Heterogeneous Design Approach for Ground Control Stations to Marginalize Human Factors Mishaps in Unmanned Aircraft Systems

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Dedication

This dissertation is dedicated to my wife Mahwish, who endured so much time without me during my studies, making it possible for me to earn my PhD. The dissertation also is dedicated to my son Ayaan (4 years), who was one year old when I started, my son Shafeh (2 years) who was born during this endeavor, and to my mother Nusrat, for her unfaltering prayers. Honorable mention goes to my father, Rehmat Ullah, who urged me to enroll in GWU's PhD program, but passed away shortly after I enrolled. Last, but not least, I also would like to thank my brother Faisal for helping me around the house; and my sisters, Uzma and Saima, for their constant encouragement, which kept my spirits and morale high throughout my dissertation process.

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Abstract

Heterogeneous Design Approach for Ground Control Stations to Marginalize Human Factors Mishaps in Unmanned Aircraft Systems

Unmanned Aircraft Systems (UASs) allow operators to conduct high-risk military missions without putting humans in harm’s way. The United States Department of Defense’s (DoD) usage of UASs increased six-fold from 2005 to 2011, while the DoD UAS budget has increased four-fold during the same period. However, UASs are subject to abnormally high accident rates that are traceable to human factors-related mishaps when compared to human-operated aircraft. DoD UAS Ground Control Stations (GCSs) are marred with Ergonomic Human Factors (EHF) issues. Studies indicate human factors are involved in up to 69% of all UAS mishaps. Of those, 25% may be attributed to EHF issues in UAS GCS input/output (IO) devices. Many of the EHF issues in UAS GCS IO devices continue to exist due to the lack of UAS GCS-specific EHF standards that address IO devices. An EHF standard for UAS GCS IO could help reduce these EHF issues and improve the outlook for UAS viability, airworthiness, and may reduced total lifecycle costs.

Highly automated UAS GCSs have been developed to help reduce operator workload, which has led to significant changes in the design of GCS human-machine interfaces for operators. Many of the IO devices used to operate UASs based on conventional aircraft control mechanisms are no longer employed in UAS GCS designs (e.g., throttles, rudder controls, etc.). Automation allows UAS GCS physical designs and workloads to evolve toward those of a computer workstation (CWS). The CWSs are general-purpose computer desktops that employ traditional IO devices (e.g., mouse, keyboard, display, etc).

A commercial EHF standard, the American National Standards Institute/Human Factors and Ergonomics Society-100 (ANSI/HFES-100) for CWS exists. To evaluate an ANSI/HFES-100 standard's IO category applicability to the design of DoD UAS GCSs, data were collected and evaluated from 20 DoD UAS GCSs. Data analysis was used to help determine the similarities and differences between the IO devices found in CWSs and UAS GCSs. The results demonstrated that DoD UAS GCS IO devices are up to 98% similar to those of general-purpose CWSs as described by an ANSI/HFES-100 IO category. Moreover, the usability of the IO devices in UAS GCS and CWS is similar. The finding suggests that ANSI/HFES-100's IO category can be applied to UAS GCS IO interfaces to marginalize EHF issues that are often associated with UAS mishaps.

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List of Acronyms

Acronym	Definition
AGL	Above Ground Level
AIB	Accident Investigation Board
ANSI	American National Standards Institute
ARL	Aviation Research Lab
BIFMA	Business and Institutional Furniture Manufacturer’s Association
CWS	Computer Workstation
DoD	Department of Defense
DSB	Defense Science Board
EHF	Ergonomic Human Factors
EHFE	Ergonomic Human Factors Engineering
FAA	Federal Aviation Administration
FOIA	Freedom of Information Act
GAO	Government Accountability Office
GCS	Ground Control Station
HFACS	Human Factors Analysis and Classification System
HFE	Human Factors Engineering
HFES	Human Factors and Ergonomics Society
HFIT	Human Factors Investigation Tool
HSC	Human Supervisory Control
ICAO	International Civil Aviation Organization
INCOSE	International Council on Systems Engineering
IO	Input/Output
JUAS COE	Joint Unmanned Aircraft System Center of Excellence
MIT	Massachusetts Institute of Technology
MOP	Measures of Performance
MSL	Mean Sea Level
NAS	National Airspace System
NATO	North American Treaty Organization
NTSB	National Transportation Safety Board

Acronym	Definition
OC	Operator Comfort
OHSA	Occupational Safety and Health Administration
OSD	Office of the Secretary of Defense
PGCS	Payload Ground Control Station
RF	Radio Frequency
SA	Situation Awareness
SHEL	Software, Hardware, Environment, and Liveware
U.S.	United States
UAPO	Unmanned Aircraft Program Office
UAS	Unmanned Aircraft System
UATAR	Unmanned Aircraft Technology Applications Research
UAV	Unmanned Aerial Vehicle
USAF	United States Air Force

Terms and Definitions

Unmanned Aircraft System (UAS): An aircraft that does not have an onboard pilot. UAS may perform autonomous flight tasks or be controlled from the GCS by an operator (UAPO, 2008).

UAS Groups 1 through 5: The DoD uses five groups to categorize its UAS inventory that are based on altitude, weight, and speed (Weatherington, 2010).

Ground Control Station (GCS): A system consisting of a computing unit and IO hardware that is set up and designed to allow its user to control a UAS from the ground. The GCS could be portable, handheld, stationary, preassembled, and/or fixed. (UAPO, 2008).

Human Factors Engineering (HFE): "*An understanding of human capabilities and comprehensive integration of those capabilities into system design beginning with conceptualization and continuing through system disposal*" (INCOSE, 2010).

Computer Workstation (CWS): A computer system consisting of a computing unit and IO hardware devices that form interfaces for its user (HFES, 2007).

Ergonomic Human Factors (EHF): Ergonomics, which means the study of work, was developed by Polish scientist B. W. Jastrzebowski in 1857. EHF pertains to the human abilities, characteristics, and limitations that could hamper the usability of an interface if its design does not accommodate human limitations (Salvendy, 2006).

Mishap: A mishap is a term used by the DoD to define a UAS accident in which personnel are hurt and/or a UAS is damaged or destroyed. (Williams, 2004).

Input Output (IO) Category: IO category includes input and visual display sub-categories of the ANSI/HFES-100 standard. IO provides specifications based on EHFE principles to design human-friendly interfaces for CWS auxiliary IO devices. IO devices addressed by this standard are a keyboard, mouse, puck devices, trackball, joystick, stylus, light pen, tablet, overlay, touch screen, and display (HFES, 2007).

Operator Comfort (OC) Category: OC category includes installed system and furniture sub-categories of the ANSI/HFES-100 standard. OC provides EHFE specifications for developers to design an ergonomic interface layout and a comfortable work environment. OC specifies requirements for posture, arm position, viewing, work surfaces, and foot comfort. Moreover, OC contains requirements for lighting, acoustics, temperature, ventilation, and emissions (HFES, 2007).

Chapter 1– Introduction and Overview

1.1. Introduction

Unmanned Aircraft Systems (UASs) are rapidly growing in both the military and civilian sectors. Their pilot safety features have become appealing to law enforcement, security, and military sectors for conducting intelligence, surveillance, reconnaissance, search, and rescue (Gawron, 1998). Due to their increased demand, UASs were hastily developed and deployed. The need for standardization and field testing prior to UAS deployment was bypassed, which led to the high number of UAS mishaps (Baur, 2007; DoD, 2004; Nisser & Westin, 2006). Studies indicate human factors are involved in up to 69% of all UAS mishaps. Of these mishaps, up to 25% are due to ergonomic shortfalls found in input/output (IO) interface design and configuration of Ground Control Stations (GCSs) (Manning, Rash, LeDuc, Noback, & McKeon, 2004; Rogers, Palmer, Chitwood, & Hover, 2004; Seagle, 1997; Thompson & Tvaryanas, 2005; Thompson & Tvaryanas, 2008). The use of automation for UAS flight control has rapidly increased in the last decade. With the help of automation, the UAS GCS's physical design and workload is slowly evolving toward that of a general-purpose computer workstation (CWS) (Hancock, Mouloua, Gilson, Kring, & Kring, 2001; Nas, 2008). As shown in Figure 1, the CWS and UAS GCS have very similar layout and IO devices, which include display, keyboards, and mouse. Since the IO devices used in the CWS and UAS GCS are analogous, their Ergonomic Human Factor (EHF) issues are often the same. This study examines UAS GCS IO devices and their usability to determine whether commercial ergonomic standard's IO category may be applied to help minimize and manage EHF issues in UAS GCS IO interfaces.

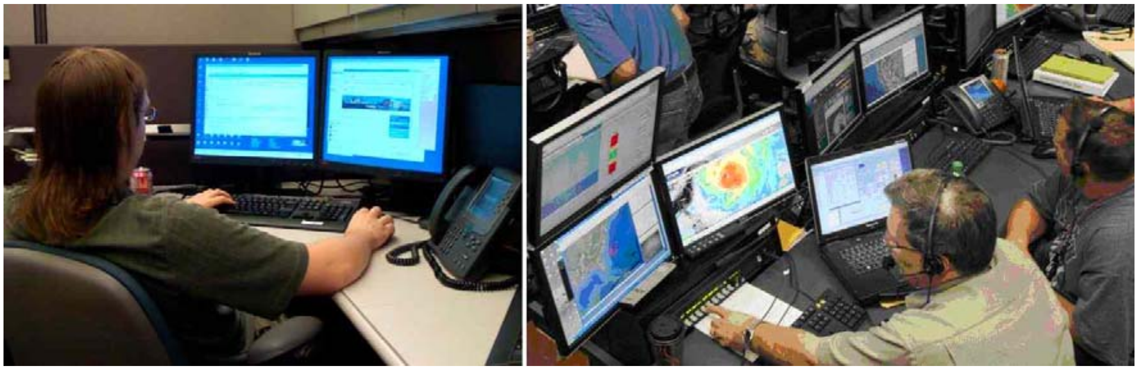


Figure 1 – Computer Workstation (left) and UAS GCS (right)

1.2. Background

The Federal Aviation Administration (FAA) regulates the United States (U.S.) National Airspace System (NAS). They define a UAS as "*A device used or intended to be used for flight in the air that has no onboard pilot*" (FAA, 2006). This includes all classes of airplanes, helicopters, airships, and translational lift aircrafts that have no onboard pilot and are controllable upon three axes (FAA, 2006; UAPO, 2008). Generally, UASs consist of an aircraft designed to perform autonomous tasks or be operated remotely from a GCS (Pastor, Lopez, & Royo, 2007). The term unmanned is often confused with no human involvement in UAS operations and may be the reason for the lack of focus on EHF analysis of UAS GCSs (Sheridan, 1992). In reality, the UAS is controlled by a pilot, who is referred to as an "operator." Operators perform the conjunctive assignment of flight planning and monitoring to satisfy mission objectives. They also are responsible for the safety of the UAS and successful completion of the mission (Hancock, et al., 2001).

Because UASs come in many different shapes and sizes (Gertler, 2012), the DoD tasked the Joint Unmanned Aircraft System Center of Excellence (JUAS COE) to develop a methodology to categorize UASs. The JUAS COE provided a list of five groups (see Figure 2) approved by the DoD (DoD, 2009a). The DoD now uses these five groups to categorize its UAS inventory. The categories are based on altitude, weight, and speed (Weatherington, 2010). The five approved UAS groups are:

- Group 1: Weight less than 20 pounds and operation below 1,200 feet above ground level (AGL) at speeds less than 250 knots.
- Group 2: Weight 21 to 55 pounds and operation below 3,500 feet AGL at speeds less than 250 knots.
- Group 3: Weight more than 55 pounds but less than 1,320 pounds and operation below 18,000 feet mean sea level (MSL) at speeds less than 250 knots.
- Group 4: Weight more than 1,320 pounds and normal operation below 18,000 feet MSL at any speed.
- Group 5: Weight more than 1,320 pounds and operation higher than 18,000 feet MSL at any speed (DoD, 2009a).

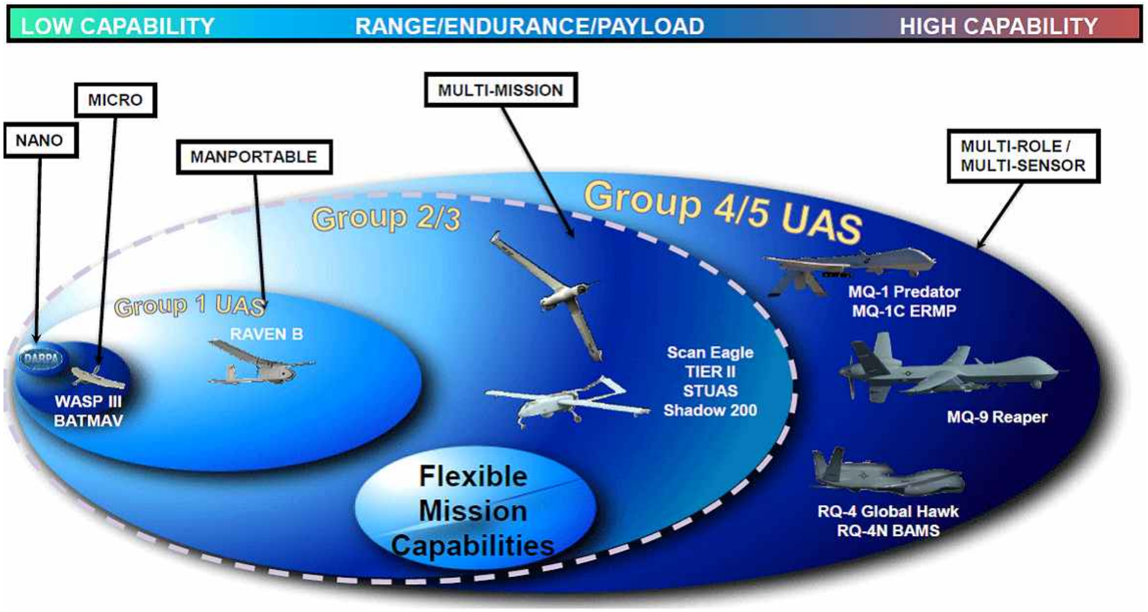


Figure 2 – UAS Groups (Tanner, 2010)

The use of UASs by the DoD has grown dramatically and they have become a primary weapon of choice during the last decade. The wars in Afghanistan and Iraq precipitated a high DoD UAS demand, which led to their rapid development and deployment (Baur, 2007; Zucchino, 2010). Subsequently, lengthy systems and software engineering design, development, and testing processes were streamlined (Baur, 2007). Accident Investigation Board (AIB) reports commonly associate EHF issues with UAS GCS IO interfaces (e.g., display, keyboard, joystick, etc.) with UAS mishaps. UAS GCS designs do not often account for human abilities, characteristics, and limitations (GAO, 2008; Thompson & Tvaryanas, 2008). Studies have associated certain EHF issues (improper height and/or non-adjustable mounting of displays, improper reach for IO devices, improper clearance for IO devices, etc.) in GCS design with UAS mishaps (Manning, et al., 2004; Thompson & Tvaryanas, 2008; Wilson, 2002). The DoD UAS mishap rates are 100 to 200 times those of human-piloted aircraft (DoD, 2009a; Tyabji, 2007; Williams, 2004). While the DoD uses standards to improve reliability and minimize development risks (Lowell, 2008), no single agency or organization, military or otherwise, bears the responsibility for developing EHF standards for DoD UAS GCSs.

1.3. Problem Statement

UAS mishap rates are 100 to 200 times that of human-operated aircraft, with 25% of the 69% of human factors mishaps caused by EHF issues and a lack of standards in the UAS GCS IO design (DoD, 2009a; Manning, et al., 2004; Rogers, et al., 2004; Thompson & Tvaryanas, 2005; Tyabji, 2007; Williams, 2004). The DoD is the largest consumer of UASs in the world, with a limitless demand; therefore, the number of EHF-related mishaps are destined to rise (DoD, 2011). ANSI/HFES-100 standard’s IO category will be examined for its applicability to the design of UAS GCS IO interfaces in order to help marginalize EHF issues associated with UAS mishaps, which may help reduce the overall UAS mishap rate.

1.4. Purpose of Study

A solution is needed to curb the proliferation of UAS GCS EHF issues and the increasing number of EHF related mishaps (OSD, 2004; Williams, 2004). The purpose of this study is to explore an existing EHF engineering standard’s IO category for CWSs that can be applied to UAS GCS design, development, and evaluation as a partial solution to reduce UAS GCS IO-related EHF issues. The CWS standard’s IO category used in this comparative study is called “American National Standards Institute/Human Factors and Ergonomics Society-100 (ANSI/HFES-100) Human Factors Engineering of Computer Workstations” (HFES, 2007). The application of EHF engineering in the design, development, and evaluation phases of a UAS GCS may improve overall operational effectiveness. The application of EHF also may enhance UAS GCS usability and user friendliness, and could potentially reduce and/or eliminate the number of UAS mishaps related to the EHF in UAS GCS IO interface design/layout (Rogers, et al., 2004; Thompson & Tvaryanas, 2008; Williams, 2004). Therefore, the use of an EHF standard for UAS GCS IO interfaces may help the DoD satisfy the goal of making UASs safer and more reliable (Dalamagkidis, Valavanis, & Piegl, 2008; Forester et al., 2004).

1.5. Scope of Study

ANSI/HFES-100 provides guidance on IO and Operator Comfort (OC). The initial UAS GCS research indicated that IO EHF issues had a greater bearing on the mishaps; therefore, the IO category of the ANSI/HFES-100 standard is the focus of this study and

OC was not evaluated. For the purpose of this study, IO devices include keyboard, mouse, puck devices, trackball, joystick, stylus, light pen, tablet, overlay, touch screen, and display. This study examines the relationship between the UAS mishaps and EHF issues with UAS GCS IO, and includes an analysis of possible application of ANSI/HFES-100 IO category to mitigate those EHF issues in UAS GCS IO.

1.6. Importance and Interest

The role of UASs has increased in the DoD and will continue to do so for years to come (Loh, Yi, & Roe, 2009). They are now considered to be “an integral part” of the fundamental DoD mission as opposed to their treatment as an “additional asset” with a minor role (OSD, 2004). The presence of EHF issues in UAS GCSs negatively affects the quality, reliability, and safety of UASs (Congress, 2009). A simple EHF issue could lead to multi-million dollar mishaps, mission failures, and/or the unwanted escape of dangerous high-value targets. UASs also may pose a direct threat to human lives and property on the ground if issues occur in populated areas (Alan, 2006). Because of their weight, size, and airspeed, EHF issues in Groups 2 through 5 UAS GCSs are significantly more expensive and can range anywhere from $1 million to more than $200 million on a per UAS basis. The DoD’s overall portfolio is worth billions of dollars (Gertler, 2012). To safeguard the DoD’s UAS investment and inventory from EHF-related issues, a significant level of interest has developed in the DoD to curtail these mishaps (GAO, 2008).

Reduced EHF in UAS GCSs will benefit other stakeholders such as developers, engineers, and managers (Mouloua, Gilson, Kring, & Hancock, 2001). They may be interested in finding methods to improve reliability of UASs and their associated GCSs

(GAO, 2008; Owings, 2010). This study provides an EHF standard for UAS GCS IO, which may help improve UAS reliability by reducing the EHF-related risks in GCS designs.

1.7. Organization and Outline

Chapter 1 introduces the subject matter and problem, briefly describes the approach taken, states the study's significance, and identifies potential beneficiaries that may be interested in the results. Chapter 2 describes the research problem, background, and research questions and describes the research goals, objectives, scope, terms, and definitions. Chapter 3 provides a literature review of the subject matter, purpose, and related findings, and identifies the current state of the issues examined and models used to evaluate the UAS mishaps. Information on UAS mishaps that were caused by EHF issues in the UAS GCSs and similar instances of EHF in CWSs also are described in Chapter 3. Chapter 4 describes the research framework, conceptualization, hypothesis, methodology, reliability, and validity considerations of the conceptual model. Chapter 5 describes the data collected and its analysis. Chapter 6 provides a summary of the study, recommendations, and potential areas of research for future studies. References and appendices follow Chapter 6.

Chapter 2– Research Problem

2.1. Research Background

To improve quality reliability, and reduce the cost of Government-procured products, the U.S. Congress passed legislation in 1957 to implement a "Standardization Program," which became the basis for thousands of military standards that affect almost all products and services procured by the DoD (Congress, 1957). However, the DoD has not produced a UAS GCS-specific EHF standard in spite of the proliferation of UASs. The UAS mishaps cost the DoD millions of dollars each year and the EHF issues in UAS GCS IO continue to be a leading cause for the mishaps (Congress, 2009; Higgins, 2008; Williams, 2004). EHF issues generally pertain to designing the UAS GCS interface to suit the operator by adapting displays, control layouts, input devices, and seating that provide comfort for the operators (Manning, et al., 2004; Williams, 2004). Simply stated, EHF issues continue to persist due to lack of UAS GCS EHF standards.

2.2. Research Question

The research addresses the following questions:

- Can the IO category of commercial standard, Human Factors Engineering of Computer Workstations (ANSI/HFES-100-2007), be applied to the design, development, test, and evaluation of the DoD UAS GCS IO interface?
- Are the IO devices used by the UAS GCS IO interface the same as the ones used in the CWS IO interface?
- Is the usability of CWS IO devices similar to the usability of UAS GCS IO devices when operated in normal operation and emergency operation?

2.3. Goals and Objectives

This study has the following three objectives:

- Establish the similarity between CWS and UAS GCS IO devices
- Establish the similarity of IO device usage between CWSs and UAS GCSs
- Establish the applicability of CWS EHF standards category to the design of the UAS GCS IO interface

2.4. Scope and Delimitations

The field of UAS, GCS, and human factors engineering is extremely broad. However, to constrain the complexity of such a study, several choices were made to help control and simplify its scope. This research is limited to the study of:

- DoD UASs and their GCS human-machine interface designs
- Groups 2 through 5 UASs and their GCS designs
- IO category as specified by ANSI/HFES-100
- The study of 20 DoD UAS GCSs
- Feedback from 23 DoD UAS GCS operators

2.5. Assumptions and Constraints

The research involved the following assumptions/constraints:

- The workload of a UAS GCS user is very similar to that of the CWS user who performs moderate to intensive text, data, and graphic processing tasks (Hancock, et al., 2001; HFES, 2007; Spravka, Moisio, & Payton, 2005).

Therefore, this study will not attempt to address the workload requirements of the operators in relation to the EHF.

- UAS GCSs that employ a ground control mechanism use IO devices such as throttles and rudder controllers, and their operator interface does not resemble a CWS (Larm, 1996; Mouloua, et al., 2001; Nas, 2008). Therefore, this study will not include UAS GCSs that employ a ground control mechanism.
- Group 1 UASs use portable or handheld UAS GCSs that are often not comparable to a CWS (Larm, 1996; Nas, 2008). Therefore, UAS GCSs from Group 1 are not included in the study.
- Most UASs have two types of ground control stations: (1) GCSs that control the UAS and (2) Payload GCSs (PGCS) that may be used to operate payloads mounted on the same UAS (Drew, Shaver, Lynch, Amouzegar, & Snyder, 2005). This research will not address the EHF issues pertaining to PGCSs and their IO interfaces.
- Data on UAS mishaps are extremely limited. The DoD was the main source for mishap data for this research. Not all data are available to the public. The only available information is in AIB reports, which may lead to varying interpretations when assigning causal factors to a mishap (Manning, et al., 2004).
- Each UAS GCS is equipped with a system to communicate with crewmembers. This communication system is a standalone system and does

not integrate with the UAS GCS (Drew, et al., 2005); therefore, operator communications were not included.

