.10.4 Special-purpose Console Design

The Navy requires the left and right segments of a wraparound console to be located so that they can be reached by at least 95 percent of female users without moving the torso. MIL-STD-1472G indicates the "total required left-to-right viewing angle shall be not more than 190 degrees (see Figure 3.2.1.22) and shall be reduced through appropriate control-display layout" (MIL-STD-1472G, 2012, p.263). Female operators also took part in the FST to fully evaluate the new console design.



Wraparound seated console.

Taken from: MIL-STD-1472G, 11 January 2012

Figure 3.2.1.21 Wraparound Seated Console Requirements

3.2.1.23 Requirement 5.12.2 Design of Equipment for Remote Handling

Stated within MIL-STD-1472, "warning indicators shall be presented wherever the system health or operational parameters are approaching critical limits" (MIL-STD-1472G, 2012, p.278) Since the operator of the weapon is in a remote location, certain operational characteristics won't be seen or heard. For example, a pilot can make corrections as necessary depending on the environment he's controlling the aircraft in. Whereas a remote operator will be absent from those conditions. Environmental applications of the weapon were included in the design to ensure all relevant information is conveyed from the location of the weapon to the operator.

3.2.1.24 Requirement 5.13.1 Gunner Tracking Performance

Whenever a joystick is used for tracking, support for the forearm, wrist, and hand are required. Therefore, in order to execute two-dimensional tracking without taking up the additional space for support, a single control was used for each dimension. The number of applications that are controlled by a single joystick were also limited to regulate cycle time through a single input device.

Chapter 4: Results

This section documents the Full Systems Test (FST) that was accomplished to measure the success of the prototype console, which incorporated 24 requirements of HSI military standard 1472G. A FST is an operational test in which the new console and weapon are subjected to 14 live firing scenarios. Each FST was executed by a single operator, where each scenario involved the live firing of the weapon at a steel plate mounted to the side of an airplane.

Each FST was performed by nine different weapon operators that were available to take part in the study. The final results of the FST were compared to the same results scored in the legacy console, by the same operator. Each scenario was measured by the amount of time it took the operator to track, lock, fire, and destroy the target in each executed scenario. The four areas measured in each scenario provided the basis for what would be used to determine the improvement time of a FST. The results from all 14 scenarios in a FST are entered into an algorithm, maintained in a database, which generates a final completion time for each operator in the completion of a FST. The data and results from and during a FST are closely guarded by the military. All 14 scenarios are required to be accomplished in order to obtain a final completion time.

Since the operators executed the same FST in both the legacy and prototype consoles, a statistical evaluation on their results were accomplished following a T-test for a paired difference. The question asked in their evaluation was; are average FST times lower in the prototype console than in the legacy console? A level of significance of $\alpha=0.05$ was used these calculations.

Given each operator completed a FST in both the legacy and prototype console, a comparison between the final completion times were evaluated for all nine weapon operators. This comparison will evaluate if we have statistically significant evidence to show an improvement over the legacy console.

The Null hypothesis was characterized as:

H_o: $\mu_d = 0$, where μ is our mean and $_d$ is the difference in our data.

Our alternative hypothesis was characterized as:

H_1: $\mu_d > 0$, so we can show that the results from the second FST (prototype results) are lower than the legacy console FST results.

Actual FST results and corresponding statistical values are prohibited from publication, however the P-value allowed for the rejection of the Null hypothesis and acceptance of the alternative hypothesis. There is statistically significant evidence to conclude that the mean of the prototype console is lower than the legacy weapon console.

Success for this exercise was measured by the final completion time between target acquisition and target termination. Due to the success of the FST, the concepts that were integrated into the prototype will be introduced as the new baseline for future console designs.

In addition to the statistical analysis measuring the improvement of HSI changes integrated into the prototype console, all nine FST operators provided qualitative feedback regarding the 24 changes that were implemented into the new design. The operator feedback accounted for all 24 HSI requirements in each of the 14 scenario's. An average was taken and populated into Figure 4 below.