2.6. Research Problem Summary

DoD UAS GCSs are marred with EHF issues. These issues can be minimized by adapting displays, control layouts, and input devices that provide comfort for the operators. EHF issues continue to persist due to lack of UAS GCS EHF standards. Finding an EHF standard applicable to the design and evaluation of UAS GCSs could help minimize the proliferation of EHF issues with UAS GCS IO that are commonly associated with UAS mishaps. Since UAS GCS IO is a close counterpart of CWS IO, its standard IO category may be applicable to the UAS GCS IO interface. The purpose of this study is to help determine if IO category of ANSI/HFES-100 can be applied to the design, development, test, and evaluation of the IO interface in DoD UAS GCSs in order to improve UAS viability and reliability.

Chapter 3– Literature Review

3.1. History of UASs and GCSs

UASs are being utilized by every branch of the DoD (DoD, 2011). Their history goes back to the early 1800s (Reade, 1958). Over the centuries, unmanned systems evolved to include balloons, torpedoes, missiles, decoy drones, target drones, surveillance drones, and armed drones. Likewise, UAS ground control mechanisms went through a transition of their own from no ground control to primitive radio controls (Tesla, 1898). The introduction of radio frequency (RF) relays in the 1970s increased the distances by which UASs could be controlled, while setting up the groundwork for a formal UAS GCS (Haines, 2007). A brief timeline of UAS/GCS development is shown in Figure 3.

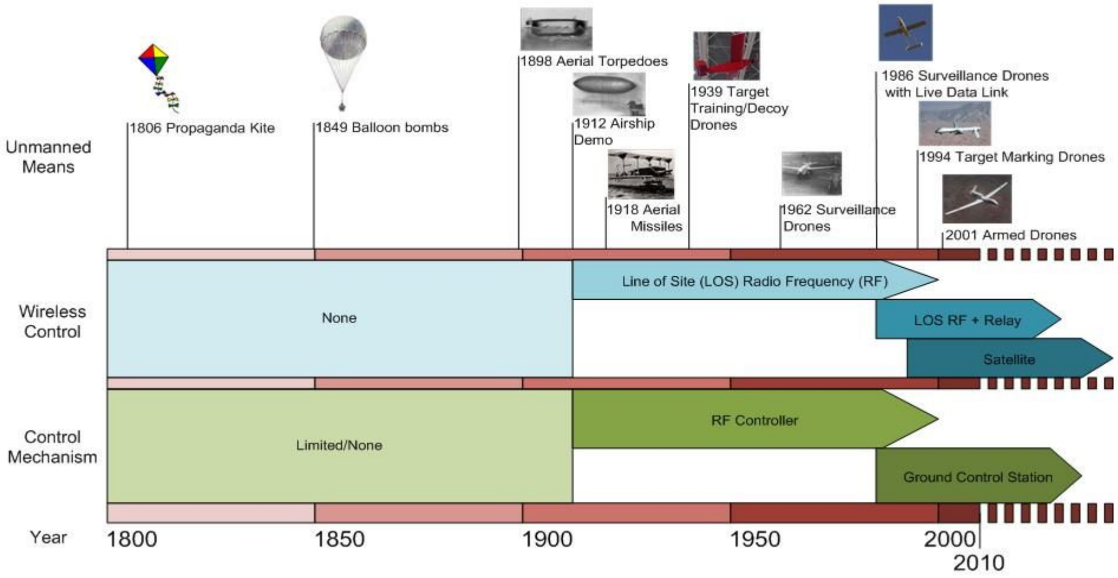


Figure 3 – Timeline of UAS/GCS Development

3.1.1. 1980 – 1999

Prior to the 1980s, UASs were heavily used during the Vietnam War at a higher than anticipated success rate. Even after the successes of unmanned systems, the U.S. military largely ignored them. In fact, the United States Air Force (USAF) despised them. A

USAF official commented, “How can you be a tiger sitting behind a console?” (Spinetta, 2011). The success of Israel’s unmanned decoys over Lebanon’s Bekaa Valley in 1982 brought the DoD’s focus back to the subject of unmanned drones (Tice, 1991). The U.S. Navy reengineered an Israeli system, resulting in the Pioneer UAS, which started a revolution in unmanned technology. Pioneer became the first system to have a formal UAS GCS and had a live data stream from the UAS to provide surveillance video feeds over an RF data link. Relays were used to provide over-the-horizon and beyond-line-of-site data links (DoD, 2009b).

The real leap forward for ground control technology came from satellite communications. The DoD successfully developed highly effective satellite-controlled Predator drones in the 1990s (Haines, 2007; Jean, 2011). The USAF was the primary operator of UASs in the 1990s. Since UASs were a relatively new concept, they lacked GCS design standards. Based on the USAF’s background with manned aircraft, they steered the development of UAS GCSs toward the paradigm of a cockpit and its associated instruments (e.g., Pioneer GCS, Predator GCS, etc.). In other words, the USAF treated UASs like traditional manned aircraft (Houston, 2009). UAS GCS operators were referred to as pilots and manned flight experience was a mandatory requirement (Button, 2009b; Houston, 2009). The USAF UASs employed “ground control” mechanisms and were fully controlled from the GCS. Joysticks, throttles, and rudder controls were the primary interface devices in UAS GCSs for manual control during the entire flight (e.g., takeoff, in-flight, and landing) (Larm, 1996; Nas, 2008).

USAF UASs first made headlines during NATO’s military operations in Kosovo in 1999. At the time, UASs were mainly used for reconnaissance, with the exception of the

Predator UAS operated by the USAF (USAF, 2012). Predator was the first UAS to utilize laser targeting for subsequent missile strikes launched from other aircraft (Mouloua, Gilson, & Hancock, 2003).

3.1.2. 2000 – Present

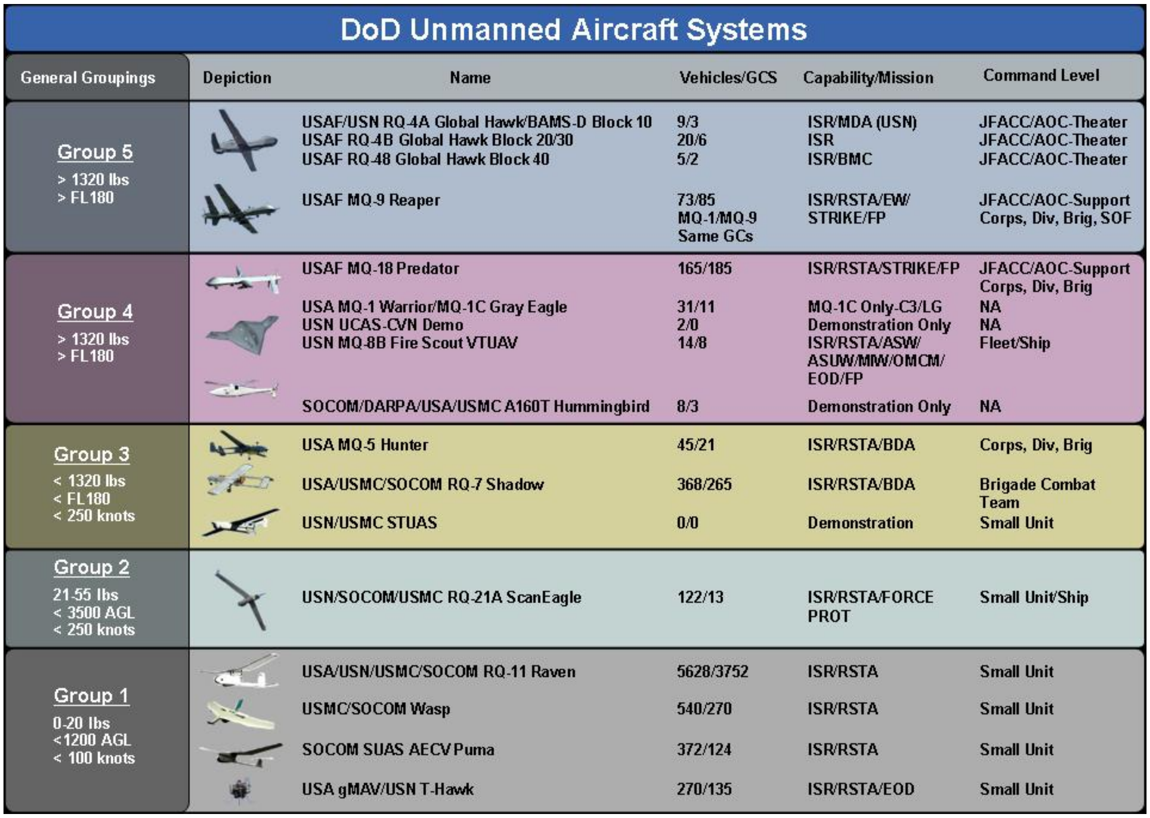
By the early 2000s, the U.S. Navy and U.S. Army were employing UASs in the battlefield. Unlike the USAF, they did not treat UASs as manned aircraft and procured UASs that employed semi-autonomous or autonomous control mechanisms. They referred to UAS pilots as "operators" and revamped their training processes for operators without manned flight experience (Houston, 2009). The success of the Army and Navy forced the USAF to eliminate manned flight experience as a requirement for its operators (Button, 2009a; Force, 2009). The lack of UAS GCS standardization gave developers leeway to experiment with different types of UAS control approaches. They designed new systems to find the right balance between "ground" and "autonomous" controls (Mouloua, et al., 2001). Development of new systems turned into a competition where developers showcased the latest and greatest UAS GCS technology. Unfortunately, this only included a minor focus on EHF shortfalls in UAS GCSs, which led to an increase in EHF-related UAS mishaps (Nisser & Westin, 2006; Rogers, et al., 2004). The USAF blamed the high number of UAS mishaps on lack of standardization and used it as a rationale to petition the Pentagon to become its UAS manager to develop standards for the UAS. They started development of an advanced UAS GCS that would look like a traditional cockpit and created the first UAS GCS standardization program (Butler & Fulghum, 2005). In 2009, the Pentagon announced an Open Architecture Ground Station Initiative and later officially endorsed UAS automation. This translated into a move away from its cockpit paradigm for the USAF. The USAF subsequently shelved the advanced cockpit program and its standardization program was rendered useless (Button, 2009b).

Recent technological advancements in miniaturizing components (such as sensors), coupled with the developments in navigation and telemetry are allowing UASs to fly and perform their tasks autonomously (OSD, 2002). Future UAS GCS designs are now based on automation and developed in such a way that a universal UAS GCS can operate multiple UASs from Groups 2 through Group 5 (Button, 2009b; DoD, 2010; Sullivan, 2009). M.L. Cummings, a former pilot who teaches UAS GCS design at the Massachusetts Institute of Technology (MIT), believes all UAS GCS designs should evolve to incorporate automation. Although already being used by the U.S. Army and U.S. Navy, the new approach no longer implements the stick-and-rudder, but instead uses a point-and-click paradigm (Hoffman, Tilghman, LaGrone, & Iannotta, 2008).

Today, many UASs are capable of conducting reconnaissance and have the ability to carry and launch multiple precision guided bombs and missiles against various targets (Gertler, 2012). The combination of reconnaissance and military payload delivery has elevated UASs to the status of a premier weapon system (Gertler, 2012). Automation is transforming the UAS GCS operator’s role into a supervisory role, similar to the ones practiced in CWS-based industrial automated systems for decades, such as those found in power generation plants, manufacturing settings, etc. (Sheridan, 1992). Automation reduces physical stress and workloads for UAS GCS operators, making UAS GCSs a close counterpart of automated industrial systems (Langevin et al., 2008; Spravka, et al., 2005).

3.2. UAS Basics

The DoD is continuing to expand its UAS inventory and holds the largest quantity and variety of UASs in the world (DoD, 2011). Figure 4 provides Group specifics and names some of the most commonly used UASs. The focus of this study is UAS GCSs from Groups 2 through 5.



DoD Unmanned Aircraft Systems

General Groupings	Depiction	Name	Vehicles/GCS	Capability/Mission	Command Level
Group 5 > 1320 lbs > FL180		USAF/USN RQ-4A Global Hawk/BAMS-D Block 10	9/3	ISR/MDA (USN)	JFACC/AOC-Theater
		USAF RQ-4B Global Hawk Block 20/30	20/6	ISR	JFACC/AOC-Theater
		USAF RQ-48 Global Hawk Block 40	5/2	ISR/BMC	JFACC/AOC-Theater
		USAF MQ-9 Reaper	73/85 MQ-1/MQ-9 Same GCs	ISR/RSTA/EW/ STRIKE/FP	JFACC/AOC-Support Corps, Div, Brig, SOF
Group 4 > 1320 lbs > FL180		USAF MQ-18 Predator	165/185	ISR/RSTA/STRIKE/FP	JFACC/AOC-Support Corps, Div, Brig
		USA MQ-1 Warrior/MQ-1C Gray Eagle	31/11	MQ-1C Only-C3/LG	NA
		USN UCAS-CVN Demo	2/0	Demonstration Only	NA
		USN MQ-8B Fire Scout VTUAV	14/8	ISR/RSTA/ASW/ ASUW/MIW/OMCM/ EOD/FP	Fleet/Ship
		SOCOM/DARPA/USA/USMC A160T Hummingbird	8/3	Demonstration Only	NA
Group 3 < 1320 lbs < FL180 < 250 knots		USA MQ-5 Hunter	45/21	ISR/RSTA/BDA	Corps, Div, Brig
		USA/USMC/SOCOM RQ-7 Shadow	368/265	ISR/RSTA/BDA	Brigade Combat Team
		USN/USMC STUAS	0/0	Demonstration	Small Unit
Group 2 21-55 lbs < 3500 AGL < 250 knots		USN/SOCOM/USMC RQ-21A ScanEagle	122/13	ISR/RSTA/FORCE PROT	Small Unit/Ship
Group 1 0-20 lbs <1200 AGL < 100 knots		USA/USN/USMC/SOCOM RQ-11 Raven	5628/3752	ISR/RSTA	Small Unit
		USMC/SOCOM Wasp	540/270	ISR/RSTA	Small Unit
		SOCOM SUAS AECV Puma	372/124	ISR/RSTA	Small Unit
		USA gMAV/USN T-Hawk	270/135	ISR/RSTA/EOD	Small Unit

Figure 4 – Commonly Used DoD UASs (DoD, 2011)

3.2.1. Uses of UAS

The advent of the UAS enabled the concept of unmanned aerial missions. The goal of increasing mission effectiveness, reducing harm to pilots, and increasing pilot safety led the DoD to invest heavily in UASs (Gertler, 2012). Even non-military agencies such as the Coast Guard and Border Patrol are utilizing UASs to conduct intelligence, surveillance, reconnaissance, search, and rescue within the U.S. and abroad (DoD, 2009a). Many other U.S. Government agencies are using UAS technology to provide safety and security, support law enforcement, survey land and capital resources, and monitor forest fires and floods (Esposito et al., 2007). The civilian sectors are slowly realizing the vast utility of UASs. Farmers are using UASs for crop assessment, forecasting, and disease and weed detection (Berni, Zarco-Tejada, Suarez, & Fereres, 2009). Geologists are using UASs for Earth observation and remote sensing. The energy sector is using UASs to monitor oil gas and electricity distribution as well as fracture management, monitoring, control, and mitigation. UASs also are being used by communications and broadcasting agencies to serve as proxy satellites to provide short-term communications services in the event of catastrophes (EU, 2007; Li, Shen, Wang, & Lei, 2010). All of these institutions are interested in seeing the UAS technology mature to the point where the UAS GCS IO interface is not prone to EHF issues.

3.2.2. UAS Control Mechanisms

The purpose of the GCS is to provide a means to control the UAS and as such, the UAS GCS is considered a logical extension of a cockpit (UAPO, 2008). The Human Supervisory Control (HSC) model by Sheridan provides a generic overview of the human-GCS interaction. In this model, human operators receive feedback from a computer while interacting with it to control a task being performed by the computer (Sheridan, 1992). All types of DoD UASs employ some level of the HSC model seen in Figure 5.

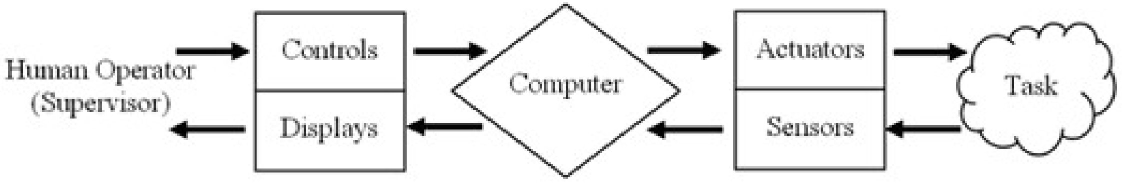


Figure 5 – Human Supervisory Control (Sheridan, 1992)

The continuous transition toward autonomy is driving the optimal level of direct UAS-operator interaction and control. Currently, this varies from one UAS platform to the next. There are three types of UAS control mechanisms: autonomous, semi-autonomous, and ground control (Larm, 1996; Mouloua, et al., 2001; Nas, 2008).

- Autonomous UASs fly a complete mission from takeoff to landing. Operators perform supervision tasks on a UAS GCS and only have the option to modify the mission, but cannot control the UAS directly. Some of the UASs from Groups 2 through 5 employ autonomous control mechanisms, while their UAS GCS closely resembles a CWS.
- Semi-autonomous UASs are capable of performing autonomous tasks. Operators perform supervision tasks and are allowed a moderate level of UAS flight control using a joystick in UAS GCS. Most of the newer UASs from Groups 2 through 5 employ semi-autonomous control mechanism, while their UAS GCSs closely resemble a CWS.
- Ground control UASs are directly controlled by operators using a UAS GCS from takeoff to landing. Most UASs in Group 1 employ a ground control mechanism, while some of the older UASs from Groups 2 through 5 also

employ ground control mechanisms. UAS GCSs that employ ground control mechanism do not resemble a CWS.

3.3. Human Factors Engineering (HFE)

Ergonomics was the first term used to describe human factors. The term was developed by Polish scientist B. W. Jastrzebowski in 1857. He believed that proper application of ergonomics facilitates work (Salvendy, 2006). HFE is defined as a study of a human's interaction with a machine and its environment. The EHF helps understand the limitations and behavior of humans when working with machines. The purpose of EHF is to improve safety and comfort for humans in order to facilitate human-machine system efficiency and reduce errors (HFES, 2007; Hollnagel, 2000). The realization of human factors only began after a large number of aircraft accidents were tied to inadequate cockpit control designs that overlooked human capabilities and limitations during WWII. In one of the many incidents, an aircraft lever for lifting its wheels was placed in an improper location. When the pilot tried to pull the lever in an emergency, he could not reach it and the aircraft crashed (Dunlap, 1947). The term "human engineering" emerged closely on the heels of these incidents.

At that time, a group of cognitive psychologists was tasked to come up with a plan to develop military aircraft to suit human operators, instead of selecting humans to suit them. Shortly after WWII, human capabilities and limitations were acknowledged in the context of military aircraft and the term "human factors" was subsequently coined (Dunlap, 1947).

The FAA defines human factors as "*a multidisciplinary effort to generate and compile information about human capabilities and limitations and apply that information to equipment, systems, facilities, procedures, jobs, environments, training, staffing and personnel management, for safe, comfortable, and effective human performance*" (Hinson, 1993). HFE traditionally consists of three domains: cognitive, organizational, and physical. The cognitive domain includes studies on human perception, memory limitations, memory processing, and response capabilities (Hollnagel, 2003). The organizational domain includes studies of interaction in organization, culture, policies, procedures, and support (Reason, 1990). The physical domain, which also is the focus of this research, includes studies on human anatomy, physiological behavior, and limitations in movements (HFES, 2007). Each of these domains is further refined into several human factors categories.

3.3.1. Human Factors Categories

EHF is one of several categories of human factors that must be considered when evaluating an impact of human factors on a system event (Andersen et al., 2002). Figure 6 shows these human factors categories.

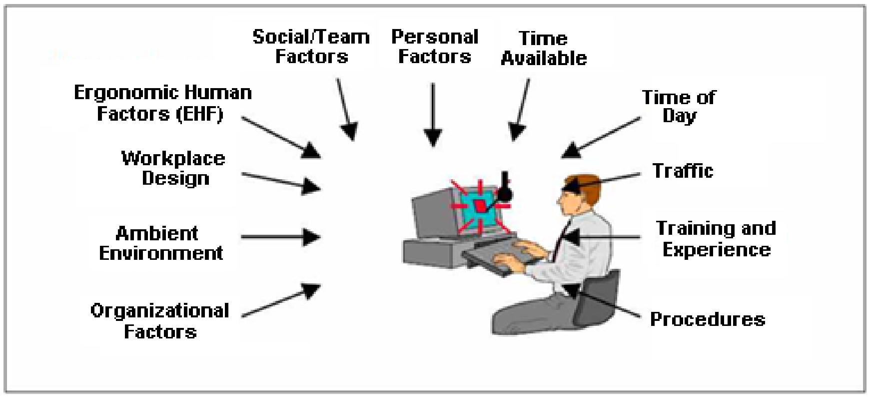


Figure 6 – Human Factors in human performance (Andersen, et al., 2002)

All the categories shown in Figure 6 are evaluated for their role in an event, at the time of that event; their definitions follow (Andersen, et al., 2002):

- **Procedures:** The procedures/processes that are in place, and determination of whether the procedures were followed.
- **Training and Experience:** The training and experience required for performing the tasks and whether the individual was qualified to perform those task.
- **Traffic:** The collective number of events that were happening (e.g., conversation, system alarms, other distractions, etc.).
- **Time of day:** The time of the day when the event took place (e.g., morning, afternoon, after lunch break, etc.).
- **Personal Factors:** The determination of whether the individual performing the tasks was going through personal issues (e.g., marriage, divorce, financial crisis, etc.).
- **Social/Team Factors:** The determination of whether the individual performing the task was getting along with the team, or if there were any personal issues between team members.
- **Ergonomic Human Factors (EHF):** The determination of whether there are factors related to human limitations and usability of interfaces.
- **Workplace Design:** The determination of whether the workplace design is adequate to perform the task (e.g., the noise contributed to a missed audio warning signal, etc.).

- **Ambient Environment:** The determination of whether the surrounding environment contributed (e.g., was it too cold or too hot?, which distracted the individual?, etc.).
- **Organizational Factors:** The determination of whether there was organizational influence that may have unintentionally led to errors (e.g., was the individual properly supervised?, etc.).

3.3.2. Taxonomies and Models for EHF Evaluation

The human operators of technology-intensive systems simply cannot foresee the accidents because they do not believe that an accident can possibly happen (Wagenaar & Groeneweg, 1987). The causes for most accidents are highly complex, as they are a collection of an intricately interrelated chain of events. The post-accident documentation of accurate and comprehensive data is the most important step that can help improve the safety of a system and possibly stop the recurrence of similar events (Gordon, Jeffries, & Flin, 2002). Taxonomies and models are developed by researchers to methodically document the post-mishap data for a human factors analysis. Due to the varying perspectives on human factors, it is difficult to make a selection of human factor taxonomy or a model appropriate for capturing mishap data and not all taxonomies evaluate IO related EHF issues (Andersen, et al., 2002; Wiegmann & Shappell, 2001). If a proper taxonomy or model is not selected to evaluate UAS mishaps, it may not capture the EHF issues associated with the UAS GCS IO interface. This may result in a missed opportunity to find and fix such issues. A report by the European Organization for the Safety of Air Navigation provides an overview of human factor taxonomies and models used in aviation mishap investigations (Andersen, et al., 2002):

- **Task-based taxonomies:** These are generic taxonomies that only state what happened from the operator's perspective. IO-related EHF issues can only be captured if the operator is able to understand and/or realize the ergonomic shortfalls of the interface.
- **System-oriented taxonomies:** These taxonomies state what happened from the system's perspective. Applying these taxonomies may or may not capture IO-related EHF issues.
- **Communication system models:** These models focus on communications, the message that was sent, and how the user interpreted the message. This model does not evaluate IO-related EHF issues.
- **Information processing models:** These models measure human memory, judgment, and decision making capability with respect to their physical actions. These models are capable of capturing IO-related EHF issues.
- **Symbolic processing models:** These models consider human thought processes and perspectives. They are not capable of capturing IO-related EHF issues.
- **Situation awareness (SA) models:** These models are commonly used in aviation and rely on the variety of information that is available to the operator prior to making a decision. These models can capture IO-related EHF issues.
- **Control system models:** These models are used to evaluate theoretical performance in a closed-loop system, situation, or scenario. These models do not capture IO-related EHF issues.

- **Error of commission models:** These models evaluate the user's capabilities with respect to the unintended or unnecessary acts that may lead to a mishap. These models are capable of evaluating IO-related EHF issues.
- **Human-system issues taxonomies:** These taxonomies evaluate human and system integration issues that are relative to physical, interpretational, and decision making capability. These models are capable of evaluating IO-related EHF issues.
- **Air traffic management models:** These models focus on the cause of incident while studying the relationship between different causes. They are capable of capturing IO-related EHF issues.
- **Human Factors Analysis and Classification System (HFACS) models:** This model is based upon the "Swiss cheese" model (Section 3.3.3.2). HFACS evaluates four levels of causation: organizational influence, unsafe supervision, preconditions for unsafe acts, and unsafe acts. This model is capable of capturing IO-related EHF issues.
- **DoD HFACS models:** This model is an enhancement of HFACS model. The model is capable of capturing IO-related EHF issues.

3.3.3. Development of Mishap Analysis Models and IO EHF

Humans are rarely solely responsible for an aviation mishap (Shappell & Wiegmann, 1997). Complex human interactions with control interfaces should be assessed when an aviation mishap is investigated (Heinrich, Petersen, & Roos, 1980). The EHF related to IO should always be a part of aviation mishap investigation models (Shappell & Wiegmann, 1997; Wiegmann & Shappell, 2001). The UASs are the beneficiaries of manned aviation research; lessons learned from manned aviation were applied to the development of UASs (Cantwell, 2009). Similarly, the models (e.g., HFACS, DoD HFACS, etc.) used for investigation of human factors in manned aircraft mishaps also are used for UAS mishap investigations (Thompson & Tvaryanas, 2008). These aviation mishap analysis models have evolved over the years and are well structured to capture the IO EHF in UAS mishaps. A brief description of each of these models in order of development, with respect to capturing IO EHF in mishaps, is provided in the following subsections.

3.3.3.1. **Software, Hardware, Environment, and Liveware (SHEL)**

The SHEL model developed in 1972 by Elwyn Edwards introduced a very simplistic view of a complex human-IO interface using four components (software, hardware, environment, and liveware) to define the human-IO interface (Molloy & O'Boyle, 2005). In this model, software is considered the regulatory authority that allows human interaction based on software's limited capabilities. Hardware is the equipment. The environment is the condition in which the operator is performing the task. Finally, liveware are the human operators themselves. Connecting lines between hardware, software, and liveware (in Figure 7) represent interfaces, while these three components also have a direct interface with the environment. The EHF IO issues in this model are represented by the interface between liveware and hardware (Shappell & Wiegmann, 1997, 2000).

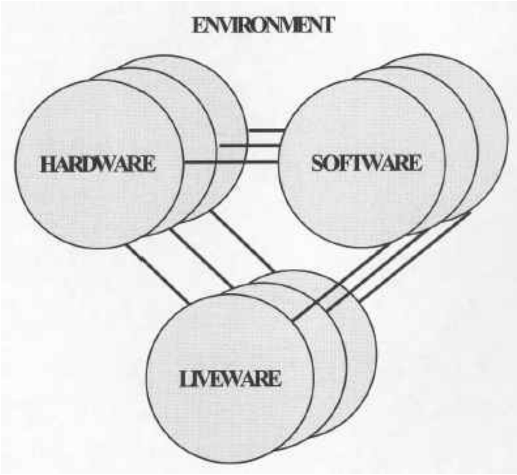


Figure 7 – SHEL Model for Human Error Evaluation (Wiegmann & Shappell, 2001)

Edwards believed that failures occur when there is a problem with one or more interfaces (Shappell & Wiegmann, 1997). In 1993, more than two decades after the development of the SHEL model, the International Civil Aviation Organization (ICAO) recommended its use to develop an aviation mishap investigation framework to capture EHF issues with the IO interface. The Airline Pilots Associations used the SHEL model to develop the framework. The use of this framework for mishap investigations resulted in a number of improvements in EHF IO issues between hardware and liveware. Although the SHEL model-based framework was successful in capturing EHF, it lacked methodology to evaluate human behavior (Wiegmann & Shappell, 2001). The "Swiss Cheese" model was later developed to help fill this void.

3.3.3.2. **Swiss Cheese Model**

In 1990, Dr. J. Reason described a human factors model in four levels: organizational influence, unsafe supervision, preconditions for unsafe acts, and unsafe acts. Each level had an influential effect on the next. He used a "Swiss Cheese" analogy in which holes in all four slices of the cheese have to be lined up for a mishap to occur (Reason, 1990).

This model is shown in Figure 8. Dr. Reason did not further refine these four levels to identify different aspects of human factors that are covered within each level; therefore, there was no way to identify which of these levels may include the EHF IO failure.

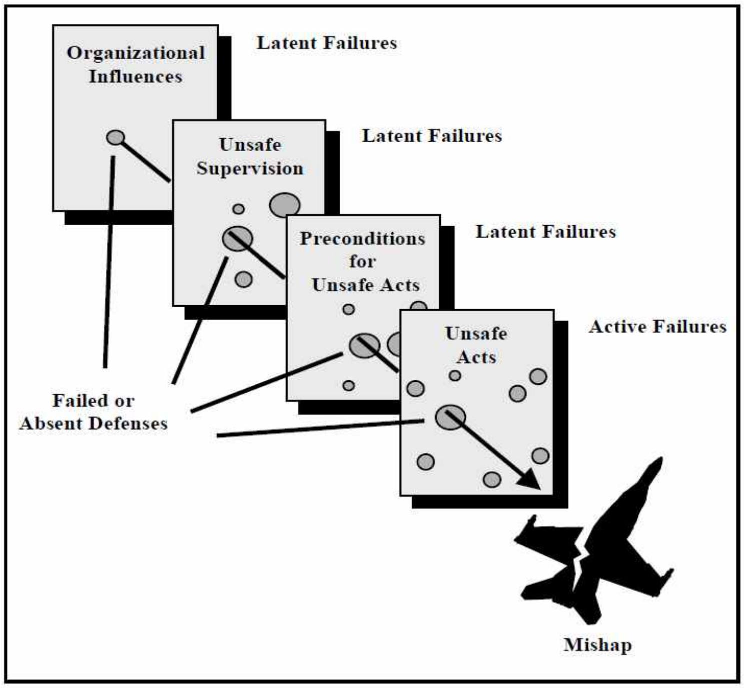


Figure 8 – The "Swiss Cheese" Model of Human Error Causation (Reason, 1990)

Shappell and Wiegmann believed "Swiss Cheese" to be a great theory, but this theory cannot be applied to a real-world situation without identifying each of the failures that represents a "hole" in the "Swiss Cheese" model. Shappell and Wiegmann worked to develop and refine the "Swiss Cheese" model into the HFACS model (Shappell & Wiegmann, 2000).

3.3.3.3. **HFACS Model**

Similar to the "Swiss Cheese" model, HFACS has four levels of causation: organizational influence, unsafe supervision, preconditions for unsafe acts, and unsafe acts. These four main levels investigate various aspects of human factors in a mishap

(Shappell & Wiegmann, 2000). The organizational influence is further subdivided into three categories: resource management, organizational climate, and organizational process (see Figure 9).

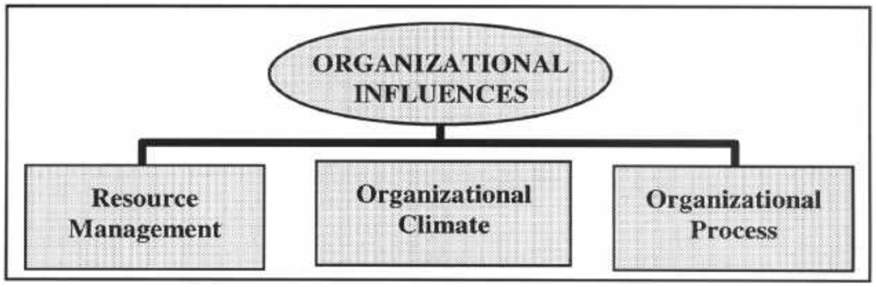


Figure 9 – HFACS Organizational Influences (Shappell & Wiegmann, 2000)

In the HFACS model, Shappell and Wiegmann considered cost to be the influencing factor behind most IO-related EHF failures. They believed that to cut cost, off-the-shelf components are sometimes used in system design without considering the fact that those components may have been designed for a very different operating environment (OSD, 2004; Shappell & Wiegmann, 2000). Overall, the focus of the HFACS role is to identify IO-related EHFs and determine why these EHFs exist. Therefore, they placed the EHFs in the IO interface under the "Organizational Influence" category of "Resource Management." The factors "poor design" and "unsuitable equipment" are listed as examples of EHF in IO in the HFACS model (Shappell & Wiegmann, 2000). Table 1 shows the examples of Resource Management.

Table 1 – Examples of Resource Management (Shappell & Wiegmann, 2000)

Resource Management
Human Resource
• Selection
• Staffing/manning
• Training
Monetary/Budget Resources
• Excessive cost cutting
• Lack of funding
Equipment/Facilities
• Poor design
• Unsuitable equipment

In 2000, HFACS was adapted by the DoD for aviation mishap evaluation. After a few years in use, the DoD modified it to develop the DoD HFACS model. The DoD HFACS model has been in use since 2005 to investigate and report human factors in all DoD aviation mishaps (DoD, 2005).

3.3.3.4. DoD HFACS Model

The DoD HFACS model used the HFACS model as a starting point. As with the HFACS model, the four levels of causation in the DoD HFACS are organizational influences, unsafe supervision, preconditions for unsafe acts, and acts. The first two causation levels in DoD HFACS, the organizational influence and unsafe supervision, were kept identical to the Shappell and Wiegmann HFACS model (DoD, 2005; Shappell & Wiegmann, 2000). However, some of the categories and subcategories for the remaining two causation levels were redefined. Notably, the IO EHF evaluation was added to the preconditions for unsafe acts causal level. An IO EHF evaluation comparison between the HFACS and DoD HFACS models is illustrated in Figure 10 (red arrows mark the instances where the IO EHFs are evaluated within each model).

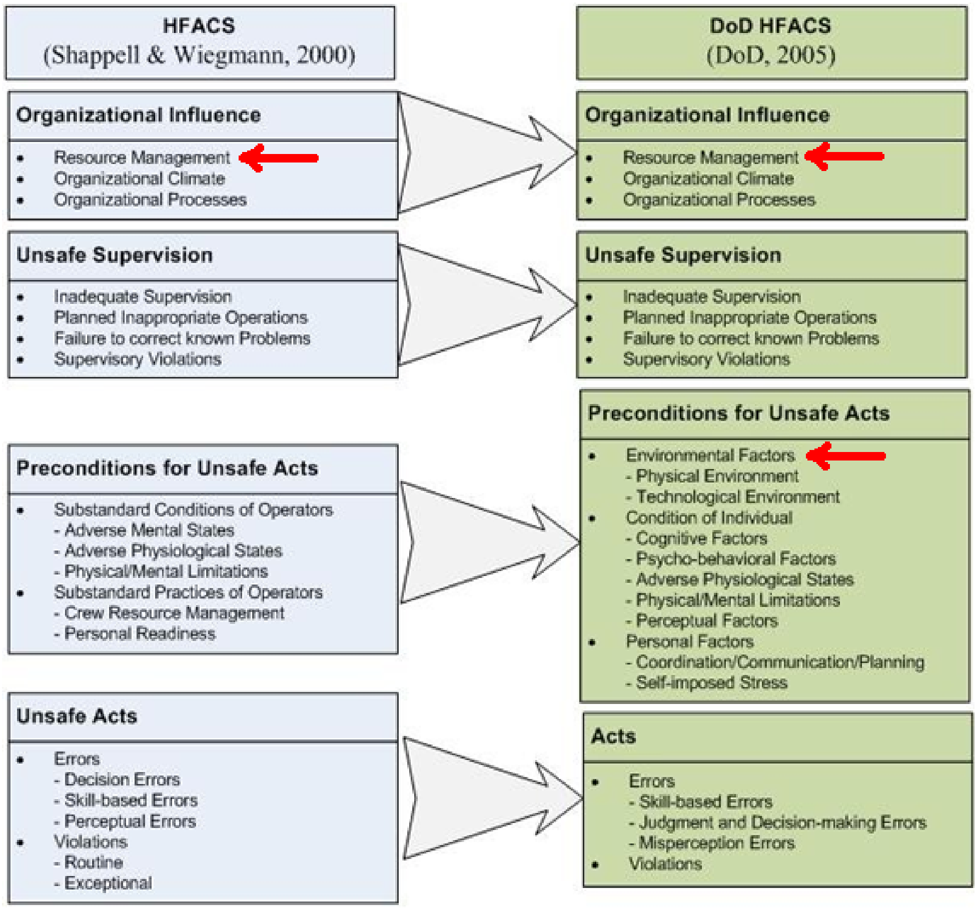


Figure 10 – HFACS and DoD HFACS (DoD, 2005; Shappell & Wiegmann, 2000)

Therefore, when using the DoD HFACS model to evaluate a UAS mishap, the IO-related EHFs can be captured at two different levels. The first example is under resource management causation, where the EHFs in the IO are investigated in the same way as non-DoD HFACS model. The second example is under preconditions for unsafe acts where the DoD HFACS model treats the EHF in the IO interface as a preexisting condition and the effects of the EHF in the IO interface are analyzed for their involvement and/or role in a mishap (DoD, 2005). This redundancy built into the DoD HFACS model allows the investigators to determine what role the IO-related EHF plays in a mishap.

The HFACS and DoD HFACS models are designed to capture human factors involvement in UAS mishaps once a mishap has already occurred. In contrast, UAS GCS developers and system engineers use Measures of Performances (MOPs) as a preventative measure to assess human and machine integration on newly designed UAS GCSs (Spravka, et al., 2005).

3.4. UAS GCS Operator MOP

The UAS GCS operators should flawlessly integrate with its IO controls throughout the duration of their flight. To evaluate operator integration with the UAS GCS IO interface, several MOPs will be evaluated (Spravka, et al., 2005). These MOPs are summarized in Table 2.

Table 2 – Human GCS Integration Areas of Evaluation (Spravka, et al., 2005)

Areas of Evaluation	Examples
• Readability (Displays)	• Text size, font, width, color, information location, etc.
• Interpretability (Displays)	• Color coding, clutter, density, etc.
• Ergonomic Human Factors (EHF)	• Body clearance, control location/reach, mouse/keyboard clearance, comfortable arm/wrist bend angles, comfortable viewing angle, etc.
• Communications	• Speech clarity
• Workload	• Task type, duration, difficulty, demand, etc.

All of these MOPs are equally valuable and can help determine the success of operator's integration into DoD UAS GCSs. Several researchers have used different methods to collect data and evaluate the UAS GCS designs based on these MOPs (Spravka, et al., 2005). A brief overview of some of this research follows:

- Readability was evaluated for proper display of information (Nikolic, Sklar, & Sarter, 1998).
- Communication was evaluated for accuracy in target location identification (M. H. Draper, Geiselman, Lu, Roe, & Haas, 2000).
- Workload was evaluated by automating the navigation, thus removing navigation from operator tasks (Wickens & Dixon, 2002).
- Communication and interpretability were evaluated by using text and speech for measuring operator capabilities (M. Draper, Calhoun, Ruff, Williamson, & Barry, 2003).
- Workload was evaluated for operator control level by performing manual duties vs. supervisory duties (Dixon, Wickens, & Chang, 2003).
- Interpretability was evaluated by testing different methods of alert systems for operator attention and response time. Multiple alerts were tested, such as alert location on screen, vibration, and auditory messages (Calhoun, Draper, Ruff, Fontejon, & Guilfoos, 2003).
- Communication was evaluated by measuring the performance of team tasks (Bell & Cooke, 2003).
- Communication was evaluated by testing radio and textual communications (McDermott, Luck, Allender, & Fisher, 2005).
- Readability and interpretability were evaluated by measuring operator response time to alerts (Donmez, Cummings, & Graham, 2009).
- Workload of an operator was evaluated by simulating multiple UASs and measuring operator task completion rate (Cummings, Clare, & Hart, 2010).

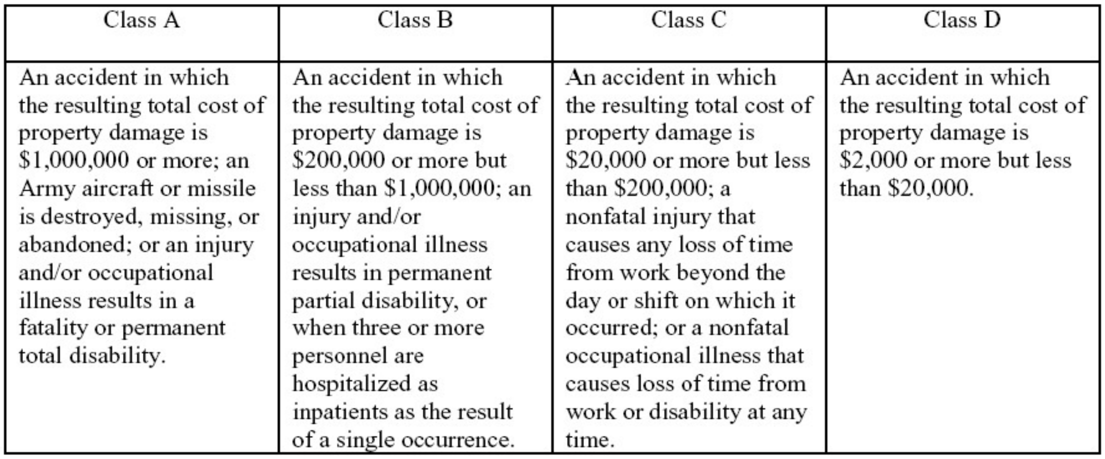
A scan of related research indicates that EHF-related MOP evaluation of DoD UAS UAS GCSs is nonexistent. Unfortunately, IO-related EHF in UAS GCSs has not been given enough attention, which may be a contributing factor in the proliferation of IO-related EHF in UAS GCSs and their subsequent involvement in UAS mishaps (Manning, et al., 2004; Williams, 2004).

3.5. UAS Mishaps

3.5.1. Difficulty in Finding UAS Mishap Data

The focus of this study is on DoD UASs; therefore, all mishap AIB reports had to be obtained from DoD UASs. The DoD does not have a central database to hold information for all UAS mishaps. Each branch of the military manages its own mishap database. Due to the military use of the UAS, a majority of the AIB reports are often kept confidential (Manning, et al., 2004; Rogers, et al., 2004; Williams, 2004). The limited availability/access of DoD UAS mishap data makes it difficult to find IO-related EHF mishap data. The mishaps data shown in this study were extracted from other studies, while some AIB reports were obtained through the Freedom of Information Act (FOIA). DoD UAS mishaps are divided into four classes (A, B, C, and D) based on their severity in terms of economic impact and loss of human life (from most costly to the least) (Williams, 2004). Table 3 defines each of the accident classes.

Table 3 – U.S. Army’s Accident Classification Classes (Williams, 2004)



Class A	Class B	Class C	Class D
An accident in which the resulting total cost of property damage is $1,000,000 or more; an Army aircraft or missile is destroyed, missing, or abandoned; or an injury and/or occupational illness results in a fatality or permanent total disability.	An accident in which the resulting total cost of property damage is $200,000 or more but less than $1,000,000; an injury and/or occupational illness results in permanent partial disability, or when three or more personnel are hospitalized as inpatients as the result of a single occurrence.	An accident in which the resulting total cost of property damage is $20,000 or more but less than $200,000; a nonfatal injury that causes any loss of time from work beyond the day or shift on which it occurred; or a nonfatal occupational illness that causes loss of time from work or disability at any time.	An accident in which the resulting total cost of property damage is $2,000 or more but less than $20,000.

Many of the UASs from Groups 2 and 3 cost less than $100k, and their repair (when vehicle is not completely destroyed) may stay well below the $20k reporting requirements established for all branches (Gertler, 2012; Paur, 2009). Of all the military branches, only the U.S. Army is required to report Class D mishaps (Williams, 2004). Therefore, many mishaps from IO-related EHF issues in a UAS GCS might not be reported. Furthermore, there is no requirement to report if a mishap is narrowly avoided. Although UAS mishap studies point to a sizeable involvement of EHF in GCS IO-related mishaps, the limited availability of mishap data hampers the ability to randomize sample selection for this research.