	Elements to be addressed by MIL-STD-1472G	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14
1	Grouping & Arrangement	high	high	high	high	high	high	high	high	high	high	high	high	high	high
2	Mechanical Controls	med	low	low	low	low	low	low	low	low	low	low	low	low	low
3	Equipment Simplicity	high	high	high	high	high	high	high	high	high	high	high	high	high	high
4	Computer Controls	high	high	high	high	high	high	high	high	high	high	high	high	high	high
5	Design Factors	high	high	high	high	high	high	high	high	high	high	high	high	high	high
6	Eye & Head Based Controls	high	high	high	high	high	high	high	high	high	high	high	high	high	high
7	Standardization	low	low	low	low	low	low	low	low	low	low	low	low	low	low
8	Legibility/Visibility	low	low	low	low	low	low	low	low	low	low	low	low	low	low
9	Training (low is good)	low	low	low	low	low	low	low	low	low	low	low	low	low	low
10	Coding	high	high	high	high	high	high	high	high	high	high	high	high	high	high
11	Visual Displays	low	low	low	low	low	low	med	low	low	low	low	low	low	med
12	Controls & Displays	low	low	low	low	low	low	low	low	low	low	low	low	med	low
13	Irrelevant Information	med	med	med	med	med	med	med	med	med	med	med	med	med	med
14	Content Display	high	high	high	high	high	high	high	high	high	high	high	high	high	high
15	Glare	low	low	low	low	low	low	low	low	low	low	low	low	low	low
16	Order of Precedence	low	low	low	low	low	low	low	low	low	low	low	low	low	low
17	System Compliance	low	low	low	low	low	low	low	low	low	low	low	low	low	low
18	Illuminance	high	high	high	high	high	high	high	high	high	high	high	high	high	high
19	Items Within Units	high	high	high	high	high	high	high	high	high	high	med	high	high	high
20	Workstation Design	low	low	low	low	low	low	low	low	low	low	low	low	low	low
21	Special Purpose Design	med	low	low	low	low	low	low	low	low	low	low	low	med	low
22	Design for Remote Handling	low	low	low	low	low	low	low	low	low	low	low	low	low	low
23	Seated Operations	low	low	low	low	low	low	low	low	low	low	low	low	low	low
24	Gunner Tracking Performance	high	high	high	high	high	high	high	high	high	high	high	high	high	high

Table 4 Qualitative Results from FST Operators

These results provide excellent insight into the requirements that were included in the new design. While 24 requirements were originally determined to improve performance, the operators only attributed 10 requirements to the FST improvements. These are represented by the ‘high’ comments in Figure 4 above. Also to note, the results given for each requirement are very consistent throughout every scenario for that particular requirement.

The qualitative results indicate that additional research needs be conducted into the exact requirements that provided the greatest improvements. This could measure the Return On Investment (ROI) for each requirement integrated into the design, thus eliminating the cost to integrate requirements that don’t improve actual performance.

The purpose of this research was to improve remote weapon console designs using HSI requirements to improve target termination time. The results of implementing the 24 requirements could also be applied beyond remote console designs. While current literature indicates a reduction in effectiveness (increased mishaps) between RPAs and manned aircraft, this research provides a means for improvements in unmanned aviation as well.

Multiple tests have been conducted on current console designs for remote weapons. Several factors are recorded, timed, and documented which rate the overall success of the weapon and system. Since the tasking for this research specified the minimizing of time between target acquisition and termination, the success of the FST was measured in a reduction of time among scenarios.

These scenarios are a series of situations that the weapon operator could find himself/herself in during combat conditions. Historic scenario times were used as a baseline to measure the new console performance. As previously stated the actual results are classified, but the improvement percentage of the FST has been approved for publication. The new console design logged a 19% reduction over previously recorded times.

This research served as a first step in the improvement of legacy console designs. It may be argued that the most important outcome of this research is the process itself, to accomplish the identification of HSI requirements to improve a system design. This process for eliciting HSI elements based on specific applications may bridge current and new technologies that involve the human element as a requirement.

Chapter 5: Discussion/Conclusion

For those directly involved with remote weaponry and their progress in combat operations, this is an exciting time to be a part of these new advancements. New developments in technologies create significant and immediate challenges which require attention from the progress also seen in HSI. "While technology can simplify the operation of individual RPAs, in the end it may create task environments that are much more complex than those seen in traditional environments" (Paez et al, 2005, p.9).

The FST results validated the methodology used in the elicitation and integration of HSI requirements from MIL-STD-1472G. The results were closely scrutinized to ensure each scenario time in the new console was compared to the same scenario in the legacy environment.

This research identified two specific areas for future research. First, the process used in the identification of requirements that were determined to improve system performance for a specific application. The adapted procedure used in this study could also be executed in other research capacities as well. This would allow for the identification of HSI improvements to be accomplished early in the design of those new research areas.

The second area was the application of those requirements into the new design criteria. The results of the FST validated the improvements that could be attained by remote weaponry when these elements were included into the console design. Future areas could include their application into RPA's and UAV's, and even into the cockpit of a piloted aircraft.

The main driver behind this research is the expectation to see these new weapons integrated onto different ship platforms. The improvements found throughout this research ensure optimal efficiency when that time will come, and a new weapon will be integrated onto a ship.

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