3.5.2. UAS Mishap Studies

Studies have been conducted to help determine the root cause of the high number of UAS mishaps. Some of these studies indicate human factors are involved in 50% to 69% of UAS mishaps. Of these, 16% to 25% of mishaps are associated with EHF shortfalls in UAS GCS designs (Manning, et al., 2004; Rogers, et al., 2004; Thompson & Tvaryanas, 2005; Thompson & Tvaryanas, 2008; Williams, 2004). The varying results from these studies are due to the taxonomies/models used to perform these analyses. Below is an overview of studies:

- Manning studied human factors in U.S. Army UAS mishaps. He used the HFACS model to evaluate the mishaps. His findings linked 61% of UAS mishaps to human factors, while 19% of the 61% were associated with EHF in UAS GCS. He attributed them to poor ergonomic design of control layouts and input devices (e.g., position/location of buttons/switches, wrist bent angle when using mouse, etc) (Manning, et al., 2004).
- Rogers conducted a study using the human-system issues taxonomy to evaluate the role of human factors in UAS mishaps. His findings linked 69% of UAS mishaps to human factors, while 16% of the 69% were associated with EHF in UAS GCS. To minimize EHF issues in UAS GCS, he recommended that UAS developers focus on human-system integration with displays and input devices during design and testing of UAS GCSs (e.g., mouse, keyboard, joystick, etc) (Rogers, et al., 2004; Williams, 2004).
- Thompson studied 221 Class A, B, and C UAS mishap reports that covered a 10-year period. The reports were evaluated for human factors using the (non-DoD) HFACS model. The results showed that human factors were involved in 60% of all mishaps, and 25% of the 60% were attributed to the EHF in UAS GCSs. His study also recommended steps to optimize the UAS GCS interface by improving the layout of input devices and displays for a better clearance/ergonomic fit for operators (e.g., mouse, keyboard, joystick, etc) (Thompson & Tvaryanas, 2005).

- Thompson studied 95 UAS mishap reports using the DoD HFACS model. The study identified 433 instances of human factors leading to mishaps. The results showed 50% of mishaps were related to human factors, and 19% of the 50% were associated with EHF in UAS GCS. He found design/clearance for input controls (e.g., mouse, keyboard, joystick, etc.) and display characteristics (e.g., viewing angle, alignment, etc.) to be the latent failures in UAS GCS EHF related mishaps (Thompson & Tvaryanas, 2008).

3.5.3. UAS GCS EHF Related Mishaps and Similarities with CWS EHF

The statistics attest to the fact that the UAS GCS IO-related EHFs have played a significant role in causing a high number of UAS mishaps. Below are examples of UAS mishaps in which poor IO interface design led to EHF in the UAS GCS, while similar examples of CWS EHF issues are described for comparability.

In 2001 and 2005, two individual Class A UAS mishaps were associated with UAS GCS display mounting causing high levels of glare. The manufacturer of both UAS GCSs did not employ EHF standards in their designs. In the first instance, a fixed-mount support was used for mounting the display and could not be adjusted to avoid glare. The operator misread the air speed due to the glare. This resulted in an inordinately fast approach, hard landing, and loss of a $1.5 million UAS. In the second instance, lighting in a UAS GCS resulted in glare on the display screen. The operator tried to adjust the display and managed to reduce the amount of glare, but could not remove the glare completely. The operator misread the UAS landing confirmation and proceeded with an engine shutoff command while the UAS was in the air. This resulted in the loss of a $4.35 million UAS. Similarly, when using CWSs in an office environment, outside light sources (e.g., lamps, outdoor light, reflection from reflective surfaces, etc.) often distract users, which could result in misinterpretation of text on displays (Anshel, 1994).

A 2006 study associated UAS mishaps with UAS GCS interface design. The UAS GCS manufacturer did not employ EHF standards in its design. The landing gear button was placed in an awkward location on the side of a joystick. The awkward location of the landing gear button caused an improper reach and straining of thumb. As the UAS was approaching the landing strip, the operator tried to reach for the landing gear switch on the joystick, while holding the joystick. In this case, the operator mistakenly pressed the ignition switch and shut off the UAS engine. This was a Class A mishap and resulted in the loss of a $1.5 million UAS. Similarly, when using a CWS in office environment, the placement of buttons and controls that hinders proper operator posture can lead to mistakes (Yang et al., 2009).

A UAS mishap in 2009 was attributed to a UAS GCS interface design. The manufacturer of the UAS GCS did not employ EHF standards in its design. The mishap investigation revealed that the keyboard and trackball had been installed too closely to each other on the flat surface of the UAS GCS. Just after a landing touchdown, the operator hastily used the trackball to get through control menus. He inadvertently hit a key on the adjacent keyboard, which updated UAS destination coordinates and caused it to veer off the landing strip. In this incident, the UAS was salvageable. This was a Class B mishap and resulted in the loss of $350,000 in damages. Similarly, when using a CWS in an office environment, not enough clearance for IO devices can lead to unintended mistakes and erroneous data entries (Soares et al., 2012; Yang, et al., 2009).

A UAS mishap in 2010 was attributed to a UAS GCS interface design. The manufacturer of the UAS GCS did not employ EHF standards in its design. The mishap investigation revealed that the UAS GCS operator had acquired "tennis elbow" (e.g., strained tendon) from operating the joystick while resting his elbow on his seat's armrest, which was positioned too high. The joystick used in the UAS GCS had a maximum displacement angle of 55 degrees, while the armrest height also was nonadjustable. When the UAS was landing, the joystick was moved to the left, causing the wing to hit the runway and resulting in a fiery crash. The report also revealed that the joystick movement during landing may have been unintentional, and could have been caused by sudden pain in the elbow. This was a Class A mishap and resulted in a loss of a $2.75 million UAS. Similarly, when using CWS in an office environment, non-ergonomic seating often causes musculoskeletal discomfort. Extreme angles of arm and wrist positions and joints also can lead to such discomfort, which may result in work-related stress and unintentional errors (May, Reed, Schwoerer, & Potter, 2004).

A UAS GCS operator who flies a Group 4 autonomous UAS was recently interviewed. He revealed that he had previously entered wrong command data using UAS GCS keyboards and/or mouse devices at least a dozen times during the last five years. He attributes many of these incidents to misaligned displays. The display is mounted a bit too high and makes it uncomfortable to look up when confirming entered data. The most recent input error had occurred in late 2011. Although the erroneous data were transmitted to the UAS, abnormal behavior from the UAS made him realize his mistakes in many of the cases. The command data mistakes were minor enough and he was able to fix them without resulting in a serious UAS mishap. To his benefit, most of these mistakes were made while the UAS was at a high altitude. This allowed him to avoid a mishap such as a UAS ground impact at lower altitudes. Although all of these mishaps were avoided, these may be properly classified as near misses. In his case, he is not required to report these incidents. These mistakes do become part of the UAS data log and are not analyzed to determine a cause. Similarly, when CWS display viewing angle is not aligned properly for operator viewing, it can causes neck and shoulder discomfort and/or unintended errors (S. L. Sauter, L. M. Schleifer, & S. J. Knutson, 1991). Figure 11 shows EHF issues with a UAS GCS IO interface (e.g., left photo—improper arm and wrist support; right photo—improper angle for joystick operation and viewing displays).

Figure 11 – UAS GCS IO EHF Issues (Goldfinger, 2005)

3.6. ANSI/HFES-100, 2007

Individualized CWSs have been the subject of intense scrutiny by cognitive psychologists and engineers for at least three decades. In other words, EHF research of CWSs is a well-established discipline (HFES, 2007). The Human Factors and

Ergonomics Society (HFES) is an internationally recognized nonprofit organization. HFES was founded in 1957 and has an American National Standards Institute (ANSI) approved standard for Ergonomic Human Factors Engineering (EHFE) of CWSs (ANSI/HFES-100, 2007). This standard was first introduced in 1988 and has been adopted by the commercial industry (HFES, 2007).

ANSI/HFES-100 provides component-level quantitative parameters that guide engineers to manufacture IO components that are designed around human limitations. The standard also provides system-level requirements that guide engineers in configuring systems that address human limitations to provide an ergonomic environment for its users. This standard has been used to configure ergonomic environments for CWS-based emergency dispatch centers, factories, and power plant control systems (HFES, 2007). ANSI/HFES-100 may be used to evaluate EHF in two categories: Operator Comfort (OC) and IO. The OC is not within the scope of this study and is only included as a reference for future research. Both of the categories are described below (HFES, 2007):

OC: OC provides EHFE specifications for developers to design an ergonomic layout and a comfortable work environment. OC specifies requirements for posture, arm position, viewing, work surfaces, and foot comfort. When properly applied, OC reduces discomfort for operators (Steven L. Sauter, Lawrence M. Schleifer, & Sheri J. Knutson, 1991). Moreover, OC contains requirements for lighting, acoustics, temperature, ventilation, and emissions. Appropriate lighting enhances viewing for workstation displays. Proper acoustic levels minimize unnecessary audio distractions. Proper temperature, ventilation, and emissions create a comfortable work environment. These requirements improve operator productivity and well-being (Corlett & McAtamney, 1988).

Input Output (IO): IO provides specifications based on EHFE principles to design human friendly interfaces for CWS auxiliary IO devices. IO devices addressed by this standard are a keyboard, mouse, puck devices, trackball, joystick, stylus, light pen, tablet, overlay, touch screen, and display (HFES, 2007). This study verifies the applicability of IO category of the standard on UAS GCS IO interfaces.

3.7. Identified EHF – UAS GCS Gaps or Problem Areas

The gaps identified by this study are:

- EHF tools, standards, or models to evaluate UAS GCS IO interfaces that are currently in inventory.
- EHF tools, standards, or models for the design and development of new UAS GCSs.
- EHF tools, standards, or models to evaluate UAS GCS IO interfaces during the acquisition process.

3.8. Literature Review Summary

The DoD has become increasingly reliant upon UASs as its primary platform of choice to achieve U.S. military objectives in the last decade. UAS mishap rates, many of which are attributed to EHF issues in UAS GCS IO interfaces, remain high. An EHF standard for UAS GCS design, development, and evaluation may improve overall operational effectiveness and UAS reliability, and may reduce mishaps.

Chapter 4 – Research Methodology

4.1. Hypotheses

The hypotheses tested in this research are based on research questions generated in Section 2.3. The following three hypotheses were formed:

- **H_1:** The "ANSI/HFES-100 2007" standard's IO category applies to Groups 2 through 5 DoD UAS GCS IO interfaces.
- **H_2:** The IO devices employed by Groups 2 through 5 of DoD UAS GCSs are the same as those listed in the CWS "ANSI/HFES-100 2007" standard's IO category.
- **H_3:** The usability of CWS IO devices is similar to the usability of Groups 2 through 5 DoD UAS GCS IO devices, when operated in normal operation and emergency operation.

If both hypotheses H2 and H3 apply, then H1 also applies. The relationship between research questions and hypotheses is illustrated in Figure 12.

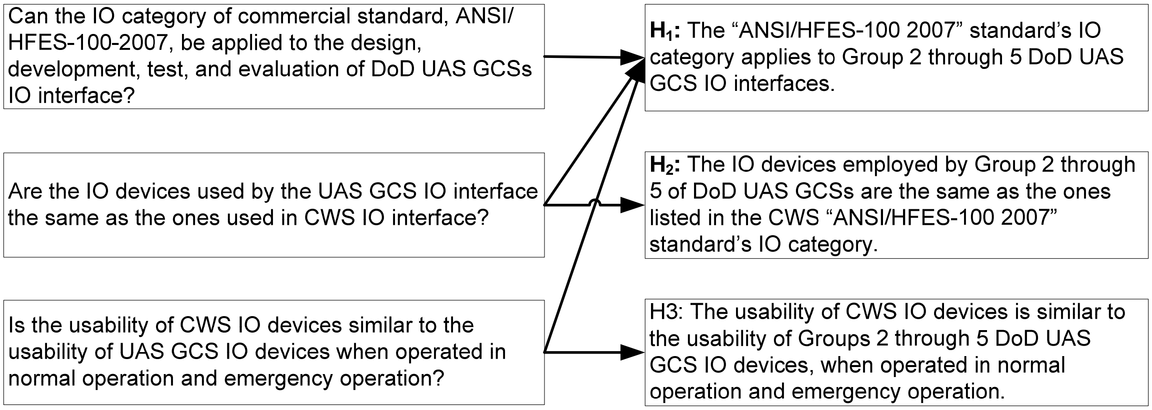


Figure 12 – Relationship between Research Questions and Hypotheses

4.2. Research Design

A mixed-method research design was selected for collecting data and evaluating the applicability of ANSI/HFES-100 IO category to Groups 2 through 5 DoD UAS GCS IO interfaces. Mixed methods have evolved over the years and are a relatively new research approach. Many journals emphasize the application of this method and research experts encourage its use when working with a combination of quantitative and qualitative data (Creswell, 2009). The mixed methods approach allows data analysis and integration at any point during the course of the research (Hanson, Creswell, Clark, Petska, & Creswell, 2005). Mixed method was found to be the right method for this research since both qualitative and quantitative data were used. Data collection and analyses were performed at varying times and in three phases during the course of this research. Data from the earlier phases were input into the latter phases. Figure 13 illustrates the sequence of the three phases. Each of the following subsections describes the research design to capture data for that phase.

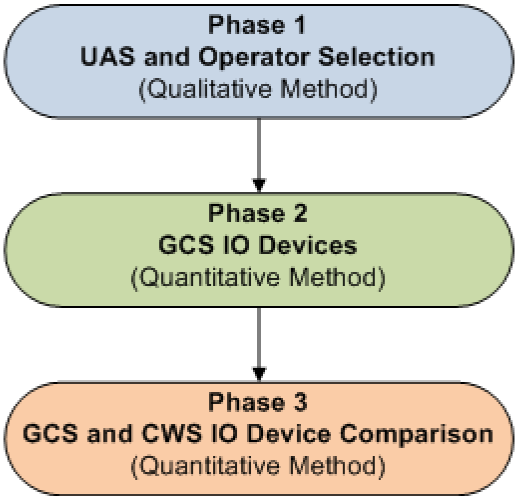


Figure 12 – Three-Step Research Process (Mixed Methodology)

4.2.1. Phase 1: UAS GCS and Operator Selection Purpose

This phase consisted of developing a shortlist of potential UAS GCS candidates and their operators. The UAS GCS subjects were selected based on the following selection criteria: (1) UASs shall be from Groups 2 through 5; (2) UAS GCSs shall employ semi-autonomous or autonomous control mechanism; and (3) an experienced operator shall be willing to complete the measurement instrument for each of the selected UAS GCSs in Phase 2. A UAS GCS measurement instrument Phase 1 (MI-1) was developed to gather this information (See Appendix A). Each UAS GCS operator was required to have at least six months of hands-on flying experience with his or her corresponding UAS GCS. The candidate UAS GCS operators were contacted to assess their qualification and willingness to participate. It was clarified with the operators that their personal (e.g., name, contact information, etc.) and UAS GCS (e.g., manufacturer, name, etc.) information would not be published. The operators also were given a preliminary measurement instrument Phase 2 (MI-2) that contained a sample questionnaire. Typically, most operators were reluctant to provide manufacturer-specific information about their UAS GCSs. By assuring them of confidentiality and providing a sample MI-2, they were given the opportunity to see the simplicity of the study, thus aiding their decision to participate in this study (See Appendix B). Figure 14 provides a sequence of events taken to complete first phase.

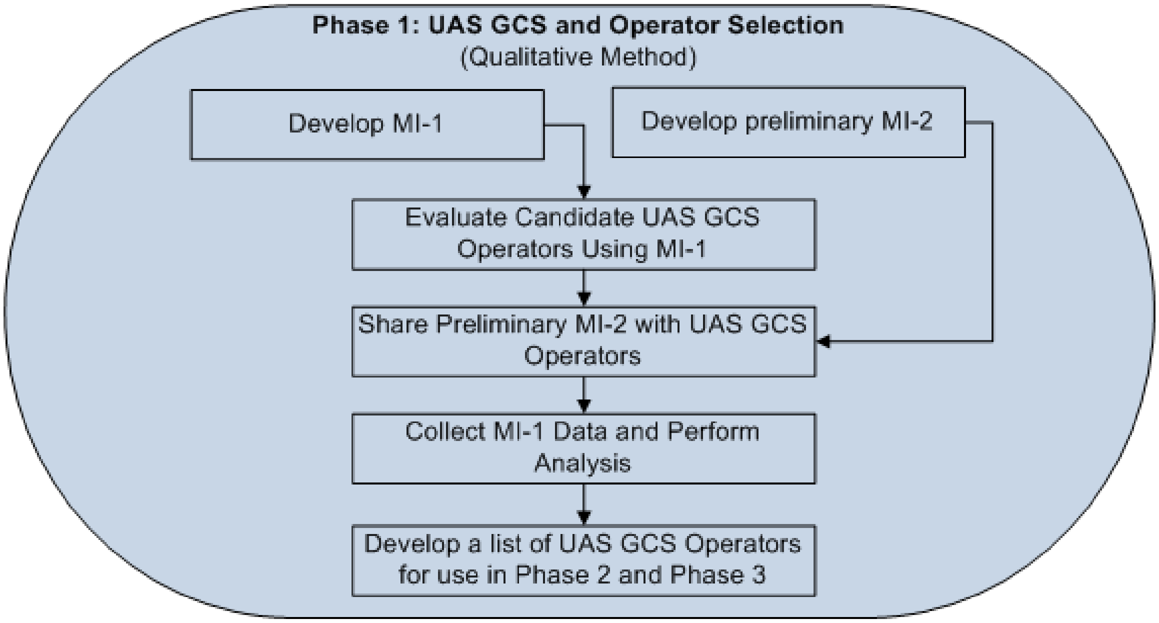


Figure 13 – UAS GCS and Operator Selection (Phase 1)

4.2.2. Phase 2: UAS GCS IO Devices

The MI-2 was designed to be completed by operators of UAS GCSs selected in Phase 2 (See Appendix C). The main purpose of the MI-2 was to clearly and objectively identify the IO devices in each of the selected GCSs to control the corresponding UAS. An extensive literature review failed to yield existing measurement instruments directly applicable to DoD UAS GCSs for comparative analysis and use. IO device lists for the MI-2 were derived from the IO category of the ANSI/HFES-100 standard (HFES, 2007). This was due in part to the absence of a DoD UAS GCS IO standard. A draft MI-2 was developed in conjunction with subject matter experts. Three UAS GCS design engineers were given a hard copy of the draft MI-2 in a face-to-face cognitive interview, in which they were asked to evaluate each of the questions for clarity, accuracy, precision, relevancy, readability, and length. Their feedback allowed modifications and adjustments mainly to the wording of the questions used to collect targeted data. Figure 15 provides an overview of sequential steps taken to complete Phase 2.

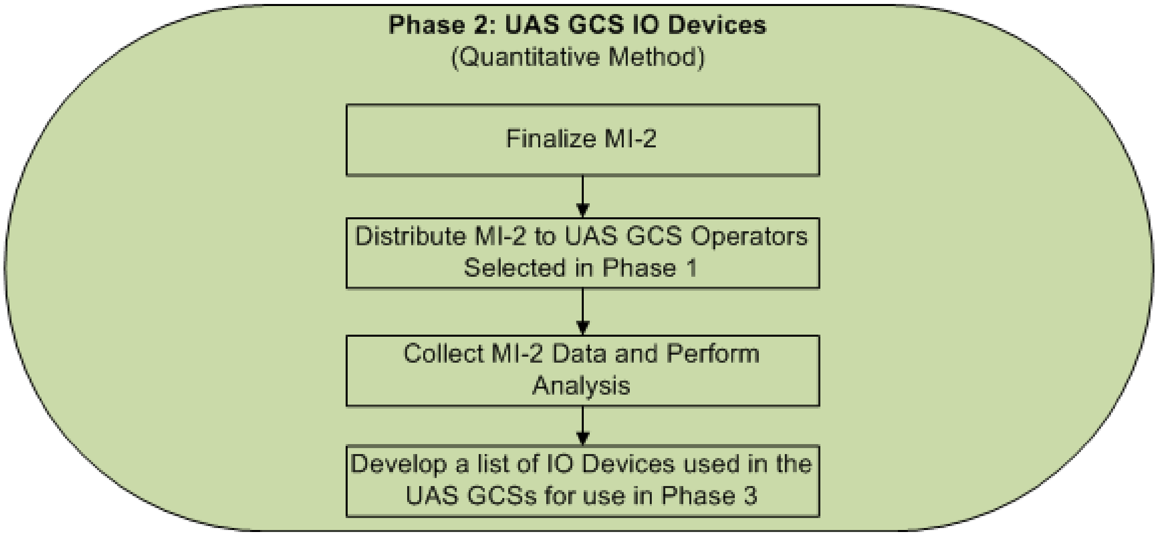


Figure 14 – UAS GCS IO Devices (Phase 2)

4.2.3. Phase 3: UAS GCS and CWS IO Device Comparison

The measurement instrument Phase 3 (MI-3) was designed to be completed by operators of UAS GCSs selected in Phase 1 (See Appendix D). The purpose of the final MI-3 was to clearly and objectively compare the usability of IO devices that were found in both general-purpose CWSs and Groups 2 through 5 DoD UAS GCSs. Using information from Phase 2, IO device similarity in usability between UAS GCSs and CWSs was evaluated by the participants under two different scenarios: (1) normal operation and (2) emergency operations. The literature review did not yield existing measurement instruments to fit this research, but it provided the basic characteristics for IO device usability. These characteristics include physical shape, functionality, physical settings, and software setting of IO devices. Physical shape refers to the shape of the IO device. Functionality refers to the use of the IO device, e.g., using the mouse to drag text or to select a field. Physical settings refer to the different adjustments of the IO device, e.g., keyboard angle or display angle adjustment. The software settings allow the user to adjust IO device interaction with hardware, e.g., speed of the mouse cursor with respect to its physical movement or mouse button settings for its use in right hand versus left hand (Eason, 1991; Keraminiyage, Amaratunga, & Haigh, 2009; Sibert & Marchionini, 1993). These characteristics were then used to develop a single MI-3 to assess IO device similarities. A draft MI-3 was shared with two A+ certified computer support professionals to assess its validity. The A+ certification holders have foundation-level knowledge of computers and IO devices (Rubenstein, 2003). The input received from computer support professionals validated the questions asked in the measurement instrument. The draft MI-3 was then shared with a UAS GCS operator to assess the clarity, accuracy, precision, and relevancy. The operator's positive feedback contributed to the finalization of the measurement instrument. The final MI-3 was developed to be completed by UAS GCS operators (See Appendix D). Figure 16 provides an overview of sequential steps taken to complete Phase 3.

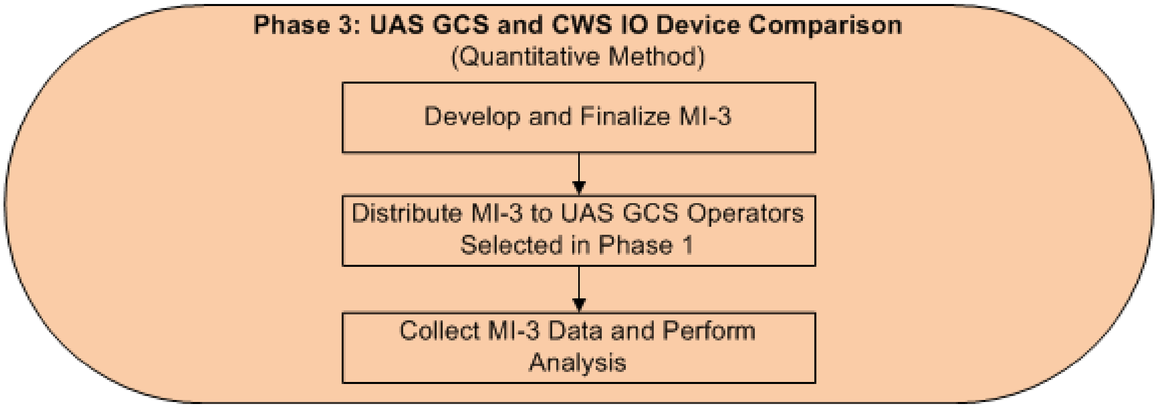


Figure 15 – UAS GCS and CWS IO Device Similarity (Phase 3)

4.3. Measurement Instruments

This section has three subsections – one for each phase of the research. Each of the subsections describe the factors and selection criteria used to develop the measurement instrument; and provide a brief overview on the type of questions and scales used to quantify data for that phase.

4.3.1. Phase 1: UAS GCS and Operator Selection

The MI-1 evaluated the following four factors: (1) UAS Group, (2) GCS configuration, (3) control mechanisms, and (4) participation. The UAS Group consisted of four selection criteria: (1) Group 2, (2) Group 3, (3) Group 4, and (4) Group 5 (Weatherington, 2010). GCS configuration consisted of two selection criteria: (1) fixed and (2) handheld. Control mechanisms consisted of three selection criteria: (1) ground control, (2) semi-autonomous, and (3) autonomous (Larm, 1996; Mouloua, et al., 2001; Nas, 2008). Participation consisted of three selection criteria: (1) full, (2) data only, and (3) none. These factors and selection criteria were derived from the literature review and data needs of the research. The relationship between factors and selection criteria are shown in Figure 17.

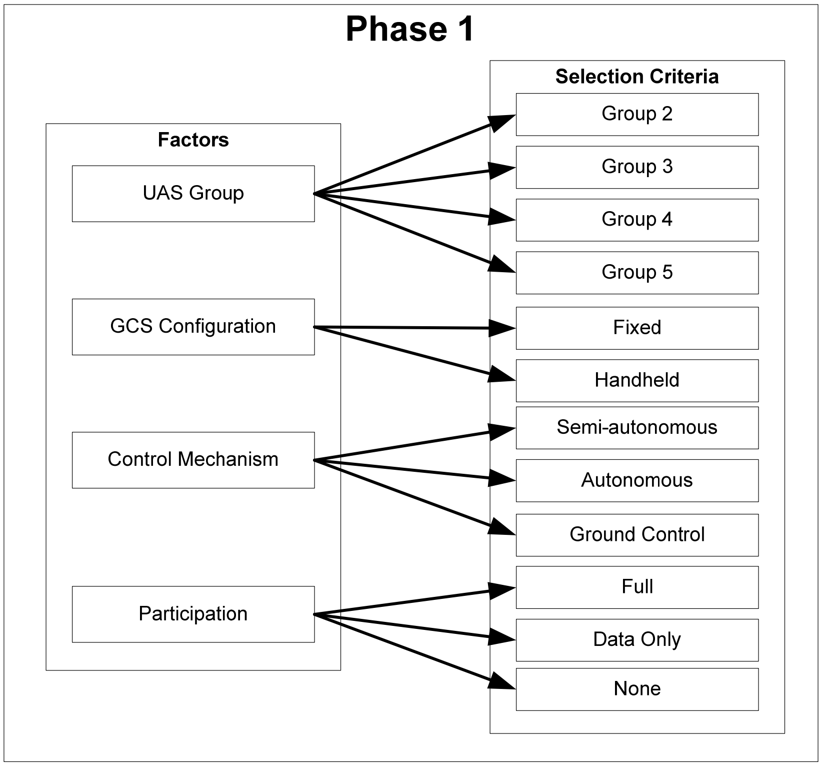


Figure 16 – Relationship between Factors and Selection Criteria

The MI-1 was designed to be completed through interviews with UAS GCS operators. MI-1 used a combination of open and closed-ended research. For closed-ended research questions, simple “yes” or “no” questions also were utilized. The closed-ended research questions were used to help gauge the UAS GCS operator’s willingness to participate in this study (e.g., Would you like to provide further information and/or participate in this research?, Would you be willing to provide access to a knowledgeable operator for a survey?, etc.). Open-ended question were used to confirm UAS GCS selection criteria (e.g., What control mechanism is used in this UAS GCS design?, To what group does this UAS belong?, etc.). A final copy of MI-1 is in Appendix A.

4.3.2. Phase 2: UAS GCS IO Devices

The MI-2 evaluated two factors: (1) demographic information and (2) IO devices. Demographic information consisted of three open-ended questions: (1) operator age, (2) operator experience, and (3) UAS GCS identity. IO devices consisted of 10 selection criteria: (1) display, (2) keyboard, (3) mouse, (4) trackballs, (5) joystick, (6) touch-panel, (7) styli and light pen, (8) tablets and overlays, (9) puck device, and (10) other (HFES, 2007). The UAS GCS IO selection criteria “other” (selection criteria ‘10’ above) consisted of additional space for operators to write-in IO devices that were not listed in the measurement instrument. The IO devices identified by the “other” write-in selection criteria were not included in the Phase 3 measurement instrument. Their only purpose is to determine the percentage of IO devices that are employed by UAS GCSs and are covered by the ANSI/HFES-100 2007 IO category of the standard. Operators also were asked to describe UAS GCS IO device usage modes (e.g., departure/takeoff, in-flight maneuvers, and return/landing). The research questions were designed to measure the degree to which CWS IO devices were used in UAS GCS designs. The relationship between factors and selection criteria is shown in Figure 18.

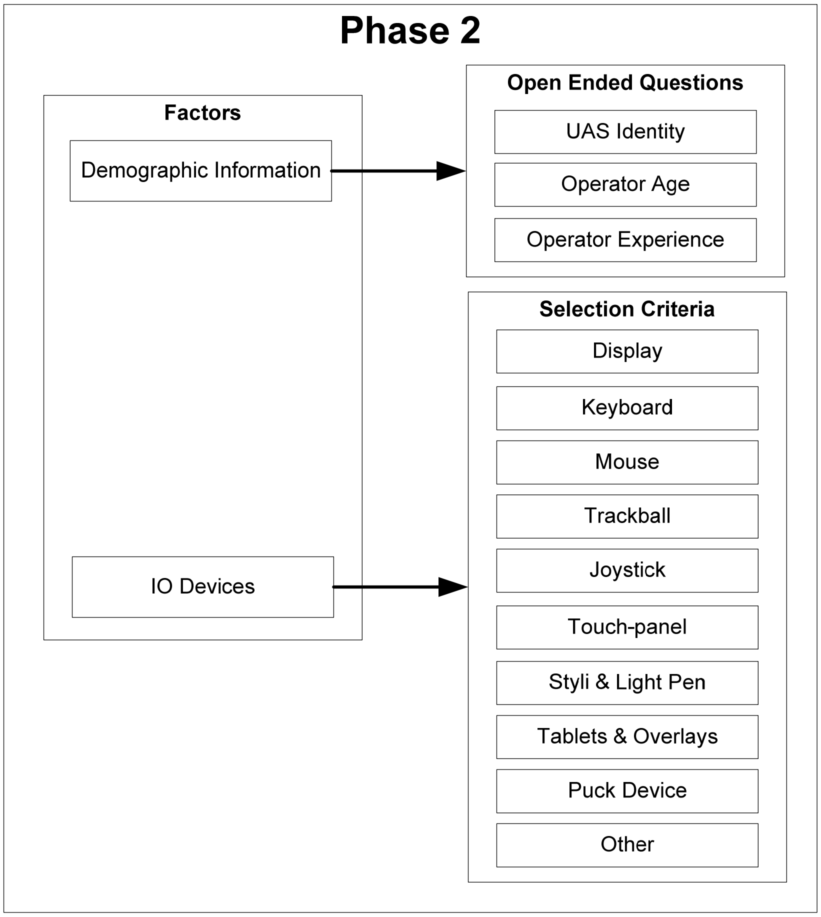


Figure 17 – Relationship between Factors, Open Ended Questions and Selection Criteria

The MI-2 was designed to be completed by qualified operators who were selected to provide responses on 24 different types of UAS GCSs in Phase 1. The research questions were intended to be simple and straightforward. Contradictory, negative research questions were avoided to maximize consistency of responses from UAS GCS operators. The final measurement is in Appendix C.

4.3.3. Phase 3: UAS GCS and CWS IO Device Comparison

The MI-3 assessed UAS GCS IO usability under two different factors: (1) normal operation and (2) emergency operations. Six of the nine IO devices listed in the MI-2 selection criteria were identified (by the operators) to be used in the DoD UAS GCSs. Under the “other” write-in selection criteria of MI-2, the operators identified one additional IO device (gamepad). As explained in Section 4.3.2, the “other” selection criteria for write-in IO devices was not intended for inclusion in the MI-3. The GCS IO devices included in MI-3 were: (1) display, (2) keyboard, (3) mouse, (4) trackball, (5) joystick, and (6) touch-panel (HFES, 2007). Each was evaluated for similarity in usability between CWSs and UAS GCSs on the following four evaluation criteria: (1) physical shape, (2), functionality, (3) physical settings, and (4) software setting (Eason, 1991; Keraminiyage, et al., 2009; Sibert & Marchionini, 1993). The relationship between IO devices and evaluation criteria is shown in Figure 19.

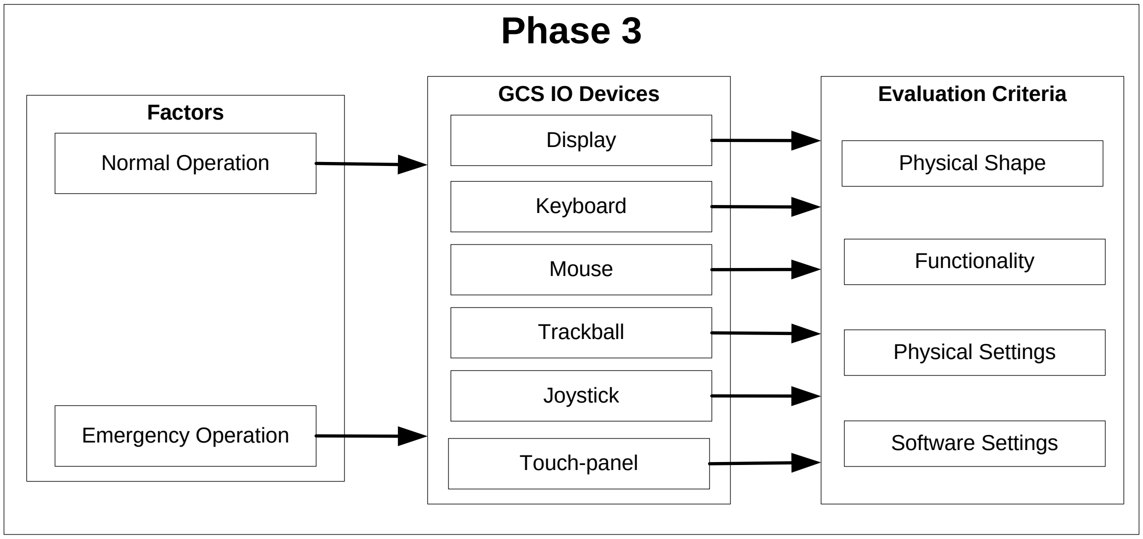


Figure 18 – Relationship between Factors, UAS GCS IO Devices, and Evaluation Criteria

The MI-3 was designed to be completed by the UAS GCS operator. In this case, a seven-point Likert-scale was used to provide a wider variety of choices as opposed to a five-point scale. This helped maximize variability of the response data. The scale was organized in increasing levels of agreement: (1) strongly disagree, (2) disagree, (3) somewhat disagree, (4) neutral, (5) somewhat agree, (6) agree, and (7) strongly agree. The scale was organized in this manner to help minimize the possibility of incorrect responses and inadvertently reverse encoding the response data during analysis (James & Lee, 2011). To avoid misunderstanding and confusion, a similar research scale was used for all closed-ended questions in Phase 3. The final MI-3 is in Appendix D.

4.4. Data Collection

This section has three subsections, one for each phase of the research. Each of the subsections describes the methods employed to capture research data for that phase.

4.4.1. Phase 1: UAS GCS and Operator Selection

Phase 1 of the research was mainly conducted in the public domain. Literature searches, interviews, professional networking, and Internet searches were used to identify candidate UAS GCSs. Developers of several UAS GCSs were contacted to provide information regarding the UAS and GCS. Most of the information was gathered through interviews and conversations. The collected information was first entered in MI-1 (shown in Appendix A). The information was later converted and saved in a database. Qualitative data were gathered from Phase 1.

4.4.2. Phase 2: UAS GCS IO Devices

DoD UAS GCS operators located in the immediate vicinity were interviewed in person. Due to the small number of UAS GCSs and operators in the study, it was critical to maximize the response rate and data validity. Efforts were made to seek out and obtain inputs from as many UAS GCS operators as possible, even if they were outside of the immediate vicinity. Therefore, local as well as remote UAS GCS operators were visited numerous times, frequently contacted, and gently reminded to satisfy their participatory requirements for this study by submitting their data in a timely manner. The collected data were moved into a database. Quantitative data were gathered from Phase 2.

4.4.3. Phase 3: UAS GCS and CWS IO Device Comparison

Operators who were on the shortlist from Phase 1 were given hardcopies of the MI-3 in person. A completed MI-3 was collected in person. A quick review was performed to check for completion or errors to further enhance reliability and validity of collected data. The collected data were moved into a database. Quantitative data were gathered from Phase 3.

4.5. Data Analysis

This section has three subsections, one for each phase of the research. Each of the subsections describes the methods employed to perform data analysis for that phase.

4.5.1. Phase 1: UAS GCS and Operator Selection

The data analysis strategy in this phase was based on human judgment. First, the operators who did not express a desire to participate in this study were excluded from further analysis. Second, the data were used to determine if the UAS GCS represented by the operator belongs to a Group 2 through Group 5 UAS and whether the GCS employed semi-autonomous or autonomous controls. Otherwise, that UAS GCS platform was excluded from the study. Therefore, this phase and data may be properly termed as an initial screening, selection, and sampling phase, upon which latter phases would depend.

4.5.2. Phase 2: UAS GCS IO Devices

The data analysis strategy for Phase 2 was simple statistical analysis. Simple descriptive statistics were used to determine the types, kinds, and frequency-of-use for each of the IO devices along with their use (e.g., takeoff, in-flight, and landing). Pattern analysis of the data provided an early validation of the basic goals, objectives, research question assumptions, hypotheses, and overall direction of this study.

4.5.3. Phase 3: UAS GCS and CWS IO Device Comparison

The data analysis strategy for Phase 3 was statistical in nature. Therefore, data analysis employed non-parametric statistical analysis. The data for normal and emergency operations were of the same size. The response data from the operators in normal operation were compared with the operator response data for emergency operation using Mann-Whitney U, a non-parametric statistical hypothesis test.

$$U_1 = n_1 n_2 + \frac{n_2(n_2+1)}{2} - R_2$$

$$U_2 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1$$

$$U_1 + U_2 = n_1 n_2$$

Where n_i is the number of data pairs, R_i is the sum of ranks for sample 1 and sample 2, and lastly the $\alpha = 0.05$. The Mann-Whitney U test helped determine if the usability of UAS GCS IO devices under normal situation and under emergency operation is the same.

4.6. Threats to Reliability and Validity

Several steps were taken to ensure the reliability and validity of data collection and analysis. The well-established ANSI/HFES-100 standard IO category was used as the basis for design of the conceptual model. That is, its six IO devices intended for general-purpose CWSs were used as a basis for analyzing DoD UAS GCS IO devices. It was critical to collect data from relevant UAS GCSs and expert operators; therefore, the first phase was used to ensure all UASs and GCS operators met the criteria and were qualified to provide inputs for further analysis and evaluation. To maximize reliability and validity, subject matter experts reviewed the measurement instruments. Simple scales were selected to minimize recording, collection, encoding, and analysis errors. The operators were contacted to provide clarification on their completed measurement instrument if their input was not understood properly; this helped ensure correct encoding when data were transferred in electronic form.

Some of the threats to reliability and validity must be noted as well. Original measurement instruments were designed for all phases because preexisting ones with proven reliability and validity considerations were not available. However, to minimize this threat, they were designed in conjunction with subject matter experts, and cognitive interviews with GCS engineers and operators were used to enhance content validity.

4.7. Ethical and Privacy Considerations

Every opportunity to maximize ethical and privacy considerations was utilized. A scientific research methodology was employed to maximize the objectivity of the study. A multiple phase mixed methods approach with both qualitative and quantitative elements was used, rather than a single, narrowly focused study designed to bias the outcome. The study was open and transparent from beginning to end, and nothing was kept hidden from the reader in terms of research questions, conceptual model, methodology, analysis, or conclusions. Subject matter experts within academia and the DoD UAS GCS community were consulted from beginning to end to evaluate the assumptions, research design, study execution, findings, and development of the written research study. Furthermore, actual UAS GCS names were not reported to maintain the integrity and market reputation of the developers. Information on the psycho-sociological profiles of UAS GCS operators was neither collected, implied, nor intended. The results of this study were published in the open public as a scientific journal article, which was subject to rigorous peer review, minimizing ethical and privacy considerations.

4.8. Research Method Summary

Due to the distinct qualitative and quantitative nature of this research, a mixed methods research approach was taken. The study was conducted in three phases: (1) UAS GCSs that fit the research criteria were identified, (2) IO devices that are used in the UAS GCS designs were identified, and (3) the level of similarity in usability of IO devices between the UAS GCS and CWS under both normal and emergency operations was analyzed. The data were gathered from the public domain, data calls and requests from UAS GCS designers and their operators, interviews (e.g., subject matter experts, engineers, researchers, operators, etc.), and by using multiple data collection instruments. Data analysis technique was identified for each of the three phases individually. The research study itself was designed to maximize reliability and validity of the findings and was conducted to ensure ethical and privacy considerations to the maximum extent possible.

Chapter 5 – Data Analysis and Findings

5.1. Data Definition and Analysis

5.1.1. Phase 1: UAS GCS and Operator Selection

The purpose of this phase was to identify a list of UAS GCSs that could be included in the study. After a thorough research in public domain, a total of 40 possible UAS GCSs were selected for inclusion in the analysis (UVS, 2011). Program managers and engineers were then contacted for further information and to access their willingness to participate. After a thorough evaluation, a shortlist of 24 Groups 2 through 5 UAS GCSs was made. The shortlist included seven UAS GCSs from Group 2, five UAS GCSs from Group 3, six UASs from Group 4, and six UASs from Group 5 (see Figure 20). All 24 of the UAS GCSs included in the shortlist were fixed GCSs (they were not deployable or handheld). The control mechanism was evenly split; 12 UAS GCSs employed semi-autonomous control mechanisms and the remaining 12 UAS GCSs employed autonomous control mechanisms (see Appendix E). The interviews with program managers and engineers from all 24 UAS developers indicated that none of them had applied any human factors standard in the design, development, and evaluation of their GCSs. The data collected were in accordance with the research design of Phase 1; therefore, a list of UASs and their corresponding GCS operators were included on a list of potential candidates for Phase 2 & 3 participation.

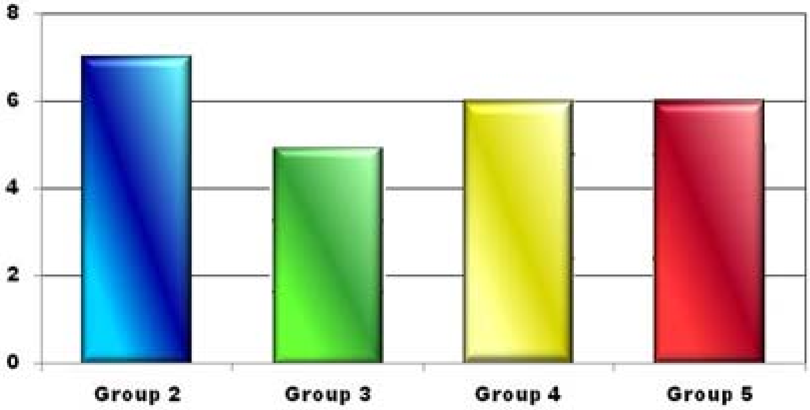


Figure 19 – Groups 2 through 5 DoD UAS GCSs Utilized in this Study

5.1.2. Phase 2: UAS GCS IO Devices

In Phase 2, 24 MI-2s were distributed. Responses from 20 UAS GCS operators were collected; four operators were on work-related travel and were not able to complete MI-2. The 20 MI-2s received came from seven UAS GCSs from Group 2, three UAS GCSs from Group 3, four UAS GCSs from Group 4, and six UAS GCSs from Group 5. The UAS GCS flying experience for operators responding to the MI-2 was 6.5 years on average, while the maximum was 15 years and the minimum was two years. Figure 21 shows the frequency of IO devices found in the UAS GCSs. “CWS IO” refers to devices identified by the ANSI/HFES-100 standard’s IO category and “Non-CWS IO” refers to devices not covered by the IO category of the standard.

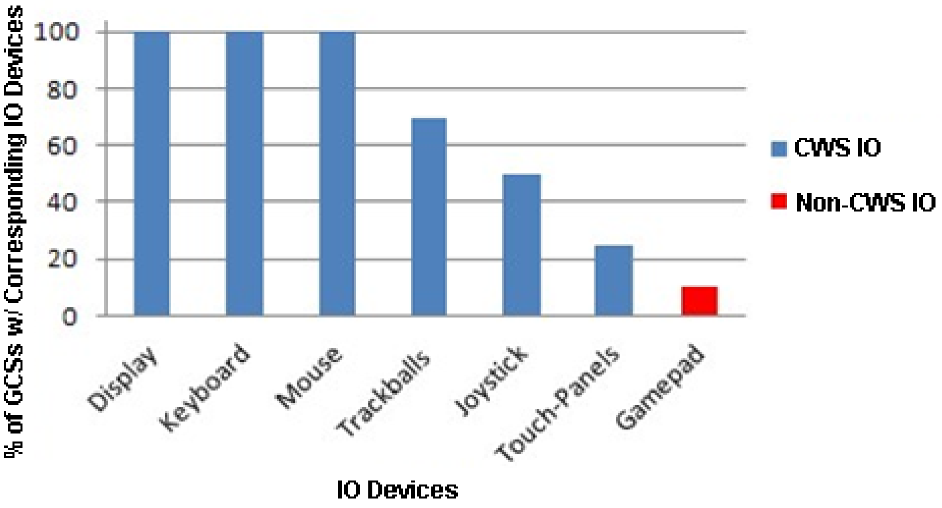


Figure 20 – ANSI/HFES-100 Compliant IO Devices Used in DoD UAS GCSs

The 20 completed MI-2s identified six of the nine IO devices listed its selection criteria (Figure 21, CWS IO "blue"), one additional IO device gamepad was identified under the "other" write-in selection criteria of MI-2 (Figure 21, Non-CWS IO "red"). From all IO devices identified by MI-2, only gamepad was not covered by the ANSI/HFES-100 standard's IO category and it was found to be used only in two UAS GCSs. This helps confirm the theory that DoD UAS GCS IO devices are nearly indistinguishable from general-purpose CWSs. A general analysis of each of the UAS GCS IO devices follows:

- **Display**: A device used in CWSs to display text, data, and graphics to users (also referred to as a monitor). The purpose of the UAS GCS display is similar to that of a CWS. Display is used by the operator during takeoff, landing, and in-flight operations. Display is an integral part of the GCS and operators heavily rely on it for health and status monitoring, geo-location, and overall control and maneuvering.

- **Keyboard**: A device that provides CWS users with an interface to enter alphanumeric data. Its purpose in UAS GCSs is similar to that of a CWS. The keyboard allows operators to enter pre-flight configurations, in-flight modifications, and pre-landing adjustments. Keyboards are an important device in the GCS and were found in all of the UAS GCSs in this study.
- **Mouse and Trackball**: Devices that provide CWS users with the ability to manipulate graphical user interface controls by pointing, clicking, and performing other fine-grained adjustments. The purpose of these devices in GCSs is to operate computer programs, select data input fields, and make fine-grained adjustments by clicking "+" or "–", which is very similar to that of a CWS. They are used by the operators during takeoff, landing, and in-flight operations. Mice and trackballs were found in most (if not all) of the GCSs studied. These two devices are interchangeable; however, the majority of the GCS interfaces used both the mouse and trackball, while some had one or the other.
- **Joystick**: A device that provides CWS users with a hand-operated stick that pivots on a base and reports its angle and/or direction to the CWS. A joystick is similar to the center stick used by pilots to control aircraft. A joystick provides the most efficient, user-friendly, and easy-to-use means to input angle and direction into the GCS, much like its use in a CWS. A joystick is used by the operator to conduct in-flight maneuvers only. Joysticks were found in 50% of the GCSs in the study.

- **Touch Panel**: A device that provides CWS users with a touch-sensitive panel for controlling a system without the use of a keyboard, mouse, or trackball. Its purpose in a GCS is similar to that of a CWS. Touch panels are very similar to the touch screens on modern-day smart phones or tablets. However, their function is that of virtual buttons, switches, dials, and other analog controls versus physical ones. Touch panels are used during pre-flight configuration, in-flight modifications, and pre-landing adjustments. Touch panels were found in 25% of the UAS GCSs in this study.
- **Gamepad**: Gamepads (also known as Joypads and Control Pads) are typically not used with CWSs. In fact, they are supplied with gaming consoles such as PlayStation and Xbox. The user holds the gamepad in his or her hands to operate it with both thumbs. Shoulder buttons are often included, which can be operated with an operator’s index fingers. When used with gaming consoles, gamepads provide a means to control an on-screen object or allow the user to move through menus to make selections. Its use in the GCS is limited to surfing through menus and making selections. Gamepads are used during pre-flight configuration, in-flight modifications, and pre-landing adjustments. Gamepads were found in 10% of the GCSs.

We can conclude from the above information that not only the IO devices are physically the same in CWS and UAS GCS, but their purpose (inputting data) also is very similar. Table 4 shows IO devices used in the GCSs from each of the UAS Groups 2 through 5.

Table 4 – IO Device Usage in Groups 2 through 5 UAS GCSs

IO Devices	Group 2	Group 3	Group 4	Group 5	Overall
Display	100%	100%	100%	100%	100%
Keyboard	100%	100%	100%	100%	100%
Mouse	100%	100%	100%	100%	100%
Trackball	57%	100%	75%	80%	70%
Joystick	72%	67%	50%	17%	50%
Touch-Panel	15%	0%	25%	60%	25%
Tablet and Overlay	0%	0%	0%	0%	0%
Puck Device	0%	0%	0%	0%	0%
Styli and Light Pen	0%	0%	0%	0%	0%
Gamepad	14%	0%	25%	0%	10%

The display, keyboard, and mouse IO devices are very common. They are used in all 20 UAS GCSs that were studied. The trackball, joystick, and touch-panel are common in all UAS GCS groups (with some exceptions). The trackball and joystick are common in more than 50% of all UAS GCSs. The use of the touch-panel dropped off significantly and was absent in Group 3 UAS GCSs. The tablet and overlay, puck device, and styli and light pen were not used at all. A gamepad was occasionally used. Table 5 shows the IO devices used in semi-autonomous and autonomously controlled UAS GCSs.

Table 5 – IO Device Usage in Semi-autonomous Vs. Autonomous UAS GCSs

IO Devices	Semi-autonomous	Autonomous
Display	100%	100%
Keyboard	100%	100%
Mouse	100%	100%
Trackball	90%	50%
Joystick	100%	0%
Touch-Panel	10%	40%
Tablet and Overlay	0%	0%
Puck Device	0%	0%
Styli and Light Pen	0%	0%
Gamepad	0%	20%

All semi-autonomous and autonomously controlled UAS GCSs used a display, keyboard, and mouse. The trackball is found in a majority of the semi-autonomous UAS GCSs, while half of the autonomous UAS GCSs employ it. The joystick is only found in semi-autonomous UAS GCSs. That is because its primary function is to directly control the UAS, whereas autonomous-controlled UASs do not allow direct operator control of the aircraft.

There were a total of 127 IO devices identified on 20 studied UAS GCSs and only two (gamepads) were not compliant to ANSI/HFES-100 IO category. From these statistics, we can calculate that nearly 98% of all IO devices used in the UAS GCSs are specified by ANSI/HFES-100 IO category. Based on this information, we can accept Hypothesis 2 that ANSI/HFES-100 IO specifications apply to UAS GCS IO devices.

The IO devices employed by Groups 2 through 5 of DoD UAS GCSs are the same as those listed in the CWS “ANSI/HFES-100 2007” standard’s IO category.

5.1.3. Phase 3: UAS GCS and CWS IO Device Comparison

In Phase 3, 24 MI-3s were distributed. Responses from 23 UAS GCS operators were collected; one operator was on travel and did not complete MI-3. Table 6 illustrates the response data for normal operation of ANSI-compliant IO devices.

Table 6 – UAS GCS-CWS IO Comparison (Normal Operation)

Factors	Variables	1 Strongly Disagree	2 Disagree	3 Somewhat Disagree	4 Neutral	5 Somewhat Agree	6 Agree	7 Strongly Agree	Average Score
Display	Physical Shape	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Functionality	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Physical Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Software Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
Keyboard	Physical Shape	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Functionality	0%	0%	0%	0%	0%	9%	91%	6.91/ 7 (99%)
	Physical Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Software Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
Mouse	Physical Shape	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Functionality	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Physical Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Software Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
Trackballs	Physical Shape	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Functionality	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Physical Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Software Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
Joystick	Physical Shape	0%	0%	0%	0%	30%	44%	26%	5.96/7 (85%)
	Functionality	0%	0%	0%	8%	18%	56%	18%	5.83/7 (83%)
	Physical Settings	0%	0%	0%	0%	4%	44%	52%	6.48/7 (93%)
	Software Settings	0%	0%	0%	0%	0%	22%	78%	6.78/7 (97%)
Touch-panel	Physical Shape	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Functionality	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Physical Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Software Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)

For the display, mouse, trackball, and touch-panel, there was a consensus among all operators who completed the measurement instrument. They reported that the UAS GCS IO devices' usability under normal operating conditions is exactly the same as their usability in CWSs (e.g., physical shape, functionality, physical settings, and software settings). For the keyboard, its physical shape, physical settings, and software settings were reported to be exactly the same as the ones used in CWS by all operators, while the majority of the operators (91%) considered its functionality to be exactly the same in CWS. The joystick had the most variation when its use was compared to CWSs under normal operation. For physical shape, physical settings, and software settings, all of the operators either strongly agreed, agreed, or somewhat agreed that the use of the joystick in UAS GCSs under normal operation is similar if not identical to its use in the CWS. For joystick functionality, a minority (8%) of the operators selected neutral (option 4) on the Likert-scale, while 92% either strongly agreed, agreed, or somewhat agreed. It is worth noting that this was the only question that received a neutral.

Table 7 illustrates use of ANSI/HFES-100 IO category compliant devices on Groups 2 through 5 DoD UAS GCSs under emergency operations. Operators were asked to recall a situation in the past when they used each type of device for an unplanned UAS GCS emergency situation. Most UAS GCS operators have experienced near-misses or actual UAS mishaps at some point in the recent past; therefore, they were able to evaluate the adequacy of each of the six major IO devices in these emergency situations.

Table 7 – UAS GCS-CWS IO Comparison (Emergency Operations)

Factors	Variables	1	2	3	4	5	6	7	Average Score
		Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree	
Display	Physical Shape	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Functionality	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Physical Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Software Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
Keyboard	Physical Shape	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Functionality	0%	0%	0%	0%	0%	9%	91%	6.91/ 7 (99%)
	Physical Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Software Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
Mouse	Physical Shape	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Functionality	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Physical Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Software Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
Trackballs	Physical Shape	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Functionality	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Physical Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Software Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
Joystick	Physical Shape	0%	0%	0%	0%	39%	35%	26%	5.87/7 (84%)
	Functionality	0%	0%	0%	13%	26%	48%	13%	5.61/7 (80%)
	Physical Settings	0%	0%	0%	0%	4%	44%	52%	6.48/7 (93%)
	Software Settings	0%	0%	0%	0%	0%	22%	78%	6.78/7 (97%)
Touch-panel	Physical Shape	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Functionality	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Physical Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)
	Software Settings	0%	0%	0%	0%	0%	0%	100%	7.00/7 (100%)

For display, keyboard, mouse, trackballs, and touch-panel, the results between normal and emergency operation remain unchanged. For the joystick, most respondents either somewhat agreed, agreed, or strongly agreed when drawing an analogy between the CWS and UAS GCS joystick. Only 13% of respondents were neutral on comparing CWS and UAS GCS joysticks.

A preliminary comparison analysis of two sets of data from normal and emergency operation of UAS GCSs shows that most of the data lies in the "strongly agree" range (e.g., 100%). The data help make the case that the display, keyboard, mouse, trackball, and touch-panel used in UAS GCSs are in fact very similar to the ones used in CWSs. Furthermore, based on the Phase 3 analysis, the software settings, physical settings, physical shape, and functionality also were found to be very similar. When comparing the joystick in UAS GCS normal and emergency operations, a minor variation (from 8% to 13%) was noted. This is mainly due to the fact that under emergency operations, the operators have to be more careful when moving the joystick because there is satellite link latency involved. The UAS may not instantly respond to GCS inputs from the joystick in real-time (Hancock, et al., 2001; Hansman & Weibel, 2004). The fact worth noting is that none of the operators disagreed (by selecting option 1, 2, or 3 on the measurement instrument) with the joystick's similarity with CWS during normal or emergency operation.

The data from UAS GCSs' normal and emergency operations analysis are equal in sample size and are independent. A Mann-Whitney U test with an α of .05 was used to test the hypothesis (see Table 8).

Table 8 – UAS GCS-CWS Comparability Mann-Whitney U Test Results

Hypothesis Test	Results
Sample Size	23
Alpha α	0.05
P-Value	0.983
Decision	**Accept H_3**

The Mann-Whitney U test results showed acceptance of the hypothesis H_3. With an α of 0.05, there is 95% confidence in the test results. Based on this information, we can accept Hypothesis 3—that usability of six IO devices studied in Phase 3 is similar in both UAS GCS and CWS.

The usability of CWS IO devices is similar to the usability of Groups 2 through 5 DoD UAS GCS IO devices, when operated in normal operation and emergency operation.

Since hypotheses H_2 and H_3 are true, hypothesis H_1 is supported. That is, the ANSI/HFES-100 IO category of the standard can be applied to the UAS GCS IO interface, and its application could lead to a reduction of EHF in GCSs and may reduce EHF associated UAS mishaps.

The "ANSI/HFES-100 2007" standard's IO category applies to Groups 2 through 5 DoD UAS GCS IO interfaces.

5.2. Summary of Data Analysis and Findings

In Phase 1, 24 UAS GCS operators were selected to participate in the study. In Phase 2, 24 MI2s were distributed, while 20 were completed and returned. These results helped identify the six most common ANSI/HFES-100 IO category compliant devices used in UAS GCSs. Phase 2 helped determine that 98% of all IO devices employed by the UAS

GCSs are similar to those used in CWSs. In Phase 3, 24 MI3s were distributed and 23 were completed and returned. Quantitative statistical analysis using Mann-Whitney U test indicated that IO devices and usability between CWSs and UAS GCSs are very similar if not identical. Therefore, there is some evidence to show that IO category of ANSI/HFES-100 can be applied to UAS GCSs. The data analyses proved that all three hypotheses are supported.

Chapter 6 – Conclusion and Future Research

6.1. Conclusion

Of the nine CWS IO devices specified by the ANSI/HFES-100 IO category, only six IO devices (display, keyboard, mouse, trackball, joystick, and touch-panel) were found to be frequently used in the 20 DoD UAS GCSs that were studied. All UAS GCSs studied use at least three (display, keyboard, and mouse) or more IO devices that are similar to those of CWSs and are specified by the ANSI/HFES-100 IO category. The study also identified one IO device “gamepad” as a write-in selection on two UAS GCSs. Gamepad is not identified/specified to be a CWS IO device by the ANSI/HFES-100 IO category. Overall, 98% of all IO devices found/used in the 20 studied DoD UAS GCSs were identical to those specified by ANSI/HFES-100 standard’s IO category. Moreover, the usability of IO devices in UAS GCSs is not significantly different from their use in CWSs today. The breadth of information contained in the IO category of the ANSI/HFES standard addresses individual and specific EHF issues between humans and the IO interface. When applied collectively, the individual requirements could ensure optimal human maneuverability and usability of the UAS GCS IO interface. Based on these findings, it is possible to apply the ANSI/HFES-100 IO category of the standard to the design, development, and evaluation of UAS GCS IO interfaces. The application of the standard’s IO category can be made to improve usability of UAS GCS IO devices, and doing so may reduce EHF issues in GCS IO interfaces that lead to mishaps.

6.2. Future Research

The design of this research was exploratory in nature. The research was designed to explore the scope of the EHF issues associated with the UAS GCS IO interface. The results of this study are very preliminary and limited. These findings open the door to future, in-depth case studies, simulations, and experiments. Overall, this study has made significant contributions to the body of knowledge regarding UAS GCS human factors.

For future research, a sophisticated conceptual model should be developed based on one or more human factors standards. ANSI/HFES-100 alone has many more considerations than those incorporated into this study. Further research is recommended to investigate the OC category of the standard to determine if OC is applicable to UAS GCS designs. Doing so would provide a more complete portrait of the applicability of ANSI/HFES-100 to DoD UAS GCS designs.

Only 20 UAS GCSs and 23 operators were included in this study. A larger sample size of UAS GCSs, operators, engineers, human factors experts, and other subject matter experts could be studied to utilize regression analysis techniques to generate sophisticated statistical models. Greater levels of randomization in selecting the sample should be sought. Researchers can take the basic assumptions explored in this study and expand them into a true randomized experiment.

If the ANSI/HFES-100 standard's IO category is made applicable to the DoD UAS GCSs, it is critical to study post-application GCS IO-related EHF mishaps as well as the overall mishap rates. An indication of decreasing numbers of IO-related EHF mishaps (similar to ones mentioned in Section 3.5.3) could further certify the findings of this study. The individual instances of UAS GCS IO-related EHF mishaps discussed earlier are considered below in a hypothetical application of ANSI/HFES-100 IO category of the standard:

- **Display (2001 & 2005):** The standard's IO category provides guidelines on display support surfaces, viewing angles/adjustments, and antiglare screens to help avoid glare (HFES, 2007). Therefore, its application could have helped avoid glare on displays andpossibly prevent these mishaps.

- **Button Layout (2006):** The standard's IO category specifies shape and proper reach (i.e., hand movements, extreme thumb and/or finger motions, etc.) for buttons and knobs to reduce layout confusion (HFES, 2007). Therefore, the mishap may have helped avoid button layout confusion, which could have helped avoid this mishap.

- **Keyboard and Trackball (2009):** The IO category specifies proper clearance around IO devices to avoid inadvertent data entry in IO devices (HFES, 2007). Therefore, the application of proper IO device clearances could have helped avoid the mishap.
- **Joystick (2010):** The standard's IO category specifies maximum displacement angle of 45º from the rest position (HFES, 2007). The joystick used in that UAS GCS design exceeded maximum displacement angle by 10º, and could have contributed to "tennis elbow." Therefore, the application of joystick displacement could have helped reduce strain on the elbow and may have helped avoid the mishap.

Although, all hypothetical application of the standard's IO category above indicate that mishaps may have been avoided; however, future research should examine the frequency of similar mishaps to access the feasibility and/or benefits of applying the ANSI/HFES-100 IO category on UAS GCS IO interface design.

In addition, studies should be performed on the human factors associated with commercialization of UAS technology. That is, once UAS development migrates from the public to the private sector, commercial firms may need to apply greater levels of EHF engineering. Lastly, although UASs were the main topic of this study, future studies can include GCSs for unmanned underwater, ground, and space systems. It is very possible that the GCSs from these systems may have very similar EHF issues.

References

Alan, L. (2006, August 07). Safety a concern as drones catch on. *USA Today*. Retrieved from http://proxygw.wrlc.org/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=J0E047766830606&site=ehost-live

Andersen, H., Bove, T., Isaac, A., Kennedy, R., Kirwan, B., & Shorrock., T. (2002). *Short Report on Human Performance Models and Taxonomies and Human Error in Air Traffic Management (HERA)*: European Organization for the Safety of Air Navigation.

Anshel, J. (1994). Visual ergonomics in the workplace: How to use a computer and save your eyesight. *Performance + Instruction, 33*(5), 20-22.

ANSI/HFES-100. (2007). Human Factors Engineering of Computer Workstations. Santa Monica, CA: Human Factors and Ergonomics Society.

Baur, J. (2007). *The NASA Dryden Flight Research Center Unmanned Aircraft System Service Capabilities*. Retrieved from http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20070024645_2007021347.pdf.

Bell, B. G., & Cooke, N. J. (2003). Cognitive Ability Correlates of Performance on a Team Task. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 47*(9), 1087-1091.

Berni, J., Zarco-Tejada, P. J., Suarez, L., & Fereres, E. (2009). Thermal and Narrowband Multispectral Remote Sensing for Vegetation Monitoring From an Unmanned

Aerial Vehicle. *Geoscience and Remote Sensing, IEEE Transactions on, 47*(3), pp. 722-738.

Butler, A., & Fulghum, D. A. (2005). New Frontiers. *Aviation Week & Space Technology, 162*(10), 22-24.

Button, K. (2009a). Different courses. *C4ISR Journal, 8*(10), 34-36.

Button, K. (2009b). Ground plan. *C4ISR Journal, 8*(5), 24-26.

Calhoun, G., Draper, M., Ruff, H., Fontejon, J., & Guilfoos, B. (2003). Evaluation of Tactile Alerts for Control Station Operation. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 47*(20), 2118-2122.

Cantwell, H. R. (2009). Operators of Air Force Unmanned Aircraft Systems. *Air & Space Power Journal, 23*(2), 67-77.

Congress. (1957). *House Committe on Government Operations Defense Standardization Program, 85th Congress, 1st Session, House of Representatives 822*.

Congress. (2009). *Budget Request on UAV and ISR Capabilities*. Retrieved from http://www.fas.org/irp/congress/2007_hr/uav.pdf.

Corlett, E. N., & McAtamney, L. (1988). Ergonomics in the Workplace. *Physiotherapy, 74*(9), 475-478.

Creswell, J. W. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches (3rd ed.)*. Thousand Oaks, CA US: Sage Publications, Inc.

Cummings, M. L., Clare, A., & Hart, C. (2010). The Role of Human-Automation Consensus in Multiple Unmanned Vehicle Scheduling. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 52*(1), 17-27.

Dalamagkidis, K., Valavanis, K. P., & Piegl, L. A. (2008, 25-27 June 2008). *A survey of unmanned aircraft systems regulation: Status and future perspectives.* Paper presented at the Control and Automation, 2008 16th Mediterranean Conference on.

Dixon, S. R., Wickens, C. D., & Chang, D. (2003). Comparing Quantitative Model Predictions to Experimental Data in Multiple-UAV Flight Control. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 47*(1), 104-108.

DoD. (2004). *Airspace integration plan for unmanned aviation*. Washington, DC: Office of the Under Secretary of Defense.

DoD. (2005). *Department of Defense Human Factors Analysis and Classification System*.

DoD. (2009a). *FY2009-2034 Unmanned Systems Integrated Roadmap*. Washington, DC: Department of Defense.

DoD. (2009b, February 18, 2009). RQ-2A Pioneer Unmanned Aerial Vehicle (UAV) Retrieved February 10, 2011, from http://www.navy.mil/navydata/fact_display.asp?cid=1100&tid=2100&ct=1

DoD. (2010). *Department of Defense Report to Congress on Addressing Challenges for Unmanned Aircraft Systems*. Retrieved from http://www.acq.osd.mil/psa/docs/2010-uas-annual-report.pdf.

DoD. (2011). *Unmanned Systems Integrated Roadmap FY2011-2036*. Retrieved from http://www.defenseinnovationmarketplace.mil/resources/UnmannedSystemsIntegratedRoadmapFY2011.pdf.

Donmez, B., Cummings, M. L., & Graham, H. D. (2009). Auditory Decision Aiding in Supervisory Control of Multiple Unmanned Aerial Vehicles. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 51*(5), 718-729.

Draper, M., Calhoun, G., Ruff, H., Williamson, D., & Barry, T. (2003). Manual Versus Speech Input for Unmanned Aerial Vehicle Control Station Operations. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 47*(1), 109-113.

Draper, M. H., Geiselman, E. E., Lu, L. G., Roe, M. M., & Haas, M. W. (2000). Display Concepts Supporting Crew Communication of Target Location in Unmanned Air Vehicles. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 44*(13), 85-88.

Drew, J. G., Shaver, R., Lynch, K. F., Amouzegar, M. A., & Snyder, D. (2005). *Unmanned Aerial Vehicle End-to-End Support Considerations*. Santa Monica.

Dunlap, J. W. (1947). Men and machines. *Journal of Applied Psychology, 31*(6), pp. 565-579.

Eason, K. D. (1991). Ergonomic perspectives on advances in human-computer interaction. *Ergonomics, 34*(6), 721-741.

Esposito, F., Rufino, G., Moccia, A., Donnarumma, P., Esposito, M., & Magliulo, V. (2007, 3-10 March 2007). *An Integrated Electro-Optical Payload System for Forest Fires Monitoring from Airborne Platform.* Paper presented at the Aerospace Conference, 2007 IEEE.

EU. (2007). *Study Analysing the Current Activities in the Field of UAV*: Enterprise and Industry Directorate-General.

FAA. (2006). *Unmanned Aircraft Operations in the National Airspace System*. Retrieved from http://www.faa.gov/about/initiatives/uas/reg/media/frnotice_uas.pdf.

Force, D. o. t. A. (2009). *Air Force Recruiting, Retention and End Strength*.

Forester, J., Bley, D., Cooper, S., Lois, E., Siu, N., Kolaczkowski, A., et al. (2004). Expert elicitation approach for performing ATHEANA quantification. *Reliability Engineering & System Safety, 83*(2), 207-220.

GAO. (2008). *Unmanned Aircraft Systems: Federal Actions Needed to Ensure Safety and Expand Their Potential Uses within the National Airspace System*. Retrieved from http://proxygw.wrlc.org/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=tsh&AN=32129402&site=ehost-live.

Gawron, V. J. (1998). *Human factors issues in the development, evaluation, and operation of uninhabited aerial vehicles.* Paper presented at the Proceedings of the Association for Unmanned Vehicle Systems International '98.

Gertler, J. (2012). *U.S. Unmanned Aerial Systems*. Retrieved from http://www.fas.org/sgp/crs/natsec/R42136.pdf.

Goldfinger, J. (2005). *Designing Humans for Unmanned Aviation.* Paper presented at the ERAU, Daytona Beach, FL.

Gordon, R. P., Jeffries, J. R., & Flin, R. (2002). *Designing a Human Factors Investigation Tool to Improve the Quality of Incident Investigations*. Paper presented at the SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production.

Haines, P. (2007, Dec. 2007). *Satellite Communications with UAVs: Practical Lessons from High Speed Trains and Planes.* Paper presented at the Communicating with UAV's, 2007 IET Seminar on.

Hancock, P., Mouloua, M., Gilson, R., Kring, E. D., & Kring, J. (2001). Ergonomics of UAVUCAV Mission Success: Considerations for Data Link, Control, and Display Issues. *Human Factors and Ergonomics Society Annual Meeting Proceedings, 45*, 144-148.

Hansman, J., & Weibel, R. (2004). *Human and Automation Integration Considerations for UAV Systems*. Paper presented at the MIT International Center for Air Transportation. Retrieved from http://mit.espe.edu.ec/courses/aeronautics-and-astronautics/16-422-human-supervisory-control-of-automated-systems-spring-2004/lecture-notes/040804alertsys_2.pdf

Hanson, W. E., Creswell, J. W., Clark, V. L. P., Petska, K. S., & Creswell, D. J. (2005). Mixed Methods Research Designs in Counseling Psychology. *Journal of Counseling Psychology, 52*(2), 224-235.

Heinrich, H., Petersen, D., & Roos, N. (1980). *Industrial Accident Prevension: A Safety Management Approach* (5th ed.). New York: McGraw-Hill.

HFES. (2007). Human Factors Engineering of Computer Workstations. Santa Monica, CA: Human Factors and Ergonomics Society.

Higgins, K. (2008). Safety Board Probes a Manned/Unmanned NAS. *Air Safety Week, 22*(18), pp. 1-1.

Hinson, D. R. (1993). *Human Factors Policy*. Retrieved from https://www.hf.faa.gov/docs/508/docs/FAA%20Order%209550.8_1993.pdf.

Hoffman, M., Tilghman, A., LaGrone, S., & Iannotta, B. (2008, Dec 21). Are enlisted airmen next to pilot UAVs? *Air Force Times*. Retrieved from http://www.airforcetimes.com/news/2008/12/airforce_enlisted_uas3_122108/

Hollnagel, E. (2000). Looking for errors of omission and commission or The Hunting of the Snark revisited. *Reliability Engineering and System Safety, 68*(2), 135-145.

Hollnagel, E. (2003). *Handbook of cognitive task design*. Mahwah, NJ US: Lawrence Erlbaum Associates Publishers.

Houston, R. C. (2009). Operators of Air Force Unmanned Aircraft Systems: Breaking Paradigms*. *Air & Space Power Journal, 23*(2), 67-77,127.

INCOSE. (2010). *Systems engineering handbook v3.2 tutorial*. Hampton, VA U6 - ctx_ver=Z39.88-2004&ctx_enc=info%3Aofi%2Fenc%3AUTF-8&rfr_id=info:sid/summon.serialssolutions.com&rft_val_fmt=info:ofi/fmt:kev:mtx:book&rft.genre=book&rft.title=Systems+engineering+handbook+v3.2+tutorial&rft.date=2010-01-01&rft.pub=INCOSE&rft.externalDocID=8583073 U7 - Book U8 - FETCH-gwu_catalog_85830731: International Council on Systems Engineering.

James, T. C., & Lee, O. (2011). Using Likert-Type Scales in the Social Sciences. *Journal of Adult Education, 40*(1), 19-22.

Jean, G. V. (2011). Remotely Piloted Aircraft Fuel Demand for Satellite Bandwidth. [Article]. *National Defense, 96*(692), 38-39.

Keraminiyage, K., Amaratunga, D., & Haigh, R. (2009). A Human-Computer Interaction Principles Based Framework to Assess The User Perception of Web Based

Virtual Research Environments. *International Journal of Strategic Property Management, 13*(2), 129-142.

Langevin, S., Joseph, B., Brenkle, J., Straussberger, S., Guiost, B., Lantes, J.-Y., et al. (2008). *Human-centered design methodology: an example of application with UAVs mission*. Paper presented at the Humans Operating Unmanned Systems (HUMOUS). Retrieved from http://conferences.telecom-bretagne.eu/data/humous08/proceedings/05-langevin08humous.pdf

Larm, D. (1996). *Expendable Remotely Piloted Vehicles for Strategic Offensive Airpower Roles.* Air University, Maxwell Air Force Base, Alabama.

Li, C., Shen, L., Wang, H.-b., & Lei, T. (2010, 27-29 March 2010). *The research on unmanned aerial vehicle remote sensing and its applications.* Paper presented at the International Conference on Advanced Computer Control (ICACC).

Loh, R., Yi, B., & Roe, T. (2009). UAVs in civil airspace: Safety requirements. *Aerospace and Electronic Systems Magazine, IEEE, 24*(1), pp. 5-17.

Lowell, S. (2008). *Defense Standardization Program*. Retrieved from http://www.strategicstandards.com/files/DefenseStandardization.pdf.

Manning, S. D., Rash, C. E., LeDuc, P. A., Noback, R. K., & McKeon, J. (2004). *The role of human causal factors in U.S. Army unmanned aerial vehicle accidents*. Ft. Rucker, AL: U.S. Army Aeromedical Research Laboratory.

May, D. R., Reed, K., Schwoerer, C. E., & Potter, P. (2004). Ergonomic Office Design and Aging: A Quasi-Experimental Field Study of Employee Reactions to an Ergonomics Intervention Program. *Journal of Occupational Health Psychology, 9*(2), 123-135.

McDermott, P. L., Luck, J., Allender, L., & Fisher, A. (2005). Effective Human to Human Communication of Information Provided by an Unmanned Vehicle. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 49*(3), 402-406.

Molloy, G. J., & O'Boyle, C. A. (2005). The SHEL model: a useful tool for analyzing and teaching the contribution of Human Factors to medical error. *Academic medicine : journal of the Association of American Medical Colleges, 80*(2), 152-155.

Mouloua, M., Gilson, R., & Hancock, P. (2003). Human-Centered Design of Unmanned Aerial Vehicles. *Ergonomics in Design, 11*, 6-11.

Mouloua, M., Gilson, R., Kring, J., & Hancock, P. (2001). Workload, Situation Awareness, and Teaming Issues for UAVUCAV Operations. *Human Factors and Ergonomics Society Annual Meeting Proceedings, 45*, 162-165.

Nas, M. (2008). The Changing Face of the Interface: An Overview of UAS Control Issues & Controller Certification, *Unmanned Aircraft Technology Applications Research (UATAR) Working Group 27,* : Murdoch University.

Nikolic, M. I., Sklar, A. E., & Sarter, N. B. (1998). Multisensory Feedback in Support of Pilot-Automation Coordination: The Case of Uncommanded Mode Transitions. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 42*(3), 239-243.

Nisser, T., & Westin, C. (2006). *Human Factors Challenges in Unmanned Aerial Vehicles (UAVs): A Literature Review.* Lund University, Lund, Sweden.

OSD. (2002). *Unmanned Aerial Vehicle Roadmap 2002-2027.* Retrieved from https://docs.google.com/file/d/0B62WuA0JJcx2YTdmNGI2OGQtYjE0Mi00ZDI yLThhYWEtMTVhNjNhMTM4ZGRm/edit?hl=en_GB&authkey=CJO71c0K&pli=1.

OSD. (2004). *Defense Science Board Study on Unmanned Aerial Vehicles and Uninhabited Combat Aerial Vehicles*. Washington, D.C.

Owings, T. (2010). Unmanned Aircraft Systems (UAS) Project Office (PO) Finds Powerful Cost Efficiency Advantages Through Proper Performance-Based Logistics (PBL). [Article]. *Army AL&T Magazine*, 14-19.

Pastor, E., Lopez, J., & Royo, P. (2007). UAV Payload and Mission Control Hardware/Software Architecture. *Aerospace and Electronic Systems Magazine, IEEE, 22*(6), 3-8.

Paur, J. (2009). Boeing's Best-Selling Aircraft Fits on Your Shoulder. *Wierd*. Retrieved from http://www.wired.com/autopia/2009/08/boeing-uav/

Reade, L. (1958). BOMBS OVER VENICE. *History Today, 8*(6), 421-425.

Reason, J. (1990). *Human Error*. New York: Cambridge University Press.

Rogers, B., Palmer, B., Chitwood, J., & Hover, G. (2004). *Human-systems issues in UAV design and operation*. Wright-Patterson Air Force Base, OH: Human Systems Information Analysis Center.

Rubenstein, C. (2003). An A+ certification program. *Tech Directions, 62*(6), 26-26.

Salvendy, G. (2006). *Handbook of human factors and ergonomics (3rd ed.)*. Hoboken, NJ US: John Wiley & Sons Inc.

Sauter, S. L., Schleifer, L. M., & Knutson, S. J. (1991). Work Posture, Workstation Design, and Musculoskeletal Discomfort in a VDT Data Entry Task. *Human*

Factors: The Journal of the Human Factors and Ergonomics Society, 33(2), 151-167.

Sauter, S. L., Schleifer, L. M., & Knutson, S. J. (1991). Work posture, workstation design, and musculoskeletal discomfort in a VDT data entry task. *Human Factors, 33*(2), 151-167.

Seagle, J. D. (1997). *Unmanned aerial vehicle mishaps: a human factors analysis [Thesis]*. Embry-iddle Aeronautical University Extended Campus, Norfolk, VA.

Shappell, S. A., & Wiegmann, D. A. (1997). A Human Error Approach to Accident Investigation: The Taxonomy of Unsafe Operations. [Article]. *International Journal of Aviation Psychology, 7*(4), 269.

Shappell, S. A., & Wiegmann, D. A. (2000). *The Human Factors Analysis and Clasification System (HFACS)* (No. DOT/FAA/AM-00/7). Oklahoma City, OK: Fedral Aviation Administration.

Sheridan, T. B. (1992). *Telerobotics, automation, and human supervisory control*. Cambridge, MA US: The MIT Press.

Sibert, J., & Marchionini, G. (1993). Human-computer interaction research agendas. *Behaviour & Information Technology, 12*(2), 67-68.

Soares, M. M., Jacobs, K., Pagnan, A. S., Ribeiro, G. F. R., Gonçalves, M. G. S., Câmara, J. J. D., et al. (2012). Interface design and contemporary: human creating new guidelines for high-tech products. [Article]. *Work, 41*, 1524-1530.

Spinetta, L. (2011). The Rise of UNMANNED AIRCRAFT. *Aviation History, 21*(3), 30-37.

Spravka, J. J., Moisio, D. A., & Payton, M. G. (2005). *Unmanned Air Vehicles: A New Age in Human Factors Evaluations* (No. AFFTC-PA-05069). Edwards Air Force Base, CA: Air Force Flight Test Center.

Sullivan, M. J. (2009). *Opportunities Exist to Achieve Greater Commonality and Efficiencies among Unmanned Aircraft Systems*: U.S. Government Accountability Office.

Tanner, S. (2010, June 24). *Small UAS in Joint Doctrine*. Paper presented at the Johns Hopkins, Small UAS Symposium, Laurel, MD.

Tesla, N. (1898). USA Patent No.: U. S. P. Office.

Thompson, W. T., & Tvaryanas, A. P. (2005). *U.S. military unmanned aerial vehicle mishaps: assessment of the role of human factors using HFACS*. Retrieved from http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA435063.

Thompson, W. T., & Tvaryanas, A. P. (2008). *Unmanned Aircraft System (UAS) Operator Error Mishaps: An Evidence-based Prioritization of Human Factors Issues*. Brooks City, TX: North American Treaty Organization (NATO).

Tice, B. P. (1991). UNMANNED AERIAL VEHICLES. *Airpower Journal, V*(1).

Tyabji, A. (2007). Unique problems associated with UAV employment. *Flying Safety, 63*(5), pp. 14-15.

UAPO. (2008). *Interim Operational Approval Guidance 08-01; Unmanned Aircraft Systems Operations in the U.S. National Airspace System*: Unmanned Aircraft Program Office, AIR-160.

USAF. (2012, January 5, 2012). MQ-1B PREDATOR. Retrieved January 13, 2012, 2012, from http://www.af.mil/information/factsheets/factsheet.asp?id=122

UVS. (2011). 2011-2012 UAS Yearbook - UAS: The Global Perspective *International UAS Community* (9th ed.): Blyenburgh & Co.

Wagenaar, W. A., & Groeneweg, J. (1987). Accidents at sea: Multiple causes and impossible consequences. *International Journal of Man-Machine Studies, 27*(5-6), 587-598.

Weatherington, D. (2010, April 20, 2010). *Unmanned Aircraft Systems.* Paper presented at the Precision Strike Annual Review, Springfield, VA.

Wickens, C. D., & Dixon, S. (2002). *Workload Demands of Remotely Piloted Vehicle Supervision and Control* (No. ARL-02-10/MAD-02-1). Savoy, IL: University of Illionois, Aviation Research Lab.

Wiegmann, D. A., & Shappell, S. A. (2001). Human Error Perspectives in Aviation. [Article]. *International Journal of Aviation Psychology, 11*(4), 341-357.

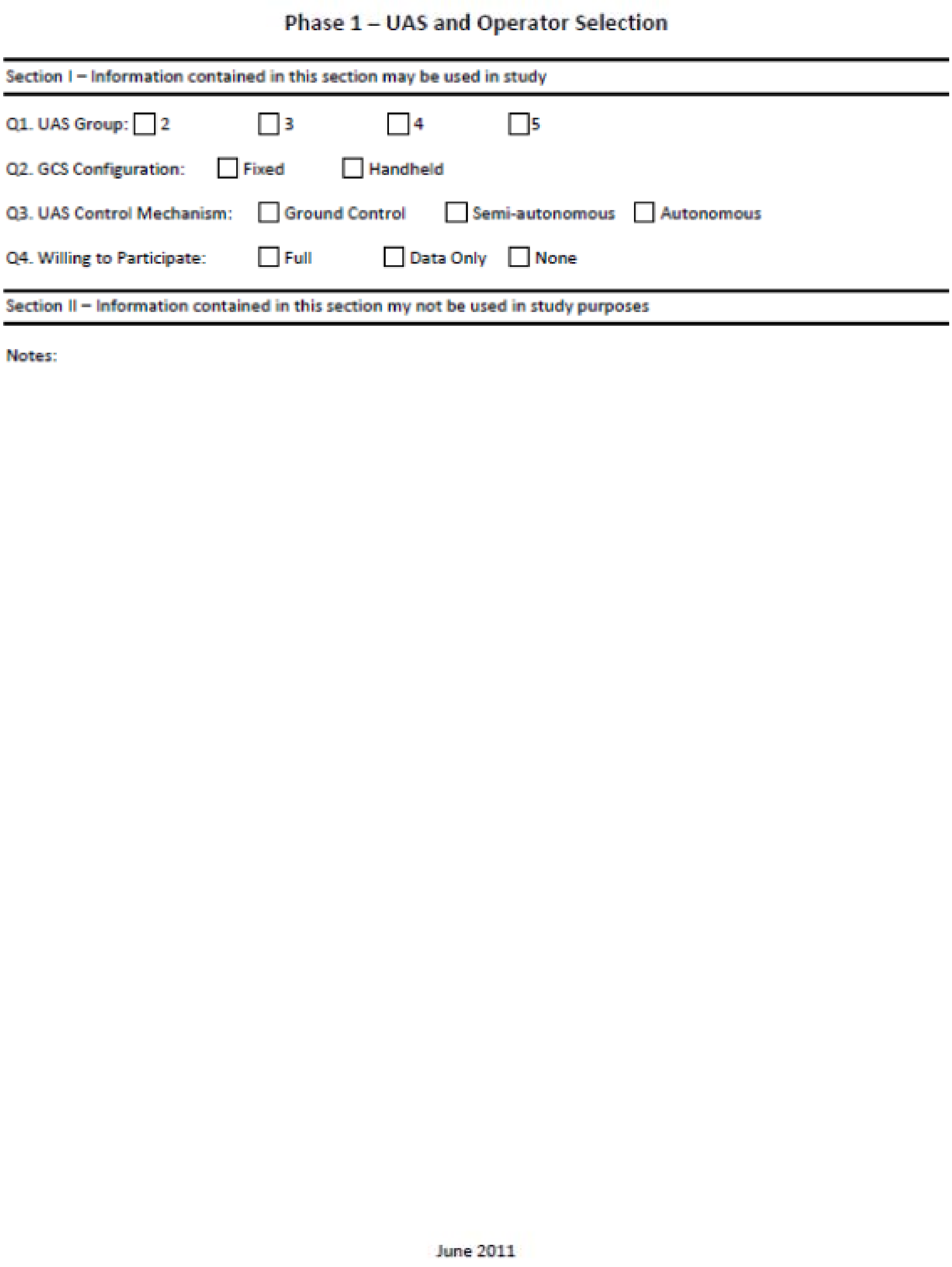
Williams, K. W. (2004). *A Summary of Unmanned Aircraft Accident/Incident Data: Human Factors Implications* (No. DOT/FAA/AM-04/24). Oklahoma City, OK: Civil Aerospace Medical Institute, Federal Aviation Administration.

Wilson, J. R. (2002). UAVs and the human factor. *Aerospace America, 40*(7), pp 54-57.

Yang, J., Verma, U., Marler, T., Beck, S., Rahmatalla, S., & Harrison, C. (2009). Workspace zone differentiation tool for visualization of seated postural comfort. [Article]. *International Journal of Industrial Ergonomics, 39*(1), 267-276.

Zucchino, D. (2010, July 06, 2010). War zone drone crashes add up. *Los Angeles Times*. Retrieved from http://articles.latimes.com/2010/jul/06/world/la-fg-drone-crashes-20100706

Appendix A – Phase 1: Measurement Instrument



Phase 1 – UAS and Operator Selection

Section I – Information contained in this section may be used in study

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Q1. UAS Group: ☐ 2 ☐ 3 ☐ 4 ☐ 5

Q2. GCS Configuration: ☐ Fixed ☐ Handheld

Q3. UAS Control Mechanism: ☐ Ground Control ☐ Semi-autonomous ☐ Autonomous

Q4. Willing to Participate: ☐ Full ☐ Data Only ☐ None

Section II – Information contained in this section my not be used in study purposes

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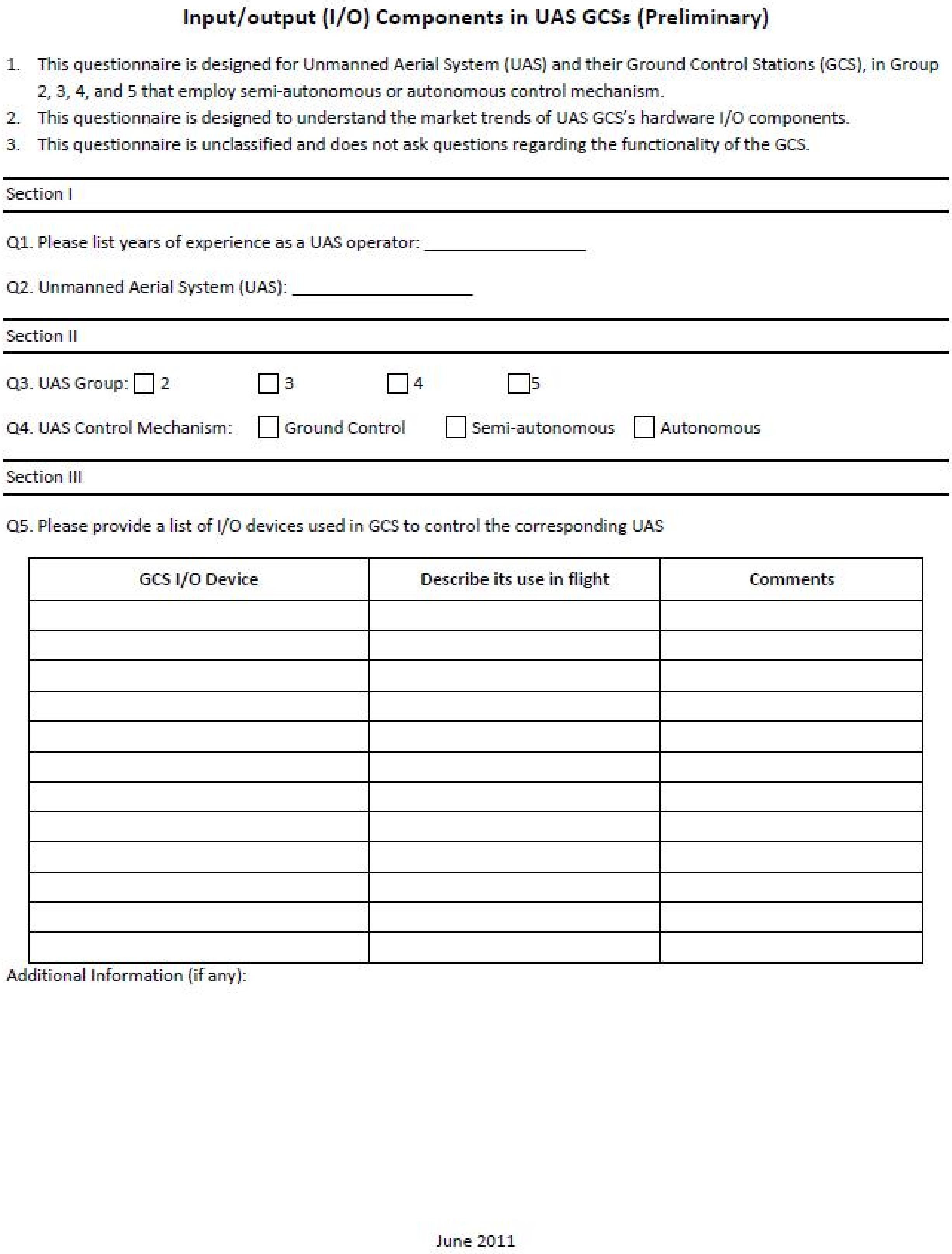
Notes:

June 2011

Appendix B – Phase 1: Preliminary Phase 2 Measurement Instrument



Input/output (I/O) Components in UAS GCSs (Preliminary)

1. This questionnaire is designed for Unmanned Aerial System (UAS) and their Ground Control Stations (GCS), in Group 2, 3, 4, and 5 that employ semi-autonomous or autonomous control mechanism.
2. This questionnaire is designed to understand the market trends of UAS GCS's hardware I/O components.
3. This questionnaire is unclassified and does not ask questions regarding the functionality of the GCS.

Section I

Q1. Please list years of experience as a UAS operator: ________________

Q2. Unmanned Aerial System (UAS): __________________

Section II

Q3. UAS Group: ☐ 2 ☐ 3 ☐ 4 ☐5

Q4. UAS Control Mechanism: ☐ Ground Control ☐ Semi-autonomous ☐ Autonomous

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Section III

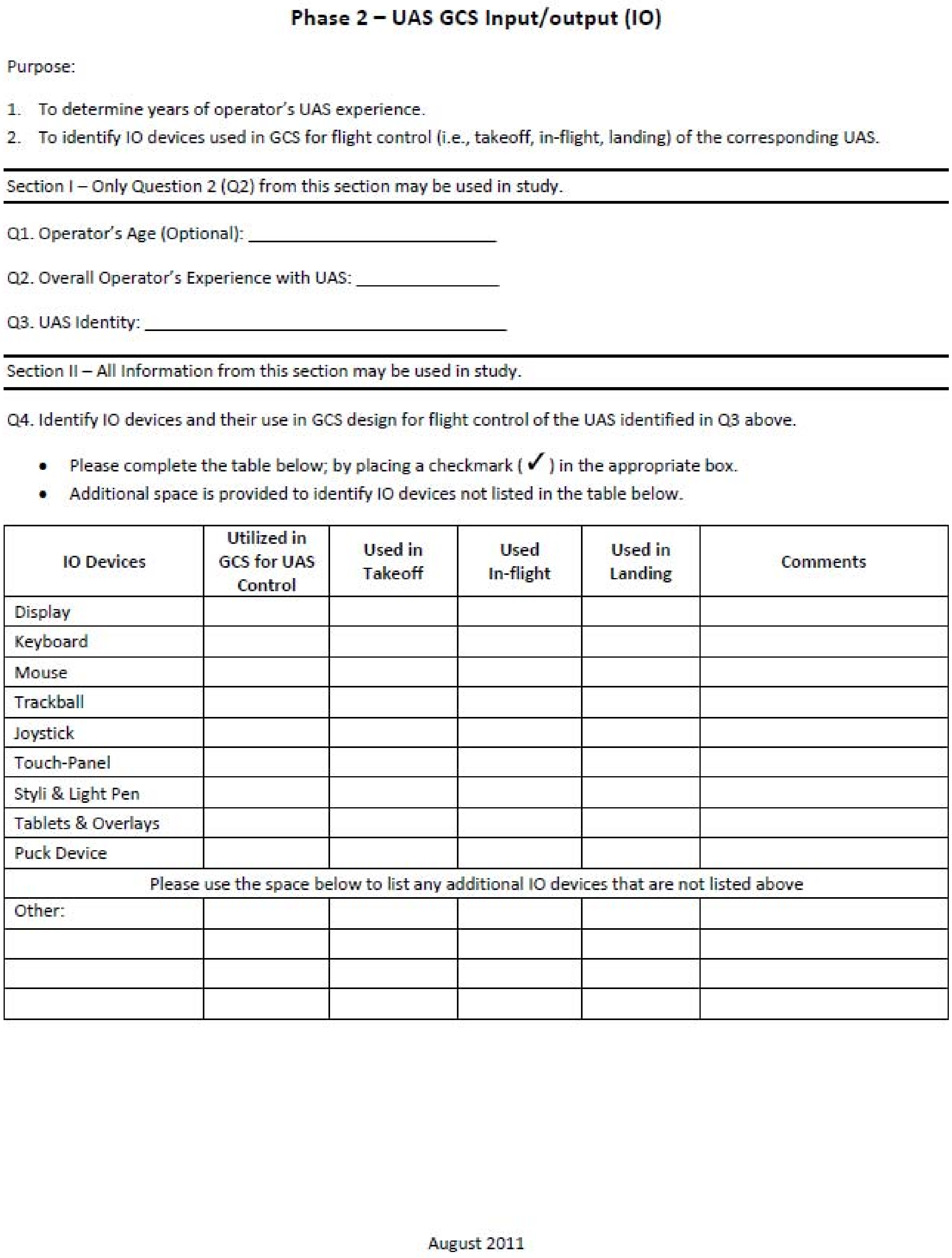
Q5. Please provide a list of I/O devices used in GCS to control the corresponding UAS

GCS I/O Device	Describe its use in flight	Comments

Additional Information (if any):

June 2011

Appendix C – Phase 2 Measurement Instrument



Phase 2 – UAS GCS Input/output (IO)

Purpose:

1. To determine years of operator's UAS experience.
2. To identify IO devices used in GCS for flight control (i.e., takeoff, in-flight, landing) of the corresponding UAS.

Section I – Only Question 2 (Q2) from this section may be used in study.

Q1. Operator's Age (Optional): ___________________________

Q2. Overall Operator's Experience with UAS: _______________

Q3. UAS Identity: _______________________________________

Section II – All Information from this section may be used in study.

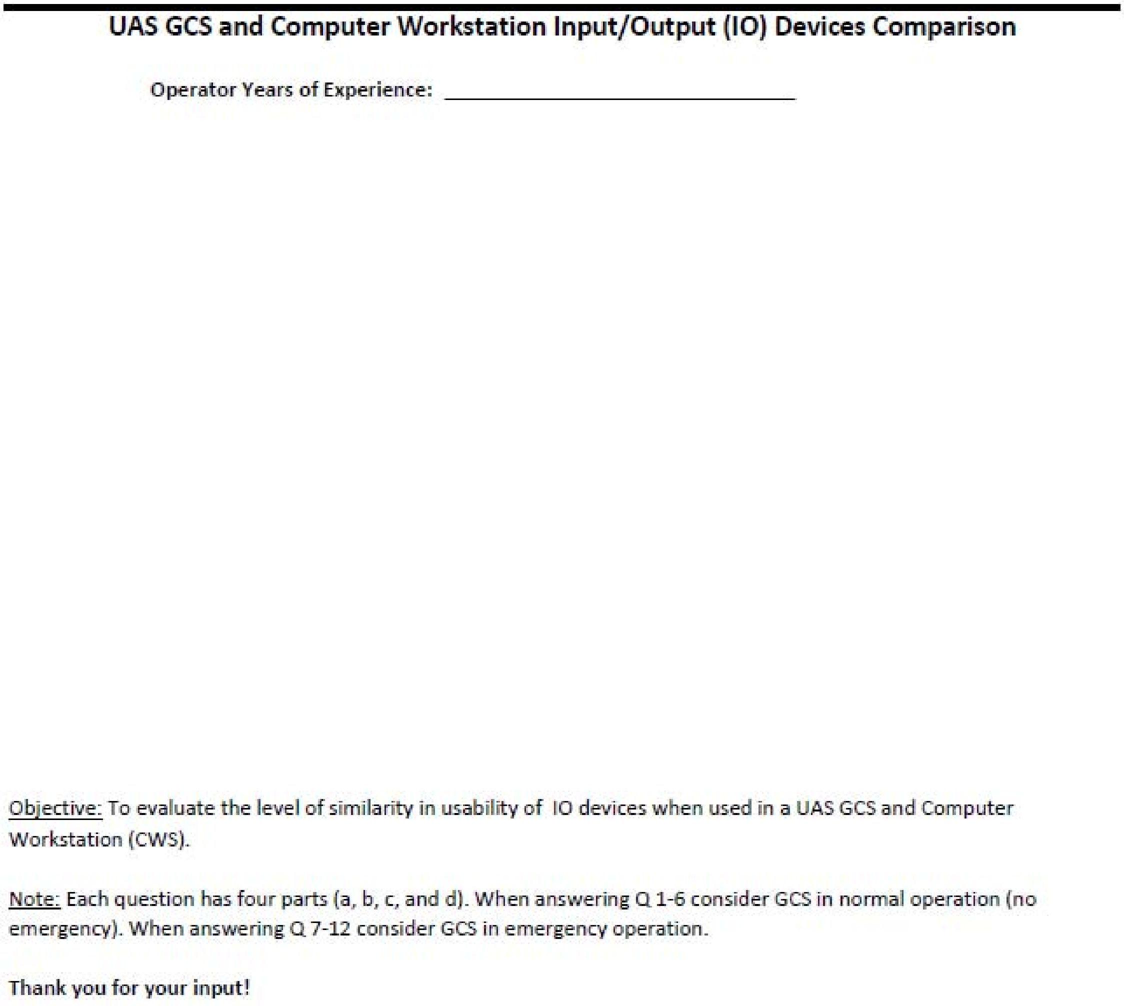
Q4. Identify IO devices and their use in GCS design for flight control of the UAS identified in Q3 above.

- Please complete the table below; by placing a checkmark (✓) in the appropriate box.
- Additional space is provided to identify IO devices not listed in the table below.

IO Devices	Utilized in GCS for UAS Control	Used in Takeoff	Used In-flight	Used in Landing	Comments
Display					
Keyboard					
Mouse					
Trackball					
Joystick					
Touch-Panel					
Styli & Light Pen					
Tablets & Overlays					
Puck Device					
Please use the space below to list any additional IO devices that are not listed above					
Other:					

August 2011

Appendix D – Phase 3 Measurement Instrument



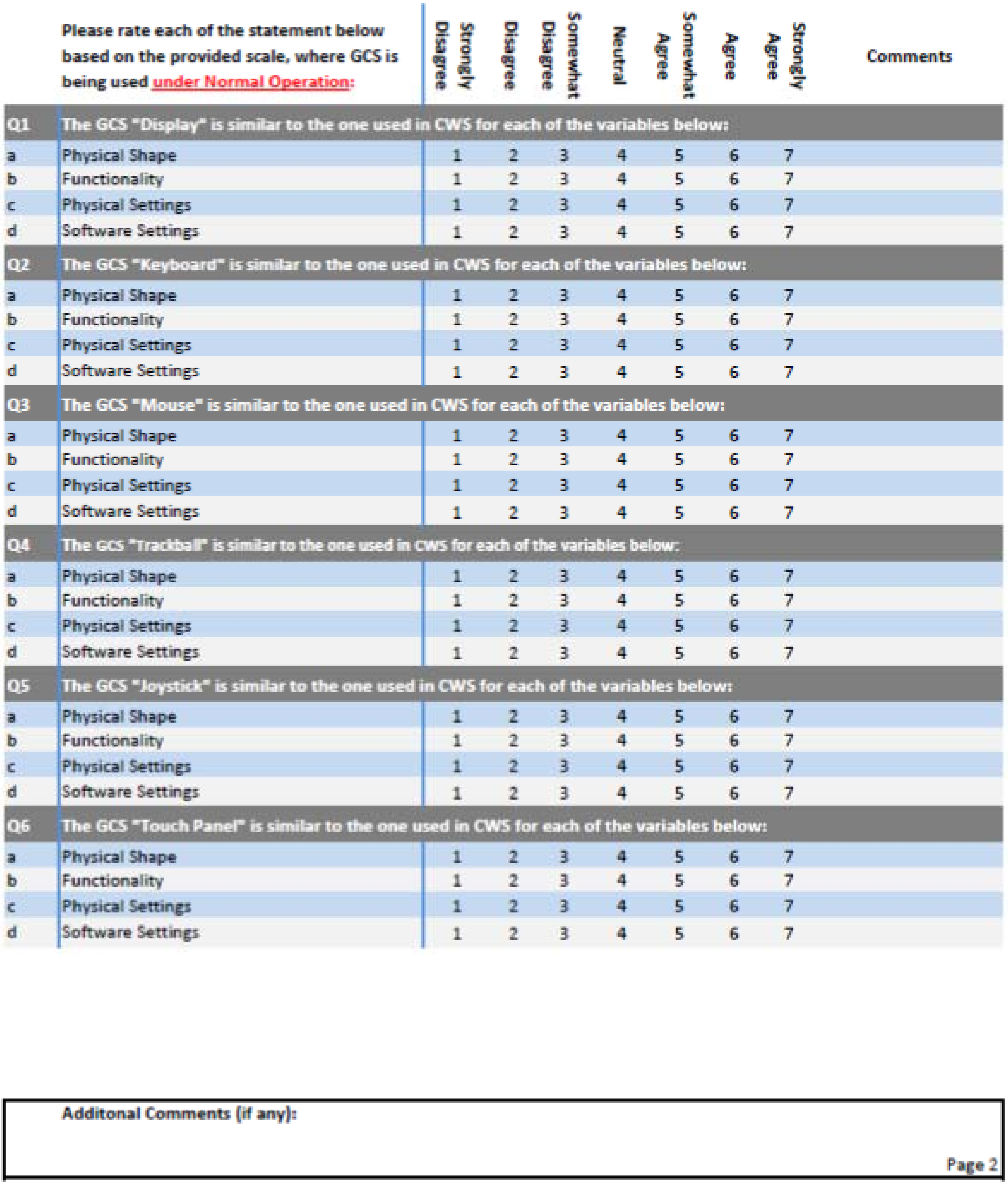
UAS GCS and Computer Workstation Input/Output (IO) Devices Comparison

Operator Years of Experience: ______________________________

Objective: To evaluate the level of similarity in usability of IO devices when used in a UAS GCS and Computer Workstation (CWS).

Note: Each question has four parts (a, b, c, and d). When answering Q 1-6 consider GCS in normal operation (no emergency). When answering Q 7-12 consider GCS in emergency operation.

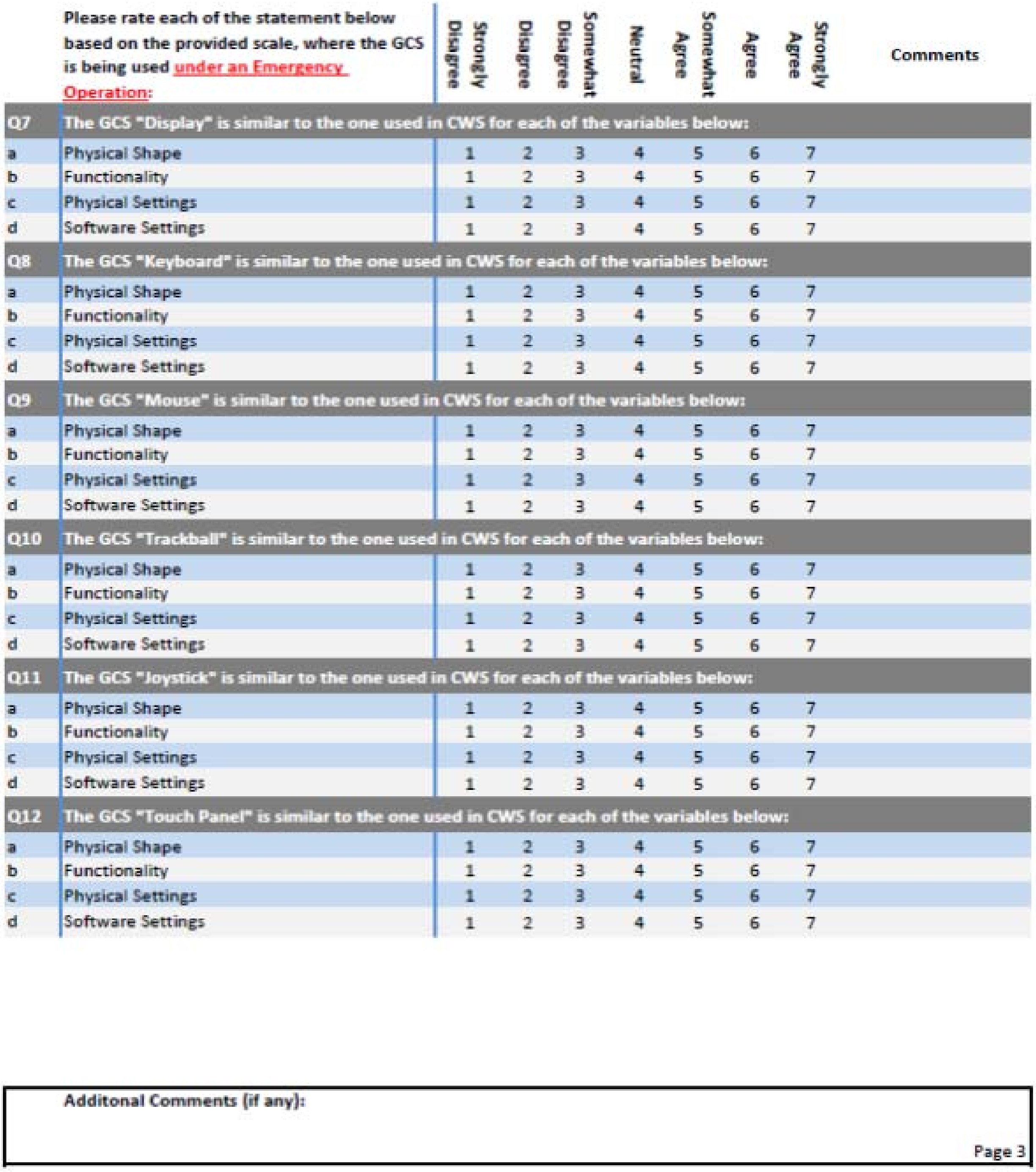
Thank you for your input!



	Please rate each of the statement below based on the provided scale, where GCS is being used under Normal Operation:	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree	Comments
Q1	**The GCS "Display" is similar to the one used in CWS for each of the variables below:**								
a	Physical Shape	1	2	3	4	5	6	7	
b	Functionality	1	2	3	4	5	6	7	
c	Physical Settings	1	2	3	4	5	6	7	
d	Software Settings	1	2	3	4	5	6	7	
Q2	**The GCS "Keyboard" is similar to the one used in CWS for each of the variables below:**								
a	Physical Shape	1	2	3	4	5	6	7	
b	Functionality	1	2	3	4	5	6	7	
c	Physical Settings	1	2	3	4	5	6	7	
d	Software Settings	1	2	3	4	5	6	7	
Q3	**The GCS "Mouse" is similar to the one used in CWS for each of the variables below:**								
a	Physical Shape	1	2	3	4	5	6	7	
b	Functionality	1	2	3	4	5	6	7	
c	Physical Settings	1	2	3	4	5	6	7	
d	Software Settings	1	2	3	4	5	6	7	
Q4	**The GCS "Trackball" is similar to the one used in CWS for each of the variables below:**								
a	Physical Shape	1	2	3	4	5	6	7	
b	Functionality	1	2	3	4	5	6	7	
c	Physical Settings	1	2	3	4	5	6	7	
d	Software Settings	1	2	3	4	5	6	7	
Q5	**The GCS "Joystick" is similar to the one used in CWS for each of the variables below:**								
a	Physical Shape	1	2	3	4	5	6	7	
b	Functionality	1	2	3	4	5	6	7	
c	Physical Settings	1	2	3	4	5	6	7	
d	Software Settings	1	2	3	4	5	6	7	
Q6	**The GCS "Touch Panel" is similar to the one used in CWS for each of the variables below:**								
a	Physical Shape	1	2	3	4	5	6	7	
b	Functionality	1	2	3	4	5	6	7	
c	Physical Settings	1	2	3	4	5	6	7	
d	Software Settings	1	2	3	4	5	6	7	

Additonal Comments (if any):

Page 2



	Please rate each of the statement below based on the provided scale, where the GCS is being used under an Emergency Operation:	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree	Comments
Q7	**The GCS "Display" is similar to the one used in CWS for each of the variables below:**								
a	Physical Shape	1	2	3	4	5	6	7	
b	Functionality	1	2	3	4	5	6	7	
c	Physical Settings	1	2	3	4	5	6	7	
d	Software Settings	1	2	3	4	5	6	7	
Q8	**The GCS "Keyboard" is similar to the one used in CWS for each of the variables below:**								
a	Physical Shape	1	2	3	4	5	6	7	
b	Functionality	1	2	3	4	5	6	7	
c	Physical Settings	1	2	3	4	5	6	7	
d	Software Settings	1	2	3	4	5	6	7	
Q9	**The GCS "Mouse" is similar to the one used in CWS for each of the variables below:**								
a	Physical Shape	1	2	3	4	5	6	7	
b	Functionality	1	2	3	4	5	6	7	
c	Physical Settings	1	2	3	4	5	6	7	
d	Software Settings	1	2	3	4	5	6	7	
Q10	**The GCS "Trackball" is similar to the one used in CWS for each of the variables below:**								
a	Physical Shape	1	2	3	4	5	6	7	
b	Functionality	1	2	3	4	5	6	7	
c	Physical Settings	1	2	3	4	5	6	7	
d	Software Settings	1	2	3	4	5	6	7	
Q11	**The GCS "Joystick" is similar to the one used in CWS for each of the variables below:**								
a	Physical Shape	1	2	3	4	5	6	7	
b	Functionality	1	2	3	4	5	6	7	
c	Physical Settings	1	2	3	4	5	6	7	
d	Software Settings	1	2	3	4	5	6	7	
Q12	**The GCS "Touch Panel" is similar to the one used in CWS for each of the variables below:**								
a	Physical Shape	1	2	3	4	5	6	7	
b	Functionality	1	2	3	4	5	6	7	
c	Physical Settings	1	2	3	4	5	6	7	
d	Software Settings	1	2	3	4	5	6	7	

Additonal Comments (if any):

Page 3

Appendix E – Data Collected for MI-1 Questions

UAS #	UAS Group	GCS Configuration	UAS Control Mechanism	Willing to Participate	UAS Selected
1.	2	Fixed	Autonomous	Full	Yes
2.	2	Fixed	Autonomous	Full	Yes
3.	2	Fixed	Semi-autonomous	Full	Yes
4.	2	Fixed	Semi-autonomous	Full	Yes
5.	2	Fixed	Semi-autonomous	Full	Yes
6.	2	Fixed	Semi-autonomous	Full	Yes
7.	2	Fixed	Semi-autonomous	Full	Yes
8.	3	Fixed	Autonomous	Full	Yes
9.	3	Fixed	Semi-autonomous	Full	Yes
10.	3	Fixed	Semi-autonomous	Full	Yes
11.	3	Fixed	Semi-autonomous	Full	Yes
12.	3	Fixed	Semi-autonomous	Full	Yes
13.	4	Fixed	Autonomous	Full	Yes
14.	4	Fixed	Autonomous	Full	Yes
15.	4	Fixed	Autonomous	Full	Yes
16.	4	Fixed	Autonomous	Full	Yes
17.	4	Fixed	Semi-autonomous	Full	Yes
18.	4	Fixed	Semi-autonomous	Full	Yes
19.	5	Fixed	Autonomous	Full	Yes
20.	5	Fixed	Autonomous	Full	Yes
21.	5	Fixed	Autonomous	Full	Yes
22.	5	Fixed	Autonomous	Full	Yes
23.	5	Fixed	Autonomous	Full	Yes
24.	5	Fixed	Semi-autonomous	Full	Yes